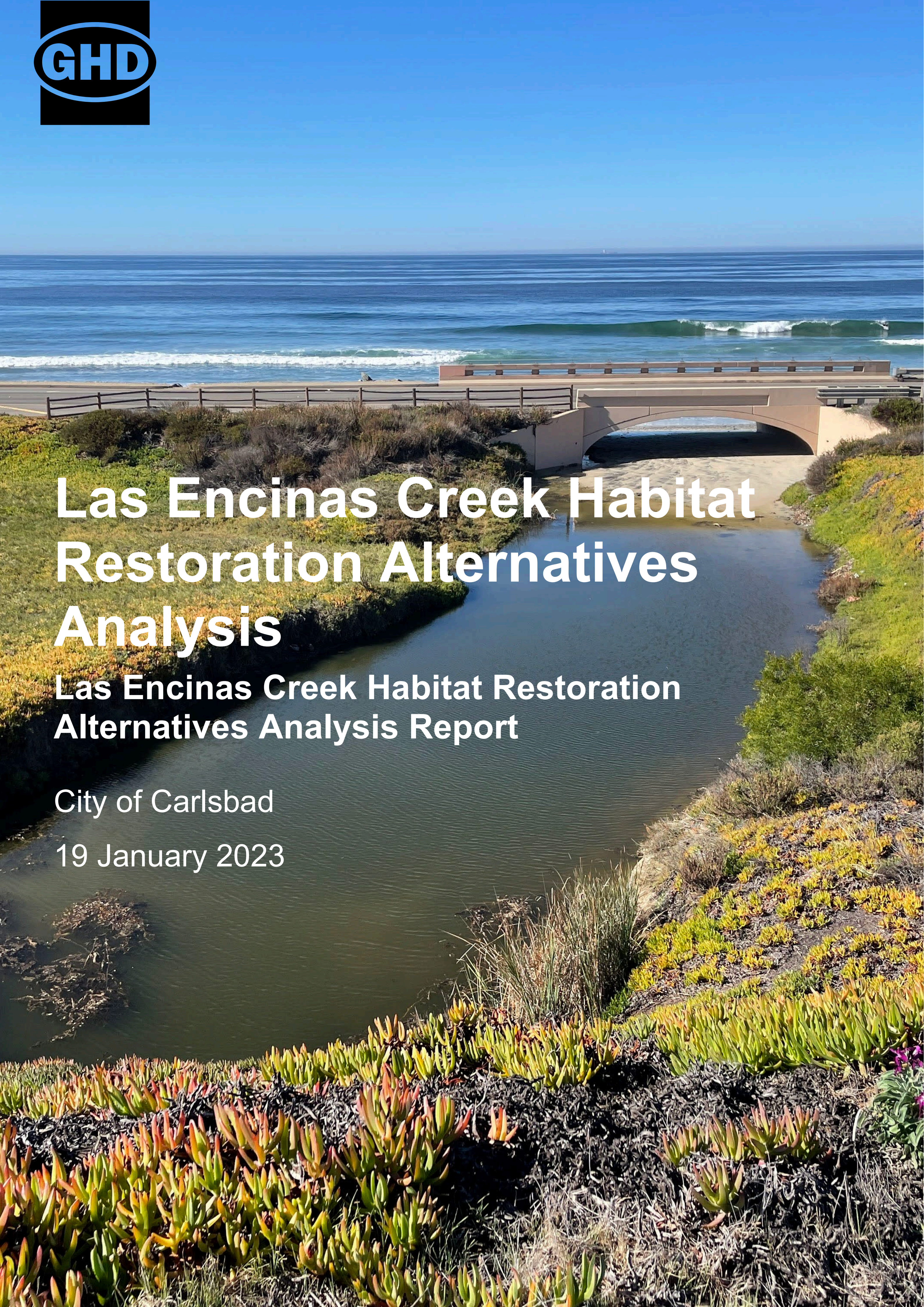

Las Encinas Creek Habitat Restoration Alternatives Analysis

Las Encinas Creek Habitat Restoration Alternatives Analysis Report

City of Carlsbad

19 January 2023

Executive summary

A study was conducted to understand the hydrology and biology of the Las Encinas Creek estuary, a small wetland system along central Carlsbad's coastline, in order to better predict how the habitats might evolve under two proposed roadway realignment scenarios being considered as part of the South Carlsbad Climate Adaptation Project and with consideration of up to 6.6 feet (feet) of sea level rise (SLR). The roadway options under evaluation are specific to the southernmost portion of the Project area within the vicinity of the Las Encinas Creek estuary and are being referred to as the Retreat Now or Phased Adaption options. The Phased Adaptation alternative would either leave in place or partially remove the Southbound Carlsbad Boulevard infrastructure for passive or active recreational uses until coastal hazards overwhelm the repurposed space. Once this trigger is met, the roadway in this area would be demolished and vehicular and recreational users would shift to the new bi-directional roadway corridor. The Retreat Now alternative, refers to the naturalization of the area by removing infrastructure from Southbound Carlsbad Boulevard and restoring the Las Encinas Creek estuary system.

A baseline understanding of the Encinas Creek estuary guided the development of habitat restoration concepts for each of these roadway options that considered how the shoreline, tidal marsh habitat, and creek hydrology would respond to SLR. This study compared these two roadway options, and the opportunities they present for sandy beach and habitat restoration/preservation, against a number of key criteria to aide in the decision-making process. Key findings from this analysis are summarized in Table ES-1 below:

Table ES-1. Key findings for the Retreat Now and Phased Adaptation Alternatives

Category	Retreat Now	Phased Adaptation
Sandy Beach: *Will the alternative sustain a dry, sandy beach in the Study Area?*	**Yes.** Alternative is anticipated to increase the beach area immediately through removal of infrastructure and potentially sustain this beach through 6.6' of SLR as the beach and created dune are allowed transgress landward.	**No.** It is anticipated that with 1.7' of SLR the existing narrow beach within the Study Area will be eroded until the southbound roadway is removed/relocated.
Habitat Restoration: *Does the alternative restore previously developed areas for habitat purposes?*	**Yes.** The alternative would restore about half of the developed area that exists within the Study Area and restores it to coastal strand habitat.	**Yes.** The developed areas will be restored in later phases of the Project once coastal hazards overwhelm southbound Carlsbad Boulevard.
Tidal Wetland Migration: *Does the alternative allow for upland tidal migration?*	**Yes.** Both alternatives accommodate wetland habitat migration with future SLR.	
Riparian Habitat: *Do the alternatives sustain Arroyo willow riparian habitat with SLR?*	**No.** Both alternatives (and the existing conditions) are anticipated to result in a decline of Arroyo willow riparian habitat with SLR. The loss could be reduced with establishment of additional riparian habitat in suitable areas around the periphery of the Study Area that are contiguous with similar riparian habitat types.	
Coastal Hazards & Public Safety: *Would the alternative provide public protection from existing and projected future coastal hazards?*	**Yes.** This alternative would relocate public infrastructure out of the coastal hazard zone. Recreational uses of the abandoned space would be protected through nature-based design techniques such as a cobble-sand dune system.	**Yes.** This alternative would repurpose the roadway for recreational uses until it becomes unsafe to use for this purpose. The existing rock shoreline protection would remain in place to protect the roadway from erosion. Physical triggers will be established to demarcate when the space needs to be abandoned.

Next steps for this study include further progressing the design of the Las Encinas Creek estuary restoration component of the Project once a decision is made between the Phased Adaptation and Retreat Now options. Should the Phased Adaptation option be selected, future study may be needed to define appropriate triggers for future management actions (e.g. RSP improvements and eventual retreat). Coordination with the resource agencies, and specifically the California Coastal Commission, would be beneficial to discuss the triggers and potential management actions associated with this option. The restoration design option would ultimately become part of the roadway design package at the conclusion of the South Carlsbad Climate Adaptation Project phase.

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1. Introduction

The South Carlsbad Climate Adaptation Project (Project) seeks to realign Carlsbad Boulevard to re-vision acres of coastal land between approximately Terramar Point and Island Way with multi-use trails, community spaces and habitat restoration areas. The repurposing of this space will be accomplished primarily through consolidating roadway infrastructure into a bi-directional transportation corridor along the existing Northbound South Carlsbad Boulevard alignment. Relocation of this roadway would build resilience into the transportation corridor from current and projected future coastal hazards; specifically, the coastal and cliff erosion that is anticipated as sea levels rise (SLR) over the next 100 years. The aim is to achieve Project resilience without the need for new shoreline protection (and possibly the removal of existing protection) with a focus on retreating from coastal hazards and the use of nature-based design techniques to slow erosion while restoring habitat.

During the design phase of the Project and specifically during stakeholder outreach activities, questions arose surrounding whether the Project should be phased over time or initially built to the ultimate (i.e. 2120-time horizon) configuration. These two phasing options are being referred to commonly within this study as "Phased Adaptation" or "Retreat Now". Key themes around the question of phasing relate to the proposed uses of these abandoned spaces and the types, function and viability of habitat restoration options at Las Encinas Creek in each of these scenarios. This study seeks to help answer questions regarding the quality and resilience of habitat restoration options at Las Encinas Creek as they relate to the two Project implementation options being considered. The Study Area is focused on the Las Encinas Creek area to inform implementation phasing in this segment of the Project Area (Figure 1-1).

Figure 1-1. South Carlsbad Boulevard Climate Adaptation Project – Las Encinas Creek Habitat Restoration Study Area

2. Study Purpose & Scope

The purpose of this study is to aide in the decision-making process between the two Project implementation options being considered with a focus on a comparison between the habitat restoration opportunities and challenges they present. The study includes the following scope of work:

- Fill identified biological and topographic data gaps for Las Encinas Creek estuary;
- Assess tidal, freshwater and groundwater influences using collected water level and water quality data;
- Conduct supplemental vegetation mapping to characterize existing and future habitat gradients;
- Develop a numerical hydrodynamic model to assess fluvial and coastal flooding associated with existing and future sea level rise scenarios;
- Characterize the coastal processes that influence form/function of habitat types; and
- Develop conceptual restoration designs for two (2) alternatives.

In addition, this study aims to address the following questions that were heard during agency coordination meetings in which Las Encinas Creek concepts were discussed:

1. How does the Las Encinas Creek system function today?
2. How could the Las Encinas Creek system be restored under each of these implementation options?
3. How would the restored system function in the future with SLR under the Project implementation options being considered (Retreat Now vs Phased Adaptation)?

3. Coastal & Hydrological Setting

The Study Area has undergone significant development in the last century. Historically, the area was likely a tidal lagoon consisting of salt flats subject to frequent overwash. Evidence of overwash can be seen in Figure 3-1 as sand splay deposits, which appear to reach as far east as the Interstate 5 (I-5) alignment. The construction of South- and Northbound Carlsbad Boulevard and the North County Transit District (NCTD) rail prism would have reduced the frequency of overwash events and landward migration of the foredune strand and dune field.

Currently, Encinas Creek flows through an engineered channel through the Encina Wastewater Treatment Plant and enters the Project Area through a single concrete box culvert under Avenida Encinas and the rail prism. Encinas Creek continues from the rail prism culvert outfall to the Northbound Carlsbad Boulevard crossing, which consists of a double concrete box culvert, and then Southbound Carlsbad Boulevard crossing, which consists of a concrete arch culvert and discharges directly to the beach and Pacific Ocean.

Figure 3-1. Encinas Creek Study Area Present Day (Left) & and 1932 (Right)

3.1 Coastal Setting

The coastline fronting the Project Area is predominantly narrow sandy beaches backed by steep coastal cliffs. The cliff geology is described in upper and lower layers with varying thickness. The upper layer consists of a weak marine terrace deposit, while the lower layer varies in type and thickness.

The beaches along this reach of shoreline are narrow and chronically eroding. This beach condition has led to a history of damage occurring to the low-lying segment of Carlsbad Boulevard fronting Encinas Creek, which resulted in two extensions to the bridge abutment rock slope protection (Figure 3-2). The wave climate in the City of Carlsbad can be characterized by long period swells predominately from the southwest through the summer and spring months. During the winter and fall months, high energy waves approach from the northwest and west.

Figure 3-2. Study Area Shoreline

3.1.1 Coastal Water Levels

The National Oceanic and Atmospheric Administration (NOAA) maintains and operates tidal stations throughout the Unites States. The representative tide gauge for the Project site is located in La Jolla, approximately 18 miles south of the Study Area. The datums used in this study are shown in Table 3-1 relative to North American Vertical Datum of 1988 (NAVD88).

Table 3-1. Tidal Datums for La Jolla, CA (NOAA Sta. 9410230)

Datum	Elevation, feet (NAVD88)
Highest Observed (11/25/2015)	7.62
Highest Astronomical Tide (HAT)	7.01
Mean Higher High Water (MHHW)	5.13
Mean High Water (MHW)	4.41
Mean Sea Level (MSL)	2.54
Mean Low Water (MLW)	0.71
NAVD88	0.00
Mean Lower Low Water (MLLW)	-0.19
Lowest Astronomical Tide (LAT)	-2.20
Lowest Observed (12/17/1993)	-3.06

The shoreline fronting the Project site shoreline is classified by the Federal Emergency Management Agency (FEMA) as Zone VE, with a base flood elevation (BFE) of 18 feet (NAVD 88). Zone VE is defined as an area subject to a 100-year flood with exposure to waves. The offshore area is classified by a BFE of 21 feet.

3.1.2 Sea Level Rise Projections

In the State of California, the *Sea-Level Rise Guidance 2018 Update* published by the Ocean Protection Council (OPC) is considered to be the best available science concerning SLR projections. Projections are provided for 12 active tidal gauges in California and the La Jolla projections are representative of the Project site. The range of SLR projections at time horizons of interest for the Project are shown in Table 3-2.

Table 3-2. 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 OPC SLR Guidance document and the California Coastal Commission's *Sea Level Rise Policy Guidance* (2018), we have assumed the appropriate risk category for the Project is the "medium-high risk aversion" for which the guidance document recommends using the 0.5% probability SLR projections. The Project planning horizon is 100 years (or out to year 2120) due to the importance of the proposed transportation infrastructure.

3.1.3 Shoreline Erosion

The Project site is located within the northern portion of the Oceanside littoral cell, which extends from Oceanside Harbor to the La Jolla submarine canyon. The Study Area has a limited dry sandy beach, in which the Mean High Water (MHW) shoreline position is typically at the toe of the rock revetment. The foreshore of the beach profile contains a significant amount of cobble that is typically exposed in the spring and summer months. The presence of an overlying thin layer of sand varies seasonally and is often seen in the fall and winter months.

The San Diego Association of Governments (SANDAG) commissions beach profile surveys of numerous shore-perpendicular transects throughout San Diego County on a bi-annual basis. The transect that is nearest to the Project site is located at North Ponto (transect # CB-0760), approximately 600 feet south of the Las Encinas Creek mouth. This beach, similar to most in southern California, is at its widest in the fall and narrowest in the spring. The general beach width trend at this site is erosional at a rate of about 2.5 feet/year, despite regional beach nourishment efforts that occurred in 2001 and 2012 (Figure 3-3).

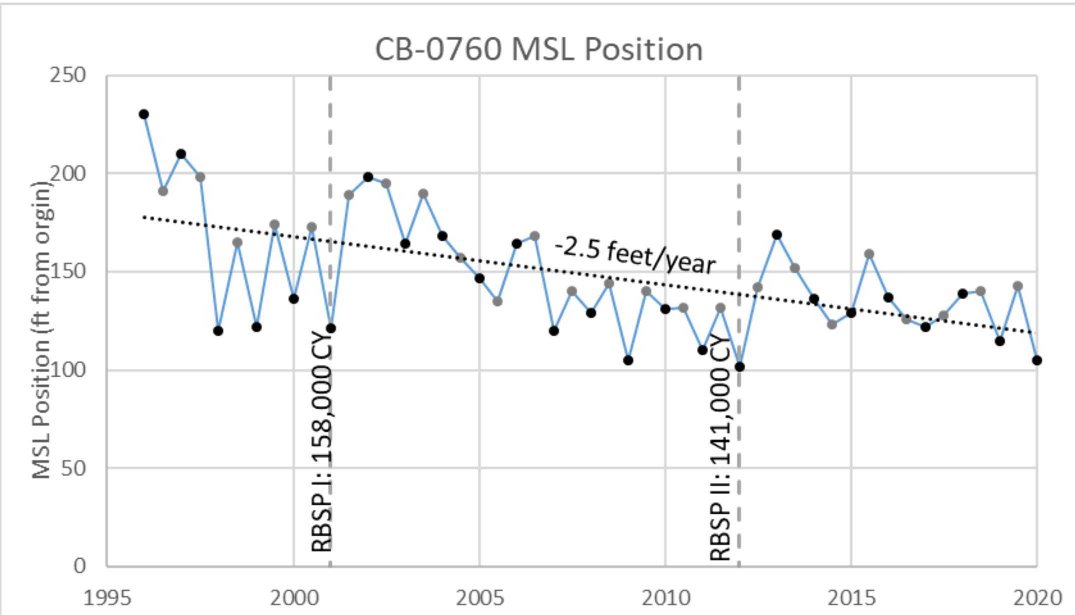

Figure 3-3. Beach Widths within the Study Area (SANDAG CB-0760 Profile)

3.1.4 Cliff Erosion

The realigned, bi-directional roadway and other Project features are being designed to meet the community's needs while minimizing exposure to coastal hazards throughout the design life. A Cliff Erosion Assessment Report was prepared by the Scripps Institution of Oceanography (SIO) in March 2022 to determine hazard setback distances through the Project Area (i.e. potential cliff erosion zones for various sea level rise scenarios). This study examined cliff change from 1998 to 2020 and forecasted future bluff edge positions using four predictive models over a subset of the overall Project Area. A subset of these results as they pertain to the Study Area are presented in Table 3-3. The Cliff Erosion Assessment Report is included as Appendix A for reference.

Table 3-3. Cliff Retreat Setbacks within the Study Area (SIO, 2022)

Time Horizon	Sea Level Rise (ft)	Modelled Cliff Retreat (ft)		
		Min	Median	Max
2050	2.0	2	22	56
2070	3.6	3	38	96
2100	7.1	6	71	169

3.1.5 Shoreline Protection

The cliff fronting South Carlsbad Boulevard in the vicinity of Encinas Creek has a history of erosion and instability. Slope stabilization of this approximately 1,300-foot segment has occurred through three incremental placements of rock shoreline protection (RSP) from 2009 to 2016. The RSP is a two to four ton rock placed at a 1.5:1 (H:V)[1] slope underlain by a geotextile fabric. The last segment of RSP was placed during the 2015/2016 El Niño winter where a succession of wave events caused significant erosion and cliff/roadway instability (Figure 3-4), which led to a partial closure of the roadway and emergency repair work. The California Coastal Commission permit granted during that time was conditional on the completion of an analysis of viable alternatives for this area. A study was prepared titled *Final Alternatives Analysis Report: Las Encinas Revetment* (Moffat & Nichol 2017), which looked at various shoreline protection options alongside a roadway realignment option. The City requested a five year permit extension from the California Coastal Commission to develop a long-term management plan for the roadway that incorporates one of these alternatives. This Project is in direct response to this long-term management plan requirement.

[1] Horizontal: Vertical

Figure 3-4. Erosion along Southbound Carlsbad Boulevard near Encinas Creek (Photo taken 3/17/2016 by City of Carlsbad)

3.2 Hydrologic Setting – Encinas Creek

The Encinas Creek watershed has a drainage area of approximately 3.7 square miles, extending from the McClellan-Palomar Airport westward to the Pacific Ocean (Figure 3-5). Similar to most of Southern California, Encinas Creek is an ephemeral stream whose drainage basin receives an average annual precipitation of approximately 13-inches, most of which occurs October-April. This basin has a mean elevation of 198 feet with a relief of 435 feet. The vast majority of the drainage basin is developed, with close to 50% of the land determined by the United States Geological Survey (USGS) to be impervious (USGS StreamStats, 2021).

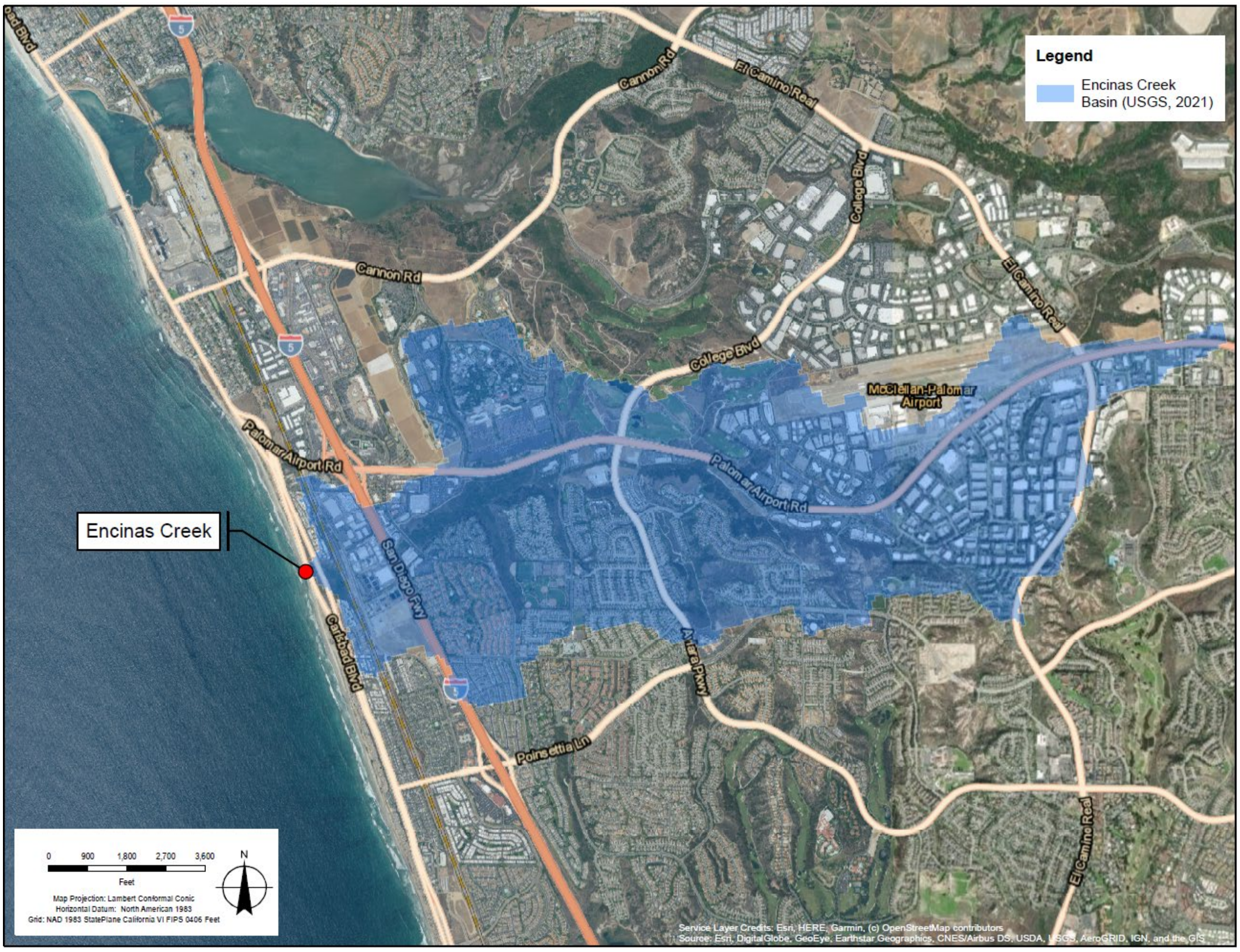

Figure 3-5. Las Encinas Creek Basin

Encinas Creek morphology has been highly altered by upstream urbanization, culverts and shoreline modifications. Urban stormwater runoff has likely increased frequency and magnitudes of peak flow rates and velocities, resulting in channelization of Encinas Creek between the rail prism and Northbound Carlsbad Boulevard. A deep scour pool exists at the large culvert outlet below Avenida Encinas/rail prism at the south-eastern end of the Study Area (Figure 3-6), and seasonal channels radiate out from the pool, with one small perennial channel flowing west to the toe of the Northbound Carlsbad Boulevard bank.

Figure 3-6. Large scour pool at the outlet of the large culvert under Avenidas Encinas

Water flowing approximately due west from the Avenida Encinas culvert outlet and scour pool into the west might have diverted flow away from a more defined historic Encinas Creek channel, which had already run dry at the time of the mid-August field surveys. The upper portion of the larger channel has become braided and has lost a clearly defined bed, bank, and channel through much of the upper portion. The toe of Northbound Carlsbad Boulevard serves as a seasonal channel that coalesces with other seasonal channels into the widened perennial creek on the north end of the site near the culvert under Northbound Carlsbad Boulevard. There has likely been a major increase in peak flows that have substantially changed the morphology of Encinas Creek as indicated by the scour pool, apparent change in dominant flow direction, and lack of a clearly defined creek bed and bank through most of the eastern portion of the Project area. The existing thalweg profile, or the longitudinal profile of the deepest portion of the channel, of Encinas Creek within the Project area is shown in Figure 3-7.

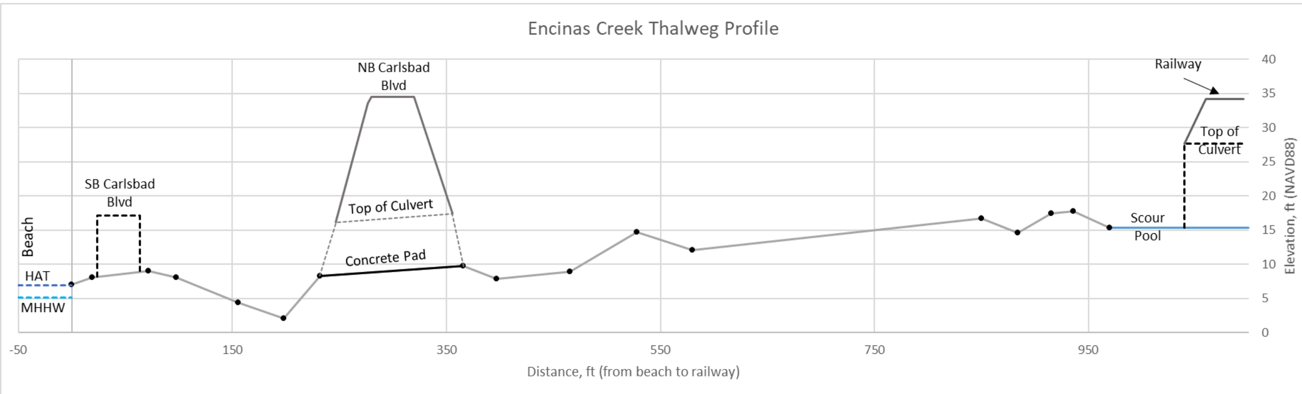

Figure 3-7. Encinas Creek Thalweg Profile

Based on widespread signs of seasonal inundation including high wrack caught in willows, sediment deposits, soil cracks, and obligate wetland plants at high elevations, the site is subject to flash flooding east of Northbound Carlsbad Boulevard during major winter precipitation or extreme tide events. In the northeast portion of the site, a basin characterized by pickleweed and cracked fine sandy soil appeared to seasonally collect stormwater runoff and/or floodwaters. The presence of pickleweed and other halophytic plants in this relatively high basin area (~13-16 feet elevation NAVD88) likely indicated that it may seasonally flood with brackish water from wave runup and accumulate salt in the soil without getting flushed by flowing freshwater inputs like much of the area immediately surrounding Encinas Creek. Downstream of the culvert under Northbound Carlsbad Boulevard, the creek has been scoured approximately eight feet below the concrete double box culvert outlet approximately seven feet below Ordinary High Water Mark as indicated by undercut banks, breaks in slope, and vegetation type). The mouth of Encinas Creek was mostly blocked by beach sand accreting on the concrete arch culvert sill, with a very low flow observed under Southbound Carlsbad Boulevard during the August field investigation. Lower Encinas Creek, bound by North- and Southbound Carlsbad Boulevard, was surrounded by brackish to salt marsh vegetation (e.g. pickleweed and Menzies goldenbush) and appeared to have some regular tidal influence with ocean waves likely overtopping the accreted sand at higher tides. South of the Encinas Creek mouth, a concrete pad exists with a marker indicating the presence of a stormwater outfall pipe. Unusual patterns of dead vegetation and wetland plants, such as cattails, around the pad may indicate that the outfall pipe is another source of hydrology onsite.

Hydrology onsite is subject to natural seasonal variation as well as increased watershed runoff and altered channel morphology that may increase the “flashiness” of the system. Surges of water into the system during periods of high surf and tides in the winter are expected to increase the extent of saltwater inundation onsite, and this could coincide with high flow events that cause the scour pool below Avenida Encinas to overflow and flood the eastern portion of the site. The site was investigated during the dry season, when Encinas Creek flow was likely at its lowest. Additionally, a smaller culvert under Avenida Encinas, a culvert and ditch originating at Northbound Carlsbad Boulevard, and non-point source stormwater runoff all contribute seasonal or ephemeral discharges to the Study Area.

4. Biological Site Assessment

This section provides a summary of previously completed biological studies as well as site assessments conducted as part of this study to fill data gaps.

4.1 Previous Biological Studies & Mapping

Habitat delineations at the Study Area were previously undertaken by EDAW and AECOM in 2005 and 2013, respectively. These mapping efforts were not completed at scale suitable to develop vegetation-elevation relationships. Furthermore, the best publicly available elevation dataset (light detection and ranging, or LiDAR) is not precise enough to resolve ground surface elevations at habitat breaks. Thus, a habitat and topographic survey was needed to accurately assess the project site.

At the eastern segment of the site, between Northbound Carlsbad Boulevard and the rail prism, vegetation had previously been mapped as Diegan coastal sage scrub, southern willow scrub, and willow scrub/coastal salt marsh (Figure 4-1). To the west of the Northbound Carlsbad Boulevard, much of the area was described as disturbed southern coastal salt marsh or disturbed habitat (Figure 4-1).

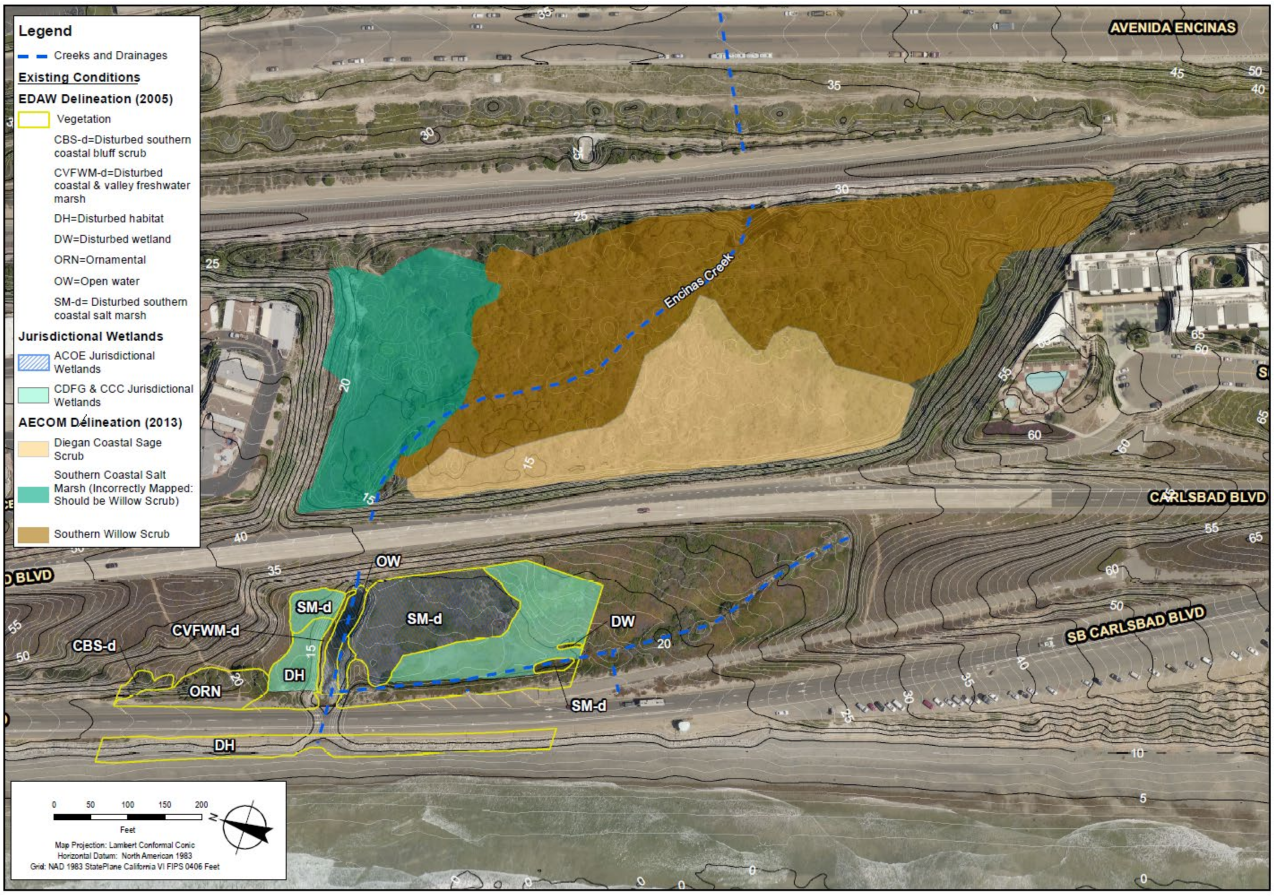

Figure 4-1. Previous habitat mapping by EDAW and AECOM

Species surveys were also performed by AECOM in 2013. The results of the survey are shown in Figure 4-2 relative to the Study Area. Some of the species observed include the Brown-Headed Cowbirds (parasitic native), White-tailed Kite, and the Willow Flycatcher.

Figure 4-2. Vegetation map and avian observations, project site is shown in red. (AECOM, 2013). CAGN – Coastal California Gnatcatcher; WTKI – White-tailed kite; WIFL – Willow Flycatcher; YBCH – Yellow breasted Chat; YWAR – Yellow Warbler

4.2 Updated Topographic & Biological Assessment

GHD performed a topographic and biological field assessment to define elevations associated with habitat breaks to better understand the hydrology associated with each habitat zone. This information will provide a baseline for which to estimate how these habitat distributions may change with SLR.

4.2.1 Mapping Methods

Habitat mapping was undertaken from August 16 to August 18, 2021 led by GHD ecologist Kelsey McDonald. Habitat mapping consisted of categorizing communities onsite according to functional habitat type and then characterizing the habitat according to dominant vegetation. Habitat polygon boundaries were primarily drawn in the field using the EOS Arrow Gold Global Navigation Satellite System (GNSS) receiver and ArcCollector. Field points and aerial imagery assisted with digitizing major vegetation breaks in the office. Native vegetation communities were then keyed to Vegetation Alliance according to the Vegetation Classification Manual for Western San Diego County (2011).

The vegetation mapping was supplemented with a topographic survey, which consisted of collecting elevations with the EOS Gold GNSS receiver and ArcCollector along stream cross-sections and cross-shore profiles. Encinas Creek and secondary channel topography was characterized by collecting elevations of

Ordinary High-Water Mark (OHWM), thalweg, toe of slope, and bench elevation above top of bank at a total of 24 stream cross-sections. Cross-section locations included two along the beach, six between Southbound and Northbound Carlsbad Boulevard, four along the discernible main channel above Carlsbad Boulevard, two along the cattail marsh channel, five along the upper scour pool and channels, four along a seasonal ditch, and one showing an additional area of seasonal flow below a smaller eastern culvert. Four cross-shore profile transects were established to characterize topography and the associated vegetation types across the site. Elevation and generalized vegetation data were collected at approximately every 10 meters and at major breaks in topography or dominant vegetation type. Benchmark elevations along the road shoulder and culverts were also collected to compare the data with remotely sourced LiDAR elevations and to provide reference points for monitoring flow conditions.

4.2.2 Habitat and Topographic Mapping

The results of the habitat, hydrologic and topographic mapping are shown in Figure 4-3 and Figure 4-4. Much of the site is dominated by iceplant and non-native scrubs. There is also a strong presence of Arroyo willow, cattail marsh, and pickleweed marsh. The topographic/hydrologic mapping found three main channels that flow into Encinas Creek, one of which results from a stormwater conveyance feature found at the southern extend of the Study Area. The other two flow paths originate from the scour pool at the culvert under the railway prism. These results will be discussed in more detail in the following sections.

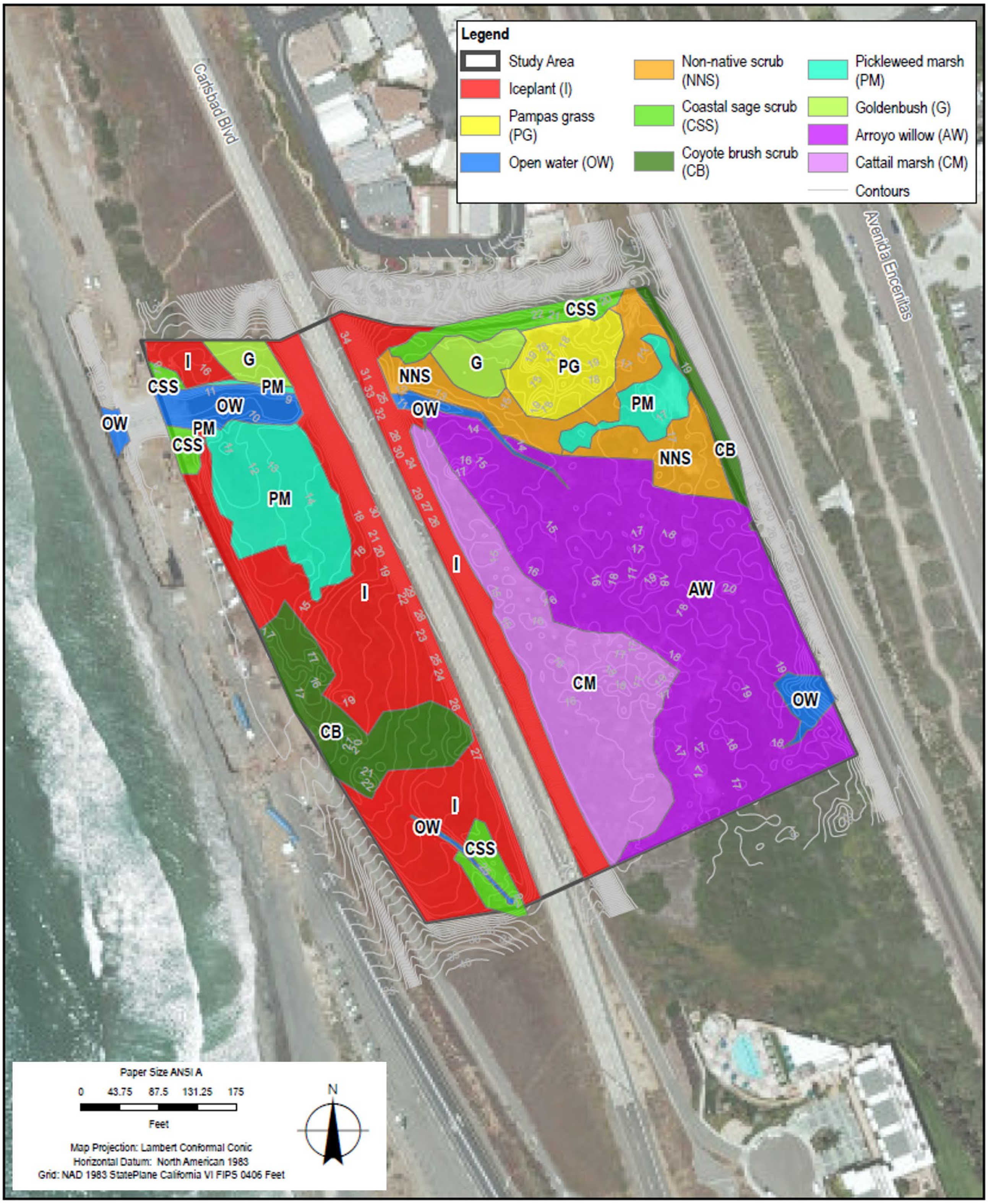

Figure 4-3. Vegetation mapping results at Study Area

Figure 4-4. Topography and Hydrology of the Study Area

4.2.3 Vegetation Communities

The Study Area is located in an anthropogenically altered estuarine setting crossed by road and rail prisms. Brackish to salt marsh habitat was observed near the mouth of Encinas Creek and in areas with accumulated salts east of Southbound Carlsbad Boulevard. Freshwater wetland habitat fed by Encinas Creek was observed upstream of the Northbound Carlsbad Boulevard culvert. Patches of native coastal scrub habitats weredistributed within the Study Area. Non-native and invasive species have also established dominance in several areas (Figure 4-5).

Figure 4-5. Iceplant Dominant Portion of the Study Area

The total acreage of each vegetation type mapped within each habitat is provided in Table 4-1 below. The brackish to saline pickleweed and Menzies goldenbush marsh vegetation alliances were found at the lowest elevations (Figure 4-6). Freshwater cattail marsh, pampas grass (invasive), and non-native scrub (invasive) was observed at low-to-mid elevations. Arroyo willow scrub was found at mid-to-high elevations around Encinas Creek. Coyote brush scrub and coastal sage scrub was also observed atmid-to-high elevations. Iceplant (invasive) has invaded a wide elevational range, and it was particularly dominant along the high-elevation road prisms.

Table 4-1. Total acreage of each vegetation type mapped in the Study Area

Vegetation Type	Total Acreage	% of Total
Pickleweed Marsh	0.75	8.17%
Goldenbush	0.23	2.51%
Cattail Marsh	1.13	12.31%
Arroyo Willow Scrub	2.53	27.56%
Coastal Sage Scrub	0.32	3.49%
Coyote Brush Scrub	0.59	6.43%
Iceplant (invasive)	2.37	25.82%
Non-native Scrub	0.61	6.64%
Pampas Grass	0.32	3.49%
Open Water	0.33	3.59%

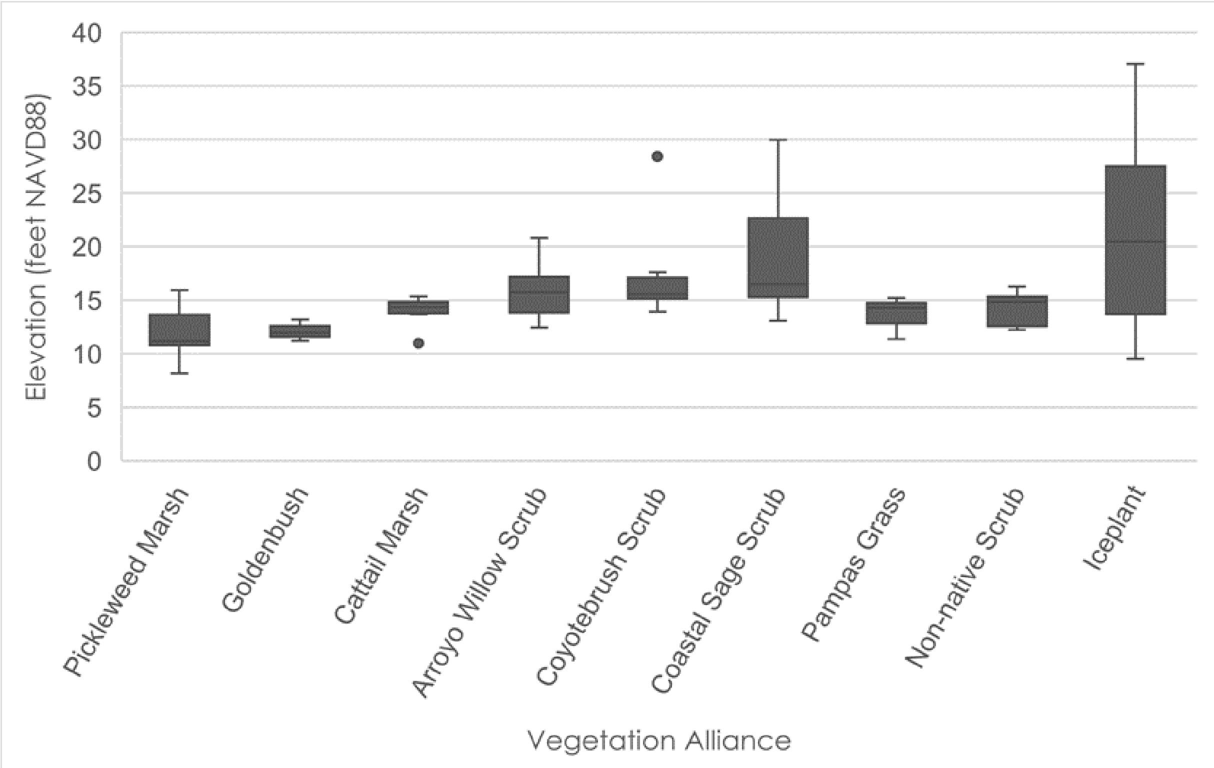

Figure 4-6. Vegetation Alliance elevation bands within the Study Area

The elevation range for which pickleweed dominated marsh was observed at the Project site are consistent with marsh elevations in other California intermittent breached estuaries. As stated by Thorne et al. (2021), marsh elevations in intermittent lagoons are found above mean higher high water (MHHW), whereas tidal marsh elevations in open estuaries are typically found at a lower elevation.

4.2.3.1 Freshwater Wetland and Riparian Communities

Cattail Marsh (**Typha domingensis*****) Alliance***

Southern cattail strongly dominated a wide swath of lower-elevation freshwater marsh (~11 to 16 feet NAVD88) east of Northbound Carlsbad Boulevard (covering a total of 1.13 acres) (Figure 4-7). Other species observed in this area included California bulrush (*Schoenoplectus californicus*) and low cover of emergent Arroyo willow (*Salix lasiolepis*). The cattail marsh was saturated at lower elevations near Northbound Carlsbad Boulevard during the investigation. The cattail marsh received perennial flow from upper Encinas Creek at the Avenida Encinas/rail prism culvert and then flowed back into Encinas Creek near the Northbound Carlsbad Boulevard culvert.

Figure 4-7. Cattail marsh bordered by dense arroyo willow

Arroyo Willow (Salix lasiolepis) Alliance

Arroyo willow strongly dominated 2.53 acres of the south-eastern portion of the Study Area between Avenida Encinas and the cattail marsh to the west at elevations of 12 to 20 feet NAVD88. Non-native red gum (*Eucalyptus camaldulensis*, Cal-IPC Limited) was also observed in this area around the large culvert and scour pool in the southeast corner of the Study Area. Mule fat (*Baccharis salicifolia ssp. Salicifolia*) and salt marsh fleabane (*Pluchea odorata*) occurred in the understory adjacent to the culvert. Additionally, California bulrush was observed in the understory at the lower extent of the willow thickets in Encinas Creek. To the west and northwest of the culvert, Arroyo willow formed a dense thicket with braided channels, and showed evidence of past flooding in the form of drift deposits and very few plants in the understory (Figure 4-8).

Figure 4-8. Dry braided channels and sediment deposits within the willow thicket

4.2.3.2 Native Scrub Communities

Coastal Sage Scrub (Artemisia californica-Eriogonum fasciculatum) Alliance

California buckwheat (*Eriogonum fasciculatum*) was a prominent species in mid-to-higher elevation native scrub in the Study Area (13 to 30 feet NAVD88) and was observed to be co-dominant with California sagebrush (*Artemisia californica*), Menzies goldenbush, bush sunflower (*Encelia californica*), and coyote brush (Figure 4-9). Coastal sage scrub was patchily distributed around the site, covering a total of 0.32 acres, and species composition and relative dominance varied throughout the coastal sage scrub community. Iceplant has invaded less densely vegetated areas of coastal sage scrub and has established dominance in many areas that would otherwise be at a suitable elevation range and habitat for coastal sage scrub. Non-native Canarian sea lavender (*Limonium perezii*) and common stock (*Matthiola incana*) also occurred in this habitat.

Figure 4-9. Coastal sage scrub with many non-native species at the base of the northern cliff east of Northbound Carlsbad Boulevard

Coyote brush (Baccharis pilularis) Scrub Alliance

Coyote brush dominated the majority of the native scrub within the Study Area (covering 0.59 acres), and it was dominant in the lower ditch drainage on the western end of the Study Area (Figure 4-10). Coyote brush is tolerant of a wide range of conditions, and the alliance was observed at a wide range of elevations (~13 to 28 feet NAVD88). Coyote brush intergraded with other native coastal scrub species including California buckwheat, lemonade berry, and Menzies goldenbush. Coyote brush also dominated some of the higher elevation area at the northeastern extent of the Study Area along the rail prism, where it intergraded with non-native shrubs and halophytes on the edge of the pickleweed-dominant basin.

Figure 4-10. Coyote brush dominates a large patch of the western portion of the Study Area

4.2.3.3 Non-Native Vegetation

Non-native mixed scrub

Lollypop tree (*Myoporum laetum*, Cal-IPC Moderate), Brazilian pepper tree (*Shinus terebinthifolius*, Cal-IPC Limited), and cyclops acacia (Cal-IPC Watch List) have invaded 0.61 acres east of Northbound Carlsbad Boulevard. These non-native small trees and shrubs have established dominance along Encinas Creek east of Northbound Carlsbad Boulevard and around the high salt marsh basin and rail prism. This non-native vegetation type was primarily observed in disturbed transition zones between wetland and upland habitats at middle elevations (12 to 16 feet NAVD88).

Pampas grass (**Cortaderia jubata*****)***

Invasive pampas grass (Cal-IPC-High) has established a dense near-monospecific stand in a 0.32-acre north- central patch east of Northbound Carlsbad Boulevard (Figure 4-11). Cracked sandy soils and some pickleweed and saltgrass in this location appears to indicate that this area may be subject to occasional flooding, and this area was relatively low elevation (11 to 15 feet NAVD88). Salt cedar (*Tamarix ramosissima*, Cal-IPC High) was also observed around the edges of this highly invaded patch of pampas grass. Pampas grass also occurred in non-native scrub habitat and other disturbed areas of the Study Area.

Figure 4-11. Dense pampas grass in the northeast portion of the Study Area

Iceplant mats (*Carpobrotus edulis*)

Iceplant (Cal-IPC High) has severely invaded 2.37 acres of the Study Area and established thick monospecific mats throughout much of the western portion of the Study Area and on both sides of Northbound Carlsbad Boulevard. Freeway iceplant was observed at a wide range of elevations onsite (~9 to 33 feet NAVD) and appeared to be invading brackish wetland and upland habitats.

4.2.4 Summary of Habitat and Topographic Mapping Findings

Field investigations and analysis of elevation data showed that species distributions are influenced by the complex hydrology onsite as well as elevation. Pickleweed and other halophytic vegetation, such as Menzies goldenbush, were found at the lower end of the site's elevation range on both sides of Northbound Carlsbad Boulevard. Salt to brackish vegetation types were observed at elevations beyond regular tidal influence, including a high basin that appeared to seasonally flood east of Northbound Carlsbad Boulevard. Cattail marsh spanned across the lower portion of the site east of Northbound Carlsbad Boulevard, where freshwater from upper Encinas Creek collected before draining back to the main channel at the Northbound Carlsbad Boulevard culvert. Arroyo willow was strongly dominant across the northeast portion of the site around upper Encinas Creek. Native coastal sage scrub and coyote brush scrub was patchily distributed at middle to high elevations across the site. Much of the site was highly invaded by iceplant and other non-native species. Non-native species have invaded the site across the elevation range, but iceplant was especially dominant at higher elevations around the disturbed road prisms.

5. Hydrological Site Assessment

Water level and water quality (salinity and temperature) were actively monitored within the Study Area to better understand and characterize the seasonal variability influenced by tidal and surface water influences. These data were used to inform the design of the habitat restoration concepts. The methods and results of this monitoring effort is summarized in this section.

5.1 Methods

In mid-August 2021, two monitoring wells were installed within Encinas Creek, one located on the western side of the Northbound Carlsbad Boulevard culvert, and one located on the eastern side (Figure 5-1). The instruments deployed into the monitoring wells were Solinist Leveloggers, which measure pressure (water levels), conductivity (salinity), and temperature. The housing for the wells was standard two-inch diameter plastic pipe and are mounted via steel rebar and anchored in a fixed position to the bed of Encinas Creek. A barometer was also installed on site to compensate the collected data with local barometric pressure.

The instruments log data continuously at 15-minute intervals and data was downloaded manually monthly. Post-processing of data was performed using the Solinist Levelogger™ software. Additionally, post-processing includes referencing the observed water level data to a benchmark elevation. Benchmark elevations were collected during the initial topographic surveys. The western benchmark is located at the first concrete step southern culvert wall and is an elevation of 9.31 feet (NAVD88). The eastern benchmark is located on the eastern extent of the concrete pad and is an elevation of 9.72 feet (NAVD88).

Figure 5-1. Las Encinas Creek Monitoring Well Locations

5.2 Results

Figure 5-2 shows the water levels and salinity concentrations measured at the west and east locations within the Study Area during the period of data collection (August 2021 to January 2022) relative to daily precipitation measured at the McClellan-Palomar Airport and tidal elevations measured at La Jolla (NOAA Tide Gauge 9410230). The measured water levels and salinity concentrations vary due to fluvial (freshwater) flow from rainfall runoff within Encinas Creek watershed, saltwater inflow from wave overwash and groundwater flux.

The measured water levels show two perched pools (west and east) separated by Northbound Carlsbad Boulevard arch culvert crossing. The concrete sills on the south- and Northbound Carlsbad Boulevard culvert crossings influence the exchange of surface fresh- and saltwater between the pools and are approximate elevation eight feet and 9.7 feet (NAVD88), respectively. The Southbound Carlsbad Boulevard culvert sill was observed at times exposed above the beach profile but then also buried from sand and cobble after periods of high surf. The culvert sill elevations are reflected in the relatively uniform measured water levels at the west and east locations between discrete events, which are described below.

Event A: During this period, water levels increased at the west and east locations from wave run-up that propagated through both culvert crossings during spring tides and a large swell event that resulted in a brief spike of salinity concentrations in the east location.

Event B: During this period, the first appreciable precipitation event of the season occurred and resulted in short increases in water levels. Immediately following the increases, the west location shows the elevations drop, likely resulting from scour of sand/cobble down to the concrete sill elevation at the Southbound Carlsbad Boulevard crossings. The freshwater inflow also depresses salinity concentrations which slowly increase at the west location but remain low in the east location.

Event C: Similar to Event B, during this period a precipitation event resulted in short increases in water levels and depressed salinity concentrations from the freshwater inflow. Following the event, the salinity concentrations gradually increased at the west location but remained low in the east location.

Between the events, the water levels and salinity concentrations equilibrate as can be seen in the monitoring data. Generally, water levels remain perched at or above the culvert sill elevations with salinity concertation ranging between 15-25 parts per thousand (ppt) in the west location and less than 5 ppt in east location. Between events, the west water levels show a mixed semi-diurnal tidal signature, which is result of wave overwash through the Southbound Carlsbad Boulevard culvert or through water seepage through the road prism. It should also be noted that during routine site visits, observations of kelp/seagrass deposits are common within the creek and variations in the sand (sill) deposition at the culvert/bridge crossing is common. An example of sill formation can be seen in Figure 5-3, which shows the culvert conditions at a timeframe of one month.

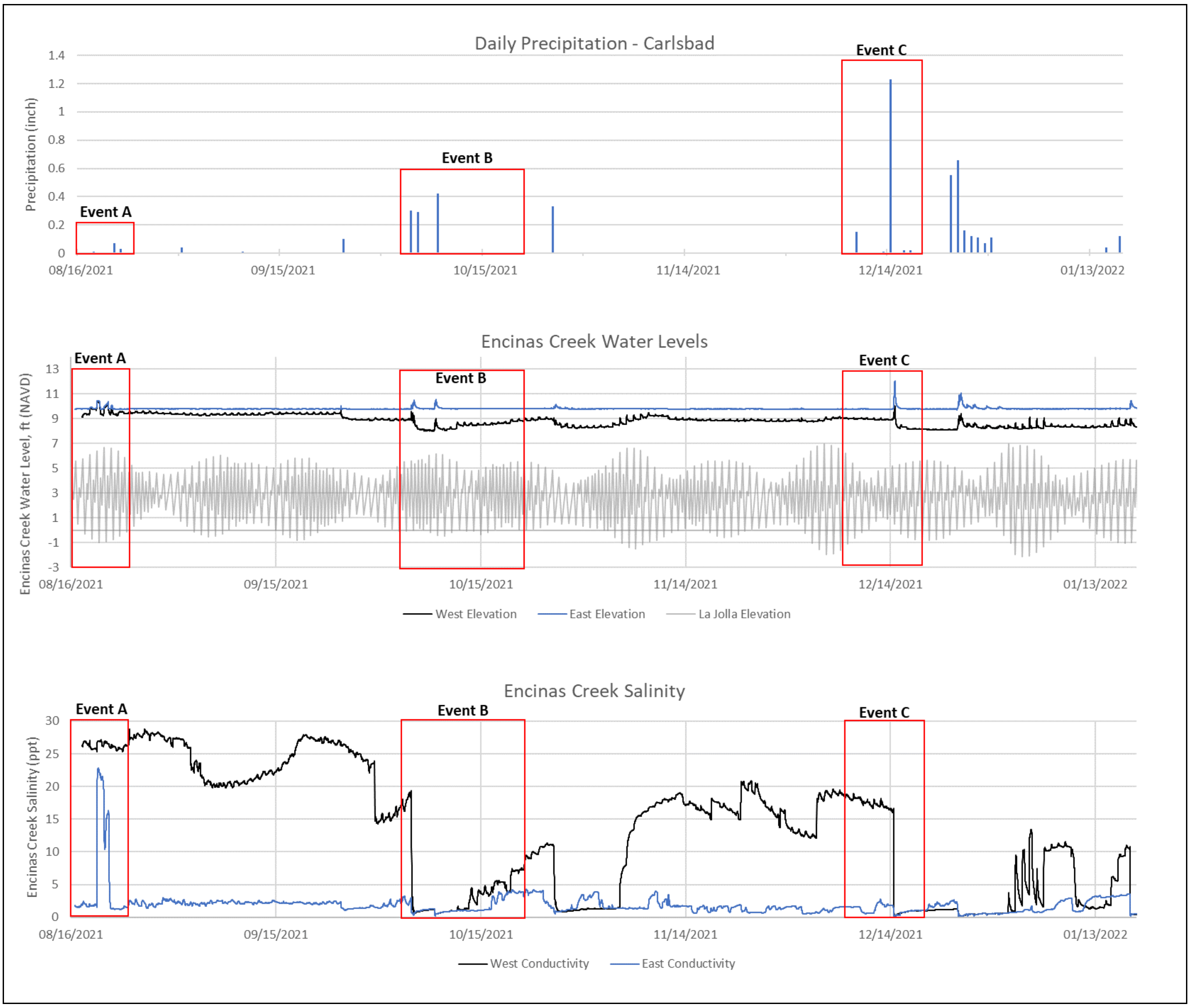

Figure 5-2. Daily Precipitation for McClellan-Palomar Airport (top); Encinas Creek & La Jolla (NOAA Tide Gauge 9410230) Water Levels (middle); Encinas Creek Salinity (bottom)

Figure 5-3. Southbound Carlsbad Boulevard Culvert on 12/15/2022 (A & B) and 01/19/2022 (C & D)

5.3 Key Findings

The key findings from the hydrological site assessment are based on the water level monitoring data, habitat elevations, and visual observations during the period of study. These findings are summarized below:

1. Water levels and salinity concentration measured at the west location are indicative of an intermittent closed estuary which refers to an estuary that is periodically (or seasonally) closed to the open ocean. The morphology exhibits variable conditions influenced by freshwater inflow, saltwater overwash and seepage through the road prism fill. While the concrete culvert sill elevations remain fixed, the Southbound Carlsbad Boulevard sill exhibits characteristics of a natural bar-built estuary mouth formed by sand and cobble transported up the wave slope during high swells and then breached/scoured during high fluvial flows. While these discrete events can significantly alter water levels and salinity concentration within the estuary episodically, the mixed semi-diurnal tidal signature continuously observed during mouth closure periods of neap tides and no freshwater inflow indicates a direct influence from seepage (groundwater exchange) through the Southbound Carlsbad Boulevard fill prism between the beach and estuary. Thus, the current water levels and salinity concentration trends observed at the west location would likely persist with replacement of the existing Southbound Carlsbad Boulevard with a naturalized shoreline and dune that would intermittently breach and exchange groundwater seepage.
2. The inlet morphology and breach characteristics of this type of estuary are dependent on several factors including wave and tide exposure, availability of sediment, freshwater input, concrete culvert sill and as observed in the measured data described above. The basics of these processes are shown in Figure 5-4, in which tide and wave exposure deposit sediment at the inlet to create a temporary berm or sill. In addition, sediment from upstream fluvial sources, while assumed to be minimal given the developed watershed, may be transported and deposited at the shoreline and ocean via freshwater flow. The Southbound Carlsbad Boulevard culvert acts as the inlet of the estuary, and a sill is created as sand and cobble are deposited by waves and tides. This morphology of this sill is dependent on spontaneous event-based trends that are dictated by oceanographic conditions and freshwater inflow.
3. Tidal marsh elevations within the intermittent closed estuary were observed to be higher than that of closed or perennially open estuaries and are dictated by the tidal prism, water levels, and accretion within the estuary. As the sea level rises, tidal marsh elevations will increase to maintain a state of equilibrium. Specific to intermittent breached estuaries, more frequent inlet breaching allows for marsh inundation and sediment accretion within the estuary. This process aids the marsh transition with sea level rise.

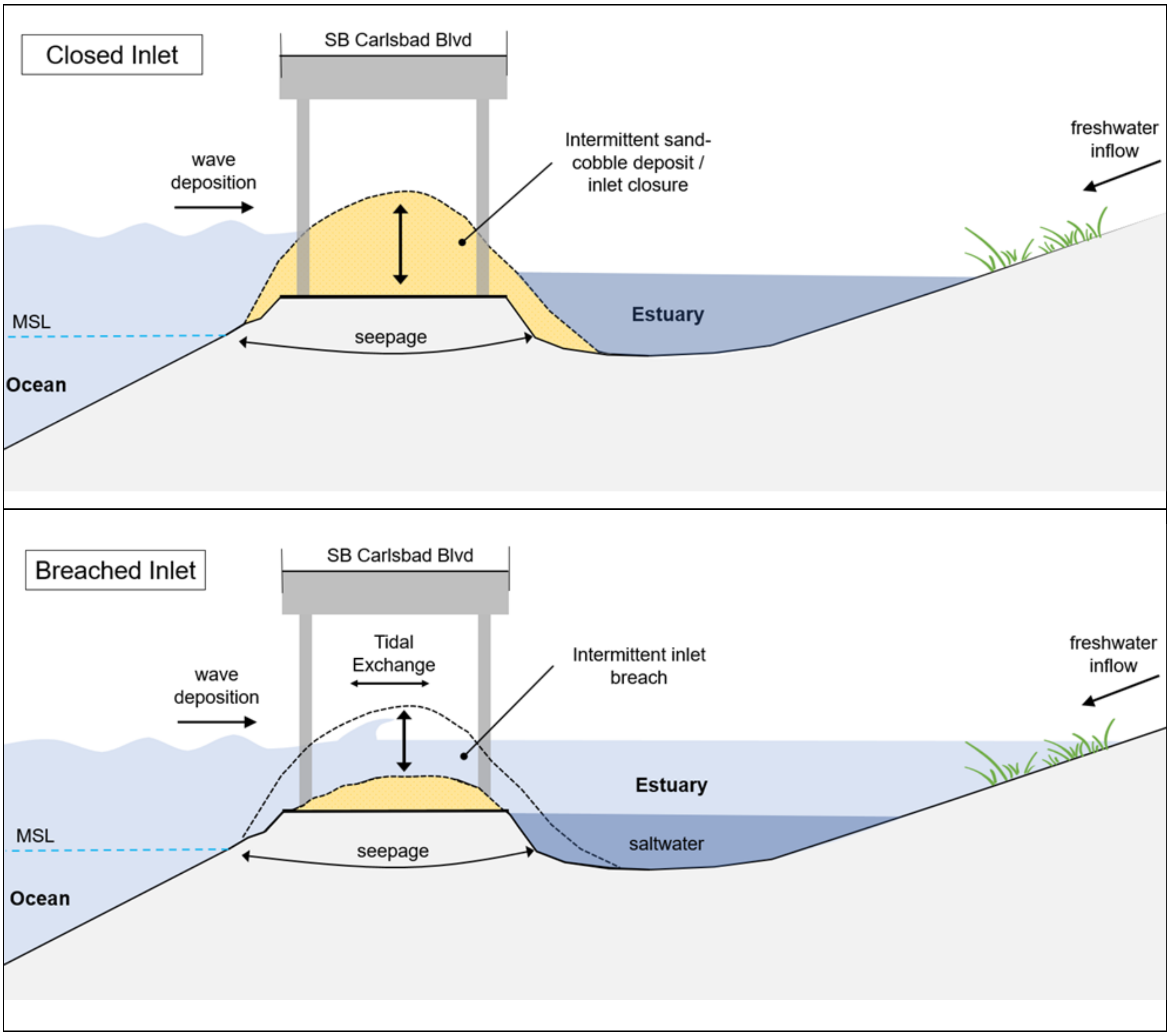

Figure 5-4. Intermittent Breached Estuary Physical Processes during Open Inlet Condition (top) and Closed Inlet Conditions (bottom)

6. Las Encinas Creek Estuary Habitat Restoration Concepts

Habitat restoration concepts were developed for the two Project implementation options being considered. These concepts are presented in this section with simplistic graphics illustrating the main components proposed. Preliminary design drawings for each of these concepts are included as Appendix B.

6.1 Phased Adaptation

The Phased Adaptation alternative would either leave in place or partially remove the Southbound Carlsbad Boulevard infrastructure for interim passive or active recreational uses until coastal hazards overwhelm the repurposed space. Once this trigger is met, Southbound boulevard would be demolished and public access and recreational uses would shift to the new bi-directional roadway corridor. Major infrastructure elements (e.g. the roadway) would be constructed at its ultimate location while other temporary, movable, and/or low-cost Project features would occupy spaces identified as being vulnerable to projected coastal hazards. The existing rock shoreline protection may persist for a period of time to support the use of these spaces.

The phasing of the Project will couple adaptive management measures to be implemented once specific physical triggers are met. Triggers may consist of proximity of shoreline or bluff face to infrastructure, flooding along Southbound Carlsbad Boulevard, or damage to infrastructure. The Phased Adaptation approach allows for desired uses of the area to continue until it is unsafe to do so. Triggers will be developed by the project team and vetted with key stakeholders and the resource agencies.

The “Phased Adaptation” option includes the following elements and is shown below in Figure 6-1:

- Southbound Carlsbad Boulevard:
  - Repurpose existing roadway and arch culvert for public access and recreational uses.
  - Retain existing rock shoreline protection (RSP) to protect these features until future coastal hazard triggers are met.
- Restoration of Las Encinas Creek estuary:
  - Expand existing salt marsh and dendritic tidal channel network in footprint of removed Northbound Carlsbad Boulevard fill prism (i.e. under the new bridge) and increase transition zone habitat area
  - Enhance Las Encinas Creek stream-estuary ecotone and reduce erosion potential at rail prism culvert outlet. Removal of iceplant / other non-native vegetation and active restoration (planting) with native species.

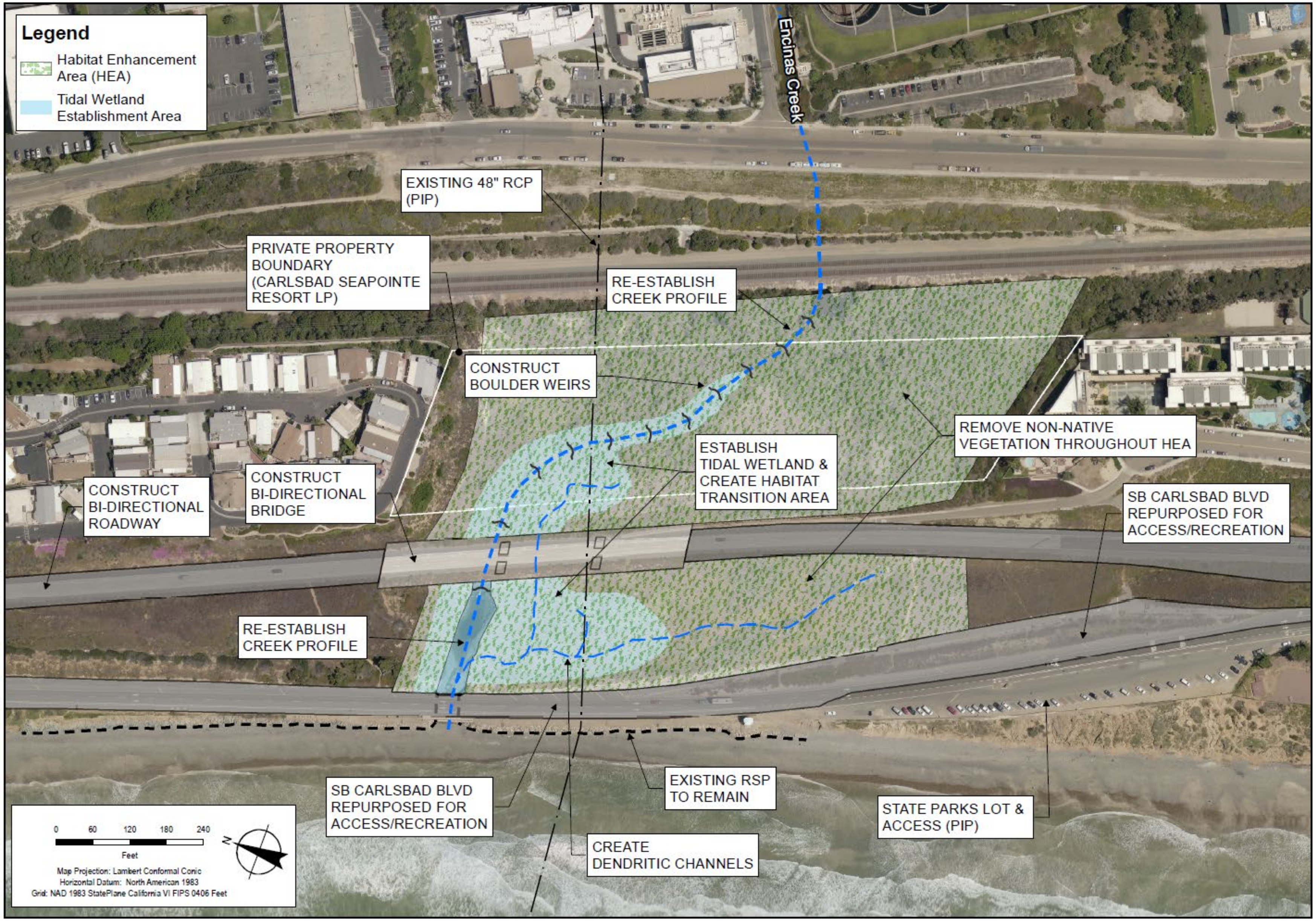

Figure 6-1. Proposed Project Elements for the "Phased Adaptation" Alternative

6.2 Retreat Now

The “Retreat Now” alternative, refers to the naturalization of the area by removing infrastructure within the 2120 projected coastal hazard zone and restoring the Las Encinas Creek estuary system. More specifically, this alternative seeks to establish a more natural cross-shore gradient promoting morphological processes that support formation and resilience of a coastal pocket beach, dune, and dune-slack wetlands. The Las Encinas Creek estuary and beach would be allowed to evolve naturally and without major maintenance after constructed. The option would include the following elements which are shown graphically in Figure 6-2:

- Southbound Carlsbad Boulevard:
  - Remove existing roadway, roadway fill, arch culvert and RSP.
- Restoration of Las Encinas Creek estuary:
  - Construct cobble/sand dune along landward edge of abandoned southbound roadway alignment to form the backshore of a bar-built estuary type system.
  - Cobble/sand dune would be allowed to naturally erode and migrate landward over time, accommodating the formation of a pocket beach.
  - Las Encinas Creek estuary restoration is same as that specified in the ”Phased Adaptation” Alternative; however, depending upon the constructed dune approach and estimated rate of retreat, persistence of constructed tidal channels could be reduced from more frequent overwash and cobble/sand dune landward migration.

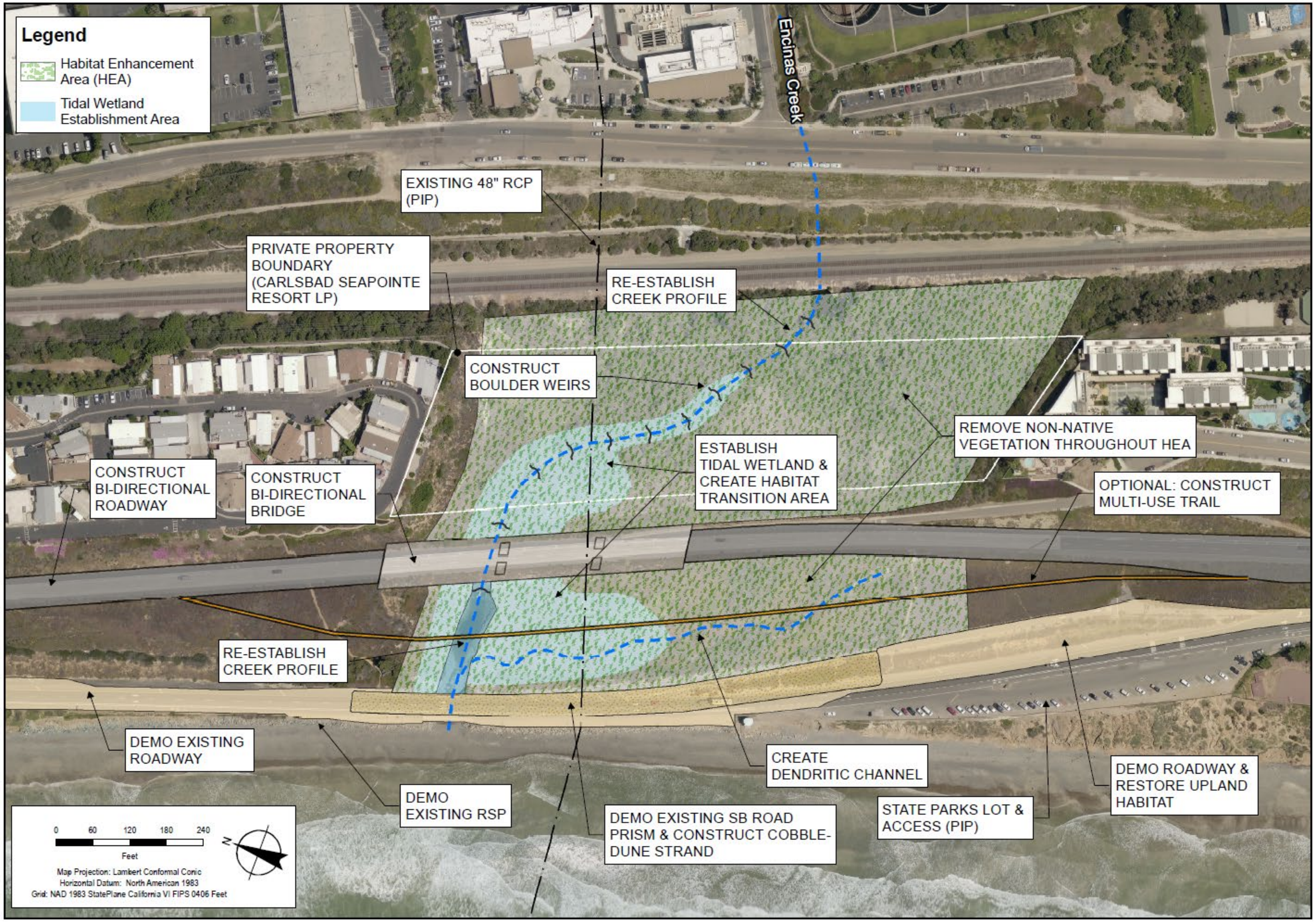

Figure 6-2. Proposed Project Elements for the Retreat Now Alternative

7. Hydraulic Site Assessment

The U.S. Army Corps of Engineers River Analysis System (HEC-RAS) was used to assess hydraulic conditions of Las Encinas Creek within the Study Area under existing conditions and the proposed two alternatives. The primary purpose of the hydraulic analysis was to:

1. Assess the potential change in water surface elevations between existing conditions and proposed alternatives under current and future SLR scenarios, and
2. Assess the potential for increased scour of Las Encinas Creek with the proposed alternatives

The preliminary model results have been used to inform the conceptual restoration design grading and anticipated need for scour counter measures at the proposed bridge abutments and within Las Encinas Creek. Once an alternative is selected, additional hydraulic modeling will be necessary to advance the design.

7.1 Model Domain & Bathymetry

HEC-RAS 2D was selected for the assessment of flood event modeling. The model domain extends from the railroad crossing west into the Pacific Ocean and far enough offshore to mitigate any hydraulic grade line influences of the tidal boundary condition. Mesh size varies within the model domain with a higher resolution within the Project Area, and larger mesh sizes off the coast to minimize model run times (Figure 7-1).

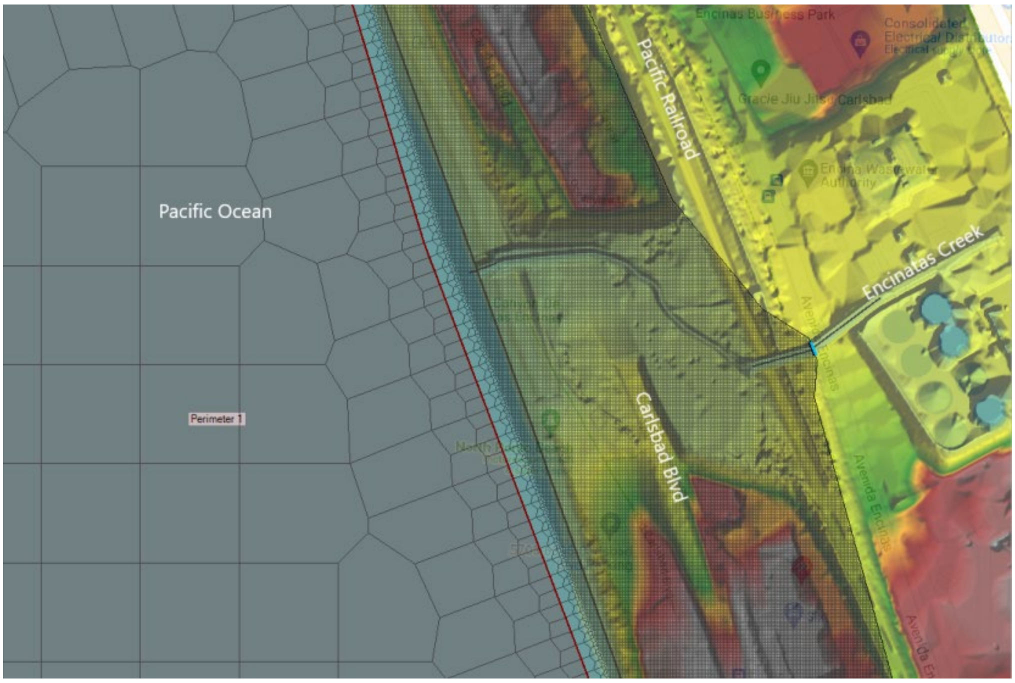

Figure 7-1. HEC-RAS 2D Model Domain

Topographic data (2016 USGS West Coast El Nino LiDAR Digital Elevation Model) was exported from the NOAA Digital Coast and processed in AutoCAD 3D to develop a Digital Elevation Model and imported into HEC-RAS. The conceptual grading design for both the Retreat Now and Phased Adaptation alternatives were simulated in the model.

7.2 Model Boundary Conditions

The HEC-RAS model contains two boundary conditions. The upstream boundary condition was assigned in Encinas Creek upstream of the railroad crossing and is used to represent fluvial flow. The fluvial input was selected as the two and 100-year peak flows as described in the Encinas Creek Location Hydraulic Study, Section 12 (Caltrans, 2009) which are 427.6 cubic feet per second (cfs) and 1,910 cfs, respectively. Tidal water levels obtained from La Jolla, (Gage #9410230) were used for the downstream model water surface elevations and included the Highest Astronomical Tide (HAT) of 7.01 feet and the Mean Low Water of 0.71 feet (NAVD 88).

7.3 Flood Potential Results

Figure 7-2 shows the computed water surface elevations between the rail crossing and Southbound Carlsbad Boulevard crossing during the two and 100-year fluvial flow occurring coincident with the HAT and HAT plus 6.6 feet of SLR. The results indicate that under existing conditions, both south- and Northbound Carlsbad Boulevard crossings have capacity to convey the 100-year flow without road surface flooding during the HAT. The results also indicate that an increase in SLR by 6.6 feet during the 100-yr flow event does not alter the upstream water surface elevations because both culverts are inlet controlled which creates a backwater condition that propagate up to the rail crossing.

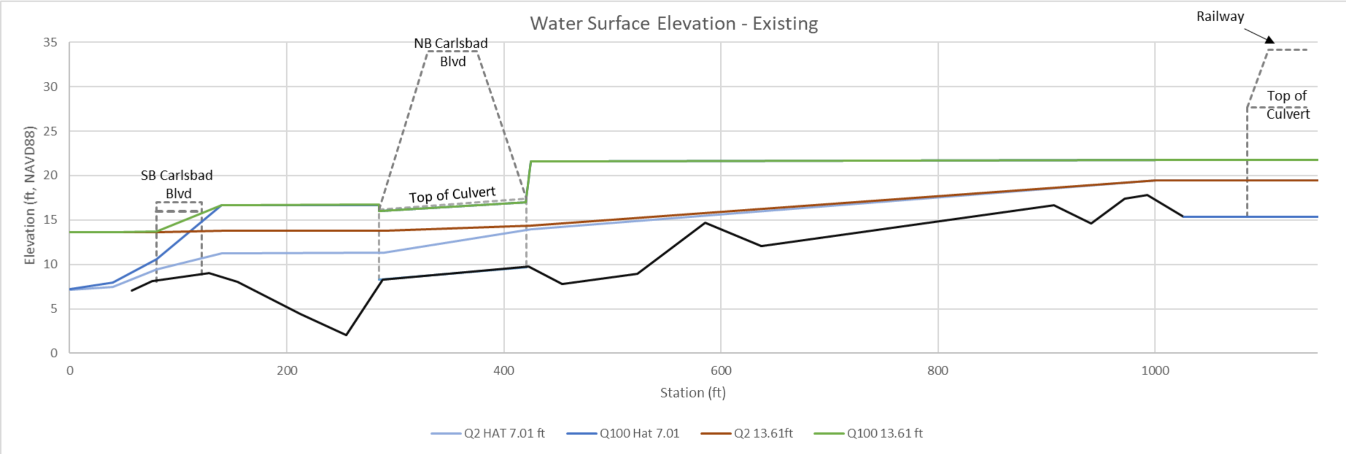

Figure 7-2. Modelled water surface elevation for existing conditions

The Phased Adaptation alternative replaces the Northbound Carlsbad Boulevard fill prism and double box culvert with a bridge which effectively eliminates the backwater condition created by the culvert during the 100-year flow and lowers the water surface elevation through the rail crossing (Figure 7-3). The hydraulic conditions of Southbound Carlsbad Boulevard crossing remain unchanged from existing conditions.

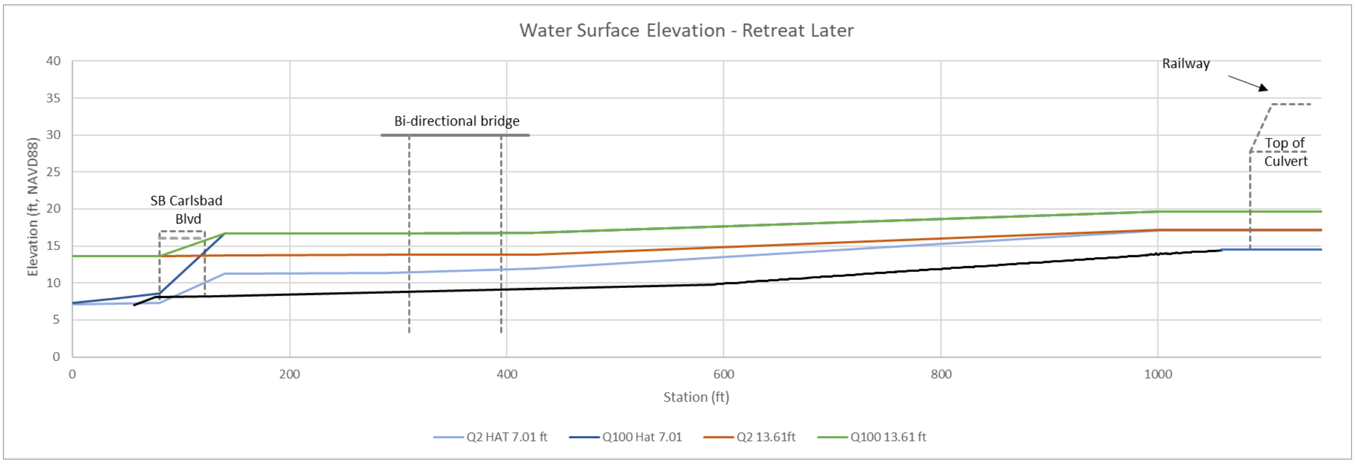

Figure 7-3. Modelled water surface elevation for Phased Adaptation Alternative

Similar to the Phased Retreat alternative, the Retreat Now alternative replaces the Northbound Carlsbad Boulevard fill prism and double box culvert with a bridge and also replaces the existing Southbound Carlsbad Boulevard and arch culvert with a naturalized dune. The dune crest will breach intermittently, similar to existing conditions, but will also retreat landward and upward with SLR as previously described. To assess water surface elevations associated with this alternative, the 100-year flow was simulated with dune crest elevations for 1.7, 3.3 and 6.6 feet of SLR and as described in the shoreline response assessment section of this report. These crest elevations result in a conservative backwater condition that does not account for a breach that would likely occur at a much lower elevation (Figure 7-4). The results indicate the 100-year fluvial flow water surface elevation created from the dune crest elevation at 6.6 feet SLR (22 feet) is equivalent to the 100-year water surface elevation through the rail prism culvert under existing conditions. Based on these results, the proposed alternatives would not increase water surface elevations within or beyond the Project Area.

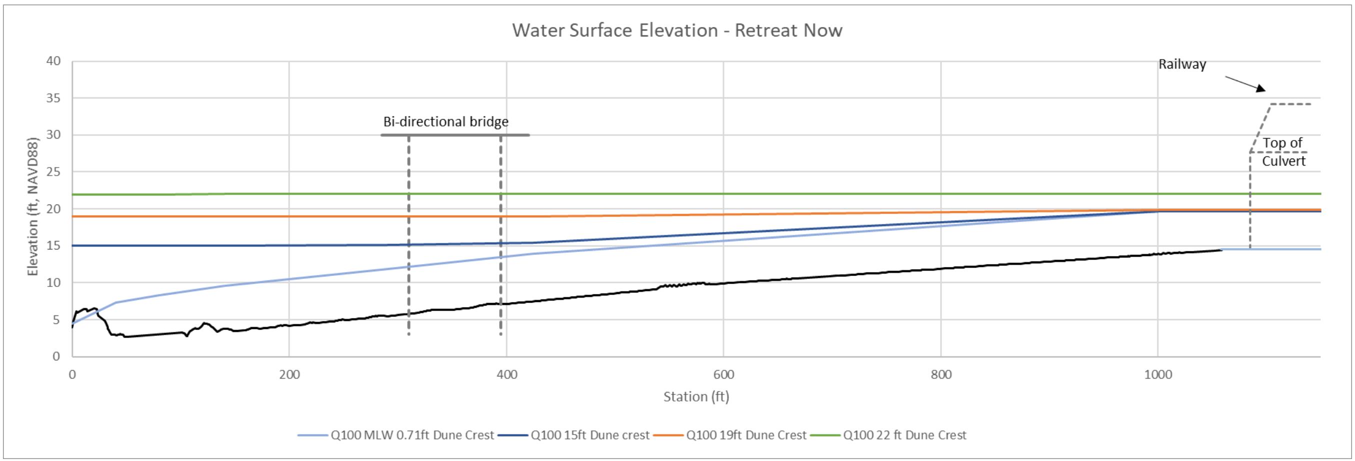

Figure 7-4. Modelled water surface elevation for Retreat Now Alternative

Under existing conditions, the existing culvert crossings create backwater conditions. Removal of the culverts results in lower water surface elevation potential and increased flow velocities. Indications of scour are present onsite and have the potential to increase. To better understand the erosion potential of Las Encinas Creek through the Project Area, the hydraulic model was run with a 100-year flow and tidal boundary condition of Mean Low Water (0.71 feet) which would emulate a dune breach. The water surface elevation and velocity profile of Las Encinas Creek are shown on Figure 7-5. The velocity distribution throughout the Project Area is shown in Figure 7-6. The results indicate an erosion potential within Las Encinas Creek and, therefore, a series of boulder weirs and pools have been shown on the conceptual plans between the rail crossing and new bridge to prevent headward incision of Las Encinas Creek that could undermine the rail prism culvert and/or expose the existing buried wastewater treatment discharge pipe. During subsequent phases of design, alignment and profile options can be further assessed as well as use of a roughened channel in lieu of boulder weirs as counter measures to minimize channel erosion and scour potential.

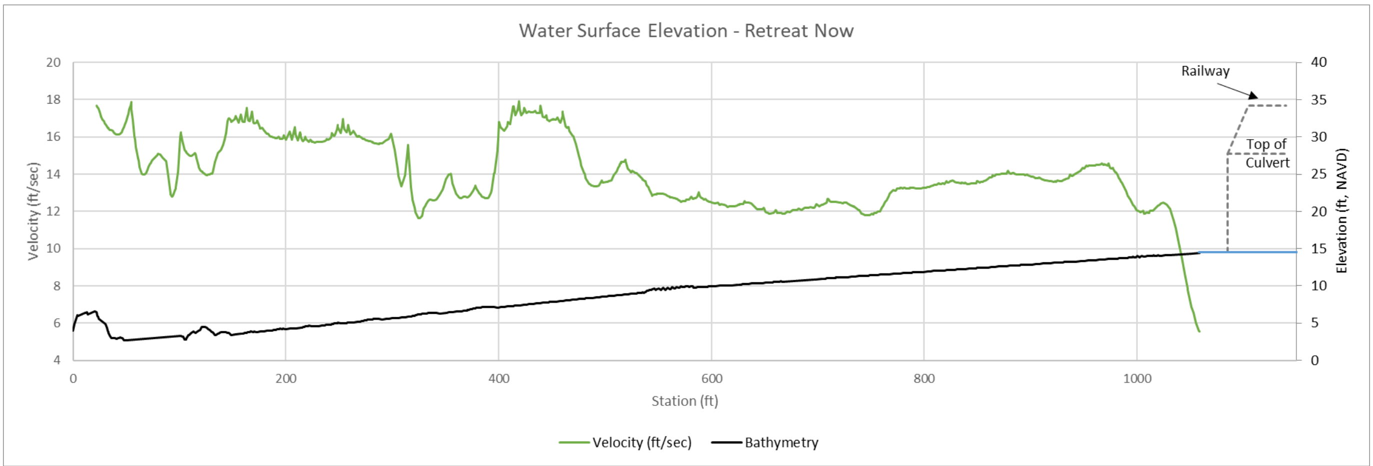

Figure 7-5. Velocity profile for Q100 (MLW tide, 0.71 feet) under Retreat Now Alternative

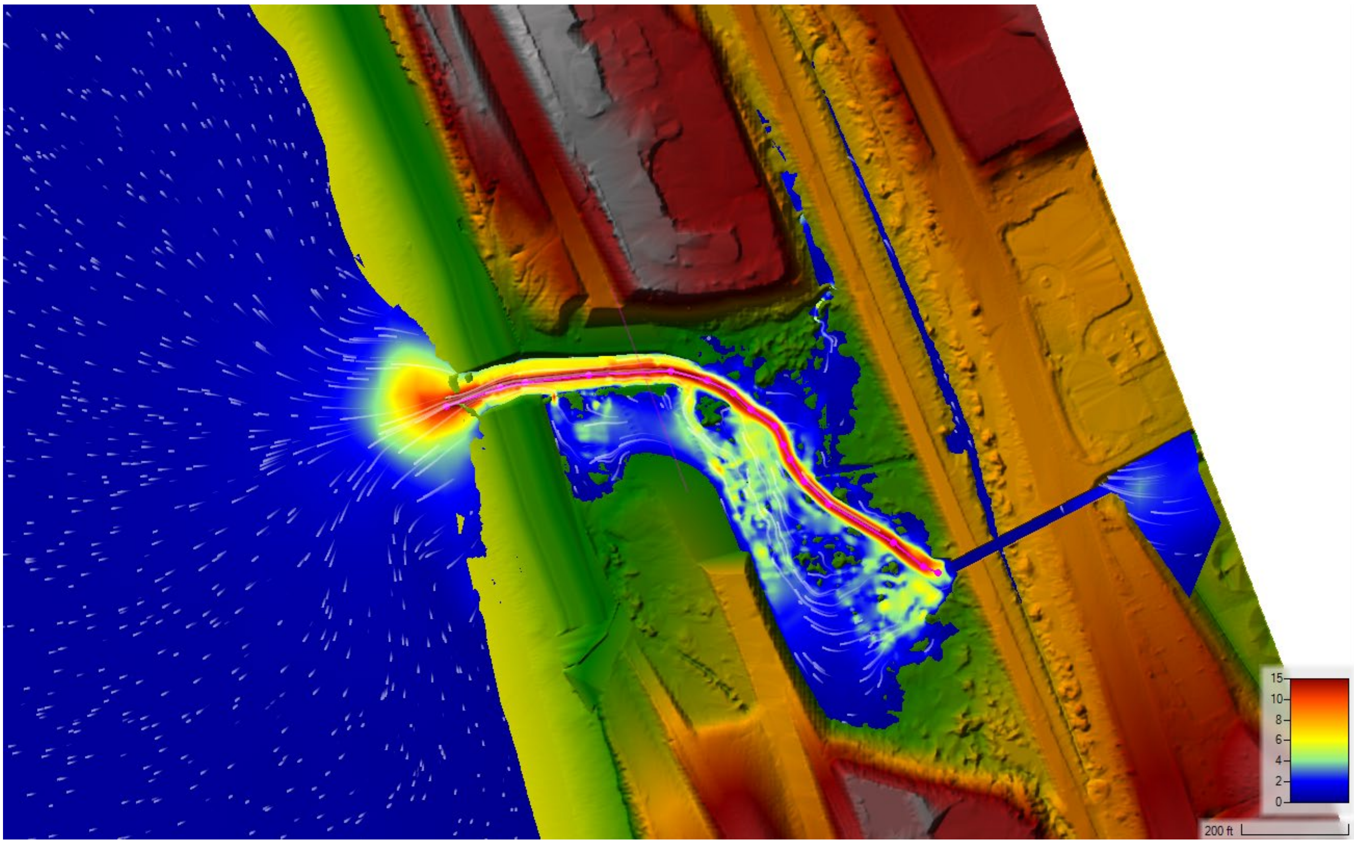

Figure 7-6. Velocity for Q100 (MLW tide, 0.71 feet) under Retreat Now Alternative

8. Shoreline Response Assessment

The purpose of this assessment is to estimate the potential shoreline response of each approach to projected sea level rise scenarios. The rate of SLR and shoreline retreat will affect habitat transgression, the evolution of the Las Encinas Creek channel, and the overall public interaction and access through the site.

8.1 Methods & Assumptions

The first step in this assessment was to determine baseline shoreline erosion rates and projected erosion rates with sea level rise. The Coastal Storm Modeling System Coastal One-Line Assimilated Simulation Tool (CoSMoS-COAST) led by USGS, published regional shoreline projections with SLR scenarios from 0.5 meters (1.6 feet) to 5 meters (16.4 feet). These shoreline retreat projections use historical trends of the MHW shoreline with models that compute long and cross shore transport at evenly spaced transects (Barnard, P.L, et al., 2018). The CoSMoS shoreline projections were used to determine rates of shoreline erosion with SLR by measuring from the current MHW shoreline to the projected eroded shoreline.

Since the CoSMoS results are only available in discrete SLR increments, the data used to estimate coastal hazards may not precisely correlate with the SLR projections listed in Table 3-2. 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.

To further examine a potential shoreline response with sea level rise, the Bruun rule was applied to the nearest SANDAG beach profile (i.e. CB-0760). The Bruun Rule is a one-dimensional shoreline assessment which assumes that the profile is in equilibrium. The beach profile will retain its shape and sand eroded from the beach will be deposited in the nearshore within the active profile (bounded by the depth of closure). Bruun Rule assumes that as the sea level rises, the profile shifts landward and upward to maintain a position relative to MSL. The landward shift is calculated with the berm/dune crest elevation, closure depth, relative sea level rise, and the total distance of the active profile. The results from the Bruun Rule calculations were compared against the CoSMoS shoreline retreat results, in which the CoSMoS results yielded a more conservative estimate. Due to the assumptions and uncertainties with both the Bruun Rule and CoSMoS methods, the more conservative (CoSMoS) shoreline projections were chosen to represent the upper range of retreat for the project area.

8.2 Cobble Reduction Factor

Since the proposed Retreat Now Project alternative includes a mixed sand/cobble dune, an additional analysis was performed to estimate retreat rates of a cobble dominant shoreline. Currently, there is limited data available on the physical performance of mixed sand / cobble beaches and berms on the open coast of southern California. Additionally, it is poorly understood how these systems will respond to projected sea level rise. Although, some studies have noted that cross and alongshore transport of cobble is much less than that of the transport of sand based on observations in San Diego County and southern California (Everts, 2002; Hironori et al 2019). Furthermore, it has been observed that waves and tidal action transport cobble onshore to form steep cobble berms (Everts, 2002; Hironori et al 2019). This information suggests that the cobble berms can be used to slow the erosion of a shoreline or add a layer of dynamic protection to a shoreline.

To evaluate this shoreline erosion reduction for cobble-dominated beaches, projected retreat rates with SLR were assessed at various cobble and sandy beach reference sites. Reference areas in southern California were chosen that contain both a cobble and sand-dominant profile within close proximity such that the oceanographic forcing is similar. The reference beaches selected include:

- Henamans (cobble) vs Pacific Beach / Tourmaline (sand) in the City of San Diego
- Ventura (sand) vs Ventura River Mouth (cobble) in the City of Ventura

Projected erosion rates for these reference sites were obtained from the CoSMoS data, in which retreat rates of the cobble beaches were then compared to the sand-dominant beaches. The comparison was a simple percent decrease calculation for each SLR projection between the sand and cobble beaches [(starting value-final value)/starting value]. The erosion rate for each SLR scenario was then averaged to yield a common reduction factor for both references sites, which could then be applied to the shoreline retreat at the Study area. An example is shown in Figure 8-1 and Figure 8-2, in which erosion rates for the historically cobble beach (Henamans) are roughly half that of the nearby sand-dominant beach (Pacific Beach/Tourmaline). The reduced cobble erosion rates provide a lower bound estimate of shoreline retreat projections for this analysis.

Figure 8-1. Location of Cobble Influence Shoreline Erosion Analysis. Top: Henamans Beach (cobble beach) and Pacific Beach / Tourmaline (sand beach); Bottom: Ventura (sand beach) and Ventura River Mouth (cobble beach)

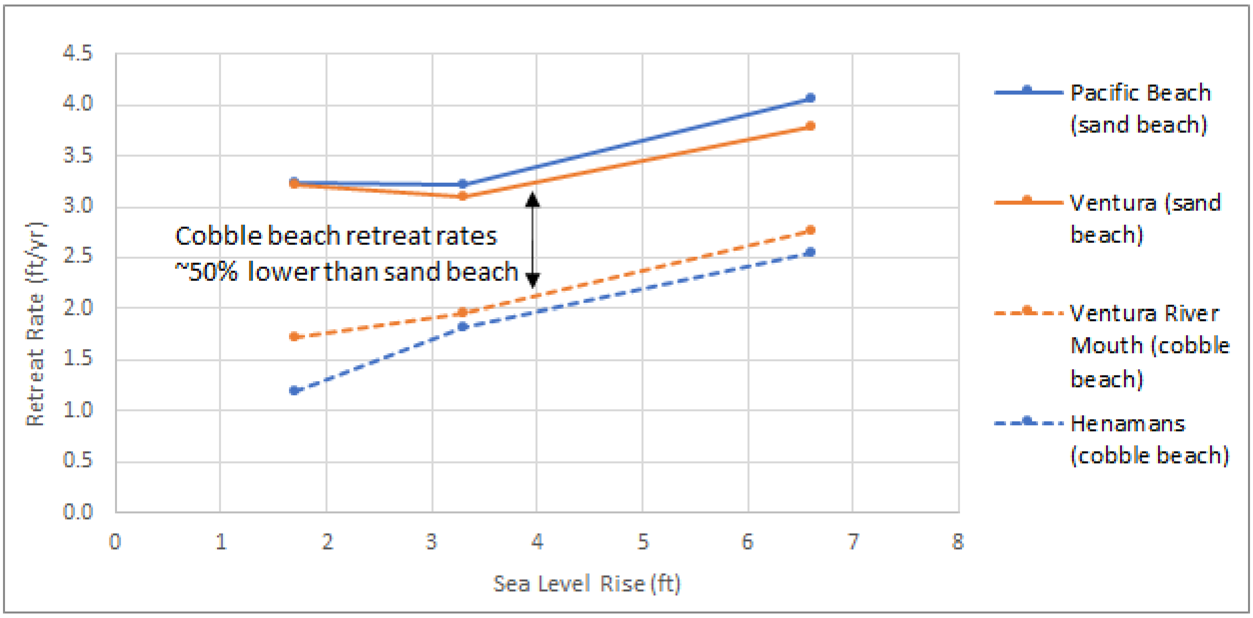

Figure 8-2 Comparison of Shoreline Erosion Rates for Henamans and Pacific Beach

The projected shoreline erosion rates for the Study Area were found to range from 2.8 feet/yr to 3.4 feet/year for the upper (assumed sand dominant shoreline) scenario and 1.5 feet/year to 1.8 feet/yr for the lower (assumed cobble dominant shoreline) scenario (Table 8-1). The cobble erosion reduction factor was assumed to be approximately 50% of the sand dominant shoreline based on analysis of the reference sites listed above. In other words, cobble dominant beaches were assumed to retreat at a rate 50% lower than sandy beaches.

Table 8-1. Projected Shoreline Erosion Rates for the Study Area

Time Horizon	Sea Level Rise (feet)	Shoreline Erosion Rate (feet/yr)		Shoreline Erosion Distance (feet)	
		Cobble Beach	Sand Beach	Cobble Beach	Sand Beach
2050	1.7	1.5	2.8	44	84
2070	3.3	1.3	2.5	66	127
2100	6.6	1.8	3.4	141	271

8.3 Shoreline Response to Sea Level Rise

To evaluate the geomorphic response and apply the determined shoreline retreat rates to the Study Area alternatives, conceptual profiles for each option were developed. This section discusses the potential range of shoreline responses specific to each alternative.

8.3.1 Phased Adaptation

The phased retreat alternative proposes to partially repurpose the existing Southbound Carlsbad Boulevard, thus the geomorphic response of the road prism and associated components are being evaluated here. As the site has already experienced spontaneous erosion in 2015-2016, past events provide insight to future conditions with SLR. In addition, the geology of the road prism as it compares to the adjacent cliffs will help understand the potential response of this feature.

From a geologic perspective, the road prism has been documented by SIO as loose fill material (Appendix A). It is understood that this material has a high vulnerability to erosion and RSP is required to maintain a stable roadway. In addition, the dry sand beach profile is minimal, and the current high-water shoreline is typically at the toe of the RSP. With SLR, it can be expected that the dry sand beach widths will be lost entirely. In addition, wave action and undercutting at the road prism may be accelerated with SLR should the RSP lose its integrity.

The elevation of the roadway at the Las Encinas Creek bridge is approximately 17’ and significant wave overtopping was observed at this location during the 2015-2016 El Niño. Under the “Phased Adaptation” alternative, wave runup from extreme wave events in combination with SLR will result in more frequent, episodic flooding of the roadway and damage to the existing RSP. The maintenance and repair of the RSP will be a determining factor in the long-term shoreline response under this alternative.

With little or no maintenance, the RSP will settle lower on the profile becoming less effective against erosion from storm events and SLR. Eventually, the road prism will be subject to episodic erosion behind the failed RSP, likely impacting the recreational opportunities available in this area. With increased maintenance and repair activities, the RSP could continue to provide protection of the abandoned roadway although this strategy would involve significant cost and regulatory challenges.

8.3.2 Retreat Now

The shoreline retreat rates were applied to the ”Retreat Now” concept, which proposes to use a cobble-sand combination to create a dune strand feature in place of the existing Southbound Carlsbad Boulevard roadway. The overall resiliency to erosion of this feature will depend on the ratio of sand to cobble. A sand-cobble dune was constructed in south Imperial Beach, fronting the Tijuana Slough National Wildlife Estuary (Figure 8-3). This Project alternative proposes to use similar techniques to protect the restored habitat area of Las Encinas Creek.

Figure 8-3. Cobble-Dominant Dune fronting the Tijuana Slough National Wildlife Refuge in Imperial Beach (source: govisitsandiego.com)

To account for the uncertainties associated with cobble shorelines, erosion rates were applied to a conceptual profile for both the sand and cobble scenarios, providing a potential range of outcomes. The geomorphic response associated with these erosion rates follows the assumptions of the Bruun rule, meaning the profile shape is preserved, despite a landward and upward migration of the dune with SLR.

The results suggest that with 6.6’ of SLR under the sand-dominant scenario, the shoreline will be as far landward as the existing Northbound Carlsbad Boulevard. However, with 6.6’ of SLR under the cobble-dominant (lower) scenario, the shoreline may only erode to about half of that distance (Figure 8-4).

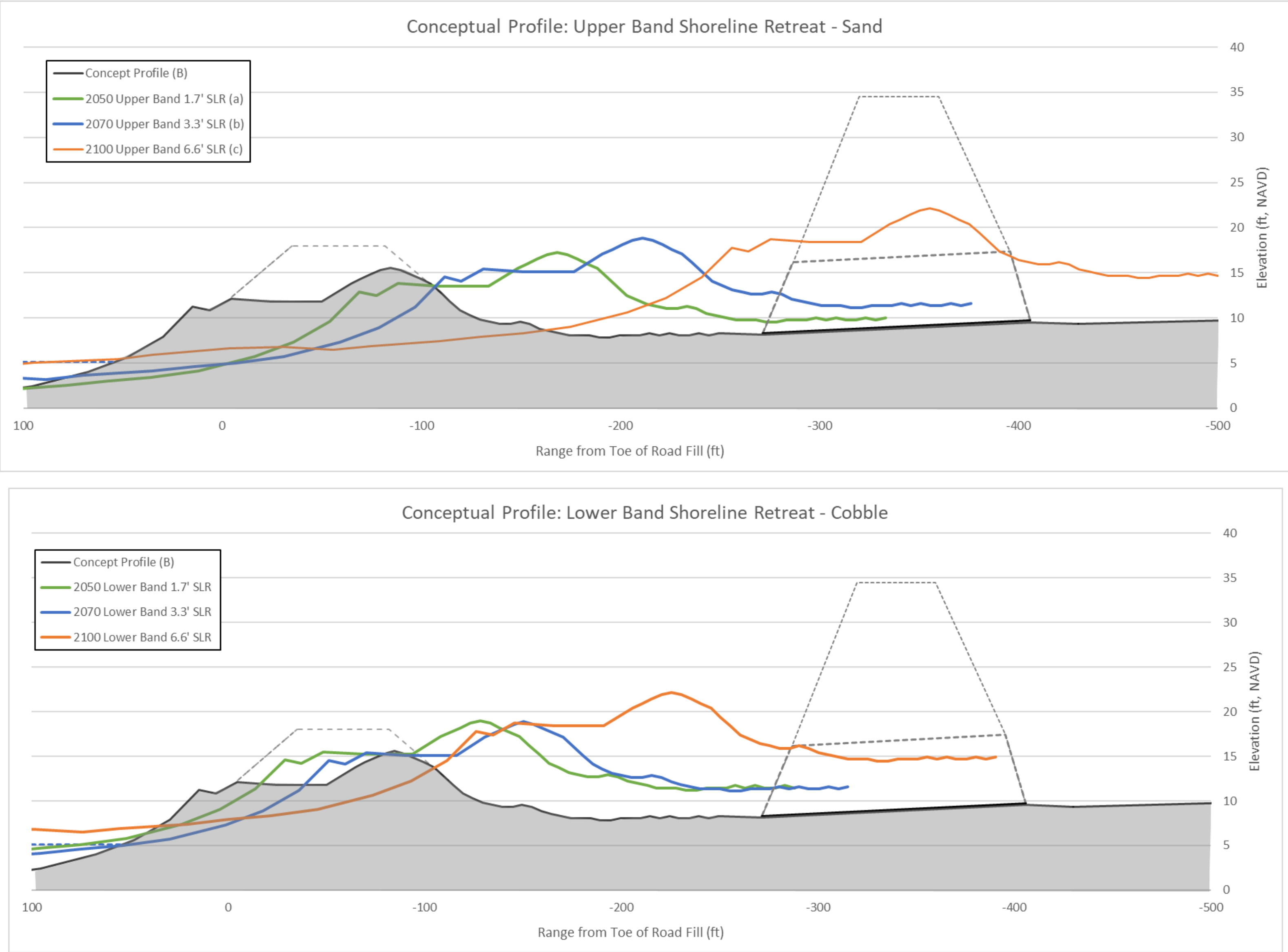

Figure 8-4. Shoreline Evolution Projections for Assumed Sand Dune (top) and Cobble/Sand Dune (bottom)

8.3.2.1 Beach Formation

Since the shoreline erosion rates at the Study Area are higher than the adjacent cliffs there is potential for a sand/cobble beach area to exist over the long-term. Figure 8-5 depicts the difference in erosion rates between the shoreline and the adjacent cliffs which would favor beach formation within the Study Area. As the shoreline retreats to a position further landward of the adjacent high ground, the cliff formations will reduce the longshore transport of sediment. This would have a stabilizing effect on the sand/cobble beach in the vicinity of Las Encinas Creek, providing multiple public and ecological benefits in a region that may have very limited beach area in the future.

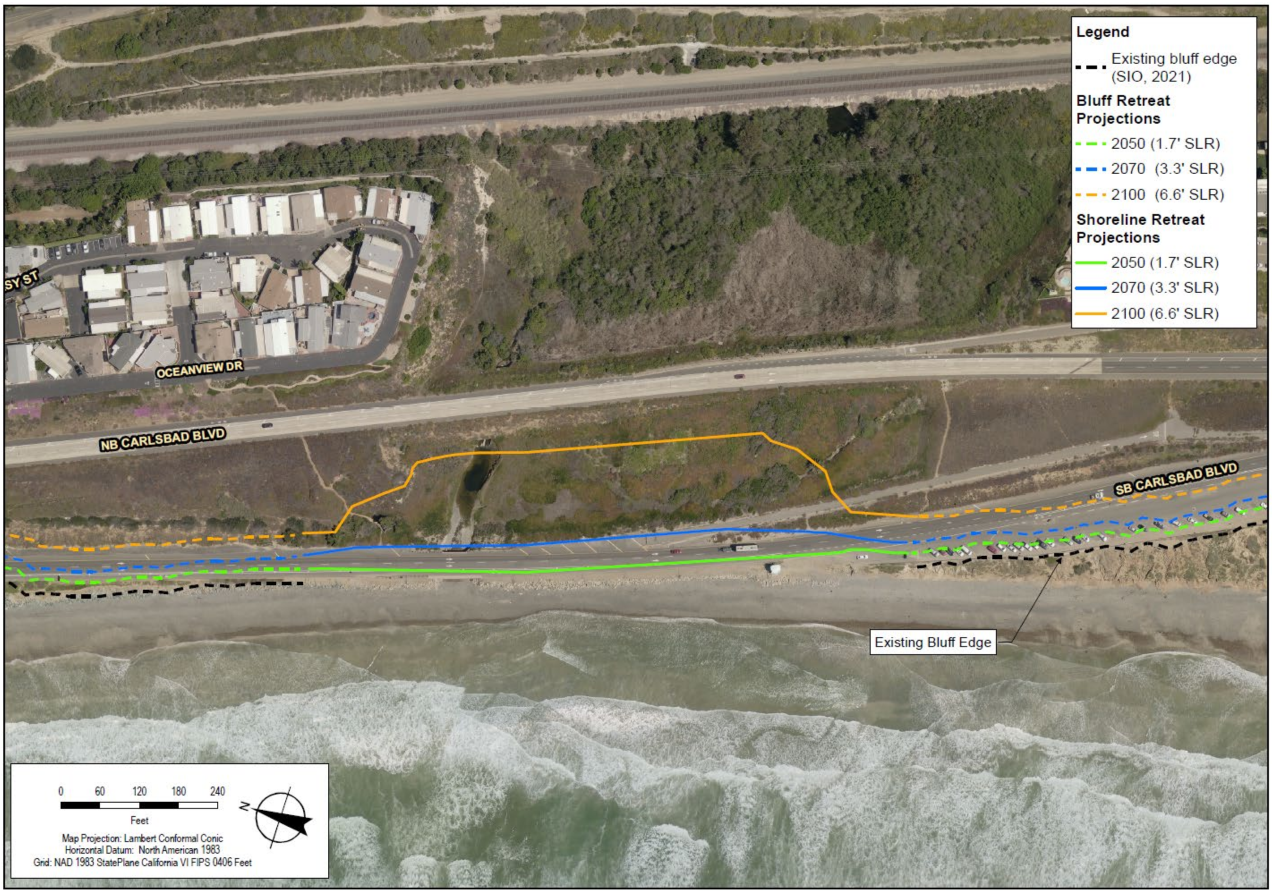

Figure 8-5. Shoreline vs Cliff Erosion Projection through Year 2100

9. Habitat Migration Projections

Using the vegetation and topographic mapping, conceptual grading plans were developed and analyzed to predict post-project habitats for both alternatives and for comparison to existing conditions or the “No Project” alternative. The elevation zones mapped for estuarine dependent habitat types, including pickleweed marsh (tidal wetland) and open water, between South- and Northbound Carlsbad Boulevard were used as analog elevation ranges for developing the conceptual grading plans and corresponding habitat types for each alternative. With SLR and lack of fine sediment accretion, the estuarine dependent habitat types are expected to migrate upslope and those in lower elevations “drowning” and becoming open water. The proposed removal of the Northbound Carlsbad Boulevard culvert and replacement with a bridge will promote habitat connectively through the Las Encinas Creek Estuary-Stream ecotone; accommodating vegetation migration with SLR. The SLR projections assessed included 1.7 feet (near-term), 3.3 feet (mid-century) and 6.6 feet (late-century).

9.1 Existing Conditions or “No Project”

The habitat projections for existing conditions or the “No Project” alternative are shown in Figure 9-1 and Figure 9-2. The assessment assumes the RSP and Southbound Carlsbad Boulevard would remain in place into the future and necessary repairs to maintain the RSP and road prism would occur. Key findings of the projected habitat changes for the No Project option are as follows:

- The small beach area that exists will be lost with 1.7’ of SLR.
- Tidal wetland area has the potential to expand where gradual topography allows but would compete with existing non-native vegetation, such as iceplant, that would require removal to accommodate colonization of native species.
- Arroyo willow and coastal scrub habitats will decrease from expansion of tidal wetlands and open water.
- Non-native vegetation would persist unless treated.

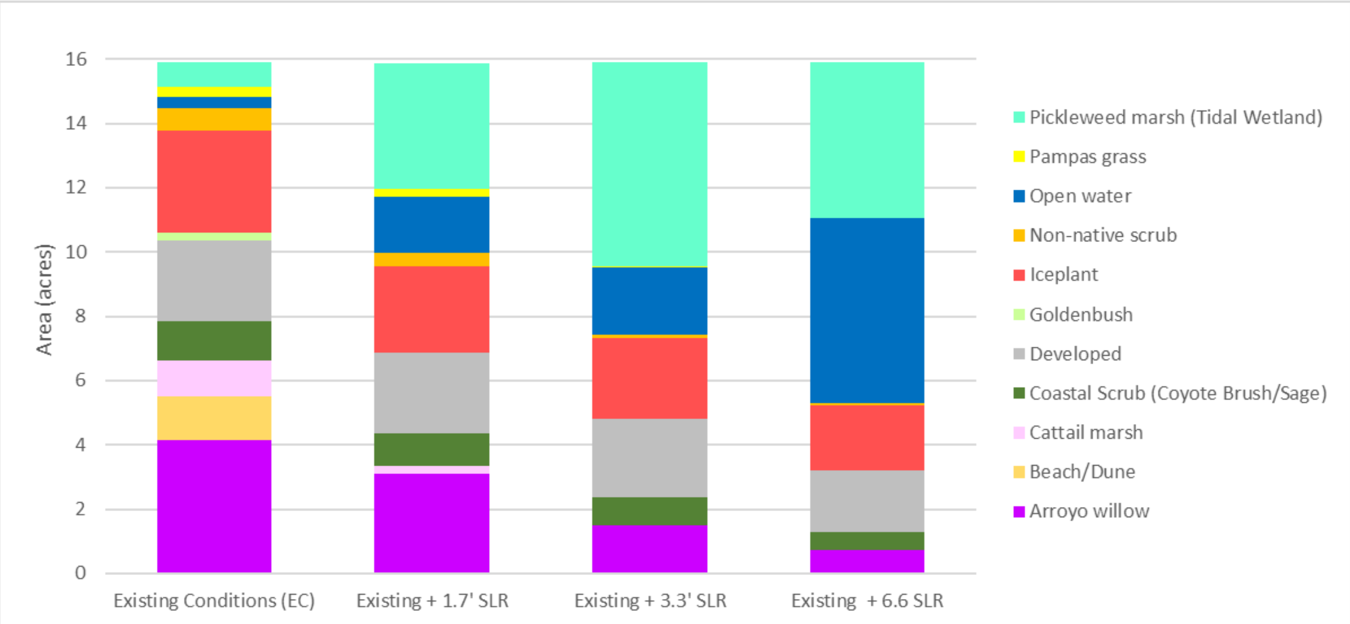

Figure 9-1. Habitat projections with projected SLR under Existing Conditions

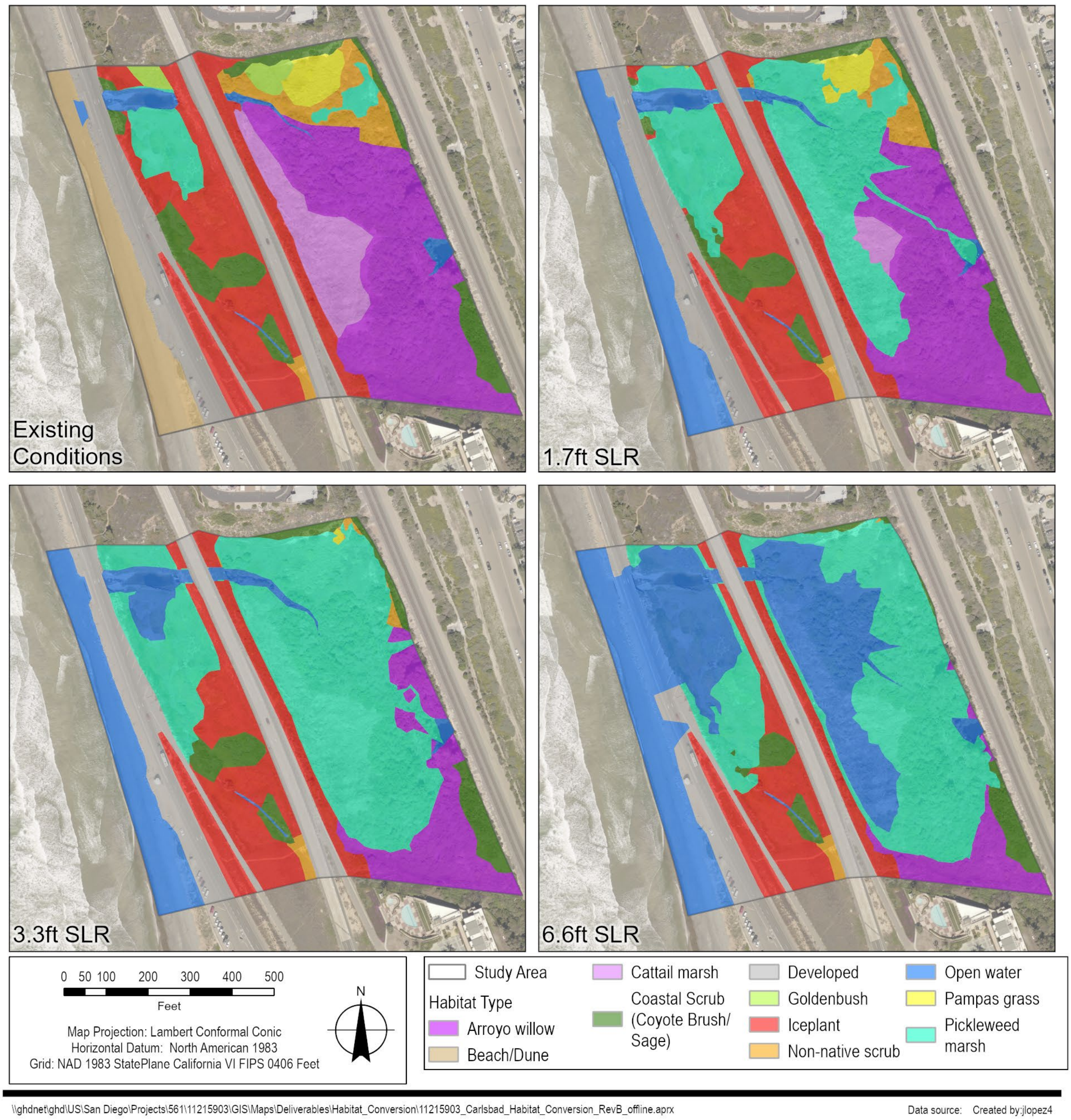

Figure 9-2. Habitat Projections for Existing Conditions

9.2 Phased Adaptation

The Phased Adaptation alternative removes a portion of the Northbound Carlsbad Boulevard fill prism within Las Encinas Creek through the construction of a free spanning bridge to accommodate an expanded salt marsh and dendritic tidal channel network as well as enhancing the Las Encinas Creek stream-estuary ecotone. This alternative would also replace non-native vegetation with native species and minimize impacts to existing native vegetation, such as Arroyo willow and cattail. This option does not remove the southbound roadway prism and instead repurposes this area with public access and recreation amenities. Similar to the existing condition assessment, this alternative assumes the RSP and Southbound Carlsbad Boulevard would remain in place into the future and necessary repairs to maintain the RSP and road prism would occur.

The habitat projections for the "Phased Adaptation" alternative are shown in Figure 9-3 and Figure 9-4. The habitat response under this alternative has commonalities to that of the existing conditions. With this alternative, the main takeaways of the projected habitat changes are as follows:

- The narrow beach area that exists will be lost with 1.7 feet of SLR.
- An initial increase of tidal wetlands are created with the restoration design but over time with SLR the total area will track similar to existing conditions. The projected tidal wetland habitat assumes removal of non-native vegetation to accommodate colonization of native species.
- Decrease in iceplant and other non-natives by removing and preplacing initially with native transition zone habitat such as coastal scrub which would persist through 6.6 feet of SLR.
- Arroyo willow and coastal scrub habitats will decrease from expansion of tidal wetlands and open water; and over time with SLR the total area will track similar to existing conditions.

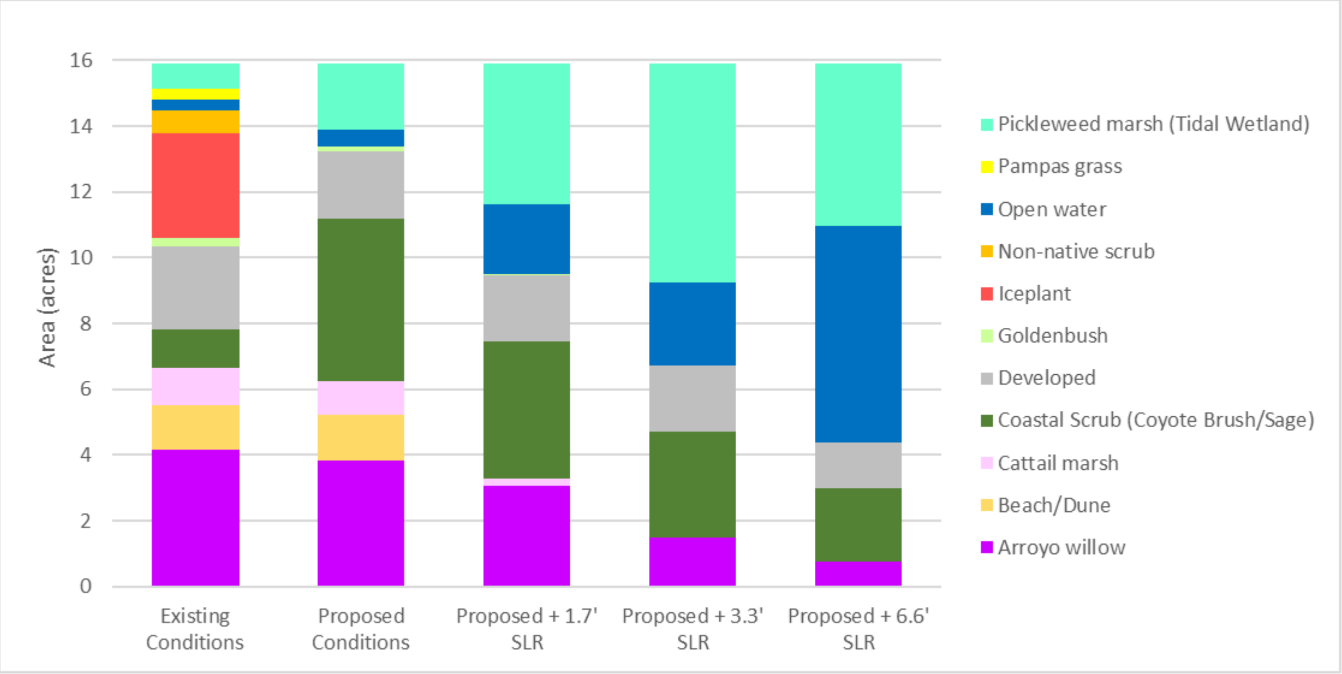

Figure 9-3. Habitat projections for projected SLR under the Phased Adaptation alternative

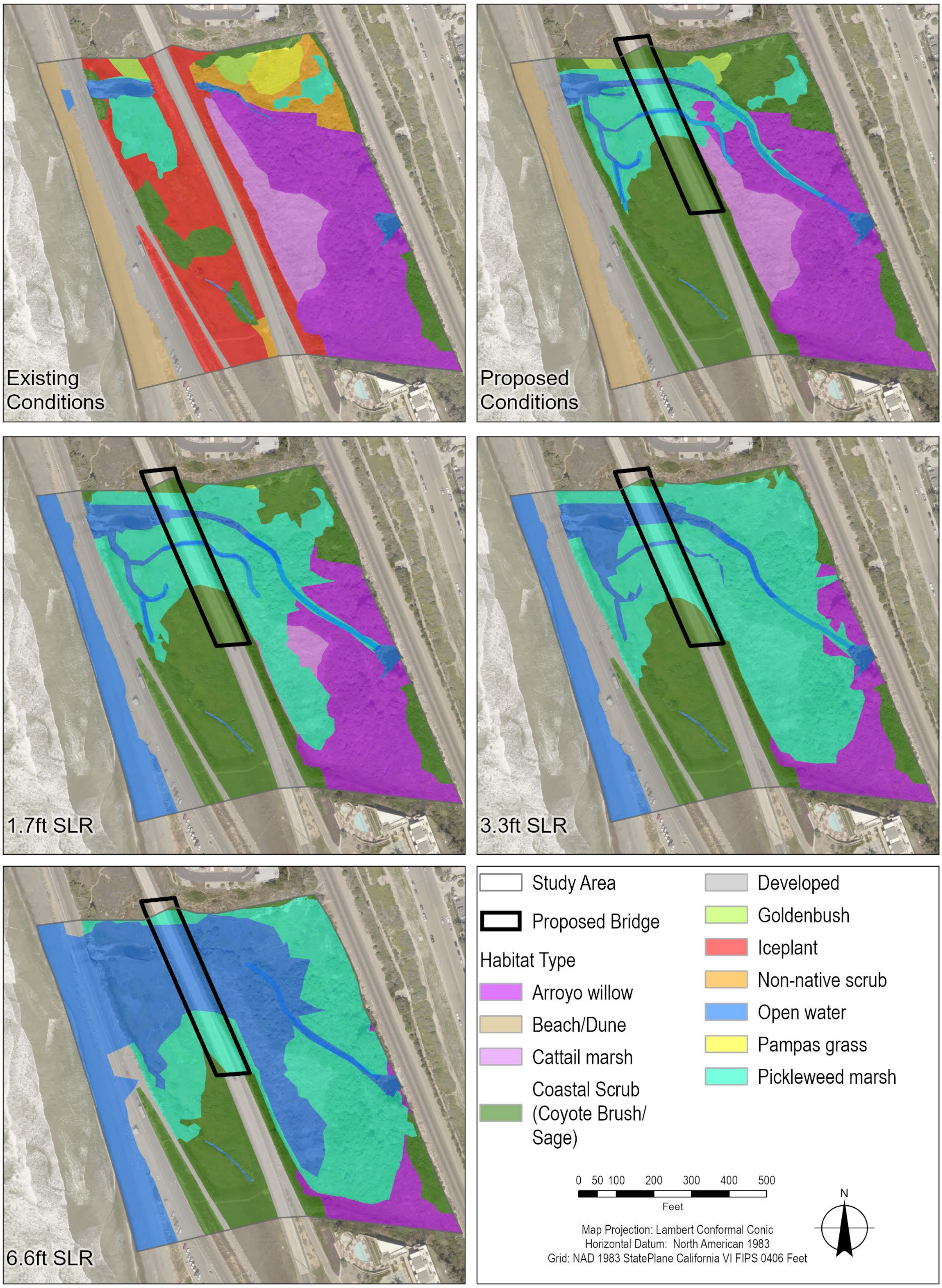

Figure 9-4. Habitat Projections under "Phased Adaptation" Alternative

9.3 Retreat Now

Similar to the Phased Adaptation alternative, the Retreat Now alternative removes a portion of the Northbound Carlsbad Boulevard fill prism within Las Encinas Creek through the construction of a free spanning bridge to accommodate an expanded salt marsh, enhances the Las Encinas Creek stream-estuary ecotone but also removes Southbound Carlsbad Boulevard fill prism and creates a naturalized dune shoreline. Given the potential increase in landward migration of sand at the mouth, this alternative includes a simpler dendritic tidal channel network relative to Phased Adaptation alternative. This alternative would also replace non-native vegetation with native species and minimize impacts to existing native vegetation, such as Arroyo willow and cattail. The habitat projections for the Retreat Now alternative are shown in Figure 9-5 and Figure 9-6. The main findings from the projected habitat changes for this option are as follows:

- Provides a sustained beach and dune with SLR.
- Reduces the developed area by about half through the removal of the southbound roadway and RSP.
- An initial increase of tidal wetlands are created as a result of the restoration design; however, over time with SLR the total area will evolve similar to existing conditions and Phased Adaptation alternative. The projected tidal wetland habitat assumes removal of non-native vegetation to accommodate colonization of native species.
- An initial increase of open water area but over time with SLR the total area will evolve similar to the “No Project” and Phased Adaptation alternatives.
- Decrease in iceplant and other non-natives by removing and preplacing initially with native transition zone habitat such as coastal scrub which would persist through 6.6 feet of SLR.
- Arroyo willow and coastal scrub habitats will decrease from expansion of tidal wetlands and open water and over time with SLR the total area will evolve similar to the “No Project” and the Phased Adaptation alternative.

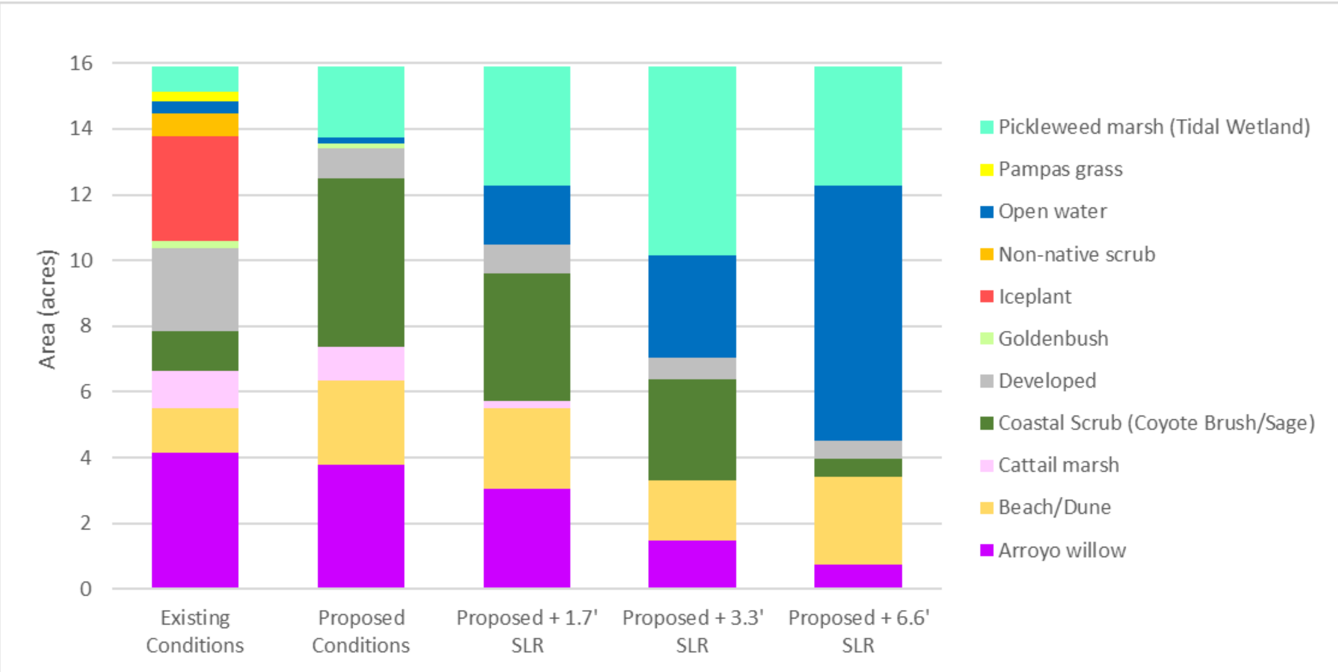

Figure 9-5. Habitat projections with projected SLR under Retreat Now alternative

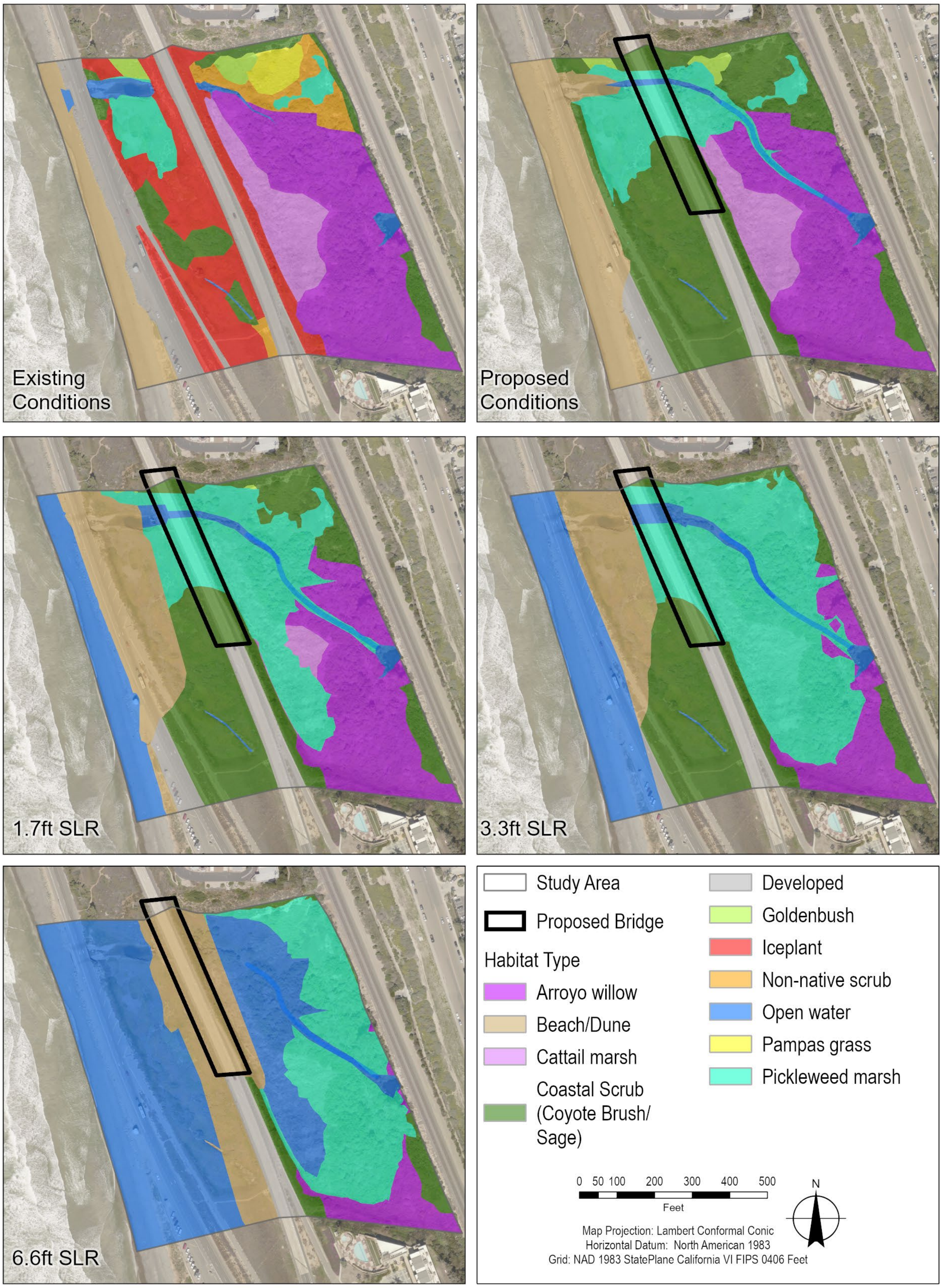

Figure 9-6. Habitat Projections under Retreat Now alternative

10. Comparison of Implementation Options

The habitat migration projections modelled for existing conditions and Phased Adaptation option assumed the Southbound Carlsbad Boulevard prism and existing RSP would remain in place into the future. However, wave runup from extreme wave events in combination with SLR will result in more frequent, episodic flooding of the roadway and damage to the existing RSP. As previously described, with little or no maintenance the RSP will settle lower on the profile becoming less effective against erosion from storm events and SLR. While not directly analyzed in this Study, if continued maintenance of the RSP and road prism is not completed following storm events, the road prism erosion behind the failed RSP can be expected between 1.7 feet and 3.3 feet of SLR.

A comparison of the habitat projections for each of the implementation options is shown in Figure 10-1 relative to the existing conditions. The key findings from these assessments are as follows:

- **Persistence of a sandy beach.** With 1.7 feet of SLR the existing narrow beach within the Study Area will be lost if Southbound Carlsbad Boulevard remains under existing conditions and the Phased Adaptation option. The Retreat Now option increases the beach area now and sustains this beach through 6.6 feet of SLR as the beach and created dune are allowed move landward.

- **Restoration of developed areas**. The Retreat Now option would remove about half of the developed area that exists within the study area. These developed areas would be restored to coastal strand habitat.

- **Tidal wetland migration.** Under existing conditions and with both implementation options, the gradual topographic relief east of the Southbound Carlsbad Boulevard can accommodate tidal wetland habitat migration with future SLR. The habitat projections for both implementation options assume removal of non-native vegetation and replacement with tidal wetlands and coastal scrub, which provides immediate habitat benefit and accommodates the migration of the tidal wetlands long-term. Restoration of this area can maximize tidal wetland creation now and can increase resiliency through 6.6 feet of SLR for both implementation options. Removal of the non-native vegetation to accommodate native plantings will be an important restoration goal to achieve desired vegetation communities in both the short and long-term.

- **Transition of riparian habitat.** The habitat projections show an overall decline of Arroyo willow riparian habitat with SLR for existing conditions and both implementation options. The loss could be reduced with establishment of additional riparian habitat in suitable areas around the periphery of the Study Area that would ideally be contiguous with similar riparian habitat types.

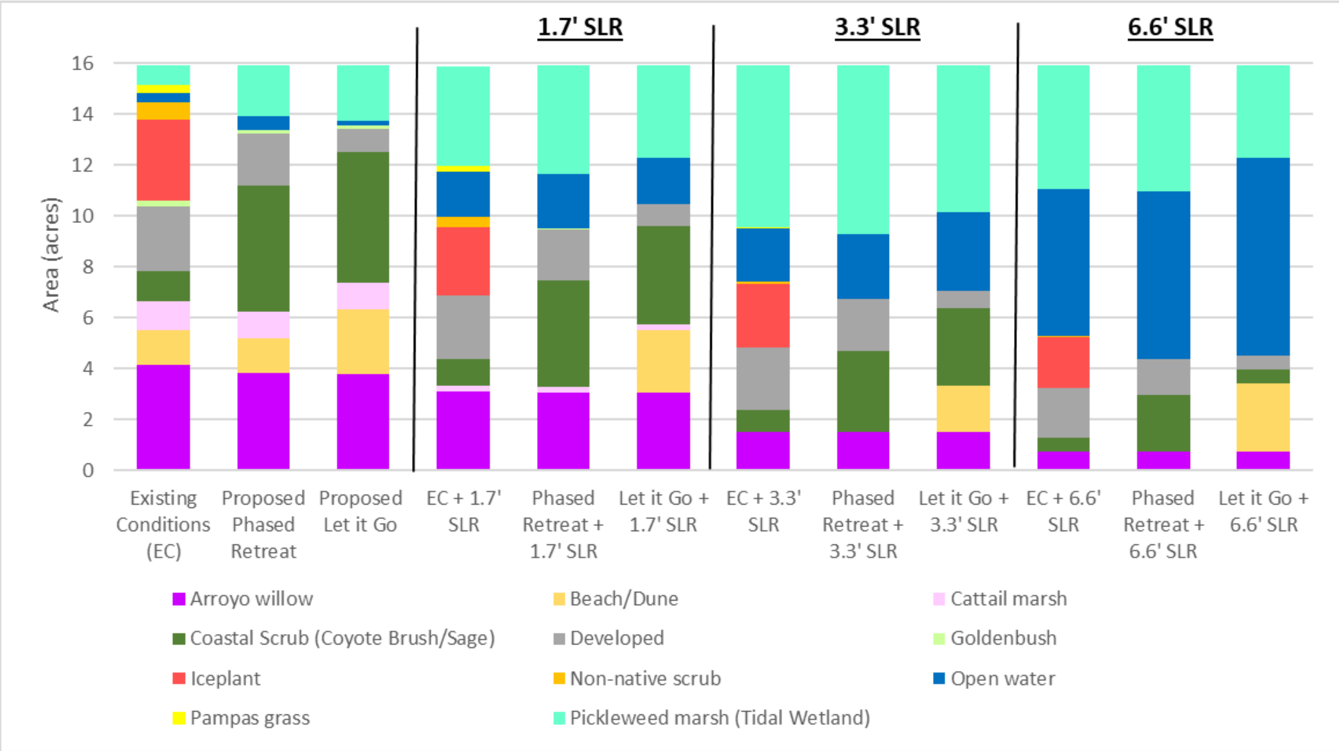

Figure 10-1. Comparison of Habitat Projections with Sea Level Rise for the Implementation Options

11. Conclusions

A key objective of this study was to develop a baseline understanding of the Las Encinas Creek estuary hydrology and biology. This combined with an understanding of the geomorphic context and historic development patterns provides an understanding of how the natural resources in the Study Area may respond to the proposed Project activities with consideration for SLR. Topographic mapping and biological field assessments were performed to define elevations associated with habitat breaks and to better understand the hydrology associated with each habitat zone. Water level and water quality (salinity and temperature) were actively monitored within the Study Area to characterize the seasonal variability influenced by tidal and surface water inflows to the system. Key findings of the baseline assessment are as follows:

– **Beach conditions:** The general beach width trend within the Study Area is erosional at a rate of about 2.5 feet/year. This erosional rate is despite regional beach nourishment efforts that occurred in the City in 2001 and 2012. SLR projections are expected to accelerate this trend of erosion resulting in potentially significant shoreline retreat over the long-term.

– **Encinas Creek Hydrology:**

- Site investigations and monitoring data indicate two perched estuarine pools exist, one located between the Southbound and Northbound Carlsbad Boulevard roadways and the other east of Northbound Carlsbad Boulevard. The typical water levels were approximately 8 feet (NAVD88) in the west pool and 9.7 feet (NAVD88) in the east pool. Both pools were controlled by their respective culvert sill elevations.
- Monitoring results indicate hydrology was strongly influenced by groundwater seepage, with periodic breaching events (high tides and large waves) temporarily increasing water levels throughout the estuary. More frequent inlet breaching allows for marsh inundation and sediment accretion within the estuary, a process which aids the marshes transition with SLR.
- Tidal marsh elevations within the intermittently breached estuary are commensurate with other southern California intermittently breached estuaries which are higher than that of open estuaries exposed to the diurnal tidal prism.

– **Habitat Distributions:** Habitat distributions are influenced by the complex hydrology onsite as well as elevation within the study area. Key findings were as follows:

- Pickleweed and other halophytic vegetation were found at the lower end of the site's elevation range on both sides of Northbound Carlsbad Boulevard.
- Salt to brackish vegetation types were observed at elevations beyond regular tidal influence, including a high basin that seasonally floods east of Northbound Carlsbad Boulevard during large wave events.
- Cattail marsh and Arroyo willow are present across the northeast portion of the site around upper Las Encinas Creek.
- Iceplant was the predominant non-native species observed throughout the estuary at a range of elevations from approximately 9 to 33 feet (NAVD) invading both brackish wetland and upland habitats.

A baseline understanding of the Las Encinas Creek estuary guided the development of two restoration concepts that consider how the shoreline, tidal marsh habitat, and creek hydrology would respond to SLR. This study analyzed two implementation alternatives, referred to commonly as "Phased Adaptation" and "Retreat Now." The Phased Adaptation alternative proposes to repurpose the Southbound Carlsbad Boulevard corridor to provide community benefits until coastal hazards overwhelm the area at which time actions will be taken to remove the roadway prism. The Retreat Now alternative proposes to remove Southbound Carlsbad Boulevard and construct a naturalized cobble-dune strand that will allow for landward migration while also offering some protection to the proposed restored habitat within Las Encinas Creek. This study presents a comparison of these two implementation options to aide in the decision making of which restoration option to proceed with for the Project.

Shoreline response with SLR is a distinguishing feature among these alternatives. A summary of the findings of this analysis is below:

- **Phased Adaptation:** Significant wave overtopping has been observed in the Study Area during the 2015-2016 El Niño. Under the Phased Adaptation alternative, wave runup from extreme wave events in combination with SLR will result in more frequent, episodic flooding of the repurposed roadway and damage to the existing RSP. The maintenance and repair of the RSP will be a determining factor in the long-term shoreline response under this alternative. With little or no maintenance, the RSP will settle lower on the beach profile becoming less effective against erosion and flooding from storm events and SLR. Eventually, the road prism will be subject to episodic erosion behind the failed RSP, likely impacting the public access and recreational opportunities available in this area. With increased maintenance and repair activities, the RSP could continue to provide protection of the abandoned roadway although this strategy would involve significant cost and potential regulatory challenges.

- **Retreat Now:** The long-term shoreline retreat rates were applied to the Retreat Now alternative, which proposes to use a cobble-sand combination to create a dune strand feature in place of the existing Southbound Carlsbad Boulevard. The analysis found that a cobble-dominant berm (similar to the one fronting the Tijuana Slough National Wildlife Refuge in Imperial Beach) would be 50% more resilient to erosion with SLR than a similar feature comprised of sand. However, it should be noted that the overall resiliency to erosion of this dune feature will depend on the desired ratio of sand to cobble.

Another key question that this study aimed to address was how the proposed restored habitats within Las Encinas Creek would migrate with SLR within each of the implementation options being considered. Key findings from this analysis are as follows:

- **Persistence of a sandy beach.** With 1.7 feet of SLR, the existing narrow beach within the Study Area will be lost if Southbound Carlsbad Boulevard remains under the "No Project" and the Phased Adaptation alternatives. The Retreat Now option increases the beach area now and sustains this beach through 6.6 feet of SLR as the beach and created dune are allowed move landward.
- **Restoration of developed areas**. The Retreat Now option would remove about half of the developed area that exists within the study area. These developed areas would be restored to coastal strand habitat.
- **Tidal wetland migration.** Under the "No Project" and both Project alternatives, the gradual topographic relief east of the Southbound Carlsbad Boulevard can accommodate tidal wetland habitat migration with future SLR. The habitat projections for both project alternatives assume removal of non-native vegetation and replacement with tidal wetlands and coastal scrub, which provides immediate habitat benefit and accommodates the migration of the tidal wetlands long-term. Restoration of this area can maximize tidal wetland creation now and can increase resiliency through 6.6 feet of SLR for both implementation options. Removal of the non-native vegetation to accommodate native plantings will be an important restoration goal to achieve desired vegetation communities in short and long-term.
- **Transition of riparian habitat.** The habitat projections show an overall decline of Arroyo willow riparian habitat with SLR for "No Project" and both project alternatives. The loss could be reduced with establishment of additional riparian habitat in suitable areas around the periphery of the Study Area that would ideally be contiguous with similar riparian habitat types.

In summary, there are significant opportunities for habitat restoration and enhancement with either alternative including space for various habitats to migrate with SLR. The primary difference between the alternatives is the timing at which the Southbound Carlsbad Boulevard would be converted from a public access feature to a natural beach and dune area.

It is important to note that mobility improvements to the corridor for passive and active recreation is a key element of the South Carlsbad Climate Adaptation Project. The configuration of these public access and recreational improvements would be different under each alternative being considered in this study and have not been evaluated in this study. These elements will be evaluated under a separate study as a part of the overall Project.

Next steps include further progressing the design of the Las Encinas Creek estuary restoration component of the Project once a decision is made between the Retreat Now and Phased Adaptation options. Should the Phased Adaptation option be selected, a future study may be needed to define appropriate triggers for future management actions (e.g. RSP improvements and eventual retreat). Coordination with the resource agencies, specifically the CCC, would be beneficial to discuss the triggers and potential management actions associated with this option. The Las Encinas Creek restoration design option selected would ultimately become part of the roadway design package at the conclusion of the South Carlsbad Climate Adaptation Project phase.

12. References

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Appendices

Appendix A

Cliff Erosion Assessment Report

South Carlsbad Boulevard Cliff Erosion Assessment Report

Submitted March 10, 2022

Summary

This study conducted coastal cliff retreat analysis to help inform the landward relocation of a segment of South Carlsbad Boulevard. The analysis consisted of a literature review, evaluation of cliff retreat from 1998 to 2020, and modeled 21st century future cliff positions Previous high resolution studies suggest historical mean cliff retreat rates range from 0.003-0.11 m/yr with maximum localized rates up to 0.66 m/yr. A new LiDAR survey was conducted in 2020 and used to measure cliff face retreat from 1998-2020 which ranged from about 0 to 0.47 m/yr with a mean of 0.039 m/yr. One section of cliff top retreated about 10 m between 2017 and 2020. Relatively high cliff steepening (increasing cliff top hazard) occurred from 1998-2020 between Terramar and Encinas Creek, compared to the South Carlsbad State Beach campground area.

Four existing predictive forecast cliff models were run for a sub region of the study near the Solamar Dr. intersection using the OPC (2018) 0.5% probability sea level rise scenario, USGS wave projections, and the 1998-2020 cliff retreat rates. In the forecast area, future cliff retreat of 10 m impacts the proposed project at the Solamar and Carlsbad Boulevard roundabout and a recreational trail. 10 m of retreat is lower than the 25th percentile for all four model outcomes. Present infrastructure in northern end of the forecast area becomes threatened under retreat scenarios with about 20 m of retreat, which is approximately the median retreat predicted from the combined model outcomes.

1.0 Introduction

In May 2020, the City of Carlsbad (City) was awarded funding by the California State Coastal Conservancy Climate Ready Program for the South Carlsbad Boulevard Climate Adaptation Project (Project) to develop managed retreat and long-term sea level rise adaptation options for a vulnerable stretch of coastal roadway. As a component of this project, the Scripps Institution of Oceanography Center for Climate Change Impacts and Adaptation was funded to conduct a detailed cliff retreat analysis to inform the landward relocation of a segment of South Carlsbad Boulevard. The following represents the results from this research and analysis endeavor.

2.0 Study Area & Forecast Area

The overall study area extends 4.6 kilometers (km) along the coast of Carlsbad, California, from the mouth of Batiquitos Lagoon at the south end of the study area to Terramar Point/Cerezo Bluffs (approximately Cerezo Drive) at the north end (Figure 1). The study area includes South Carlsbad State Campground and Las Encinas Creek area. Riprap currently exists near Las Encinas Creek outlet and at several beach access stairways within the study area (Figure 2). Schmidt hammer values, which provide an indication of rock hardness and uniaxial compressive strength (Katz et al., 2000), were taken at the cliff base (Young, 2018) and range from 0-16. Future cliff retreat rates were estimated for a portion of the study area (Forecast Area in Figure 1) specified by GHD (the consultant for this Project) and the City.

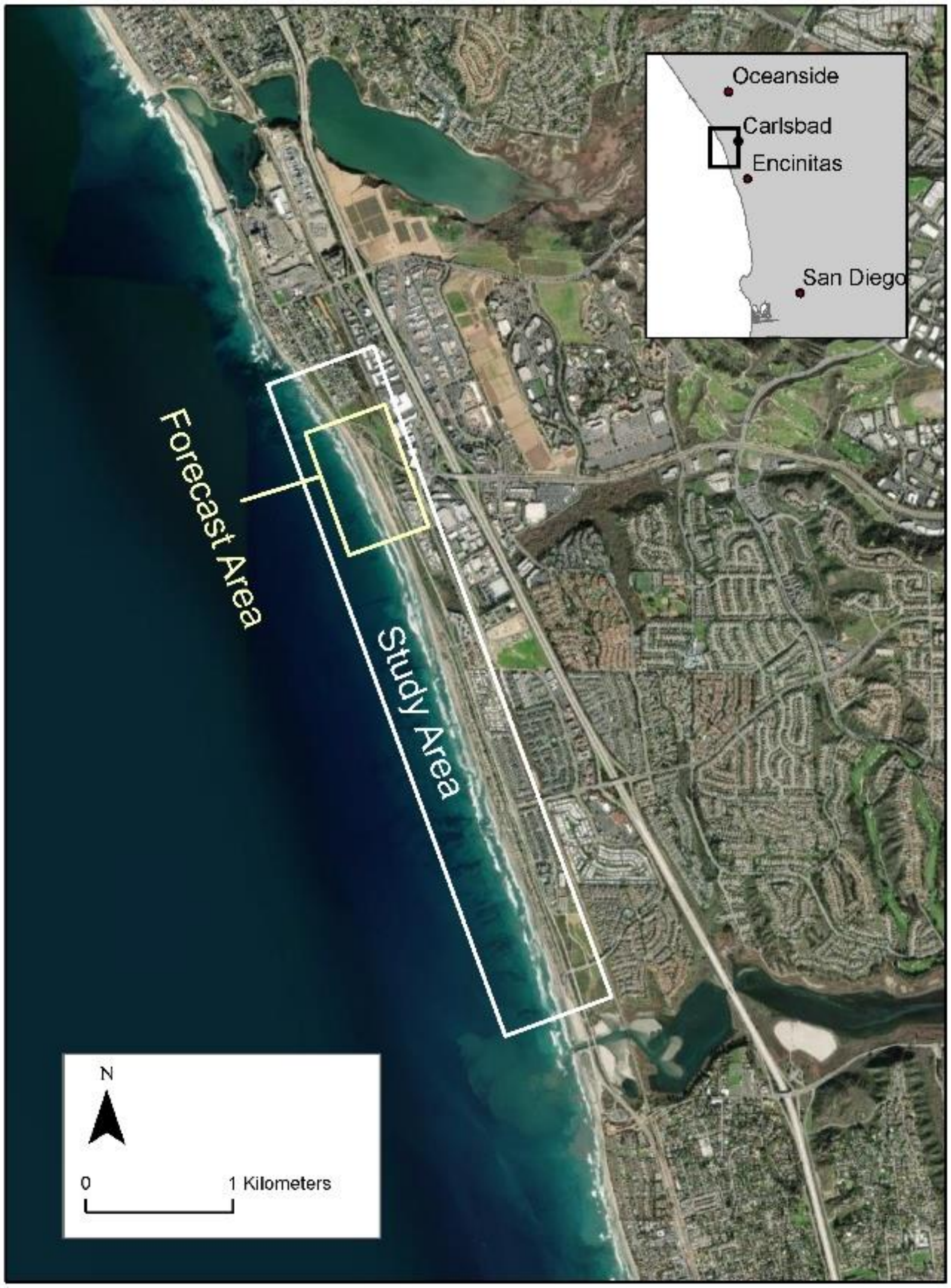


Figure 1. Study area map extending from approximately Batiquitos Lagoon to Terramar Point, and forecast area of estimated cliff retreat projections.

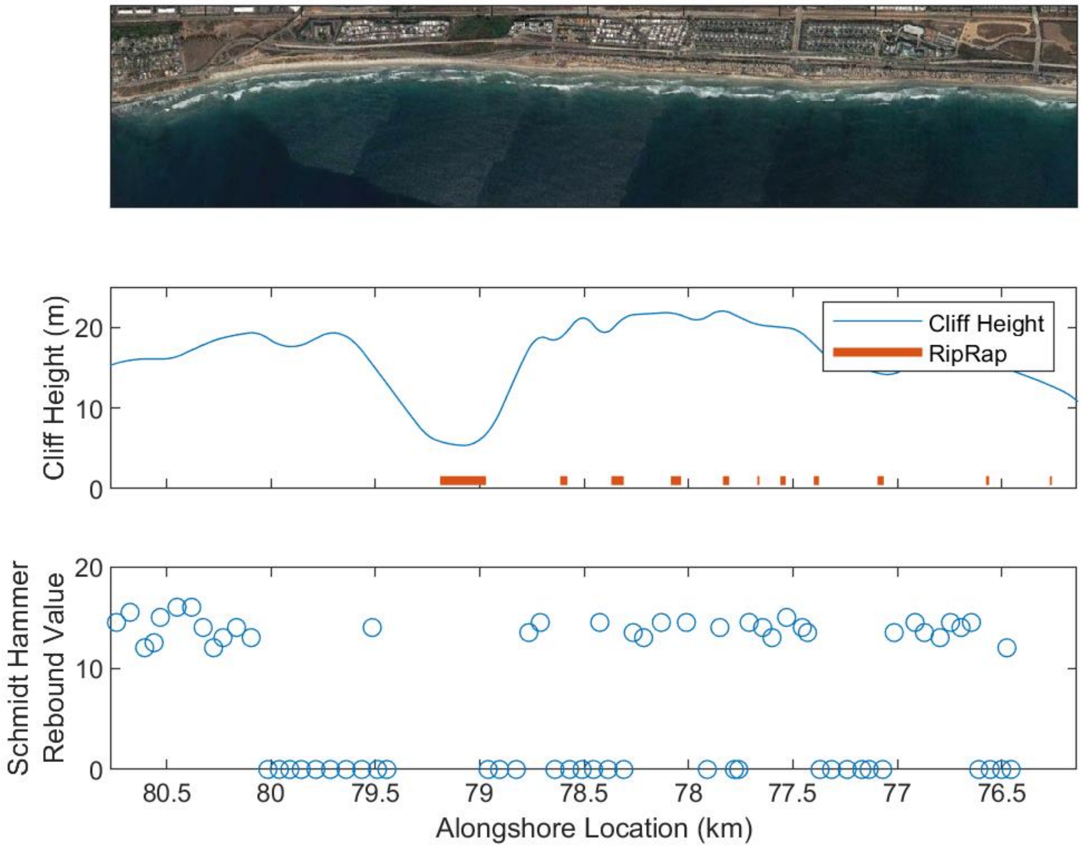
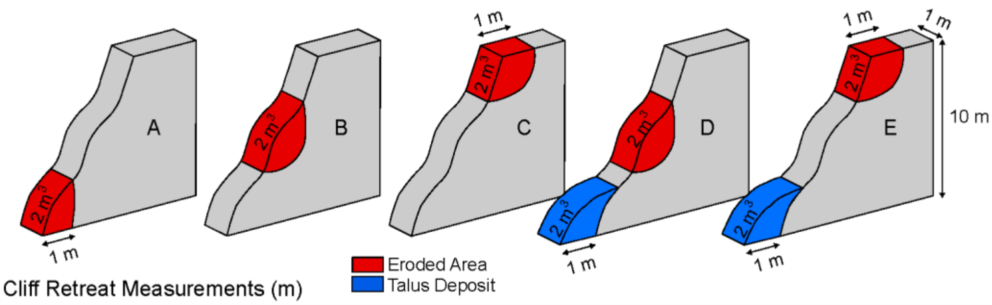


Figure 2. (Top) Aerial photograph of study area and (center) corresponding alongshore cliff height and riprap locations and (bottom) Schmidt hammer rebound values of rock hardness from Young (2018).

3.0 Previous Studies

Several studies have conducted cliff retreat analyses in the study area. Benumof and Griggs (1999) evaluated a 750 m segment in the South Carlsbad Campground using aerial photographs and estimated cliff top (Figure 3) retreat rates of 0.43 meters per year (m/yr) (standard deviation 0.08 m/yr) from 1956 to 1994. The collaborative study of Moore et al. (1999) reported cliff top retreat rates ranging from 0.03-0.58 m/yr for cliffs along South Carlsbad State Beach during the same time period. Using airborne light detection and ranging (LiDAR) data, Young and Ashford (2006) estimated cliff retreat rates averaged over the cliff face, from Batiquitos Lagoon to Oak Avenue, at 0.03-0.04 m/yr between 1998 and 2004.



Cliff Retreat Measurements (m)

	A	B	C	D	E
Top =	0.0	0.0	1.0	0.0	1.0
Face (Erosion)=	0.2	0.2	0.2	0.2	0.2
Face (Deposition) =	0.0	0.0	0.0	-0.2	-0.2
Face (Net) =	0.2	0.2	0.2	0.0	0.0
Base =	1.0	0.0	0.0	-1.0	-1.0

Figure 3. Interpretations of idealized cliff changes and cliff retreat measurements. Figure modified from Young et al. 2009b.

Hapke et al. (2008; 2009) mapped cliff top retreat in the present study area using 1933 T-sheets (NOAA historic survey maps) and 1998 airborne LiDAR data on 130 shore-normal (perpendicular to the shoreline) transects spaced 20 m alongshore (with some gaps up to about 400 m). The mean and maximum cliff top retreat rates for these transects were 0.06 m/yr and 0.21 m/yr, respectively, with estimated errors of 0.20 m/yr.

Young (2018) resampled the Hapke et al. (2008) 1933 and 1998 cliff top edge lines at a higher 5 m alongshore resolution and found mean retreat rates of 0.06 m/yr (Table 1, Figure 4). Young (2018) also used airborne LiDAR datasets to measure cliff change from 1998 to 2009 at 5 m alongshore resolution and found mean cliff top and face retreat rates of 0.11 and 0.04 m/yr, with some cliff top locations exceeding 0.40 m/yr. Recently, Swirad and Young (2021) used airborne LiDAR from 2009 and 2016 and automated procedures to estimate mean cliff top and face retreat rates of 0.003 and 0.05 m/yr, respectively.

Young et al. (2009a) used airborne LiDAR datasets and measured cliff face volume changes between 2002-2006 ranging from 0 to ~2 m^3/m/yr.

Overall, historical mean cliff top and cliff face retreat estimates for high-resolution studies in the study area range from 0.003-0.11 and 0.04-0.05 m/yr, respectively. The rates vary between these previous studies because of variability in the original data sources, differences in mapping resolution, methods, time periods analyzed, and actual differences in erosion rates and processes.

Table 1. Summary of retreat rates from previous studies with high-resolution coverage in the study area.

	Cliff Top Retreat Rate (m/yr)			Cliff Face Retreat Rate (m/yr)	
Study	Young (2018)	Young (2018)	Swirad and Young (2021)	Young (2018)	Swirad and Young (2021)
Time Period	1933-1998	1998-2009	2009-2016	1998-2009	2009-2016
Maximum	0.22	0.42	0.13	0.25	0.66
Mean	0.06	0.11	0.003	0.04	0.05
Minimum	0.00	0.01	0.00	0.00	0.00
Standard Deviation	0.04	0.07	0.02	0.04	0.08

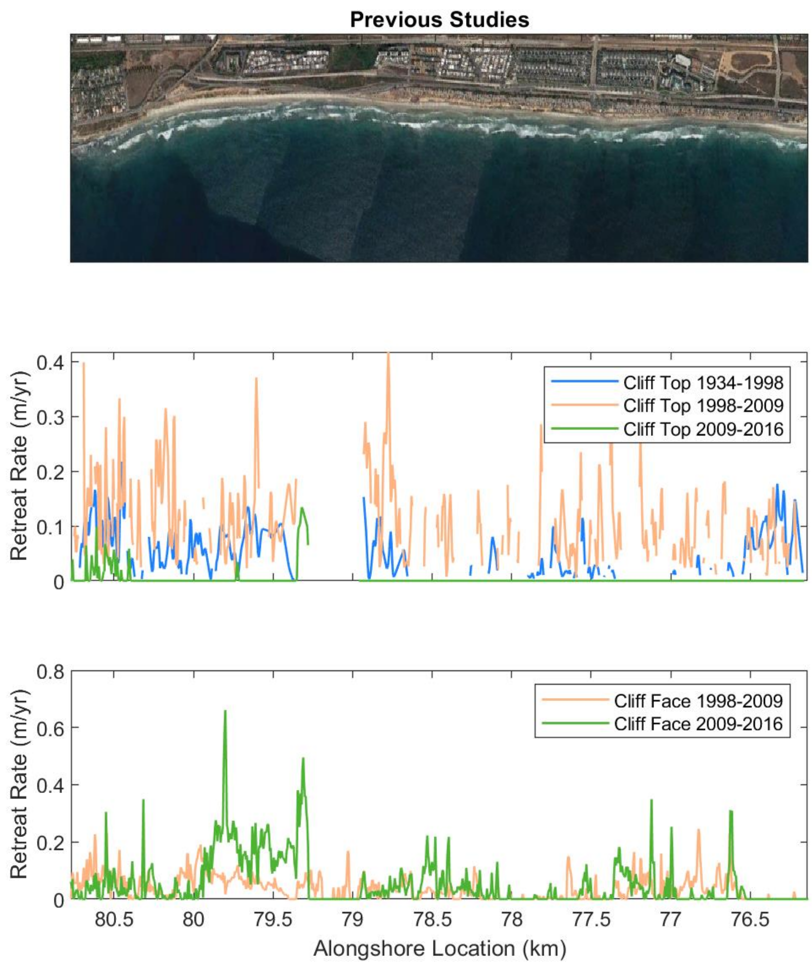


Figure 4. (top) Aerial image of study area and (center) corresponding alongshore cliff top retreat rates from previous high-resolution studies (Young, 2018; Swirad and Young, 2021), and (bottom) mean cliff face retreat rates from previous high-resolution studies (Young, 2018; Swirad and Young, 2021).

In 2017, the City of Carlsbad prepared a Sea Level Rise Vulnerability Assessment (City of Carlsbad, 2017) using cliff erosion projections for the Project study area (Figure 5) based on the United States Geological Survey (USGS) Coastal Storm Modeling System - CoSMoS 3.0 for Southern California (Barnard et al., 2018). The CoSMoS 3.0 modeling approach estimated bluff edge erosion using a baseline bluff top edge established from a 2010 digital elevation model. CoSMoS projections are based on historical erosion rates from 1933 to 1998 developed for the USGS National Shoreline Assessment (Hapke et al. 2008). The Sea Level Rise Vulnerability Assessment (City of Carlsbad, 2017) used sea level rise scenarios of 1.6 ft (0.5 m) and 6.6 ft (2.0m).

Figure 5. Map of potentially vulnerable parcels in Carlsbad with projected 2050 sea level rise of 1.6 ft and associated bluff retreat (Figure 6 in City of Carlsbad (2017)).

The USGS CoSMoS projections were updated in 2018 to CoSMoS 3.0 Phase 2 (Barnard et al., 2018) and show retreat rates from 2010-2100 and provide estimated future retreat for a range of sea level rise scenarios up to 5 m. For the transects in the Project's forecast area (Table 2), CoSMoS estimates cliff retreat of 0.06-0.12 m/yr for 1 m of sea level rise. CoSMoS 3.0 Phase 2 data are available for viewing using Our Coast Our Future online map viewer (https://ourcoastourfuture.org/, Figure 6).

Table 2. CoSMoS 3.0 Phase 2 Cliff Retreat rates for the forecast area.

	Cosmos Transect	805	806	807	808	809	810	811	812	813
	Cosmos Historical Retreat Rate (m/yr)									
		0.04	0.05	0.08	0.06	0.06	0.04	0.05	0.06	0.06
	Cosmos Projected Retreat Rate (m/yr)									
Sea Level Rise Scenario (m)	**0.25**	0.05	0.06	0.07	0.05	0.06	0.08	0.06	0.06	0.06
	0.5	0.05	0.07	0.09	0.06	0.07	0.08	0.07	0.08	0.07
	0.75	0.06	0.08	0.11	0.07	0.08	0.08	0.08	0.09	0.08
	1	0.06	0.09	0.12	0.08	0.09	0.1	0.09	0.1	0.09
	1.25	0.08	0.11	0.14	0.1	0.1	0.11	0.11	0.12	0.1
	1.5	0.1	0.13	0.17	0.12	0.12	0.13	0.13	0.14	0.12
	1.75	0.11	0.14	0.18	0.13	0.13	0.14	0.14	0.16	0.14
	2	0.14	0.17	0.2	0.14	0.16	0.16	0.15	0.18	0.16
	5	0.34	0.38	0.45	0.38	0.29	0.37	0.38	0.26	0.26
	Uncertainty	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15

Figure 6. Example CoSMoS 3.0 Phase 2 projected cliff retreat for 2.5 ft (0.75 m), 3.3 ft (1 m), and 6.6 ft (2.0 m) of sea level rise within the study area (source: Our Coast Our Future online viewer). Red is the zone of cliff retreat.

4.0 Evaluation of Existing Condidtions

To assess existing conditions, a combined drone and mobile terrestrial LiDAR survey was conducted on September 17, 2020 (Figure 7). The drone and terrestrial surveys were merged to provide complete coverage in complex topographic areas, such as the northern section of the study area where sea caves and notches are common.

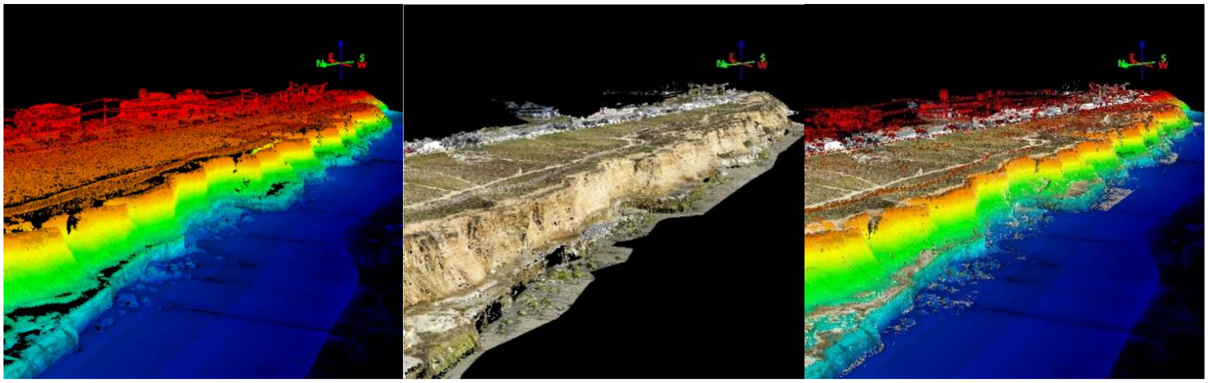


Figure 7. LiDAR data collected on Sep 17, 2020 from (left) a ground based mobile LiDAR system, (center) a drone based LiDAR system, and (right) the combined LiDAR data, used to provide complete surface coverage.

The most northern portion of the study area (Figure 8) contains numerous hazardous sea caves, notches, and bluff overhangs. As these features erode farther into the cliff, the likelihood of cliff failure increases. The depth of these over-vertical features on the lower and upper cliff were mapped using the recent 2020 LiDAR survey (Figure 8). These features can fail catastrophically and cause significant cliff top retreat, as evidenced by a collapse with 9 m of retreat shown in Figure 9 section P3.

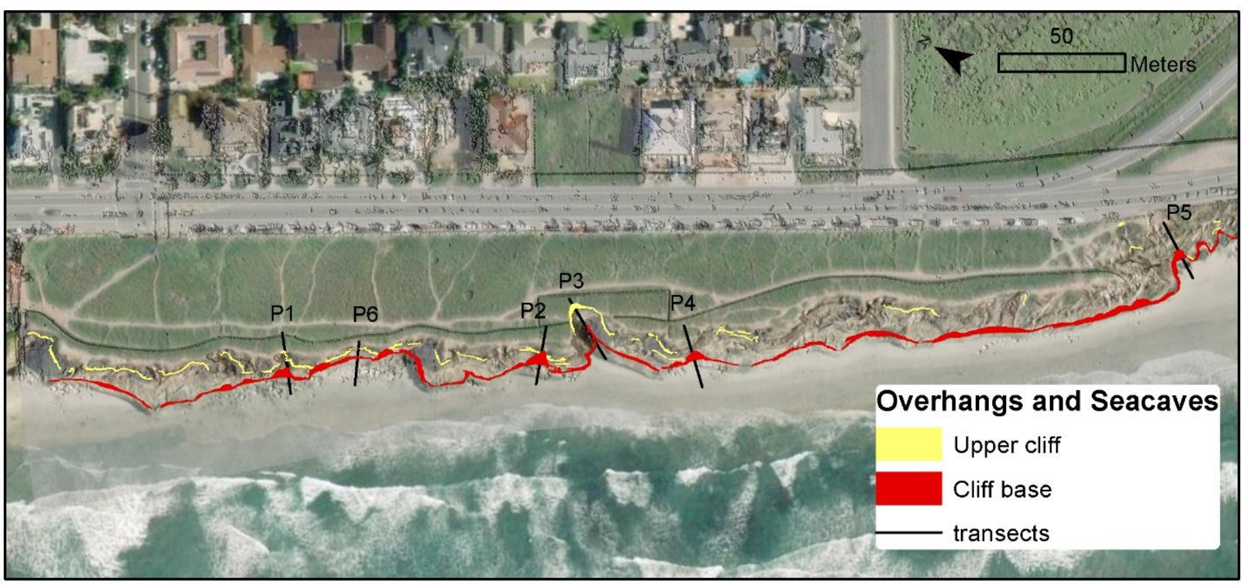


Figure 8. Areas with over-vertical topography in the upper and lower cliff obtained from a Sept. 17, 2020 LiDAR survey combined from drone- and truck-based mobile LiDAR systems. Labeled cross shore transects are shown in Figure 9.

The northern portion of the study area (Figure 8) was also inspected to evaluate recent changes by comparing a 2017 LiDAR survey to the recent 2020 data at specific cross shore profiles. Changes include lower cliff cantilever block failures at transects P1, P2, P4, and P5, a significant upper cliff failure that included ~10 m of retreat at P3, and a few meters of retreat across most of the cliff profile at P6. P2 changes observed at the cliff base could be from new notch development or changes in beach profiles inside the notch during the 2017 survey.

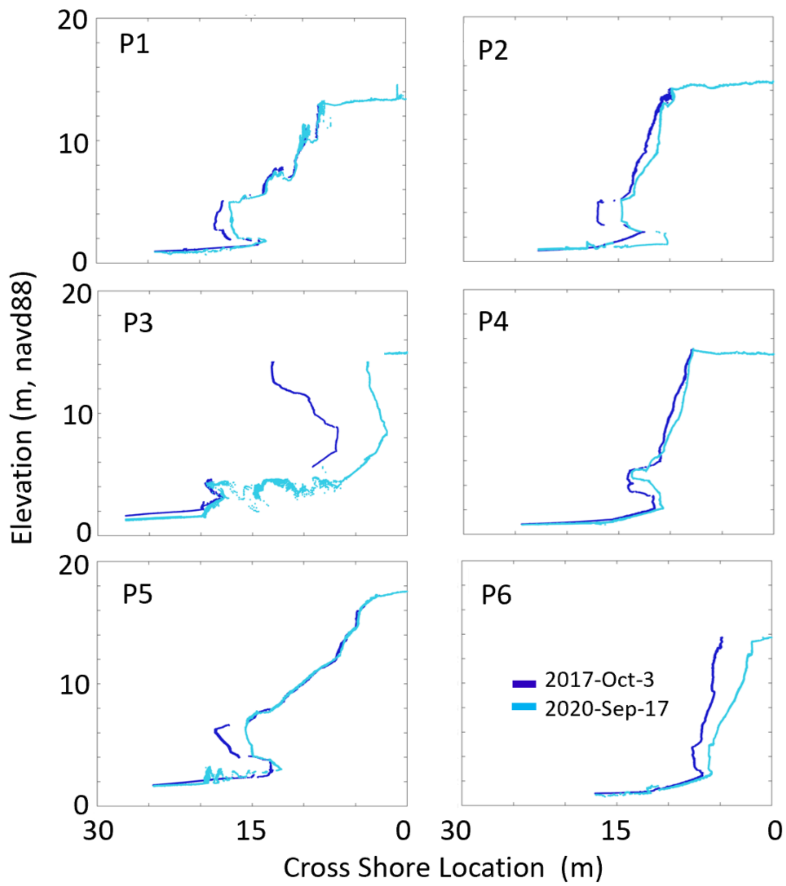


Figure 9. Selected cliff profiles (with the ocean to the left in each plot) in the northern portion of the study area showing significant changes between 2017 and 2020, including about 10 m of cliff top retreat at profile P3. Transect locations are shown in Figure 8.

5.0 Evaluation of Cliff Change 1998-2020

The new 2020 LiDAR dataset was used to evaluate cliff change from 1998 to 2020 to capture the longest time span of available high-resolution LiDAR data. Cliff top, cliff face, and cliff base retreat rates were evaluated at 5 m alongshore resolution (Figure 10) and provide change metrics on 3 different portions of the cliff. Cliff top and base positions were evaluated initially using cross shore profiles combined with automated detection methods (Swirad and Young, in review) and then visually inspected and edited.

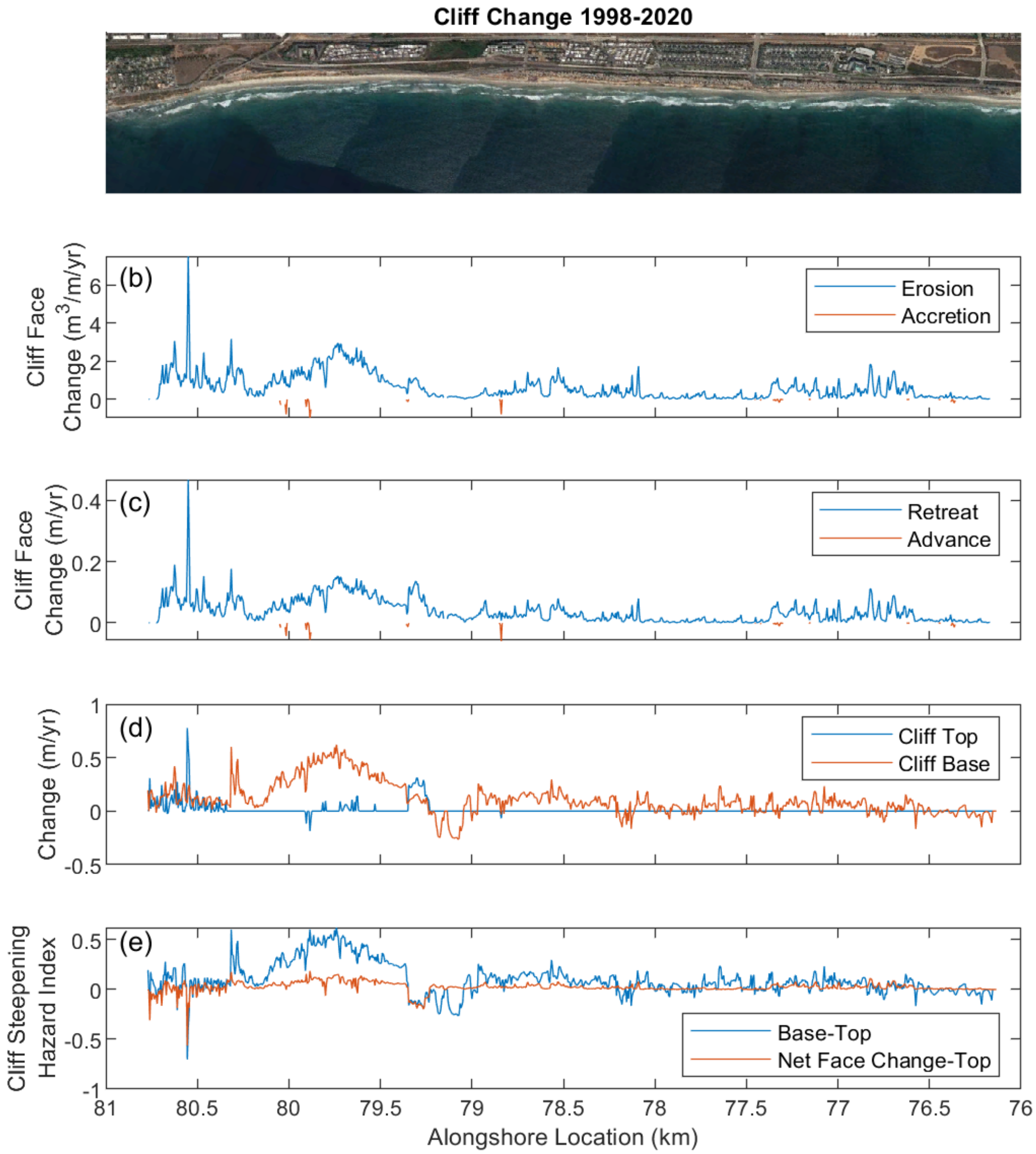


Figure 10. Cliff changes between 1998 and 2020 showing (b) volumetric change rate, (c) cliff face averaged retreat rates, (d) cliff top and cliff base change rates, and (e) a cliff steeping hazard index computed as the difference between lower and upper cliff changes. Higher values represent overall cliff steepening and increased cliff top retreat potential.

To evaluate overall vertical changes (Figures 10 and 11) and cliff face retreat rates from 1998-2020 (Figure 10) LiDAR point data were processed into 0.5-m resolution digital elevation models using the last return (if multiple returns were available) and a natural neighbors technique (Sibson, 1981). Digital change grids, estimated by differencing successive digital elevation models created using these LiDAR datasets, show both negative (erosion) and positive (accretion, talus deposits) changes. Sources of digital change grid error include the basic LiDAR observations, spatial interpolation, and vegetation. Elevation changes can indicate landslide motion, land erosion, talus deposition, topographic beach changes, and anthropogenic changes.

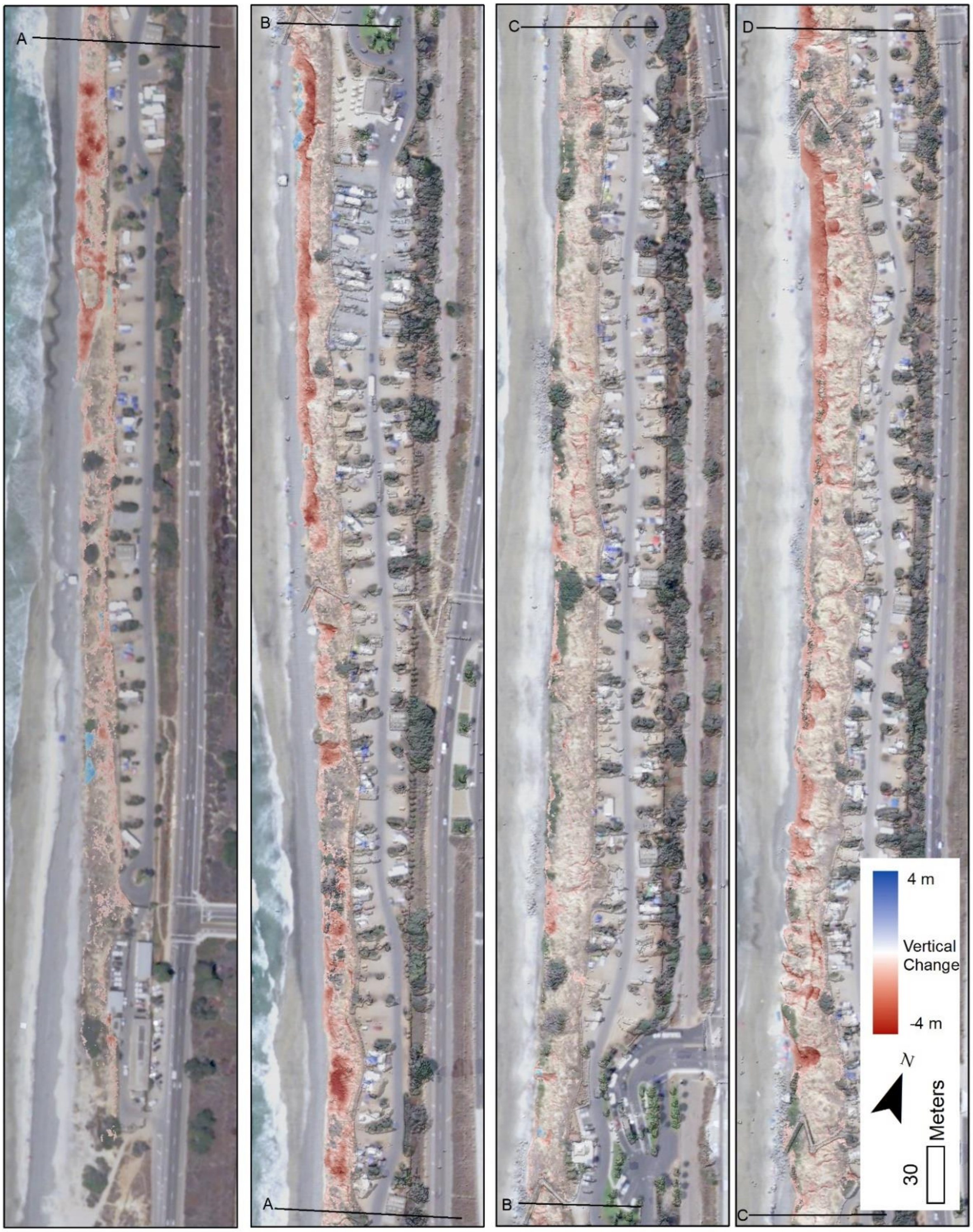


Figure 11. Vertical change maps of the south portion of the study area, spanning the South Carlsbad State Beach Campground, showing erosion (red) and deposition (blue) between 1998 and 2020. Colors saturate at +/- 4 m. From left to right, the panels go northward. Matchlines between panels and Figure 12 are indicated.

Figure 12. Vertical change maps of the north portion of the study showing erosion (red) and deposition (blue) between 1998 and 2020. Colors saturate at +/- 4 m. From left to right, the panels go northward. Matchlines between panels and Figure 11 are indicated.

Changes were separated into negative (i.e. cliff erosion) and positive (i.e. talus deposits) volumetric changes and then evaluated in 5 m wide (in the alongshore direction) compartments. Dividing the volumetric compartment changes by the cliff height and compartment width (5 m) yielded bulk negative and positive cliff face changes, equivalent to average cliff retreat/advance over the cliff face (Figure 10). Cliff heights were obtained from the digital elevation model. The cliff face retreat from 1998-2020 ranged from about 0 to 0.47 m/yr with a mean of 0.039 m/yr.

Cliff retreat measures on different parts of the cliff can differ substantially and provide information on geomorphic change and relative cliff top stability. Cliff top retreat reduces the overall cliff slope, while cliff base and cliff face erosion (not concentrated at the cliff top) cause slope steepening, thus reducing overall cliff stability. Young et al. (2009b) suggested the difference between cliff top and cliff face erosion could be used as a cliff top retreat hazard index (Figure 13). For example, as the cliff face retreat exceeds cliff top retreat, the cliff becomes more unstable, and vice versa. A cliff steepening hazard index, defined here as the cliff base or cliff face retreat minus the cliff top retreat, increases with overall cliff steepening. Positive hazard values indicate the cliff face or base retreat rates exceed the cliff top retreat rates, suggesting a higher relative potential for future cliff top failure. Based on cliff retreat rates from 1998-2020, relatively high cliff top hazard indexes exist in the northern portion of the study area between Terramar and Las Encinas Creek, compared to the South Carlsbad State Beach Campground area (Figure 10e).

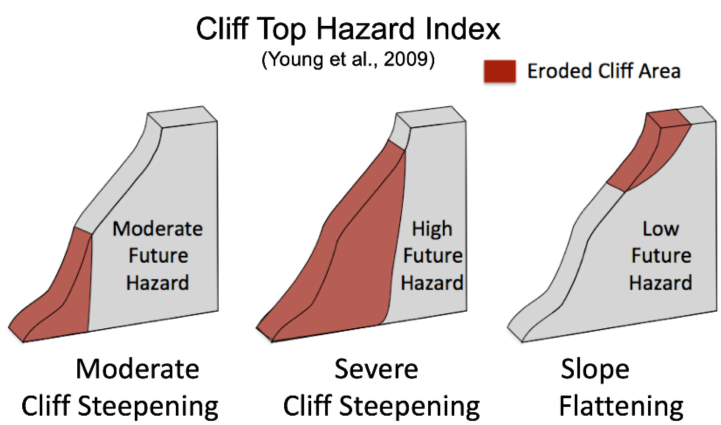


Figure 13. Conceptual cliff changes showing the cliff top hazard index developed by Young et al. (2009b). Profiles with more erosion on the lower and middle cliff cause overall cliff steepening and an increase in the cliff top hazard index.

6.0 Cliff Retreat Projections

Cliff retreat projections are limited to a 940 m section in the Solamar area, extending from the north end of Las Encinas Creek riprap to approximalely the intersection of Palomar Airport Road and Carlsbad Boulveard, approximately (Figure 1).

6.1 Model Introduction

This study estimated future cliff retreat (e.g. landward movement of cliff-base positions) of Carlsbad cliffs using four coastal cliff evolution models adapted from the existing scientific literature: modified Brunn (Bray and Hooke, 1997), modified SCAPE (Walkden and Dickson, 2008; Ashton et al., 2011), Trenhaile-Lite (Trenhaile, 2000; Limber et al., 2018), and Energy-Flux (Limber et al., 2018). All four models assume cliff erosion is primarily driven by wave action and iteratively calculate annual changes of the cross-shore profile of a cliff and fronting beach system. Other potentially important erosion factors such as rainfall (e.g. Young et al., 2009a; 2021) and groundwater are not specifically modeled but are implicitly included in the historical cliff retreat rates used to calibrate and run the models. For each iteration, the Trenhaile-Lite and Energy-Flux models update the whole cross-shore profile based on the amount of wave energy available at the cliff base and resulting cliff retreat, which subsequently influences wave transformation across the fronting beach and cliff retreat in the next iteration. Therefore, these two models work in a feedback system. On the contrary, the modified Bruun and modified SCAPE models only iteratively calculate the cliff base positions, without considering changes in the model cross-shore profile from previous time steps.

The modified Bruun and modified SCAPE models assume future cliff retreat ($R2$) depends on historical cliff retreat ($R1$), and historical ($S1$) and future ($S2$) sea level rise. The modified Bruun model is also influenced by profile geometry, closure depth (most landward depth with no significant bathymetric elevation change), and back shore geologic composition.

The models are expressed as:

$$R2 = R1 + (S2 - S1)\left(\frac{L}{P(B+h)}\right) \quad \text{(Eq. 1, Modified Bruun)}$$

$$R2 = R1\sqrt{S2/S1} \quad \text{(Eq. 2, Modified SCAPE)}$$

where L, B, h, and P in Eq. 1 are the cross-shore length of the active profile (L), cliff height (B), closure depth (h), and the proportion of sediment eroded that is sufficiently coarse to remain within the equilibrium shore profile (P), respectively.

The modified Bruun model is adapted from the widely used Bruun rule for sandy beaches (e.g. Bruun, 1962), which assumes conservation of sediment and an equilibrium profile shape and is the most basic of the four models used here. The modified SCAPE model is expressed as a relatively simple relationship (Eq. 2), but was derived from detailed process-based modeling of soft cliff coasts using the full SCAPE model version (Soft Cliff And Platform Erosion, Walkden and Dickson, 2008). Therefore, the modified SCAPE (Eq. 2) model is considered more physics-based compared to the modified Bruun model (Eq. 1), even though both models have relatively simple mathematical expressions.

The Trenhaile-Lite and Energy Flux models further assume that, in addition to historical cliff retreat (*R*1), and historical (*S*1) and future (*S*2) sea level rise, future cliff retreat (*R*2) also depends on wave energy transformation across surf and swash zones and, therefore, the slope of the beach fronting the cliff. In both models, the beach slope is defined as the linear slope from the cliff base at mean sea level and the wave breaking point, where the water depth equals $H_b/0.78$ (H_b: breaker height) (Battjes, 1974).

The wave force available for cliff erosion is calculated as follows:

$$F_w = \rho \frac{H_b}{1.56} e^{-xw} \quad \text{(Eq. 3, Trenhaile-Lite)}$$

$$F_w = \left(\frac{1}{8}\rho g H_b^2 \sqrt{\frac{gH_b}{0.78}}\right) e^{-xw} \quad \text{(Eq. 4, Energy Flux)}$$

where ρ, g, and x are the density of water (1025.2 kg/m^3), gravitational acceleration (9.8 m/s^2), and a decay constant (0.05 m^{-1}, Limber et al., 2018) that represents the dissipation of wave energy across the surf and swash zones, respectively. w is the width of the surf and swash zones and is calculated as follows:

$$w = \frac{H_b/0.78}{\tan \alpha} \quad \text{(Eq. 5)}$$

where α is the beach slope. The future cliff retreat (*R*2) in each iteration is estimated as follows:

$$R2 = K \cdot F_{w-total} \quad \text{(Eq. 6)}$$

where *K* is a calibration coefficient that converts wave energy available at a model cliff base to cliff retreat distance. $F_{w-total}$ is a measure of annual wave forcing (kg/m^2 for Trenhaile-Lite, and kg m/s^3 for Energy-Flux) calculated using a time series of wave data at a given site.

6.2 Model calibration (2000-2020)

Calibration of the Trenhaile-Lite and Energy-Flux models used modeled historical hindcast wave data, observed historical cliff retreat data ($R1$), and observed sea level rise data ($S1$) between 2000 and 2020. The observed historical sea level rise rate at the La Jolla station (~ 28 km south of the study site) was 2.13 mm/yr (Figure 14, tidesandcurrents.noaa.gov, station 9410230).

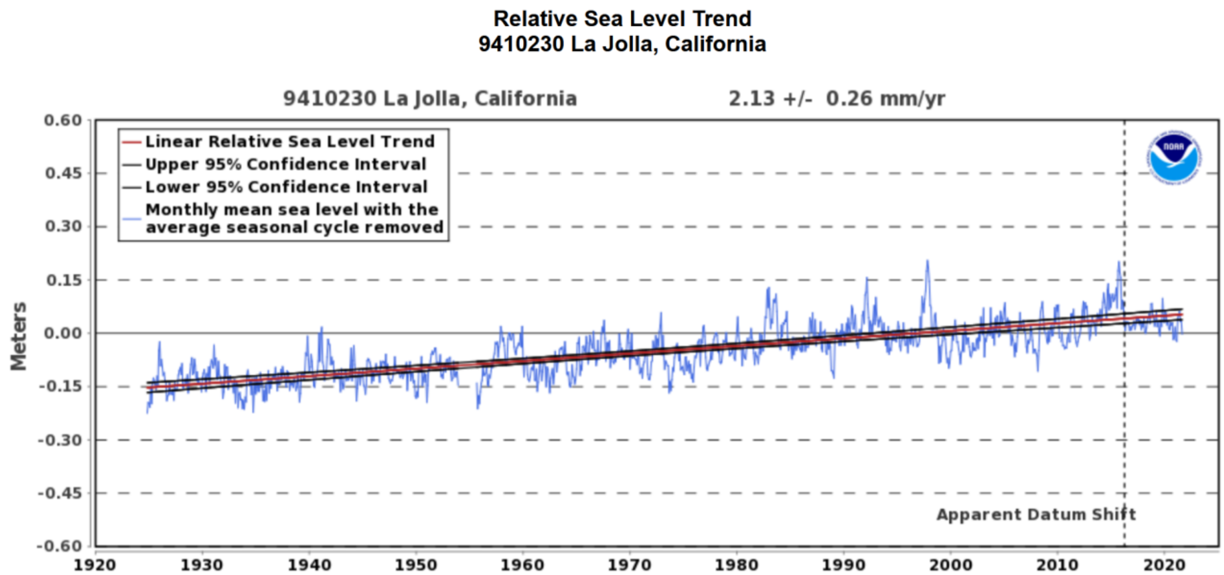


Figure 14. Relative observed sea level trends in La Jolla, CA (https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=9410230).

The calibration coefficient (K) relates the historical cliff retreat rate to historical wave force as follows:

$$K = \overline{R1} / \bar{F}_{w-total} \qquad \text{(Eq. 7)}$$

where $\bar{F}_{w-total}$ is the mean annual wave force over the 2000-2020 time period, and $\overline{R1}$ is the mean observed historical cliff retreat rate during the same period (Fig. 14a, in total 196 cases). The observed historical cliff face retreat rates from 1998-2020, evaluated in Section 5, were assumed to represent years 2000-2020 and ranged from 0.006-0.18 m/yr with a mean and median retreat of 0.076 and 0.071 m/yr, respectively.

Hourly 2000-2020 hindcast wave data (Figure 15b) was estimated using a buoy-driven regional wave model (O'Reilly et al., 2016), and converted to three-hour average wave data consistent with the USGS projected wave data (Hegermiller et al., 2016) used for model prediction. The calibration run was initiated with a simplified cross-shore profile (Figure 15c) based on 2009-

2011 LiDAR observations (2013 NOAA Coastal California TopoBathy Merge Project). No calibration was done for the modified Bruun and modified SCAPE models because both models are insensitive to wave conditions.

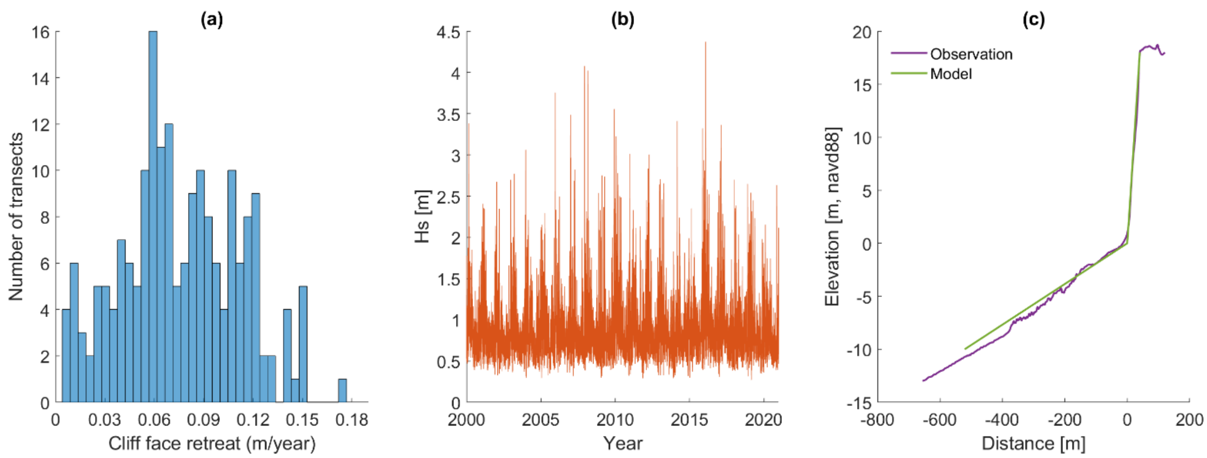


Figure 15. (a) Observed mean cliff retreat rate between 1998-2020, (b) modeled nearshore significant wave height (Hs), and (c) observed and simplified cross-shore profile used for the modeling.

6.3 Model prediction (2012-2100)

Model runs were conducted for the Ocean Protection Council (OPC) (2018) 0.5% probability La Jolla sea level rise scenario with specified water levels of 0.63 m in 2050, 1.10 m in 2070, and 2.16 m in 2100[1]. All model runs used a one-year time step. A quadratic function fit to the specified OPC (2018) water levels was used to estimate sea levels between 2012 and 2100 (Figure 16a). The simplified cross-shore profile (Figure 15c) was used to represent the forecast area.

The modified Bruun model runs used geometric parameters of the simplified observed cross-shore profile (Figure, 14c; Table 3) and measured cliff sand content of (P=0.9, Young et al., 2010). The closure depth was estimated at 8 m (Birkemeier et al., 2012). The *h* model parameter was modified to 9.5 m to account for the cliff base elevation (1.5 m) and to maintain consistency with the geometric relationships of the modified Bruun model.

For Trenhaile-Lite and Energy-Flux model runs, the future cliff retreat (*R*2) of a given year was estimated using the projected wave data (a time series of three-hour average wave data from USGS (Hegermiller, et al. 2016); Fig. 15b) and sea level rise (*S*2) of a given year, model cross-

[1] Water levels are relative to the sea level in 2000.

shore profile of a previous year, and a calibration coefficient unique to each observed cliff retreat rate (192 cases, Figure 15a). In addition, runs using Trenhaile-Lite and Energy-Flux models were initiated with a 2012 cross-shore profile obtained during the model calibration. In total, 768 prediction runs were conducted considering four models and 192 observed cliff retreat rates.

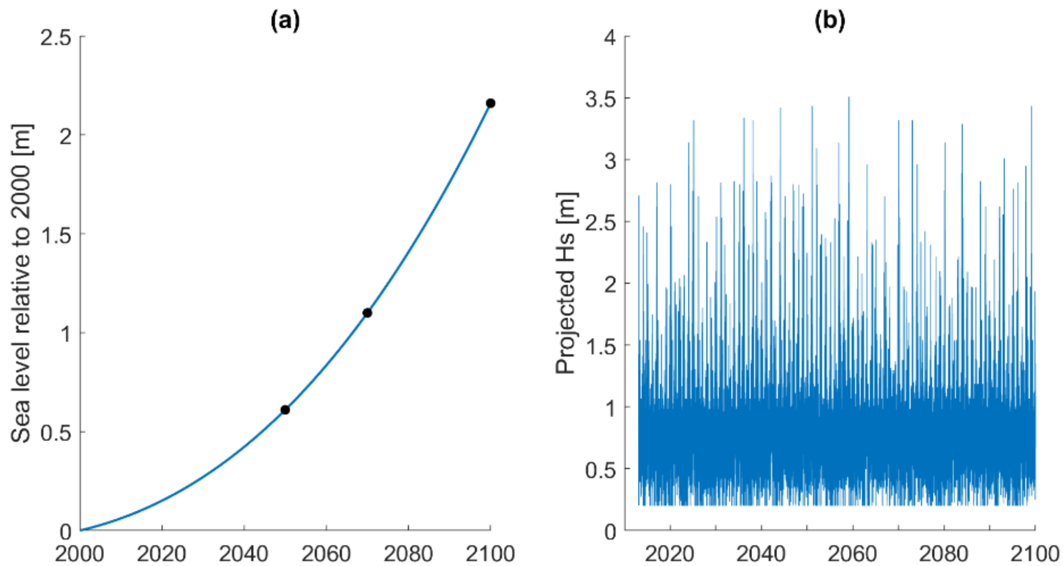


Figure 16. (a) Sea level rise scenario and (b) projected significant wave height (Hs) between 2012-2100 used for model runs.

Table 3. Parameter values for runs using the modified Bruun model

Active profile length (*L*)	400 m
Cliff height (*B*)	17.5 m
Closure depth	8 m
Proportion of sediment eroded that is sufficient coarse to remain within the equilibrium profile (*P*, from Young et al., 2010)	0.9

6.4 Model prediction output

For runs from all four models, modeled cliff retreat rates increased through time as sea level rise rates accelerated (Figure 17 and Table 4). The modified Bruun model predicted the highest cliff retreat with a median of 36.9 m in 2100 (relative to 2012 cliff base position), as opposed to 20.7 m (modified SCAPE), 17.5 m (Trenahile-Lite), and 16.5 m (Energy-Flux). Compared to other models, the modified SCAPE model predicted the largest range of 2100 cliff retreat at 1.8-51 m. Trenhaile-Lite and Energy-Flux models predicted the least cliff retreat on average with the 25th - 75th percentile ranges of 14.4-23.0 m and 13.6-21.5 m in 2100, respectively. With all model results combined, the 25th percentile, median, and 75th percentile cliff retreat in 2100 was predicted to be 15.4 m, 21.8 m, and 33.9 m, respectively.

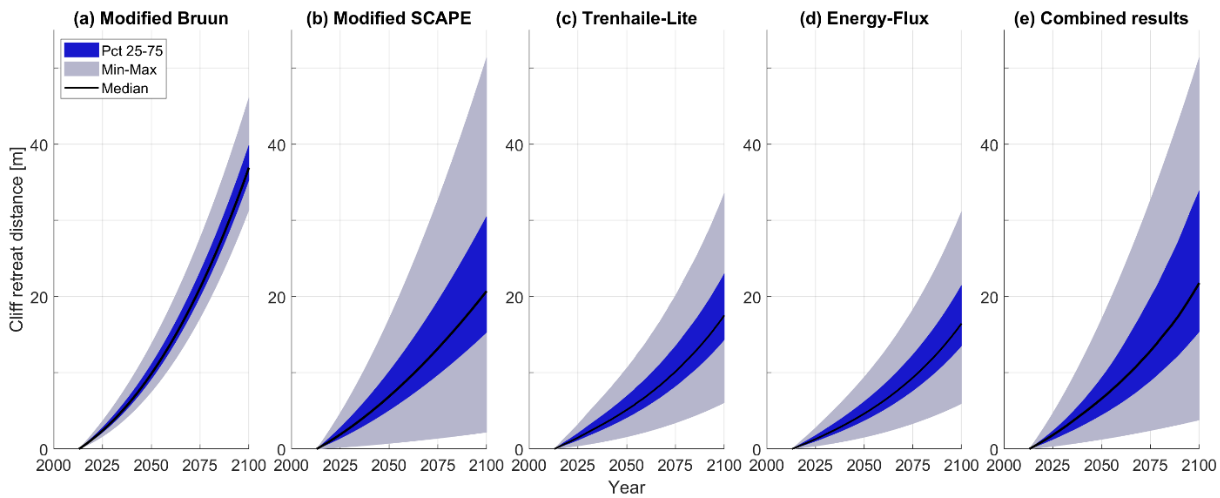


Figure 17. Median (black), minimum and maximum (gray), and 25th and 75th percentile (blue) results of simulated cliff retreat predicted by (a) modified Brunn, (b) modified SCAPE, (c) Trenhaile-Lite, and (d) Energy-Flux models. (e) Results combining all model outputs.

Table 4. Median, minimum, maximum, and 25th and 75th percentile values of simulated cliff retreat in 2100 predicted by modified Brunn, modified SCAPE, Trenhaile-Lite, and Energy-Flux models, and results combining all model outputs.

	Modified Bruun	**Modified SCAPE**	**Trenhaile-Lite**	**Energy-Flux**	**All models combined**
Minimum (m)	31.3	1.8	5.8	5.7	1.8
25th percentile (m)	35.3	15.3	14.4	13.6	15.4
Median (m)	36.9	20.7	17.5	16.5	21.8
75th percentile (m)	39.8	30.5	23.0	21.5	33.9
Maximum (m)	46.1	51.4	33.6	31.2	51.4

Scenarios with retreat of about 10 m or more intersect with the proposed project at the Solamar and Carlsbad Boulevard roundabout and a recreational trail in the southern portion of the forecast area (Figure 18). 10 m of retreat is lower than the 25th percentile for all four model outcomes (Table 4). Present infrastructure in northern end of the forecast area becomes threatened under retreat scenarios with about 20 m of retreat, which is approximately the median retreat predicted from combined model. Observed cliff retreat rate between 1998-2020 ranged up to 0.18 m/yr (Figure 15a), suggesting portions of the forecast area could exceed 10 m of retreat by 2100 even without considering the forecasted accelerated sea level rise. In addition, the cliff base retreat in the Solamar area has exceeded the cliff top retreat in many areas recently, indicating cliff steeping and increasing cliff top instability (Figure 10e). None of the models used have been validated with observations and caution should be used when interpreting the model outcomes.

Figure 18. Map of the forecast area showing proposed road alignment and zones of cliff retreat relative to the 2020 cliff top position.

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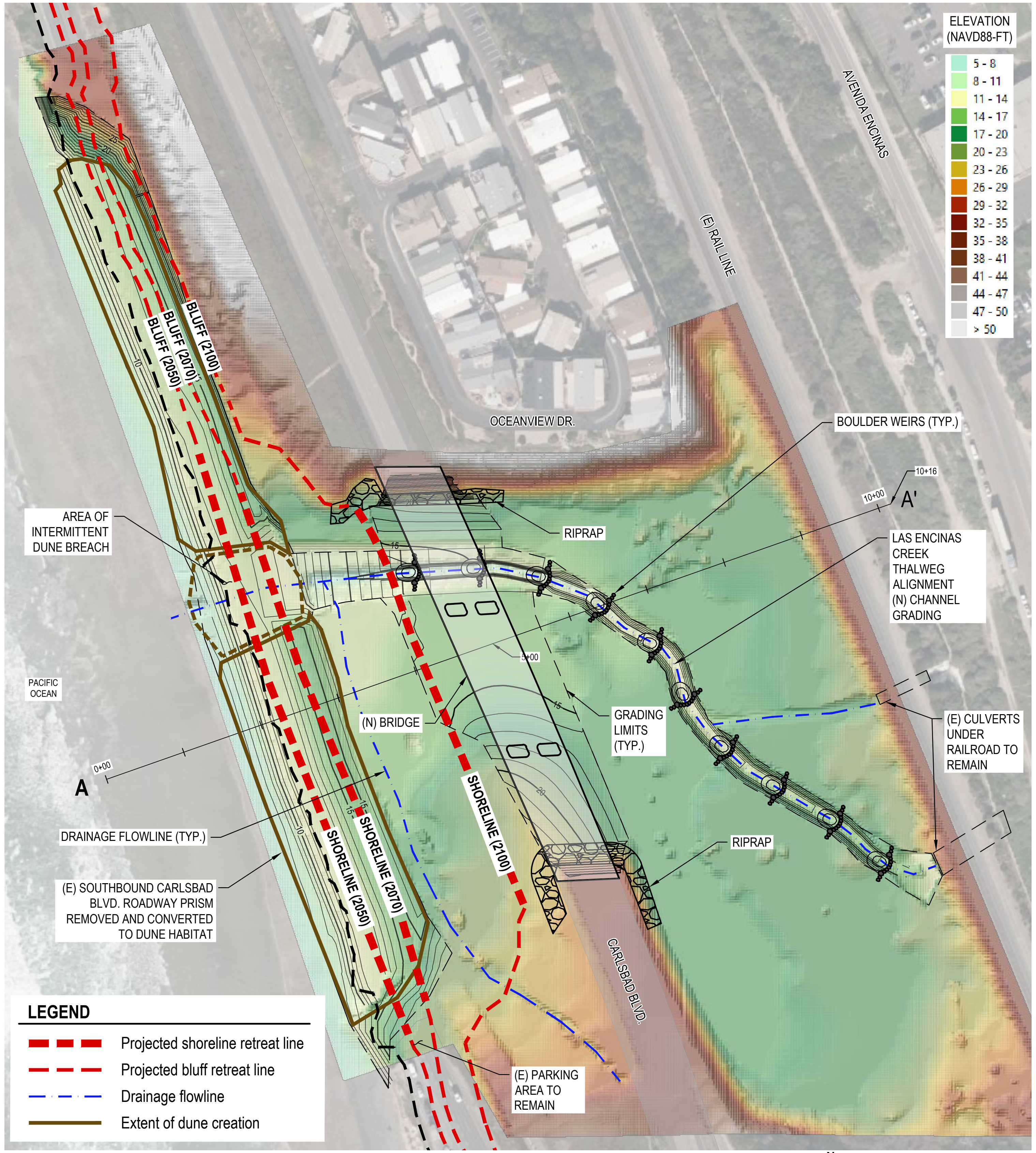
Appendix B

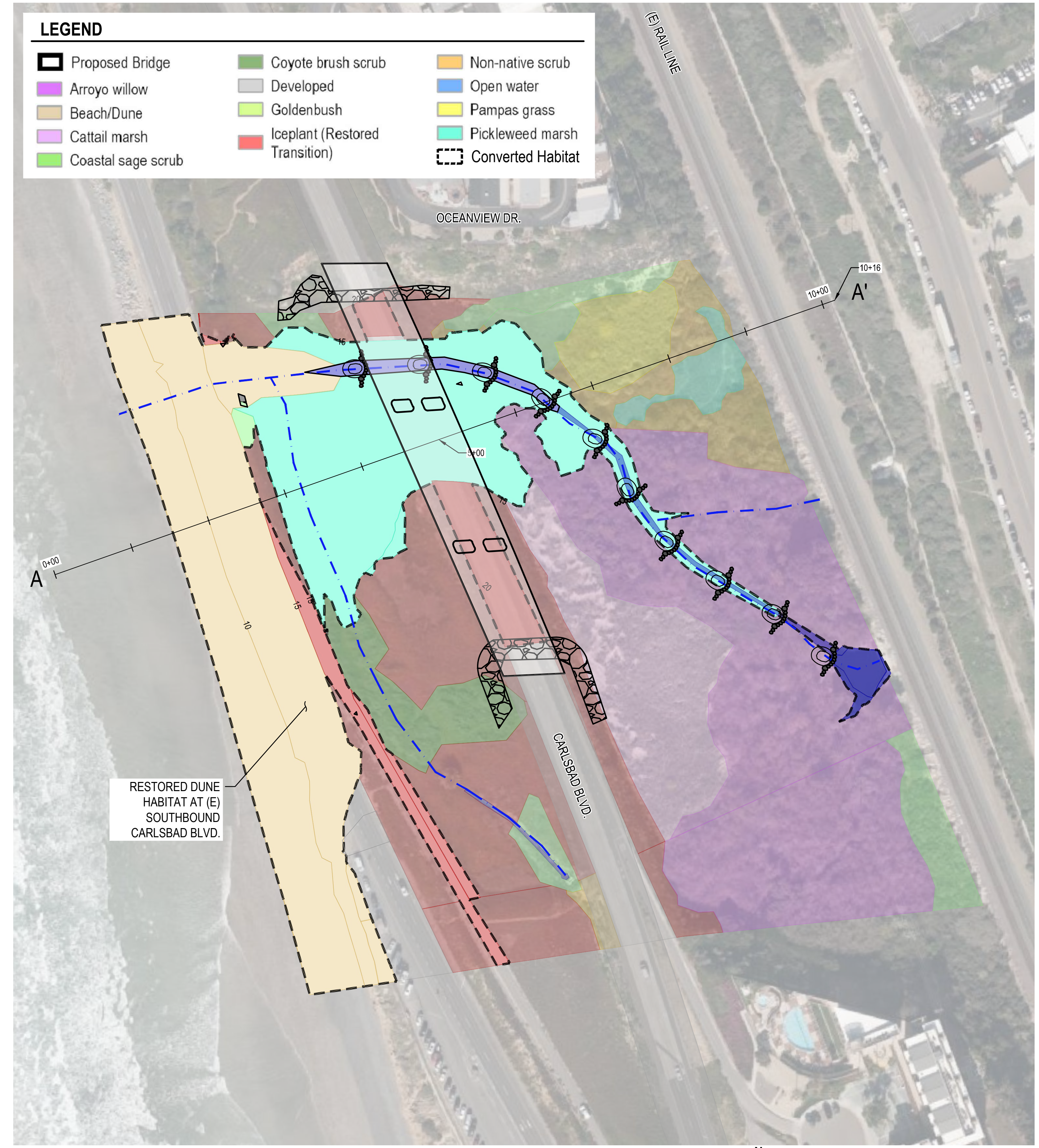
Habitat Restoration Concept Drawings



PLAN - DIGITAL TERRAIN MODEL

0 80' 160'

N



PLAN - HABITAT MAPPING

0 80' 160'

N

PRELIMINARY

No.	Issue	Checked	Approved	Date

Author | Drafting Check | Project Manager

Designer | Design Check | Project Director

Bar is one inch on original size sheet
0 1"

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Client: CITY OF CARLSBAD, CALIFORNIA

Project: LAS ENCINAS CREEK HABITAT RESTORATION

Title: **RESTORATION CONCEPTUAL DESIGN**

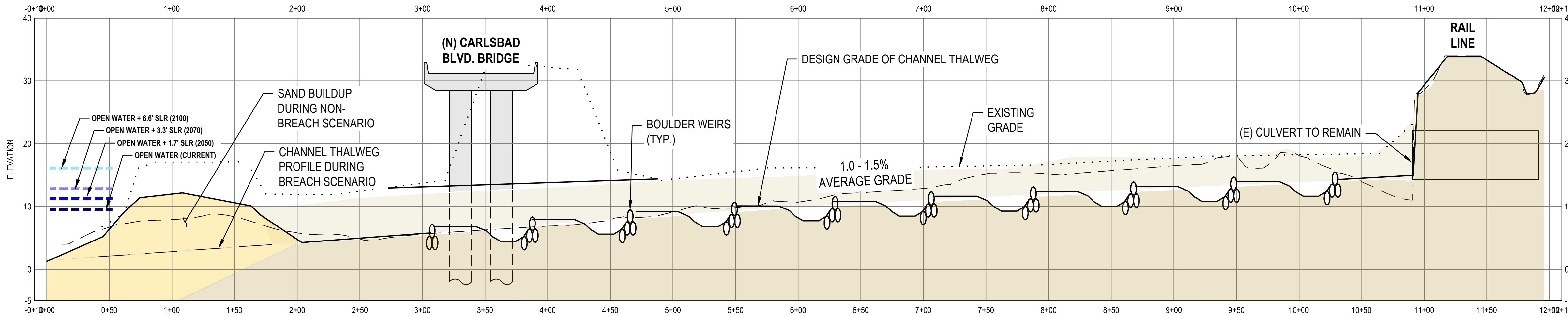
PROPOSED CONDITION - PLAN
LET IT GO OPTION

Size: **ANSI D**

Project No.	Date	Scale
11215903	2/14/2022	AS SHOWN

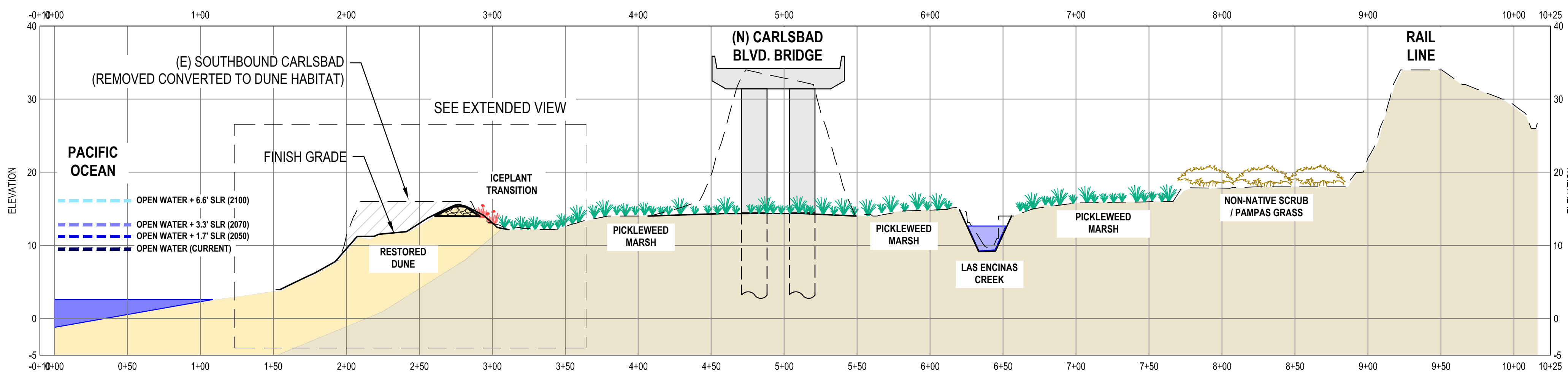
Sheet No.

Plot Date: 21 February 2022 - 1:32 PM   Plotted By: Corey Hayes   Filename: C:\Users\chayes2\Documents\0-GHD WORK\11215903 Carlesbad Shoreline Retreat\ACAD 2018\SHEETS\11215903-GHD-DWG-PROP-COND.dwg



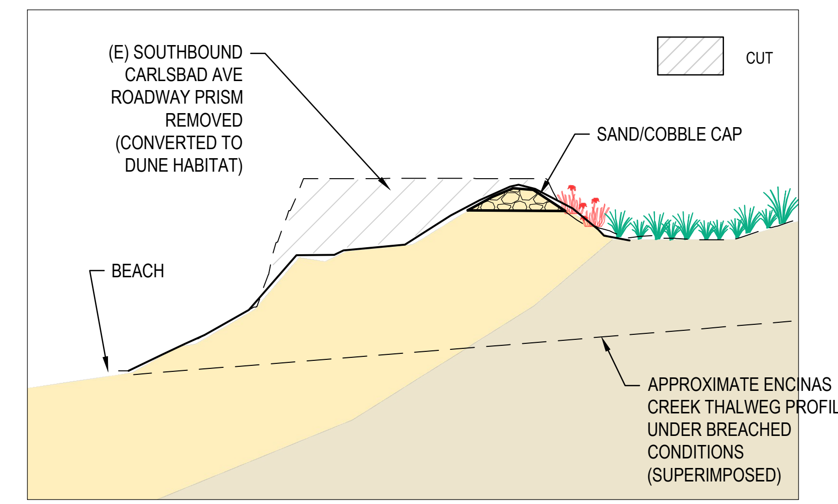
LAS ENCINAS CREEK CHANNEL THALWEG PROFILE

0 50' 100' HORIZONTAL
0 10' 20' VERTICAL



SECTION A-A' - TYPICAL SHORELINE PROFILE

0 50' 100' HORIZONTAL
0 10' 20' VERTICAL



EXISTING SOUTHBOUND CARLSBAD ROADWAY PRISM REMOVAL

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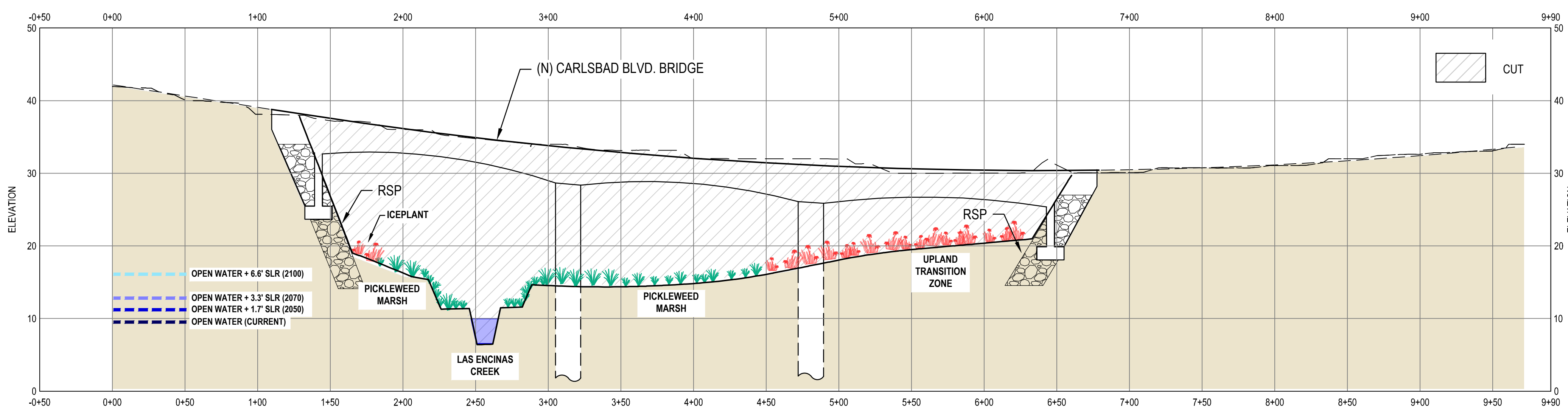

CARLSBAD BLVD. LONGITUDINAL PROFILE

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PRELIMINARY

No.	Issue	Checked	Approved	Date

Author | Drafting Check | Project Manager
Designer | Design Check | Project Director

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San Diego California 92123 USA
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www.ghd.com

Client: CITY OF CARLSBAD, CALIFORNIA
Project: LAS ENCINAS CREEK HABITAT RESTORATION

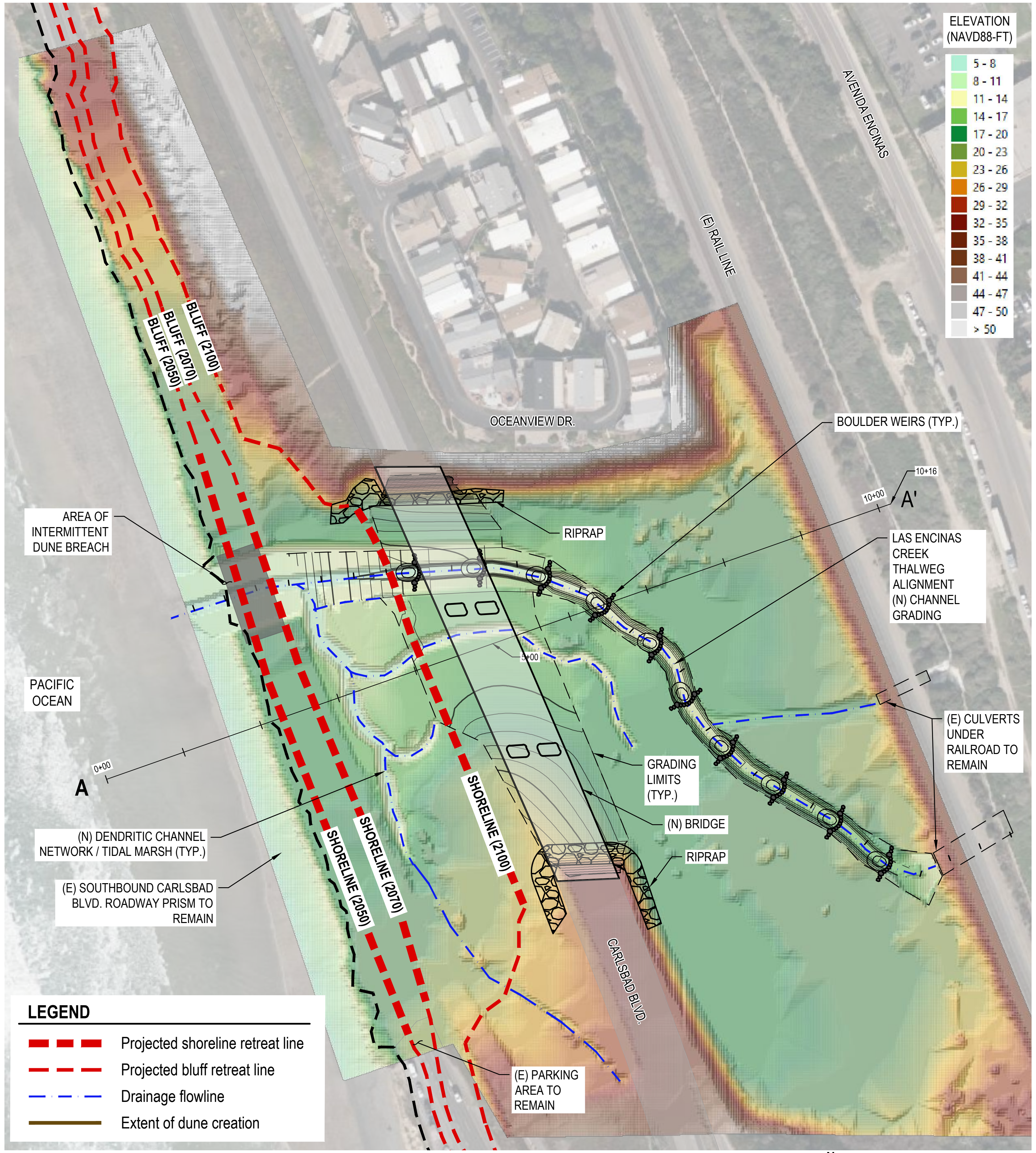
Title: RESTORATION CONCEPTUAL DESIGN

PROPOSED CONDITION - PROFILES
LET IT GO OPTION

Size: ANSI D

Project No. 11215903 | Date 2/14/2022 | Scale AS SHOWN

Sheet No.



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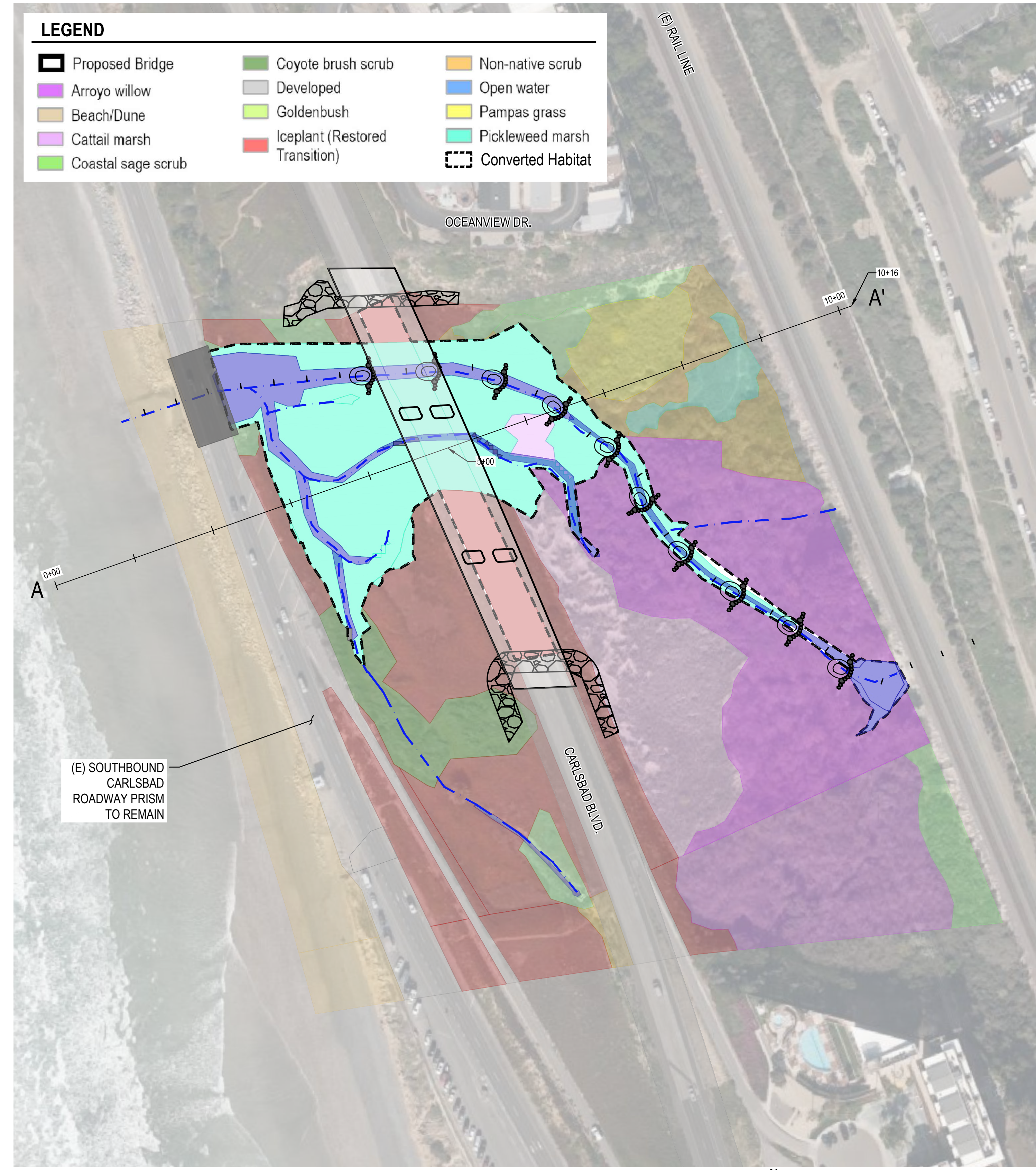

PLAN - HABITAT MAPPING

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Client: CITY OF CARLSBAD, CALIFORNIA
Project: LAS ENCINAS CREEK HABITAT RESTORATION
Project No.: 11215903 | Date: 2/14/2022 | Scale: AS SHOWN

Title: **RESTORATION CONCEPTUAL DESIGN**
PROPOSED CONDITION - PLAN PHASED RETREAT OPTION

Size: ANSI D
Sheet No.

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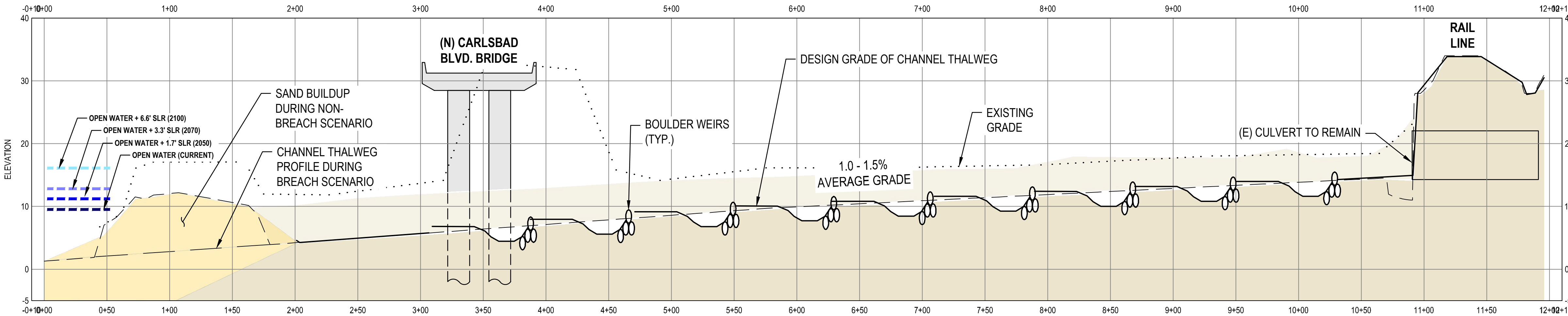

LAS ENCINAS CREEK CHANNEL THALWEG PROFILE

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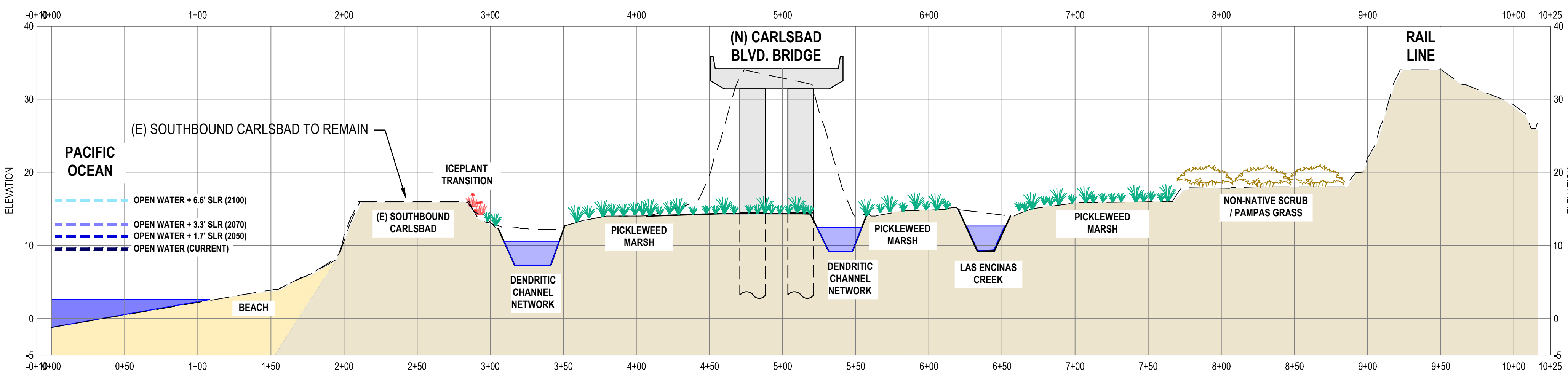

SECTION A-A' - TYPICAL SHORELINE PROFILE

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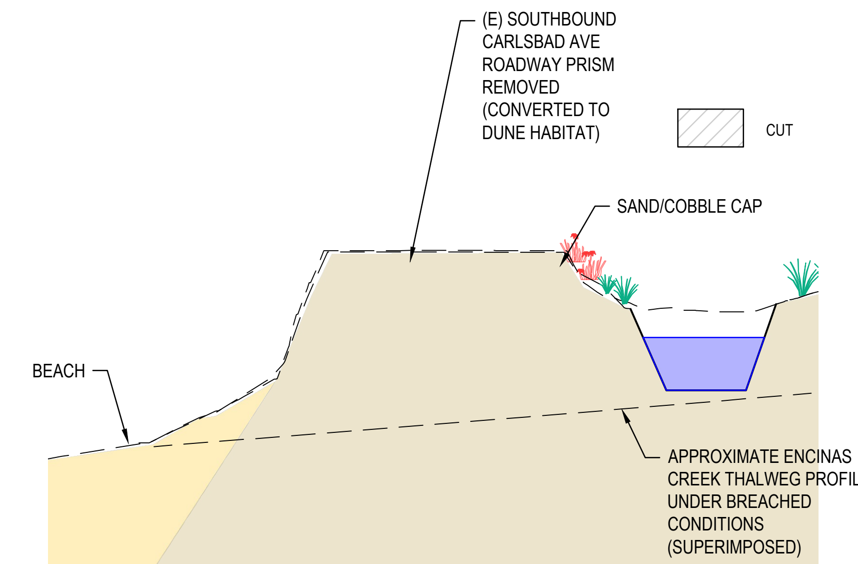
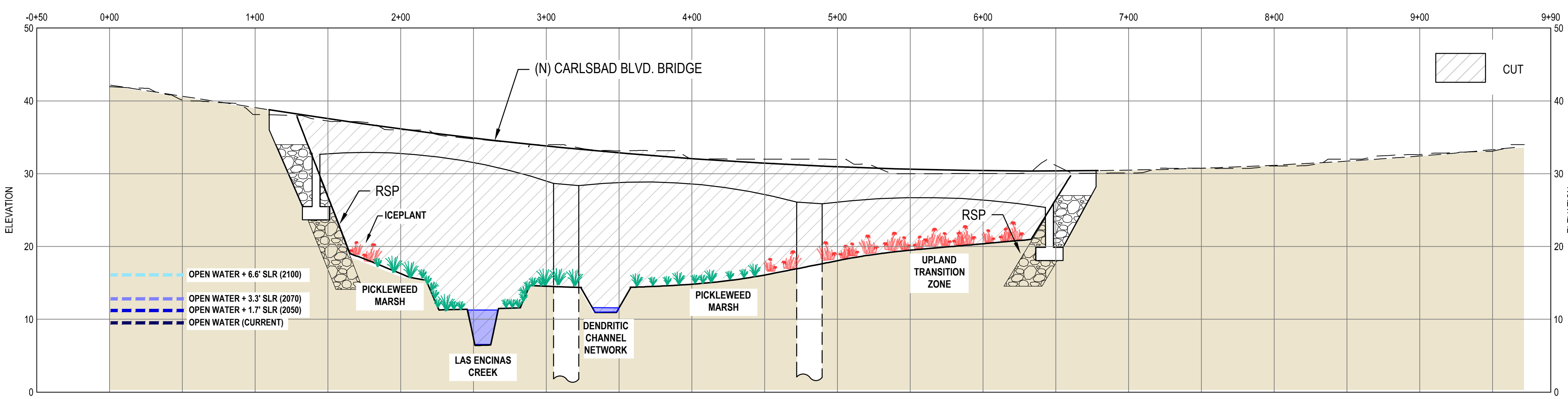


EXISTING SOUTHBOUND CARLSBAD ROADWAY PRISM REMOVAL

NOT TO SCALE



CARLSBAD BLVD. LONGITUDINAL PROFILE

0 50' 100' HORIZONTAL
0 10' 20' VERTICAL

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Project: LAS ENCINAS CREEK HABITAT RESTORATION
Title: RESTORATION CONCEPTUAL DESIGN
PROPOSED CONDITION - PROFILES
PHASED RETREAT OPTION
Size: ANSI D
Project No. 11215903 | Date 2/14/2022 | Scale AS SHOWN | Sheet No.

Plot Date: 21 February 2022 - 1:41 PM   Plotted By: Corey Hayes   Filename: C:\Users\chayes2\Documents\0-GHD WORK\11215903 Carlsbad Shoreline Retreat\ACAD 2018\SHEETS\11215903-GHD-DWG-HOLD-LINE.dwg

Appendix C

Las Encinas Creek Habitat Mapping Technical Memorandum

Technical Memorandum

October 01, 2021

To	Mike Grim, City of Carlsbad; Jennifer Fields, State Coastal Conservancy	**Tel**	
Copy to		**Email**	Kelsey.mcdonald@ghd.com
From	Kelsey McDonald, Brian Leslie, Jeremy Svehla	**Ref. No.**	11215903
Subject	Encinas Creek Habitat Mapping		

Summary

GHD conducted topographic and vegetation surveys to characterize existing conditions at the Las Encinas Creek Restoration Study Area for the South Carlsbad Boulevard Climate Adaptation Project (Project) on August 16-18, 2021. Topographic and vegetation data was collected to support hydraulic modelling, monitoring, and wetland design. Topographic data collected included Encinas Creek stream cross-sections as well as cross-shore transects to collect data on the elevation of vegetation types across the Study Area.

Vegetation was mapped in the field to characterize existing conditions (**Appendix A Figure 1**). Native vegetation communities onsite included arroyo willow (*Salix lasiolepis*) scrub, southern cattail (*Typha domingensis*) marsh, pickleweed (*Salicornia pacifica*) marsh, Menzies goldenbush (*Isocoma menziesii*), coastal sage scrub (*Artemisia californica-Eriogonum fasciculatum* Alliance), coyote brush (*Baccharis pilularis*) scrub. Non-native communities onsite included highly invaded non-native scrub, widespread iceplant (*Carpobrotus edulis*) mats, and dense pampas grass (*Cortaderia jubata*).

Field investigations and analysis of elevation data showed that species distributions are influenced by the complex hydrology onsite as well as elevation (**Appendix A Figure 2**). Pickleweed and other halophytic vegetation such as Menzies goldenbush was found at the lower end of the site's elevation range on both sides of northbound Carlsbad Boulevard. Salt to brackish vegetation types was observed at elevations beyond regular tidal influence, including a high basin that appeared to seasonally flood east of northbound Carlsbad Boulevard. Cattail marsh spanned across the lower portion of the site east of northbound Carlsbad Boulevard, where freshwater from upper Encinas Creek collected before draining back to the main channel at the northbound Carlsbad Boulevard culvert. Arroyo willow was strongly dominant across the northeast portion of the site around upper Encinas Creek. Native coastal sage scrub and coyote brush scrub was patchily distributed at middle to high elevations across the site. Much of the site was highly invaded by iceplant and other non-native species. Non-native species have invaded the site across the elevation range, but iceplant was especially dominant at higher elevations around the disturbed road prisms.

Hydrology onsite appeared to be seasonally variable; the Project site has been subject to flash floods during high flow and storm surge events which has scoured out deep pools and diverted the historic flow of Encinas Creek. Further investigations of onsite hydrology onsite during peak flow, extreme tides, and high surf conditions are recommended.

Methods

Habitat Mapping

Habitat mapping consisted of categorizing communities onsite according to functional habitat type and then characterizing the habitat according to dominant vegetation. Habitat polygon boundaries were primarily drawn in the field using the EOS Arrow Gold Global Navigation Satellite System (GNSS) receiver and ArcCollector. Field points and arial imagery assisted with digitizing major vegetation breaks in the office. Native vegetation communities were then keyed to Vegetation Alliance according to Vegetation Classification Manual for Western San Diego County (2011).

Topographic Survey and Hydrology Investigation

The topographic survey consisted of collecting elevations with the EOS Gold GNSS receiver and ArcCollector along stream cross-sections and cross-shore profiles. Encinas Creek and secondary channel topography was characterized by collecting elevations of Ordinary High Water Mark (OHWM), thalweg, toe of slope, and bench elevation above top of bank at a total of 24 stream cross-sections. Cross-section locations included two along the beach, six between southbound and northbound Carlsbad Boulevard, four along the discernible main channel above Carlsbad Boulevard, two along the cattail marsh channel, five along the upper scour pool and channels, four along a seasonal ditch, and one showing an additional area of seasonal flow below a smaller eastern culvert. Four cross-shore profile transects were established to characterize topography and the associated vegetation types across the site. Elevation and generalized vegetation data were collected at approximately every 10 meters and at major breaks in topography or dominant vegetation type. Benchmark elevations along the road shoulder and culverts were also collected to compare the data with remotely sourced lidar elevations and to provide reference points for monitoring flow conditions.

Results

Vegetation Communities

The Encinas Creek Restoration Project Study Area (Study Area) was in an anthropogenically altered estuarine setting crossed by road prisms. Brackish to salt marsh habitat was observed near the mouth of Encinas Creek and in areas with accumulated salts east of Carlsbad Boulevard. Freshwater wetland habitat fed by Encinas Creek was observed upstream of the northbound Carlsbad Boulevard culvert. Native coastal scrub habitats were pachily distributed within the Study Area. Non-native and invasive species have also established dominance in several areas (**Appendix B Photos 1-4**). The total acreage of each vegetation type mapped (**Appendix A Figure 1**) within each habitat is provided in **Table 1** below. The brackish to saline pickleweed and Menzies goldenbush marsh vegetation alliances were found at the lowest elevations (**Figure 1**). Freshwater cattail marsh, invasive pampas grass, and non-native scrub was observed at low-to-mid elevations. Arroyo willow scrub was found at mid-to-high elevations around Encinas Creek. Coyote brush scrub and coastal sage scrub was also observed at mid-to-high elevations. Iceplant has invaded a wide elevational range, and it was particularly dominant along the high-elevation road prisms.

Table 1. Total acreage of each vegetation type mapped in the Study Area.

Vegetation Type	Total Acreage
Pickleweed marsh	0.75
Goldenbush	0.23
Cattail marsh	1.13
Arroyo willow scrub	2.53
Coastal sage scrub	0.32
Coyotebrush scrub	0.59
Iceplant	2.37
Non-native scrub	0.61
Pampas grass	0.32
Open Water	0.33

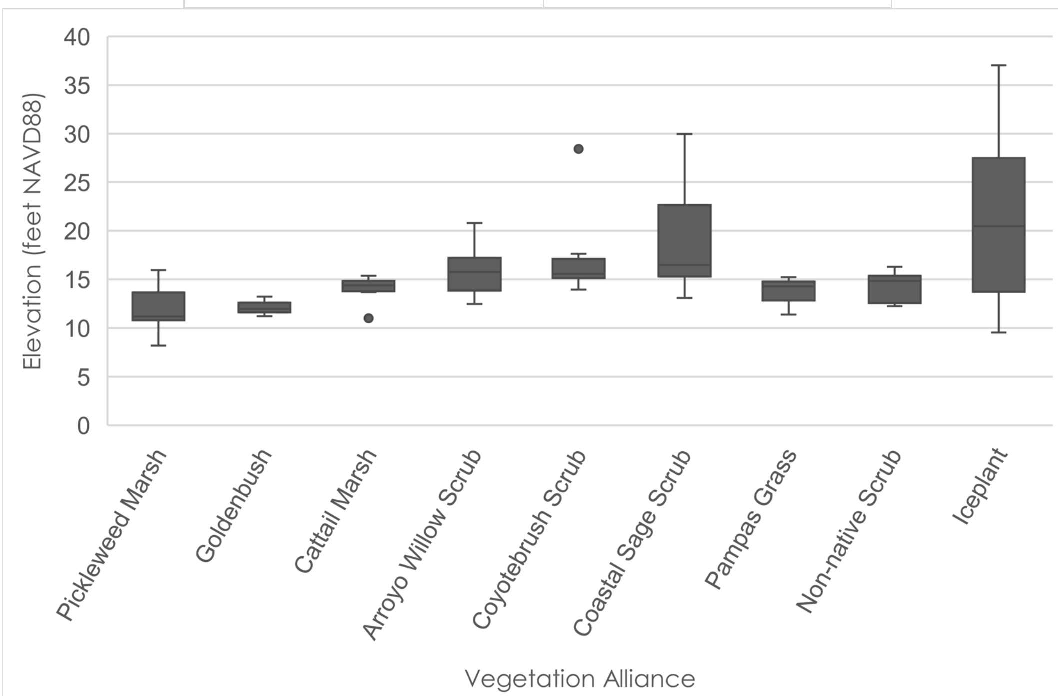


Figure 1. The elevation data collected (in feet NAVD88) for each vegetation alliance occurring within the Study Area are shown divided into quartiles centered around median elevations. Brackish to Salt Marsh Communities

Pickleweed (*Salicornia pacifica*) Alliance

Pacific pickleweed with saltgrass (*Distichlis* spicata) and alkali heath (*Frankenia salina*) dominated much of the area of estuarine influence south of the mouth of Encinas Creek west of northbound Carlsbad Boulevard (**Appendix B Photo 5**). Low cover of emergent coyote brush (*Baccharis pilularis*) and Menezies goldenbush (*Isocoma menziesii*) were sometimes present within this vegetation type. Much of the salt marsh was highly invaded by iceplant (*Carpobrotus edulis*). This vegetation type was observed in and above the area of regular tidal influence around lower Encinas Creek (~8-12ft NAVD88), and it was present at unusually high elevations around the outfall pipe in the western portion of the Study Area (**Appendix B Photo 6**) as well as in a high basin in the northeast corner of the Study Area (13-16ft NAVD88) (**Appendix B Photo 7-9**). The presence of pickleweed and other halophytes at higher elevations may indicate that salt has accumulated in these areas from prior flood events when brackish water overtopped the banks of Encinas Creek. A total of 0.75 acres of pickleweed marsh was mapped onsite.

Menzies Goldenbush (*Isocoma menziesii*) Alliance

Menzies goldenbush was widespread in the Study Area, intergrading with both pickleweed-dominant salt marsh and coastal scrub communities. Menzies goldenbush strongly dominated the north bank of lower Encinas Creek with saltgrass and alkali heath at the lower creek edge, and lemonade berry (*Rhus integrifolia*) and invasive cyclops acacia (*Acacia cyclops*) mostly at higher elevations (Photo 10). Invasive iceplant was also observed throughout this community. On the north banks east of northbound Carlsbad Boulevard, Menzies goldenbush was observed to be co-dominant with pickleweed, saltgrass, and alkali heath with emergent coyote brush (**Appendix B Photo 11**). Menzies goldenbush dominated lower elevations (11-13ft NAVD88) with some brackish to saline influence around lower Encinas Creek. A total of 0.23 acres of Menzies goldenbush dominance was mapped in the Study Area.

Freshwater Wetland and Riparian Communities

Cattail Marsh (*Typha domingensis*) Alliance

Southern cattail strongly dominated a wide swath of lower-elevation freshwater marsh (~11-16ft NAVD88) east of northbound Carlsbad Boulevard (covering a total of 1.13 acres) (**Appendix B Photos 12**). Other species observed in this area included California bulrush (*Schoenoplectus californicus*) and low cover of emergent arroyo willow (*Salix lasiolepis*). The cattail marsh was saturated at lower elevations near northbound Carlsbad Boulevard during the August 16-18 field investigations. The cattail marsh received perennial flow from upper Encinas Creek at the Avenida Encinas culvert and then flowed back into Encinas Creek near the northbound Carlsbad Boulevard culvert.

Arroyo Willow (*Salix lasiolepis*) Alliance

Arroyo willow strongly dominated 2.53 acres of the south-eastern portion of the Study Area between Avenida Encinas and the cattail marsh to the west at elevations of 12-20ft NAVD88 (**Appendix B Photo 13**). Non-native red gum (*Eucalyptus camaldulensis*, Cal-IPC Limited) was also observed in this area around the large culvert and scour pool in the southeast corner of the Study Area (**Appendix B Photo 14**). Mule fat (*Baccharis salicifolia* ssp. *salicifolia*) and salt marsh fleabane (*Pluchea odorata*) occurred in the understory adjacent to the culvert. Additionally, California bulrush was observed in the understory at the lower extent of the willow thickets in Encinas Creek. To the west and northwest of the culvert, arroyo willow formed a dense thicket with braided channels, and showed evidence of past flooding in the form of drift deposits and very few plants in the understory (**Appendix B Photo 15**).

Native Scrub Communities

Coastal Sage Scrub (*Artemisia californica-Eriogonum fasciculatum*) Alliance

California buckwheat (*Eriogonum fasciculatum*) was a prominent species in mid-to-higher elevation native scrub in the Study Area (13-30ft NAVD88) and was observed to be co-dominant with California sagebrush (*Artemisia californica*), Menzies goldenbush, bush sunflower (*Encelia californica*) and coyote brush (**Appendix B Photos**

16-18). Coastal sage scrub was patchily distributed around the site, covering a total of 0.32 acres, and species composition and relative dominance varied throughout the coastal sage scrub community. Iceplant has invaded less densely vegetated areas of coastal sage scrub and has established dominance in many areas that would otherwise be at a suitable elevation range and habitat for coastal sage scrub. Non-native Canarian sea lavender (*Limonium perezii*) and common stock (*Matthiola incana*) also occurred in this habitat.

Coyote brush (*Baccharis pilularis*) Scrub Alliance

Coyote brush dominated the majority of the native scrub within the Study Area (covering 0.59 acres), and it was dominant in the lower ditch drainage on the western end of the Study Area (**Appendix B Photo 19**). Coyote brush is tolerant of a wide range of conditions, and the alliance was observed at a wide range of elevations (~13-28ft NAVD88). Coyote brush intergraded with other native coastal scrub species including California buckwheat, lemonade berry, and Menzies goldenbush (**Appendix B Photo 20**). Coyote brush also dominated some of the higher elevation area at the northeastern extent of the Study Area along the rail prism, where it intergraded with non-native shrubs and halophytes on the edge of the pickleweed-dominant basin.

Non-Native Vegetation

Non-native mixed scrub

Lollypop tree (*Myoporum laetum*) (Cal-IPC Moderate), Brazilian pepper tree (*Shinus terebinthifolius*) (Cal-IPC Limited), and cyclops acacia (Cal-IPC Watch List) have invaded 0.61 acres east of northbound Carlsbad Boulevard (**Appendix B Photos 3, 21**). These non-native small trees and shrubs have established dominance along Encinas Creek east of northbound Carlsbad Boulevard and around the high salt marsh basin and rail prism. This non-native vegetation type was primarily observed in disturbed transition zones between wetland and upland habitats at middle elevations (12-16ft NAVD88).

Pampas grass (*Cortaderia jubata*)

Invasive pampas grass (Cal-IPC-High) has established a dense near-monospecific stand in a 0.32-acre north-central patch east of northbound Carlsbad Boulevard (**Appendix B Photo 22**). Cracked sandy soils and some pickleweed and saltgrass in this location appears to indicate that this area may be subject to occasional flooding, and this area was relatively low elevation (11-15ft NAVD88). Salt cedar (*Tamarix ramosissima*, Cal-IPC High) was also observed around the edges of this highly invaded patch of pampas grass. Pampas grass also occurred in non-native scrub habitat and other disturbed areas of the Study Area.

Iceplant mats (*Carpobrotus edulis*)

Freeway iceplant (Cal-IPC High) has severely invaded 2.37 acres of the Study Area and established thick monospecific mats throughout much of the western portion of the Study Area and on both sides of northbound Carlsbad Boulevard (**Appendix B Photo 23**). Freeway iceplant was observed at a wide range of elevations onsite (~9-33ft NAVD) and appeared to be invading brackish wetland and upland habitats.

Topography

Characterizing the elevation of the Study Area along four transects from the western study boundary at southbound Carlsbad Boulevard to the edge of the rail prism at Avenida Encinas showed that low basins occur on both sides of the elevated northbound Carlsbad Boulevard (depicted as the central peak in Figure 2, below). Transect A is northernmost and intersected the edge of Encinas Creek at the low point near the culvert. Transect B intersects the high salt marsh basin to the east. Transects C and D were cut short east of northbound Carlsbad Boulevard due to the high density of the cattail marsh and arroyo willow scrub vegetation in this area.

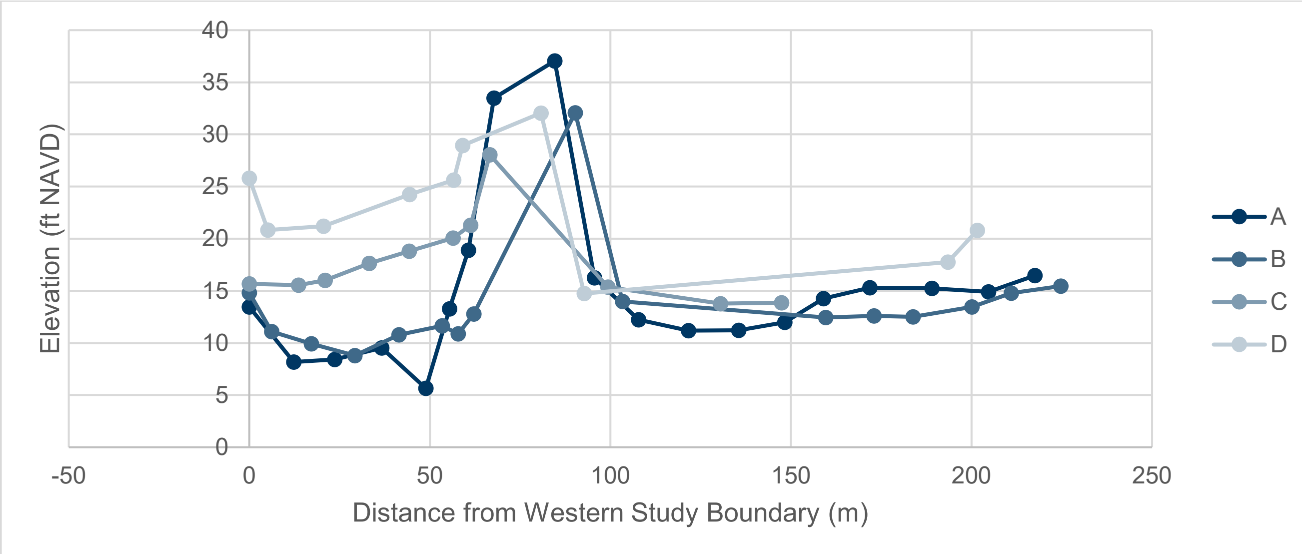


Figure 2. Elevations are shown from west to east along four parallel transects across the Study Area. Transect A is northernmost and transect D is southernmost.

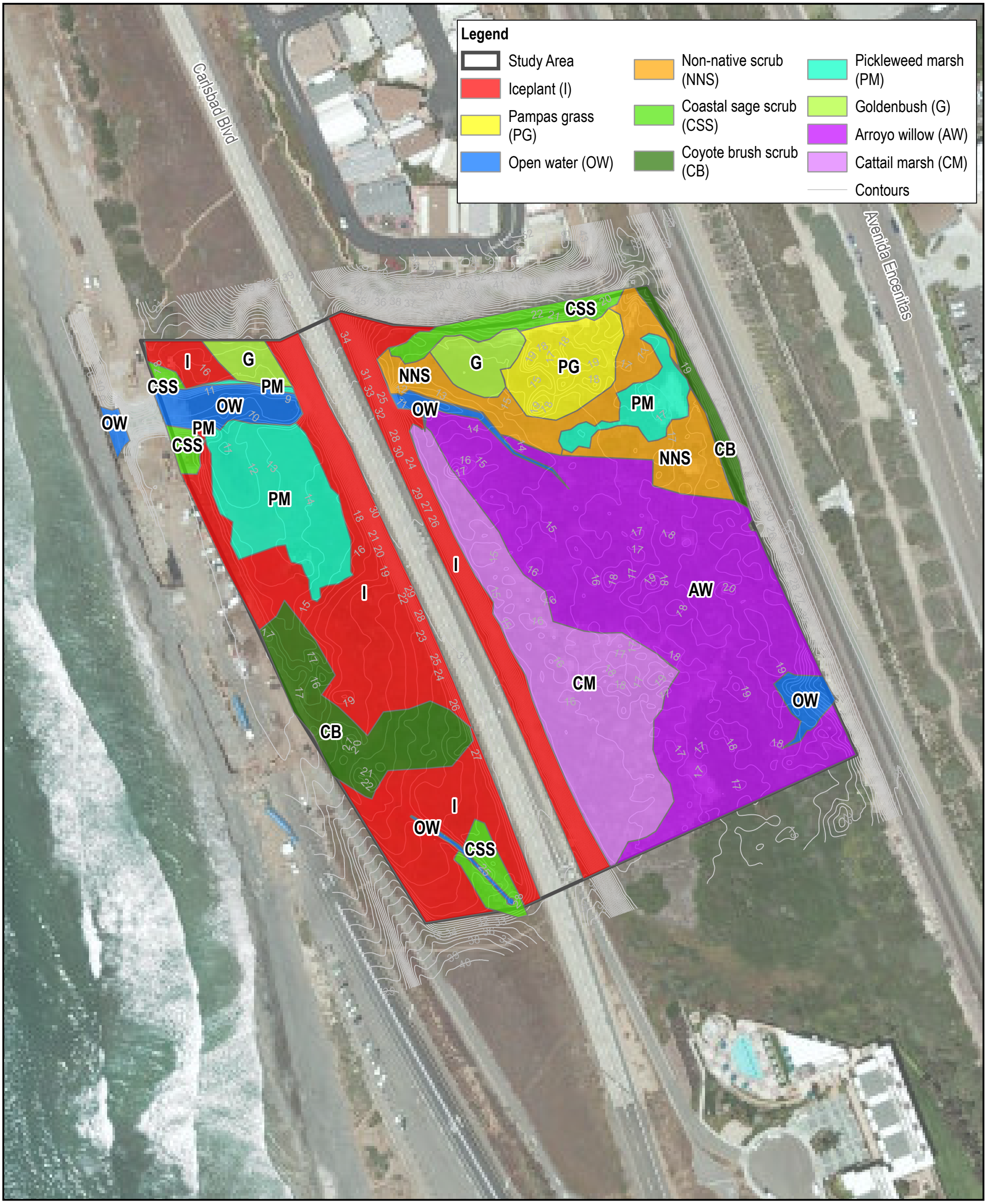
Hydrology

Encinas Creek's hydrology appears to have been highly altered by urbanization upstream and in the surrounding area. Urban stormwater runoff has likely increased peak flow volumes, and channelization of Encinas Creek immediately upstream of the site has likely increased flow velocity. A deep scour pool occurred at the large culvert outlet below Avenida Encinas at the south-eastern end of the Study Area (**Appendix B Photos 24-25**), and seasonal channels radiate out from the pool, with one small perennial channel flowing west into the cattail marsh (**Appendix A Figure 2, Appendix B Photo 26**). Water flowing approximately due west from the Avenida Encinas culvert and scour pool into the cattail marsh might have diverted flow away from the larger historic Encinas Creek channel, which had already run dry at the time of the mid-August surveys. The upper portion of the larger channel through the willow scrub has become braided and has lost a clearly defined bed, bank, and channel through much of the upper portion. The cattail marsh and seasonal channels through the willow scrub coalesce into the widened perennial creek on the north end of the site near the culvert under northbound Carlsbad Boulevard. There has likely been a major increase in peak flows that have substantially changed the hydrology of Encinas Creek as indicated by the scour pool, apparent change in dominant flow direction, and lack of a clearly defined creek bed and bank through most of the eastern portion of the Study Area.

Based on widespread signs of seasonal inundation including high wrack caught in willows, sediment deposits, soil cracks, and obligate wetland plants at high elevations, the site may be subject to flash flooding east of northbound Carlsbad Boulevard during major winter precipitation or extreme tide events. In the northeast portion of the site, a basin characterized by pickleweed and cracked fine sandy soil appeared to seasonally collect stormwater runoff and/or floodwaters. The presence of pickleweed and other halophytic plants in this relatively high basin area (~13-16 feet elevation NAVD88) likely indicated that it may seasonally flood with brackish water and accumulate salt in the soil without getting flushed by flowing freshwater inputs like much of the area immediately surrounding Encinas Creek. Downstream of the culvert under northbound Carlsbad Boulevard, the creek has been scoured out to over 8-foot depth below the top of the bank (~7 feet below Ordinary High Water Mark as indicated by undercut banks, breaks in slope, and vegetation type). The mouth of Encinas Creek was mostly blocked by beach sand accreting under southbound Carlsbad Boulevard, with a tricking flow under southbound Carlsbad Boulevard to the ocean during the August field investigation. Lower Encinas Creek was surrounded by brackish to salt marsh vegetation and appeared to have some regular tidal influence with ocean waves likely overtopping the accreted sand at higher tides. The pickleweed marsh south of the mouth of Encinas Creek extended up to a concrete pad with a marker indicating the placement of the outfall pipe. Unusual patterns of dead vegetation and wetland plants such as cattails around the pad may indicate that the outfall pipe is another source of hydrology onsite.

Hydrology onsite is subject to natural seasonal variation as well as increased watershed runoff and altered channel morphology that may increase the “flashiness” of the system. Storm surge with high surf and tides in the winter are expected to increase the extent of saltwater inundation onsite, and this could coincide with high flow events that cause the scour pool below Avenida Encinas to overflow and flood the eastern portion of the site. The site was investigated during the dry season, when Encinas Creek flow was likely at its lowest. Additionally, a smaller culvert under Avenida Encinas (**Appendix B Photo 27**), a culvert and ditch originating at northbound Carlsbad Boulevard, and non-point source stormwater runoff all contribute seasonal or ephemeral discharges to the Study Area. Additional investigation of the site during the winter after major precipitation and with king tides is highly recommended to evaluate the extent of flooding and flow conditions during these events.

Appendix A. Figures



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Grid: NAD 1983 StatePlane California VI FIPS 0406 Feet

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CITY OF CARLSBAD
CARLSBAD BLVD RDWAY RESILIENCY

Project No. **11215903**
Revision No. **-**
Date **10/1/2021**

VEGETATION

FIGURE 1

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Paper Size ANSI A

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Feet

Map Projection: Lambert Conformal Conic
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CITY OF CARLSBAD
CARLSBAD BLVD RDWAY RESILIENCY

TOPOGRAPHY AND HYDROLOGY

Project No. 11215903
Revision No. -
Date 10/1/2021

FIGURE 2

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Appendix B. Photo Index

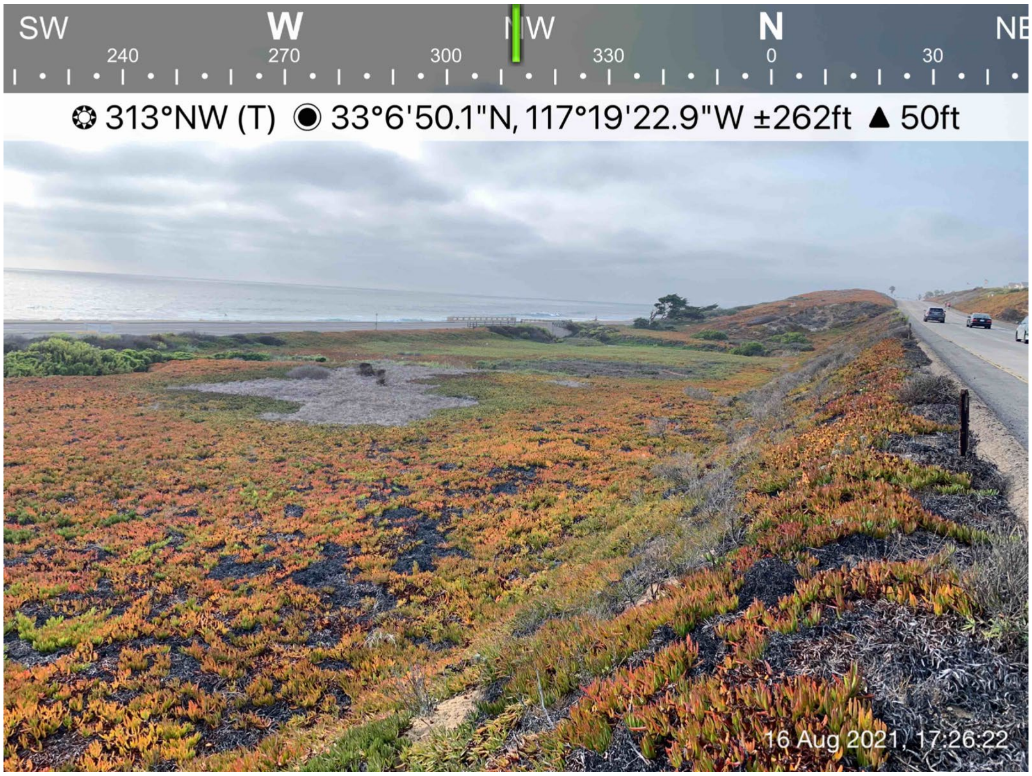

Photo 1. Overview of the western portion of the Study Area between northbound and southbound Carlsbad Boulevard, which is highly invaded by iceplant.

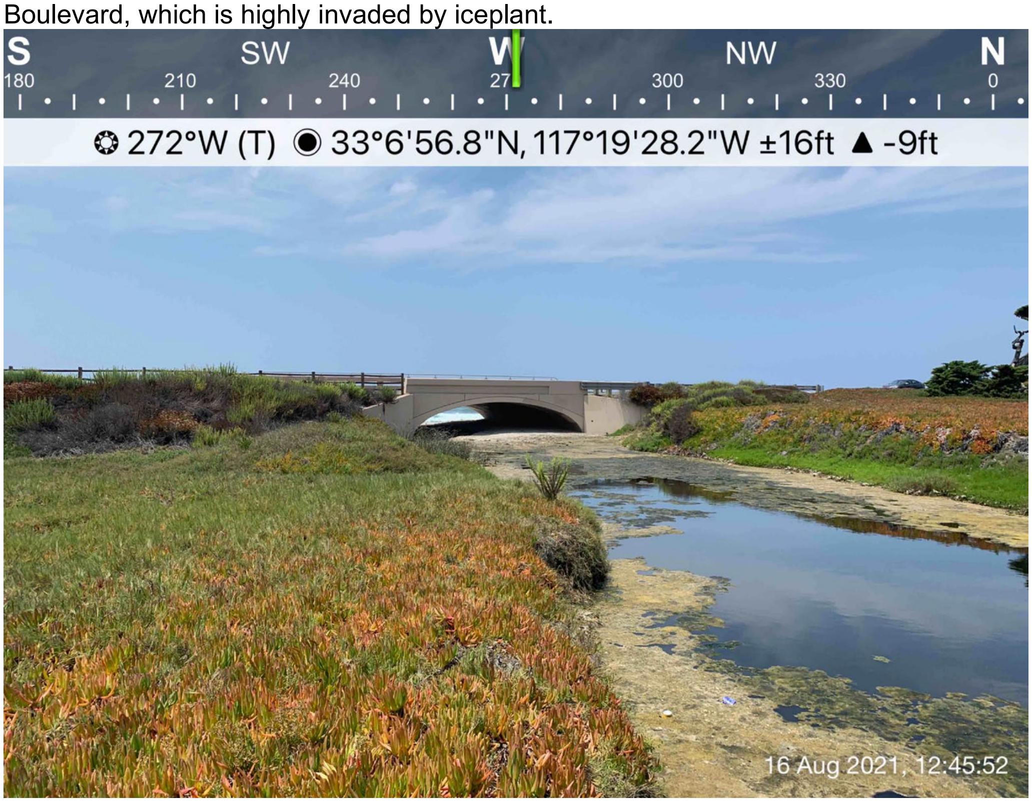

Photo 2. The mouth of Encinas Creek under southbound Carlsbad Boulevard.

Photo 3. The eastern half of the Study Area, seen from above the northbound Carlsbad Boulevard culvert.

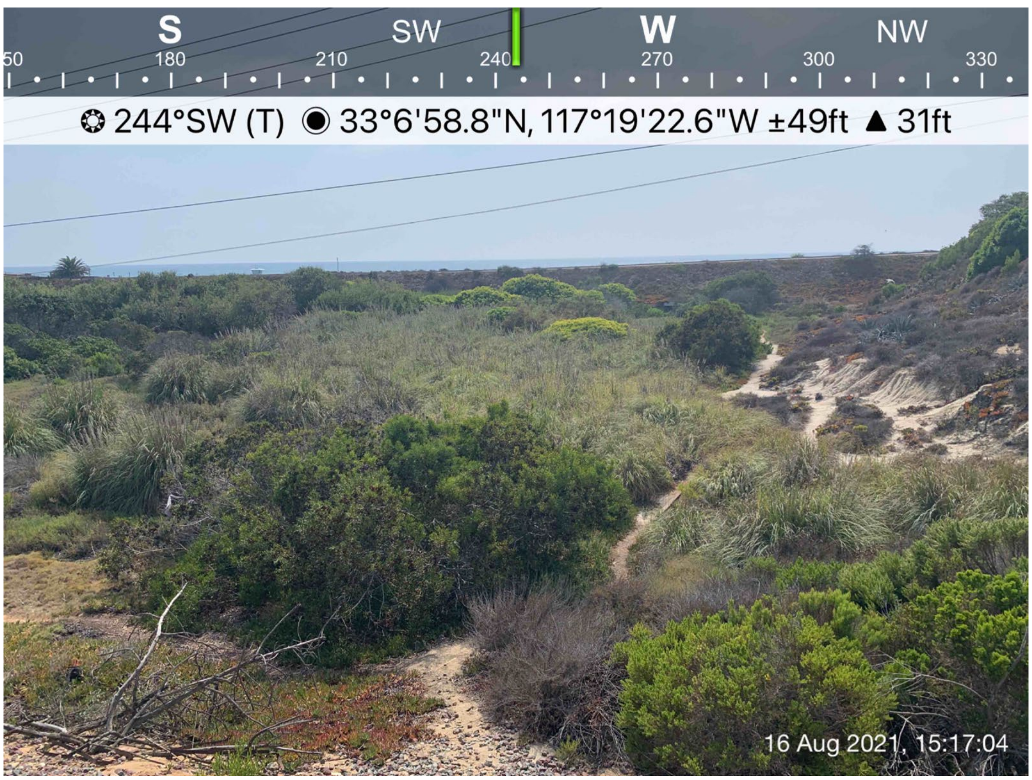

Photo 4. The eastern half of the Study Area, seen from the northeast corner of the Study Area.

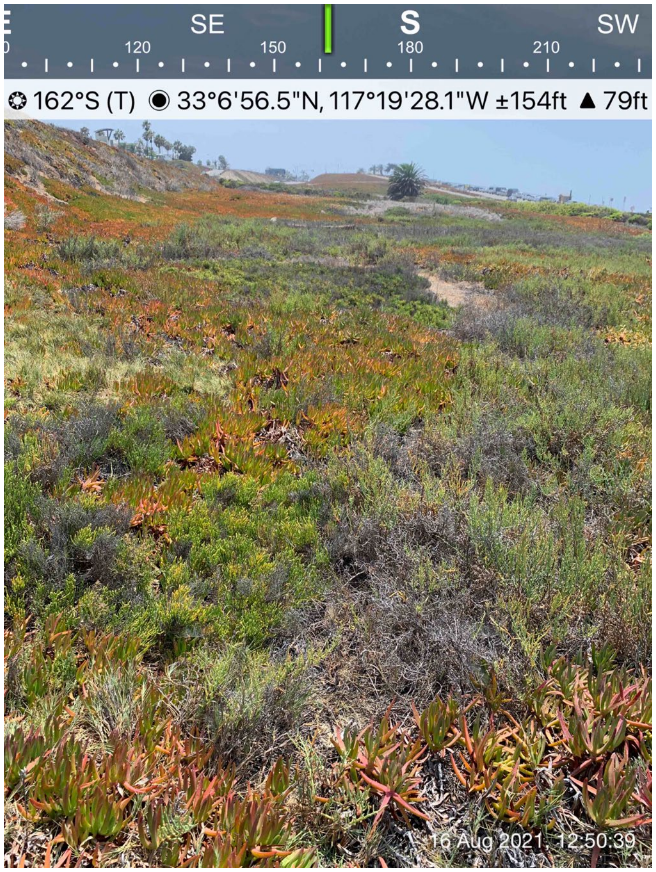

Photo 5. Pickleweed marsh to the south of the mouth of Encinas Creek was highly invaded by iceplant.

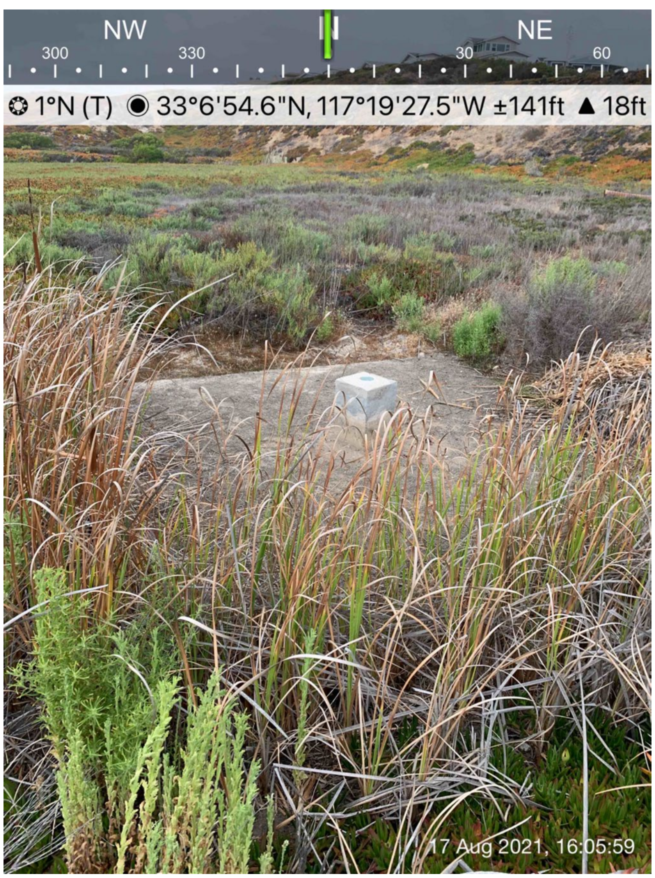

Photo 6. Pickleweed marsh south of Encinas Creek extended up to a concrete pad with a marker indicating the placement of the outfall pipe. Unusual patterns of dead vegetation and wetland plants such as cattails around the pad may indicate that the outfall pipe is another source of hydrology in the Study Area.

Photo 7. Pickleweed marsh extended nearly to the northeast edge of the Study Area in a high basin with cracked sandy soil.

Photo 8. Pickleweed marsh in the northeastern basin, surrounded by non-native scrub.

Photo 9. The northeastern pickleweed marsh bordered by dense pampas grass to the south.

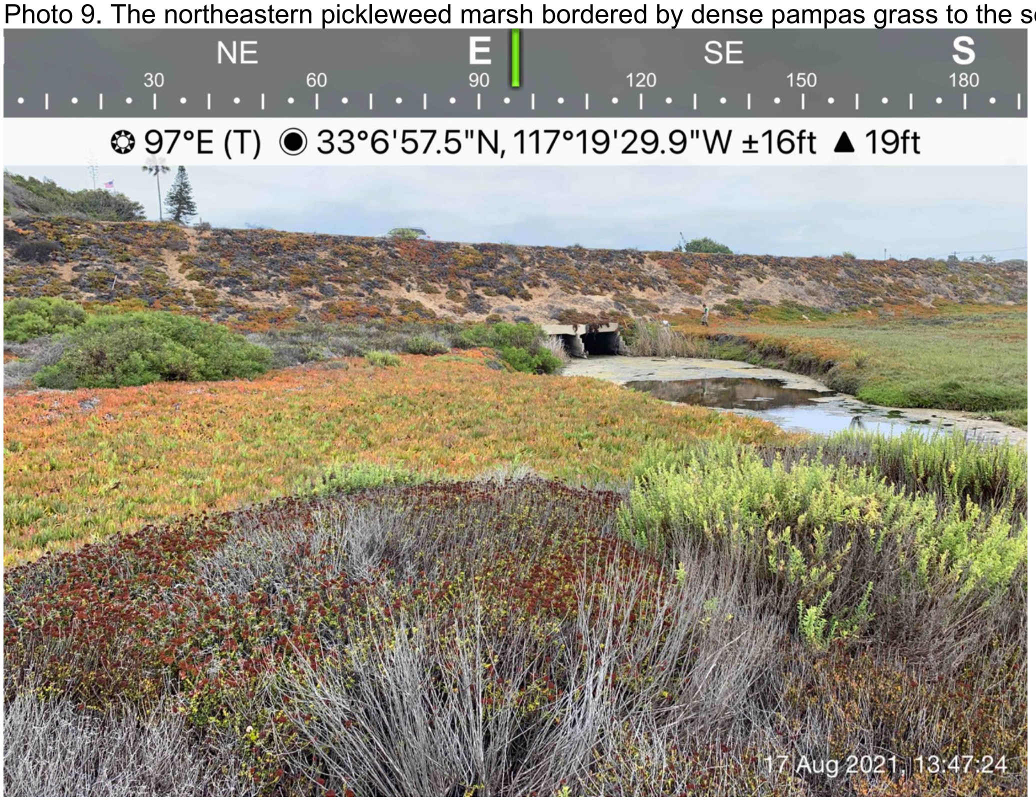

Photo 10. Menzies' goldenbush intergraded with the sage scrub community (see California buckwheat and Menzies' goldenbush in foreground) as well as dominating the lower brackish area with saltgrass and non-native scrub (shown in background north of the culvert).

Photo 11. Menzies' goldenbush with saltgrass and pickleweed dominated the northern bank of Encinas Creek east of northbound Carlsbad Boulevard.

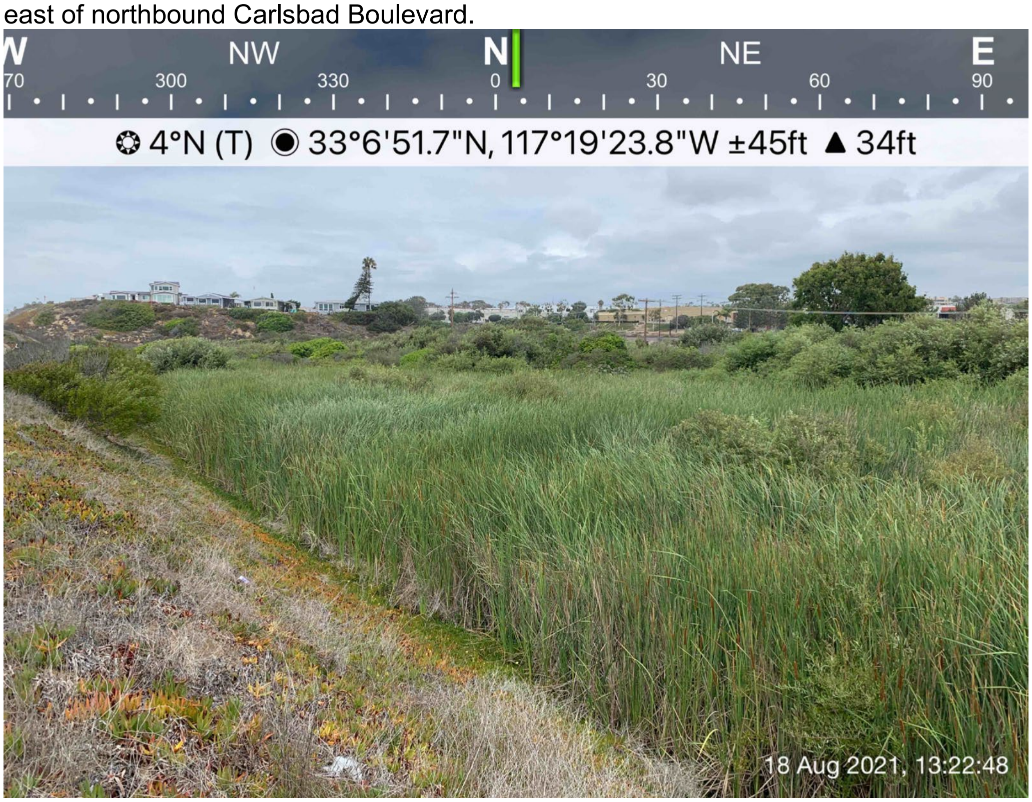

Photo 12. Southern cattail dominated the marsh east of northbound Carlsbad Boulevard.

Photo 13. The cattail marsh was bordered by dense arroyo willow.

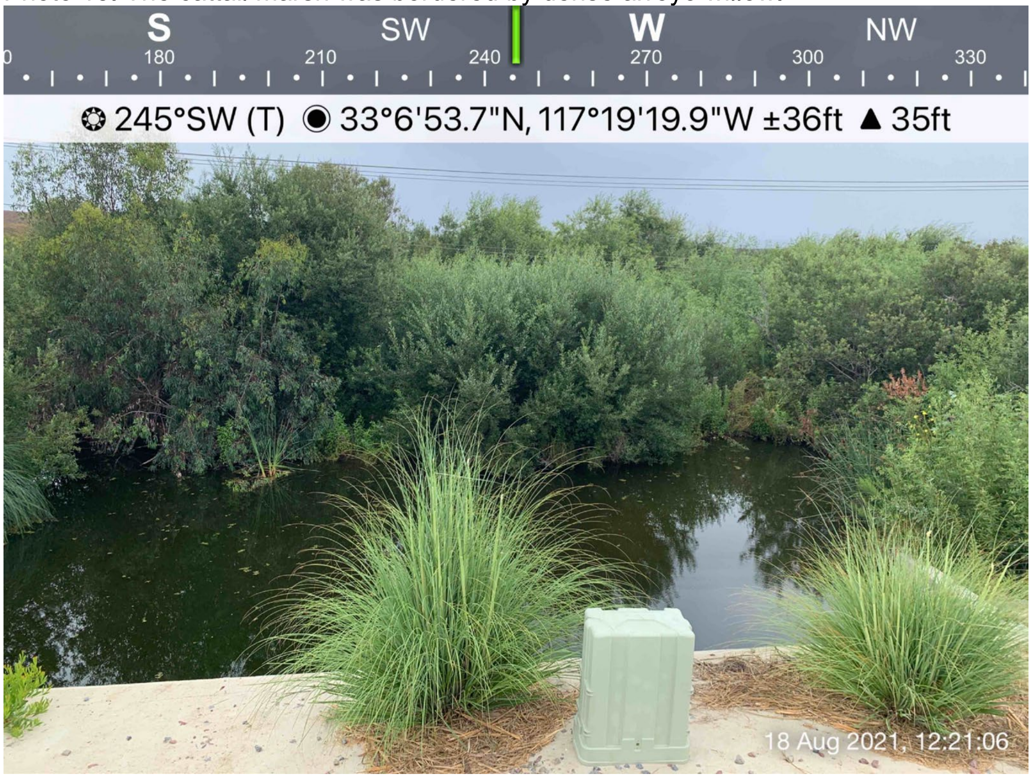

Photo 14. Dense arroyo willow surrounded the scour pool at the large Avenida Encinas culvert outlet.

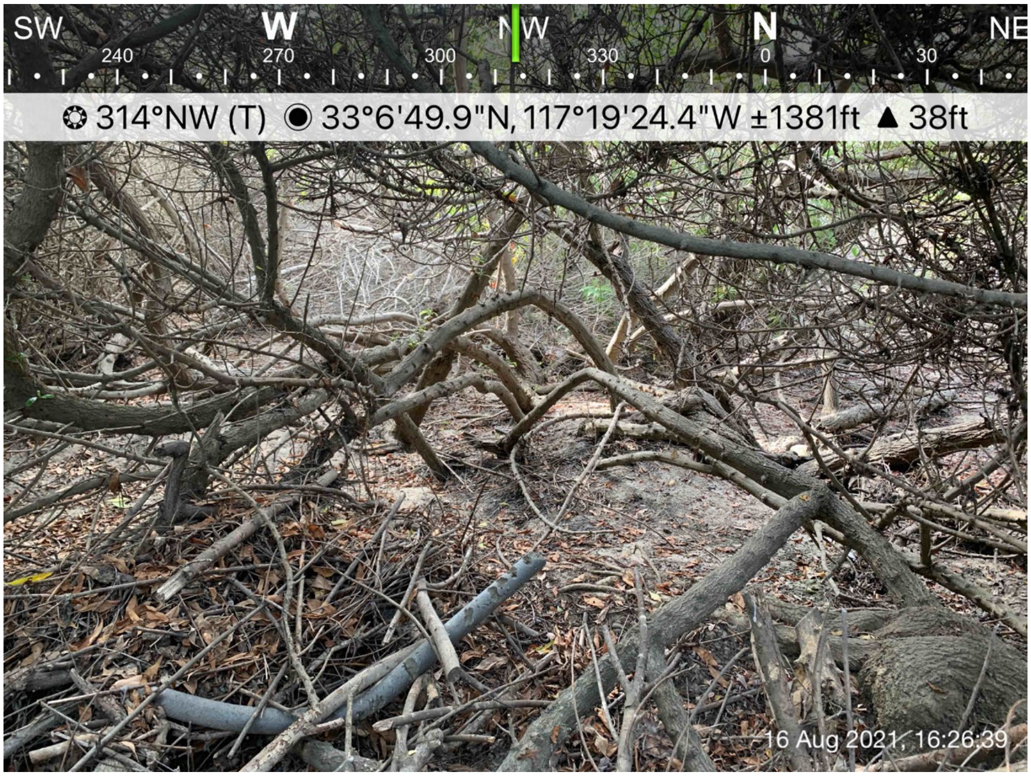

Photo 15. Dry braided channels and sediment deposits within the willow thicket.

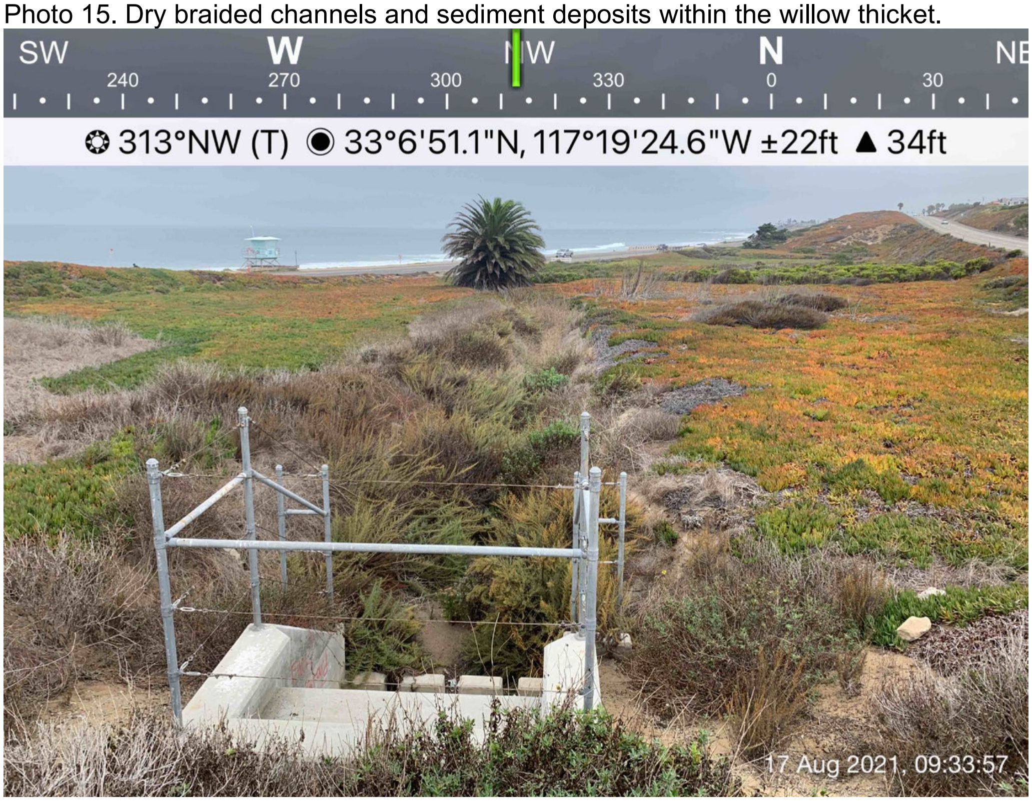

Photo 16. Coastal sage scrub surrounds the ditch on the southwestern side of the Study Area.

Photo 17. Patches of coastal sage scrub predominantly characterized by California buckwheat around southbound Carlsbad Boulevard.

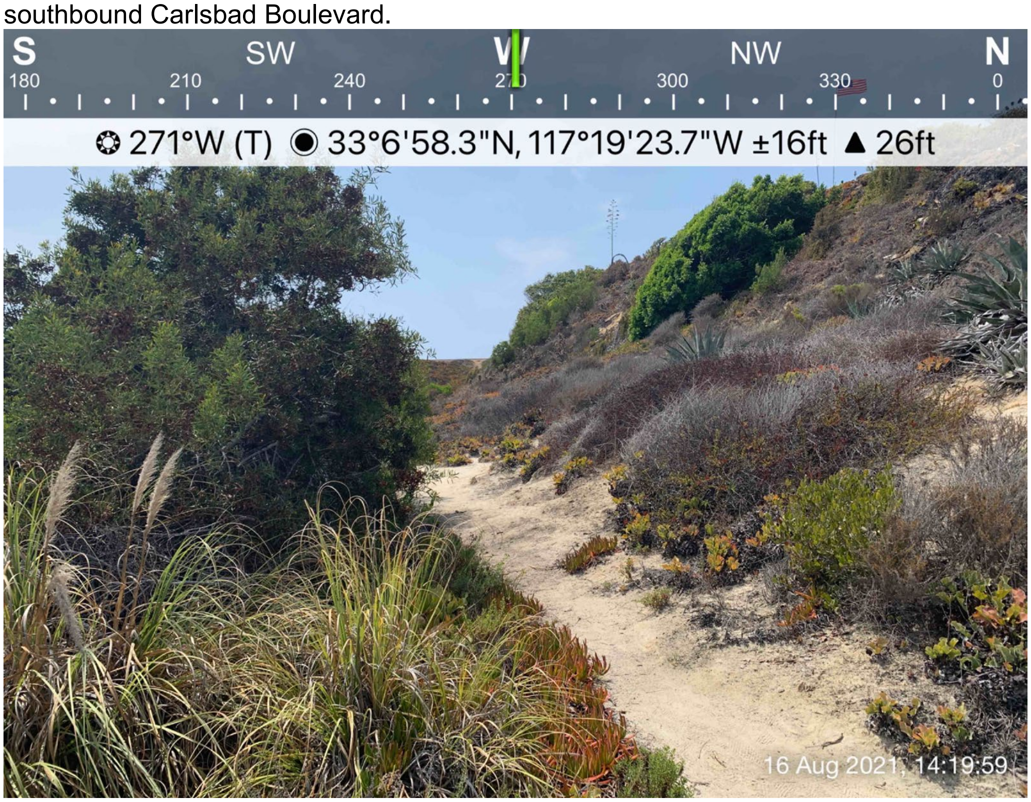

Photo 18. Coastal sage scrub with many non-native species at the base of the northern bluff east of northbound Carlsbad Boulevard.

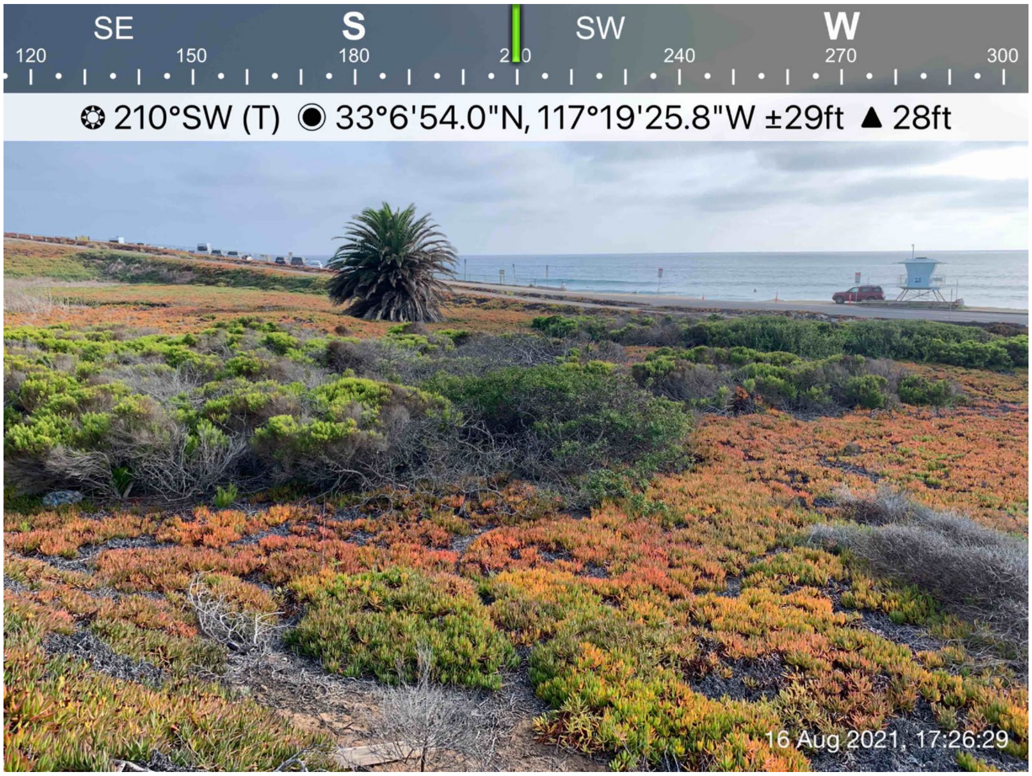

Photo 19. Coyote brush dominates a large patch of the western portion of the Study Area.

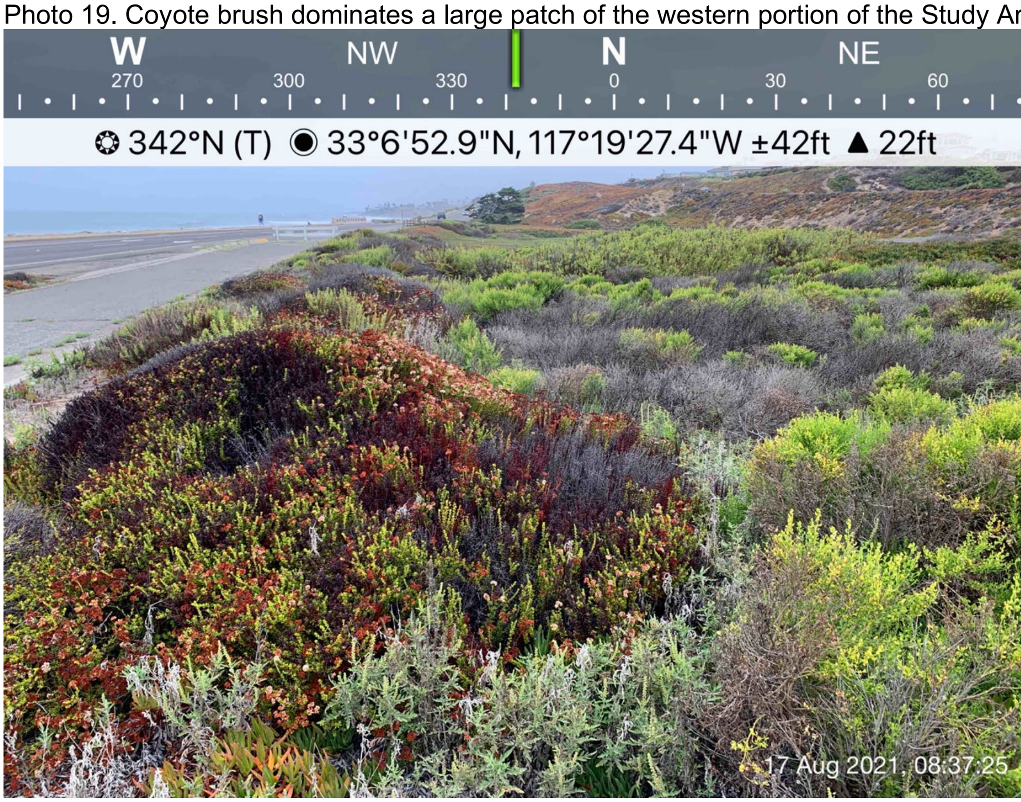

Photo 20. Coyote brush scrub intergrades with coastal sage scrub species such as California buckwheat.

Photo 21. Non-native scrub around Encinas Creek east of northbound Carlsbad Boulevard.

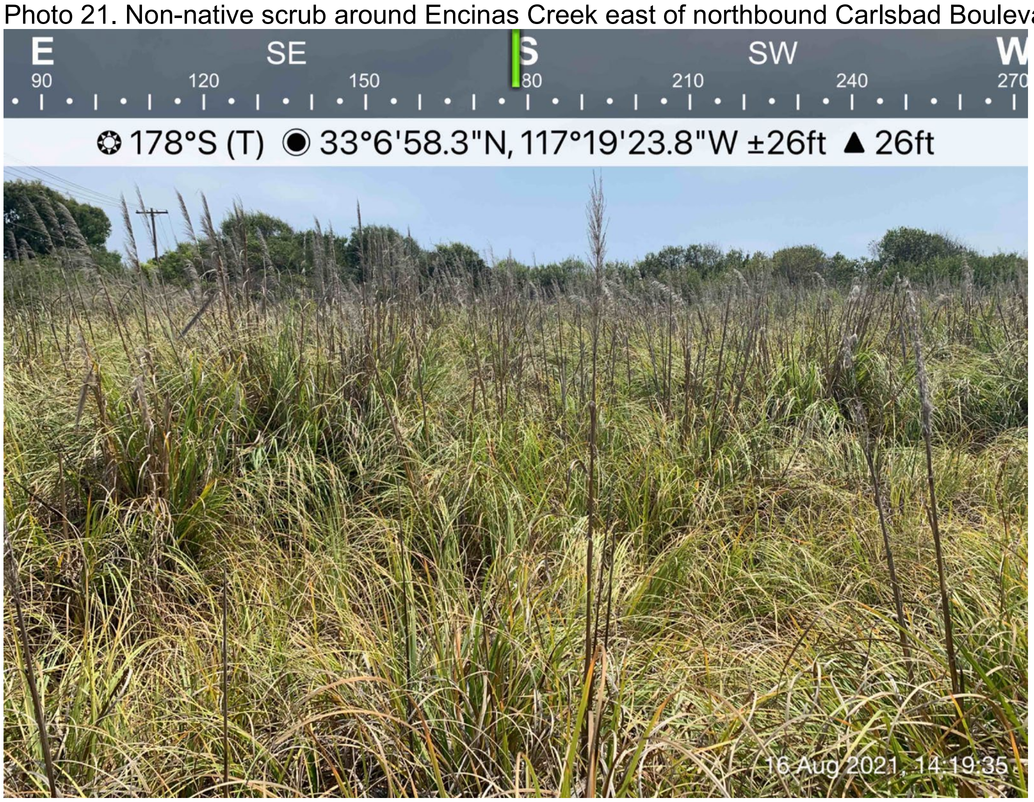

Photo 22. Dense pampas grass occurred in the northeast portion of the Study Area.

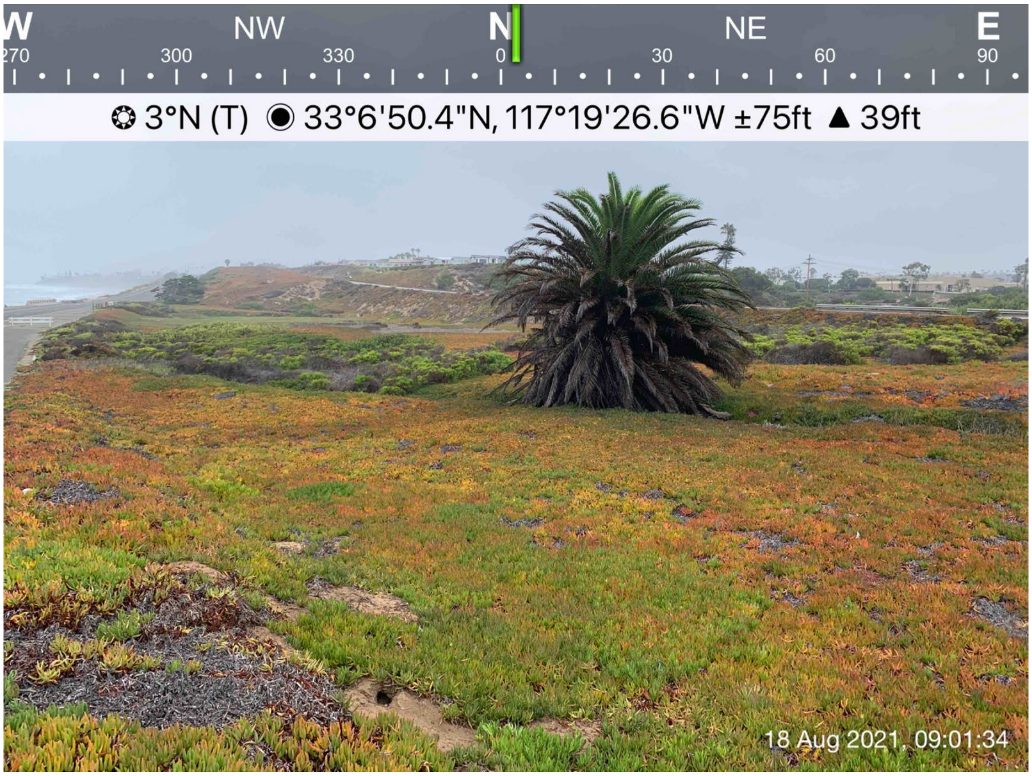

Photo 23. Iceplant has widely invaded the site and dense mats cover large areas of the Study Area.

Photo 24. A large scour pool occurs at the outlet of the large culvert under Avenidas Encinas.

Photo 25. The large scour pool appeared to be deep at the center, and depth at the thalweg is unknown.

Photo 26. A perennial channel flows west from the scour pool through the willow thicket to the cattail marsh.

Photo 27. A smaller culvert outlet under Avenida Encinas provides an additional source of seasonal hydrology.

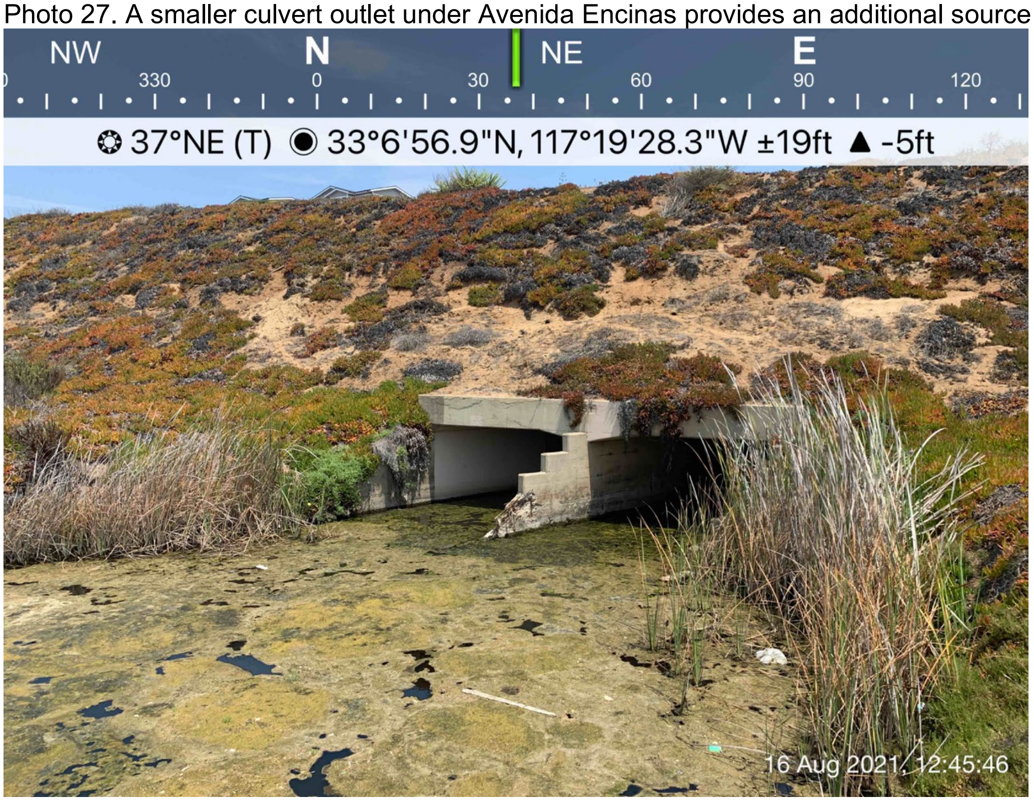

Photo 28. Encinas Creek is deeply scoured at the northbound Carlsbad Boulevard culvert outlet, and stagnant water was pooling at the time of the August surveys.

Photo 29. The culvert at southbound Carlsbad Boulevard has accreted beach sand and a low flow trickle drained Encinas Creek to the ocean outlet at the time of the August surveys.