Memorandum

October 12, 2020

To: Mike Grim, City of Carlsbad

From: Brian Leslie, GHD; Aaron Holloway, GHD; Braden Froble, GHD

CC: Dr. Adam Young, SIO; Laura Engeman, SIO; Evyan Borgnis Sloane, SCC,

Subject: South Carlsbad Climate Adaptation Project – Interim Coastal Hazard Layers Memo

1. Introduction

The South Carlsbad Climate Adaptation Project seeks to realign Carlsbad Boulevard in order to increase the resiliency of the roadway to climate change impacts while allowing for the re-visioning of acres of coastal land between approximately Terramar and Island Way with multi-use trails, community spaces and environmental restoration areas. Central to the planning of this space and the future alignment of the road are projected future coastal hazards; specifically cliff erosion, shoreline erosion and flooding. As part of the project, the Center for Climate Change Impacts and Adaptation at Scripps Institution of Oceanography (CCIA or SIO) is refining cliff erosion meaurements within the study area, which spans from Terramar to Batiquitos Lagoon. These cliff erosion refinements will be available to the Project team by the summer of 2021. The purpose of this memorandum is to document the preliminary coastal hazard layers that will be used in the interim to guide the concept layout of Carlsbad Boulevard and other recreational and public access amenities within the Project study area.

1.1 Sea level Rise Projections

Coastal hazards were evaluated based on sea level rise (SLR) projections from the 2018 State of California Sea Level Rise Guidance document (OPC, 2018). The major project elements, such as Carlsbad Boulevard, are assumed to have a design life of 75 to 100 years, which corresponds to a planning horizon of 2100 to 2120. Other project elements, such as trails, restrooms and parking areas may have a shorter design life (assumed 2050-2070 range). The hazard analysis also considers projections for 2120 to characterize potential hazards beyond the design life. SLR projections for La Jolla are assumed to be most relevant for the project site. The range of SLR projections at each time horizon of interest are shown in Table 1.

Table 1: Sea Level Rise Projections for La Jolla (OPC, 2018)

Time Horizon	Likely Range, 66% probability SLR is between... (feet)		0.5% Probability Projection (feet)	H++ Scenario Projection (feet)
2050	0.7	1.2	2.0	2.8
2070	1.1	2.0	3.6	5.2
2100	1.8	3.6	7.1	10.2
2120	2.3	4.3	8.8	14.3

Based on the State SLR Guidance document and the California Coastal Commission Sea Level Rise Policy Guidance, we have assumed the appropriate risk category for Carlsbad Boulevard is the "medium-high risk aversion" for which the guidance document recommends using the 0.5% probability SLR projections. The coastal hazard layers described in this memorandum will focus on the 0.5% probability projections for the 2050, 2070, 2100 and 2120 time horizons. However, these projections may not be appropriate for all project elements. Lower risk project elements that have a shorter design life, or higher adaptive capacity could be located within these future coastal hazard zones, provided there is an adaptation strategy in place to modify or remove these features as necessary in the future.

This approach to the preliminary design is consistent with Objective 1.1 of the Strategic Plan to Protect California's Coast and Oceans 2020-2025 to "Build Resiliency to Sea-Level Rise, Coastal Storms, Erosion and Flooding" which includes a target objective of "Ensuring California's coast is resilient to at least 3.5 feet of sea-level rise by 2050" (Target 1.1.1). The SLR projections and coastal hazards described in this memorandum will estimate hazard zones for over 7 feet of SLR which will be used to guide the preliminary layout of major project elements such as Carlsbad Boulevard. We are confident the relocated highway will be resilient to more than 3.5 feet of sea level rise upon project completion.

The State SLR Guidance also includes a specific scenario, labeled H++, which is based on projections by Sweet et al., 2017 to estimate a maximum plausible sea-level rise scenario. The H++ projections incorporate findings of Pollard & Deconto, 2016 that are based on a theory of marine ice cliff instability which results in self-sustaining ice-cliff failure that would significantly increase global sea-level rise. The validity of the marine ice cliff instability theory, which underpins the H++ scenario, remains unproven and characterized by deep uncertainty according to the most recent IPCC report titled *The Ocean and Cryosphere in a Changing Climate* (IPCC, 2019). The H++ scenario projections are based on a series of assumptions, not probabilistic modeling, and therefore the likelihood of this scenario cannot be determined.

The State SLR Guidance recommends consideration of the H++ projections on decisions which carry a high consequence to public health, public safety, or environmental impacts should this scenario occur. While Carlsbad Boulevard is an important highway for the community, the risk of damage to this roadway under an extreme H++ SLR scenario, would not pose a major risk to public health, safety or the environment.

Currently, there is high uncertainty around these projections and a very limited understanding of how local coastal hazards such as cliff erosion would respond to such a scenario. Preliminary design of the major project elements (i.e. the roadway and supporting infrastructure) will be based on estimated hazards for a 7 foot SLR projection, which will provide a significant amount of adaptive capacity for future coastal hazards throughout the design life. However, potential hazards beyond the design life, including the H++ scenario, will be considered in the project design. If the project cannot easily accommodate higher rates of sea level rise, risks associated with these projections will be addressed in an adaptive management plan that will include monitoring and phased addition of protective elements. According to the H++ projections, 7 feet of SLR would not occur until after 2080. Thus, there will be adequate time to monitor, learn and adapt to future rates of SLR, including the H++ scenario.

2. Methods

Coastal hazards along the project area were evaluated using results of the Coastal Storm Modeling System (CoSMoS), a multi-agency effort led by the United States Geological Survey (USGS) to estimate coastal flooding and erosion hazards for a range of future sea level rise scenarios for Southern California. The hazard data available is available in 0.8 feet (25 cm) increments from 0 to 6.6 feet (200 cm) and an extreme scenario of 16.4 feet (500 cm). Since the CoSMoS results are only available in discrete increments the data used to estimate coastal hazards may not precisely correlate with the SLR projections listed in Table 1. However, the differences between the nearest CoSMoS data increment and the SLR projections are insignificant when considering the uncertainties in predicting SLR and coastal hazards over the long-term.

2.1 Coastal Flooding Hazard Layers

CoSMoS flood hazard layers provide modeling output data for coastal storm events with various return intervals. For interim purposes, flood hazard projections for a 100-year storm were used to delineate future hazard zones in the vicinity of Encinas Creek. As CoSMoS data does not directly align with the projections in Table 1, coastal flood hazards for SLR scenarios of 3.3 ft (100 cm) and 6.6 ft (200 cm) flood polygons were used as approximate hazard zones for the 2070 and 2100 time horizons. Coastal hazards for the 2050 time horizon are not depicted in this memorandum since the projected flooding from this scenario would not influence the layout of major project elements. Subsequent phases of design may warrant a closer look at wave runup and flooding from potential coastal hazards in 2050. Photographic and anecdotal evidence indicate overtopping and flooding of the existing roadway occurs in the vicinity of Encinas Creek under present day storm events. We can assume these runup and overtopping hazards will increase with SLR and eventually overwhelm the revetment which protects the existing road. However, the threshold of SLR and storm combination at which the revetment would fail cannot be determined from the CoSMoS data. Some additional analysis may be of value when planning interim uses of the existing highway corridor.

2.2 Shoreline Erosion Hazard Layers

The low-lying segment of existing highway near Encinas Creek could be subject to shoreline erosion hazards, depending on what adaptation measures are implemented as part of this project or any future effort. Currently, there is a rock revetment along most of this highway segment, with a seasonally narrow to non-existent sandy beach. If the structure is left in place, SLR will further reduce opportunities for beach access and recreation along this segment. If the structure is removed, or relocated, the shoreline would likely retreat landward in response to SLR and coastal processes.

CoSMoS shoreline erosion projections include long-term erosion resulting from SLR and projected wave conditions based on the Coastal One-line Assimilated Simulation Tool (COAST), which includes a suite of models that consider historic erosion trends, long- shore and cross-shore sediment transport, and shoreline changes due to increased water levels. The COAST model includes shoreline management scenarios referred to as “Hold-the-Line” and “No-Hold-the-Line.” The “No Hold-the-Line” scenario assumes no coastal armoring is in place and projects future shoreline position based on a natural response to future waves and water levels. The estimated future shoreline positions for each time horizon and 0.5% SLR projection are illustrated in Figure 2-1. These results indicate that the shoreline could retreat landward of the existing southbound Carlsbad Blvd. corridor under a 3.3 ft SLR scenario and would reach the northbound Carlsbad Blvd. embankment under a 6.6 ft SLR scenario. In other words, shoreline erosion could pose a long-term threat to the stability of the relocated roadway should the embankment be unimproved or not bridged. However, the significant setback from the present day shoreline offers space for a variety of adaptation strategies that could offer multiple benefits to the community in addition to providing long-term protection of Carlsbad Boulevard. Bridging of the realigned northbound lane would add resiliency to roadway to these higher rates of sea level rise while providing more substaintal opportunities for habitat and water quality benefits.

Figure 2-1: CoSMoS COAST Future Shoreline Position assuming Exiting Revetment Removal

2.3 Cliff Erosion Hazard Layers

SIO has provided guidance to the Project team as to what they believe are reasonable cliff erosion hazard layers to use on an interim basis while these hazard projections are being refined. The preliminary hazard layers are based on data provided by the USGS's CoSMoS 3.0 phase 2 effort. CoSMoS provides cliff erosion rates for each SLR scenario and each transect along the study area, shown in Figure 2-2. CoSMoS did not model cliff erosion on transects 800 to 802 in the low lying area around Encinas Creek .

Figure 2-2. CoSMoS Cliff Erosion Transects within the Study Area

2.3.1 Establishing the Baseline Cliff Position

The CoSMoS regional modeling effort used a baseline cliff edge position from 2010 with transects spaced 100 meters apart (Figure 2-2). In order to develop a more detailed baseline cliff edge for our study area, the cliff edge was digitized from a 2009-2011 lidar survey dataset between the CoSMoS transect points. In some cases, a straight line between points was representative of the cliff edge position (e.g. southern portion) but in other areas this is not an accurate assumption (e.g. northern portion). The baseline cliff edge position and CoSMoS transect points along the northern portion are depicted in Figure 2-3.

Figure 2-3. Baseline (2010) Cosmos points and cliff edge position

2.3.2 Local Geologic Factors

The CoSMoS erosion projections are based on historic rates of cliff retreat measured by the estimated cliff top position on historic survey data. The historic rates were then extrapolated for each future sea level rise scenario based on a variety of empirical methods. The regional scale and scope of the CoSMoS study does not factor in the site-specific geologic factors that could affect the rate of cliff retreat along the study area.

SIO has conducted some preliminary investigations of the cliff composition and performed Schmidt Hammer measurements within the study area (Young, 2018). Schmidt hammer measurements are a measure of rock hardness with higher values being indicative of harder rock. It is performed using a rebound device in which rebound values are measured on a scale of 10 to 100. Findings of the Schmidt hammer tests and field observations are described below:

- The cliff geology within the Project area is described in upper and lower layers with varying thicknesses. The upper layer consists of a weak marine terrace deposit. The lower layer varies in type and thickness.
- The north section (approximate limits shown in red in Figure 2-4) includes transects 818 to 815 and is comprised of the hardest material along the study reach with Schmidt Hammer measurements ranging from 12-16. While the material is more resistant to erosion the area is characterized by active sea caves and undercutting which can compromise the stability of the upper cliff.
- The central section (approximate limits shown in green in Figure 2-4, which represents transects 814 to 811, also has hard rock at the base but it is a different layer than the red area and has Schmidt Hammer measurements ranging from 12-14.
- The southern section (approximate limits shown in blue in Figure 2-4, which represents transects 810 to 803 has a lot of talus and weak material at the cliff base. There are some small areas where the harder rock outcrops in the blue area but it is unclear how extensive it might be because it could be covered up. Rainfall / runoff erosion are an issue in this area. At the very south end its possible the material is just fill placed for the road, but difficult to discern with the rip rap obstructing views. There were several areas with significant groundwater coming out of the cliff.

The Schmidt Hammer measurements indicate the north section lower cliff consists of a more erosion resistant geologic formation that observed south of transect 811. The cliff composition south of transect 811 consists of loose material that would be more vulnerable to coastal erosion. This data is also supported by the plan view position of the cliff edge showing slight shoreward protrusion in the northern section. Interestingly, the CoSMoS cliff erosion projections predict the highest rates of erosion along the north reach where the harder rock exists (Figure 2-5).

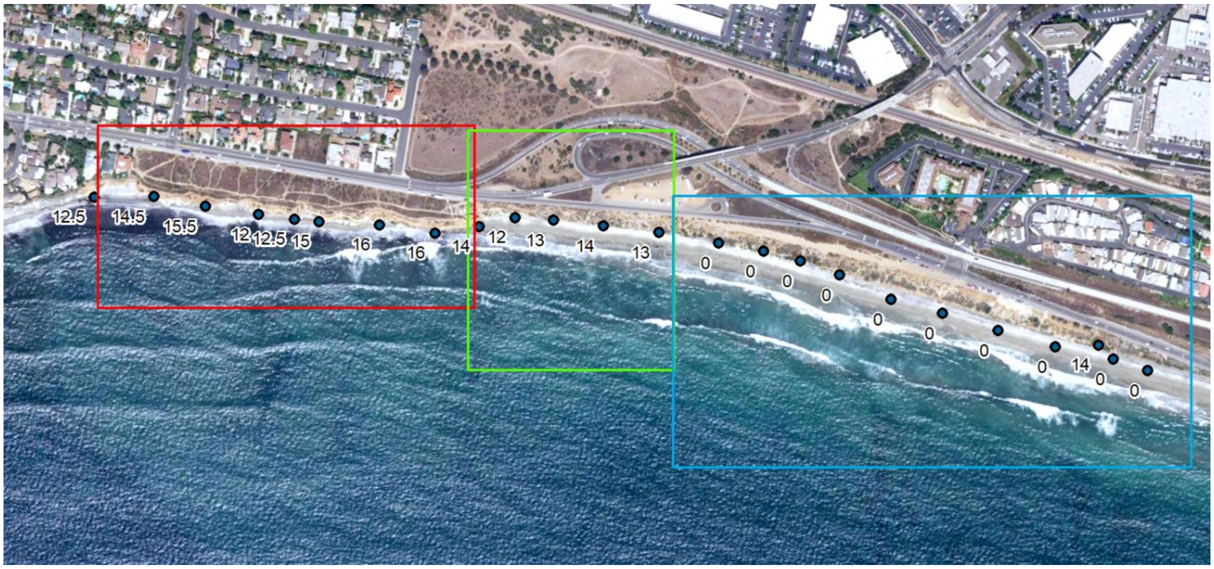

Figure 2-4. Lower Cliff Hardness Findings. Zero values represent locations with cliff material too soft to make Schmidt hammer measurements. (Source: Schmidt rebound hammer data from Young, 2018)

2.3.3 Estimates of Interim Cliff Erosion Hazard Layers

CoSMoS provides historic cliff retreat rates for each transect as well as estimated erosion rates for each sea level rise scenario. Individual erosion rates were obtained from CoSMoS Coastal Cliff Retreat Projections (Do Not Hold the Line) layer. It should be noted that the erosion rates provided by CoSMoS have an uncertainty rate of +/- 0.5 ft/yr (0.15 m/yr). Figure 2-5 displays the CoSMoS projected erosion rates within the study area for transects 817 to 794 (North to South) relative to the estimated historical erosion rate used for the CoSMos projection analysis. A few observations from this figure include:

- The greatest cliff erosion rates projected by CoSMoS are between transects 813 and 817
- The results suggest the historic rate of erosion will increase significantly with sea level rise. Erosion rates increase by ~50% for a 3.3 foot SLR scenario and ~100% or more for a 6.6 foot SLR scenario.

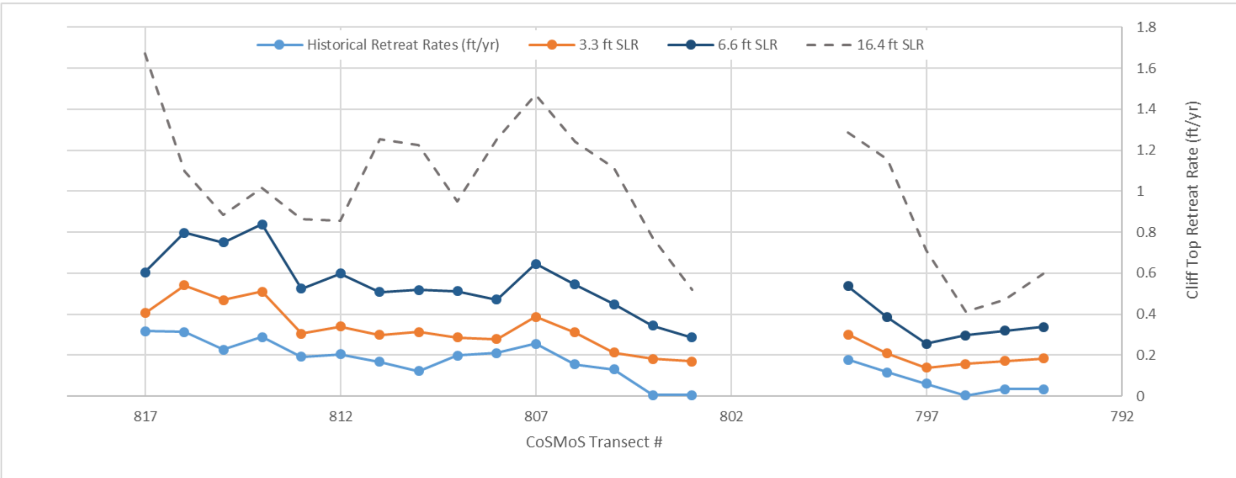

Figure 2-5. Cliff Erosion Rates within the Study Area (derived from CoSMoS 3.0)

Based on coordination with SIO, the maximum cliff retreat rate among all of the study area transects will be applied across the study area as an interim and conservative approach to estimating the landward extent of cliff erosion hazards. The average and maximum cliff retreat rates for the study area increases with SLR as illustrated in Figure 2-6. Cliff top retreat rates for SLR greater than 6.6 ft were interpolated between the maximum available CoSMoS scenario of 16.4 ft.

The cliff erosion hazard zones for each time horizons of interest were based on rates identified for the 0.5% probability SLR projections listed in Table 1. Finite difference approximations were used to increase the rate of erosion based on the average and maximum curves shown in Figure 2-6. For each time horizon, the hazard zones were mapped between the average and maximum retreat distances. These retreat distances are summarized in Table 2 and illustrated in Figure 4-1 to Figure 4-3.

A similar analysis of cliff erosion hazard zones were developed for the worst-case H++ SLR projections listed in Table 1. The cliff top retreat rates were increased at each time horizon based on the H++ projections to understand how these hazard zones may increase. The results provided similar cliff erosion distances for the 2050 and 2070 time horizons (i.e. within a few feet of hazard zones identified for 0.5% SLR projections). Based on this analysis the 2100 and 2120 cliff erosion hazard zones would extend further landward by 10 and 15 feet, respectively, under an H++ scenario. The increasd hazard zone for the 2120 time horizon is illustrated in Figure 4-1 to Figure 4-3.

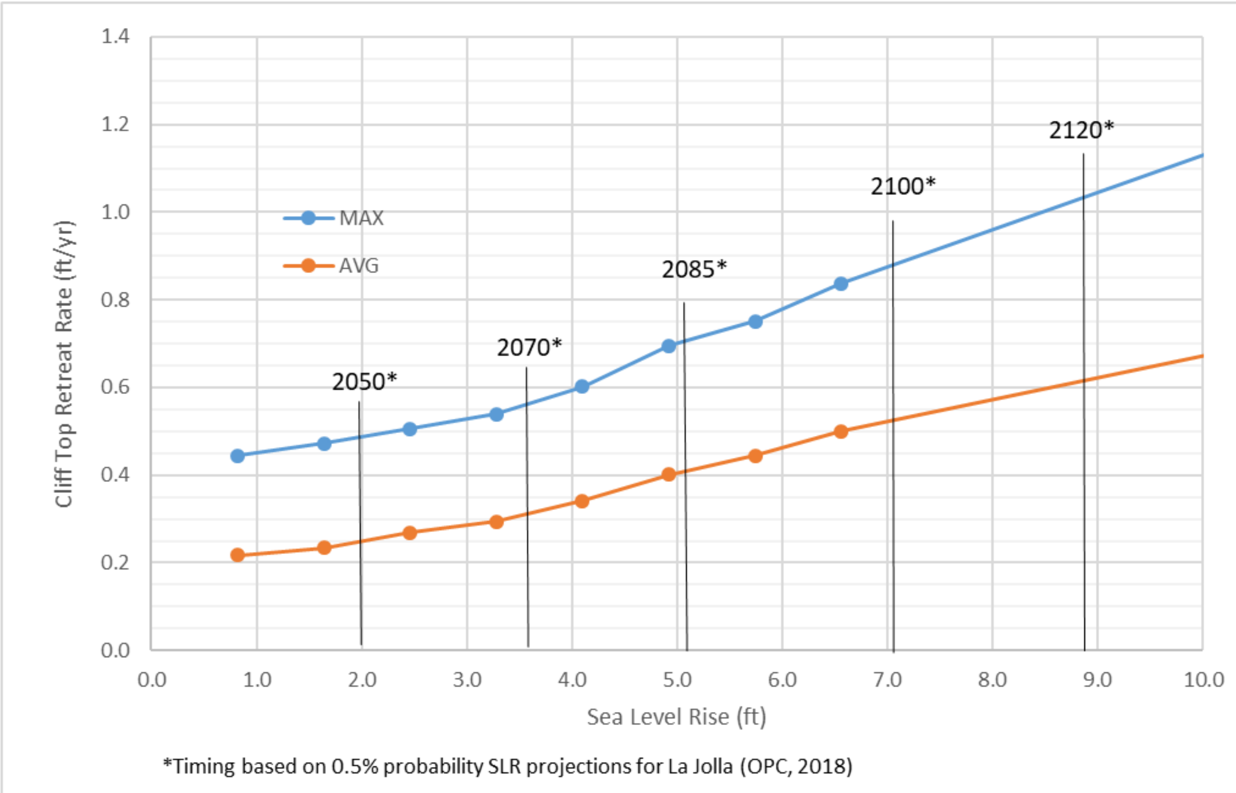

Figure 2-6. Maximum and Average Cliff Erosion Rate vs Sea Level Rise

Table 2: Cliff Erosion Hazard Zones

Time Horizon	Distance from 2010 cliff edge (ft)	
	Avg erosion rate	Max erosion rate
2050	12	25
2070	18	35
2100	33	61
2120	50	71

3. Summary

The coastal hazards within the study area are shown in Figure 4-1, Figure 4-2, and Figure 4-3. Cliff top retreat represents the primary coastal hazard of concern when considering relocation of Carlsbad Boulevard. We have assumed the appropriate risk category for Carlsbad Boulevard is the “medium-high risk aversion” for which the guidance document recommends using the 0.5% probability SLR projections. The coastal hazards described in this memorandum focus on the 0.5% probability projections for the 2050, 2070, 2100 and 2120 time horizons. Lower risk project elements (e.g. trails, parking, and recreation amenities) that have a shorter design life, or higher adaptive capacity could be located within these future coastal hazard zones, provided there is an adaptation strategy in place to modify or remove these features as necessary in the future.

The relocated highway will have an estimated service life of 75-100 years and will consider potential hazards for the 2100 to 2120 time horizon. To the extent possible, the highway will be relocated outside of these hazard zones (i.e. setback more than 70 feet from 2010 cliff edge). The coastal hazard zones and design setbacks will be refined based on additional investigations and coordination with SIO. In some areas, constraints may prohibit relocation entirely outside future hazard zones. In this case a monitoring and adaptation plan will need to be implemented to mitigate the potential for cliff erosion to undermine the highway.

The results from the CoSMoS flood projection scenarios for 3.3 ft and 6.6 ft of sea level rise revealed an insignificant threat for the majority of the project site. However, the low-lying region near Encinas Creek is most at risk to flood hazards and coastal squeeze due to shoreline retreat. This region of shoreline is armored by a rock revetment and would likely experience frequent flooding under the 3.3 ft SLR scenario. This section of the existing highway may warrant a closer look at coastal erosion and flooding hazards depending on what uses are planned for this segment of the Project area.

4. References

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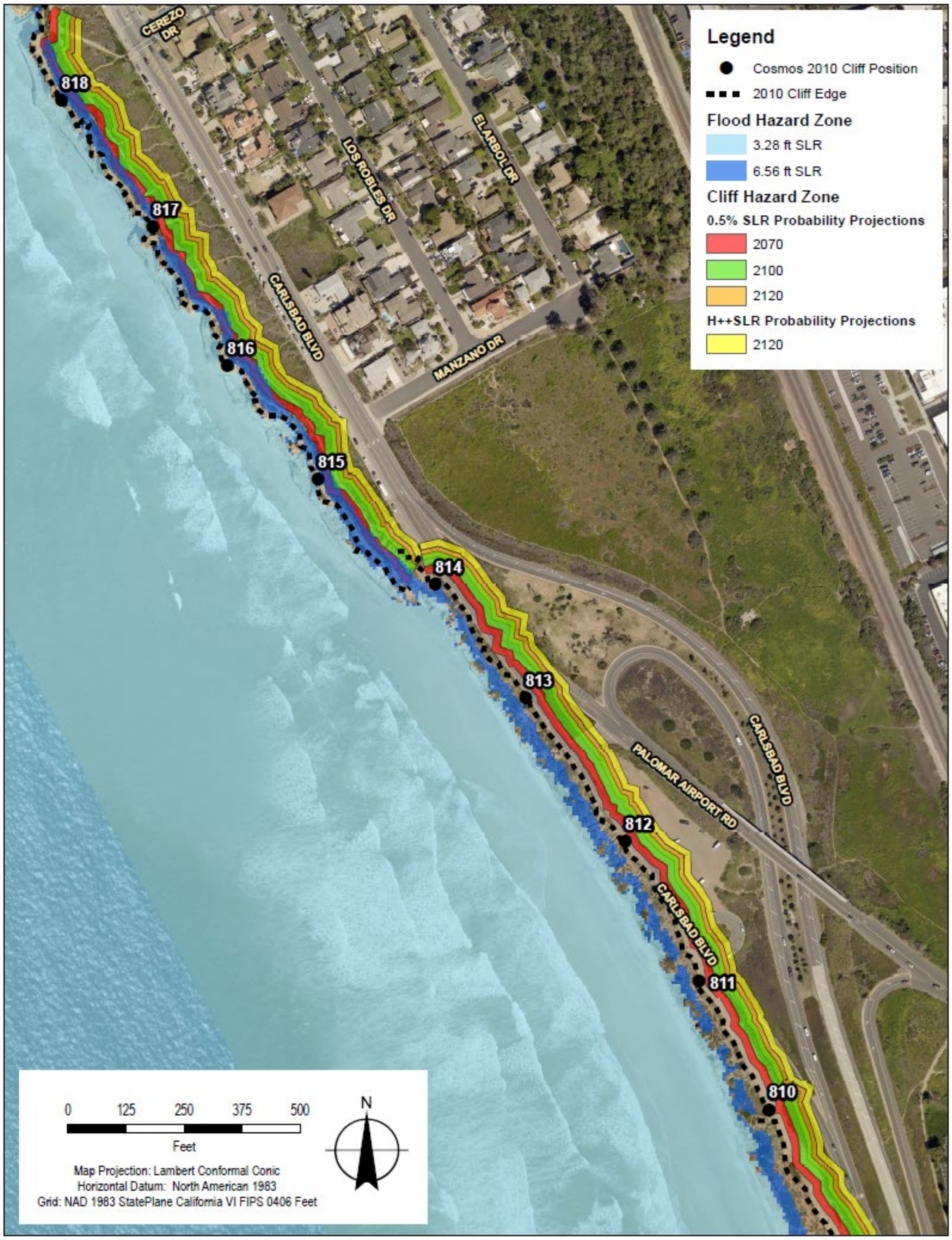

Figure 4-1. Interim Coastal Hazards in the Northern Project Area

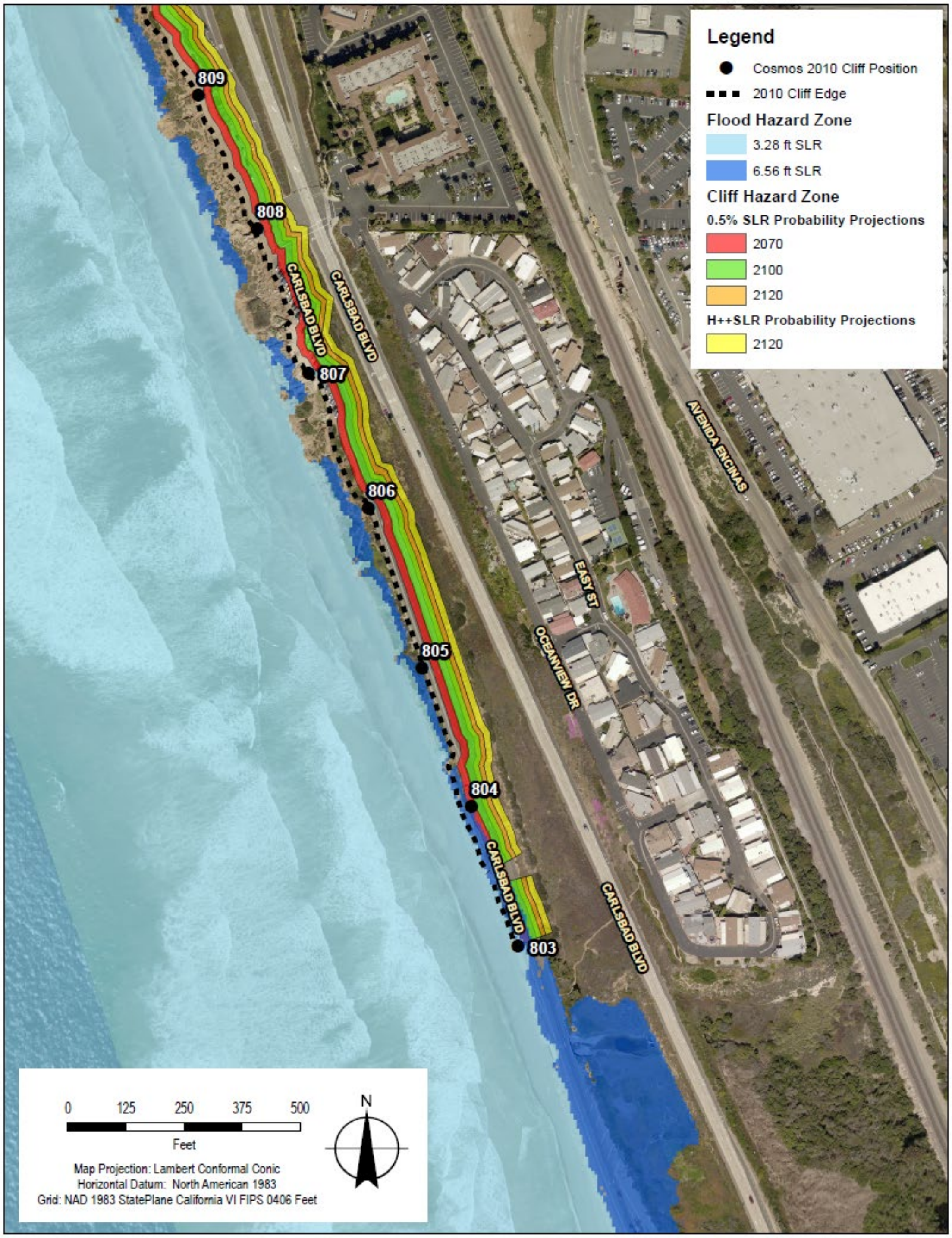

Figure 4-2. Interim Coastal Hazards in the Central Project Area

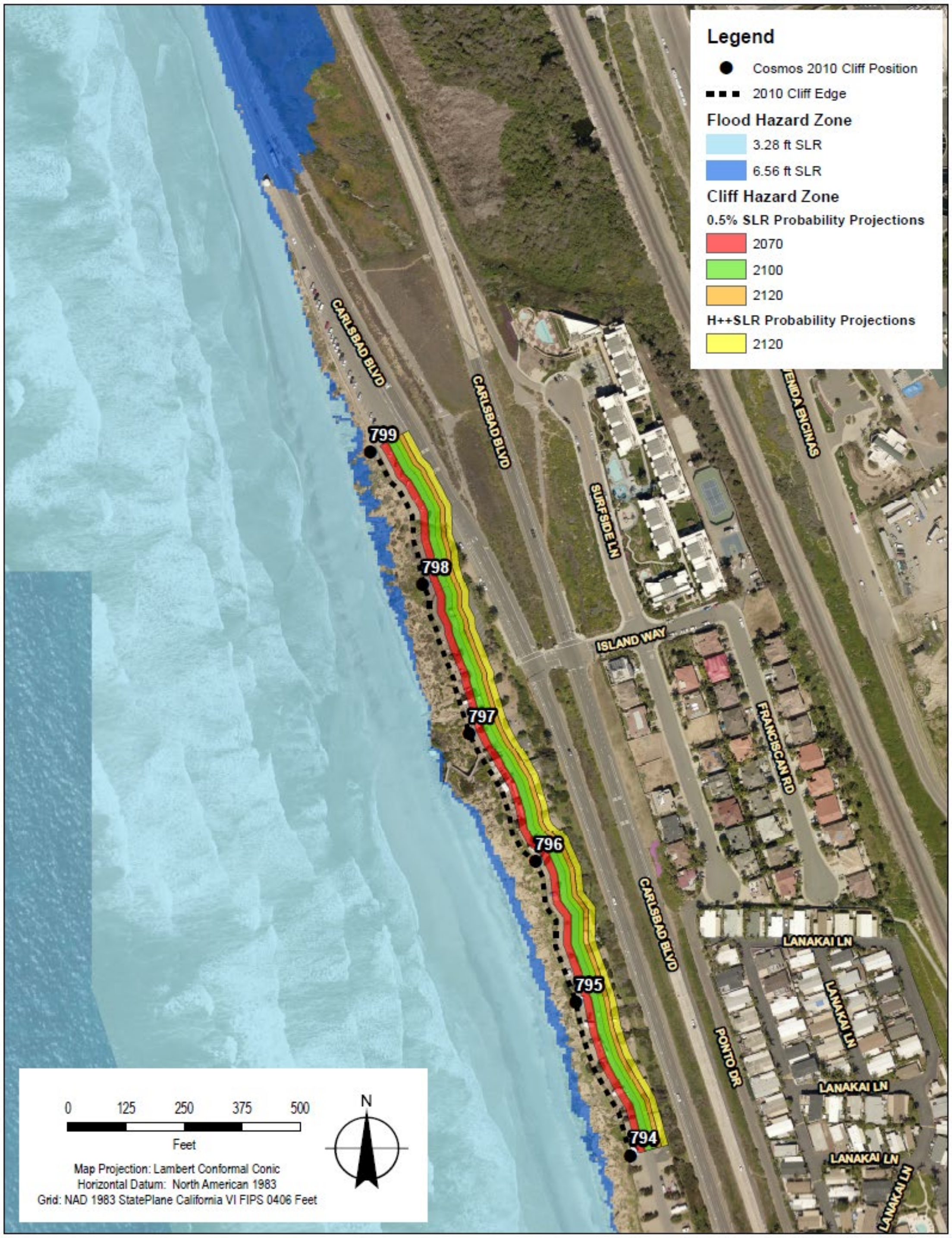

Figure 4-3. Interim Coastal Hazards in the South Project Area