CITY OF CARLSBAD

SEA LEVEL RISE VULNERABILITY ASSESSMENT

December 2017

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1. INTRODUCTION

There is broad agreement in the scientific community that the earth is predicted to warm and that sea levels will rise as a result of the thermal expansion of water and increased contributions from melting glaciers (Coastal and Ocean Working Group of the California Climate Action Team (CO-CAT) 2013; California Coastal Commission 2015). Though there is consensus among the scientific community on these concepts, the timing and severity of sea level rise is relatively uncertain and is dependent on region-specific conditions. The uncertainty in the sea level rise projections is a result of future global emissions of carbon dioxide (a function of future social behavior) and the non-linear response of the ocean to warmer temperatures and contributions from land-based ice sources. Thus, planning for sea level rise must consider high and low estimates of sea level rise. Planning for a range of potential future conditions provides the City of Carlsbad with the tools to make current and future planning decisions that allow the city's resources to adapt to changing conditions.

This vulnerability assessment presents a Carlsbad-specific sea level rise analysis to support an update to the city's Local Coastal Program and Zoning Ordinance. The assessment evaluates the degree to which important community assets are susceptible to, and unable to, accommodate adverse effects of projected sea level rise. The assessment identifies the assets that are likely to be impacted and the causes and components of each asset's vulnerability. This document is considered "living" as it is to be updated as the best available science changes and modeling improves.

The study area was divided into four shoreline and three lagoon planning areas, which were incorporated into three larger planning zones for the purposes of discussion. These planning zones are shown in Figure 1 and are described as follows:

- **Planning Zone 1** – Includes one shoreline and one lagoon planning area in the northern portion of Carlsbad, as follows:
  - <u>The Village Shoreline</u> – Approximately 1.4 miles of shoreline from the northern city boundary to Tamarack Avenue. From north to south, the sandy shoreline is backed by a low-lying residential area that transitions to a higher-relief, beach-front roadway (Carlsbad Boulevard). Approximately 80% of this portion of shoreline is armored with various coastal structures (i.e., rip rap, revetments and seawalls).
  - <u>Buena Vista Lagoon</u> – Includes the southern shore of the lagoon within Carlsbad city limits (approximately 5.3 miles of shoreline). Land uses adjacent to this portion of the lagoon include residential, commercial and open space. None of this lagoon's shoreline within the City of Carlsbad is armored.

    The lagoon is primarily a freshwater system due to a weir system that controls tidal flushing at its outlet. The San Diego Association of Governments (SANDAG) is currently considering the restoration of this lagoon. Alternatives being considered include removal of this weir system to allow for increased tidal flow into the lagoon. This assessment evaluates sea level rise for the years 2050 and 2100, as described below in Section 3; for year 2050 this assessment assumed the weir system remains in place as it exists and is still functioning as designed. The removal of the weir system in the near term would not significantly change the lagoon's vulnerability to sea level rise. By year 2100 this assessment concludes that the sea level will overwash the weir, if still in place in year 2100. This vulnerability assessment will be periodically updated, and if the weir is removed in the future, the lagoon's vulnerability to sea level rise can be reevaluated.

- **Planning Zone 2** – Includes two shoreline and one lagoon planning area in the central portion of Carlsbad, as follows:
  - Tamarack/ Warm Waters Shoreline - Approximately 1 mile of shoreline from Tamarack Avenue to the northern boundary of the Terramar neighborhood. This shoreline area consists of sandy beach backed by a coastal roadway (Carlsbad Boulevard) and pedestrian promenade. Approximately 71% of this shoreline is armored, with gunite, vertical seawalls, jetties, revetments and rip rap.

    Two jetty systems (four total structures) exist along this shoreline to control the mouth of the Agua Hedionda Lagoon and water-cooled effluent from the Encina Power Station. The power station's water effluent control structures are referred to as the "warm water jetties" and include a short groin on the downdrift side of these features to control erosion. In the near future, the Encina Power Station (a water-cooled facility) will be replaced by an air-cooled, gas-fired, peaker plant that will not require seawater for cooling. The Carlsbad Seawater Desalination Plant will use the Encina Power Station water intake/discharge system once Encina Power Station begins this conversion.
  - Terramar/Palomar Shoreline – Approximately 1.4 miles of shoreline from the northern boundary of the Terramar neighborhood to Las Encinas Creek. The area consists of a bluff-top residential community (Terramar) to the north and transitions to a beach-front roadway (Carlsbad Boulevard) to the south. Bluffs along this portion of shoreline are mostly moderate to high-relief bluffs with the exception of its lowest point at the mouth of Las Encinas Creek. Approximately 15% of this portion of shoreline, primarily the bluffs in the northern portion (in the vicinity of Terramar) is armored with gunite, seawalls and revetments protecting Carlsbad Boulevard and residential homes at Terramar.
  - Agua Hedionda Lagoon – Includes approximately 6.3 miles of lagoon shoreline, as well as lagoon waters and adjacent lands, which includes the 186-acre Agua Hedionda Lagoon Ecological Reserve, owned by the State of California and managed by the California Department of Fish & Wildlife. The lagoon is used for commercial and recreational purposes. Land uses adjacent to the lagoon include residential, open space, agriculture, commercial, as well as the power station and desalination plant. Approximately 37% of the lagoon shoreline is armored, primarily with rock revetments to stabilize inlet channels.
- **Planning Zone 3** - Includes one shoreline and one lagoon planning area in the southern portion of Carlsbad, as follows:
  - Southern Shoreline – Approximately 2.4 miles of shoreline from Las Encinas Creek to the southern city boundary at South Carlsbad State Beach. The shoreline generally consists of narrow sandy beaches backed by moderate to high relief bluffs. The bluff tops are developed with camping facilities owned and operated by the State of California Department of Parks and Recreation. This portion of shoreline also includes the mouth of the Batiquitos Lagoon, which is controlled by a jetty system. Approximately 9% of this portion of shoreline is armored, primarily with rock revetment at Las Encinas Creek and scattered rip rap within the State Parks.
  - Batiquitos Lagoon - Includes approximately 7.4 miles of lagoon shoreline, as well as the lagoon waters and all adjacent lands. The lagoon was previously restored and is a nature preserve. Lands surrounding the lagoon have high-relief and are developed with residential, commercial and open space uses. Approximately 11% of the lagoon shoreline is armored, primarily with rock revetments in the vicinity of inlets and bridges.

Figure 1. Vulnerability Assessment Planning Areas

2. SCOPE OF WORK

As part of a contract with the City of Carlsbad to conduct analysis of sea level rise and to update the city's Local Coastal Program and Zoning Ordinance, Moffatt & Nichol and Revell Coastal, as sub-consultants to Michael Baker International, are conducting the following services for the city:

1. Analysis and mapping of sea level rise hazards – Utilize Coastal Storm Modeling System (CoSMoS) 3.0 results to map sea level rise hazards for two future planning horizons (2050 and 2100).
2. Risk assessment – Determine and prioritize the relative risks to assets within each of the planning areas based on potential consequences and likelihood of impacts. Develop adaptation strategies to minimize risks from hazards and to protect coastal resources.
3. Stakeholder and agency coordination – Attend community stakeholder and technical workshops, public hearings, and coastal commission meetings to support the Local Coastal Program and Zoning Ordinance updates.

This vulnerability assessment will inform the development of sea level rise adaptation strategies, as well as the update to the city's Local Coastal Program and Zoning Ordinance.

3. COASTAL HAZARD MAPPING

This section summarizes how coastal hazards were mapped in this vulnerability assessment. See Attachment A for more detailed information on data inputs, assumptions and limitations.

Carlsbad's exposure to future rates of sea level rise was determined using preliminary results from the CoSMoS 3.0 model. CoSMoS is a multi-agency effort led by the U.S. Geological Survey (USGS) to make detailed predictions (meter scale) of coastal flooding and erosion based on existing and future climate scenarios for southern California. The modeling effort depicts coastal flooding, shoreline change and bluff response to a composite, 100-year wave event in combination with various rates of sea level rise and baseline water levels (i.e., high tide, storm surge, sea level anomaly and river discharge).

The results from four CoSMoS sea level rise scenarios (i.e., 0.5 meters [m], 1.0 m, 1.5 m and 2.0 m) were made available in the preliminary (Phase I) CoSMoS data release in November 2015. The CoSMoS 0.5-m and 2.0-m sea level rise scenarios roughly align with the projected high sea level rise from the 2012 National Research Council's report for the 2050 and 2100 planning horizons. Therefore, these sea level rise scenario results were used as the basis for this vulnerability analysis. A comparison of the National Research Council's 2012 sea level rise projections for the planning horizons compared to the CoSMoS scenarios used is shown in Table 1.

Table 1: Comparison of Sea Level Rise Scenarios

Year	2012 National Research Council Sea Level Rise Projections				CoSMoS 3.0 Sea Level Rise Scenario	Difference (CoSMoS vs. 2012 National Research Council – High SLR) (ft)
	Projection (ft)	Uncertainty (ft, +/-)	Low Range (ft)	High Range (ft)		
2050	0.9	0.3	0.4	2.0	0.5 m (1.6 ft)	0.4
2100	3.1	0.8	1.5	5.5	2.0 m (6.6 ft)	1.1

CoSMoS provides projections of shoreline erosion, coastal flooding and bluff erosion in the city. These results were used to represent inundation, coastal flood and bluff hazard zones. In addition to these hazards, a fluvial flood hazard zone was developed by Moffatt & Nichol to more accurately depict areas subject to future river floods. The hazard zones used in this analysis are described as follows:

- **Inundation Hazard Zone –** Sea level rise will result in the migration of existing coastal and lagoon shorelines in the landward direction. The inundation hazard zone is an area that will be subject to daily wetting and drying associated with tides. For beaches, CoSMoS future mean sea level (located at a beach elevation of 2.9 feet, MLLW) shoreline positions were used as a proxy for the future inundation hazard zone. For the lagoons, an elevation of mean higher high water (5.3 feet, MLLW) was used as a proxy for the future inundation hazard zone. The inundation hazard zone, shown on the coastal hazard maps in this assessment, represents the future shoreline position or the beach position at future high tide. The inundation hazard zone does not reflect potential wave run up with storm impacts, which could add to water level and increase flooding. The flood hazard zone, described below, reflects areas vulnerable to flooding.
- **Bluff Hazard Zone –** Rising sea levels may result in the increased erosion of coastal bluffs due to more frequent exposure to wave attack. Coastal bluff erosion may be gradual or may be episodic with a more significant loss related to a storm event. CoSMoS bluff erosion projections were used to represent the bluff hazard zone for the two planning horizons.

- **Flood Hazard Zone –** Includes coastal and lagoon zones, described as follows:
    - Coastal – coastal flooding events are typically short in duration (i.e., hours) and occur episodically in association with extreme wave events (e.g., 100-year return period event). These events, in combination with high tides represent the coastal flood hazard zone. CoSMoS flooding limits were used to represent the coastal flood hazard zone for the two planning horizons.
    - Fluvial (lagoon) – sea level rise has the potential to result in higher water levels in the city's lagoons during significant precipitation events (i.e., 100-year return period river flood). Moffatt & Nichol found that CoSMoS underestimates the potential fluvial flood limits within the city. A revised fluvial flood hazard zone was generated based on the results of existing numerical models of the lagoons within the city.

4. VULNERABILITY AND RISK ASSESSMENT METHODS

Methodology for assessing vulnerability and risk were based on the following guidelines developed to assist with adaptation planning efforts aimed at preparing for the effects of climate change and sea level rise:

- *California Coastal Commission Sea Level Rise Policy Guidance* adopted by the California Coastal Commission, August 12, 2015.
- *Preparing for Climate Change: A Guidebook for Local, Regional, and State Governments*, published by ICLEI-Local Governments for Sustainability (Snover, A.K. et al. 2007).
- *California Adaptation Planning Guide, Planning for Adaptive Communities* prepared by CalEMA, now known as CalOES, and the California Natural Resources Agency (CalEMA 2012).

A vulnerability assessment was performed to identify impacts that sea level rise and coastal hazards, as described in Section 3, may have on existing resources and assets within the city. Vulnerability was assessed as a function of an asset's exposure, sensitivity, and adaptive capacity. A numerical rating system was used to develop an overall vulnerability score for each asset category at the 2050 and 2100 time horizons. The definition of these terms and the rating system used are described in Table 2. A vulnerability rating of low (score of 3-4), moderate (score of 5-7), or high (score of 8-9) was assigned for each asset category based on the sum of ratings for exposure, sensitivity and adaptive capacity.

While the vulnerability assessment was performed to identify impacts from sea level rise, a risk assessment was performed to evaluate the magnitude of these impacts and likelihood of occurrence. The risk assessment was performed qualitatively to help the city manage risk related to sea level rise in their planning and decision-making process. Assessment of risk can be subjective and is not intended to establish priorities for future planning.

Table 2: Vulnerability Rating System

<table>
<tr><td colspan="3">Exposure is the degree to which an asset or resource is susceptible to coastal hazards such as flooding, inundation and bluff erosion for a given sea level rise scenario. The mapped hazard zones, shown in Section 5 and Attachment B were used to rate the level of exposure to a given asset or category.</td></tr>
<tr><td>Category</td><td>Rating</td><td>Explanation</td></tr>
<tr><td rowspan="3">Exposure</td><td>Low (1)</td><td>Asset or resource partially exposed to flooding, inundation or bluff erosion.</td></tr>
<tr><td>Moderate (2)</td><td>Asset or resource moderately exposed to flooding, inundation or bluff erosion.</td></tr>
<tr><td>High (3)</td><td>The majority of the asset or resource is exposed to flooding, inundation or bluff erosion.</td></tr>
<tr><td colspan="3">Sensitivity is the degree to which the function of an asset or resource would be impaired (i.e., weakened, compromised or damaged) by the impacts of sea level rise. <i>Example: Carlsbad Boulevard in the vicinity of Tamarack Beach has a high sensitivity to sea level rise because even minor flooding can cause significant disruption in service.</i></td></tr>
<tr><td>Category</td><td>Rating</td><td>Explanation</td></tr>
<tr><td rowspan="3">Sensitivity</td><td>Low (1)</td><td>Asset or resource is not affected or minimally affected by coastal hazards at a given sea level rise scenario.</td></tr>
<tr><td>Moderate (2)</td><td>A moderately sensitive asset or resource may experience minor damage or temporary service interruption due to coastal hazard impacts, but can recover relatively easily.</td></tr>
<tr><td>High (3)</td><td>A highly sensitive asset or resource would experience major damage or long-term service interruptions due to coastal hazard impacts, requiring significant effort to restore/rebuild to original condition.</td></tr>
<tr><td colspan="3">Adaptive capacity is the inherent ability of an asset or resource to adjust to sea level rise impacts without the need for significant intervention or modification. <i>Example: Some wetland habitat has a high adaptive capacity due to their ability to naturally migrate landward and upward with rising water levels provided adequate space exists.</i></td></tr>
<tr><td>Category</td><td>Rating</td><td>Explanation</td></tr>
<tr><td rowspan="3">Adaptive Capacity</td><td>High (1)</td><td>Asset or resource can easily be adapted or has the ability and conditions to adapt naturally.</td></tr>
<tr><td>Moderate (2)</td><td>Asset or resource can be adapted with minor additional effort.</td></tr>
<tr><td>Low (3)</td><td>Asset or resource has limited ability to adapt without significant changes.</td></tr>
</table>

The following vulnerability assessment evaluates exposure, sensitivity, and adaptive capacity for different asset categories in each of the three planning zones. The assessment includes evaluation of shoreline area vulnerabilities, as well as lagoon vulnerabilities. Sea level rise impacts within the shoreline planning areas are discussed in terms of inundation (area of future daily tidal influence as a result of beach erosion), flooding (as a result of wave run-up associated with extreme waves), and bluff erosion. Additionally, inland waters at the Buena Vista, Agua Hedionda, and Batiquitos Lagoons were evaluated for inundation (shoreline position change as a result of daily tidal inundation) and fluvial flooding (from extreme precipitation events) as a result of sea level rise.

In order to assess the vulnerability in each planning zone, assets were sorted into defined categories. These asset categories and general vulnerability assumptions are described below:

- **Beaches –** The exposure of sandy beaches to sea level rise impacts is high with anticipated erosional impacts with any sea level rise scenario. In a natural setting, beaches can be thought to have a high adaptive capacity because they will naturally adjust to a rising sea level if adequate sand exists in the system. However, the adaptive capacity of beaches can be low in areas where beaches are backed by coastal structures or development or where insufficient sand exists in the system. Continuation of sand bypassing projects, such as the Oceanside Harbor and Agua Hedionda projects, are important in restoring littoral transport of sand to beaches downdrift of these sediment blocking features. Continuation of episodic beach nourishment projects will also be important to offset regional sediment deficits.

- **Public Access Ways –** Public access ways consist of vertical access ways to and lateral access ways along the beach and lagoons. A city GIS data layer was used to identify these vertical and lateral public access ways.
- **State Parks** – Numerous state park facilities exist along the city's shoreline and consist of public day-use parking lots and campgrounds. State park facilities are recognized as important assets to the city in terms of economic and recreation value. The state park facilities also provide an important low cost visitor-serving amenity with prime access to coastal resources. Though economic impacts to the physical structures (i.e., asphalt paving, restrooms and some utilities) within the affected state parks would be relatively low, loss of these amenities would be significant since space for these features to move inland is not available.
- **Parcels -** Parcels evaluated for sea level rise impacts include privately held lots of various land uses or zoning. Current city zoning data was used to categorize the parcels into their respective zones. Parcels generally have a low adaptive capacity and high sensitivity though these ratings can be affected by the life expectancy of the development, the permit history and the physical condition of any shoreline protective device that may exist. Additionally, the adaptive capacity of buildings could potentially be moderate for some parcels with finished floors on an elevated building pad. Note that impacts to parcels may not necessarily represent impacts to the physical buildings on that parcel.
- **Critical Infrastructure (i.e., water/sewer/electrical utilities**) – Critical infrastructure includes facilities necessary to run the city effectively and efficiently since loss of water, sewer or power would significantly disrupt quality of life for residents. This infrastructure typically has a high sensitivity and low adaptive capacity.
- **Transportation Infrastructure (roadways, bike/pedestrian paths, trails)** – Roadways are generally highly sensitive to flooding hazards as even minor amounts of flooding on roads can cause significant traffic delays and potentially disrupt emergency service vehicles and evacuation routes. Maintenance and repair requirements may also increase after significant flooding and erosion events (similar to the bluff erosion repair work occurring along Carlsbad Boulevard at Las Encinas Creek). Roadways typically have a low adaptive capacity in that significant costs are associated with relocation or raising of these structures.
- **Environmentally Sensitive Lands** – Environmentally sensitive lands include wetlands, riparian areas, coastal prairies, woodlands and forests, and other natural resources in the coastal zone. These lands can have a high adaptive capacity in areas where adequate space exists for them to naturally shift landward to a rising sea level. Steep topography and existing development in the coastal zone present challenges for the landward migration of many of these lands in the City of Carlsbad. Thus, these areas are generally described as having a low adaptive capacity in the city.

A particular asset's exposure to sea level rise was characterized in terms of hazard type and quantity of assets impacted for each planning horizon.

Some resources impacted by sea level rise are difficult to quantify; thus, a qualitative analysis is provided below to generally describe how these assets may be affected by sea level rise. These resources include visual resources, cultural resources, saltwater intrusion into groundwater resources and lifeguard services. These resources are described below:

- **Visual Resources –** Visual resources in the city include views of the beaches, bluffs, and the Pacific Ocean. Sea level rise is not anticipated to affect the existing viewing opportunities of the bluffs and ocean in the city, however, beaches may be impacted as a result of accelerated erosion if no management actions are taken to mitigate these impacts (e.g., beach nourishment). Without such actions, beaches would become narrower and beach views would be impacted. Views of the ocean may also be impacted if coastal structures are built to protect assets from sea level rise or if structures are raised in height to accommodate sea level rise. Design standards in designated scenic areas can be implemented to protect visual resources while minimizing hazards.

- **Cultural (historical, archaeological and paleontological) Resources –** Exposure of historical sites to coastal hazards can lead to irreplaceable loss of cultural heritage. Identified historical sites in the City of Carlsbad were determined to not be at risk to sea level rise hazards through year 2100.

  Archaeological and paleontological resources in the city may be vulnerable to sea level rise hazards. Maps of these resources are not made publicly available for their protection. New development requires a site-specific evaluation of potential sea level rise impacts to these resources. Monitoring programs and plans may be imposed on new development where artifacts may be vulnerable to sea level rise. Additionally, consultation with Native American tribes and State Historic Preservation Officer (SHPO) would be required if cultural resources are found to be at risk to sea level rise on a new development site.

- **Saltwater Intrusion –** As sea levels rise, saltwater migrates inland through the soil and underground pathways into groundwater resources. Research suggests that sea level rise is likely to degrade fresh groundwater resources in certain areas. The degree of impact will vary due to local hydrogeological conditions. Unconfined aquifers are generally found to be the most vulnerable to saltwater intrusion from sea level rise. Groundwater use is limited and not widespread for potable or irrigation purposes in the City of Carlsbad. Thus, potential saltwater intrusion impacts because of sea level rise is not considered significant.

- **Lifeguard Services –** Lifeguard services in the city are predominately managed by State Parks, and most lifeguard facilities in the city are temporary and seasonal. Some lifeguard facilities are fixed in permanent locations and others are mobile. Those that are temporary and mobile are moved to different locations on the beach seasonally. Lifeguard facilities may be impacted by sea level rise as a result of accelerated beach erosion if no management actions are taken to mitigate these impacts (e.g., beach nourishment). Without such actions, beaches would become narrower and lifeguard facilities, especially those in locations with bluff backed beaches without area to retreat, may need to be relocated.

5. VULNERABILITY AND RISK ASSESSMENT

Results of the vulnerability assessment are discussed by planning zone in this section. Shoreline protective devices were considered in different ways for the various hazard zones in the CoSMoS model. A summary of how these structures were considered in the modeling is provided below. A more detailed description of these assumptions and limitations is provided in Attachment A.

- **Inundation Hazard Zone (Coastal) –** This zone represents the results from the CoSMoS shoreline erosion model. This model included coastal structures (rip rap, revetments and seawalls) and coastal infrastructure as a non-erodible layer. Thus, shoreline erosion stops once the beach erodes to the point where it encounters the coastal structure or infrastructure. This assumes the structure serves to protect upland assets from frequent wave attack, which may not be the case in all areas. Thus, inundation hazards may be understated in some areas where this non-erodible layer was set. A more detailed analysis of structures approached by this hazard zone may be warranted in some areas.

- **Inundation Hazard Zone (Lagoon) –** Shoreline protection structures are not included in the modeling of this hazard zone. However, since this lagoon area is a tidal system (no wave driven flooding and erosion), these results are not anticipated to be greatly affected by the lack of these structures.

- **Bluff Hazard Zone –** The CoSMoS model did not include bluff shoreline protection structures in the city. Examples of bluff protection structures that were excluded include coastal structures (seawalls, revetments, riprap) and bluff stabilization treatments that exist in the community of Terramar. The CoSMoS model states that coastal structures were not included if the armoring was low enough to be easily overwashed. Determination as to whether armoring was easily overwashed was subjective and was determined by the USGS. Not accounting for these bluff protection structures in the city likely overestimates bluff erosion hazards in areas.

- **Flood Hazard Zone (Coastal) –** Coastal structures were implicitly captured in the CoSMoS model when structures were large enough (e.g., revetments in the Village Planning Area) to be captured in the topographic data set used for the regional study. Small scale features, such as vertical seawalls along Carlsbad Boulevard in the Tamarack Planning Area, were not captured in the model due to the resolution of the topographic data used. Coastal flooding limits are likely overstated in areas where these small scale coastal structures were not captured. A more detailed analysis of this structure would be needed to more accurately define the flood hazard zone in these areas.

- **Flood Hazard Zone (Lagoon) –** Shoreline protection structures are not included in the modeling of this hazard zone. However, since this a tidal system (no wave driven flooding and erosion), these results are not anticipated to be greatly affected by the lack of these structures.

Year 2050 and 2100 results are presented and discussed in this section. For simplicity, vulnerability graphics are provided in this section for year 2050 only; vulnerability graphics for year 2100 are included in Attachment B.

5.1. PLANNING ZONE 1

Planning Zone 1 includes the Village Shoreline and Buena Vista Lagoon planning areas. Assets within this zone are vulnerable to inundation, flooding and bluff erosion in the 2050 and 2100 planning horizons. A summary of the vulnerability assessment rating is provided in Table 3. A discussion of the vulnerability and risk assessment is also provided for each asset category.

Table 3: Planning Zone 1 Vulnerability Assessment Summary

Asset Category	Horizon	Hazard Type	Impacted Assets	Exposure Rating	Sensitivity Rating	Adaptive Capacity Rating	Vulnerability Rating (Score)
Beaches	2050	Inundation/ Erosion, Flooding	6 acres (erosion)	3	1	3	Moderate (7)
	2100		66 acres (erosion)	3	3	3	High (9)
Public Access Ways	2050	Inundation/ Erosion, Flooding	Vertical – 13 access points Lateral (trails) - 5,039 linear feet	2	2	1	Moderate (5)
	2100	Inundation, Flooding	Vertical – 15 access points Lateral (trails) - 9,626 linear feet	3	2	1	Moderate (6)
Parcels	2050	Flooding	145 parcels	1	2	3	Moderate (6)
	2100	Inundation, Flooding, Bluff Erosion	151 parcels	2	3	3	High (8)
Critical Infrastructure	2050	None	N/A	N/A	N/A	N/A	N/A
	2100	Flooding	1 parcel	2	2	3	Moderate (7)
Transportation (Road, Bike, Pedestrian)	2050	Flooding / Bluff Erosion	2,915 linear feet	1	3	3	Moderate (7)
	2100		3,857 linear feet	2	3	3	High (8)
Environmentally Sensitive Lands	2050	Flooding	124 acres	0	0	3	Low (3)
	2100	Inundation, Flooding	125 acres	2	3	3	High (8)

5.1.1. Beaches

Approximately 6 acres of beach area is projected to be impacted by inundation/erosion by year 2050. Beaches are exposed to any rise in sea levels (high exposure) but will continue to provide recreation and storm protection benefits during this time horizon (low sensitivity). Beaches are formed by natural processes and have the ability to adapt to rising sea levels, assuming sufficient sand supplies exist and there is adequate space for the beach to migrate landward. However, the adaptive capacity of beaches is low in areas where beaches are backed by coastal structures or development or where insufficient sand exists in the system. This is the case in this planning area. Development backed beaches are common in southern California and in much of the City of Carlsbad. Thus, the overall vulnerability rating for beaches is moderate for year 2050. This vulnerability poses a moderate risk to the city because there is a high likelihood of beach loss occurring due to sea level rise.

Vulnerability is rated high for beaches in the 2100 horizon due to the significant erosion expected as the beaches are squeezed between rising sea levels and coastal development. This vulnerability poses a high risk to the city as increased beach erosion will reduce the natural barrier to storm waves and reduce opportunity for beach access and recreation. There are also economic costs associated with such impacts; beach visitation from both in-town and out-of-town guests results in economic benefits to city businesses (e.g., retail, restaurants, hotel).

5.1.2. Public Access Ways

Coastal flooding and erosion has the potential to impact vertical (access to) and lateral (access along) beach access ways in the city. For example, erosion of the beach may create a large scarp (or drop off) at the end of a beach access stairway. Wave forces during large surf may also physically damage stairways making them impassable temporarily.

A total of 15 vertical beach access ways exist within Planning Zone 1. Most of these beach access ways (i.e., 13) were determined to be potentially impacted by coastal flooding by year 2050. All 15 were found to be vulnerable to flooding and erosion by year 2100.

Lateral beach access ways in this planning area include existing trails in the vicinity of Hosp Grove Park and along Carlsbad Boulevard. Approximately 1 mile of existing trails were found to be vulnerable by year 2050. Approximately 2 miles of existing trails were vulnerable by year 2100.

The vulnerability of trails in both planning horizons was found to be moderate, owing mostly to the relatively high adaptive capacity of these assets. Beach access ways can generally accommodate flooding and can typically be repaired relatively easily. Similarly, lagoon trails can accommodate some level of flooding and can be relocated when maintenance costs become too high.

5.1.3. Parcels

Portions of parcels, where buildings are located, along the northern portion of the Village Planning Area and Buena Vista Lagoon may be exposed to flooding during an extreme event in year 2050. However, the majority of buildings themselves do not appear flooded in this scenario and are fronted by shore protection in the form of a revetment or seawall (low exposure). Parcels were assigned a vulnerability rating of moderate since development is typically sensitive to episodic flooding with little adaptive capacity. This vulnerability poses a moderate risk to parcel owners due to the high consequence of flooding impacts on parcel usage and value. The likelihood of occurrence of this type of impact is relatively low and would only be expected during extreme storm events.

Vulnerability of parcels is rated high for the 2100 scenario due to the increased exposure and sensitivity of parcels to flooding, inundation and bluff erosion during an extreme storm event. This poses a high risk to parcel owners due to the higher consequence of damage under the storm scenario evaluated for the 2100 planning horizon.

5.1.4. Critical Infrastructure

There were no impacts to parcels identified as critical infrastructure for the 2050 planning horizon. A portion of a sewer pump station parcel was found to be exposed to flooding by the 2100-time horizon. This asset has sensitive electrical components and could fail should flooding of the facility occur. The pump station was assigned a moderate vulnerability since the pump station itself was not shown to be exposed to flooding. Thus, the likelihood of flooding is low and may only be expected during extreme storm events (greater than 100-year return period events). However, the flooding of the pump station has the potential to result in sewer spills and service interruptions. There are storm drains and culverts within Planning Zone 1, however, these facilities are not considered critical infrastructure for the purposes of this assessment (for more information refer to Appendix A, section 3.5.7).

5.1.5. Transportation Infrastructure

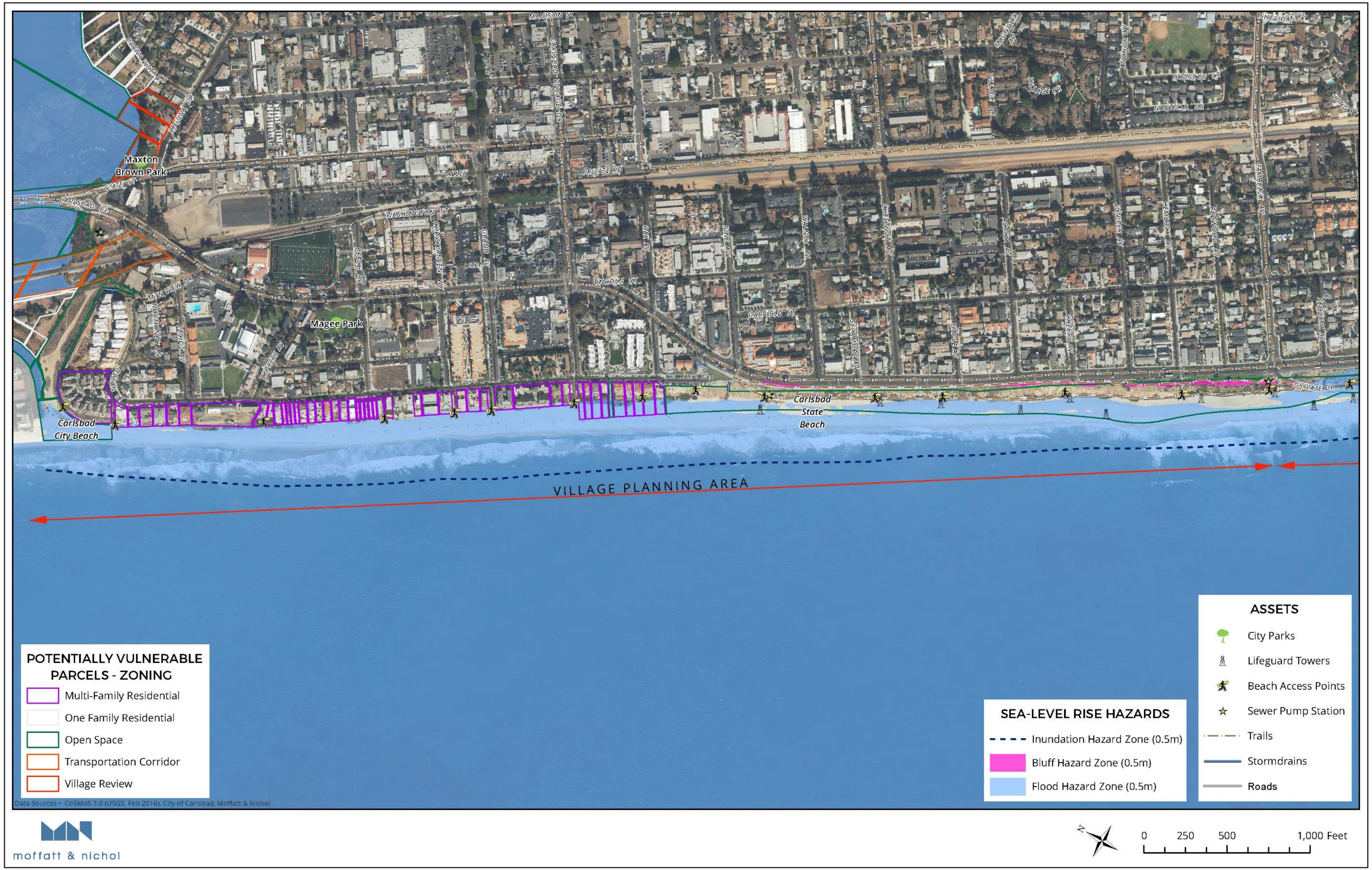
Carlsbad Boulevard provides a vital north-south connection and will be partially exposed to flooding and bluff erosion during extreme storms in the 2050 planning horizon. Flooding exposure is localized to the Carlsbad Boulevard crossing of Buena Vista Lagoon in an area that has historically experienced flooding. Bluff erosion potential is identified along the southern portion of the Village Planning Area from about Pine Avenue to Tamarack Avenue. The bluff hazard assumes that the seawall in this area fails or is overwhelmed; thus, allowing erosion to continue landward of this feature. Although Carlsbad Boulevard is only partially exposed, the asset was assigned a moderate vulnerability in 2050 because of high sensitivity to flooding (temporary service interruptions) and low adaptive capacity. This is considered a high vulnerability in 2100 because of the vital north-south connection provided by Carlsbad Boulevard (high consequence).

Vulnerability is considered high for the 2100 planning horizon as the exposure of Carlsbad Boulevard increases. The risk of this impact remains high for the 2100 planning horizon due to service interruptions or road closures that can result in traffic delays, emergency service delays and loss of evacuation routes. Damage to Carlsbad Boulevard in 2100 would also likely result in higher repair costs.

5.1.6. Environmentally Sensitive Lands

Environmentally sensitive lands (e.g., lagoon, surrounding open lands, etc.) in the Buena Vista Lagoon area are exposed to increased tidal inundation as a result of sea level rise in year 2100 only because of the presence of the inlet weir structure. The weir elevation restricts tidal exchange through year 2050 planning horizon. Assuming no change to the existing condition, the weir becomes overwhelmed by year 2100 sea levels. Therefore, conditions within the lagoon remain unchanged/unaffected (no exposure and low sensitivity) by sea levels in the 2050 planning horizon. The vulnerability of environmentally sensitive lands to sea level rise in 2050 is low.

By 2100, the lagoon would become subject to tides exposing environmentally sensitive lands to daily inundation (high exposure). These assets are highly sensitive to this exposure as wetland hydrology may be altered by the rising freshwater-saltwater interface (CalEMA and CNRA 2014) and intertidal and subtidal ecosystems may be affected by changes in water depth and sunlight penetration. Due to the steep topography and development along the lagoon, the ability for flora and fauna to adapt by migrating vertically and/or horizontally may be limited (low adaptive capacity). The vulnerability to environmentally sensitive lands in year 2100 is high. The vulnerability poses a high risk to the environmental resources in the city because impacts to environmentally sensitive lands are likely to occur and may adversely affect the density and diversity of these resources (high consequence). Risk of this vulnerability remains high as the consequence to density and diversity of environmental resources are significant.



Data Sources: CoSMoS 3.0 (USGS, Feb 2016), City of Carlsbad, Moffatt & Nichol

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Figure 2: Village Shoreline Hazards in Year 2050

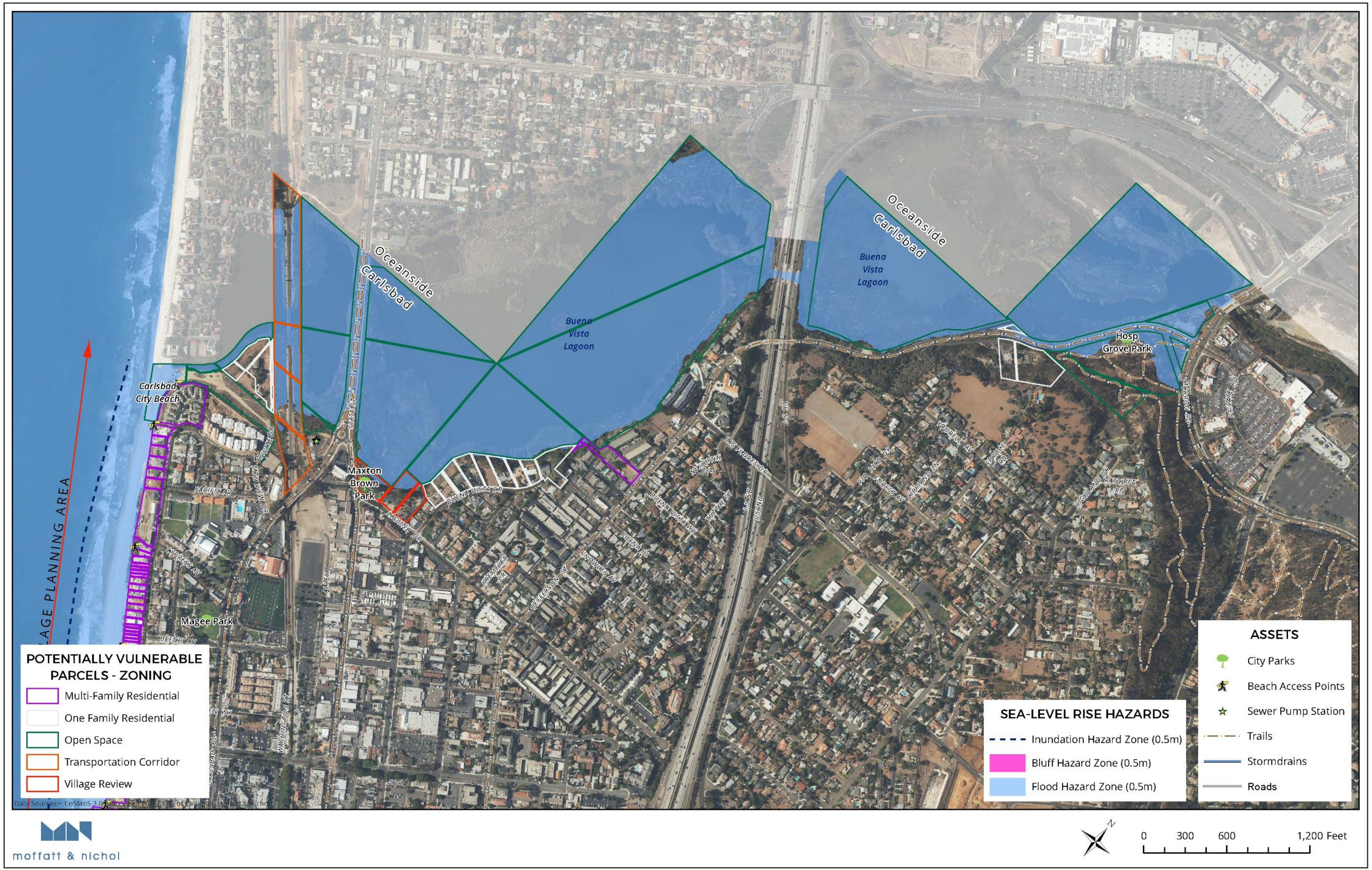

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Figure 3: Buena Vista Lagoon Hazards in Year 2050

5.2. PLANNING ZONE 2

Planning Zone 2 consists of two shoreline planning areas (Tamarack/Warm Water Shoreline and Terramar/ Palomar Shoreline) and the Agua Hedionda Lagoon. Assets within this zone are vulnerable to inundation, coastal flooding and bluff erosion in the 2050 and 2100 planning horizons. A summary of the vulnerability assessment rating is provided in Table 4. A discussion of the vulnerability and risk assessment is also provided for each asset category.

Table 4: Planning Zone 2 Vulnerability Assessment Summary

Asset Category	Horizon	Hazard Type	Impacted Assets	Exposure Rating	Sensitivity Rating	Adaptive Capacity Rating	Vulnerability Rating (Score)
Beaches	2050	Inundation/ Erosion, Flooding	7 acres (erosion)	3	1	3	Moderate (7)
	2100		26 acres (erosion)	3	3	3	High (9)
Public Access Ways	2050	Inundation/ Erosion, Flooding	Vertical – 7 access points Lateral (trails) – 4,036 linear feet	2	2	1	Moderate (5)
	2100	Inundation, Flooding	Vertical – 12 access points Lateral (trails) - 14,941 linear feet	3	2	1	Moderate (6)
State Parks	2050	Flooding / Bluff Erosion	2 parcels	2	1	2	Moderate (5)
	2100		2 parcels	3	2	2	Moderate (7)
Parcels	2050	Flooding	370 parcels	2	2	3	Moderate (7)
	2100	Inundation, Flooding, Bluff Erosion	451 parcels	3	3	3	High (9)
Critical Infrastructure	2050	None	N/A	N/A	N/A	N/A	N/A
	2100	Flooding	7 parcels	1	1	3	Moderate (5)
Transportation (Road, Bike, Pedestrian)	2050	Flooding, Bluff Erosion	4,229 linear feet	3	3	3	High (9)
	2100		15,326 linear feet	3	3	3	High (9)
Environmentally Sensitive Lands	2050	Inundation, Flooding	392 acres	3	2	3	High (8)
	2100		434 acres	3	3	3	High (9)

5.2.1. Beaches

Approximately seven acres of beach area is projected to be impacted by inundation/erosion in 2050. As stated above, beaches are exposed to any rise in sea levels (high exposure) but will continue to provide recreation and storm protection benefits during this time horizon (low sensitivity). Beaches in this planning zone are backed by coastal structures and development; thus, have a low adaptive capacity. The overall vulnerability rating for beaches is moderate for 2050. This impact poses a moderate risk to the city because there is a high likelihood of beach loss occurring due to sea level rise, but low consequence to overall beach function based on shoreline change results from the CoSMoS 3.0 model.

Vulnerability is rated high for the 2100 horizon due to the significant erosion expected as the beaches are squeezed between rising sea levels and bluffs or coastal structures. This vulnerability poses a high risk to the city as increased beach erosion will reduce the natural barrier to storm waves and reduce opportunity for beach access and recreation. There are also economic costs associated with such impacts; beach visitation from both in-town and out-of-town guests results in economic benefits to city businesses (e.g., retail, restaurants, hotel).

5.2.2. Public Access Ways

A total of 12 vertical beach access ways exist within Planning Zone 2. A total of seven of these beach access ways were determined to be potentially impacted by coastal flooding by year 2050. All 12 were found to be vulnerable to flooding and inundation by year 2100.

Lateral beach access ways in this planning area include trails along Agua Hedionda Lagoon and along Carlsbad Boulevard. Approximately 4,000 feet of existing trails were found to be vulnerable to flooding by year 2050. Approximately 15,000 feet of existing trails were vulnerable to flooding by year 2100.

The vulnerability of existing trails in both planning horizons was found to be moderate, owing mostly to the relatively high adaptive capacity of these assets. Beach access ways can generally accommodate flooding and can typically be repaired relatively easily. Similarly, existing lagoon trails can accommodate some level of flooding and can be relocated when maintenance costs become too high.

5.2.3. State Parks

The Tamarack State Beach parking lot becomes partially exposed to flooding during extreme storm events by 2050. The shoreline position/Inundation Hazard Zone is well seaward of the parking lot (i.e., wide sandy beach) in this scenario. State Park lands in the southern Terramar Planning Area are exposed to bluff erosion in 2050. The sensitivity of State Park lands varies in this planning area. The Tamarack State Beach parking lot has a low sensitivity and high adaptive capacity since it can tolerate episodic flooding during extreme storms while remaining functional at other times. The overall vulnerability rating for State Park lands is considered moderate due to the varied levels of sensitivity and adaptive capacity. This vulnerability poses a relatively low risk in 2050 since the consequence of episodic flooding/erosion during extreme storms will have a limited effect on access and recreational opportunities within the State Park.

Exposure to flooding increases in year 2100 and complete flooding of the Tamarack State Beach parking lot can be expected during extreme storms events. The shoreline position/Inundation Hazard Zone has eroded to the existing revetment in this area by this time; thus, no beach exists in this scenario. Since shoreline erosion is projected to stop at the existing revetment line (set as non-erodible in the CoSMoS model), no erosion of the bluff landward of the parking lot occurs. Exposure to bluff erosion in the southern Terramar planning zone also increases. The overall vulnerability rating for state park lands will increase in 2100 but is still considered moderate. This vulnerability poses a moderate risk in 2100 since the consequence of more frequent flooding and erosion could result in permanent impacts to recreational opportunities within the state park.

5.2.4. Parcels

A number of residential parcels in the vicinity of Terramar Point were determined to be exposed to bluff erosion hazards in the 2050 sea level rise scenario. Portions of parcels along the northern shoreline of Agua Hedionda Lagoon may also be exposed to flooding during an extreme event in year 2050 (moderate exposure). Parcels were assigned a vulnerability rating of moderate since development is typically sensitive to episodic flooding with little adaptive capacity. This vulnerability poses a moderate risk to parcel owners due to the high consequence of flooding impacts on parcel usage and value. The likelihood of occurrence of this type of impact is relatively low and would only be expected during extreme storm events.

Vulnerability of parcels is rated high for the 2100 scenario due to the increased exposure and sensitivity of parcels to flooding and bluff erosion during an extreme storm event. Residential parcels along Terramar Point and the northern shoreline of Agua Hedionda Lagoon were found to be highly exposed to coastal hazards in 2100. The Hubbs Sea World Research Institute, the Carlsbad AquaFarm and the YMCA facility are also impacted as flood and tidal waters encroach onto these parcels. This poses a high risk to property owners due to the higher consequence of damage and disruption of operations during the 2100 planning horizon.

5.2.5. Critical Infrastructure

There were no impacts to parcels identified as critical infrastructure for the 2050 planning horizon. The Encina Power Station and the desalination plant parcels were identified as being partially exposed to fluvial flooding from Agua Hedionda Lagoon as a result of sea level rise in 2100. The Encina Power Station and the desalination plant appear minimally impacted (low sensitivity) as the flooding does not appear to encroach onto critical facilities. However, confirmation of the future uses of the intake/discharge system relative to flood risks is needed to fully understand this vulnerability. Note that the Encina Power Station is scheduled to be demolished by 2020; thus, the vulnerability of this existing facility is negligible. The existing power station will be replaced with a new facility (Carlsbad Energy Center Project) that uses peaker plant technology; the new facility will be located between the railroad and Interstate 5. The Agua Hedionda Sewer Lift Station and future Carlsbad Energy Center Project (both located between the railroad and Interstate-5) are outside the coastal hazards mapped for the 2050 and 2100 scenarios. However, a project-specific sea level rise analysis may be warranted for these projects depending on specific components being proposed. Critical infrastructure was assigned a moderate vulnerability due to the low adaptive capacity and uncertainty regarding future uses of the intake/discharge system. There are storm drains and culverts within Planning Zone 2, however, these facilities are not considered critical infrastructure for the purposes of this assessment (for more information refer to Appendix A, section 3.5.7).

5.2.6. Transportation Infrastructure

Approximately 4,229 linear feet of Carlsbad Boulevard within Planning Zone 2 is exposed to bluff erosion hazards during the 2050 scenario (high exposure). Carlsbad Boulevard provides a vital north-south linkage within the city; thus, its sensitivity to sea level rise is high. The adaptive capacity of the road is low since raising or relocating it may be challenging. This is considered a high-risk vulnerability because of the vital north-south connection provided by Carlsbad Boulevard (high consequence).

Vulnerability remains high for the 2100 planning horizon as 15,326 linear feet of Carlsbad Boulevard are exposed to bluff erosion and flooding during an extreme storm event. The risk of this vulnerability remains high for the 2100 planning horizon due to service interruptions or road closures that can result in traffic delays, emergency service delays and loss of evacuation routes. Damage to infrastructure due to hazards identified in 2100 may result in major infrastructure repair or relocation costs.

5.2.7. Environmentally Sensitive Lands

Environmentally sensitive lands (e.g., lagoon, surrounding open lands, etc.) in the Agua Hedionda Lagoon area are exposed to increased tidal inundation and flooding with any rise in sea levels (high exposure). These assets are moderately sensitive to this exposure as wetland hydrology may be altered by the rising freshwater-saltwater interface (CalEMA and CNRA 2014) and intertidal and subtidal ecosystems may be affected by changes in water depth and sunlight penetration. Due to the steep topography and development along the Agua Hedionda Lagoon, the ability for flora and fauna to adapt by migrating vertically and/or horizontally may be limited (low adaptive capacity). This high vulnerability poses a high risk to the environmental resources in the city because impacts to environmentally sensitive lands are likely to occur and may adversely affect the density and diversity of these resources (high consequence).

A high vulnerability rating was also assigned for the 2100 time horizon as adaptive capacity remains limited. However, despite the large increase in sea level rise between 2050 and 2100, the overall impacted acreage increased by less than 10%. Risk of this vulnerability remains high as the consequence to density and diversity of environmental resources are significant.

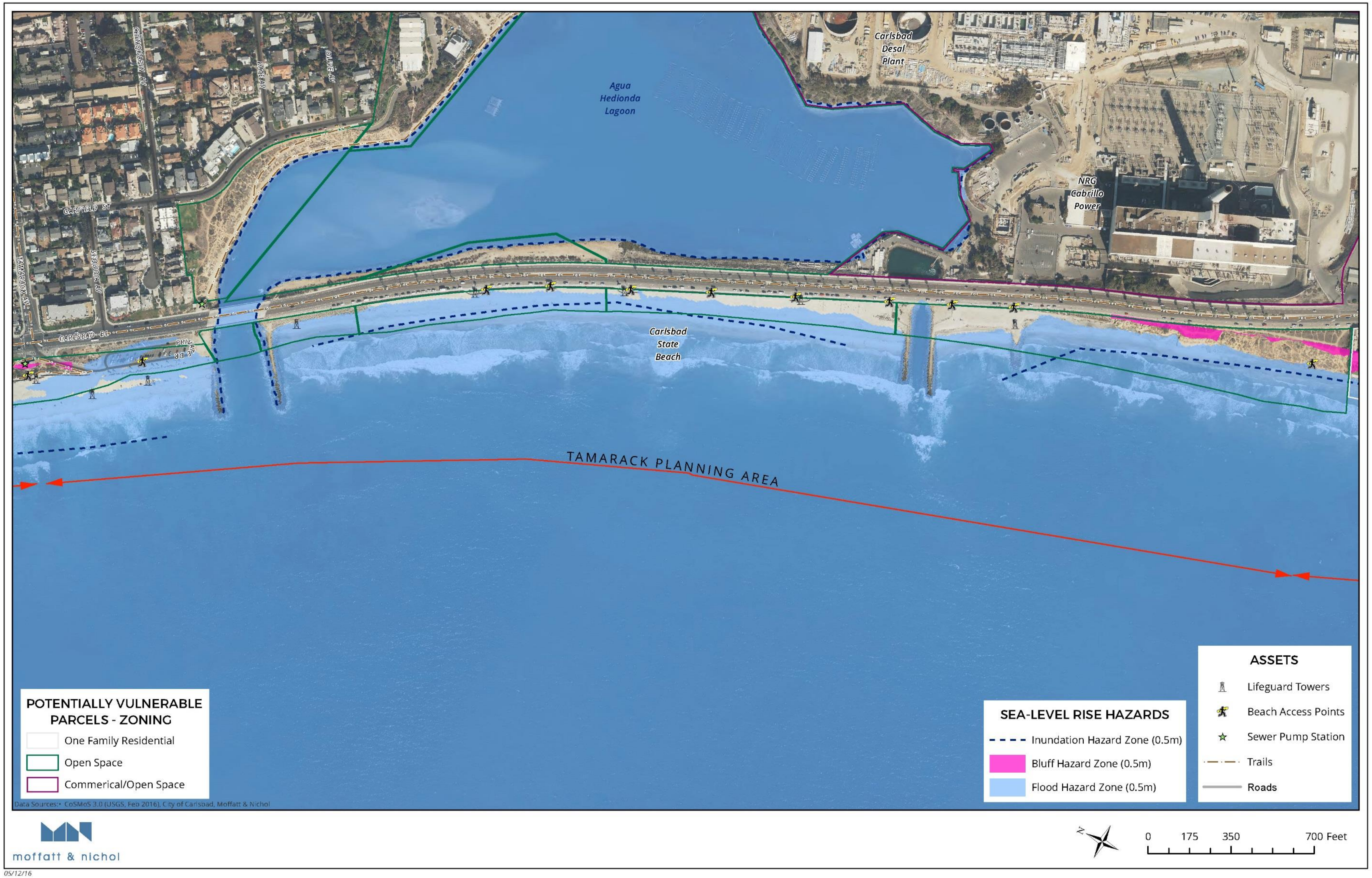

Figure 4: Tamarack Planning Area – Year 2050

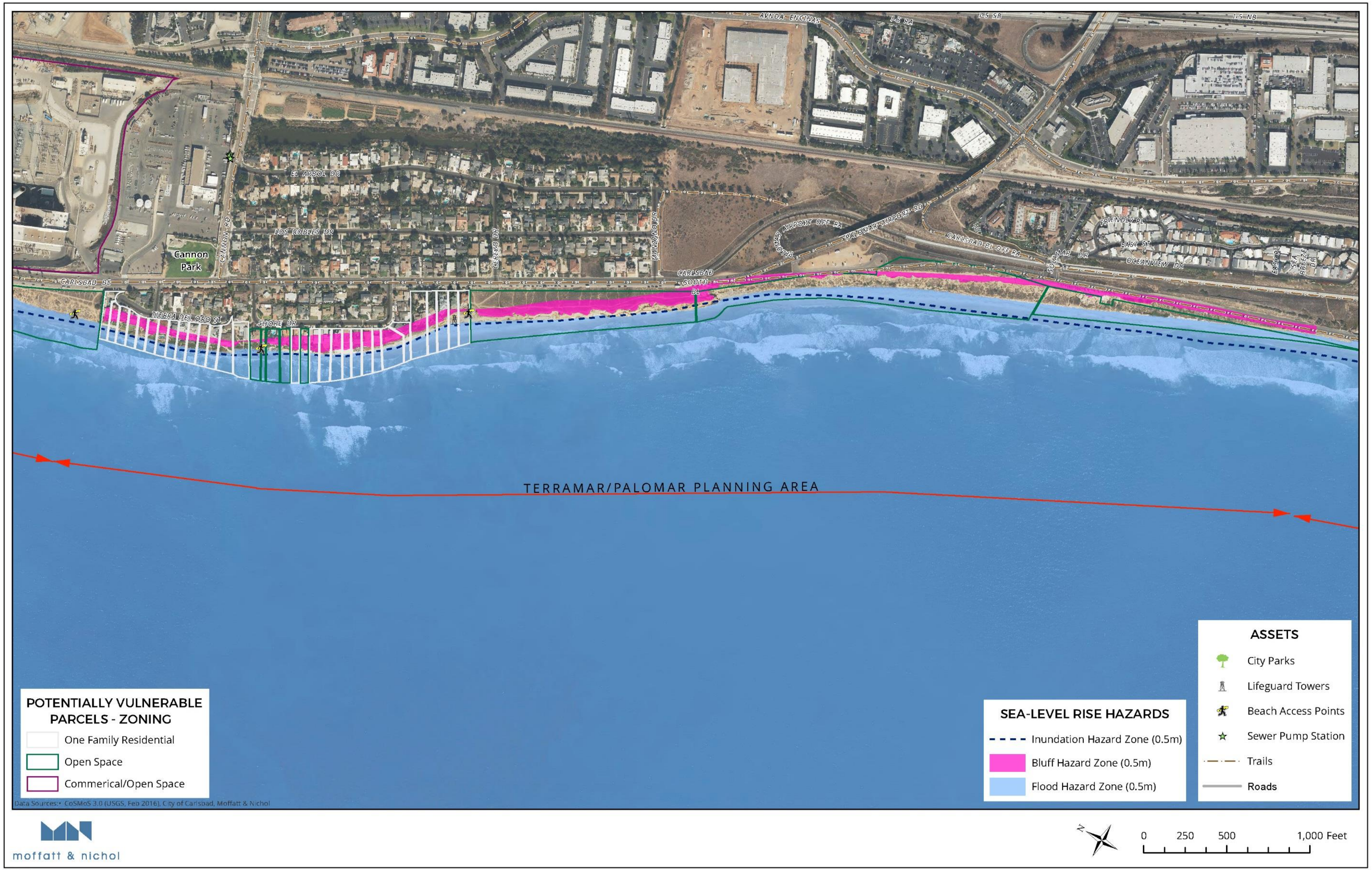

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Figure 5: Terramar / Palomar Planning Area – Year 2050

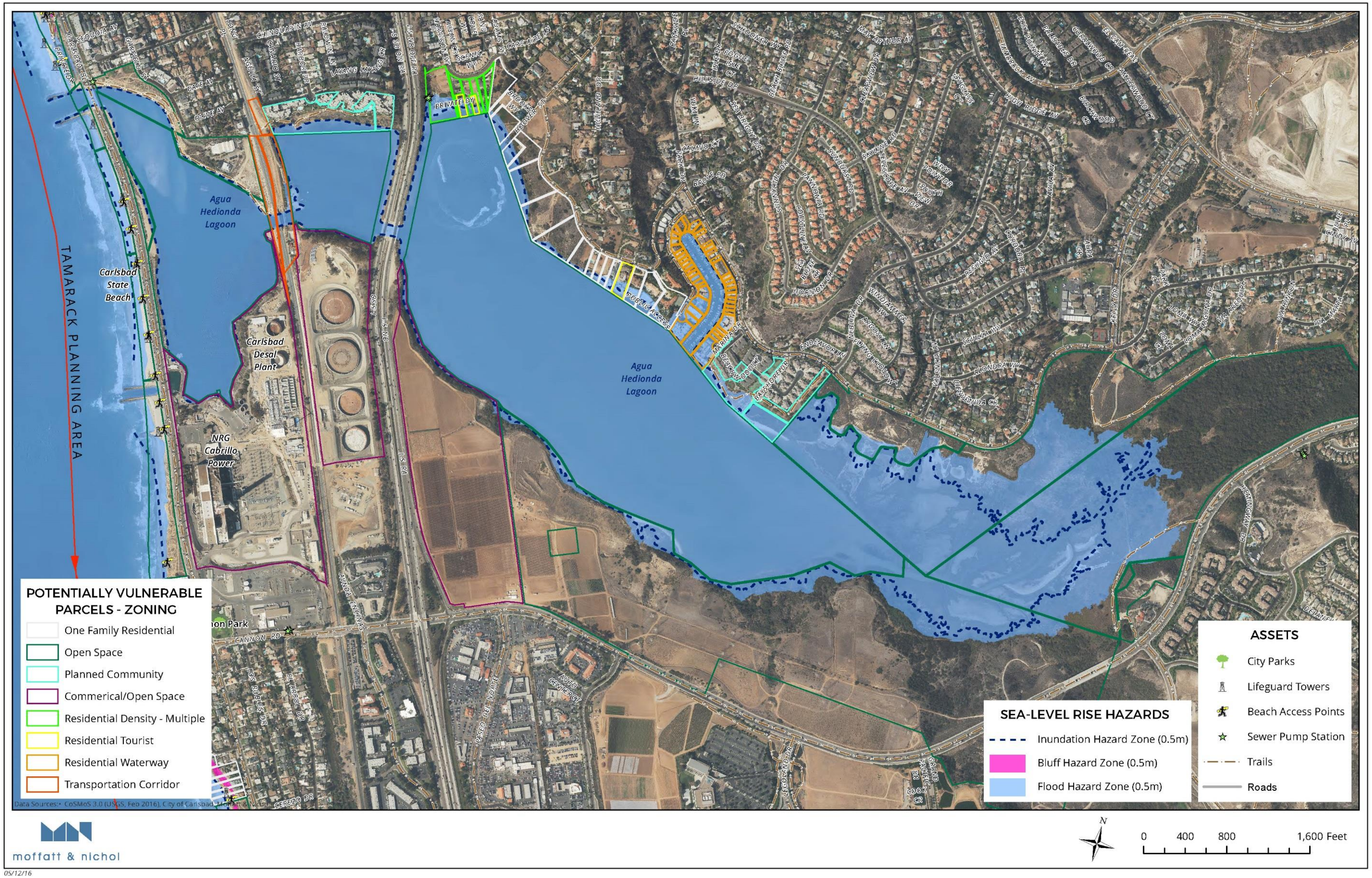

Figure 6: Agua Hedionda Lagoon Planning Area – Year 2050

5.3. PLANNING ZONE 3

Planning Zone 3 consists of the Southern Shoreline Planning Area and the Batiquitos Lagoon. Assets within this zone are vulnerable to inundation, coastal flooding and bluff erosion in both planning horizons (2050 and 2100). A summary of the vulnerability assessment rating is provided in Table 5. A discussion of the vulnerability and risk assessment is also provided for each asset category.

Table 5: Planning Zone 3 Vulnerability Assessment Summary

Asset Category	Horizon	Hazard Type	Impacted Assets	Exposure Rating	Sensitivity Rating	Adaptive Capacity Rating	Vulnerability Rating (Score)
Beaches	2050	Inundation/ Erosion, Flooding	14 acres (erosion)	3	1	2	Moderate (6)
	2100	Inundation/ Erosion, Flooding	54 acres (erosion)	3	2	2	Moderate (7)
Public Access Ways	2050	Inundation, Flooding	Vertical – 6 access points Lateral (trails) – 4,791 linear feet	2	2	1	Moderate (5)
	2100	Inundation, Flooding	Vertical – 10 access points Lateral (trails) - 14,049 linear feet	3	2	1	Moderate (6)
State Parks	2050	Flooding, Bluff Erosion	4 parcels	2	3	3	High (8)
	2100		4 parcels	3	3	3	High (9)
Parcels	2050	Flooding, Bluff Erosion	49 parcels	1	1	1	Low (3)
	2100		55 parcels	1	1	1	Low (3)
Critical Infrastructure	2050	N/A	N/A	N/A	N/A	N/A	N/A
	2100	N/A	N/A	N/A	N/A	N/A	N/A
Transportation (Road, Bike, Pedestrian)	2050	Bluff Erosion	1,383 linear feet	1	3	3	Moderate (7)
	2100	Flooding, Bluff Erosion	11,280 linear feet	2	3	3	High (8)
Environmentally Sensitive Lands	2050	Inundation, Flooding	572 acres	3	2	2	Moderate (7)
	2100		606 acres	3	3	3	High (9)

5.3.1. Beaches

Approximately 14 acres of beach area is projected to be impacted by inundation/erosion in 2050. Beaches are exposed to any rise in sea levels (high exposure) but will continue to provide recreation and storm protection benefits during this time horizon (low sensitivity). Beaches in this planning area are backed by unarmored coastal bluffs. Sand derived from the natural erosion of the bluff as sea levels rise may be adequate to sustain beach widths, thus, beaches in this reach were assumed to have a moderate adaptive capacity. The overall vulnerability rating for beaches is moderate for 2050. This impact poses a moderate risk to the city because there is a moderate likelihood of beach loss occurring due to sea level rise, but low consequence to overall beach function based on shoreline change results from the CoSMoS 3.0 model.

Vulnerability is rated moderate for the 2100 horizon due to the significant amount of erosion expected as the beaches are squeezed between rising sea levels and bluffs. Assuming the bluffs are unarmored in the future, sand derived from bluff erosion may sustain some level of beaches in this planning area. A complete loss of beaches poses a high risk to the city as the natural barrier from storm waves is lost as well as a reduction in beach access, recreation and the economic benefits the beaches provide.

5.3.2. Public Access Ways

A total of 10 vertical beach access ways exist within Planning Zone 3. Six of these beach access ways were determined to be potentially impacted by coastal flooding by year 2050. All 10 were found to be vulnerable to flooding and inundation by year 2100.

Lateral beach access ways in this planning area include trails along Batiquitos Lagoon and along Carlsbad Boulevard. Approximately 5,000 feet of existing trails were found to be vulnerable by year 2050. Approximately 14,000 feet of existing trails were vulnerable by year 2100.

The vulnerability of existing trails in both planning horizons was found to be moderate, owing mostly to the relatively high adaptive capacity of these assets. Beach access ways can generally accommodate flooding and can typically be repaired relatively easily. Similarly, existing lagoon trails can accommodate some level of flooding and can be relocated when maintenance costs become too high.

5.3.3. State Parks

A majority of the South Carlsbad State Beach day-use facilities and campgrounds (separated into four parcels) were determined to be exposed to bluff erosion by the 2050 sea level rise scenario (moderate exposure). This resource is considered to have a high sensitivity since bluff erosion could significantly impair usage of the facilities. Though economic impacts to the physical structures within South Carlsbad State Beach would be relatively low, the loss of this park would be significant since adequate space for the park to move inland is not available (low adaptive capacity). State parks was assigned a high vulnerability in the 2050 planning horizon. State park facilities are recognized as important assets to the city in terms of economic and recreation value as well as providing low-cost visitor serving amenities. This vulnerability poses a high risk to coastal access, recreation, and tourism opportunities in this planning area.

In 2100, bluff erosion of South Carlsbad State Beach day-use facilities and campgrounds become more severe and the South Ponto State Beach day-use area becomes exposed to coastal flooding during extreme events. The sensitivity of the South Ponto day-use area is low because impacts to usage will be temporary and no major damage to facilities would be anticipated. Vulnerability and risk to State Parks remains high by 2100 due to the impacts to South Carlsbad State Beach in combination with flooding impacts to South Ponto.

5.3.4. Parcels

Portions of privately held parcels within Batiquitos Lagoon may be exposed to flooding during an extreme event by year 2050 (low exposure). These parcels include undeveloped lands and a golf course on the north side of the lagoon. No buildings are flooded under this scenario; thus, sensitivity is considered low. Adequate space seems to exist to accommodate sea level rise (high adaptive capacity). Overall vulnerability is considered low. Due to the relatively minor consequence and low likelihood of occurrence the risk of this vulnerability is also low.

A total of 55 parcels were found to be impacted by year 2100. These parcels are open space, planned communities and transportation corridors. Impacted open space and planned communities are undeveloped (i.e., buildings not present), thus, vulnerability and risk to these land uses and function are considered low. Impacted transportation corridor parcels are owned by the North County Transit District. The rail line is elevated on a dike and bridged over the lagoon. Impacts to these parcels are not considered significant.

5.3.5. Critical Infrastructure

No critical infrastructure is identified as vulnerable in the 2050 or 2100 years in Planning Zone 3. There are storm drains and culverts within Planning Zone 3, however, these facilities are not considered critical infrastructure for the purposes of this assessment (for more information refer to Appendix A, section 3.5.7).

5.3.6. Transportation Infrastructure

Southbound Carlsbad Boulevard is exposed to bluff erosion in the vicinity of its intersection with Avenida Encinas and near Las Encinas Creek (low exposure). Bluff erosion recently resulted in emergency shore protection work along Carlsbad Boulevard in the vicinity of Las Encinas Creek. The sensitivity is high since bluff erosion hazards could significantly impact usage of transportation infrastructure. Right of way does appear available on the landward side of the southbound roadway at Las Encinas Creek. However, modifying the roadway alignment would result in significant costs (low adaptive capacity). The overall vulnerability is considered moderate at the 2050 time horizon. Damage to the southbound lanes of Carlsbad Boulevard poses a high risk due to the potential service interruptions and associated repair costs along this vital north-south connection (high consequence).

Approximately 11,280 linear feet of transportation infrastructure may be exposed to bluff erosion and flooding by the 2100 scenario. This includes both northbound and southbound lanes of Carlsbad Boulevard in the vicinity of Las Encinas Creek and Batiquitos Lagoon, La Costa Avenue along the south side of Batiquitos Lagoon, and a private road within North Ponto State Beach Campgrounds. The sensitivity of all roadway segments is high because of the significant disruption to transportation circulation during these events. It is not likely that temporary flooding events will result in the need for major repairs to the roadway, but repairs due to bluff erosion could be significant. The adaptive capacity of these roadways is low since raising or relocating them would be costly. Damage to Carlsbad Boulevard from bluff erosion and flooding poses a high risk due to the potential service interruptions and associated repair costs along these routes (high consequence).

5.3.7. Environmentally Sensitive Lands

Environmentally sensitive lands (e.g., lagoon, surrounding open lands, etc.) in the Batiquitos Lagoon are exposed to increased tidal inundation with any rise in sea levels (high exposure). These assets are moderately sensitive to this exposure as wetland hydrology may be altered by the rising freshwater-saltwater interface (CalEMA and CNRA 2014) and intertidal and subtidal ecosystems may be affected by changes in water depth and sunlight penetration. Due to the topography and development conditions in Batiquitos Lagoon, it is anticipated that most flora and fauna may be able to adapt by migrating vertically and/or horizontally, keeping pace with the rate of sea level rise up to 2050 (moderate adaptive capacity). The overall vulnerability of environmentally sensitive lands is moderate in 2050. The vulnerability poses a high risk to the environmental resources in the city because impacts to environmentally sensitive lands are likely to occur and may adversely affect the density and diversity of these resources (high consequence).

Due to the steep topography and development along the lagoon, the ability for flora and fauna to adapt by migrating vertically and/or horizontally may be limited in 2100 (low adaptive capacity). Thus, a high vulnerability rating was assigned for the 2100 horizon. Despite the large increase in sea level rise between 2050 and 2100, the overall impacted acreage increased by only 6%. Risk of this vulnerability remains high as the consequence to density and diversity of environmental resources is significant.

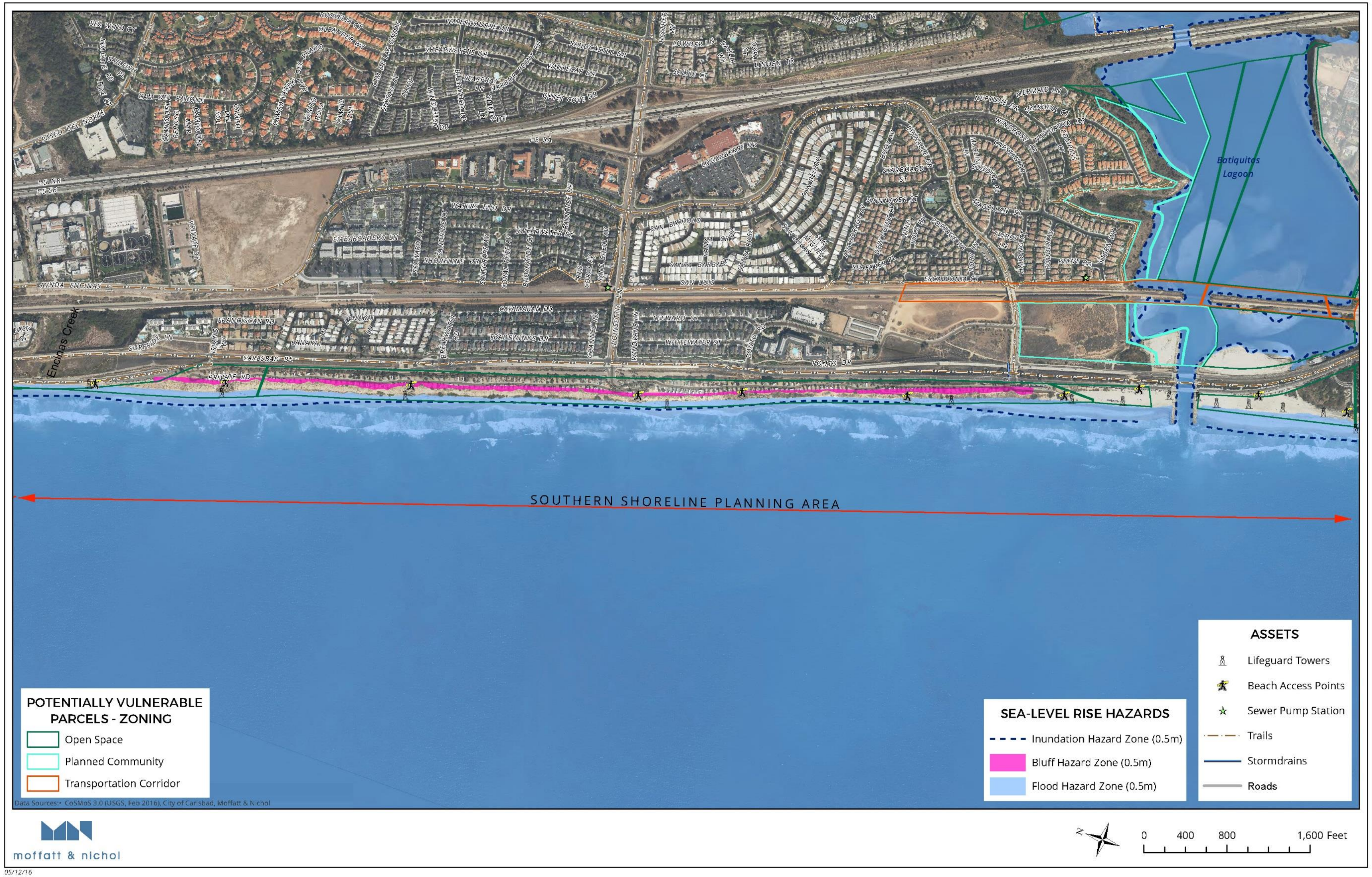

Figure 7: Southern Shoreline Planning Area – Year 2050

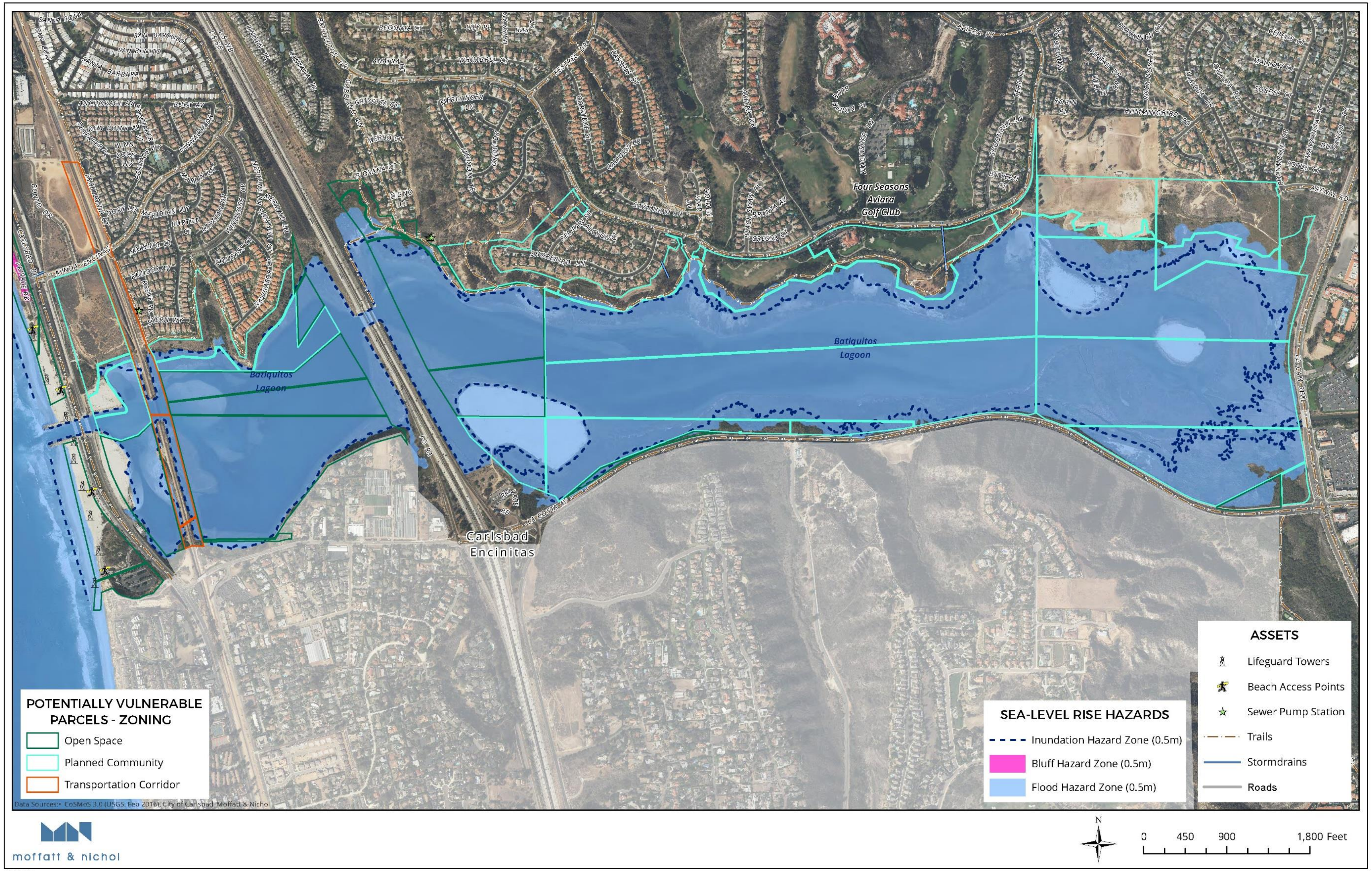

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Figure 8: Batiquitos Lagoon Planning Area – Year 2050

6. ADAPTING TO SEA LEVEL RISE

Adaptation to sea level rise, and other results of climate change, involves taking appropriate actions to prevent or minimize the adverse effects of climate-induced impacts. Adaptation planning involves a range of policies, programmatic measures and specific engineered projects that can be taken in advance of the potential impacts, or reactively, depending on the degree of preparedness, the willingness to tolerate risk, financial capacity and political acceptability. Effective adaptation planning will improve community resilience to natural disasters and climate change.

Adaptation strategies, according to Coastal Commission Sea Level Rise Policy guidance (CCC 2015), generally fall into four main categories: do nothing, protect, accommodate and retreat. These strategies are generally described Section 6.1 below. When considering which strategy (or combination of strategies) is most appropriate in a particular circumstance, it is important to consider the associated secondary impacts (e.g., loss of beach resulting from the use of seawalls) and trade-offs (i.e., who/what will benefit and who/what will be adversely impacted?). Sections 6.2 and 6.3 describe the secondary impacts and trade-offs associated with the various adaptation approaches. The adaptation strategies that may be most effective in Carlsbad are then presented in Section 6.4.

Many of the adaptation strategies described below can be integrated into Local Coastal Program policies and implemented through zoning regulations.

6.1. ADAPTATION STRATEGIES

6.1.1. The Do Nothing Approach

Choosing to "do nothing" or following a policy of "non-intervention" can be considered an adaptive response. Doing nothing results in the need to react when sea level rise impacts occur. The reactive approach involves emergency response, attempts to maintain the status-quo and respond to impacts caused by episodic storm events and other sea level rise impacts. Reactive efforts can be more costly than other adaptation strategies, and the clean-up post disaster is often lacking in vision and leads to reconstruction of the same types of non-resilience strategies.

6.1.2. The Protection Approach

Protection strategies employ some sort of engineered structure or other measure to protect or flood-proof development (or other coastal resources) in its current location without changes to the development or resources themselves. Protection strategies can be further divided into "hard" and "soft" defensive measures. Examples of a hard approach would be to construct a seawall or revetment, while a soft approach may be to nourish beaches with sand or build sand dunes.

Although the California Coastal Act allows for potential protection strategies for "existing development" (i.e., development that was in existence when the Coastal Act was enacted in 1976), it also directs that new development (i.e., development after 1976) be sited and designed to avoid hazards and not require future protection that may alter a natural shoreline. When issuing a permit to allow a hard protective structure, such as a seawall, for the purpose of protecting a building or other improvement, the Coastal Commission has imposed conditions that identify when a building/improvement no longer requires protection or encroaches onto state tidelands, then the hard protective structure must be removed.

Currently, much of the coastline of Carlsbad is armored with seawalls, revetment or rip rap. Documenting the age, height, condition, and permit conditions of both protective structures and the development they were built to protect will be important to determine the remaining life expectancy of protective structures, and the longer-term viability of maintaining these structures in a regulatory sense. Additional engineering work, including increasing the elevation of existing protective devices, and maintenance will likely be required in the future to ensure the structure effectively protects against the impacts of sea level rise.

When evaluating whether or not the protection approach is an appropriate adaptation strategy, it is important to evaluate the long-term viability of protective structures and any potential impacts to coastal resources that could result if protective structures are maintained in place (see Section 6.2 for more information related to secondary impacts). It is critical to also understand the possible impacts to coastal resources that could manifest over time if protective structures are maintained in place. Passive erosion of the beach as a result of a coastal structure is one of the most significant to consider. Understanding how fast these impacts could occur, the magnitude of those impacts, and the efficacy of any measures that could mitigate those impacts is critical for determining whether – and for how long – the protection approach is appropriate for use in the city and, therefore, what policy and development standards should be included in the Local Coastal Program.

Given the negative impacts of hard protective structures (as described in Section 6.2), more attention is being focused on the implementation and resulting effectiveness of soft solutions. Soft options, sometimes called living shorelines or natural infrastructure, include sediment management to reduce erosion by building wider beaches (beach nourishment) and higher sand dunes, as well as cobble placement. These soft solutions tend to mimic natural processes and can help lessen erosion and flooding while also providing habitat, water filtration and recreational opportunities. The effectiveness of soft solutions to mitigate the impacts of sea level rise is the topic of ongoing research and pilot projects. Generally, these solutions are found to be effective for shoreline protection when applied at appropriate areas. More study would be needed to determine the effectiveness of soft solutions to address sea level rise vulnerabilities in Carlsbad.

6.1.3. The Accommodation Approach

Accommodation strategies employ methods that modify existing or design new developments or infrastructure in a manner that decreases hazard risks and, therefore, increases the resiliency of the development/infrastructure to the impacts of sea level rise.

On an individual project scale, these accommodation strategies include actions such as elevating structures, retrofitting or using materials to increase the strength of development/infrastructure such as: the ability to handle additional wave impacts; building structures that can easily be moved and relocated; or using additional setback distances to account for acceleration of erosion.

On a community scale, accommodation strategies include appropriate land use designations, zoning regulations or other measures that require the above types of actions; as well as strategies such as clustering development in less vulnerable areas or requiring mitigation actions to protect natural areas.

6.1.4. The Retreat Approach

Retreat strategies relocate or remove existing development out of hazard areas and limit the construction of new development in vulnerable areas. These strategies include creating land use policies and zoning regulations that encourage building in less hazardous areas and the gradual removal and relocation of existing development as it becomes threatened or damaged. There are a variety of mechanisms to implement this approach including: acquisition and buy-out programs, transfer of development rights programs and removal of structures where the right to protection was waived (i.e., via permit condition).

Other retreat strategies include use of conservation easements or rolling easements that limit or prohibit development in order to allow coastal erosion processes to occur into upland property; as well as hazard overlay zones that require all properties within the zone assume the risk of being in a hazardous environment, and identify triggers indicating when development needs to be relocated.

6.2. SECONDARY IMPACTS

Almost all adaptation strategies have secondary impacts associated with them. Some of these are minor issues, such as short-term habitat impacts following removal of infrastructure or undergrounding of overhead power lines. Other strategies can be difficult and expensive, such as the burial of beaches under rocks following construction of revetments, or a retrofit to a critical infrastructure component. Another example of secondary impacts is the potential impacts to visual resources associated with adaptation strategies that elevate buildings or armor coastal bluffs to protect against elevated levels of flooding. The following information describes some of common secondary impacts that may result from sea level rise adaptation strategies.

6.2.1. Secondary Impacts of Doing Nothing

Doing nothing can be thought of an adaptive response and one that can result in secondary impacts. Initial costs are low for this strategy; however, the long-term costs of maintenance of existing coastal structures and emergency repair of vulnerable coastal infrastructure (i.e., roadways) can be costly. Therefore, an analysis of long-term maintenance and emergency repair of existing and future vulnerable areas should be considered. Note that this analysis should include more frequent maintenance and emergency repairs over time to account for sea level rise.

Coastal resources can also be impacted by doing nothing as a result of beaches and environmentally sensitive lands being squeezed between rising water levels and coastal infrastructure. Areas where these resources will change significantly or be lost by doing nothing should be considered in the long-term. The loss of beach may also lead to the loss of "towel" and recreation space, decrease in tourism, loss of beach habitat and loss of storm protection. Adopting a "do nothing" approach may limit future adaptation strategies that require long term planning for the development of funding mechanisms.

6.2.2. Secondary Impacts of Protection Strategies

6.2.2.1. Soft Protection Strategies

The impacts of soft protection solutions, such as sediment management through beach nourishment and sand dunes, are generally limited to cost, as the maintenance costs of soft protection solutions can be higher than hard protective solutions. Sediment management can be costly, and ongoing sand supplies for large projects have become scarcer, which has resulted in high construction costs. Secondary impacts from sediment management vary depending on the volume, frequency and method of placing, but typically include impacts to sandy beach ecosystems, temporary recreational impacts and rocky intertidal habitat impacts.

6.2.2.2. Hard Protection Strategies

The inevitable impacts associated with hard protective solutions are commonly described within the context of the following impact categories:

- ***Placement loss*** **–** Wherever a hard structure is built, there is a footprint of the structure. The footprint of this structure results in a loss of coastal area known as placement loss. This inevitable impact can reduce the usable beach for recreation or habitat purposes. For example, a 10-foot high revetment constructed at a 2:1 slope can occupy 20 feet of usable beach for only the sloping portion of the structure. A vertical seawall or sheet pile groin typically has a smaller placement loss than a revetment or rubble mound groin.

- ***Passive erosion*** **–** Wherever a hard structure is built along a shoreline undergoing long-term net erosion, the shoreline will eventually migrate landward to (and potentially beyond) the structure. The effect of this migration will be the gradual loss of beach in front of the seawall or revetment as the water deepens and the shore face moves landward. While structures may be temporarily saved, the public beach is lost. This process of passive erosion is a generally agreed-upon result of fixing the position of the shoreline on an otherwise eroding stretch of coast, and is independent of the type of seawall constructed. Passive erosion may impact recreational beach area, as well as beach habitat area. While beach nourishment may protect the recreational value of the beach, it may not mitigate the impacts to the value and function of beach habitat. Excessive passive erosion may impact the beach profile such that shallow areas required to create breaking waves for surfing are lost.

- ***Limits on beach access*** **–** Depending on the type of structure, impacts to beach access vary. Typically, vertical beach access (ability to get to the beach) can be impacted unless there are special features integrated into the engineering design; however, as passive erosion occurs (see above), lateral (along) beach access is usually impacted.

- ***Active erosion*** **–** Refers to the interrelationship between wall and beach whereby, due to wave reflection, wave scouring, "end effects" and other coastal processes, the wall may increase the rate of loss of beach in front of the structure, and escalate the erosion rates along adjacent unarmored sections of the coast. Active erosion is typically site-specific and dependent on sand input, wave climate, specific design characteristics and other local factors.

- ***Ecological impacts*** **–** Scientific studies have documented a loss of ecosystem services, loss of habitat and reduction in biodiversity when seawall-impacted beaches were compared to natural beaches.

As described above, hard protective solutions can adversely affect a wide range of coastal resources and uses, and by doing so, may conflict with the policies of the California Coastal Act, as follows:

- Hard protective solutions can impede or degrade public access and recreation along the shoreline by occupying beach area or tidelands and by reducing shoreline sand supply. Protecting the back of the beach with a protective structure, such as a seawall, ultimately leads to the loss of the beach as coastal erosion from sea level rise continues on adjacent unarmored sections. Where there is a protective structure the beach may drown and be lost; in contrast, where there is no hard protective structure, bluff erosion will continue and add sand supply to the beach.

- Hard protective solutions can also fill coastal waters or tidelands and harm marine resources and biological productivity.

- Hard protective solutions can prevent the inland migration of intertidal and beach species during large wave events. This disruption will prevent intertidal habitats, saltmarshes, beaches and other low-lying habitats from advancing landward as sea levels rise over the long-term.
- Hard protective solutions can degrade the scenic quality of coastal areas and alter natural landforms. The visual impact of hard protective structures and the aesthetic degradation that results from the loss of beach can have adverse economic and fiscal impacts on the local economy tied to reduced tourism and community character changes.

Recent trends in coastal armoring permitting by the Coastal Commission have been to tie the coastal armoring to the structure it is required to protect, and identifying when that subject structure either no longer requires the protection or encroaches onto State tidelands. At which time, the coastal armoring is to be removed.

6.2.3. Secondary Impacts of Accommodation Strategies

The primary secondary impact associated with the accommodation strategy is that it can result in impacts to visual resources and community character. Raising a building to allow for a floodable first floor can result in ocean and beach views from other portions of the city being lost. Similarly, raising coastal infrastructure or a coastal structure can impact visual resources to the public and eventually result in a change in the character of a city.

Accommodation alone is not always protective of evolving coastal resources. For example, a coastal building that is raised to avoid being damaged by a future coastal storm does not protect the sandy beach. The beach will erode as sea levels rise underneath the coastal building. The beach condition underneath the building has limited function recreationally and ecologically at this state. Thus, the fate of adjacent coastal resources should be considered when considering accommodation strategies.

6.2.4. Secondary Impacts of Retreat Strategies

Many communities have relied on setbacks in an effort to reduce hazard risk, and some are currently experimenting with establishing setback lines that are based on modeled predictions of the future coastline location. Setbacks alone are potentially insufficient protection and create a false sense of security because they may eventually lead to structures being at risk due to the uncertainty in the modeled predictions of the future coastline. Therefore, to be most effective at minimizing hazard risks, it is important to consider other elements of retreat, such as requiring movable foundations or identifying locations for transfer of development. Further, establishing clear triggers for action, such as relocation of development, could work in conjunction with regulatory setback policies. Finally, development located in hazardous areas should assume the risk of being located in a hazardous environment, and waive the right to any future shoreline armoring.

Another example of secondary impacts from retreat strategies is cost; for example, the use of public acquisition and buy-out programs can be very costly for local, state and/or federal agencies. However, these costs should be compared against the construction and maintenance of hard engineered solutions and other adaptation approaches over the long-term.

6.2.5. Maladaptation

Adaptation measures that reduce the ability of people and communities to deal with and respond to climate change over time are called maladaptation. Maladaptation has several characteristics that help identify when it is occurring: 1) It creates a more rigid system that lead property owners and communities into a false sense of security (i.e., should one of these strategies fail, the consequences could be severe); 2) it increases greenhouse gas emissions; and 3) it reduces incentives to adapt.

6.3. UNDERSTANDING TRADEOFFS

There are trade-offs associated with the various adaptation strategies, particularly in terms of "who" benefits from the adaptation strategy. For example, with hard protection strategies, like seawalls, the private property owner takes the greatest benefit through protection of their existing structures; however, as described in Section 6.2, hard protective solutions have negative impacts. The Coastal Commission has addressed these negative impacts through the use of in-lieu fees assessed for the loss of recreational beach area and sand supply. The Coastal Commission is also attempting to develop a means to calculate the replacement value of the sandy beach ecosystem.

For any segment of eroding shoreline, the choice of which adaptation option to implement is affected by multiple interested parties, advisers and decision-makers, such as:

- Property owners;
- The public (i.e., community members and visitors of the beach);
- Experts and consultants (such as civil engineers and geologists);
- Government regulators, permitting and compliance officials;
- Special interest groups such as chambers of commerce, or non-government organizations (e.g., environmental groups, social justice); and
- Policy-makers or lawmakers.

The motivations and constraints of the different interested parties, advisers and decision-makers vary depending on their relation to the property, their knowledge of different types of shoreline protection options, their stewardship responsibilities, their professional interests, regulatory framework, legal precedence, and local preferences. Thus, often the choice of adaptation strategy involves conflict and tension between private versus public benefits.

For example, proponents of shoreline protection are usually property owners driven by a desire to preserve upland area and value or by a desire to protect, create, or restore recreational opportunities that a beach may provide. They seek an outcome that will protect and maximize their uses of the shoreline and their investment. Also, the existence of shoreline protection may reduce property insurance costs, which is another reason property owners may support construction of shoreline protection structures.

Regarding private interests, a key consideration is the Public Trust Doctrine ("public trust"). Public trust ensures that the government holds title to resources for public use, such as coastal shoreline areas between the high and low tide lines (tidelands). The government is the trustee of tidelands and nearshore waters for the benefit of the public and maintains this stewardship responsibility even though some of these areas may be privately owned.

The public trust has implications for all decisions regarding shoreline erosion control options that inevitably produce an impact on public trust lands. The options to benefit public trust interests vary and may also conflict. For example, some erosion control options, such as wetland creation and "living shorelines," may impede the public trust interest of navigation while enhancing other public interests such as environmental quality and fishery habitat. Other erosion control options, such as breakwaters and jetties, may degrade the quality of nearshore environments (e.g., reduce their quality as fish habitat), but maintain navigation. If protecting natural shorelines, wetlands, and beaches is a priority in an area, then some erosion control options, such as vertical seawalls, may not be feasible. In other areas, protection of private or public infrastructure interests might be paramount and lead to erosion control options that conflict with conservation of natural areas.

An additional issue that often complicates the subject of trade-offs is public access. Not only does common law recognize the riparian right of access to navigable waters, it also guarantees the public's right to navigate on waters. This latter concept may create obstacles for adaptation strategies that interfere unreasonably with the public's access to navigable waters, as well as the public navigation interest. Erosion control options, such as beach creation, may also create new opportunities for public access to the fringes of navigable waters.

Sea level rise adaptation strategies may also result in conflicts and trade-offs when applying the Coastal Act to a proposed adaptation strategy. Coastal Act Section 30235 allows for the construction of shoreline protection, such as a seawall, when it is necessary to protect "existing structures" (i.e., existing when the Coastal Act was enacted in 1976) or public beaches from erosion. However, the construction of shoreline armoring may cause impacts that are inconsistent with other Coastal Act requirements; for example, Coastal Act Section 30253 prohibits new development from in any way requiring "the construction of protective devices that would substantially alter natural landforms along bluffs and cliffs." Shoreline protective devices can also conflict with other coastal resources and uses that the Coastal Act protects, such as public access and recreation along the shoreline.

6.4. POTENTIAL ADAPTATION STRATEGIES FOR CARLSBAD

6.4.1. Adaptation Policy Strategies

Chapter 7 of the Coastal Commission's Sea Level Rise Policy Guidance describes many sea level rise adaptation alternatives. Of those, the list below represents adaptation strategies that can be considered in Carlsbad, but does not specify if a particular strategy should be applied or when and where a strategy could be implemented. As part of the city's Local Coastal Program update, policies and regulations will be created to implement adaptation strategies that address the vulnerabilities identified in this study. When developing policies and regulations, and when determining the appropriate adaptation to implement in a given circumstance/point in time, consideration should be given to the long-term effectiveness of a particular adaptation strategy, as well as and the economic, ecological, and other potential costs/impacts.

Also, when considering appropriate adaptation in a given circumstance/point in time, the assumptions and limitations of this vulnerability assessment should be considered. For example, the potential for under or over estimation of hazards may influence the geographic extent and/or timing of implementation of certain adaptation strategies. Key assumptions in this assessment, such as protective devices will not fail, should be evaluated and contingency plans developed, if applicable. If a limitation of the assessment restricts the understanding of the geographic extent of hazards, such as the removal of the weir at Buena Vista Lagoon, then the area or hazard may warrant further study as part of a future planning effort.

Additionally, some projects will be subject to additional site specific analysis of potential sea level rise and coastal hazard impacts. Future development projects may require site specific analysis to incorporate changed conditions or to reflect the best available science regarding sea level rise and coastal hazard impacts.

Based on the findings of this study, it is recommended that the city consider the following adaptation policy strategies:

1. **Continue to participate in regional beach nourishment projects.** Beach nourishment has been found to be an adequate approach to keep pace with low levels of sea level rise (Flick and Ewing 2009). Beach nourishment requires placement of sand from a source outside of the littoral zone; thus, providing a new source of sand to the system. Beach nourishment opportunities should continue to be pursued within Carlsbad. Continued participation and coordination with the SANDAG regional beach nourishment program should be included, as regional actions tend to provide for larger project opportunities.

2. **Continue existing sand bypassing program.** The beaches in Carlsbad, especially those adjacent to infrastructure (such as portions of Carlsbad Boulevard) and/or residential development, have a low adaptive capacity. Continued sand bypassing and beach nourishment projects improve the adaptive capacity rating of these beaches. Continuation of sand bypassing activities from Oceanside Harbor, which presently occur annually, is important. The city should support the continuation of this dredge bypass program.

3. **Continue to implement local opportunistic sand management plan.** Presently, the city has multiple sources of beach quality sand and other sediments available from local sources. It is suggested that the city continue to implement its opportunistic sand use program that identifies appropriate sediment characteristics and locations for placing the sediment to achieve the maximum benefit to recreational resources and coastal dependent uses along the city waterfront. Currently there are two routine sources of sediment in the city - Agua Hedionda Lagoon that produces 200 - 400 thousand cubic yards, on a 2-3 year cycle and Batiquitos Lagoon - that produce 50-100 thousand cubic yards, on a 4-5-year cycle. In addition, future development or restoration projects may produce additional sediment, such as the Buena Vista Lagoon restoration project.

4. **Consider constructing winter berm or dune system.** Residential properties in the Village Planning Area may consider a winter berm or dune system fronting their properties to provide protection during extreme events. A winter berm would protect the homes from wave run-up vulnerabilities from winter storms and could be lowered in the summer to allow for unimpeded recreational uses. A dune would be a more persistent, year-round feature that would offer similar protection. Further analysis would be needed to determine if adequate space exists and to properly size this feature. Assuming a winter berm or dune system were technically feasible and could be approved consistent with the Coastal Act on the beach fronting the Village Planning Area, a beach-wide approach would be more appropriate than implementing these on a private, per parcel basis. A geologic hazard abatement district could be established as a potential funding mechanism. The percentage share could be based on the proportional contributions made by each landowner to the construction costs. The costs could be shared based on the proportion of land frontage, or some other arrangement agreed by the landowners submitting the development application.

5. **Consider landward relocation of public assets.** Consideration should be given to landward relocation of development or infrastructure in areas where adequate space exists. Carlsbad Boulevard in the vicinity of Las Encinas Creek is an example of a potential landward relocation opportunity. Consideration of landward relocation should take place at the time of planned capital improvements or after repetitive emergency repairs. The landward relocation analysis should consider the cost to maintain or protect the asset and the associated secondary impacts of doing so, versus the cost to relocate over the asset's design life. The analysis should also consider the coastal resource and economic impact as well as the potential value of added recreational opportunities that could result from such relocation.

6. **Adopt hazard overlay zones.** This strategy would identify areas that are vulnerable to a set of specific hazards. Within each hazard zone, there could be a restriction on the types of development (e.g., residential), a basis for setback lines, or triggers for site-specific technical analyses or studies (e.g., geologic report triggers, slope stability analysis).

7. **Require site-specific coastal hazard reports.** For properties located in a coastal hazard overlay zone, this strategy would require a coastal development permit application to include a site-specific coastal hazard investigation that evaluates the exposure of the property to existing and future coastal hazards.

8. **Management of prioritized existing hard shoreline protection**. This strategy would employ hard protection only if allowable and if no feasible less damaging alternative exists. In some cases, caissons and pilings may also be considered hard shoreline protective devices. Under current law, shoreline protection for existing structures in danger from erosion may be allowed if coastal resource impacts are avoided or minimized and fully mitigated where unavoidable. On intensely developed, urbanized shorelines, if the removal of armoring would put existing development (in existence when the Coastal Act was enacted in 1976) at risk and not otherwise result in significant protection or enhancement of coastal resources, it may be appropriate to allow properly designed shoreline armoring to remain for the foreseeable future, subject to conditions that provide for potential future removal in coordination with surrounding development.

9. **Real estate disclosures for coastal hazards.** This strategy would require that upon any real estate transaction, buyers of properties in a coastal hazard overlay zone are made aware of the potential hazards to their property. This disclosure informs buyers that they may face such hazards as erosion, coastal flooding, inundation, wildfire, or flooding as a result of climate-induced impacts, such as sea level rise. It is important to note that disclosures for earthquake hazards and creek flooding already exists if a property is required to carry flood insurance.

10. **Building and zoning code revisions**. This approach would involve incorporating flexibility into development codes to help adapt to changes in climate. This could include limiting development in flood-prone areas, increasing building heights, using movable foundations, or requiring materials and foundations that are resistant to hazards such as fires or extreme wind. Updating height restrictions by freeboard elevation (i.e., difference in elevation between the water surface and the crest or floor of a structure), which would allow buildings to be raised for flood protection purposes, and revising the grading ordinance to reflect sea level rise projections are two examples. Structural adaptation is the modification of the design, construction, and placement of structures sited in or near coastal hazardous areas to improve their durability and/or facilitate their eventual retreat, relocation, or removal. This is often done through the elevation of structures, specific site placement, and innovative foundation construction.

11. **Develop rolling easements along the oceanfront or lagoon edge.** The term "rolling easement" refers to a policy or policies intended to allow coastal lands and habitats, including beaches and wetlands, to migrate landward over time as the mean high tide line and public trust boundary moves inland with sea level rise. Such policies often restrict the use of shoreline protective structures, limit new development, and encourage the removal of structures that are seaward (or become seaward over time) of a designated boundary. This boundary may be designated based on such variables as the mean high tide line, dune vegetation line, bluff edge, or other dynamic line or legal requirement. In some cases, implementation of this can be through a permit condition (such as the "no future seawall" limitation) or purchased (such as purchasing the land between the MHW boundary and the dune vegetation line plus 5 additional feet in the landward direction so the easement can adjust with sea level rise).

12. **Fee simple acquisition.** This approach is the purchase of vacant or developed land in order to prevent or remove property from the danger of coastal hazards such as erosion or flooding. One such example of this adaptation strategy is to purchase properties at risk and to demolish structures and restore habitats and physical processes, as has been done in Pacifica, California. A hybridized version of this adaptation strategy may be a public acquisition program in which an entity purchases the hazardous property and then leases the land back to the previous landowner with the deed restriction and understanding that when the structure or parcel is damaged that the lease may expire.

13. **Require special considerations for critical infrastructure and facilities.** Addressing sea level rise impacts to critical facilities and infrastructure (e.g., roads, bridges, water, sewer facilities, etc.) will likely be more complex than for other resources and may require greater amounts of planning time, impacts analyses, public input, and funding. To address these complexities, the city could establish measures that require continued function of critical infrastructure, or the basic facilities, service, networks, and systems needed for the functioning of a community. Programs and measures within a Local Coastal Program could include identification of critical infrastructure that is vulnerable to sea level rise hazards, establishment of a plan for managed relocation of at-risk facilities, and/or other measures to ensure functional continuity of the critical services provided by infrastructure at risk from sea level rise and extreme storms. Repair and maintenance, elevation or spot-repair of key components, or fortification of structures where consistent with the California Coastal Act may be implemented through coastal development permits.

14. **Limit redevelopment or upgrades to existing legal non-conforming structures in at-risk locations.** The city could develop and enforce policies and regulations that define non-conforming development in coastal hazard zones and place limits on expansion, redevelopment, or upgrades to legal non-conforming structures. These may require redevelopment proposals to comply with requirements for new development, including regulations that minimize sea level rise hazards; also, deed restrictions or other mechanisms could be required to notify existing and future property owners about such limitations.

15. **Continue to monitor beaches.** The city's existing beach monitoring program provides a long-term record of beach width change in Carlsbad. It is recommended that this program be continued into the future to track local beach response to sea level rise. As part of this program, it is also recommended that storm events be documented through photographs and field notes. This documentation will assist in validation of the numerical modeling results and to track the frequency of these events.

16. **Periodically update this Sea Level Rise Vulnerability Assessment.** Update this assessment when significant changes in climate science or coastal hazard mapping methods occur. Addenda to this document could be an approach to capture these updates.

17. **Develop a coastal armoring database and action plan.** The city could create a database of the status and condition of existing armoring in the city. The database can build off the GIS database developed for this study and should be compatible with the redesigned coastal armoring database developed by the California Coastal Commission. A coastal armoring database will provide the city to with an inventory of the age, type and condition of coastal structures in the city as well as similar information about the structure or asset the armoring serves to protect. This data is important for future decision making and implementation of future Local Coastal Program policies related to sea level rise adaptation.

18. **Revise development setbacks**. Existing building setback requirements should be revised to account for accelerated erosion caused by increasing sea levels and hours of wave attack, as well as a factor of safety distance that is related to the erosion mechanism (e.g., dune erosion versus cliff erosion). The setback should factor in the life expectancy of the proposed development or redevelopment. For example, in a bluff-backed shoreline, where historic failures have shown to be capable of a 30-foot failure, the setback should include accelerated erosion rates in addition to a failure distance that could occur at the end of the development's life expectancy.

19. **Develop a repetitive loss program**. One way to implement managed retreat would be to develop a repetitive loss program that could include the following strategies in response to requests to repair property damaged by sea level rise related storm damage: 1) permit the first request to repair storm damage; 2) when a property is damaged a second time, permit the repairs and apply zoning limitations or a zone change that precludes future development/improvements on the property or the portion of the property that is vulnerable to sea level rise impacts; and 3) when a property is damaged a third time, repairs would not be permitted unless it is demonstrated that the repairs will remove the structure/property from future hazard.

20. **Identify triggers to shift implementation to different adaptation strategies**. Over time, the city may implement all or most of the potential adaptation strategies, likely in the following order: protect, accommodate, and retreat. Given the uncertainty in timing and severity of impacts, it is important to identify triggers, which once reached, will commence planning and implementation actions for the next set of adaptation strategies. Triggers can vary widely, but generally fall into four categories:

    a. By sea level rise elevation or rate of sea level rise observable at tide gages.

    b. By time, such as upon closure of the once through cooling power plants.

    c. By exposure, such as how frequently Carlsbad Boulevard is closed to travel due to wave action.

    d. By damages, such as a structure needs to be removed once it is damaged by more than 50% or has multiple insurance claims for flood damages.

    To be effective, these triggers should be implemented through specific measurable metrics with clear direction on what should happen once a threshold is triggered.

Carlsbad Boulevard is an example of an asset vulnerable to sea level rise in different locations along the roadway, and it may be necessary to implement different adaptation strategies over time. The following describes the areas of the roadway that may become vulnerable to sea level rise over time:

- The far northern stretch of the road that crosses Buena Vista Lagoon; to adapt raising that portion of the roadway above the level of vulnerability may be necessary.
- Portions of the road in Planning Zones 1 and 2; to adapt, additional coastal armoring with raised seawalls may be appropriate to protect the road.
- Portions of the road in the southern shoreline area of Planning Zone 3; to adapt construction of a dune restoration or cobble berm may be an appropriate strategy.

6.4.2. Adaptation Project Strategies

This section generally describes the types of adaptation projects that would be effective in minimizing coastal hazards within geographic areas that are vulnerable to sea level rise, which include Carlsbad's low-lying beaches, low-lying estuaries, and the bluff-backed shoreline segments.

6.4.2.1. Low-Lying Beaches

Low-lying beaches are exposed to coastal hazards related to wave flooding, coastal erosion, stormwater coastal confluences (rainfall runoff trapped by high tides and sea level rise), and eventually tidal inundation. Carlsbad's low-lying beaches are predominately within the northern portion of the Village Planning Area. To adapt to these coastal hazards, the following types of adaptation projects are likely to be most effective and are listed in order of soft strategies to hard strategies:

- Managed retreat (soft)
    - *Landward relocation of public assets*
    - *Hazard overlay zones*
    - *Real estate disclosures*
    - *Rolling easements*
    - *Fee simple acquisition*
    - *Limit redevelopment/upgrades*
    - *Repetitive loss program*
- Dune restoration (soft)
- Beach nourishment (soft)
- Sand retention with nourishment (soft)
    - *Regional beach nourishment*
    - *Sand bypassing*
    - *Sand management plan*
    - *Winter berm or dune*
- Elevating structures (hard)
- Coastal armoring (hard)

6.4.2.2. Low-Lying Estuaries

Low-lying estuaries are exposed to coastal hazards of stormwater confluences (rainfall runoff trapped by high tides and sea level rise) and increasing tidal inundation. These areas include Buena Vista Lagoon, Aqua Hedionda Lagoon and Batiquitos Lagoon. To adapt to these coastal hazards, the following types of projects are likely to be most effective and are listed in order of soft strategies to hard strategies:

- Managed retreat (soft)
    - *Landward relocation of public assets*
    - *Hazard overlay zones*
    - *Real estate disclosures*
    - *Rolling easements*
    - *Fee simple acquisition*
    - *Limit redevelopment/upgrades*
    - *Repetitive loss program*
- Dune or wetland restoration (soft)
- Elevating structures (hard)
- Coastal armoring (hard)

6.4.2.3. Bluff-Backed Shoreline

Most of the Carlsbad shoreline is bluff-backed, which includes much of Terramar and the Southern Planning Areas. In bluff-backed shoreline reaches, the physical processes causing the vulnerabilities are largely due to wave velocity, erosion of the bluffs, some minor coastal flooding along low lying bluffs, and acceleration of bluff erosion in the future as sea levels rise. Of particular concern, bluff-backed shoreline segments provide public access, as well as state park campgrounds. To adapt to the coastal hazards in the bluff-backed shoreline reaches, the following types of projects are likely to be the most effective and are listed in order of soft strategies to hard strategies:

- Managed retreat (soft)
    - *Landward relocation of public assets*
    - *Hazard overlay zones*
    - *Real estate disclosures*
    - *Rolling easements*
    - *Fee simple acquisition*
    - *Limit redevelopment/upgrades*
    - *Repetitive loss program*
- Movable foundation (soft/hard hybrid)
- Coastal armoring (hard)

6.4.3. Adaptation Strategy Costs

The monetary and non-monetary costs associated with the various adaptation strategies should be considered when developing adaptation policies and regulations. An example of non-monetary costs is the loss of san supply and recreation opportunities that may result from the construction of hard protective structures. The monetary cost to construct and maintain hard protective structures can be significant, and consideration of the initial construction and periodic maintenance costs should be evaluated over time to develop life-cycle cost of a coastal armoring strategy. When planning for sea level rise, the life-cycle cost to protect should be compared to the cost of the asset being protected or cost to relocate that asset. As an example of construction and maintenance costs, the rough order of magnitude costs (in 2017 dollars) of common protection strategies are provided in Table 6.

Table 6: Rough Order of Magnitude Costs for Coastal Protection Strategies

Protection Strategy	Approx. Initial Construction Cost ($/unit)	Approx. Maintenance Costs ($ every 5 years)*	Assumptions
Revetment	$2,500/linear foot	$150/linear foot	Revetment of 3- to 5-ton stone with a crest elevation of +18 ft MLLW.
Seawall	$5,000/linear foot	$50/linear foot	Sheet pile or gravity wall seawall fronted with rip rap for scour protection. Seawall crest constructed to +22 ft MLLW.
Beach Nourishment	$40/CY	$50/CY	Assumes 100,000 CY nourishment project constructed via offshore dredge methods.

**Assumes inflated cost of 5% of initial construction costs every 5 years.*

7. CONCLUSIONS AND RECOMMENDATIONS

The purpose of this vulnerability assessment was to identify assets and planning areas at risk to future rates of sea level rise within Carlsbad. The study considered vulnerabilities to flooding, inundation and bluff erosion as a result of two sea level rise scenarios (2050 and 2100) as predicted by preliminary results from CoSMoS 3.0 and supplemental fluvial flooding zones generated by Moffatt & Nichol. Although the scientific community has identified that ocean levels will rise in the future, there remains uncertainty regarding the timing and magnitude of these future conditions. Appendix A includes more information on how each assumption or limitation of the model may result in under or over estimations of hazards. The results of the vulnerability assessment are summarized in Table 7.

Table 7: City-Wide Sea Level Rise Vulnerability Summary

Asset Category	Horizon	Impacted Assets	Overall Vulnerability Rating (Low - High)
Beaches	2050	27 acres	Moderate
	2100	146 acres	High
Public Access Ways	2050	26 beach access ways 2.6 miles of lateral access ways	Moderate
	2100	37 beach access ways 7.3 miles of lateral access ways	Moderate
State Parks	2050	6 Parcels	Moderate - High
	2100	6 Parcels	Moderate - High
Parcels	2050	564 Parcels	Moderate
	2100	657 Parcels	High
Critical Infrastructure	2050	0 Parcels	Low
	2100	8 Parcels	Moderate
Transportation	2050	1.6 miles	High
	2100	5.8 miles	High
Environmentally Sensitive Lands	2050	1,088 acres	Moderate
	2100	1,164 acres	High

The results of the vulnerability assessment, as based on the USGS CoSMoS 3.0 modeling outputs, are described by asset type below:

- **Beaches –** Beach erosion impacts do not appear significant until year 2100. Carlsbad beaches were found to lose 146 acres of shoreline by this time horizon. The loss of beach results in numerous adverse impacts, including reduction of beach "towel space" or recreational area for visitors and residents, reduction of coastal public access, loss of coastal habitat and ecological value, and impacts to the beach's ability to function as a natural storm buffer. In addition, the loss of beaches has been found to result in direct and indirect economic impacts; direct impacts are a byproduct of the protection that they provide to coastal infrastructure; and indirect impacts are a result of a reduction in visitation from residents and visitors, which would then impact visitor-serving businesses. The overall vulnerability of beaches by year 2050 is considered moderate.

- **Public Access Ways –** Coastal flooding and erosion has the potential to impact vertical (access to) and lateral (access along) beach access ways in the city. A total of 37 vertical beach access ways exist in the city. All of these access ways were determined to be vulnerable to flooding and inundation by year 2100. About three quarters of these access ways were vulnerable to flooding during the 2050 time horizon.

  About 7 miles of lateral access ways (trails) were found to be vulnerable by year 2100. The public access ways exist along the beach and lagoons in the city. About 2.5 miles of trails are vulnerable to flooding in the 2050 time horizon. The overall vulnerability of public access ways in year 2050 was determined to be moderate.

- **State Parks –** Though state parks are not owned or operated by the city, they provide a valuable asset to the city by providing recreation and a low-cost visitor serving amenity. State parks are most at risk in Planning Zones 2 and 3 where beaches, campgrounds (South Carlsbad and Ponto) and day-use parking facilities are within coastal hazard zones. The primary coastal hazard is bluff erosion, which may result in the loss or partial loss of campsites and day use facilities. The overall vulnerability to this asset by year 2050 is considered moderate-high.

- **Parcels –** The majority of the parcels at risk are in Planning Zones 1 and 2, where 515 parcels were found to be impacted by the 2050 sea level rise scenario. The parcels that are at risk to flooding and bluff erosion are located on coastal and lagoon-front properties in these planning zones. The most parcels at risk are in Planning Zone 2, where 451 parcels were found to be at risk by 2100. The overall vulnerability to this asset by year 2050 is considered moderate.

- **Critical Infrastructure –** Critical infrastructure was found to be at risk to sea level rise in Planning Zones 1 and 2. Critical infrastructure was limited to sewer pump stations and the commercial uses adjacent to the Agua Hedionda Lagoon. The overall vulnerability to these assets by year 2100 is considered moderate. The overall vulnerability to this asset by year 2050 is considered low due to no parcels being impacted.

- **Transportation –** Transportation infrastructure in all planning zones was found to be at risk to flooding and bluff erosion by year 2050. Carlsbad Boulevard was determined to be the most vulnerable due to the critical north-south linkage it provides; however, La Costa Avenue, Jefferson Street, and private roads within state parks campgrounds were also found to be vulnerable. The overall vulnerability to this asset by year 2050 is considered high.

- **Environmentally Sensitive Lands –** Environmentally sensitive lands include wetlands, riparian areas, coastal prairies, woodlands and forests, and other natural resources in the coastal zone. Planning Zone 3 had the most environmentally sensitive lands at risk to flooding with a total of 606 acres at risk by year 2100. Due to the steep topography and development along much of the lagoon shorelines in Carlsbad, the ability for flora and fauna to naturally adapt by migrating vertically and/or horizontally may be limited. The overall vulnerability to this asset by year 2050 is considered moderate.

To address identified vulnerabilities, the adaptation measures described in this report provide a range of available options for the city to consider in the development of its Local Coastal Program update. These potential adaptation options are as follows:

- Continue to participate in Regional Beach Nourishment Projects
- Continuation of Sand Bypassing Program
- Continue to implement local opportunistic sand management plan
- Construct winter berm or dune system
- Landward relocation of public assets
- Adopt Hazard Overlay Zones
- Require site-specific coastal hazard reports
- Management of prioritized existing hard shoreline protection
- Real estate disclosures for coastal hazards
- Building and zone code revisions
- Develop rolling easements along the oceanfront bluff edge
- Fee simple acquisition of vulnerable properties
- Require special considerations for critical infrastructure and facilities
- Limit redevelopment or upgrades to existing legal non-conforming structures in at-risk locations
- Continue to monitor beaches
- Periodically update Vulnerability Assessment
- Develop a coastal armoring database and action plan
- Revise development setbacks
- Develop a repetitive loss program
- Identify triggers to shift implementation to different adaptation strategies. Triggers may include sea level elevation, time, exposure or damage.

Generally, the shoreline areas in Carlsbad that are vulnerable to sea level rise include: low lying beaches, low lying estuaries, and bluff-backed shoreline. Current and future coastal hazard vulnerabilities to these shoreline segments vary and, likewise, the most effective adaptation responses differ. The following types of adaptation responses are the most effective for the respective shoreline type and are listed in order of “soft” to “hard” strategies:

- Low lying beaches
  - Managed retreat
  - Dune restoration
  - Beach nourishment
  - Sand retention with nourishment
  - Elevating structures
  - Coastal armoring
- Low lying estuaries
  - Managed retreat
  - Dune or wetland restoration
  - Elevating structures
  - Coastal armoring
- Bluff-backed shoreline
  - Managed retreat
  - Movable foundation
  - Coastal armoring

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Attachment A: Sea Level Rise Science & Coastal Hazard Mapping Assumptions

This attachment presents technical information on sea level rise science, the City of Carlsbad's (City) coastal setting and limitations and assumptions related to coastal hazard mapping.

1. SEA LEVEL RISE SCIENCE AND PROJECTIONS

Sea levels are projected to rise in the coming decades as a result of increased global temperatures associated with climate change (Intergovernmental Panel on Climate Change 2013). When discussing sea level rise (and when reviewing sea level rise projections), it is important to distinguish the differences between global and local sea level rise rates. Global sea level rise rates disregard local effects such as tectonics (i.e., land uplift/subsidence), water temperatures, and wind stress patterns that can act to subdue or amplify the global sea level rise rates. Local (or relative) sea level rise refers to the observed changes in sea level relative to the shoreline in a specific region and takes into account these local factors.

It should be noted that guidance related to sea level rise evolves as new science is released. The most relevant science and guidance from the international, federal, and state levels at the time of this report is summarized in this section.

1.1. STATE GUIDANCE

The 2012 National Research Council report titled "Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future," is considered the best available science for California (CCC 2015, CO-CAT 2013). Thus, both state guidance documents utilize the sea level rise projections from the National Research Council's report. The National Research Council is a conglomerate of scientists and research organizations that act as an advisory group for government agencies.

1.1.1. California Coastal Commission Sea Level Rise Policy Guidance (CCC 2015)

The document states that the best available science should be utilized when incorporating sea level rise into planning documents or when applying for a coastal development permit. As stated above, the 2012 National Research Council's report is generally considered as the best available science for the region at the time of this report. The 2012 National Research Council's report predicts a 0.9-ft increase of relative sea level rise (i.e., relative rise of the ocean water level compared to land) by 2050 and a 3.1-ft increase by 2100 in the City (Table 1). These projections are described as being applicable to all areas south of Cape Mendocino in the study. The sea level rise projection values in Table 1 indicate the mean and uncertainty (i.e., standard deviation) for a specific IPCC future greenhouse gas emission scenarios (i.e., A1B). The A1B scenario represents a world of rapid economic growth and a balanced use of fossil and non-fossil energy sources. The sea level rise ranges in Table 1 represent the means for the B1 (low greenhouse gas emission scenario) and A1FI (high greenhouse gas emission scenario). Note that the certainty in projections decrease with time, as indicated by the increasing uncertainty values.

Table 1: Sea Level Rise Projections for Los Angeles Region

Year	Projected Sea Level Rise (ft.)	Projection Uncertainty (ft., +/-)	Low Range (ft.)	High Range (ft.)
2030	0.5	0.2	0.2	1.0
2050	0.9	0.3	0.4	2.0
2100	3.1	0.8	1.5	5.5

(Source: National Research Council 2012)

1.1.2. State of California Sea-level Rise Guidance Document (CO-CAT 2013)

A state sea level rise guidance document, titled "State of California Sea-Level Rise Guidance Document (Interim Guidance)" (CO-CAT 2013), was originally released in October 2010 and re-released/updated in March 2013 to provide guidance to state agencies for incorporation of sea level rise projections into project planning and decision making. The document recommended use of the ranges of sea level rise presented in the 2012 National Research Council's report as a starting place. CO-CAT recommends that specific project design sea level rise scenario ranges should then be based on agency- and context-specific considerations of risk tolerance and adaptive capacity of the affected assets. The Ocean Protection Council intends to update the state sea level rise guidance in early 2018 to reflect new research on sea level rise projections. This vulnerability assessment will be periodically updated and the guidance in effect at the time of the update will be utilized.

2. COASTAL SETTING

2.1. WATER LEVELS

The nearest, long-term sea level record in proximity to the study area is the La Jolla tide gage (Station 9410230) operated by the National Oceanic and Atmospheric Administration (NOAA). The gage is located on the Scripps Pier, which has been collecting data since 1924. These data are applicable to the San Diego region open-ocean coastline and are summarized in Table 2.

Table 2: Water Levels in La Jolla (1983-2001 Tidal Epoch)

Description	Datum	Elevation (ft MLLW)
Highest Observed Water Level (1/11/2005 5:00:00 PM)	Maximum	7.66
Highest Astronomical Tide	HAT	7.14
Mean Higher-High Water	MHHW	5.32
Mean High Water	MHW	4.60
Mean Sea Level	MSL	2.73
Mean Low Water	MLW	0.90
Mean Lower-Low Water	MLLW	0.00
North American Vertical Datum of 1988	NAVD88	0.19
Lowest Astronomical Tide	LAT	-1.88
Lowest Observed Water Level (12/17/1933 11:36:00 PM)	Minimum	-2.87

(Source: NOAA 2015)

2.2. LITTORAL PROCESSES

A littoral cell is a segment of shoreline in which sand is bounded or contained. The City is located within the Oceanside Littoral Cell, which extends from Dana Point Harbor to La Jolla, a distance of approximately 50 miles (Patsch and Griggs 2007). The cell's shoreline consists of a narrow beach that is backed by seacliffs, bluffs, and mouths of coastal streams and rivers. Inputs to the Oceanside Littoral Cell include: fluvial sources (rivers), bluff erosion, gully and terrace erosion, and anthropogenic sources (i.e., beach nourishment). Natural sand loss occurs at sand sinks, which include the La Jolla and Scripps submarine canyons, lagoons, and offshore bars (Patsch and Griggs 2007).

Human intervention has significantly influenced the coastal processes in the Oceanside Littoral Cell. The construction of coastal structures (i.e., jetties, seawalls, etc.) and inland flood control structures (i.e., dams) have reduced the amount of sand traveling along the coast and being delivered to the coast, respectively. In particular, the Oceanside Harbor jetty system effectively traps sand from naturally traveling from north to south. The harbor captures sand, which is dredged and placed on downdrift beaches. This is approximately equal to the net littoral drift from Oceanside Harbor to Scripps Submarine Canyon (Patsch and Griggs 2007).

The City currently monitors the beaches by measuring beach profiles throughout the city at historic beach profile locations. Beaches have been monitored at 12 sites for 20 years. Data from the monitoring indicate that Carlsbad beaches are relatively stable, with seasonal shifts in beach width and gains associated with beach nourishment or bypassing projects. Specifically, North Carlsbad Beach is relatively stable due to the effects of periodic nourishment from the Regional Beach Sand Projects (RBSPs), and from more regular nourishment from maintenance dredging and bypassing in and around Agua Hedionda Lagoon. Beaches south of the Agua Hedionda Lagoon mouth (middle beach) vary, with stability from sand placed as part of the lagoon maintenance dredge material placed between the inlet jetties. Beaches south of Terramar Point through the Southern Planning Area are actively eroding, with periodic widening from San Diego Association of Governments (SANDAG) sand replenishment projects (see Section 2.4, below) followed by narrowing. Farthest to the south, the beaches on both sides of the Batiquitos Lagoon mouth are relatively wide due to the sand retention effects of the lagoon mouth jetties, from benefits of nourishment from initial 1995 lagoon restoration, and from on-going maintenance dredging of the lagoon since approximately 2005.

2.3. WAVES

Waves act to carry sand in both the cross-shore and longshore directions and can also cause short-duration flooding events by causing dynamic increases in water levels. Thus, the wave climate (or long-term exposure of a coastline to incoming waves) and extreme wave events are important in understanding future sea level rise vulnerabilities.

Offshore wave data was analyzed for Carlsbad from Wave Information Studies (WIS) Station 83105 from 1980 to 2011 (Figure 1). WIS, developed by the USACE, is an online database of estimated nearshore wave conditions covering U.S. coasts. The wave information is derived based on a database of collected wind measurements (a process known as wave “hindcasting”) and is calibrated by offshore wave buoys. The hindcast data provides a valuable source of decades-long nearshore wave data for coastlines in the U.S.

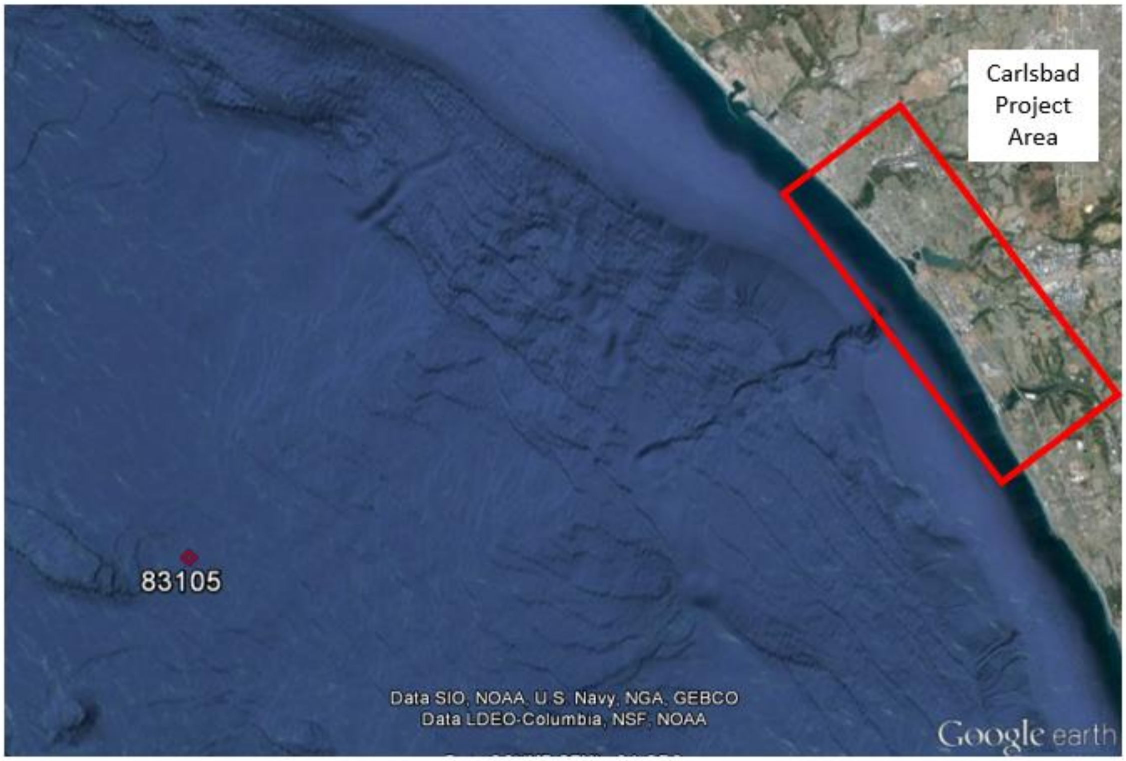


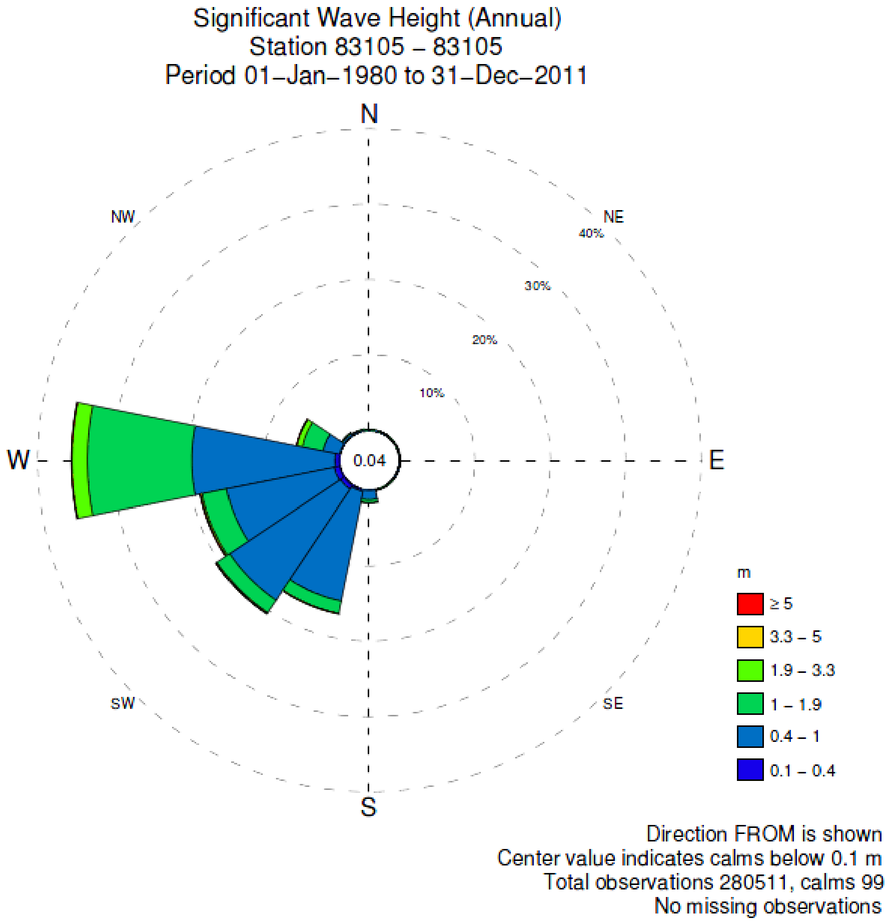
Figure 1: Location of WIS Station 83105

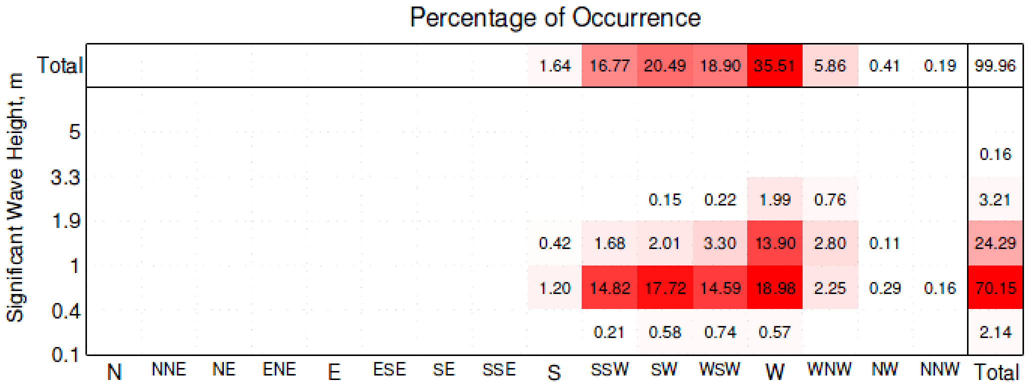
2.3.1. Wave Climate

The largest percentage (36%) of the waves approaching Carlsbad are from the west (270 degrees). The most frequent wave height is 1.5 to 3 ft., as shown in Figure 2. Wave periods were between 12 and 16 seconds with 14 to 15 seconds occurring the most frequently (Figure 3).

2.3.2. Extreme Waves

The 50- and 100-year return period wave heights in Carlsbad are approximately 19.6 and 22 ft, respectively (Figure 3). The largest waves occur in the winter when northern hemisphere cyclonic storms generate powerful, long period waves. These waves can result in coastal erosion, flooding and bluff failures.




Percentage of Occurrence

Significant Wave Height, m	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total
Total									1.64	16.77	20.49	18.90	35.51	5.86	0.41	0.19	99.96
5 – 3.3																	0.16
3.3 – 1.9											0.15	0.22	1.99	0.76			3.21
1.9 – 1									0.42	1.68	2.01	3.30	13.90	2.80	0.11		24.29
1 – 0.4									1.20	14.82	17.72	14.59	18.98	2.25	0.29	0.16	70.15
0.4 – 0.1										0.21	0.58	0.74	0.57				2.14

Figure 2: Annual Significant Wave Height and Direction (WIS Sta. 83105)

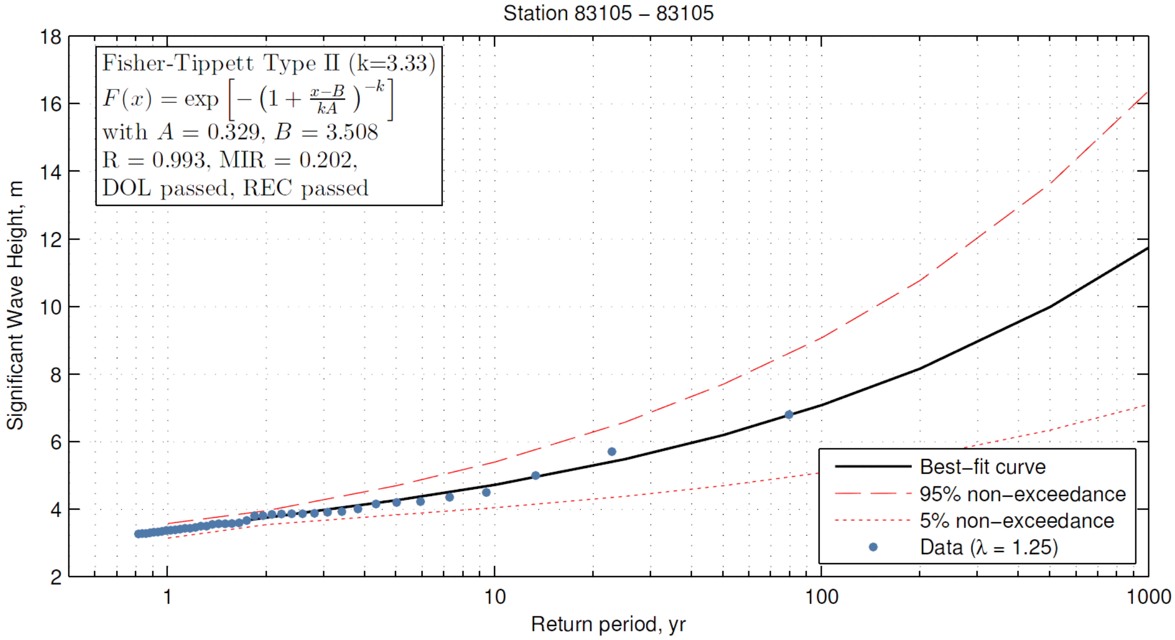


Figure 3: Wave Return Periods, WIS Station 83105

2.4. SHORELINE MANAGEMENT

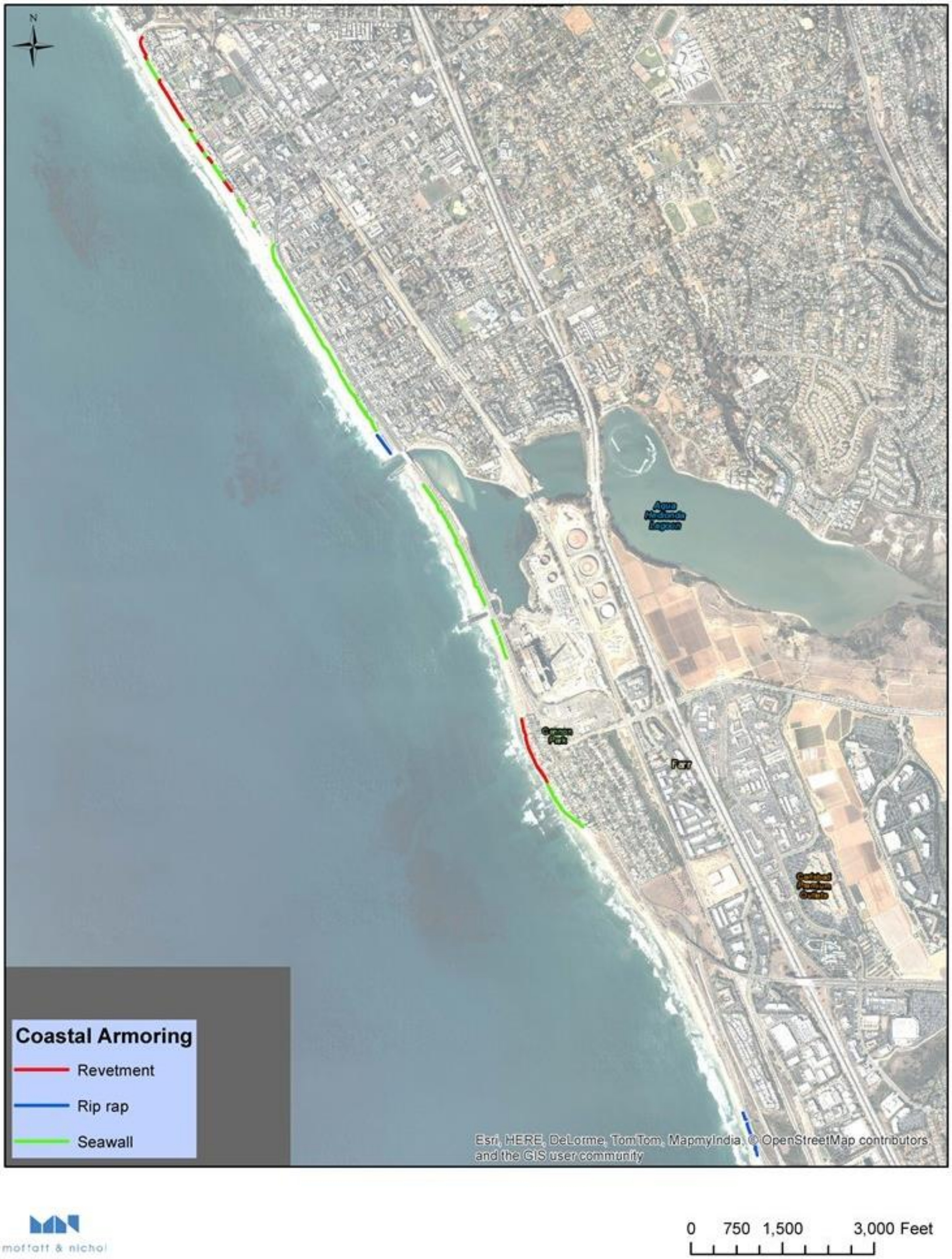
In addition to dredging projects along the Oceanside Littoral Cell coast, periodic beach nourishment projects have added to the sediment budget. The City of Carlsbad has actively participated in the Shoreline Preservation Working Group within SANDAG since its inception as the Shoreline Erosion Committee in 1991. SANDAG issued its Shoreline Preservation Strategy in the early 1990s that called for pilot beach nourishment projects to restore the region's beaches (SANDAG 1993). The two RBSPs in the city were implemented as RBSP I in 2001 and RBSP II in 2012 that included sand placed at two beach locations along Carlsbad's coastline.

The city's other sand management activities include coordinating with the sand bypassing by Encina Power Station at Agua Hedionda Lagoon. At the request of the city, the sand from the lagoon entrance is placed on the beach both north and south of the jetties. City leaders work through an appointed Beach Preservation Committee that makes recommendations regarding sand management.

As mentioned above, the city has also participated in two RBSPs. One of the sites was located at North Carlsbad Beach, just south of the Buena Vista Lagoon mouth, and the other site was located at South Carlsbad North just north of the mouth of Las Encinas Creek. Sand from other placement sites adjacent to Carlsbad (i.e., Oceanside and Encinitas) also moved both up and down the coast to benefit the city.

2.5. SHORELINE ARMORING

Shoreline armoring exists along much of the city's coastline, though is concentrated along the north coastline. Armoring consists of seawalls, revetments, and rip rap, as shown in Figure 4. A shoreline armoring GIS shapefile was created for the city to inventory the presence and type of shoreline structures. This file was based on a prior shoreline armoring database created by the Coastal Commission in 2005 (Dare 2005). The database was revised to include proper structure type (where applicable) and improved to be spatially explicit. The Dare 2005 database was previously set to an arbitrary, straight offshore line in the city. This line was revised to represent the approximate location of coastal structures in the city. The legality, age, and state of repair of the structure was not detailed as part of this effort.



moffatt & nichol

Figure 4: Shoreline Armoring in Carlsbad

3. COASTAL HAZARD MODELING AND MAPPING

Carlsbad's exposure to future rates of sea level rise was determined using preliminary results from the CoSMoS 3.0 model. CoSMoS is a multi-agency effort led by the U.S. Geological Survey (USGS) to make detailed predictions (meter scale) of coastal flooding and erosion based on existing and future climate scenarios for Southern California. The modeling effort depicts coastal flooding, shoreline change and bluff response to a composite, 100-year wave event in combination with various rates of sea level rise and baseline water levels (i.e., high tide, storm surge, sea level anomaly and river discharge).

Details on the sea level rise scenarios selected and how the respective coastal hazards were mapped are provided in this section.

3.1. SEA LEVEL RISE SCENARIOS

Years 2050 and 2100 were selected as planning horizons for this vulnerability assessment. The CoSMoS 0.5 m and 2 m sea level rise scenarios roughly align with the projected high sea level rise from the 2012 National Research Council's report for the 2050 and 2100 planning horizons. Therefore, these sea level rise scenario results were used as the basis for this vulnerability analysis. The National Research Council's high range projection is slightly higher (0.3 ft.) for year 2050 and slightly lower (1.1 ft.) for year 2100 compared to CoSMoS projections. Thus, the hazards predicted by CoSMoS projection for 2050 will be marginally less than hazards resulting from the National Research Council's projection and the hazards for 2100 will be greater as predicted by CoSMoS projections compared to the National Research Council projections. A comparison of the National Research Council's 2012 sea level rise projections for the planning horizons compared to the CoSMoS scenarios used is shown in Table 3.

Table 3: Comparison of Sea Level Rise Scenarios

Year	2012 National Research Council Sea Level Rise Projections				CoSMoS 3.0 Sea Level Rise Scenario	Difference (CoSMoS vs. 2012 National Research Council) (ft.)
	Projection (ft.)	Uncertainty (ft., +/-)	Low Range (ft.)	High Range (ft.)		
2050	0.9	0.3	0.4	2	0.5 m (1.7 ft.)	0.3
2100	3.1	0.8	1.5	5.5	2.0 m (6.6 ft.)	1.1

3.2. BLUFF EROSION

Projections of coastal cliff-retreat rates (or cliff erosion rates) and positions for future sea level rise scenarios were made using numerical and statistical models based on field observations such as historical cliff retreat rate, submarine slope, coastal cliff height, and mean annual wave power (CoSMoS 2015). Bluff profile evolution models relate breaking-wave height and period to bluff erosion, and distribute erosion vertically over a tidal cycle.

The above modeling approach was run assuming a bluff edge baseline established from the 2010 digital elevation model. Determining the bluff edge is a subjective process and spatial projections will depend on the interpretation of the bluff edge. The bluff hazard zone for each projection year was shown as the area between the baseline bluff positon and the projected bluff position for the 0.5 m and 2.0 m sea level rise scenarios. Bluff erosion rates are based on historical rates from the USGS National Assessment of Shoreline Change and assume that sea level rise does accelerate erosion. Figure 5 provides a schematic depicting the projected CoSMoS 3.0 bluff erosion results for various sea level rise scenarios (shown as blue to red polylines) and uncertainty limits for the 2.0 m scenario (shown as a light grey).

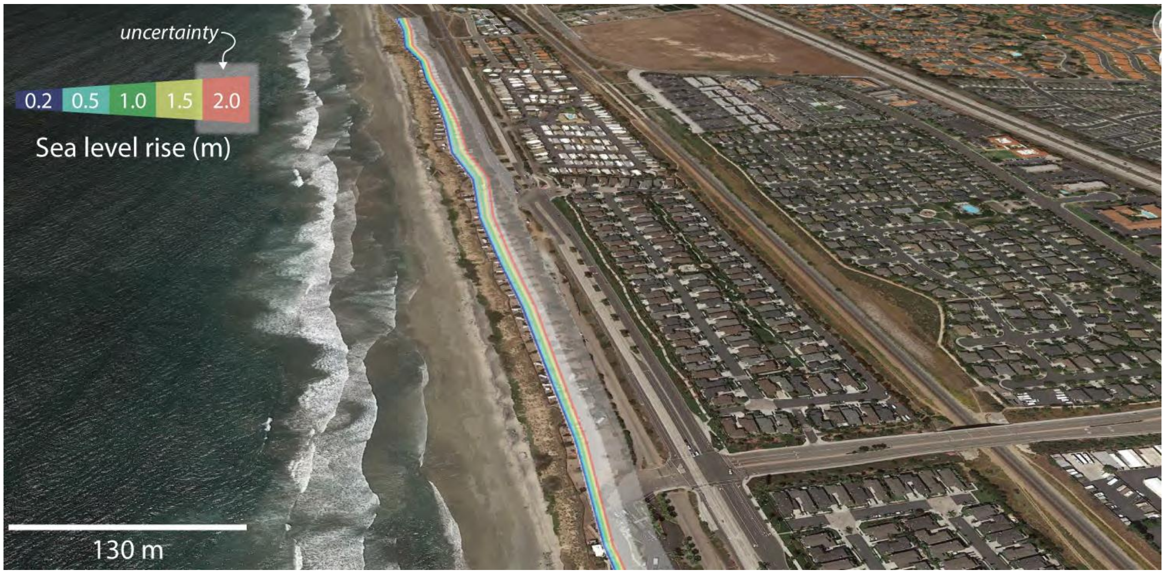


Figure 5: CoSMoS Bluff Erosion Projections by 2100
(CoSMoS-COAST 2015)

3.3. COASTAL FLOODING

The CoSMoS model is comprised of three tiers that transform the offshore wave climate to the shoreline and inland. Tier I contains two models: a hydrodynamics (motions and forces of fluids) flow model (Delft 3D) that computes tides, water level variations, flows, and currents; and a wave generation and propagation model (SWAN). Tier II refines the resolution of the model by segmenting the Southern California Bight (coastline from Point Conception to San Diego) area into 11 sections and incorporating fluvial discharge through the FLOW model to simulate flooding from elevated water (coastal and river) levels. Tier III uses the XBeach model to run hydrostatic, morphodynamic (water and beach interaction and resulting adjustments and changes) simulations.

The resulting projected flood hazards mapped are areas vulnerable to coastal flooding due to storm surge, sea-level anomalies (e.g., higher water levels due to warm water temperatures or low atmospheric pressure), tide elevation, and wave run-up during the 2100 storm simulation in combinations with the maximum elevation of still-water level.

3.4. SHORELINE EROSION

Projections of shoreline change as a result of future sea level rise scenarios were made using CoSMoS-COAST model (Figure 6). This shoreline model uses a series of global-to-local nested wave models (such as WaveWatch III and SWAN) forced with Global Climate Model (GCM) derived wind fields. Historical and projected time series of daily maximum wave height and corresponding wave period and direction from 1990 to 2100 force the shoreline model (CoSMoS-COAST 2015).

Additionally, the CoSMoS-COAST model incorporates the following relevant processes in sediment transport: longshore transport and shoreline equilibrium equations; wave-driven cross-shore transport and resulting equilibrium beach profiles; and long-term beach profile changes due to sea level rise. Light detection and ranging (LIDAR) data is then used to adjust the model parameters in an effort to estimate the effects of unresolved processes, such as natural and anthropogenic (beach nourishment and bypassing) sediment supply.

Figure 6: CoSMoS Shoreline Erosion Projections by 2100

3.5. MODEL LIMITATIONS

The preliminary CoSMoS 3.0 release is a useful dataset for the first-order identification of future at-risk areas. The data is preliminary; therefore, is subject to revision prior to being finalized in 2017. However, even when the final CoSMoS product is released, due to the regional nature of the modeling exercise, city-scale details can be lost. Other limitations of the CoSMoS 3.0 data set are discussed in this section.

3.5.1. Topographic / Bathymetric Model Resolutions

CoSMoS developed a seamless, topo-bathymetric digital elevation model combining land based topographic elevation data with below water bathymetric elevation data, which was based on bare-earth LIDAR data collected in 2009-2011 for the California Coastal Conservancy LIDAR Project, bathymetric LIDAR from 2009-2010 as well as acoustic multi- and single-beam data collected primarily between 2001 and 2013. Though this data was the best-available to the study team, some local-scale details in the city were lost in this data set (e.g., vertical seawalls).

3.5.2. Bluff Erosion (Bluff Hazard Zone)

The CoSMoS model makes regional assumptions using a uniform bluff substrate, meaning that the bluff is assumed to be made up entirely of the same sediment; thus, oversimplifies many bluffs in San Diego County that consist of multiple sediment layers of varying erosive tendencies, the degree of prediction provided by these assumptions is unknown. The modelers cited a sparsity of data on bluff substrate as the reason for this assumption. The model used the USGS National Shoreline Assessment study for data on historical bluff retreat. This study analyzed bluff change from about 1933 to 1998 and found that bluffs within the Oceanside region, which captures the City of Carlsbad, are retreating at an average rate of 0.7 ft. per year. The accuracy of these bluff erosion predictions is dependent on the deviation from the uniform bluff substrate assumed at each bluff location. These historic erosion rates which account for acceleration due to sea level rise, however may underestimate the effects of sea level rise on erosion over time.

The model did not include shoreline protection structures in the city. Examples of bluff protection structures that were excluded include coastal structures (seawalls, revetments, riprap) and bluff stabilization treatments that exist in the community of Terramar. The model states that coastal structures were not included if the armoring was low enough to be easily overwashed. Determination as to whether armoring was easily overwashed was subjective and was determined by the USGS. Not accounting for these bluff protection structures in the city likely overestimates bluff erosion hazards in certain areas. CoSMoS 3.0 bluff erosion data includes uncertainty bands and, therefore, bluff hazards described in this vulnerability assessment could under- or over-estimate impacts.

3.5.3. Shoreline Erosion (Inundation Hazard Zone)

The shoreline model includes a variable for long-term beach accretion or erosion based on an analysis of historical shoreline change. This variable represents sediment contributions from beach nourishment, bluff erosion and fluvial (river) contributions and was calculated through analysis of historical shoreline change dataset from 1970s to present. Based on coordination with the USGS, the long-term shoreline change variable included in the shoreline model for the city is 0.5 ft of shoreline gain per year on average.

Historical averages of beach or bluff erosion does not account for accelerated erosion due to sea level rise. Fluvial conditions may also differ from historical norms as a result of climate change. Past rates of beach nourishment may not accurately represent beach management practices in the future. Beach nourishment rates and volumes have been decreasing over time in many areas in southern California because of funding and regulatory constraints for these types of projects.

The shoreline model included coastal structures (rip rap, revetments and seawalls) and coastal infrastructure. Thus, shoreline erosion model results become invalid as the beach becomes fully eroded and possibly undermines coastal structures and infrastructure. Therefore, shoreline erosion is understated where the projected shoreline encounters a coastal structure or infrastructure.

3.5.4. Coastal Flooding (Flood Hazard Zone - Shoreline)

Coastal flooding results were de-coupled with future shoreline position data. Thus, the coastal flooding results shown are based on today’s shoreline position instead of an eroded, future condition. This likely understates the flooding results and was recognized as a limitation in the preliminary data release. The future coastal flooding data will utilize the future shoreline position to then generate coastal flooding limits. Flooding limits are anticipated to be greater and extend more landward with the coupling of these analyses in the future release.

The landward extent of coastal flood limits was based on the USGS, bare-earth DEM. Topographic features captured in this DEM effected the landward propagation of flooding. Coastal structures were implicitly captured in these results when these structures were large enough (revetments in the Village Planning Area). Small scale features, such as seawalls along Carlsbad Boulevard in the Tamarack Planning Area, were not captured in the DEM. Thus, coastal flooding limits are likely overstated in areas where small scale coastal structures were excluded from the modeling domain.

3.5.5. Lagoon Inundation (Inundation Hazard Zone)

Areas in the lagoons subject to future daily tides were mapped using a DEM provided by city GIS staff. A mean higher high water vertical elevation of 5.3 feet (MLLW) was used to represent future, daily-high still water tidal elevations in the lagoons. The mean higher high water elevation was added to the projected sea level rise for each planning year (i.e., 2050 and 2100). Since the weir at Buena Vista Lagoon has a crest elevation of 7.89 feet (MLLW), it was found that this lagoon would only experience tidal inundation during the 2.0 m, year 2100 scenario.

3.5.6. Lagoon Flooding (Flood Hazard Zone - Lagoons)

Moffatt & Nichol conducted a review of the CoSMoS model outputs with existing fluvial (river) models of the three lagoons in the city. Existing fluvial models of these lagoons were performed in connection with the North Coast Corridor project being led by SANDAG. Based on this review, Moffatt & Nichol found the following deficiencies in the CoSMoS 3.0 lagoon flooding model outputs:

- Coastal lagoons are included in the Tier II high resolution CoSMoS models; however, the lagoon bathymetry is derived from topo LIDAR. Thus, the lagoon area below the water surface is a simple flat surface that may not correctly represent the effects of tides and storms within the lagoon, this can lead to both under estimation and over estimation of hazards.
- CoSMoS is intended to model the 100-year storm from ocean conditions. The hydrograph (graphical representation of storm flow) is idealized and the peak flow included in the model is based on atmospheric pressure conditions that are produced during the coastal storms. The peak flow rate of the CoSMoS storm is about 10% of the FEMA 100-year fluvial discharge. The small storm used in the CoSMoS model underestimates the hazards that could exist during a 100-year fluvial storm with sea level rise conditions.
- Culverts or other manmade and natural underground pathways between coastal waters and land are not considered. This likely underestimates flooding hazards that may occur in areas connected to coastal waters by culverts and other manmade and natural conduits.

Based on these deficiencies, Moffatt & Nichol developed a new data layer showing the limits of these lagoon flood hazards. Inundation hazard zones (areas subject to daily tides) were also mapped to show the migration of the lagoon shoreline landward. More detailed assessment of each of the findings per lagoon is provided in this section.

3.5.6.1. BATIQUITOS LAGOON

At Batiquitos Lagoon, CoSMoS results provide an adequate prediction scenario for a 100-year coastal storm and should be used for the nearshore area outside of the lagoon. The impacts of a 100-year fluvial storm are not included in the CoSMoS model, the small fluvial storm used in CoSMoS does not represent the effects of a 100-year fluvial storm in the lagoon during sea level rise conditions. The Moffatt & Nichol RMA-2 model results provide an adequate prediction scenario for the 100-year fluvial storm with sea level rise and should be used in the lagoon area for planning purposes. Batiquitos Lagoon and referenced basins are shown in Figure 7. A comparison of water surface elevations for the models reviewed are summarized in Table 4.

Figure 7: Batiquitos Lagoon

Table 4: Comparison of Water Surface Elevations for Batiquitos Lagoon

					Water Surface Elevation ft, NAVD 88			
Model	**Sea Level Rise Year**	**Sea Level Rise, ft. (m)**	**Fluvial Storm, cfs (cms)**	**Return Frequency**	**Beach**	**West Basin**	**Central Basin**	**East Basin**
FEMA	Current	0	15,700 (444.6)	100-Yr	10	-	-	-
COSMOS	Current	0	1,646 (46.6)	N/A	***12**	7	7	7
	2050	1.6 (0.5)	1,646 (46.6)	N/A	***14**	8.5	8.5	8.5
	2100	6.6 (2.0)	1,646 (46.6)	N/A	***17**	14	14	14
Moffatt & Nichol	Current	0	1,646 (46.6)	N/A	7.1	7.1	7.1	7.2
	2050	1.6 (0.5)	1,646 (46.6)	N/A	8.7	8.7	8.8	8.8
	2100	6.6 (2.0)	1,646 (46.6)	N/A	13.7	13.7	13.7	13.7
	Current	0	16,560 (468.9)	100-Yr	7.1	***7.9**	***8.7**	***10.2**
	2050	1.6 (0.5)	16,560 (468.9)	100-Yr	8.7	***9.3**	***9.9**	***11.3**
	2100	6.6 (2.0)	16,560 (468.9)	100-Yr	13.7	***14.0**	***14.4**	***15.2**

**** Results used for planning purposes***

Note: Cosmos water surface elevations estimated from shapefiles
FEMA flood elevations are not established for the lagoon

3.5.6.2. AGUA HEDIONDA LAGOON

At Agua Hedionda, CoSMoS results provide an adequate prediction scenario for a 100-year coastal storm and should be used for the nearshore coastal area outside of the lagoon. The impacts of a 100-year fluvial storm are not included in the CoSMoS model, the small fluvial storm used in CoSMoS does not represent the effects of a 100-year fluvial storm in the lagoon during sea level rise condition. The Chang Hydraulic and Scour Studies for Proposed Interstate 5 Bridge Widening across Three Lagoons HEC-RAS model results adjusted by Moffatt & Nichol to account for sea level rise conditions under the 100-year fluvial storm provide a conservative prediction scenario and should be used in the lagoon area for planning purposes, additional fluvial modeling study is recommended if accurate results similar to that for Batiquitos Lagoon are desired. A comparison of model water surface elevations is shown in Table 5. Agua Hedionda Lagoon and referenced basins are shown in Figure 8.

Figure 8: Agua Hedionda

Table 5:Comparison of Water Surface Elevations for Agua Hedionda Lagoon

					Water Surface Elevation ft, NAVD 88			
Model	**Sea Level Rise Year**	**Sea Level Rise, ft. (m)**	**Fluvial Storm, cfs (cms)**	**Return Frequency**	**Beach**	**West Basin**	**Central Basin**	**East Basin**
FEMA	Current	0	9,850 (278.9)	100-Yr	11	-	-	-
COSMOS	Current	0	918 (26)	N/A	***11**	7	7	5.5
	2050	1.6 (0.5)	918 (26)	N/A	***13**	9	8	5.5
	2100	6.6 (2.0)	918 (26)	N/A	***18**	14	13	8
CHANG	Current	0	10,500 (297.3)	100-Yr	-	***6.9**	***7.8**	***9.9**
Moffatt & Nichol **	2050	1.6 (0.5)	10,500 (297.3)	100-Yr	-	***8.5**	***9.4**	***11.5**
	2100	6.6 (2.0)	10,500 (297.3)	100-Yr	-	***13.5**	***14.4**	***16.5**

**** Results used for planning purposes***

Note: Cosmos water surface elevations estimated from shapefiles
FEMA flood elevations are not established for the lagoon

***WATER SURFACE ELEVATIONS ARE ESTIMATED BASED ON CHANG CONSULTANTS STUDY AND MOFFATT & NICHOL INTERPRETATIONS FOR SEA LEVEL RISE*

3.5.6.3. BUENA VISTA LAGOON

CoSMoS results provide an adequate prediction scenario for a 100-year coastal storm and should be used for the nearshore area outside of the lagoon. The impacts of a 100-year fluvial storm are not included in the CoSMoS model, the small fluvial storm used in CoSMoS does not represent the effects of a 100-year fluvial storm in the lagoon during sea level rise conditions. The two-dimensional Everest model results for current lagoon conditions from the Buena Vista Lagoon Enhancement Project DEIR provide an adequate prediction of water surface elevations for current sea level conditions with a 100-year fluvial storm and estimates for sea level rise conditions under the 100-year fluvial storm, these results should be used in the lagoon area for planning purposes.

Figure 9: Buena Vista Lagoon

Table 6: Comparison of Water Surface Elevations for Buena Vista Lagoon

					Water Surface Elevation ft, NAVD 88				
Model	**Sea Level Rise Year**	**Sea Level Rise, ft (m)**	**Fluvial Storm, cfs (cms)**	**Return Frequency**	**Beach**	**Weir Basin**	**Railroad Basin**	**Coast Hwy Basin**	**I-5 Basin**
FEMA	Current	0	8,500 (240.7)	100-Yr	11	-	-	-	
COSMOS	Current	0	671 (19)	N/A	***11**	9	8	8	14
	2050	1.6 (0.5)	671 (19)	N/A	***15**	9	8	8	14
	2100	6.6 (2.0)	671 (19)	N/A	***23**	16	12	12	14
EVEREST	Current	0	8,500 (240.7)	100-Yr	-	***14.2**	***14.2**	***14.2**	***17.9**
	2050	1.6 (0.5)	8,500 (240.7)	100-Yr	-	***14.8**	***14.9**	***15**	***19**
	2100	6.6 (2.0)	8,500 (240.7)	100-Yr	-	***15.2**	***15.3**	***15.4**	***19.1**

* ***Results used for planning purposes***

NOTE: COSMOS water surface elevations estimated from shapefiles
FEMA flood elevations are not established for the lagoon

3.5.7. Culverts and Storm Drain Systems

The CoSMoS model currently does not include culverts, storm drain systems or other manmade and natural underground pathways between coastal waters and land. Thus, flooding limits may be understated in some areas. Increased water levels due to sea level rise, fluvial storms, coastal storms, high tides, and wave run-up can back into these conduits and result in flooding of upland areas into which these conduits drain. The potential for flooding of drainage areas connected to these systems is dependent on topography, conveyance invert elevations, slopes, backwater conditions, drainage structures, and other hydraulic factors. Increased tail water levels at the outlet of storm drain systems may cause flooding of low lying areas connected to these systems and flooding due to reduced drainage capacity of the system. Culverts intended to provide drainage during storm events could cause backwater flooding if the tail water levels are higher than the invert of the these structures.

Culverts and storm drain systems that outlet into coastal lagoons or beach areas that could have potential backwater flow problems were identified using the city's storm drain GIS database. Note that backwater flooding should not be expected for storm drains having functional flapgates. This data was not available at the time of this study.

Storm water vulnerabilities as a result of tail water from future rates of sea level rise are summarized in

Table 7 through Table 11. Culverts and storm drain systems could result in additional flooding not predicted by the CoSMoS model and additional study is recommended to validate the vulnerability of these storm drains.

Table 7: Storm Drain Systems Outlet to Batiquitos Lagoon – Planning Zone 3

Object ID	Facility ID	Type	Size	Downstream Invert	Upstream Invert	Vulnerable Year
7571	SDC6092	RCP	18	0	0	current
7570	SDC6091	RCP	24	0	0	current
7569	SDC6090	RCP	24	0	0	current
5658	SDC3342	RCP	24	0	0	current
6354	SDC3341	RCP	24	0	0	current
8669	SDC9741	PVC	18	0	0	current
8668	SDC9740	PVC	18	0	0	current
13194	SDP100860	RCP	30	0	0	current
5661	SDC3345	RCP	30	0	0	current
7796	SDC7560	RCP	10	0	0	current
6411	SDC3376	RCP	18	0	0	current
12876	SDC3374	RCP	24	0	0	current
7886	SDC7769	RCP	24	0	0	current
8723	SDC10072	RCP	60	0	0	current
8702	SDC10041	RCP	24	0	0	current
8688	SDC9914	CMP	24	0	0	current
13090	SDP100755	RCP	24	0	0	current
13091	SDP100756	RCP	24	0	0	current
7155	SDC4379	RCP	36	6.27	0	current
6308	SDC4296	RCP	18	6.27	6.4	current
6925	SDC4313	CMP	36	0	0	current
8710	SDC10048	RCP	30	0	0	current
7156	SDC4380	RCP	36	3.3	0	current
6647	SDC3730	RCP	72	3.3	20.76	current
6644	SDC3727	RCP	48	5.4	0	current
6645	SDC3728	RCP	48	5.4	5.6	current
6519	SDC3509	RCP	60	8.8	9	2050
6517	SDC3507	RCP	36	1.35	14.03	current
6512	SDC3502	RCP	18	13.5	35.67	2100
7045	SDC4227	RCP	72	0	0	current
6374	SDC3583	RCP	42	10	11.76	current
6618	SDC3700	RCP	72	11.6	14.12	2100
6583	SDC3664	RCP	72	0	0	current
6412	SDC3378	CMP	36	6.53	10.26	current
13616	SDP101287	RCP	30	2.81	3.06	current
5662	SDC3348	RCP	18	0	0	current

Note: Invert elevations with a zero value may be due to missing data

Table 8: Storm Drain Systems Outlet to Shoreline between
Agua Hedionda Lagoon and Batiquitos Lagoon Shorelines – Planning Zones 2 and 3

Object ID	Facility ID	Type	Size	Downstream Invert	Upstream Invert	Vulnerable Year
7179	SDC4407	RCP	18	13.47	33.75	2100
7215	SDC4447	RCP	24	0	0	current
8335	SDC8550	RCP	18	0	0	current
7944	SDC7949	RCB	9X20	0	0	current
7914	SDC7904	CMP	18	0	0	current
7943	SDC7948	RCP	18	0	0	current
6337	SDC3237	CMP	12	0	0	current
6335	SDC2924	CMP	18	0	0	current
2963	SDC1250	RCP	18	0	0	current
2436	SDC2925	CMP	18	0	0	current
12776	SDC1308	RCP	18	0	0	current
1743	SDC1332	RCP	18	12.4	33.67	2050

Note: Invert elevations with a zero value may be due to missing data

Table 9:Storm Drain Systems Outlet to Agua Hedionda Lagoon – PLanning Zone 2

Object ID	Facility ID	Type	Size	Downstream Invert	Upstream Invert	Vulnerable Year
1753	SDC1342	RCP	48	4.25	4.6	current
12698	SDC1351	RCP	18	0	0	current
12696	SDC1349	RCP	18	0	0	current
12694	SDC1347	RCP	18	0	0	current
12692	SDC1345	RCP	18	0	0	current
1754	SDC1343	RCP	18	0	0	current
2844	SDC9833	RCP	96	0	0	current
2933	SDC10009	RCP	24	0	0	current
1536	SDC684	RCP	24	0	0	current
10554	SDC683	RCP	36	0	0	current
11575	SDC949	RCP	36	4.1	5	current
764	SDC1719	RCP	36	5.4	0	current
11671	SDC3246	RCP	60	-1.47	-0.55	current
11686	SDC951	RCP	18	3.8	5.13	current
3142	SDC11611	PVC	6	0	0	current
3143	SDC11618	PVC	6	7.5	9.35	current
3146	SDC11621	PVC	6	7.5	9.35	current
11674	SDC9283	RCP	24	0	7.9	current
13078	SDP100743	RCP	18	8.03	16.39	current
12293	SDC1245	CMP	12	0	0	current
12301	SDC1427	CMP	12	0	0	current
12291	SDC1426	CMP	21	6	21	current
14029	SDP101710	CMP	48	0	0	current
2838	SDC9775	RCP	24	0	0	current
2440	SDC2934	RCP	84	8	13.82	2050
1766	SDC1382	CMP	15	5.75	37.52	current
12691	SDC1380	RCP	48	0	0	current

Note: Invert elevations with a zero value may be due to missing data

Table 10: Storm Drain Systems Outlet to the Village Shoreline – PLanning Zone 1

Object ID	Facility ID	Type	Size	Downstream Invert	Upstream Invert	Vulnerable Year
1893	SDC1617	RCP	24	17	46	2100
2072	SDC1889	PVC	6	0	0	current
2073	SDC1890	PVC	6	0	0	current
10968	SDC2530	RCP	24	0	35.67	current
12403	SDP100471	RCP	18	10.51	22.59	current
11034	SDC1833	PVC	18	11.4	20.5	2050

Note: Invert elevations with a zero value may be due to missing data

Table 11: Storm Drain Systems Outlet to Buena Vista Lagoon – Planning Zone 1

Object ID	Facility ID	Type	Size	Downstream Invert	Upstream Invert	Vulnerable Year
2036	SDC1834	PVC	12	0	0	current
13651	SDP101322	PVC	18	12	12.29	current
13573	SDP101243	RCP	24	17.3	19.04	2100
13767	SDP101440	RCP	18	9.5	11.04	current
12721	SDC1867	RCP	66	0	20.5	current
13772	SDP101445	RCP	48	8	18	current
13972	SDP101653	RCP	10	0	0	current
2032	SDC1825	RCP	18	11	32.37	current
2901	SDC9969	RCP	48	0	0	current
2309	SDC2519	CMP	24	0	0	current
13516	SDP101185	CMP	24	0	0	current
2670	SDC10535	PVC	18	0	0	current
2311	SDC2522	CMP	18	0	0	current
13515	SDP101184	RCP	24	0	0	current
2266	SDC2457	CMP	18	0	0	current
2268	SDC2460	RCP	18	0	0	current
3044	SDC11256	RCP	18	9	10	current
2285	SDC2479	RCP	72	0	4.4	current
2407	SDC2859	RCP	24	0	0	current
2310	SDC2521	PVC	12	0	0	current
2482	SDC3253	CMP	36	0	0	current

Note: Invert elevations with a zero value may be due to missing data

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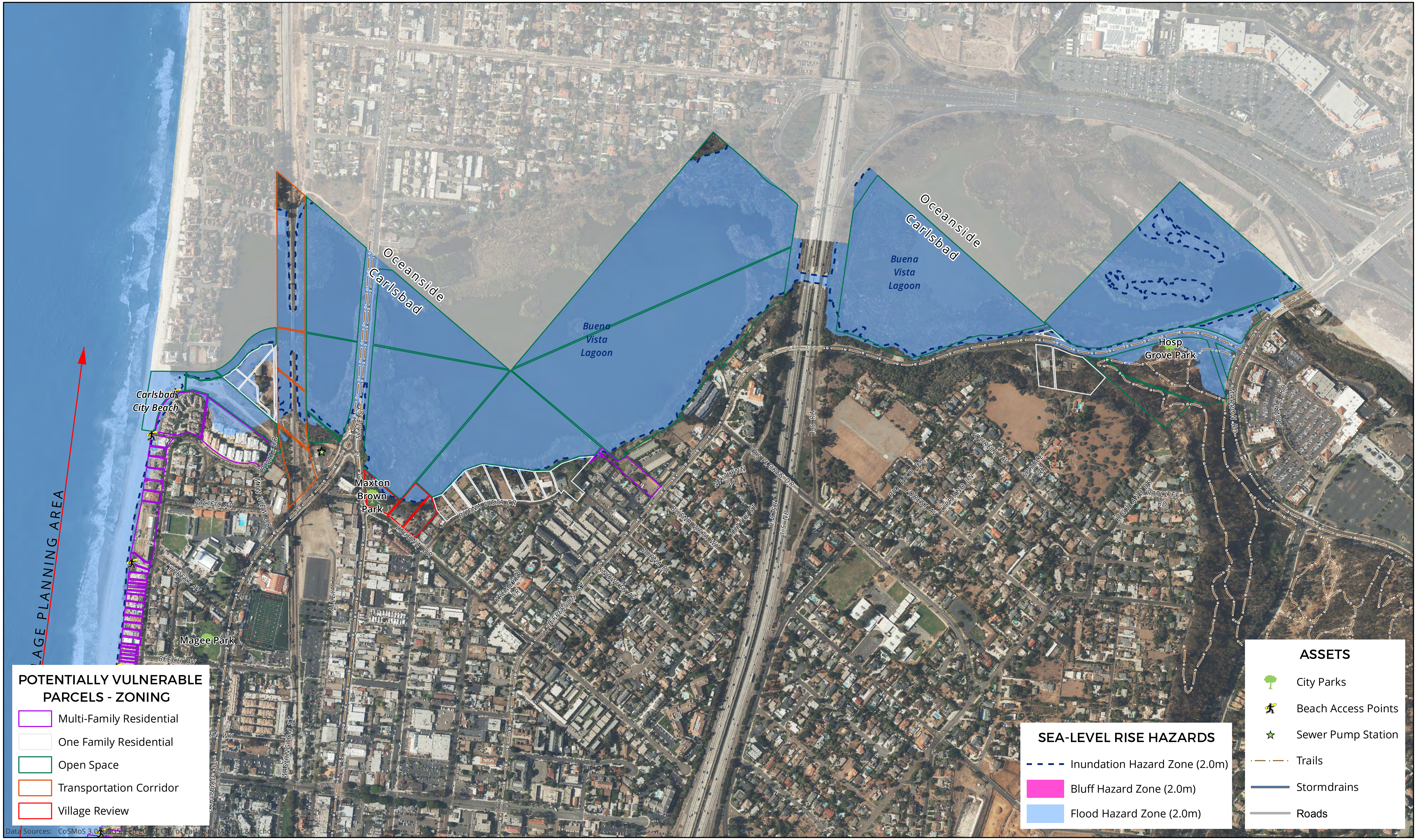
ATTACHMENT B: YEAR 2100 SEA LEVEL RISE HAZARD MAPS

Data Sources: CoSMoS 3.0 (USGS, Feb 2016), City of Carlsbad, Moffatt & Nichol

moffatt & nichol

EXHIBIT B1

05/12/16

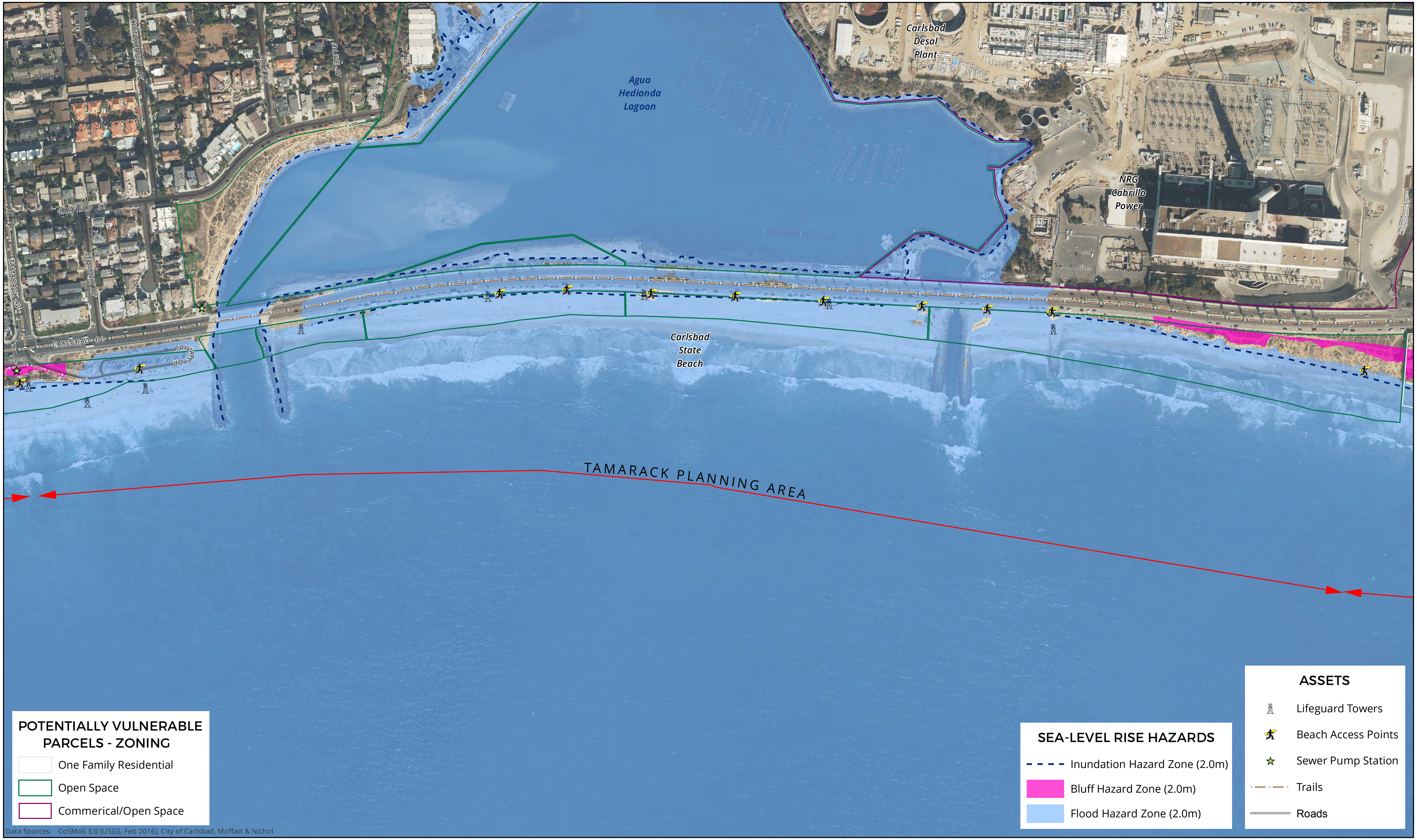


Data Sources: CoSMoS 3.0 (USGS Feb 2016), City of Carlsbad, Moffatt & Nichol

moffatt & nichol

EXHIBIT B2

05/12/16



Data Sources: CoSMoS 3.0 (USGS, Feb 2016), City of Carlsbad, Moffatt & Nichol

moffatt & nichol

EXHIBIT B3

N

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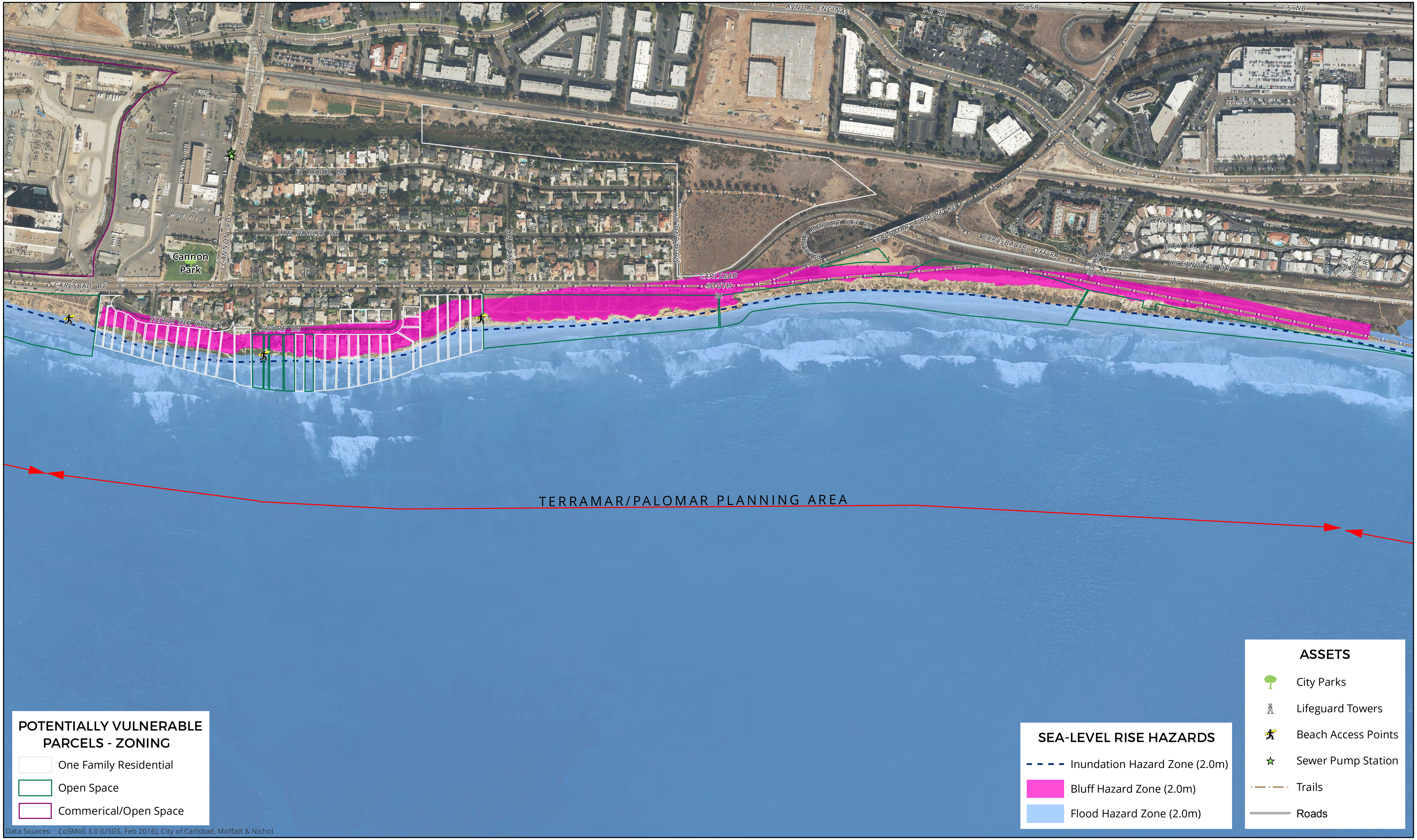
05/12/16

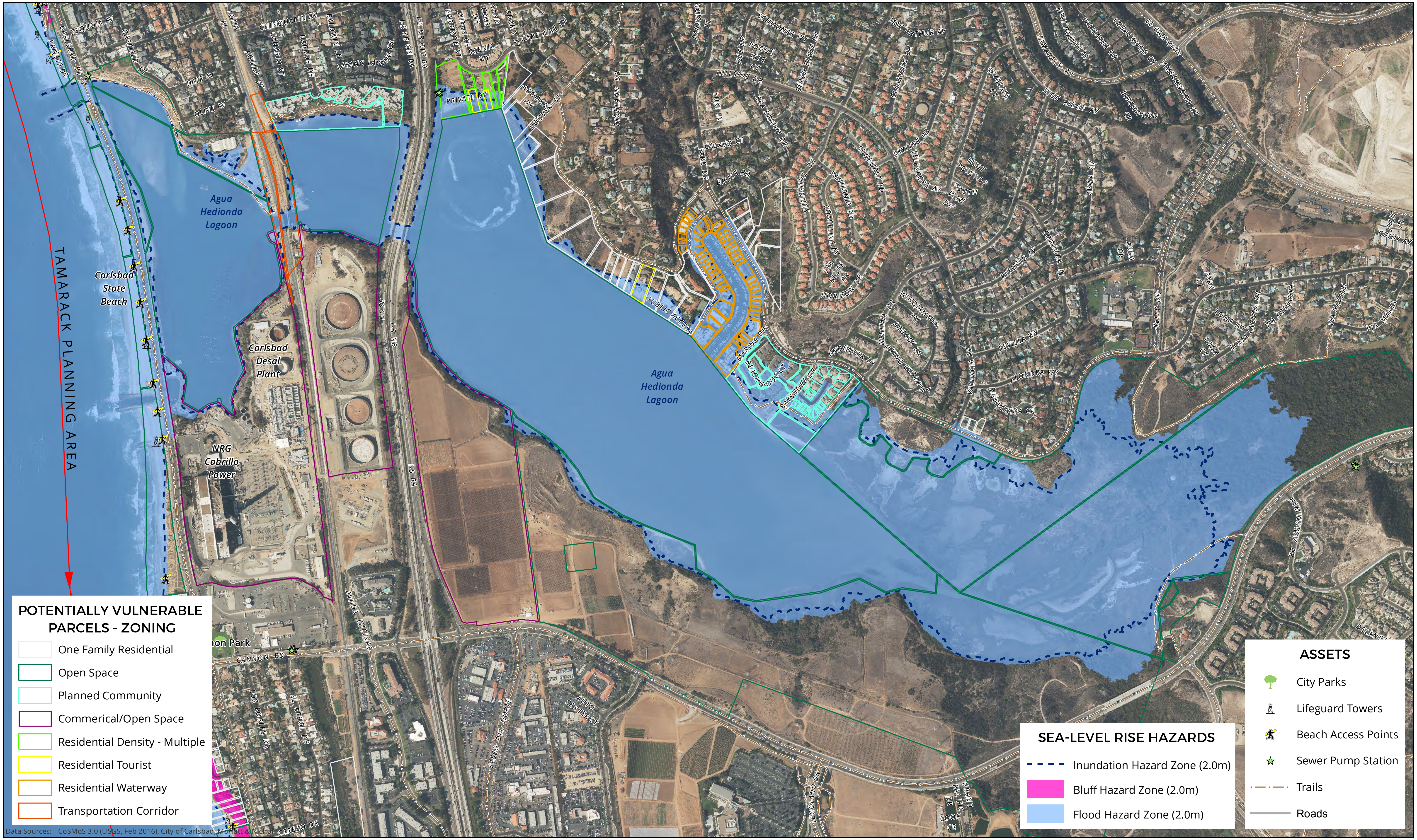


Data Sources: CoSMoS 3.0 (USGS, Feb 2016), City of Carlsbad, Moffatt & Nichol

moffatt & nichol

EXHIBIT B4

05/12/16



Data Sources: CoSMoS 3.0 (USGS, Feb 2016), City of Carlsbad, Moffatt & Nichol

moffatt & nichol

EXHIBIT B5

05/12/16

POTENTIALLY VULNERABLE PARCELS - ZONING

- ▢ Open Space
- ▢ Planned Community
- ▢ Transportation Corridor

Data Sources: CoSMoS 3.0 (USGS, Feb 2016), City of Carlsbad, Moffatt & Nichol

SEA-LEVEL RISE HAZARDS

- - - Inundation Hazard Zone (2.0m)
- ■ Bluff Hazard Zone (2.0m)
- ■ Flood Hazard Zone (2.0m)

ASSETS

- Lifeguard Towers
- Beach Access Points
- ☆ Sewer Pump Station
- Trails
- Stormdrains
- Roads

moffatt & nichol

EXHIBIT B6

N

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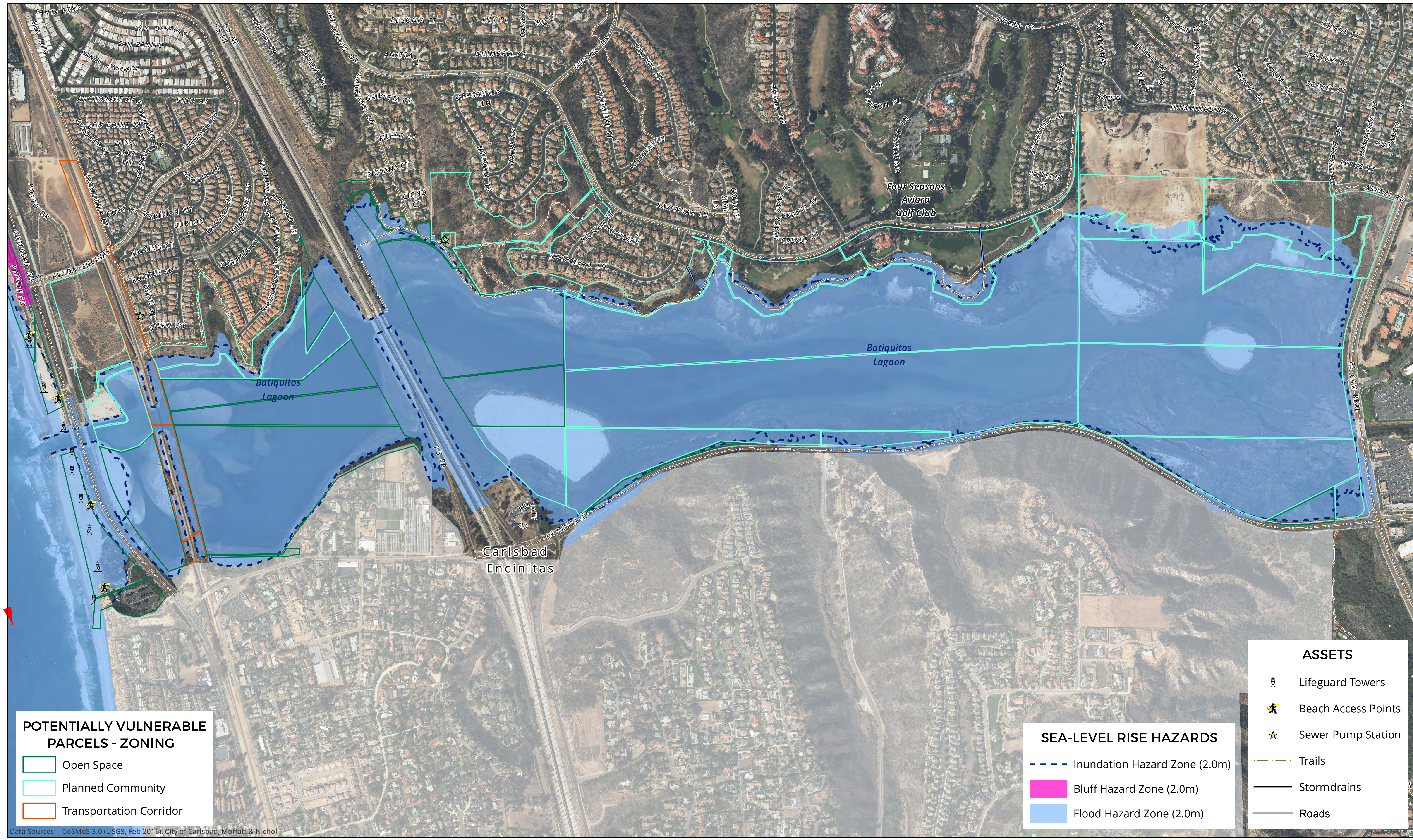
05/12/16



moffatt & nichol

EXHIBIT B7

N

0 450 900 1,800 Feet

05/12/16