Appendix A
Hydrologic and Hydraulic Study

ESA

Final

LOMA ALTA SLOUGH WETLANDS ENHANCEMENT

Hydrologic and Hydraulic Study

Prepared for
City of Oceanside

May 2020

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SECTION 1
Introduction

This report documents the hydraulic modeling of design alternatives for the Loma Alta Slough Wetland Enhancement project in Oceanside, CA. This report describes the modeling work completed to date and provides details on the project that can be used to inform the regulatory agency permitting processes, refine the project description for environmental review, and as a basis for initiating the final design.

1.1 Project Background

The Loma Alta Slough is a small, coastal, estuarine wetland located at the mouth of Loma Alta Creek next to Buccaneer Beach Park (**Figure 1-1**). The Slough is located in the City of Oceanside in north San Diego County, California. The Slough estuary has intermittent connection to the Pacific Ocean as a result of natural mouth closing and opening—the mouth closes naturally from sand deposited by ocean waves and currents in the spring and usually remains closed until storm flows breach the sand berm during the wet-weather season (September to April). The City of Oceanside does not dredge Loma Alta Slough open. The City manages the height of the sand berm and Slough water levels to keep the Slough closed during the summer months, prevent the flow of water with elevated bacteria levels from the Slough to the ocean, and maintain high water quality at Buccaneer Beach. The City manages Slough water levels during the summer months by intermittently pumping Slough water into a UV treatment plant. The estuary receives freshwater input from an approximately 6,300-acre watershed. When the lagoon is closed, standing water does not circulate and exchange with the ocean.

1.2 Previous Hydraulic Modeling

Previous modeling of the area was conducted for the Federal Emergency Management Agency (FEMA) and also by Rick Engineering, ESA, and Tetra Tech. Hydrologic and hydraulic analyses were conducted in 1982 to inform the FEMA Flood Insurance Study (FIS). In 2010, Rick Engineering prepared hydraulic analyses to support the design and construction of multiple detention facilities within the Loma Alta Creek and Garrison Creek watersheds. In 2015, ESA modeled the area as part of the Loma Alta Slough Vector Remediation Project (a previous iteration of the current restoration project), which planned to eliminate standing water for vector control. On behalf of the City of Oceanside, Tetra Tech modeled the area in 2019 to describe the impacts of the La Salina Wastewater Treatment Plant project on the FEMA Flood Insurance Rate Map (FIRM) floodplain. These reports and their results are summarized in the following sections.

Loma Alta Slough Restroration

Figure 1-1
Site Map

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1.2.1 FEMA Flood Insurance Study

In 2015, ESA submitted an FIS Data request for the FEMA model for Loma Alta Creek and received a HEC-2 model from 1982. According to the 2016 FIS for San Diego County, the hydrologic and hydraulic analyses were completed by George S. Nolte & Associates for FEMA in 1985. It is assumed that the received 1982 HEC-2 model was what was documented in the 1985 report. However, according to the 2019 FIS, the hydrologic and hydraulic analyses were completed in 1997 and their data are "not available". There are no additional notes regarding the Loma Alta Creek hydrologic and hydraulic analyses. ESA did not receive additional hydrologic or hydraulic data in its 2015 FIS data request, therefore, it is expected that the HEC-2 model dated 1982 is the most recent FEMA model. The FEMA model includes the 10-year (800 cfs), 50-year (2,500 cfs), 100-year (3,800 cfs), and 500-year (8,200 cfs) storm events.

1.2.2 Rick Engineering 2010

When the City of Oceanside was in the design and construction phase of multiple detention facilities within the Loma Alta and Garrison Creek watersheds, Rick Engineering modeled the proposed projects. They used the U.S. Army Corps of Engineer's HEC-1 and HEC-RAS modeling programs to prepare hydrologic and hydraulic calculations that summarize the corresponding discharges for the 6-hour duration peak runoff flow rates for the 10-year, 50-year, 100-year, and 500-year return frequency storm events. The hydrologic results showed a 10-year flow of 1,285 cfs and a 100-year flow of 2,859 cfs in the vicinity of the site. The 10-year flow is higher than that determined by FEMA (800 cfs), while the 100-year flow is lower (3,800 cfs).

The HEC-RAS model was run for historic, current, interim project, and ultimate project conditions. The interim conditions included the development of three detention basins, and the ultimate condition included four detention basins. The results showed that the FEMA model (historic conditions) showed lower water levels (1 to 3 feet) at the mouth of the lagoon, and higher water levels from South Coast Highway to north of Oceanside RV Resort (0.3 to 0.9 feet) than existing conditions.

The FEMA floodplain mapping does not account for the detention basins (i.e., a Letter of Map Revision or LOMR was not prepared).

1.2.3 ESA 2015

In 2015, ESA modeled the study area as part of the Loma Alta Slough Vector Remediation Project to consider alternatives for reducing standing water for vector control as part of a previous iteration of the current project. The initial planning/design phase included a hydrological and feasibility analysis to evaluate a range of alternative concept designs that addressed onsite vector habitat. The purpose of this study was to conduct a hydrologic and hydraulic analysis for the Loma Alta Creek Slough in order to determine the 2-year return period peak discharge as well as to determine the existing 2-, 10-, and 100-yr water surface elevations and flood inundation limits in the project area. The 10- and 100-year discharges were obtained from the current FEMA FIS and the San Diego Hydrology Model was used to determine the 2-year flow. The water surface elevation and flood inundation boundaries for all flows were determined using the U.S. Army Corps of Engineers' HEC-RAS hydraulic model.

1.2.4 Tetra Tech 2019

Tetra Tech prepared a Conditional Letter of Map Revision (CLOMR) application for the City of Oceanside, to describe the impacts of the Buccaneer Lift Station and La Salina Wastewater Treatment Plant Decommissioning projects on the FEMA Flood Insurance Rate Map (FIRM) floodplain. HEC-RAS version 5.0.6 (USACE 2018) was used to model the 100-year peak flow from the South Coast Highway to the Pacific Ocean. Four hydraulic models including a duplicate effective model, corrected effective model, existing conditions model, and post-project conditions model were created.

The project is not complete, so a LOMR has not been incorporated into the FEMA documentation for the area yet.

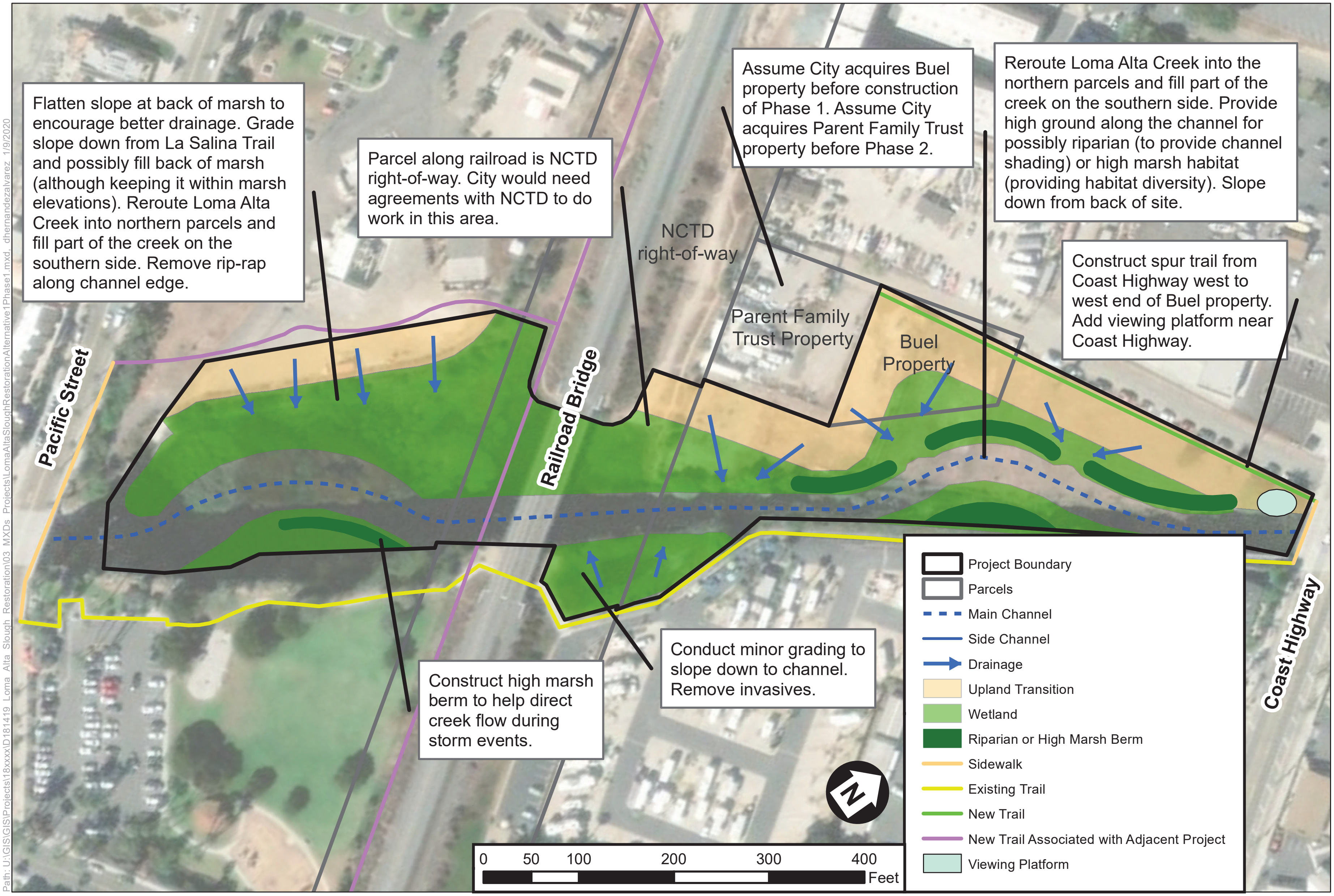
1.3 Project Description

Three conceptual project alternatives were developed for the project area. Alternative 1 would relocate Loma Alta Creek to create two channel meanders into the northern portions of the site, with one west of the railroad bridge and one east of the bridge (**Figure 1-2**). The alternative would include grading of the existing marsh area north of the creek to flatten the slope at the back of the site. On the south of the creek near Buccaneer Park, the former creek would be filled to create new habitat. East of the railroad bridge and south of the creek, the area northwest of Paradise by the Sea RV Park would be graded to improve drainage to the creek. North of the creek, the site would be graded to marsh elevations with a 50-foot buffer separating the marsh from adjacent development.

In Phase 2, assuming the city could acquire the Parent Family Trust Property, the property would be graded down to marsh elevations with a 50-foot buffer on the north of the site (**Figure 1-3**). A new channel would be excavated through the buffer in Phase 1 to connect the Parent Family Trust Property to the creek.

Alternative 2 would excavate perpendicular tidal channels from the creek into the existing marsh to improve drainage (**Figure 1-4**). East of the railroad bridge and south of the creek, the area northwest of Paradise by the Sea RV Park would be graded to improve drainage to the creek. North of the creek, the site would be graded to marsh elevations with a 50-foot buffer separating the marsh from adjacent development. Perpendicular tidal channels would be excavated to encourage improved flushing of the new marsh.

In Phase 2, assuming the city could acquire the Parent Family Trust Property, the property would be graded down to marsh elevations with a 50-foot buffer on the north of the site (**Figure 1-5**). The buffer area constructed in Phase 1 would be excavated down to marsh to increase the habitat connection between the properties. In Phase 2, the alternative could also include restoring the south side of the creek at Buccaneer Park, depending on a separate public planning process.



SOURCE:

Loma Alta Slough Restoration

Figure 1-2
Alternative 1, Phase 1

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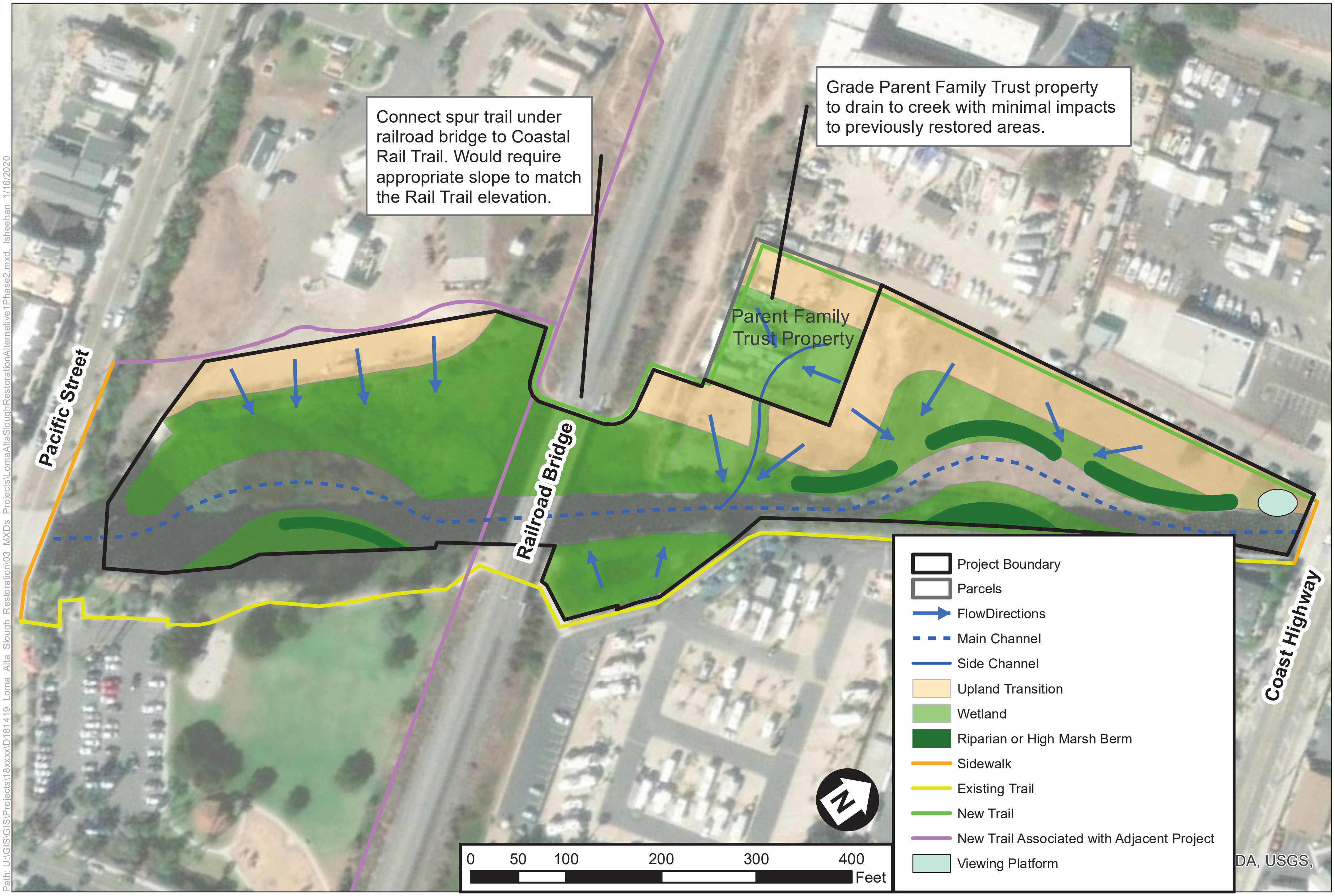

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Figure 1-3
Alternative 1, Phase 2

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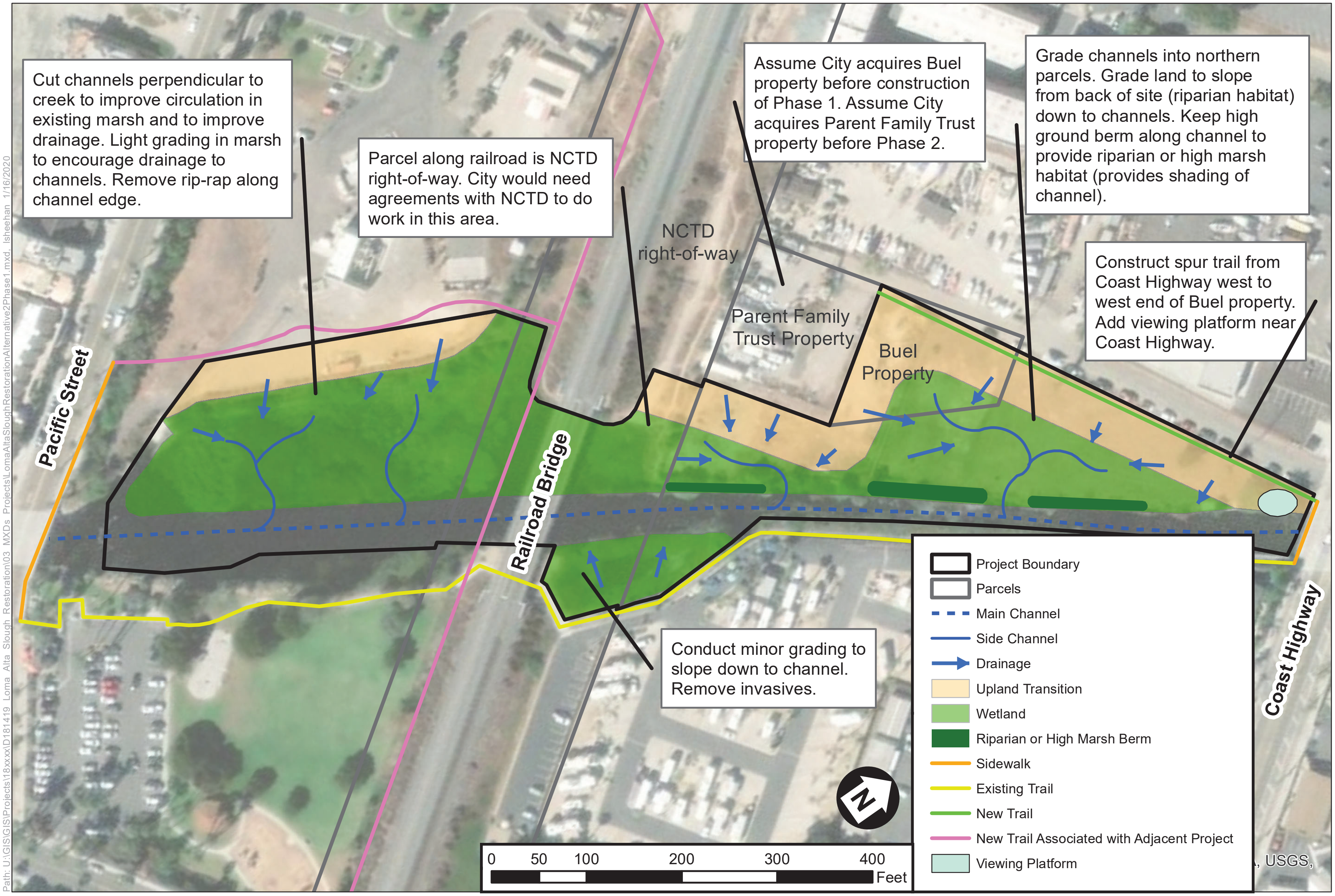

SOURCE:

Loma Alta Slough Restoration

Figure 1-4
Alternative 2, Phase 1

ESA

SOURCE:

Loma Alta Slough Restoration

Figure 1-5
Alternative 2, Phase 2

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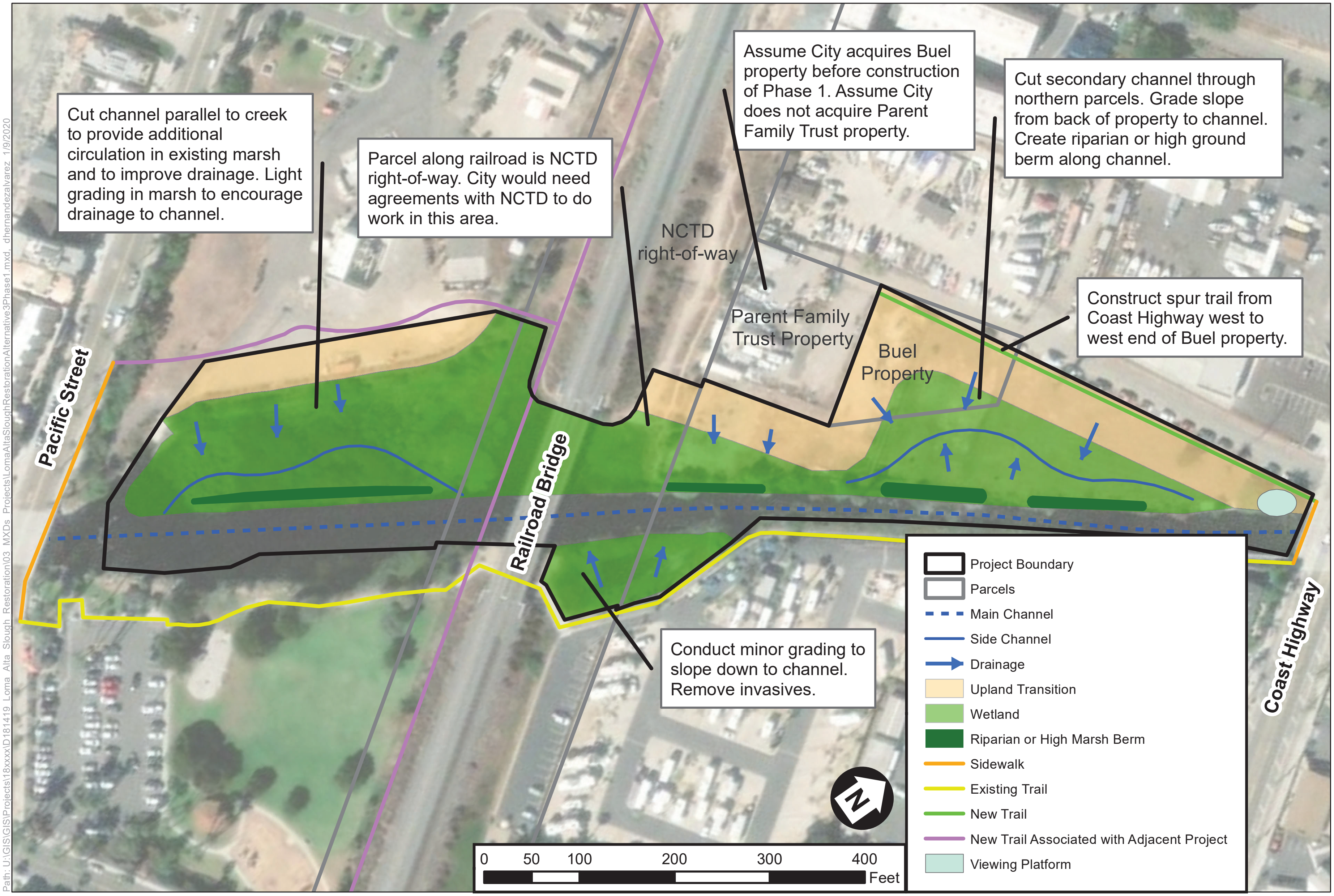
Alternative 3 would excavate a parallel side channel from the creek into the existing marsh to improve flushing (**Figure 1-6**). East of the railroad bridge and south of the creek, the area northwest of Paradise by the Sea RV Park would be graded to improve drainage to the creek. North of the creek, the site would be graded to marsh elevations with a 50-foot buffer separating the marsh from adjacent development. A parallel side channel would be excavated to encourage improved flushing of the new marsh. Alternative 3 would not include the Parent Family Trust Property, so there would be no Phase 2.

1.4 Study Approach

Focused hydrology and hydraulic studies were performed for existing conditions and the three restoration alternatives to assess the key processes that support restoration of habitats and functions to Loma Alta Slough. These studies include assessments of lagoon inlet dynamics (Section 2), hydraulics (Section 3), and eco-hydrology and sea-level rise (Section 4). The analyses focus on the final phase of each alternative.



SOURCE:

Loma Alta Slough Restoration

Figure 1-6
Alternative 3

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SECTION 2

Quantified Conceptual Model of Lagoon Opening and Closure

The purpose of the Loma Alta Slough lagoon inlet opening and closing dynamics modeling analysis is to inform the restoration design by:

- Providing a greater understanding of existing mouth dynamics, and
- Assessing the impact of restoration on lagoon and mouth function.

Section 2.1 provides a brief introduction to the modeling approach. Section 2.2 discusses the data sources and Section 2.3 summarizes the model scenarios. Section 2.4 provides the model results for existing and potential future conditions and Section 2.5 provides a summary of the results.

2.1 Lagoon Modeling Approach

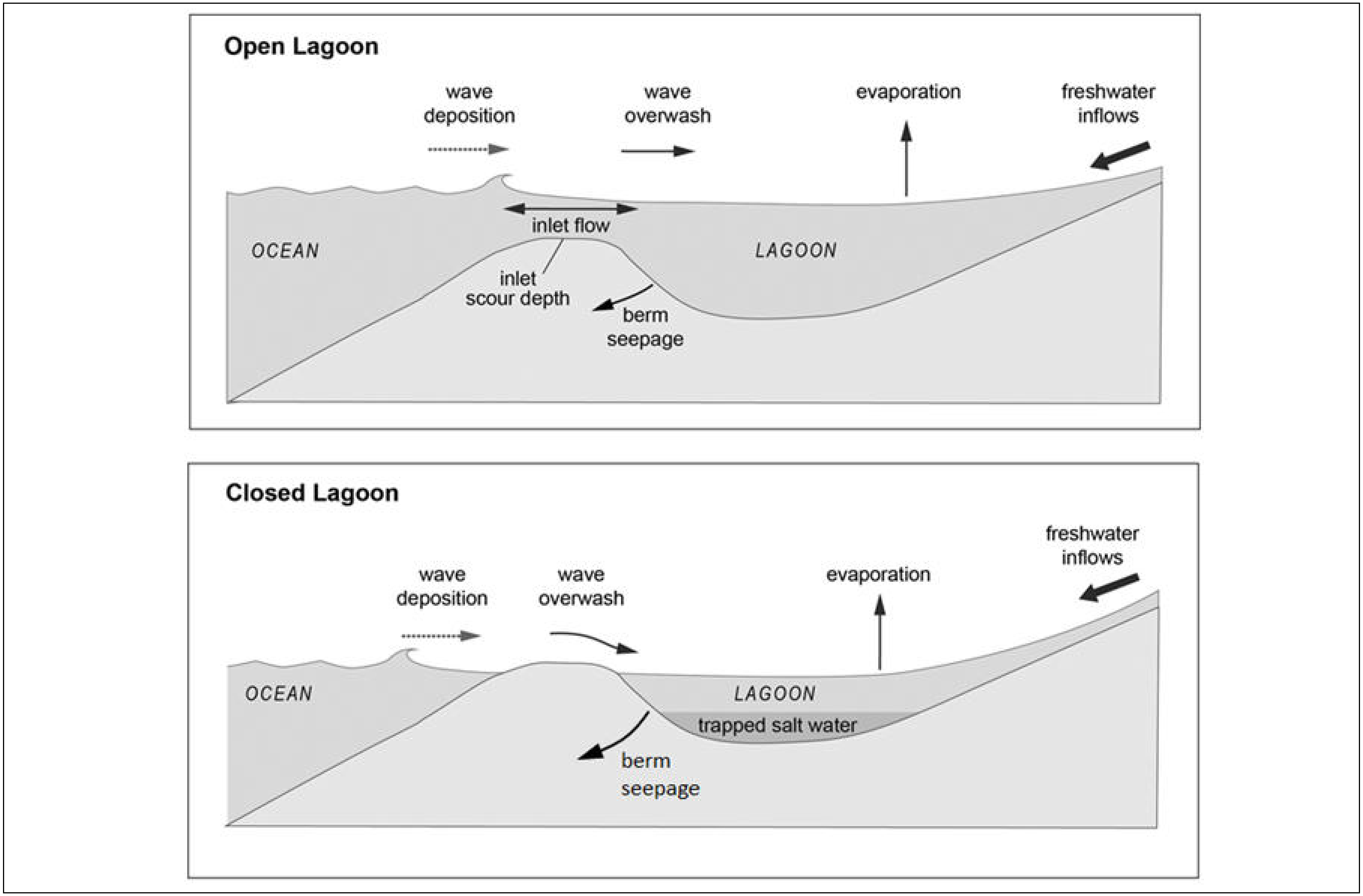
ESA has developed a lagoon hydrology/mouth morphology model to assess the mouth dynamics of coastal lagoons, referred to as the Quantified Conceptual Model or QCM. The QCM was applied to Loma Alta Slough under existing conditions, and was used to gauge the potential for change in mouth and lagoon conditions under a range of future conditions, which include the conceptual restoration alternatives and progressive amounts of sea-level rise. This model has been developed and tested specifically for small coastal lagoons in California, and provides time series predictions of lagoon water level and the timing and duration of mouth closure events.

The QCM approach is based on a water budget for the lagoon, which is coupled with a sediment budget for the lagoon mouth (inlet). The model is based on two core concepts:

- All water entering and leaving the system should balance.
- The net erosion/sedimentation of the inlet channel results from a balance of erosive (fluvial and tidal) and constructive (wave) processes.

The model uses time series of nearshore waves and tides, watershed runoff, and evapotranspiration data as boundary conditions. Using these as forcing conditions, the model dynamically simulates time series of inlet, beach, and lagoon state. With each time step, the net inflows or outflows to the system are estimated, along with the net sedimentation or erosion of the inlet bed.

As shown in **Figure 2-1**, the flow terms vary depending on whether the mouth of the lagoon is open or closed. During closed conditions, net inflows are based on watershed runoff, wave overwash into the lagoon, and losses from beach berm seepage and evapotranspiration. When the



SOURCE: Behrens et al. 2015

Loma Alta Slough Restoration

Figure 2-1
Schematic of Lagoon Hydrology with Intermittent Mouth Conditions

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inlet is open, tidal flows into and out of the inlet are included. Sand deposition in the inlet channel is based on wave power when the inlet bed is lower than ocean tides, and based on both wave power and wave runup when it is perched above tide levels. To approximate scour, inlet channel flows are used to estimate both the bedload rate and the rate that bed sediments mix with the water volume to become suspended load. For more information on how the model resolves different processes, refer to Behrens et al. (2015).

As the model steps forward in time, it continuously transitions the mouth through tidal, perched, and closed conditions. When deposition in the inlet bed exceeds erosion, the bed rises vertically, eventually perching above most tidal elevations and closing. Closure occurs in the model when sediment fills the inlet bed higher than lagoon water levels. Once closure occurs, the inlet thalweg effectively becomes the "beach," and the beach crest is allowed to grow vertically when wave runup reaches the crest height. Breaching occurs in the model when water levels eventually overtop the beach berm crest, eroding a new inlet.

Model accuracy is tested by comparing modeled lagoon water level time series against gauged observations, and by comparing the timing and length of inlet closure events to those of historical records. Although there are a large number of processes involved in this modeling approach, closure time series and lagoon water level time series usually provide a good indication of which processes are dominating the system at a given time, such as freshwater runoff during floods, or powerful waves prior to closure. Thus, approximately reproducing these time series is taken to mean that the dominant processes are meaningfully represented.

2.2 Data Sources

Table 2-1 lists the boundary condition data used for driving the model, along with observations of lagoon water level and mouth state (open or closed), which were used to train the model and test its accuracy.

Most boundary condition data were obtained from publicly-available sources. This included ocean tides from NOAA, nearshore wave estimates from CDIP, evapotranspiration data from CIMIS. Watershed runoff was estimated from a number of sources, since no long-term, continuous gauge data were available for the Slough. An approximate watershed runoff time series was developed by:

- Downloading long-term runoff data collected by the USGS at a number of nearby watersheds
- Scaling watershed runoff from these other sources to Loma Alta Creek, using watershed size as a scaling factor
- Comparing the scaled time series against the years when gauged discharge data were measured in Loma Alta Creek and ultimately choosing a site whose scaled runoff record was most similar (Trabuco Creek, near Dana Point)
- Developing a composite runoff record that included measured data at Loma Alta Creek when data were available, and replacing empty parts of the time series with scaled Trabuco Creek flows.

TABLE 2-1
SUMMARY OF SOURCES OF DATA USED FOR MODELING

Parameter	Source/Location	Measurement Period
Coastal Influences		
Offshore Waves	CDIP MOP Point D0881	1970–present
Tide Stage	NOAA La Jolla Gage (# 9410230)	1924–present
Beach and Lagoon Conditions		
Inlet Condition (Open/Closed)	City of Oceanside; ESA interpretation of water level data	2015–2019
Beach Crest/Profile	ESA surveys	2015–2019
Beach Sediment	ESA surveys	2015–2019
Lagoon Stage	City of Oceanside	2015–2019
Lagoon Hydrology		
Runoff	Trabuco Creek USGS# 11047300	2000–present
	City of Oceanside Loma Alta WSL at Intake	2015–2019
	Nature Collective* Loma Alta ALERT Station Flow and WSL	2004–2012
	Weston Solutions LLC Temporary Watershed Assessment Station (TWAS-1) Flow	2007–2015
Evapotranspiration	CIMIS Torrey Pines Station (#173)	2000–present

*Formerly San Elijo Lagoon Conservancy

Lagoon stage was provided by the City of Oceanside, and consists of daily values collected near the mouth of the lagoon. Daily values taken when the mouth of the lagoon was open to the ocean tended to match daily high ocean tides, so were probably collected at or near high tide each day. Because of this, these are not representative of the full range of water levels that would have been observed in the lagoon if hourly or more frequent measurements were taken. Daily values taken when the mouth of the lagoon was blocked by sand (‘mouth closure’) are more representative, since water levels tend to fluctuate less when tides are blocked by a closed mouth (ESA 2017; Jacobs et al. 2011).

A complete time series of mouth closure events was developed using observations from the City of Oceanside, along with ESA’s interpretation of the City’s water level data, which showed clear matching with high tides during open-mouth conditions and little day-to-day change during closed-mouth conditions.

A stage versus storage relationship was developed for the present-day lagoon by making a combined topographic/bathymetric digital elevation model (DEM) and processing the surface in ArcMap 10.6 to obtain volumetric information. The DEM was generated by combining the 2015 Aguirre & Associates’ site survey with ESA’s survey data from 2015 and 2019, 2014 USGS San Diego LiDAR, and 2016 USGS SoCal CoNED into a single surface. A stage-storage curve was also developed for each of the proposed alternatives based on the conceptual designs for each alternative. The amount of cut and fill within each alternative is so similar (since the site is relatively small and similar grading to reach marshplain would occur in all three alternatives) that the stage-storage curves were nearly identical between the alternatives. For this reason, the alternatives are discussed as one in the following sections.

Sea-level rise scenarios were chosen to match the scenarios in the City of Oceanside's Coastal Hazards Vulnerability Assessment. **Table 2-2** presents the scenario date ranges and corresponding amounts of sea-level rise. The short-term scenario of 0.8 feet of sea-level rise by 2025–2045 was not expected to have a substantial impact on the lagoon mouth dynamics, so this scenario was not modeled.

TABLE 2-2
OCEANSIDE SEA-LEVEL RISE SCENARIOS

		Potential Amount of Sea-Level Rise	
Scenario	**Date Range**	**(ft)**	**(m)**
Existing Conditions	Now	0	0
Short Term	2025–2045	0.8	0.25
Mid Term	2040–2070	1.6	0.5
Long Term	2070–2100	3.3	1
Longer Term	2100–2140	5.7	1.75

SOURCE: NRC 2012; Erikson et al. 2017

2.3 Model Scenarios

To provide a baseline for comparison, the QCM was used to create a hindcast of lagoon mouth conditions and lagoon water levels in Loma Alta Slough from May 15, 2015, to May 15, 2019. The hindcast was refined using the available data on lagoon water levels and mouth conditions. Then, to model future conditions, the same time period was run with different lagoon stage-storage relationships to reflect restoration alternatives and then lastly, with sea-level rise. The QCM was run for the following cases:

- **Existing Conditions:** A hindcast of 2014 to 2019 to train the model against water level and mouth conditions observations over this period. This was used as a way of understanding the level of uncertainty in future predictions.
- **Project Conditions:** These runs were used to predict changes to the hydrology and mouth morphology of Loma Alta Slough under the restoration alternatives described in Section 1.3. The Project Conditions runs represent all three restoration alternatives due to almost identical stage-storage curves.
- **Future Conditions:** These runs were used to understand the combined effects of sea-level rise with the present-day lagoon, and sea-level rise with the restoration:
  - Existing conditions with 1.6 feet SLR (Mid-term scenario)
  - Existing conditions with 3.3 feet SLR (Long-term scenario)
  - Existing conditions with 5.7 feet SLR (Longer-term scenario)
  - Project conditions with 1.6 feet SLR (Mid-term scenario)

- Project conditions with 3.3 feet SLR (Long-term scenario)
- Project conditions with 5.7 feet SLR (Longer-term scenario)

2.4 QCM Results

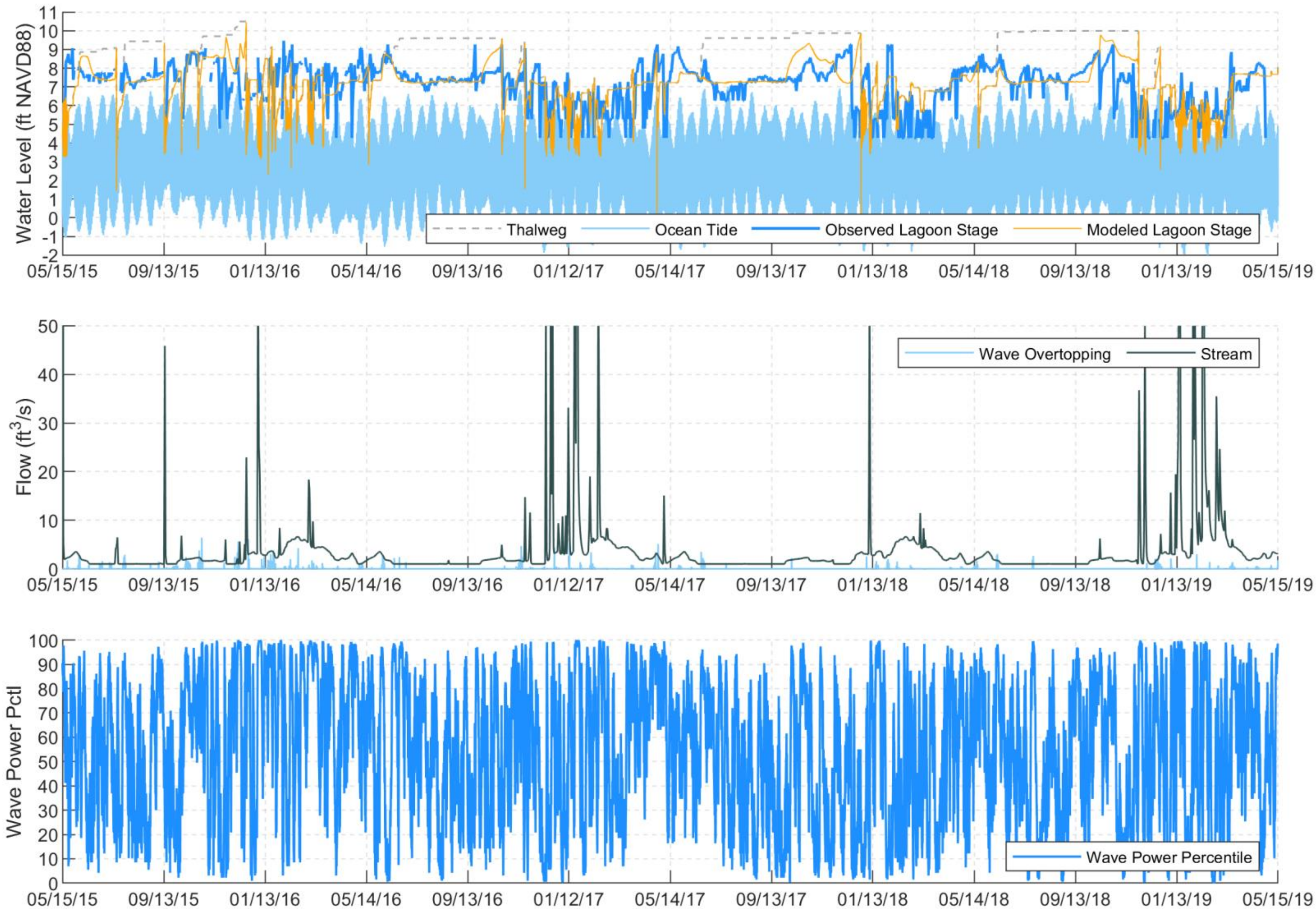
2.4.1 Existing Conditions

The model hindcast of existing conditions is shown in **Figure 2-2a**. Overall, the model compares well against the available data. The model reproduces a number of important aspects (**Figure 2-2b**), such as (1) periods of inlet scour during spring tides and high watershed runoff, (2) seepage losses and (3) sediment accumulation during closure, (4) the progressively shallower mouth cutting off lower tides in the lagoon, (5) subsequent inlet closure, and (6) inlet breaching. Also, despite the complexity of the Loma Alta Slough system, the QCM mostly predicts the timing of closure and breach events within a couple of weeks.

During relatively-wet conditions, the model reproduces the observed deep scouring of the mouth and periods of strong tidal communication between the lagoon and the ocean. The timing of scouring and stronger tidal communication suggests the system is dominated by runoff events causing peaks in streamflow entering into the lagoon. The model usually approximated flood stages to within about 1 to 2 feet of the observations, both during open-mouth fluvial flood conditions (peaks of 7 to 9 feet NAVD88) and during closed-mouth flooding immediately before mouth breach events (peaks of 8 to 10 feet NAVD88), although the model also misses flood peaks periodically. The model approximates the progressive shallowing of the mouth (cutting off low tides in the lagoon) prior to seasonal closure events, capturing the transitional weeks of muted tides that lead up to closure events in most years.

The model predicted all of the observed seasonal closure events to within a few weeks of the observed date (Figure 2-2a). Periodically the model predicts a breach during a period of high runoff, while the short breach was not observed, or skips a breach (May 2016). The model captures a key aspect of intermittently open and closed lagoons: closures are commonly associated with heightened wave power, weaker tidal currents, or both. Sediment transport increases with wave power, so days with powerful waves are expected to have more sand deposited in the inlet bed. Neap tides occur bi-weekly (i.e., every two weeks) and are associated with tide ranges of less than 4 feet, compared with over 6 feet for spring tides. Smaller tide ranges correspond to a smaller tidal prism and thus smaller flows through the inlet. During neap tides, tidal flows in the inlet have less capacity to erode away sediment deposited from waves.

To further test model accuracy, the water level exceedance in the lagoon and the seasonal closure pattern were examined in more detail. The left panel of **Figure 2-3** compares modeled and observed water level exceedance in the lagoon. This is a measure of how often water levels are greater than or equal to a certain value (e.g., water levels rarely exceed 9 feet NAVD88 but are usually above 4 feet NAVD88). The model slightly over predicts the amount of time that water levels exceeded 8 feet NAVD88, and slightly under predicts the time spent below 5 feet NAVD88, but does not show a systematic bias towards over-or under-prediction. The right panel of Figure 2-3 compares the observed and modeled number of mouth closure days per month from 2015 to 2019. The model



SOURCE: ESA 2020

Loma Alta Slough Restoration

Figure 2-2a
Time Series, Hindcast of Existing Conditions

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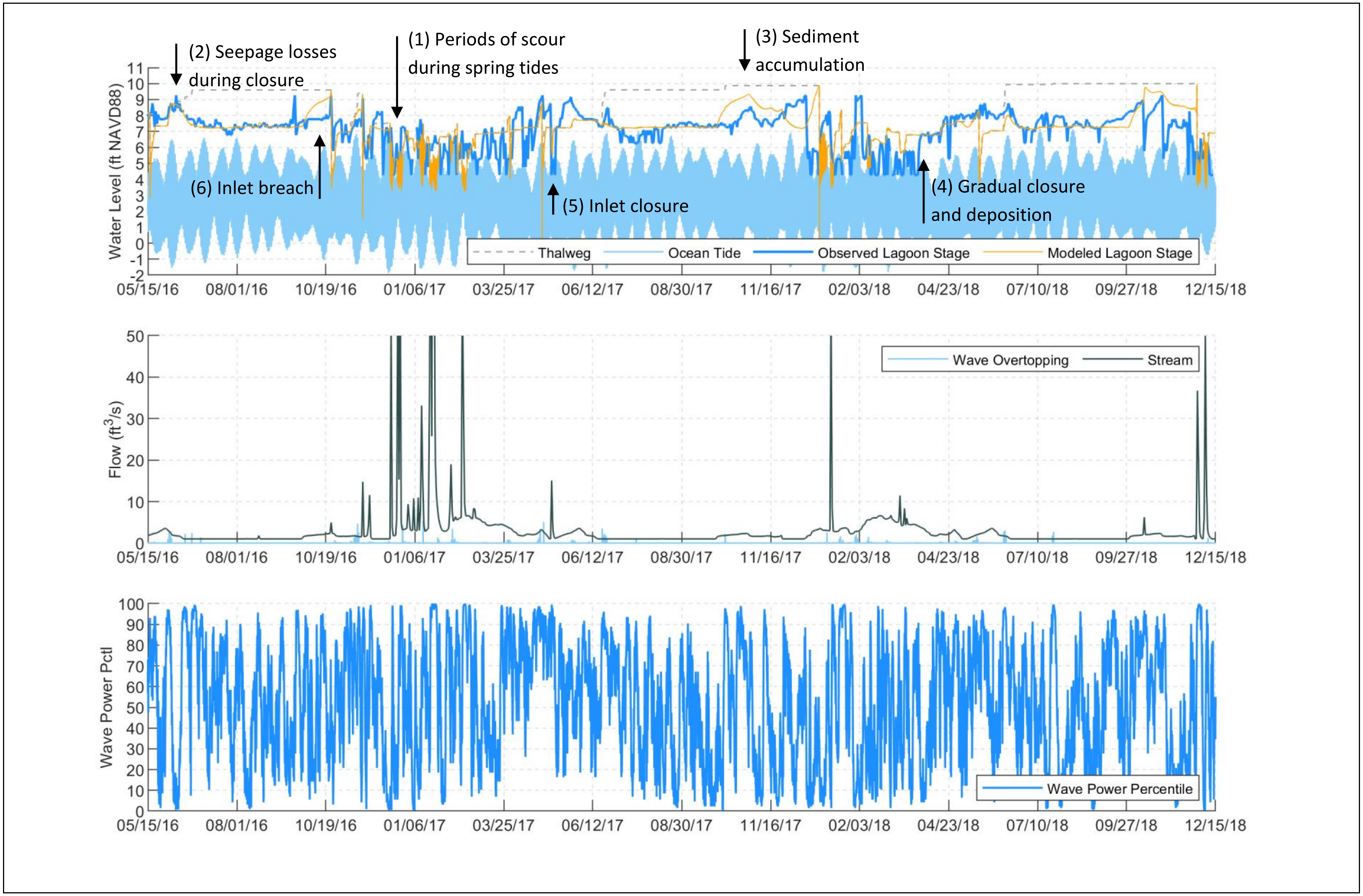

SOURCE: ESA 2020

Loma Alta Slough Restoration

Figure 2-2b
Time Series, Hindcast of Existing Conditions (Zoomed)

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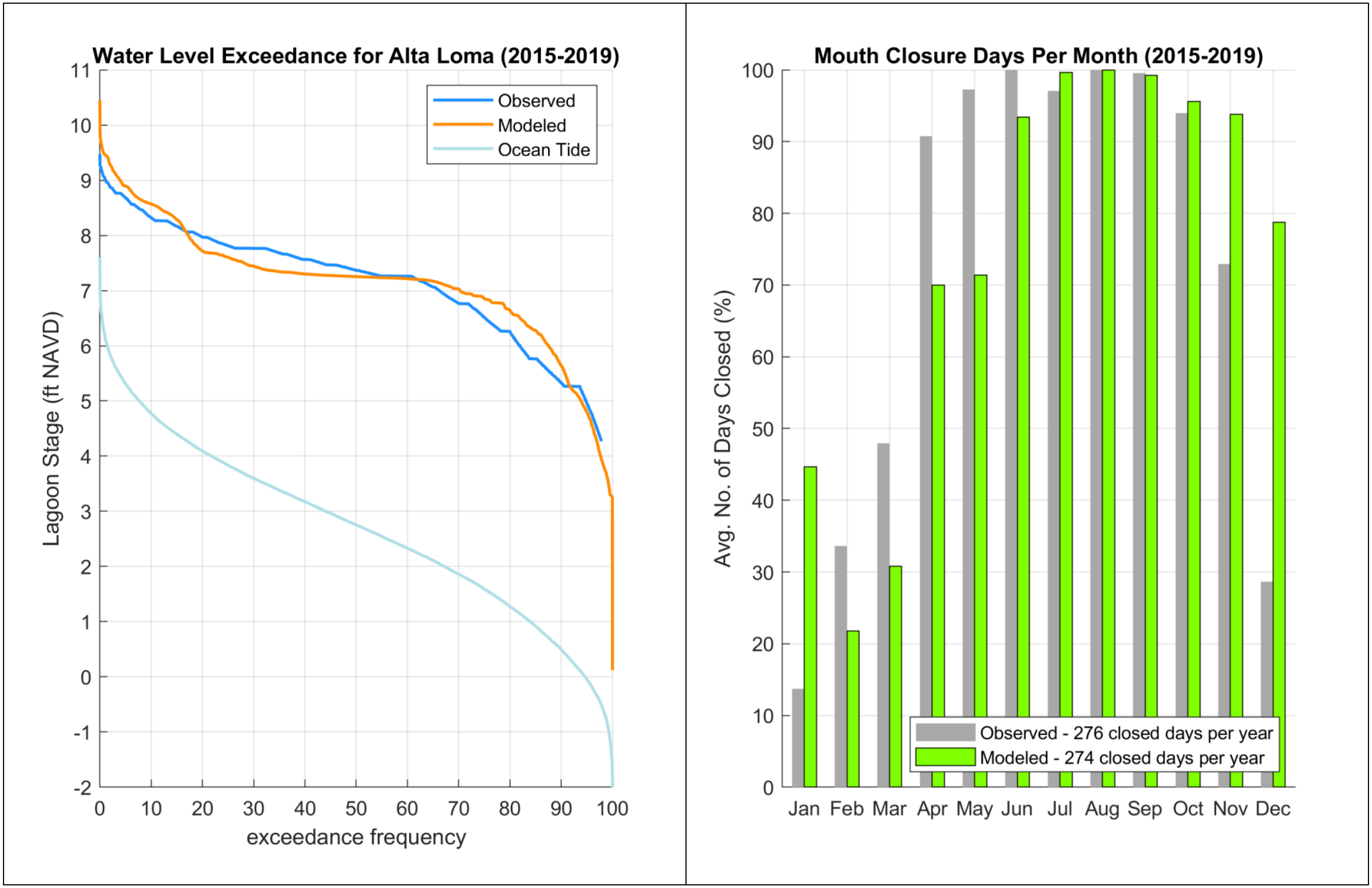


SOURCE: ESA 2020

Loma Alta Slough Restoration

Figure 2-3
Water Level Exceedance Curves

performs well in reproducing the number of days closed per year (274 predicted compared to 276 observed). The model correctly predicts the seasonality of lagoon mouth closure, with a peak in inlet closure from spring to fall and lower closure likelihood in winter. However, the model tends to over-predict the number of closure events in December and January, and slightly under-predicts closure from February to May. This may suggest that the model is not sensitive enough to higher flows in winter (which create stronger currents to keep the mouth open), and possibly not sensitive enough to wave deposition events in spring. Since freshwater runoff data were not available during the model period and had to be estimated, this is likely also a response to differences between the estimated and real seasonal hydrograph, which may under-predict peak flows in winter and under-predict flows in spring. While the model may not capture the exact timing or frequency of the closures, it provides a conceptual understanding of the typical dynamics of the system and how those could change with the project (see Section 2.4.2).

The Loma Alta Slough is a small system, and thus highly sensitive to wave power, streamflow, and all lagoon dynamics. The QCM could be refined further by gathering water level data from logging devices, to better capture variation in water levels when the mouth of the Slough is open.

2.4.2 Project Conditions

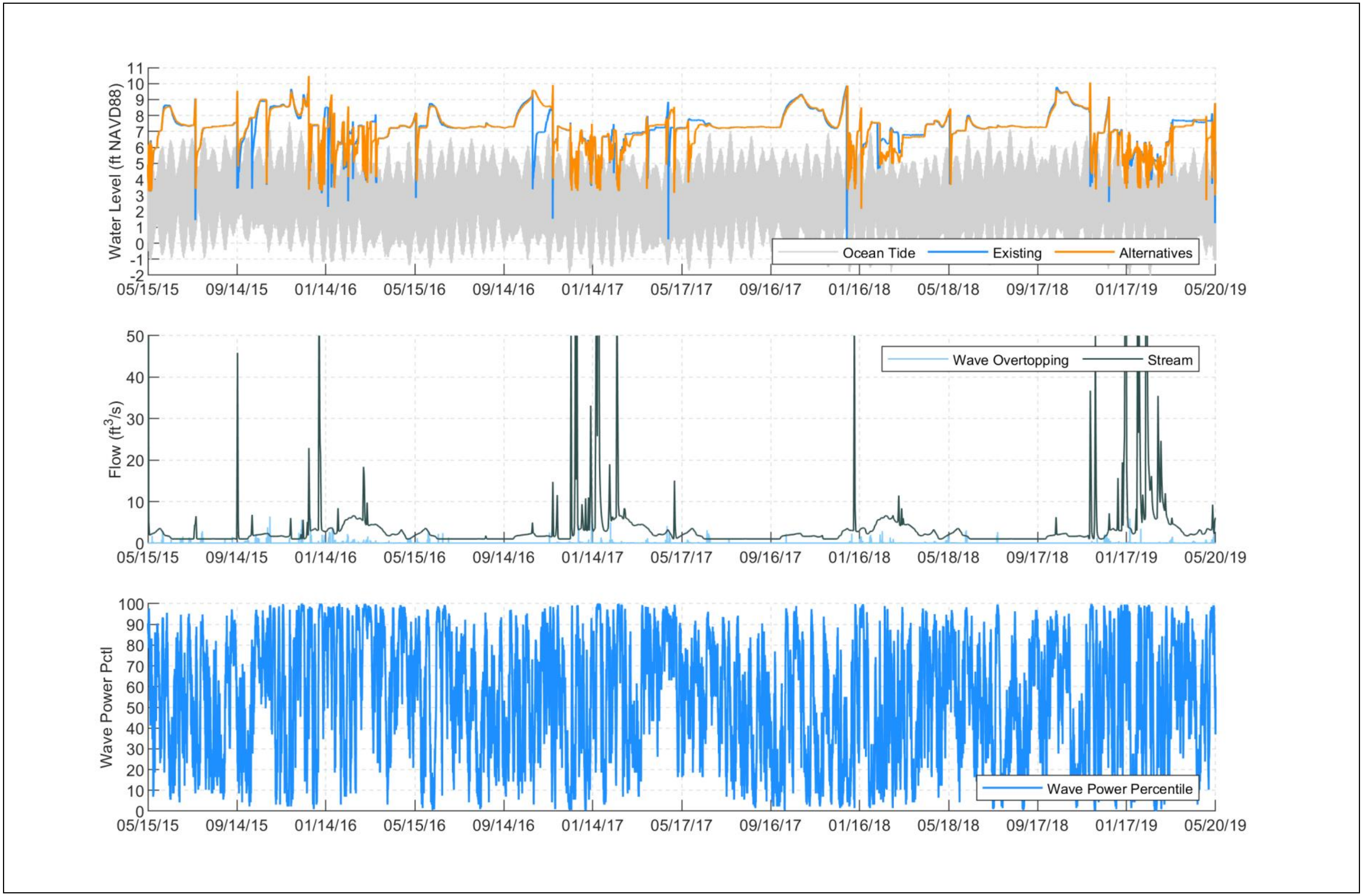
The model shows that the system is closed slightly more often in project conditions than under existing conditions (**Figure 2-4**). As **Figure 2-5** shows, the lagoon is closed about 10% more often in February, 5% more often in April, and 1-2% more often in November and December. This equates to only about 5 more days closed per year during the 2015–2019 model period.

The model results show that there are times when the mouth tends to stay closed under project conditions when a breach would have occurred under existing conditions (Figure 2-4). This occurs during minor rainfall events in October 2015 and October 2016, inducing discharges of approximately 5 to 7 cfs into the lagoon (October 2015 and 2016). This difference is a result of the slightly-larger volume of the lagoon with the project, which would take longer to fill before breaching for the same inflows. The project conditions did not alter the timing of seasonal breaching in late fall-early winter, when larger rainfall events typically lead to 10 to 50 cfs storm event discharges into Loma Alta Slough.

The model also shows that while the lagoon is open and nearing a closure event (late spring/early summer) water levels under project conditions are lower than existing conditions (by 0.1 to 0.3 feet). The difference in water levels is most likely due to the larger tidal prism of the restoration alternatives, which would increase the velocity of currents in the mouth, making it more difficult for waves to deposit sediment. The lower channel elevation at the mouth then results in lower water levels within the lagoon under the project conditions.

2.4.3 Future Conditions

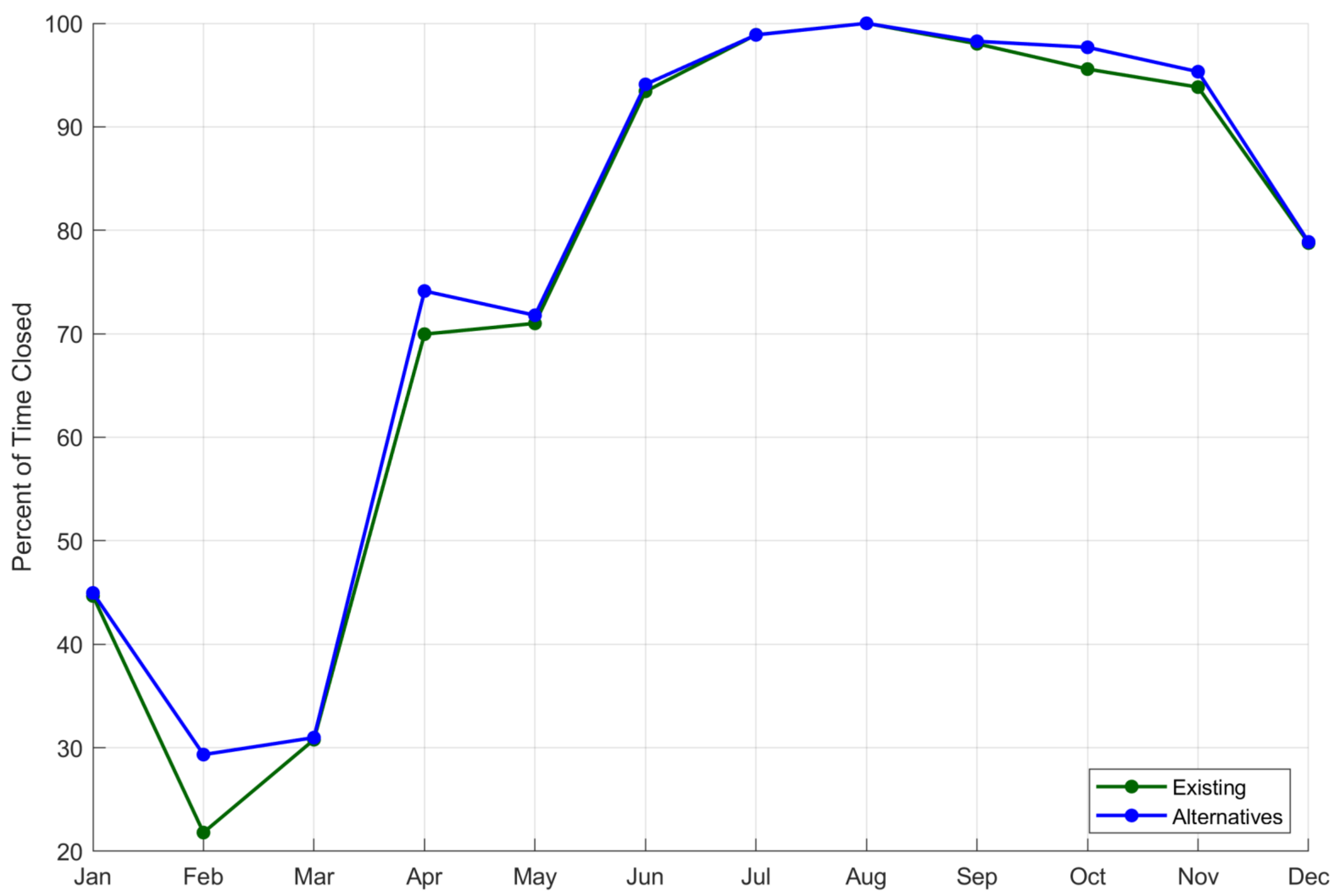
To explore how future changes in sea level could influence the behavior of the lagoon, sea-level rise was added to the existing conditions' and project conditions' 2015–2019 time series. To test the sensitivity of the lagoon to these scenarios, the ocean tides were increased by the corresponding sea-level rise amounts above current levels. It was assumed that the beach would remain a similar



SOURCE: ESA 2020

Loma Alta Slough Restoration

Figure 2-4
Time Series, Existing vs. Project Conditions



SOURCE: ESA 2020

Loma Alta Slough Restoration

Figure 2-5
Closure Seasonality, Existing vs. Project Conditions

height above tides as it does presently (i.e., the beach would grow vertically to keep pace with sea-level rise). This is a reasonable assumption given that the processes that form the beach (constructive building from wave action) are expected to simply shift upward with the tides. The beach width was assumed to remain the same in the future.

As shown in **Figure 2-6a** and **Figure 2-6b**, the model results suggest that there is an overall trend toward more inlet closures with increased sea-level rise, initially. However, when sea-level rise reaches 5.7 feet, the model shows the lagoon will be open more often (**Table 2-3**). Increased sea level is equivalent to adding volume in the lagoon, since previously-dry areas would become inundated as the tides shift upwards. Although this expands the tidal prism and thus makes it harder for the inlet to close, this larger lagoon volume also takes longer to fill, meaning that it would also take longer for the lagoon to breach during closure events. As sea-level rise continues to more extreme levels (above 5.7 feet) the tidal prism would eventually inundate much of the surrounding areas, and become dramatically larger than its current state. However, unlike larger and flatter systems (e.g., Los Peñasquitos Lagoon) the shift in tidal prism of Loma Alta Slough is not big enough to incur a dramatic increase in prevalence of open-mouth conditions. Additionally, the model assumes that the surrounding areas, much of which is developed, are inundated. In reality, adaptations will likely be implemented to reduce the risk of flooding in the developed areas with sea-level rise.

TABLE 2-3
RELATIONSHIP BETWEEN SEA-LEVEL RISE, TIDAL PRISM, AND MOUTH CLOSURE

Scenario	Amount of Sea-Level Rise (ft)	Tidal Prism (ac-ft)	No. of Closure Days per Year
Existing	0	1.6	274
	1.6	3.9	302
	3.3	10.0	310
	5.7	22.3	306
Alternatives	0	1.6	279
	1.6	4.1	307
	3.3	11.1	319
	5.7	26.7	317

When comparing existing to project conditions with future sea-level rise, the trend in mouth closure behavior is similar. The monthly percent of time closed for each case is shown in **Figure 2-7**. Sea-level rise tends to cause a net shift of the lagoon mouth behavior towards being closed more often, until the surrounding developed areas are inundated and the increased tidal prism causes more openings. Note that if adaptation is taken to prevent the inundation of adjacent developed areas (e.g., levees are constructed), these results would be different.

SOURCE: ESA 2020

Loma Alta Slough Restoration

Figure 2-6a

Time Series Model Results for Existing Conditions vs. Sea-Level Rise of 1.6 to 5.7 Feet

ESA

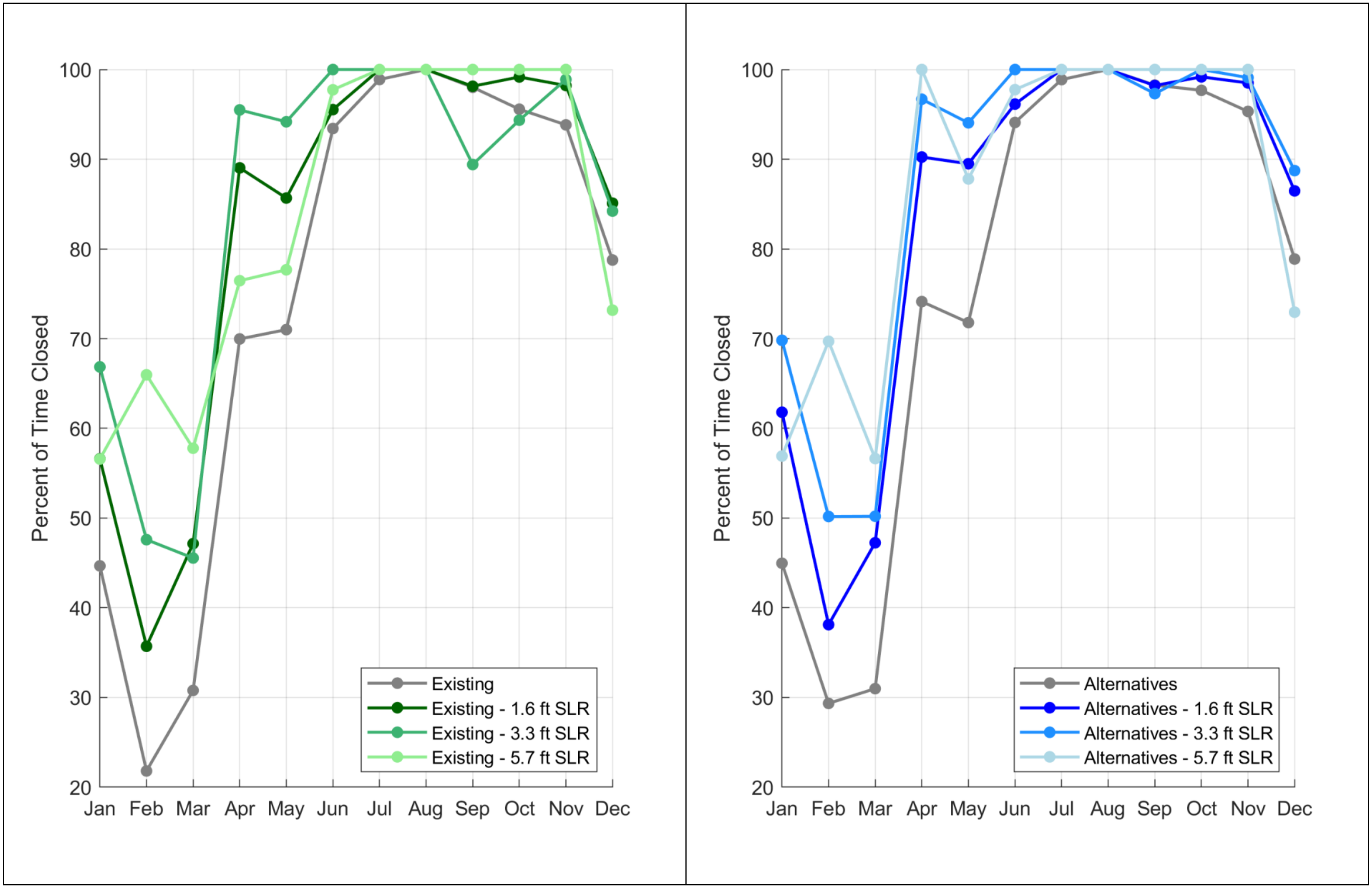
SOURCE: ESA 2020

Loma Alta Slough Restoration

Figure 2-6b

Time Series of Modeled Project Conditions under Existing Sea Level and with 1.6 to 5.7 Feet of Sea-Level Rise

ESA



SOURCE: ESA 2020

Loma Alta Slough Restoration

Figure 2-7
Closure Seasonality with Sea-Level Rise

2.5 Summary

Under present conditions, the mouth closes periodically during most years, and is most likely to close in late spring and remain closed through fall (specifically the months of April through November). Seasonal closure in the spring is a result of the seasonal decline in watershed runoff and the presence of long-period swell waves, providing sand to the mouth and a declining ability of the lagoon to remove it. The lagoon remains closed through the summer and fall since low dry-season flows are unable to fill the lagoon to a level where it would naturally overtop the beach berm that is built by waves after mouth closure. Also, the City manages the sand berm and pumps water from the Slough to keep the inlet closed. As winter storms commence, the mouth tends to open after November, as wave energy and watershed runoff increases.

Sea-level rise is predicted to have a larger impact on mouth closure than restoration actions. The proposed restoration alternatives do not greatly influence mouth closure behavior. Sea-level rise is expected to have two effects on lagoon mouth conditions:

- As tide levels increase with sea-level rise, the increasingly drowned lagoon will have a greater tidal prism (volume of water entering and leaving the mouth every day), which will increase the speed of currents in the mouth and possibly prevent some closure events. Seasonal closure is still predicted to occur.
- As the beach moves up with sea-level rise, the increased volume of the lagoon behind the beach will take longer to fill with runoff and breach naturally, meaning that seasonal closure events could lengthen.

The net change of these two effects is predicted to lead to more mouth closure with sea-level rise initially (1.6 to 3.3 feet), but results for 5.7 feet of sea-level rise suggest that a continued rise beyond that level would eventually lead to a net increase in open-mouth conditions as the lagoon continues to drown. For these higher levels of sea-level rise, the tidal prism becomes significantly larger as existing supratidal marsh areas and surrounding development become inundated. Section 4.3 discusses how these changes to the mouth dynamics could affect the habitats in the lagoon.

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SECTION 3
Hydraulic Model

3.1 Model Setup

ESA developed a one-dimensional (1D) steady-state hydraulic model of Loma Alta Slough using the USACE's HEC-RAS software package (v. 5.0.7). The model boundary, from the mouth of Loma Alta Creek to 0.43 miles upstream, includes the southern portion of La Salina Wastewater Treatment Plant, Buccaneer Park, Paradise by the Sea RV Resort, La Salina Mobile Village, Oceanside RV Resort, and the three bridges that cross Loma Alta Creek: (1) Pacific Street, (2) railroad bridge, and (3) South Coast Highway. Four model geometries were analyzed:

- Existing Conditions: this scenario includes the existing topography, bathymetry, and bridges without the project alternatives.
- Alternative 1: this scenario evaluates Alternative 1, Phase 2 conditions (see Section 1.3).
- Alternative 2: this scenario evaluates Alternative 2, Phase 2 conditions.
- Alternative 3: this scenario evaluates Alternative 3 conditions.

Sections 3.1.1 through 3.1.4 describe the development of the four model scenarios including:

- Topography/Bathymetry – land and underwater surface elevations controlling where water flows.
- Structures – bridges that influence the hydraulics of the site.
- Hydraulic Roughness – a property of different land covers that imposes a resistance to flow (e.g., grasses or open dirt areas have lower hydraulic roughness and provide a lower resistance to flow while areas with dense salt marsh have higher hydraulic roughness and provide a higher resistance to flow).

Sections 3.1.5 and 3.1.6 describe the different hydrology and tidal boundary conditions used for the different modeling runs:

- Hydrology – inflows from the Loma Alta Creek watershed.
- Tidal Boundary Conditions – downstream boundary conditions are set to critical depth at the mouth of the creeks confluence with the ocean.

3.1.1 Existing Conditions – Flood Scenario

Topography

The existing conditions model topography was developed from survey data and available aerial survey datasets (e.g., USGS Coastal LiDAR). Survey data was collected by ESA and Aguirre & Associates in 2015 as part of the previous version of this project. To supplement the 2015 data and additional and available aerial survey datasets, ESA conducted a bathymetric survey upstream of the railroad bridge in June 2019. **Figure 3-1** shows the model geometry for existing conditions.

Structures

There are three bridges that cross Loma Alta Creek within the project reach, the Pacific Street bridge, the railroad bridge, and the South Coast Highway bridge. At the creek's confluence with the Pacific Ocean, the Pacific Street bridge has a bottom chord elevation of approximately 12.7 feet NAVD88, a length of 58.6 feet, and a width of 53 feet. The railroad bridge has a bottom chord elevation of 18.6 feet NAVD88, a length of 206 feet, and a width of 39.7 feet. It has four supporting piers approximately 13 feet wide along its length. The South Coast Highway bridge has a bottom chord elevation of 12.9 feet NAVD88, a length of 48.2 feet, and a width of 80 feet.

Hydraulic Roughness

The Loma Alta Creek was assigned a hydraulic roughness (manning's n) value of 0.035, assuming the channel varies between some grass and weeds with little or no brush to some weeds with light brush on the banks based on the County of San Diego Hydraulic Design Manual (2012). Overbanks were assigned a value of 0.04 (high grass), with one exception: overbank areas with dense bulrush and cattails were assigned a value of 0.05 (heavy weeds, scattered brush).

3.1.2 Alternative 1, 2 and 3 Conditions – Flood Scenario

Topography

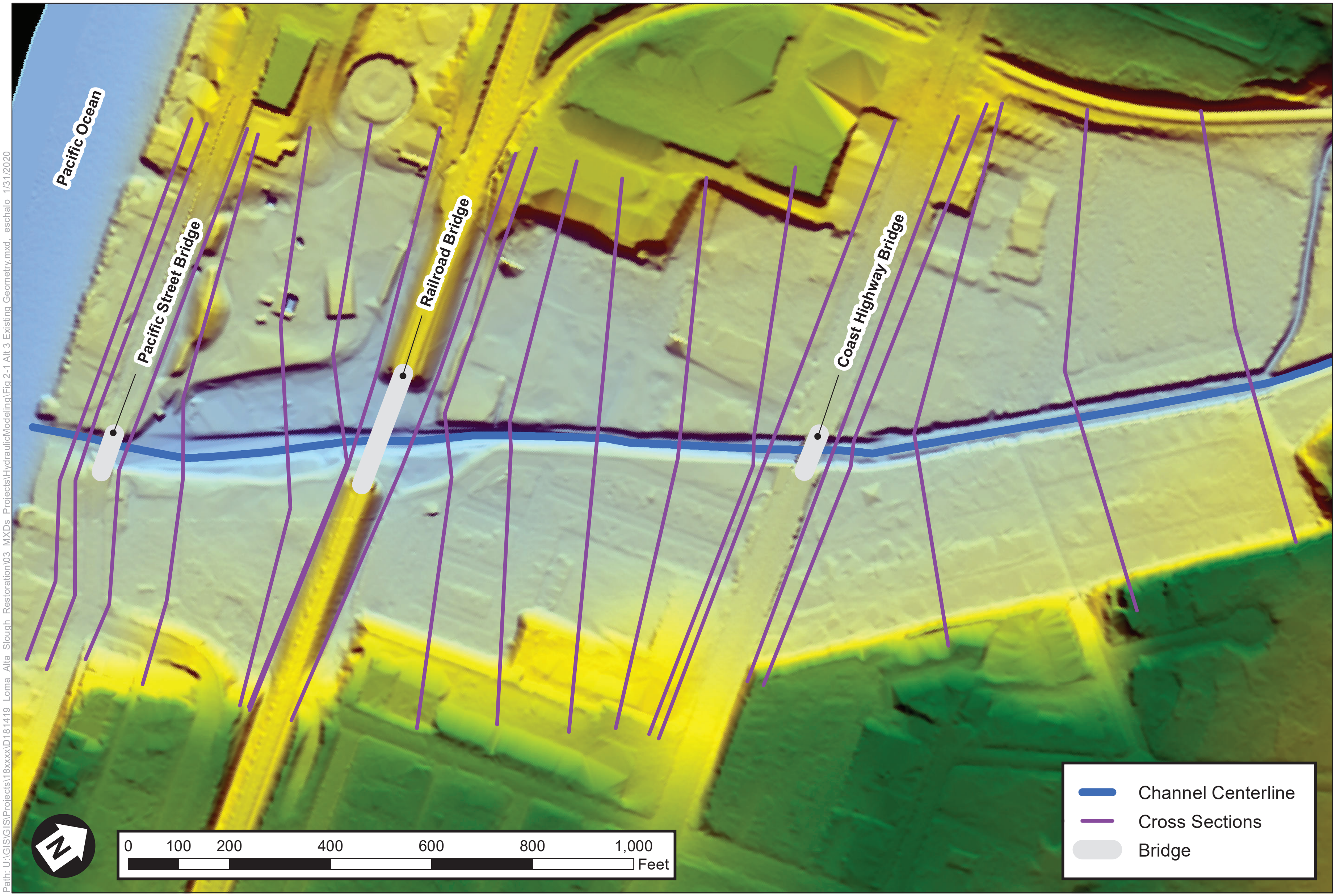
The topography for Alternatives 1, 2, and 3 were developed from the existing conditions DEM and modified based on the Alternative 1 Phase 2 design, Alternative 2 Phase 2 design, and the Alternative 3 design, respectively. The model geometries for Alternatives 1, 2, and 3 are shown in **Figure 3-2**, **Figure 3-3**, and **Figure 3-4**, respectively.

Structures

There were no modifications to the structures as described in Section 3.1.1.

Hydraulic Roughness

There were no modifications to the hydraulic roughness as described in Section 3.1.1.

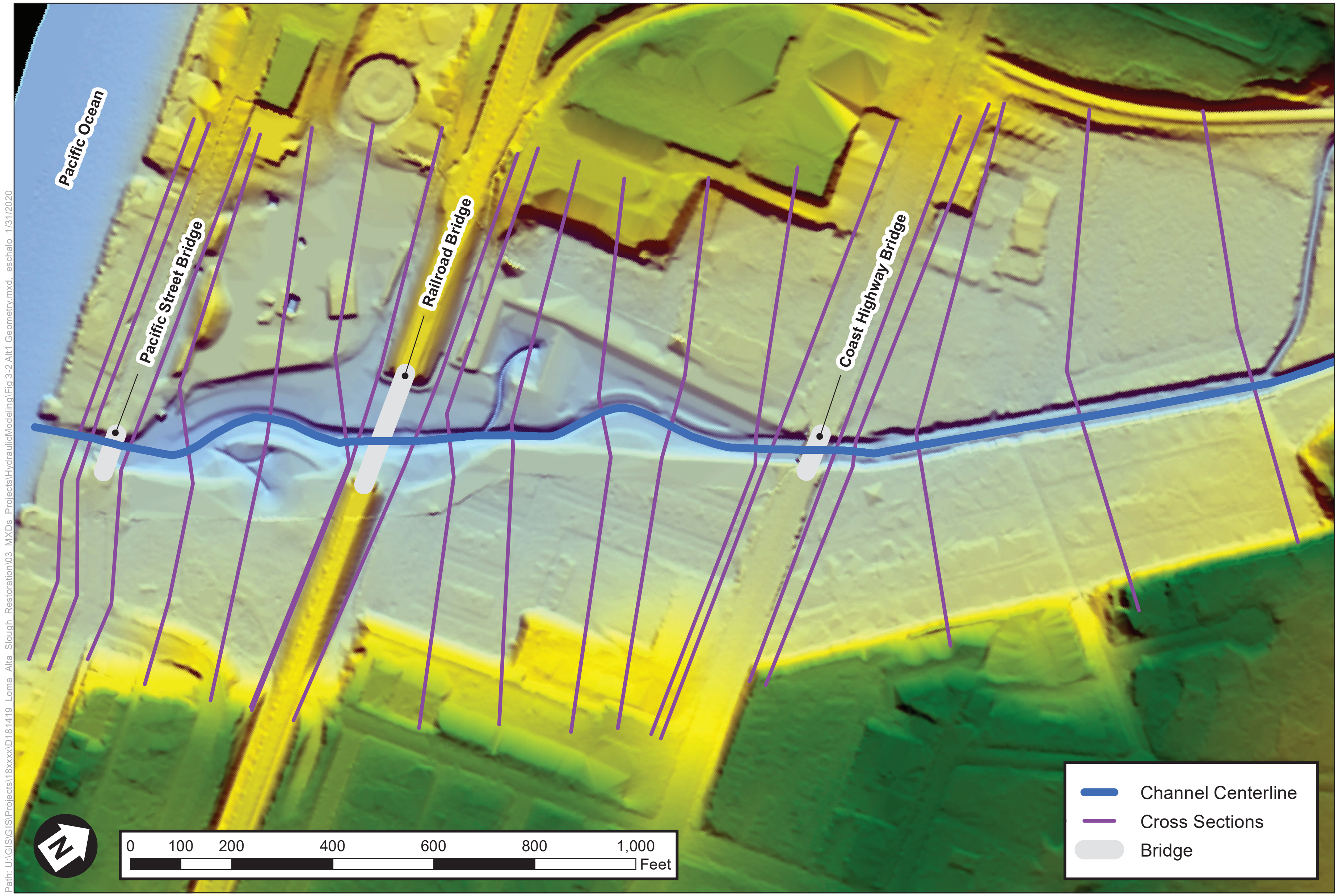


SOURCE: ESA 2020

Loma Alta Slough Restoration

Figure 3-1
Existing Condition Model Geometry

ESA

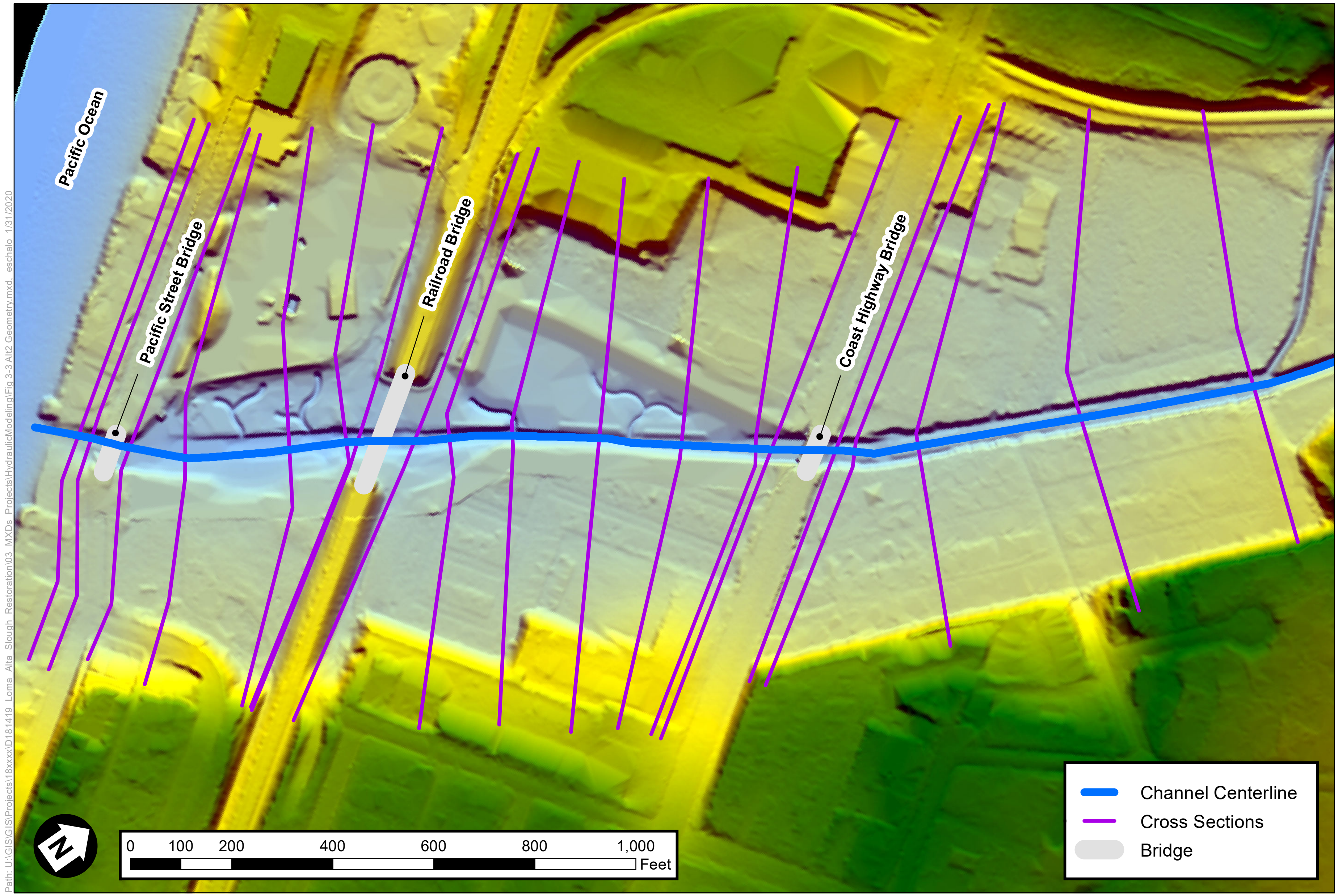


SOURCE: ESA 2020

Loma Alta Slough Restoration

Figure 3-2
Alternative 1 Model Geometry

ESA

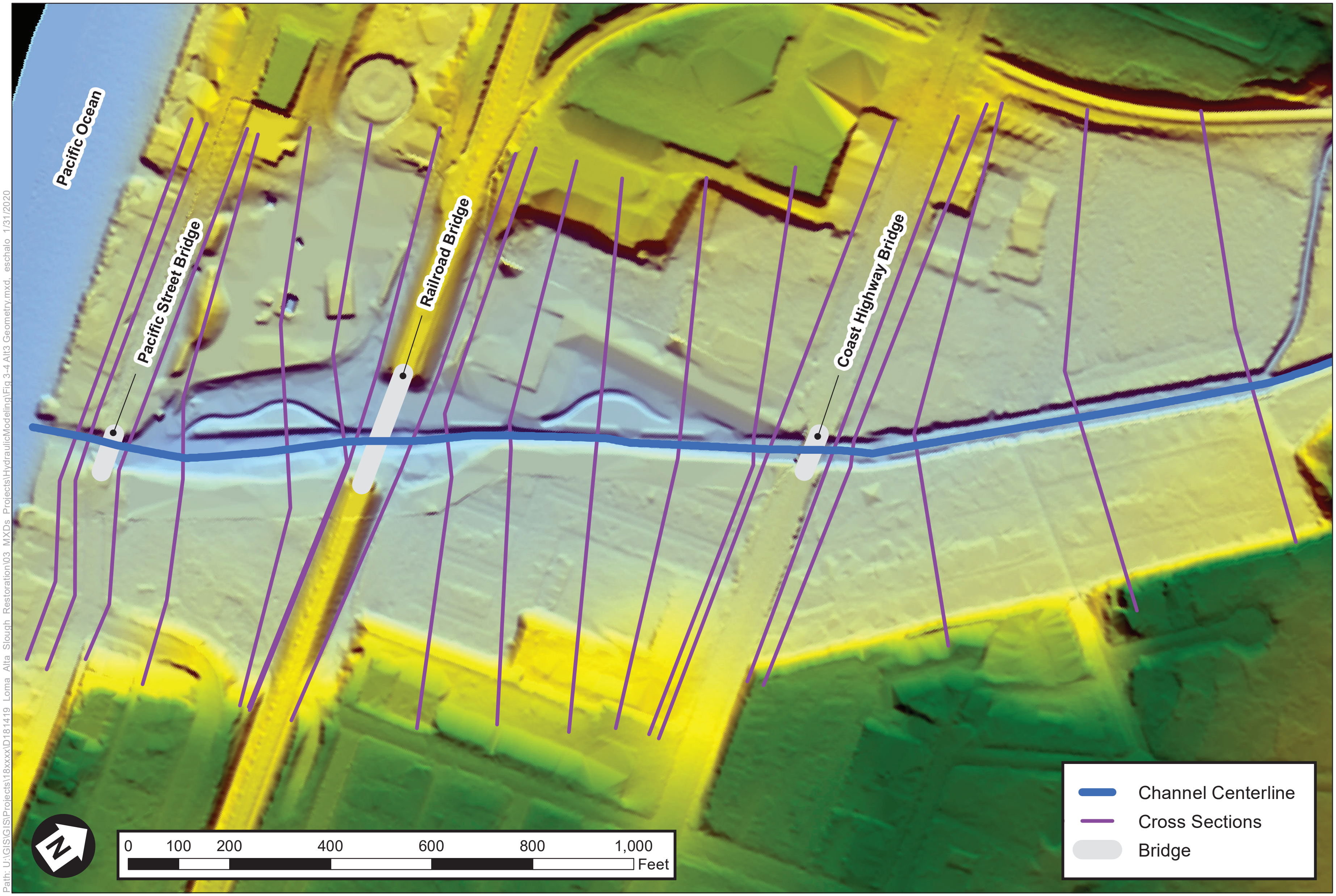


SOURCE: ESA 2020

Loma Alta Slough Restoration

Figure 3-3
Alternative 2 Model Geometry

ESA



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SOURCE: ESA 2020

Loma Alta Slough Restoration

Figure 3-4
Alternative 3 Model Geometry

ESA

3.1.3 Scour Scenario

Topography

The topography for Existing Conditions and Alternatives 1, 2, and 3 used in the scour analysis were the same as those described in Sections 3.1.1 and 3.1.2, respectively. However, the mouth of the Slough was lowered to -0.3 feet NAVD and the thalweg of the channel was adjusted accordingly.

Structures

There were no modifications to the structures as described in Section 3.1.1.

Hydraulic Roughness

Two hydraulic roughness options were considered. The first scenario ran the model with no modifications to the hydraulic roughness as described in Section 3.1.1. The second scenario looked at hydraulic roughness values one standard deviation lower than the original values to provide a sensitivity analysis of the model[1]. Lower hydraulic roughness values result in higher velocities since the water can move through the "smoother" channel more quickly. The new values used were 0.027 in the overbank and 0.025 in the channel.

3.1.5 Hydrology

The peak flows for the 100-year and 10-year recurrence interval storm events (1% annual chance storm and 10% annual chance storm, respectively) for Loma Alta Creek were taken from the FIS for San Diego County (FEMA 2019). The 100-year and 10-year peaks flows are 3,800 cfs and 800 cfs, respectively. The 2-year recurrence interval storm event (50% annual chance storm) was developed with the San Diego Hydrology Model (SDHM) by ESA in 2015. The 2-year peak flow is 190 cfs.

The peak flows were applied at the most upstream extent of the model, upstream of South Coast Highway.

3.1.6 Tidal Boundary Conditions

Two tidal boundary condition scenarios were implemented to analyze flooding and channel scour. To evaluate flooding, the model assumes the 100-year storm event occurs while a beach berm across the river mouth is at an elevation of 7.5 feet NAVD88. This assumption was used based on the FEMA model for the area, which assumes the mouth of the lagoon is closed and storm water builds up behind the berm. More likely, the beach berm would breach during a 100-year event, so this model assumption likely results in conservatively high water levels. The tidal boundary condition in the model is set to critical depth as the beach berm acts as a weir passing flow to the ocean downstream.

To evaluate channel scour, the model assumes the 100-year storm event occurs while the Slough is breached and connected to the ocean during low tide. This would result in a steeper flood profile,

[1] USACE guidance recommends using professional judgement to estimate a "reasonable" lower bound (USACE 1996).

as well as higher velocities and higher shear stresses. The tidal boundary condition in the model for this scenario is set to a spring low tide (-0.3 feet NAVD88).

3.2 Hydraulic Model Results

The 2-, 10-, and 100-year storm events were modeled for Loma Alta Creek. The results were analyzed to compare flood water levels, flooding extent, and potential scour between existing and project conditions.

3.2.1 Flooding Results

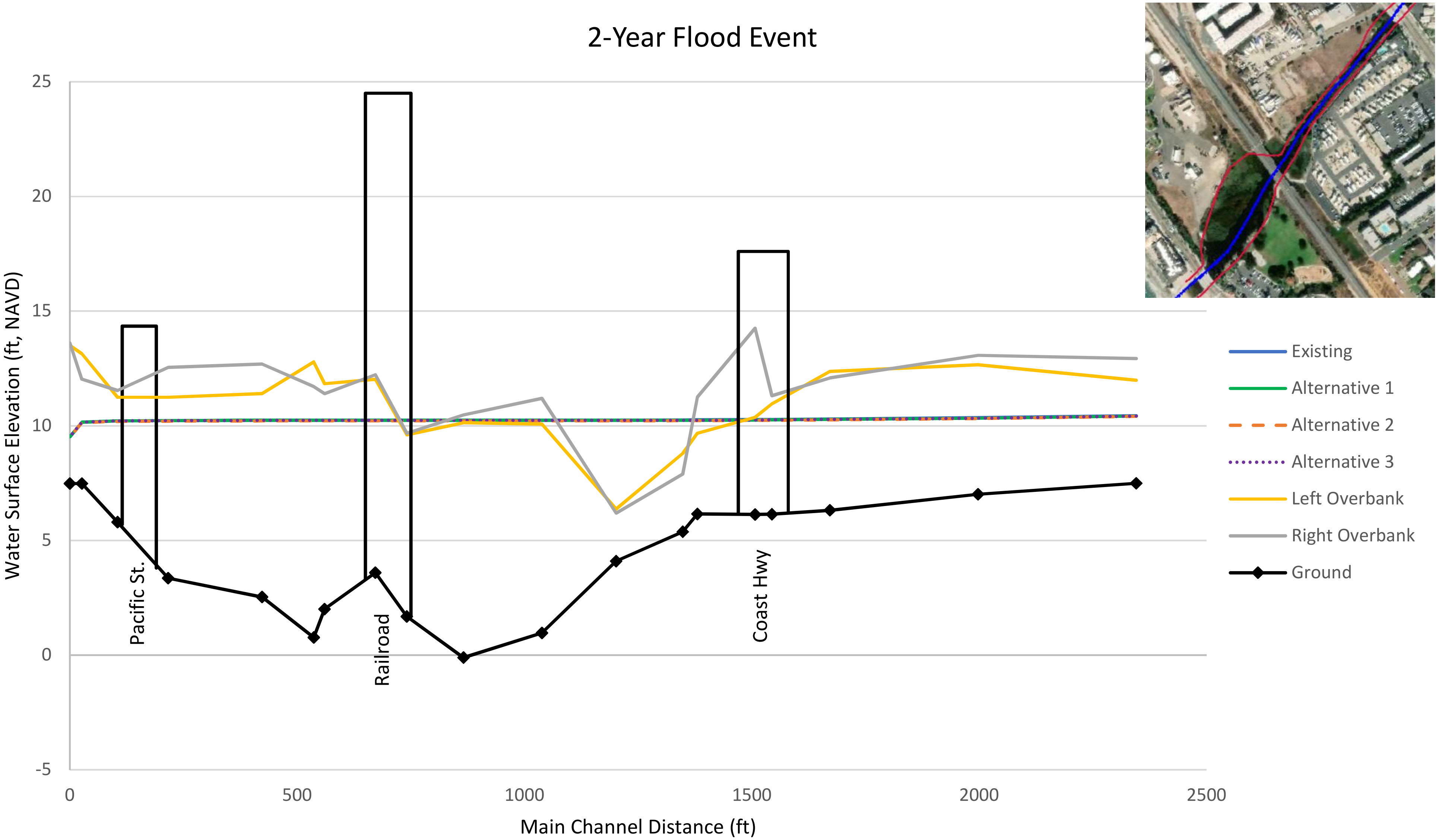
Current Conditions

The model results show that water levels for existing conditions and the project alternatives are very similar, varying at most by 0.1 feet (**Table 3-1**). The lagoon system is fairly small and so the alterations proposed by the restoration alternatives have only a minor effect on the water levels during the storm events. In all cases, the restoration alternatives result in the same or lower water levels compared to existing conditions, which may be due to the widening of the creek channel and floodplain.

TABLE 3-1
MODELED WATER LEVELS

	Water Levels in Loma Alta Creek Channel (ft NAVD)											
	2-Year Storm Event				10-Year Storm Event				100-Year Storm Event			
Scenario	Mouth	Pacific St.	Railroad	S. Coast Hwy.	Mouth	Pacific St.	Railroad	S. Coast Hwy.	Mouth	Pacific St.	Railroad	S. Coast Hwy.
Existing Conditions	9.5	10.2	10.2	10.3	11.1	12.4	12.4	12.6	14.2	16.0	16.2	16.4
Alternative 1	9.5	10.2	10.2	10.3	11.1	12.4	12.4	12.5	14.2	16.0	16.1	16.3
Alternative 2	9.5	10.2	10.2	10.2	11.1	12.4	12.4	12.5	14.2	16.0	16.1	16.3
Alternative 3	9.5	10.2	10.2	10.3	11.1	12.4	12.4	12.5	14.2	16.0	16.1	16.3
FEMA FIS	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	14.3	14.8	15.1

During the 2- and 10-year storm events, the storm waters pass under all three bridges for both existing and project conditions (**Figure 3-5** and **Figure 3-6**). Under existing conditions, the 2-year storm event (50% chance of occurring annually) causes some flooding outside the channel banks north of the creek between the South Coast Highway and railroad bridges and just east of the railroad bridge on the south side of the creek into the corner of the Paradise by the Sea property (first panel of **Figure 3-7**). Under project conditions, the 2-year storm inundates the new marsh area east of the railroad bridge (light red area in first panel of Figure 3-7). Alternative 2 is shown in Figure 3-7, but is representative of the three alternatives.

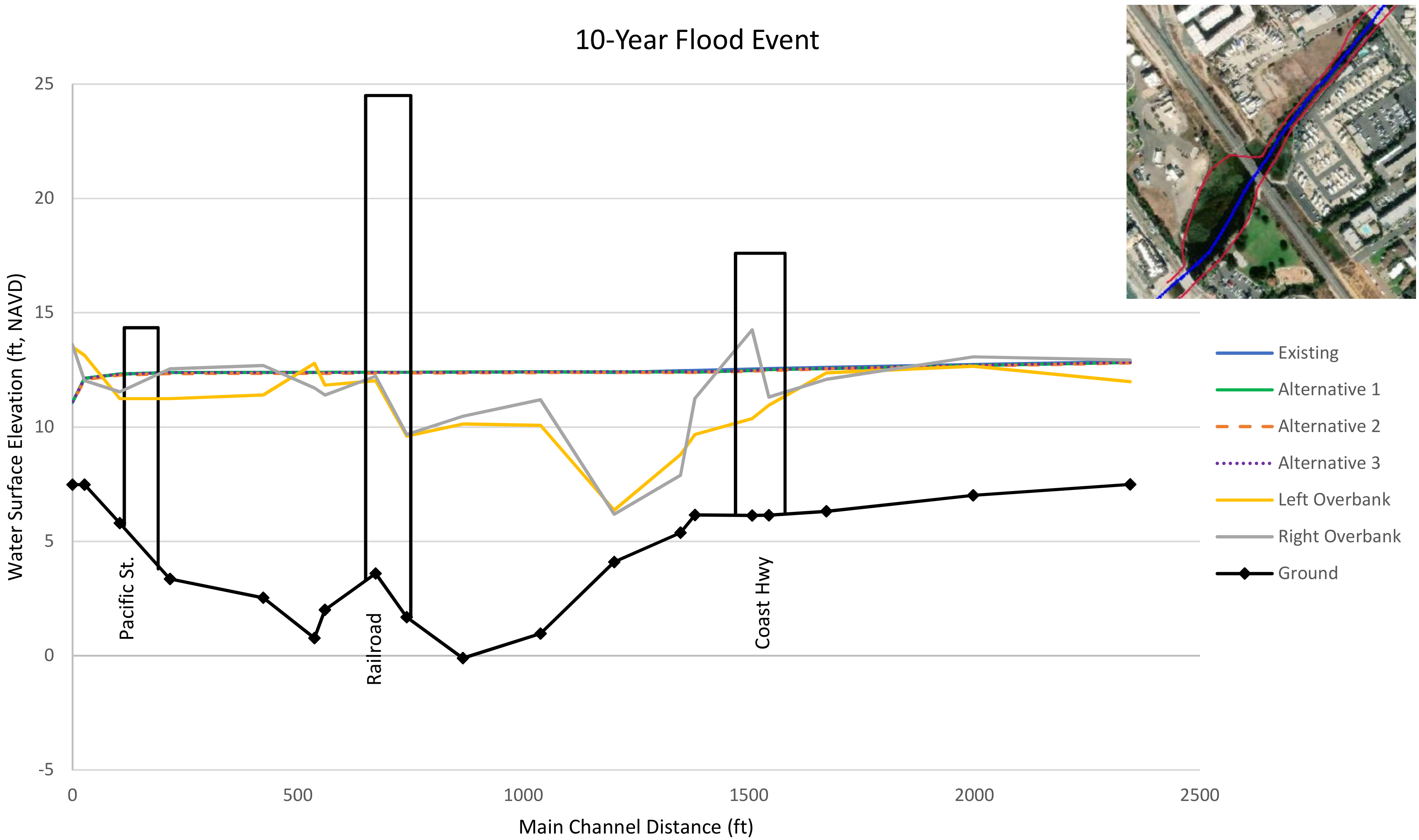


SOURCE: ESA 2020

Loma Alta Slough Restoration

Figure 3-5

Modeled Water Levels in 2-Year Flood Event

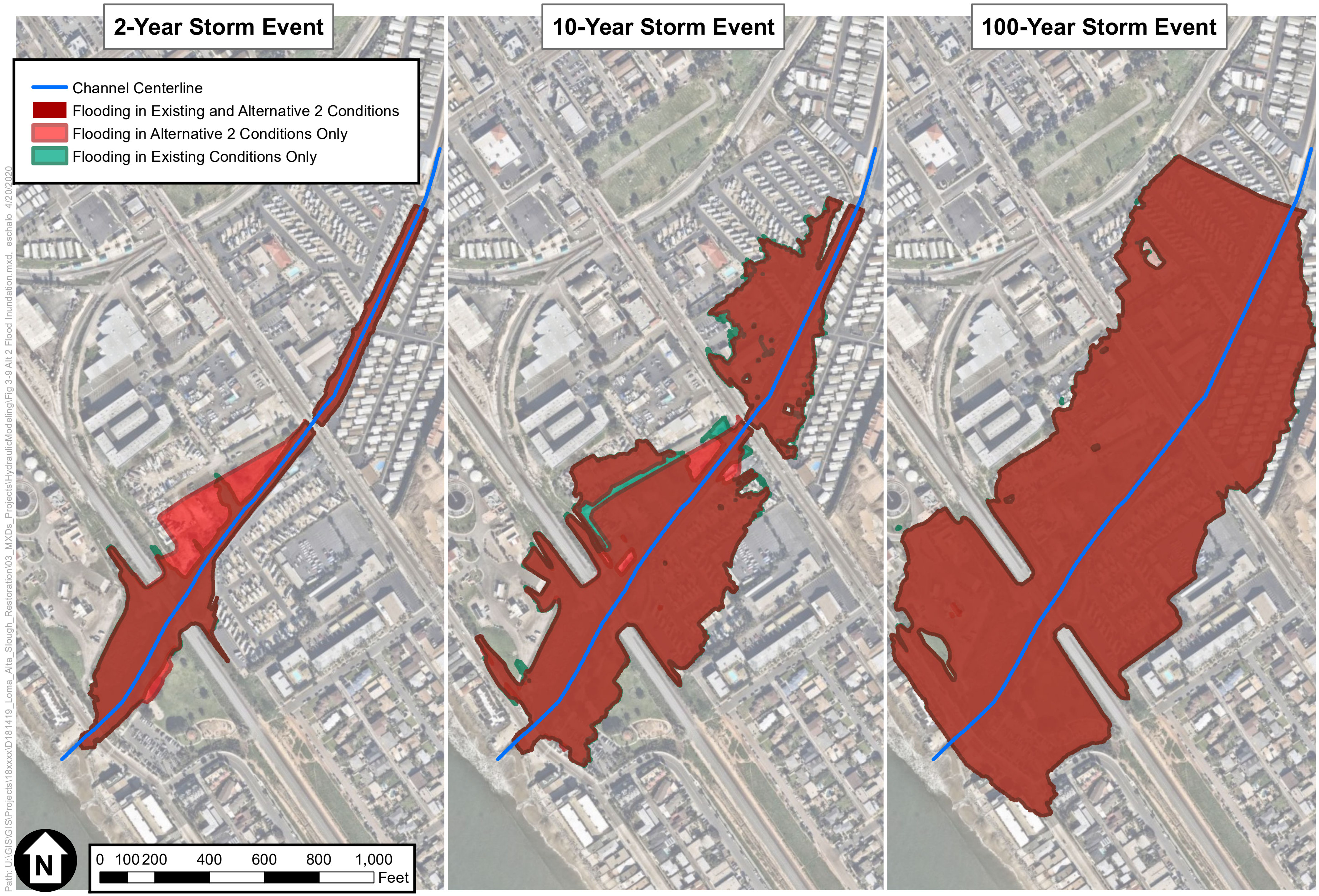


SOURCE: ESA 2020

Loma Alta Slough Restoration

Figure 3-6

Modeled Water Levels in 10-Year Flood Event



SOURCE: ESA 2020

Loma Alta Slough Restoration

Figure 3-7
Flood Extent, Alternative 2 vs. Existing Conditions

ESA

During the 10-year storm event (10 percent chance of occurring annually) under both existing and project conditions, the model shows that water levels exceed the channel banks for most of the modeled extent (second panel of Figure 3-6). Both Oceanside RV Resort and La Salina Mobile Homes would begin to flood upstream of South Coast Highway, most of Paradise by the Sea would be flooded, and the Parent Family Trust property and properties north of that would flood as well. The flood extent would extend north into the La Salina Wastewater Treatment Plant property along Pacific Street and the railroad and south into Buccaneer Park and parking lot. The project would raise the grade along the north edge of the properties between South Coast Highway and the railroad, bringing it out of the floodplain (green area in second panel of Figure 3-7).

During the 100-year storm event (1% chance of occurring annually), the model shows that water reaches the low chord of the South Coast Highway bridge and overtops the Pacific Street bridge for all scenarios (**Figure 3-8**). Flooding would inundate South Coast Highway on either side of the bridge. The model results indicate that the flood extent would cover most of Oceanside RV Resort, La Salina Mobile Homes, and Paradise by the Sea (third panel in Figure 3-7). More of the properties north of the Parent Family Trust property would be flooded and the flood extent would increase into the La Salina Wastewater Treatment Plant property. The model results show that Buccaneer Park and the parking lot would be entirely inundated during the 100-year storm.

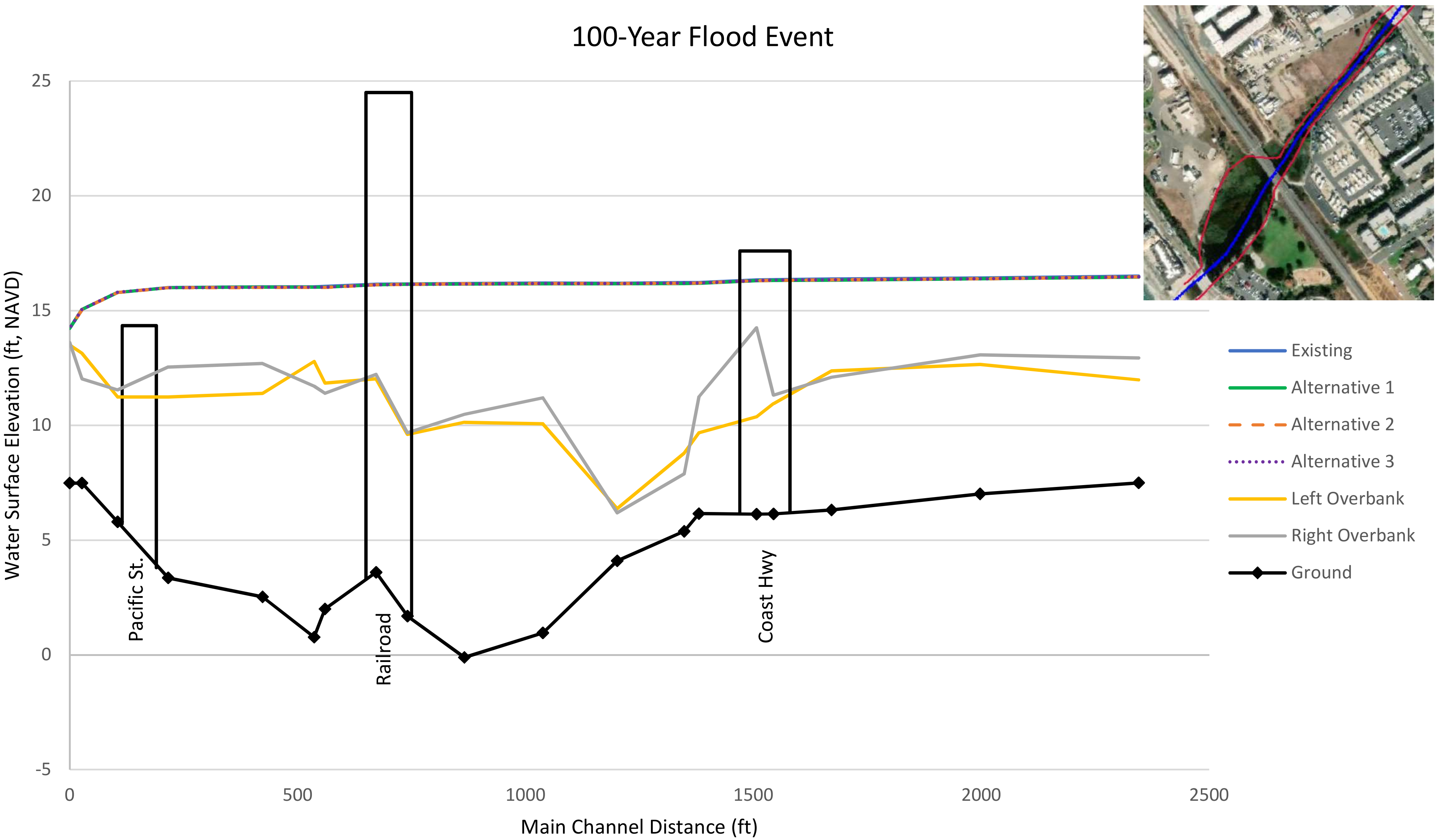
The model results were compared to the existing FEMA flood maps, which are based on a HEC-2 model that was dated 1982 (Table 3-1). The model results showed that water levels for the existing and project conditions are above the FEMA flood levels for the 100-year storm event. This is not surprising, since the FEMA model is outdated, and does not include some site changes, such as changes to the railroad bridge and the fill from its abutments in the 2000's as well as the two City-owned detention basins within the Loma Alta Creek watershed, constructed in the early 2000's to address downstream flooding risks. However, the model results show that the project conditions would maintain or marginally lower flood levels. While the project is not designed or meant to decrease flood risk, it may inadvertently provide a marginal benefit to the study area.

Future Conditions with Sea-Level Rise

As discussed in Section 2.4.3, the beach at the mouth of the lagoon is expected to keep pace with sea-level rise, building a higher berm over time. This means that water levels in the lagoon are expected to reach higher elevations before the berm breaches and the lagoon can drain out to the ocean. As a result, flooding is expected to increase with sea-level rise.

The HEC-RAS model was run for three sea-level rise scenarios, matching the runs for the QCM, as discussed in Section 2.3. The model geometry was updated to include a beach berm with an elevation increased from the existing conditions model (7.5 feet NAVD88) by the respective amounts of increase output by the QCM (e.g., the QCM results showed that 1.6 feet of sea-level rise resulted in a 1.64-ft increase in the berm height, so the model geometry includes a beach berm at 9.13 feet NAVD88).

Table 3-2 compares water levels for the no project (existing conditions) scenario to Alternative 1 (which is representative of all three alternatives). Similar to current conditions (Section 3.2.1) the model results show that water levels for the no project conditions and the project alternatives are



SOURCE: ESA 2020

Loma Alta Slough Restoration

Figure 3-8

Modeled Water Levels in 100-Year Flood Event

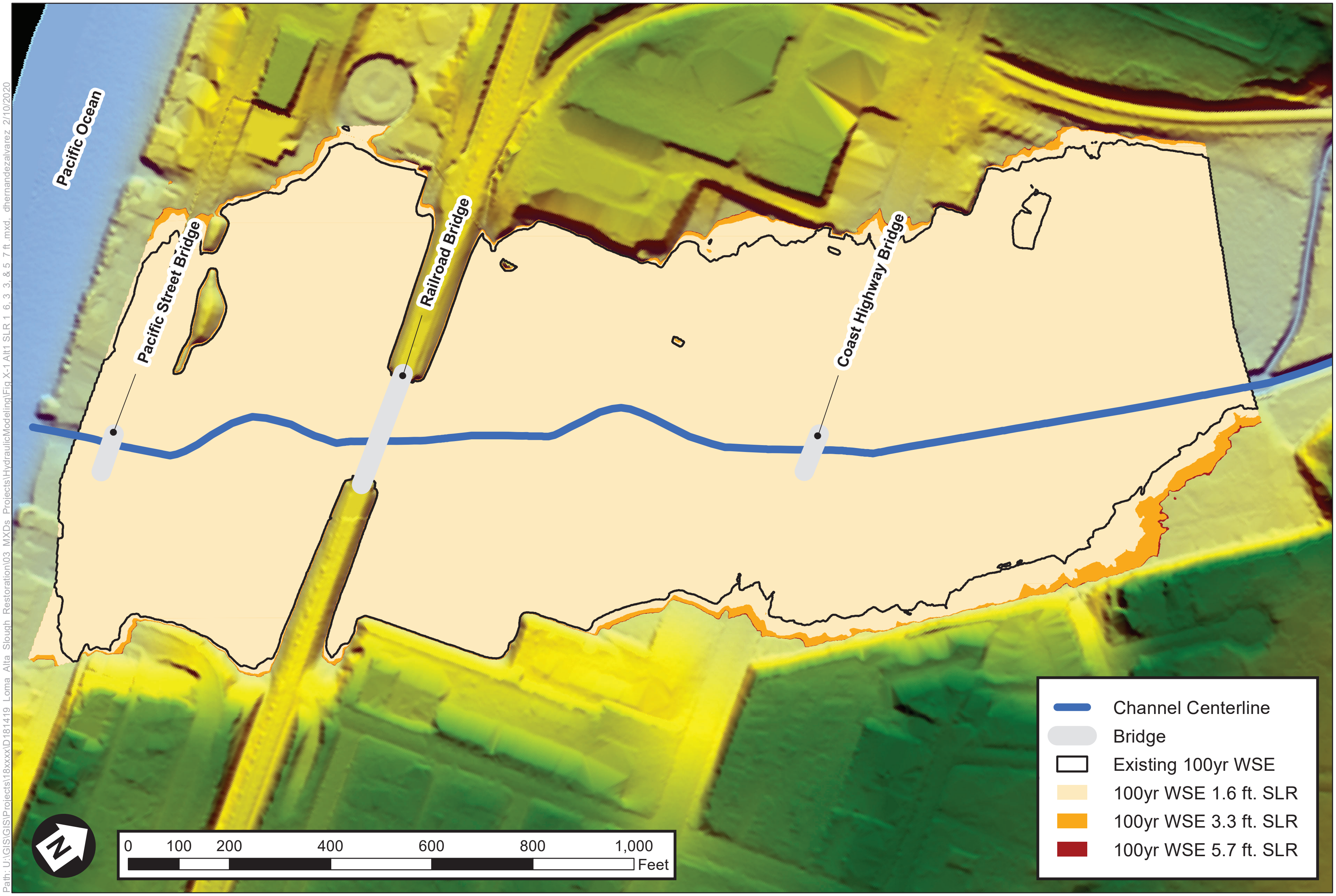
very similar, varying at most by 0.2 feet. In all cases, the restoration alternatives result in the same or lower water levels compared to existing conditions, which may be due to the widening of the creek channel and floodplain. Additionally, the flooding extent does not increase substantially with sea-level rise during the 100-year event (**Figure 3-9**).

TABLE 3-2
MODELED WATER LEVELS WITH SEA-LEVEL RISE

	Water Levels in Loma Alta Creek Channel (ft NAVD)			
Scenario	**Mouth**	**Pacific St.**	**Railroad**	**S. Coast Highway**
100-Year Storm Event with No Sea-Level Rise				
No Project	14.2	15.8	16.2	16.3
Alternative 1 (representative of all Alts)	14.2	15.8	16.1	16.3
100-Year Storm Event with 1.6 Feet of Sea-Level Rise				
No Project	15.7	17.1	17.3	17.4
Alternative 1 (representative of all Alts)	15.6	16.9	17.2	17.3
100-Year Storm Event with 3.3 Feet of Sea-Level Rise				
No Project	16.3	17.6	17.8	17.9
Alternative 1 (representative of all Alts)	16.3	17.6	17.7	17.8
100-Year Storm Event with 5.7 Feet of Sea-Level Rise				
No Project	16.3	17.7	17.8	17.9
Alternative 1 (representative of all Alts)	16.3	17.6	17.8	17.9

When sea-level rise reaches 3.3 feet of sea-level rise, the model results show the 100-year flood event would overtop the South Coast Highway bridge, as well as the Pacific Street bridge. With 5.7 feet of sea-level rise, the model assumes the beach berm would be 13.2 feet NAVD88, which is higher than the low chord of the Pacific Street bridge (12.7 feet NAVD88). This implies that the beach would be built up to the road, and water would have to pass over the bridge to flow to the ocean.

In reality, the beach berm would scour as water flows over it, so the model likely overestimates the flood levels in the lagoon, although these modeling assumptions match the methodology used for the FEMA flood mapping (see Section 3.2.1). Additionally, there may not be sufficient sand in the system to build up the beach as sea-level rise is expected to contribute to beach erosion in the area. The modeling also does not account for managed interventions in the future to mitigate impacts to beach sand from sea-level rise, such as beach sand replenishment or managed retreat. Therefore, water levels in the future may be lower than the model results show, mostly due to the assumption that the berm does not scour.



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SOURCE: ESA 2020
NOTE: WSE = water surface elevation

Loma Alta Slough Restoration

Figure 3-9
Alternative 1 Flood Extents with Sea-Level Rise

ESA

3.2.2 Scour Results and Bank Stabilization Analysis

The scour analysis was conducted in order to evaluate the feasibility of removing the riprap at the project site as part of the restoration. Documentation of the existing riprap was not available, so modeling and a geomorphic analysis were conducted to evaluate what type of channel stabilization may be needed at the site post-restoration.

Fischenich 2001 recommends adjusting modeled velocity and shear stresses to account for local variability and spatial distribution when designing bank stabilization. For example, the following equation is recommended for straight channels, like the Slough under Existing Conditions and Alternatives 2 and 3:

$$\tau_{max} = 1.5\tau$$

where τ represents shear stress.

For sinuous channels, like the proposed Slough alignment in Alternative 1, Fischenich 2001 recommends using the following equation:

$$\tau_{max} = 2.65\tau\left(\frac{R_c}{W}\right)^{-0.5}$$

where R_c represents the radius of the channel meander and W represents the top width of the channel. Adding an additional factor of 1.15 to account for instantaneous maximums is also recommended for sinuous channels. Additionally, a 1.3 factor of safety is recommended for both straight and sinuous channels on top of the adjustments for local and spatial variability.

Table 3-3 presents the adjusted shear values for existing conditions and the three alternatives during a 100-year flood event and **Figure 3-10** shows the values on a map. The results show that shear stresses for existing conditions are similar to the project alternatives, with some locations higher and some locations lower. As the flow enters the study area (as it passes under South Coast Highway), shear stresses increase under the three alternatives. In this area, the flow can expand into the graded marshplain more than under existing conditions, leading to a local acceleration that increases shear stresses from around station 1467 to 1125. The flow acceleration occurs due to the steepening of the water surface at the channel expansion transition. Downstream of this transition, velocities and shear stresses are reduced due to the expanded flow area (except under Alternative 1, where the meander results in higher shear stresses).

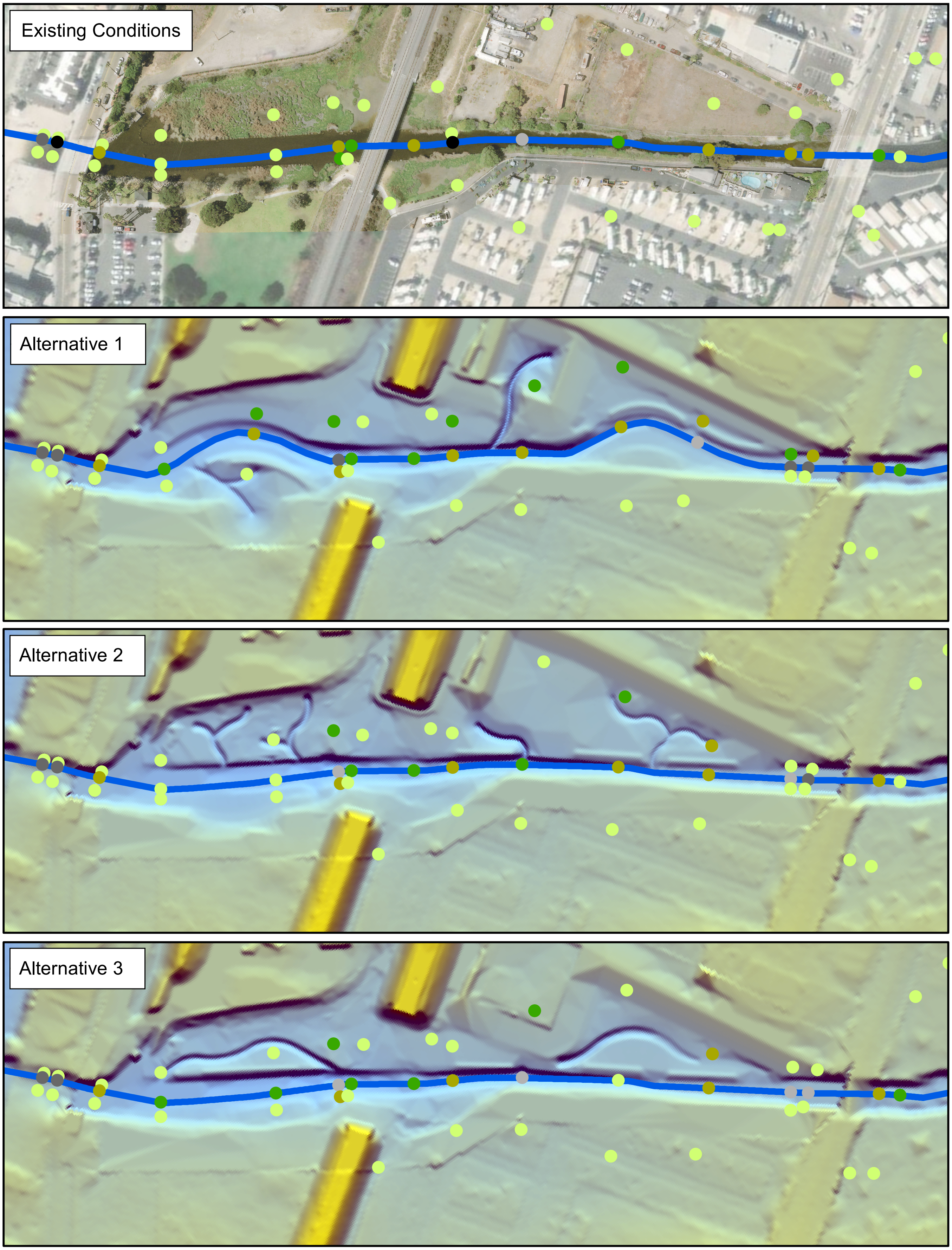
This same process occurs after the railroad bridge around station 624, but to a less degree, since the opening under the railroad bridge is much larger than the opening under South Coast Highway, so the constriction through the railroad is less. Alternative 1 increases shear stresses along the northbank of the channel due to the meander from station 624 to 304.

Table 3-3
Modeled Shear Stresses

Maximum Shear Stresses in Loma Alta Creek Channel During a 100-year Flood Event (lbs/sf)

	Existing Conditions					Alternative 1					Alternative 2					Alternative 3					
Station[1,2]	Left Overbank	Left Channel Bank	Channel Center	Right Channel Bank	Right Overbank	Left Overbank	Left Channel Bank	Channel Center	Right Channel Bank	Right Overbank	Left Overbank	Left Channel Bank	Channel Center	Right Channel Bank	Right Overbank	Left Overbank	Left Channel Bank	Channel Center	Right Channel Bank	Right Overbank	Bank Stabilization Color Key
87		5.8	7.9	6.5			5.0	6.9	5.6			5.1	6.9	5.6			5.1	6.9	5.6		Short native grasses (<0.7 lbs/sf)
114		5.5	10.9	8.4			4.0	7.4	5.8			4.1	7.4	5.8			4.1	7.4	5.8		Long native grasses (<1.2 lb/ssf)
159 BR D		5.0	7.9	6.3			5.0	7.9	6.3			5.0	7.9	6.3			5.1	7.9	6.3		Coir roll (<3.0 lbs/sf)
Pacific Street Bridge																					12 in riprap (<5.1 lbs/sf)
159 BR U		6.1	7.9	5.6			3.4	4.7	3.2			3.4	4.6	3.2			3.4	4.7	3.2		18 in riprap (<7.6 lbs/sf)
192		2.0	2.7	1.8			2.2	2.8	1.9			2.4	3.1	2.2			2.2	2.8	1.9		24 in riprap (<10.1 lbs/sf)
304/311	0.3	0.7	0.8	0.7	0.4	0.4	0.6	1.0	1.0	0.5	0.3	0.7	0.8	0.7	0.5	0.4	0.8	0.9	0.8	0.5	
510/489	0.4	0.7	0.8	0.7	0.4	0.4	1.3	2.2	2.0	0.7	0.4	0.6	0.7	0.7	0.4	0.5	0.8	0.9	0.8	0.5	
624/650	1.1	2.1	2.6	2.4	0.7	1.8	3.4	6.0	5.7	0.9	1.9	3.5	4.4	4.2	0.8	1.9	3.5	4.4	4.2	0.9	
646/673	0.3	0.9	1.1	1.0	0.5	0.3	0.9	1.1	1.0	0.5	0.3	0.8	1.0	0.9	0.5	0.3	0.9	1.1	1.0	0.5	
698/723 BR D	0.7	0.8	3.5	2.1	1.3	0.8	0.9	3.7	2.1	1.3	0.7	0.8	3.3	2.0	1.2	0.7	0.7	3.4	2.0	1.2	
Railroad Bridge																					
698/723 BR U	1.9	10.4	4.4	14.5	2.1	1.7	4.5	2.6	6.6	1.3	1.3	4.8	2.8	7.4	1.1	1.5	5.3	2.3	7.2	1.4	
759/785	0.4	1.1	1.9	1.4	0.4	0.3	0.9	1.1	0.8	0.3	0.3	0.8	1.1	0.8	0.3	0.3	0.7	1.2	0.9	0.3	
829/854	0.3	3.2	4.8	15.4		0.3	1.3	3.9	2.0	0.5	0.2	1.0	1.9	1.0	0.5	0.3	1.3	2.8	1.3	0.6	
953/979	0.5	2.7	5.5	2.8	0.5	0.1	0.9	3.5	2.4	0.7	0.1	0.6	1.6	1.2	0.6	0.2	2.5	6.6	4.7	1.1	
1125/1167	0.3	1.0	1.9	0.9	0.4	0.2	1.3	2.8	2.3		0.1	1.2	2.9	1.5	1.0	0.2	0.5	1.1	0.6	0.3	
1289/1312	0.7	2.1	4.6	2.3	0.4	0.3	1.8	3.6	3.5	1.1	0.0	1.7	4.2	2.9	2.0	0.2	1.2	2.8	2.0	1.3	
1435/1488	0.5	1.9	2.6	2.0	0.5		5.8	10.3	3.9	0.7		5.6	7.0	2.5	0.4	0.2	3.8	5.1	2.1	0.3	
1467/1519	0.5	1.7	2.3	1.8	0.4		5.6	7.4	6.2	2.0		6.9	8.4	3.1		0.1	5.4	6.8	2.4	0.3	
1557/1609 BR D	Bridge overtops during 100-year storm, so the model cannot resolve 1-D shear stresses above and below the bridge at this cross-section.																				
S. Coast Highway																					
1557/1609 BR U	Bridge overtops during 100-year storm, so the model cannot resolve 1-D shear stresses above and below the bridge at this cross-section.																				
1594/1646	0.3	1.3	1.2	0.8	0.3	0.4	1.5	1.5	1.0	0.4	0.4	1.5	1.4	1.0	0.4	0.4	1.5	1.5	1.0	0.4	
1631/1683	0.3	0.6	0.8	0.6	0.2	0.3	0.7	0.9	0.7	0.2	0.3	0.7	0.9	0.7	0.2	0.3	0.7	0.9	0.7	0.2	
1759/1811	0.2	0.4	0.4	0.4	0.2	0.4	1.9	2.5	1.9	0.3	0.2	0.5	0.6	0.5	0.2	0.2	0.5	0.6	0.5	0.2	
2085/2137	0.1	0.6	0.7	0.6	0.3	0.1	2.7	4.0	2.7	0.6	0.1	0.6	0.8	0.6	0.3	0.1	0.6	0.8	0.6	0.3	
2433/2485	0.1	1.3	1.6	1.0	0.4	0.1	1.5	1.8	1.1	0.4	0.1	1.5	1.8	1.1	0.4	0.1	1.5	1.9	1.1	0.4	

1. BR D = bridge downstream; BR U = bridge upstream
2. Where two stations are listed, the first represents the station for Existing Conditions, Alternative 2, and Alternative 3, and the second represents the station for Alternative 1, which has two meanders in the main channel



SOURCE: ESA

Lining Materials (Permissible Shear)

- Short native grasses (<= 0.7 lb/sf)
- Long native grasses (<= 1.2 lb/sf)
- 12-inch riprap (< 3 lb/sf)
- 12-inch riprap (< 5.1 lb/sf)
- 18-inch riprap (< 7.6 lb/sf)
- 24-inch riprap (< 10.1 lb/sf)

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Loma Alta Slough Restoration

Figure 3-10
Shear Stress Values Across the Channel

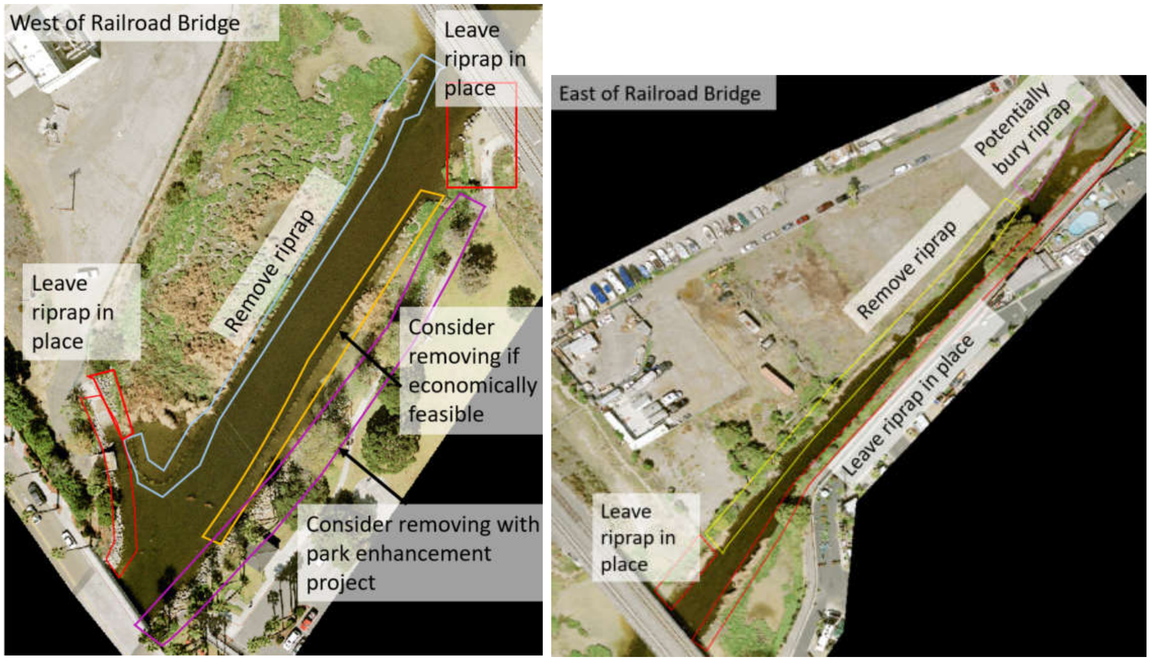
Potential bank stabilization methods can be identified by comparing the adjusted shear stress values with the resistance of materials. Guidance on lining materials are based upon the U.S. Army Engineer Research and Development Center (ERDC) Stability Thresholds for Stream Restoration Materials (Fischenich 2001). Modeled shear and velocity results for each cross section were compared to the permissible shear stress and velocity values for different treatments in **Table 3-4**. This information is used to color code the shear stress results presented in Table 3-3.

TABLE 3-4
SELECTED BIOTECHNICAL BANK STABILIZATION TREATMENTS (FISCHENICH, 2001)

Permissible shear stress (lbs/sf)	Permissible velocity (ft/sec)	Treatment
<0.7	<3	Short native grasses
<1.2	<4	Long grasses grasses
<3	<8	Coir roll
<5.1	<10	12 in riprap
<7.6	<12	18 in riprap
<10.1	<14	24 in riprap

The results suggest that in many locations vegetation is likely sufficient to stabilize the channel banks and overbanks, and riprap would not be needed along the marsh edge. In areas where the channel shear stresses are greater and could result in erosion, a combination of rock slope protection (buried as feasible) and vegetated channel banks would be used to provide both channel stability and improved habitat. Recommendations to inform the restoration design are as follows and shown in **Figure 3-11**:

- Leave riprap in place to protect bridge piers and the access ramp from La Salina WWTP
- Leave riprap in place on the southeast channel bank to protect the trail and Paradise by the Sea RV park. Typically, when riprap is removed from a slope, the slope would be regraded to be flatter, but in this location there is not sufficient space without using adjacent developed areas.
- Consider removing the riprap along Buccaneer Park as part of the project or in the future as part of the park enhancement project. This area has sufficient space to lay the bank back at a flatter slope, which would reduce shear stresses.
- Consider removing the riprap further out in the channel along Buccaneer Park, if it is cost effective.
- Remove riprap along the existing marsh (north bank west of the railroad bridge) and the proposed marsh (north bank east of the railroad bridge). Grade channel banks to be flatter slopes to reduce shear stresses. Further develop the design in the next step to use alignment of the berms and strategic buried armoring to reduce and/or protect the banks from scour.



Loma Alta Slough Wetland Enhancement Project

Figure 3-11
Riprap Removal Recommendations

SECTION 4
Eco-Hydrology Analysis

4.1 Existing Habitats

4.1.1 Elevations

As discussed in the Biological Technical Report (ESA 2020), the existing site includes coastal brackish marsh and southern coastal salt marsh habitats. The mapped locations of each habitat were compared to the project topography to estimate the elevation ranges for each habitat type (**Figure 4-1**). Additionally, a survey of elevations of different wetlands species was conducted to ground-truth the desktop analysis. **Table 4-1** provides the range of elevations for each habitat type and species.

TABLE 4-1
VEGETATION ELEVATION RANGES

	Elevation Range (ft NAVD)	Average (ft NAVD)
Wetland/Upland Boundary	7.4–9.4	7.9
Southern Coastal Salt Marsh – transition zone into uplands	8.6–10.7	10.2
Southern Coastal Salt Marsh	6.5–9.0	7.6
Salt Grass (*Distichlis spicata*)	7.7–8.6	8.3
Marsh Jaumea (*Jaumea carnosa*) & Pickleweed (*Salicornia pacifica*)		7.8
Coastal Brackish Marsh	5.9–7.4	6.7
California Bulrush (*Schoenoplectus californicus*) & Cattails (*Typha* sp.)	4.7–7.3	6.6
Unvegetated Mudflat/Salt Pan	4.6–7.3	6.7

Under existing conditions, the upper end of the jurisdictional wetlands[2] occurs around 9.4 feet NAVD, transitioning to upland above this elevation. Above this elevation, non-native species are able to compete with salt marsh species, resulting in a more disturbed habitat area that transitions from salt marsh into ruderal uplands. These types of transitions are also referred to as “ecotones.” The salt grass (*Distichlis spicata*) on-site generally occurs in the same range as the wetland/

2 Wetlands, as defined by the Environmental Protection Agency and U.S. Army Corps of Engineers for the purpose of implementing the Clean Water Act, are areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands are generally expected to exhibit hydrophytic vegetation, hydric soils, and wetland hydrology and are determined based on the procedures in the 1987 *Corps of Engineers Wetlands Delineation Manual and 2016 Regional Supplement to the Corps of Engineers Delineation Manual: Arid West Region (Version 2.0)*.

SOURCE: Mapbox 2018; ESA 2020

Loma Alta Slough Wetlands Enhancement Project

Figure 4-1
Existing Conditions Topography and Vegetation Types

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upland boundary, in some locations falling into the jurisdictional wetlands category, while in other locations, occurring in areas that would be classified as upland.

Jaumea (*Jaumea carnosa*) and pickleweed (*Salicornia pacifica*) occurred together wherever they were found on the site. Only 2 measurements were taken, but they indicated that jaumea and pickleweed occur around 7.8 feet NAVD, towards the lower end of the salt grass range. Bulrush (*Schoenoplectus californicus*) and cattails (*Typha* sp.) were found below this, ranging from 4.7 to 7.3 feet NAVD. However, in some locations on the site, this same elevation range did not support any vegetation, and only mudflat was present. This may due to poor drainage in these areas, where water may pond and evaporate, creating more of a salt pan habitat.

4.1.2 Inundation Frequency

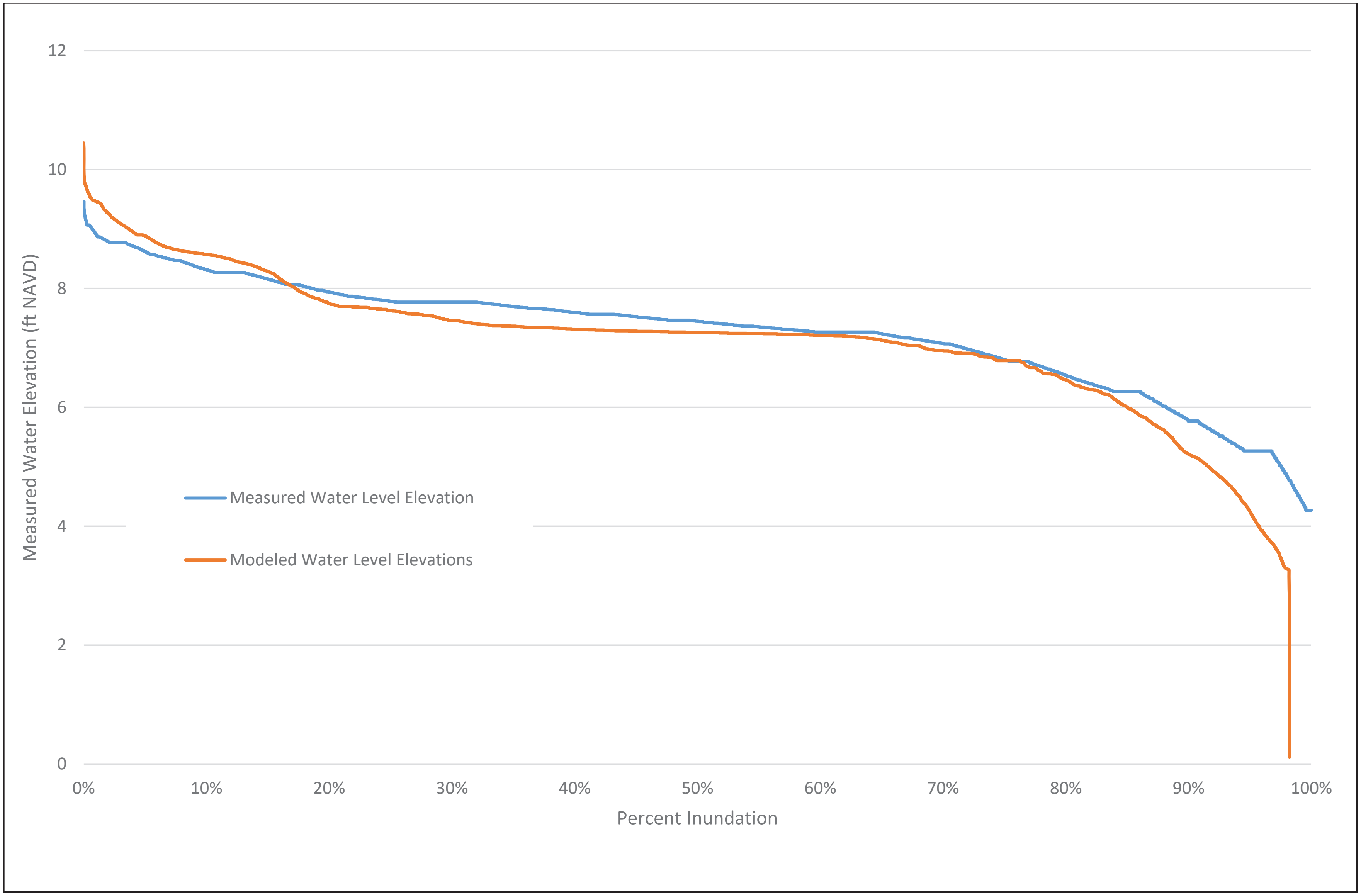
The elevations at which different wetland vegetation establishes are related to inundation frequency, as certain plants tolerate different amounts and timing of inundation. The existing inundation frequency at the site (**Figure 4-2**) was calculated (Section 2.4) and related to the elevations of existing habitats to understand the inundation frequency preference of the different species in this system. As discussed in Section 2, the measured water level data from the City was collected daily, so it does not capture the variation within a single day when the lagoon is tidal. Therefore, the water levels output by the QCM were also analyzed to determine inundation frequency. Figure 4-2 shows how the modeled results capture some of the lower water levels that the measured data does not capture.

Table 4-2 presents the inundation frequency for the existing habitats.

TABLE 4-2
INUNDATION FREQUENCY FOR EXISTING HABITATS

	Elevation Range (ft NAVD)	Water Level Exceedance Frequency at Loma Alta	Water Level Exceedance Frequency at Aliso Creek for Reference[a]
Southern Coastal Salt Marsh	6.5–9.0	4–81%	5–50%
Salt Grass	7.7–8.6	9–22%	
Jaumea & Pickleweed	7.8	~20%	
Coastal Brackish Marsh	5.9–7.4	33–87%	30–72%
Bulrush & Cattails	4.7–7.3	42–95%	
Unvegetated Salt Pan/Mudflat	4.6–7.3	42–95%	50–100%

[a] ESA and Coastal Restoration Consultants 2018



SOURCE: ESA

Loma Alta Slough, Wetland Enhancement Project

Figure 4-2
Inundation Frequency Curve

4.1.3 Salinity

Salinity also influences the type of vegetation that will establish on site. Multiple studies at Loma Alta Slough involved collecting salinity data at the site. The Southern California Coastal Water Research Project (SCCWRP 2011) collected data in 2008 to establish total maximum daily loads (TMDL)'s for nutrients and bacterial contaminants and to inform management actions to address eutrophication. The salinity data was collected from January 1 to October 21, 2008, and showed that the salinity in the lagoon tends to follow seasonal patterns. **Table 4-3** presents the average salinities during different time periods relevant to vegetation establishment. As shown in **Figure 4-3**, the lagoon experiences dramatically varying salinity during the winter as storms pass through the system, dropping the salinity as freshwater flushes through, and then increasing back toward 25 ppt as the lagoon mouth opens to the ocean and salt water can enter. In the spring, salinity generally stays around 20 to 25 ppt as the lagoon mouth closes and salt water from the ocean gets trapped inside. However, throughout the summer the closed lagoon mouth limits how much salt water can enter the site, and fresh, dry-weather flows from upstream continuously flow into the lagoon, and the salinity drops over time. By the end of the summer and early fall, the lagoon is very fresh, around 3 to 8 ppt.

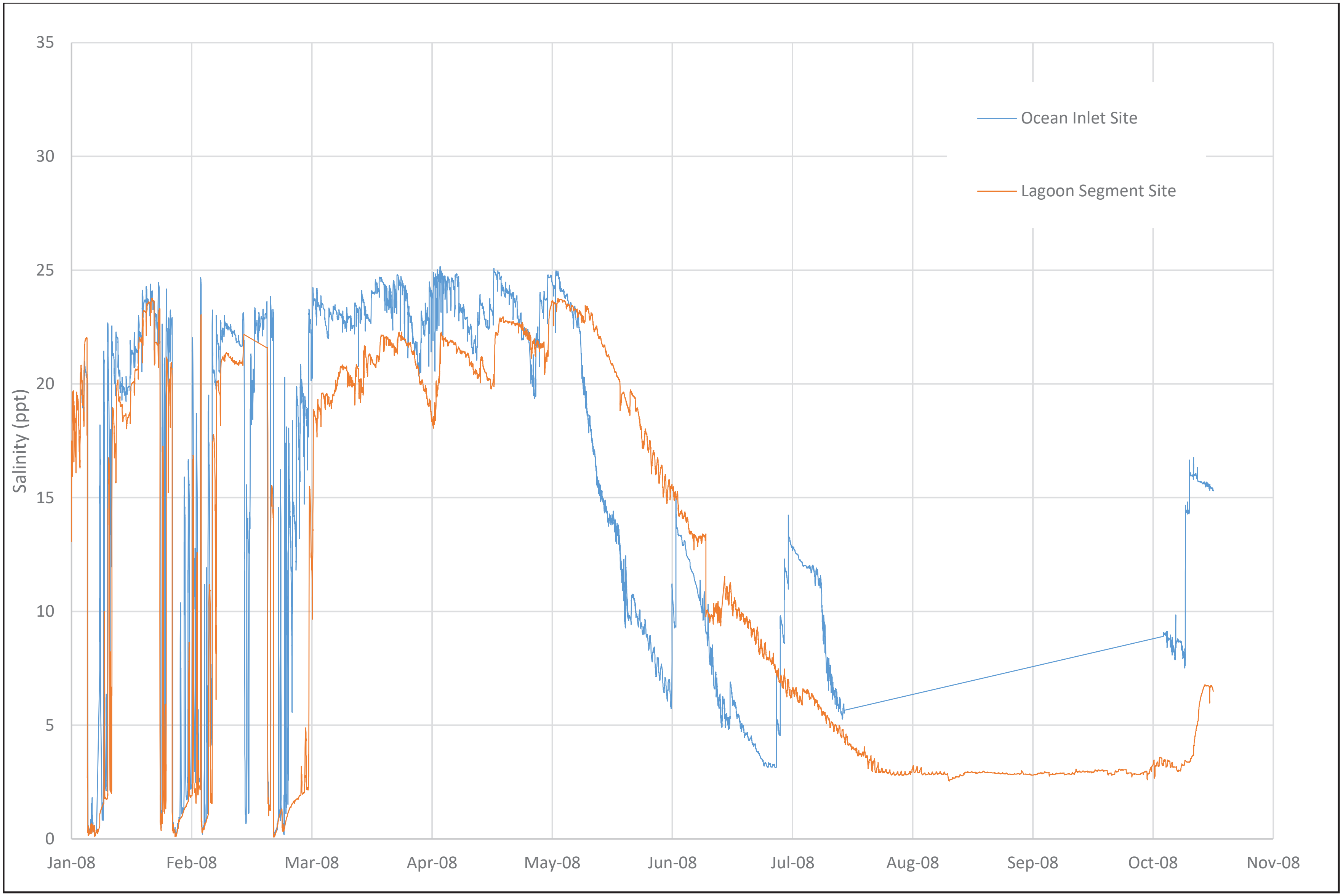
TABLE 4-3
AVERAGE SALINITY IN LOMA ALTA SLOUGH

Habitat Area	Average Salinity (ppt)	Average Summer Salinity (ppt)	Average Winter Salinity (ppt)	Average Apr–Sept (ppt)	Max Apr–Sept (ppt)
West of Railroad Bridge	16	12	19	15	25
East of Railroad Bridge	11	8	16	11	24

As part of SCCWRP's data collection, gages were installed both west and east of the railroad bridge. The data show that the salinity east of the railroad is generally lower than the salinity west of the railroad (Figure 4-3). In June and July, the data shows what is likely two wave overtopping events, where the salinity near the mouth of the lagoon increases briefly.

SCCWRP conducted a second data collection effort in 2010 (SCCWRP 2013) and looked at salinity at the top and bottom of the water column from September 17 to October 14. As shown in **Figure 4-4**, the salinity at both depths in September is very low, around 3 ppt. Around October 1, the lagoon likely breached, which dramatically increased the salinity at the bottom of the water column. The top of the water column showed more variable salinity after the breach, since freshwater from upstream was probably present.

Weston has been collecting water quality data in Loma Alta Slough as part of the TMDL since 2016 (Weston 2019). Data is generally collected in July and August and agrees with the data collected by SCCWRP. Weston's data shows that the salinity during this time is typically low since the lagoon is generally not connected to the ocean very frequently during the summer. Average salinities measured in 2018 during July-August were 7.21 ppt at the surface, 10.66 ppt mid-column, and 14.23 ppt at the bottom of the water column, indicating fresher water floating on top of the saltier water.

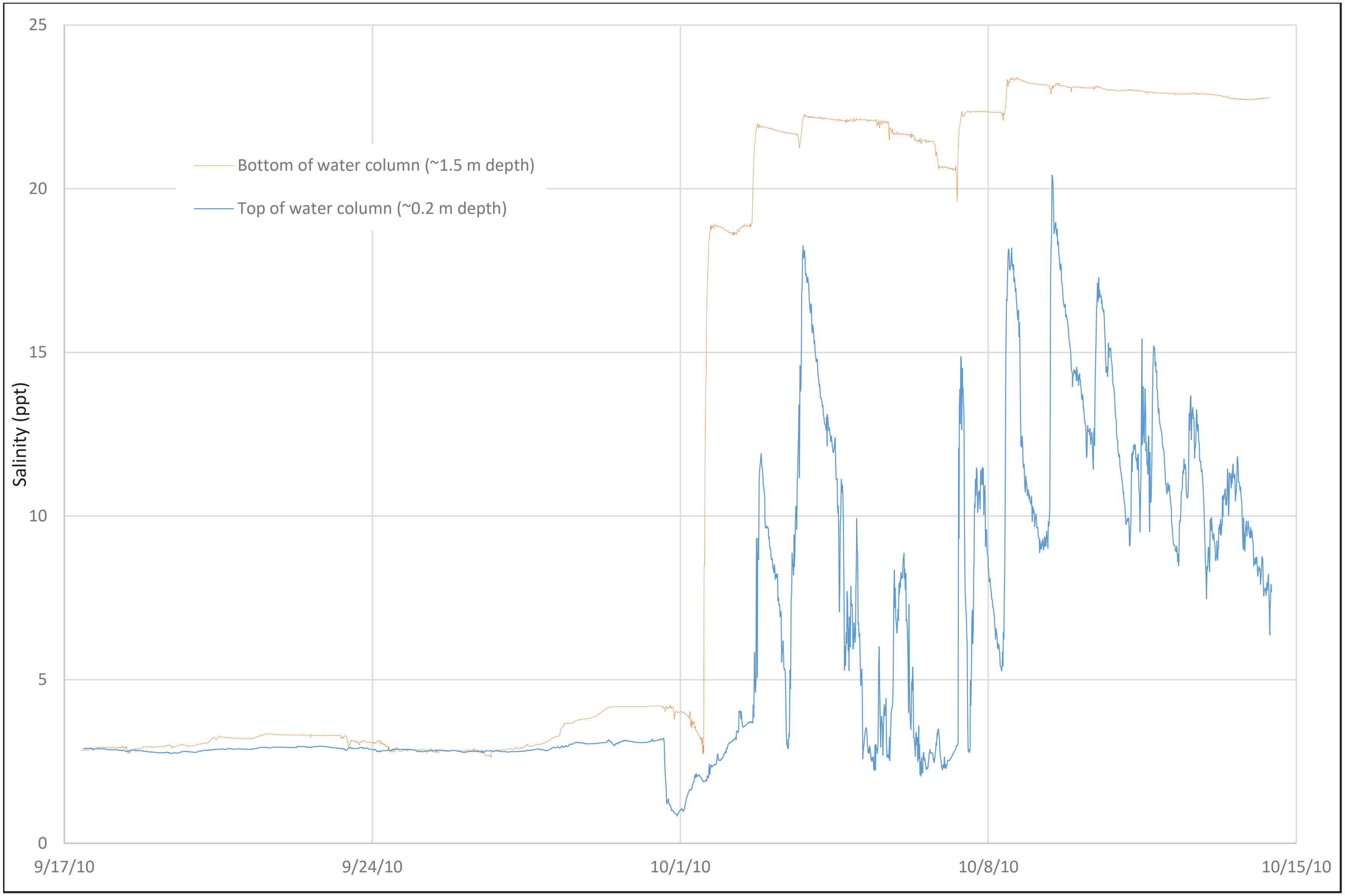


SOURCE: ESA

Loma Alta Slough, Wetland Enhancement Project

ESA

Figure 4-3
Salinity, January–November 2008



SOURCE: ESA

Loma Alta Slough, Wetland Enhancement Project

ESA

Figure 4-4
Salinity, September–October 2010

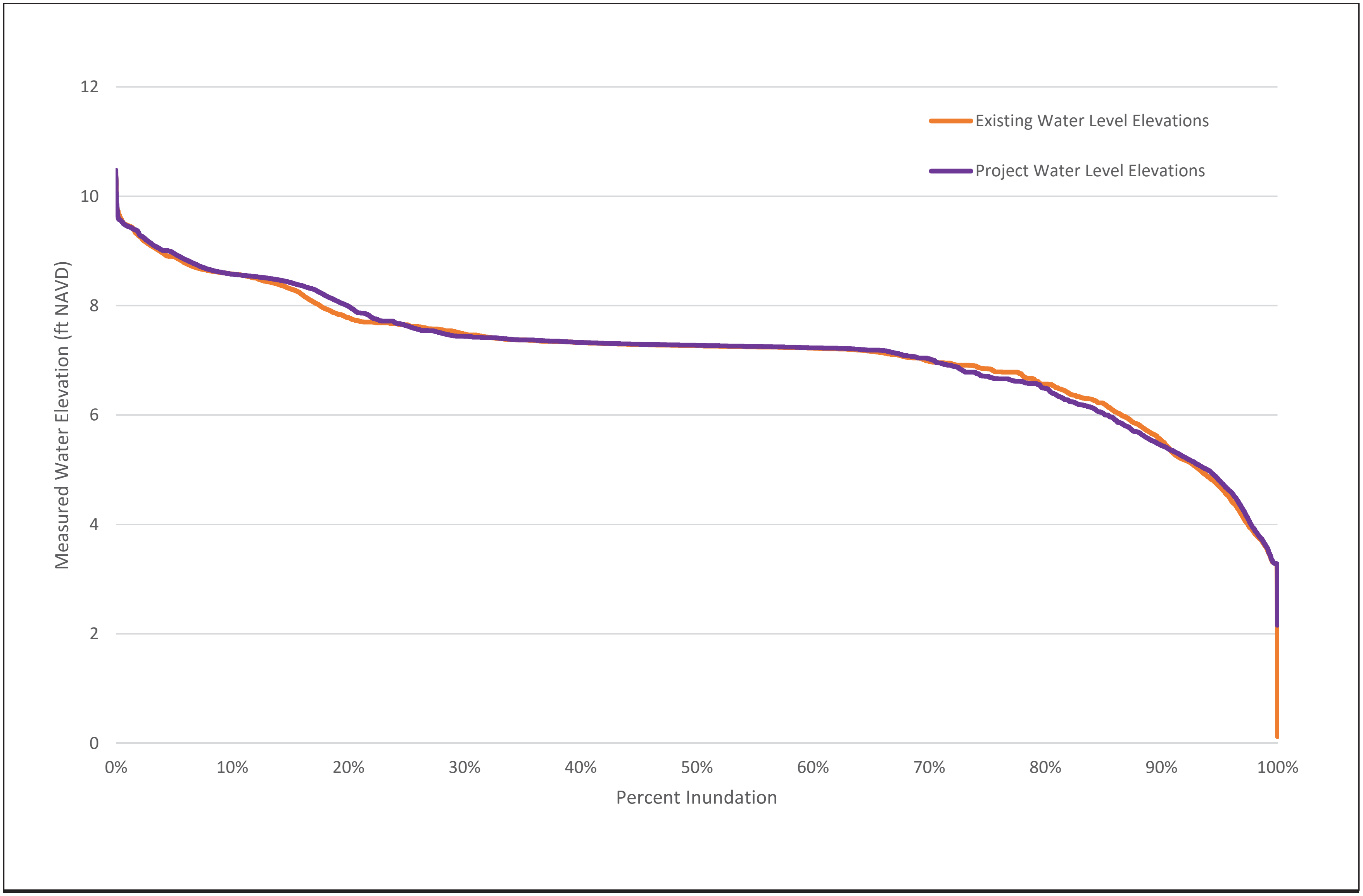
Vegetation at the site fluctuates between the saltier species like pickleweed and salt grass and the more brackish and freshwater species like bulrush and cattails. This is likely due to the timing of storm events in the spring and how this impacts salinity when vegetation is establishing. Lillebo and others (2012) found that *Scirpus maritimus*, a species analogous to the tules at Loma Alta Slough, were not killed by salinity of 15 ppt, but also did not grow. At 10 ppt, the species grew, but at 20 ppt, the vegetation would die within 40 days. During wet years, storm events are expected to open up the lagoon mouth, so after an initial flush of freshwater, the lagoon would be expected to be on the saltier side. During dry years, while fewer large pulses of freshwater would enter the lagoon, the lagoon would also not open to the ocean and the dry-weather flow into the lagoon would keep it fresher. Depending on the timing of storms and breaching events during vegetation establishment, different vegetation types are expected to occur.

4.2 Post-Project Habitats

Using the data collected for existing habitats, conceptual grading plans were developed and analyzed to predict post-project habitats. The upper end of the elevation range for the boundary between jurisdictional wetland and upland (9.4 feet NAVD) was used as the dividing line between the wetland and upland buffer in the grading plans.

The post-project inundation frequency curve at the site was calculated to determine the elevations of different wetland habitat types. The modeled water levels output by the QCM for project conditions was used for the analysis and show very similar results to the existing conditions inundation frequency curve (**Figure 4-5**).

The habitat elevation exceedance frequencies developed in Section 4.1.2 were used to develop a conceptual model of the habitats at the site. **Figure 4-6** provides the expected habitats after restoration based on elevation and salinity (location and wet versus dry years). These categories were developed based on the actual vegetation existing on the site (Section 4.1.1), a review of the literature (ESA PWA 2015, James and Zedler 2000, Josselyn and Welchel 1999, Zedler 1982, and Zedler 2000), and input from ecologists. Wetland vegetation is expected to vary from salt marsh species (pickleweed and jaumea) to brackish and even freshwater marsh species (cattails and tules) seasonally and from year-to-year depending on the timing of rain events with seed germination. The restoration feasibility study and design will further consider and develop the appropriate grading elevations and plant palette based on these results.



SOURCE: ESA

Loma Alta Slough, Wetland Enhancement Project

Figure 4-5
Project Inundation Frequency Curve

ESA

Loma Alta Slough Wetland Enhancement Project

Figure 4-6
Loma Alta Slough Wetland Expected Habitats

4.3 Future Habitats

With sea-level rise up to 5.7 feet, the habitat dynamics in the lagoon are expected to function similarly to under existing conditions. As discussed in Section 2.4.3, the mouth of the lagoon is expected to be closed slightly more often than under existing conditions (Section 2.2.3). This could lead to more brackish and freshwater species establishing, since less salt water would be entering the lagoon. Water levels in the Slough would also increase, in proportion to the increase in the beach berm at the mouth of the lagoon. This could result in "drowning" of some of the vegetation at lower elevations and establishment higher up along the slopes, as the marsh migrates upward. However, this assumes that there would be sufficient sand to build the beach berm. If no action is taken to adapt to sea-level rise and the beach in front of the Slough erodes, water levels could be lower in the Slough. The restored estuary is expected to be a dynamic ecosystem that may change over time in response to infrequent extreme creek flow events, similar to how the historic estuary ecosystem may have functioned. Future climate change and potential increases in extreme wet-weather, drought, temperature, and wildfire could potentially increase the frequency and magnitude of changes or "natural" disturbances to the restored estuary ecosystem.

SECTION 5
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