ATTACHMENT 6
Coastal Engineering Study

The Coastal Engineering Study was prepared as part of the initial engineering assessment of the Rincon facilities and prior to the finalization of the alternative descriptions (Reuse, Reefing, and Removal) as they are depicted in the Feasibility Study. Therefore, discrepancies exist between the alternative descriptions in the Feasibility Study and the Coastal Engineering Study.

Due to the complexities of the subject matter and graphics, accessibility to the document is limited. Should you require assistance with the review of this study please contact Cynthia Herzog at cynthia.herzog@slc.ca.gov.

Coastal Engineering Study for Rincon Island Decommissioning Project

June 2021

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1 INTRODUCTION

1.1 Location

Rincon Island is located approximately 3,000 feet offshore of Punta Gorda in Ventura County, approximately 7 miles northwest of the City of Ventura. The island is located immediately offshore of the community of Mussel Shoals, with the bottom at -48 feet, Mean Lower Low Water (MLLW). The vicinity map is shown in Figure 1. A one-lane causeway, or access pier, connects the island to the coastline. as shown in Figure 2.

Figure 1. Vicinity of Rincon Island

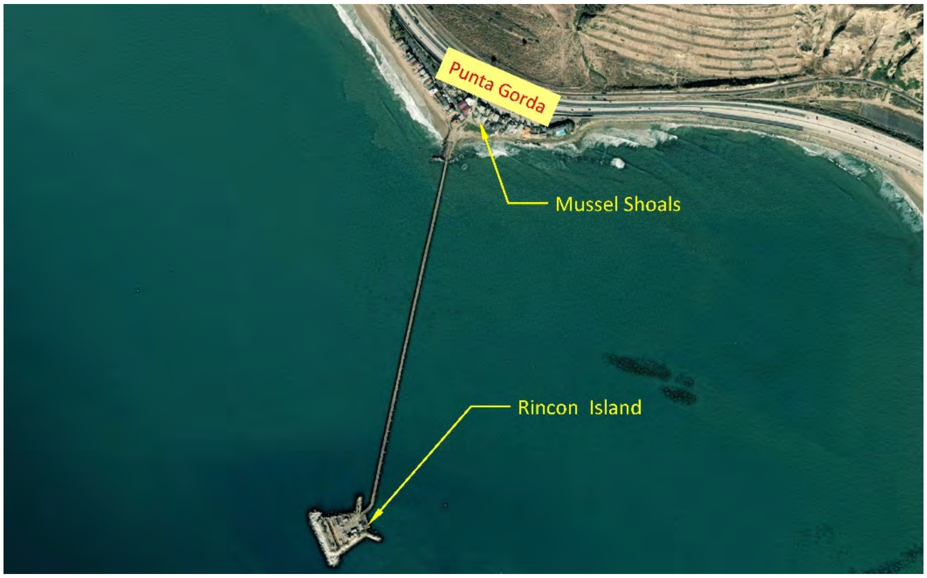

Figure 2. Location of Rincon Island

1.2 Background

Rincon Island was constructed in 1959 for the purpose of well drilling and oil and gas production. Rincon Island and its appurtenant facilities were historically leased by the California State Lands Commission to oil and gas operators, including most recently the Rincon Island Limited Partnership, which quitclaimed its lease interests to the Commission in December 2017 after becoming financially insolvent. Approximately one acre of useable space lies within the depressed interior of the island that is surrounded at its perimeter with scattered palm trees. The island contains storage tanks, oil processing equipment, and other appurtenant facilities.

Rincon Island has not produced oil or gas commercially since October 2008 due in part to the condition and integrity of the causeway that connects the island to the shore. In June 2018, the Commission hired Driltek, Inc. to perform engineering, operations, and administrative services, to develop and execute a program to permanently plug and abandon onshore and offshore wells, to perform all ancillary tasks associated with the plug and abandonment program, to provide essential personnel to continue the safe daily operations of the leases at the current baseline conditions, and to place the facilities into caretaker status or equivalent condition. Driltek is also responsible for maintaining safe conditions on the leases including monitoring and maintaining safe well pressures.

In January 2019, offshore well abandonment began. To date, 86 percent of offshore abandonments (43 of 50 wells) and 96 percent of onshore abandonments (26 of 27 wells) have been completed. The plug and abandonment program is anticipated to be completed before June 30, 2021. The process of securing and eventually decommissioning the oil and gas facilities on Rincon Island and the Onshore Facility has been planned to occur in parts. Part 1 is the ongoing plug and abandonment program. Part 2 is the development of a feasibility study, decommissioning plan, public outreach, and development of the CEQA documentation. Part 3 involves executing the decommissioning plan after approval by the Commission. The current study is part of the feasibility study for Part 2.

1.3 Study Purpose

The purpose of this proposed coastal engineering study is to assist in the preparation of a Feasibility Study Report and the CEQA document, which will be performed by Padre Associates, Inc. (Padre), for the Rincon Island Decommissioning Project. This coastal engineering study will investigate the impacts of various decommissioning alternatives on the coastal processes including nearshore wave climate, circulation, littoral transport, and shoreline morphology in the adjacent areas; and to assess the coastal hazards on Rincon Island and the stability of the island protective armor layer. The analysis will examine the alternative of a full removal of Rincon Island, the causeway, and all other associated infrastructure, the alternative of a partial decommissioning, and the alternative of island repurposing.

1.4 Scope of Services

Our proposed scope of services consists of the following:

Task 1 Coastal Engineering Study for Alternative 2 – Island Repurposing

This alternative proposes to repurpose the island for reuse with the protective armor and sand core to remain as a habitat for marine life and birds. The coastal engineering study for this alternative will focus on the coastal hazard of the island and the stability of the protective armor after considering the future Sea Level Rise (SLR). The results will be used to assess the feasibility of this alternative and assist in the delineation of the habitat. Sub-tasks include the following:

1. Research on the still water levels (SWLs) and the offshore wave conditions.
2. Determining the range of SLR based on the California Ocean Protection Council's 2018 update of the California Sea-Level Rise Guidance.
3. Calculation of the inundation frequency associated with the SWLs with SLR.
4. Wave runup and wave overtopping analysis and calculation of water propagation distance on the island if waves overtop the protective armor. The results will be used to assess the coastal flood hazard on the island.
5. Estimating the size of the protective armor rocks required for the wave protection with future SLR and comparing it with the existing rock size to assess the stability of the existing protective armor.

Since in this alternative, the island will remain and the impact of the causeway removal on the wave climate is negligible, the impact of this alternative on the nearshore processes is expected to be negligible. Therefore, a coastal impact analysis will not be included in the study for this alternative.

Task 2 Coastal Engineering Study for Alternative 3 – Partial Decommissioning

The required coastal analysis for this alternative is the same as Alternative 2. The findings for Alternative 2 will apply to this alternative.

Task 3 Coastal Engineering Study for Alternative 4 – Complete Decommissioning

This alternative involves full removal of Rincon Island, the causeway, and all other associated infrastructure. Rincon Island has provided a certain wave sheltering effect to the nearshore region. Removal of the island may intensify wave energy in some areas behind the island. The coastal analysis for this alternative will focus on the impact of removing the island and the causeway on the nearshore processes. Sub-tasks in support of this alternative include the following:

1. Nearshore wave modeling study using STWAVE or CMS-Wave model to investigate the impact of this alternative on the nearshore wave climate. Both STWAVE and CMS-Wave were developed by the U.S. Army Corps of Engineers.
2. Assessment of impact on the nearshore circulation.
3. Assessment of impact on the alongshore and cross-shore sediment transport.
4. Assessment of impact on the shoreline/beach evolution.

2 OFFSHORE OCENOGRAPHIC CONDITION

2.1 Still Water Levels

Variations of the still water level (SWL) along the California shoreline are primarily caused by astronomical tides. In addition, storm surge, wave setup, and El Niños also contribute to the local sea level variations. Storm surge is relatively small (less than 1 foot) along the California Coast when compared to the astronomical tidal fluctuations. Wave setup is the additional elevation of the water level due to the effects of transferring wave-related momentum to the shoreline. El Niños can also elevate sea level along the California coast during the winter months. El Niño is a band of anomalously warm ocean water temperatures that occasionally develops off the western coast of South America and can cause climatic changes across the Pacific Ocean.

The National Oceanic and Atmospheric Administration (NOAA) Santa Barbara Station (Station ID: 9410840) is the closest NOAA tidal station to Rincon Island and thus was used to represent the SWL characteristics for the project site. The tidal datum at Santa Barbara is summarized in Table 1.

Table 1. Tidal Characteristics at Santa Barbara (1983-2001 Tidal Epoch)

Tidal datum	Water level (ft, NAVD88)
Highest Observed Water Level	+7.51
Mean Higher High Water (MHHW)	+5.25
Mean High Water (MHW)	+4.50
Mean Sea Level (MSL)	+2.65
Mean Low Water (MLW)	+0.94
Mean Lower Low Water (MLLW)	-0.14
Lowest Observed Water Level	-3.01

The still water levels have been measured at the NOAA Santa Barbara Station since 1991 but with a data gap from 1998 to 2004. To cover a longer period of data record, the water levels measured at the NOAA Santa Monica Station, which is the second closest station to the project site, between 1998 and 2004 was added to the data gap of Santa Barbara Station. As such, the measured water levels cover a 30-year period from 1991 to 2020. It is noted that measured still water levels not only include the contribution from astronomical tides but also contributions from historical storm surge, wave setup, and El Niños.

Based on the annual maximum SWL derived from the 30-year data record, a statistical analysis was conducted to determine the annual maximum SWL for various return periods. The annual maximum SWL data and the curve-fitting of the data using the Weibull distribution are shown in Figure 3. As listed in Table 2, the 1-year SWL is +6.8 ft, NAVD88 and the 100-year SWL is +7.8 ft, NAVD 88.

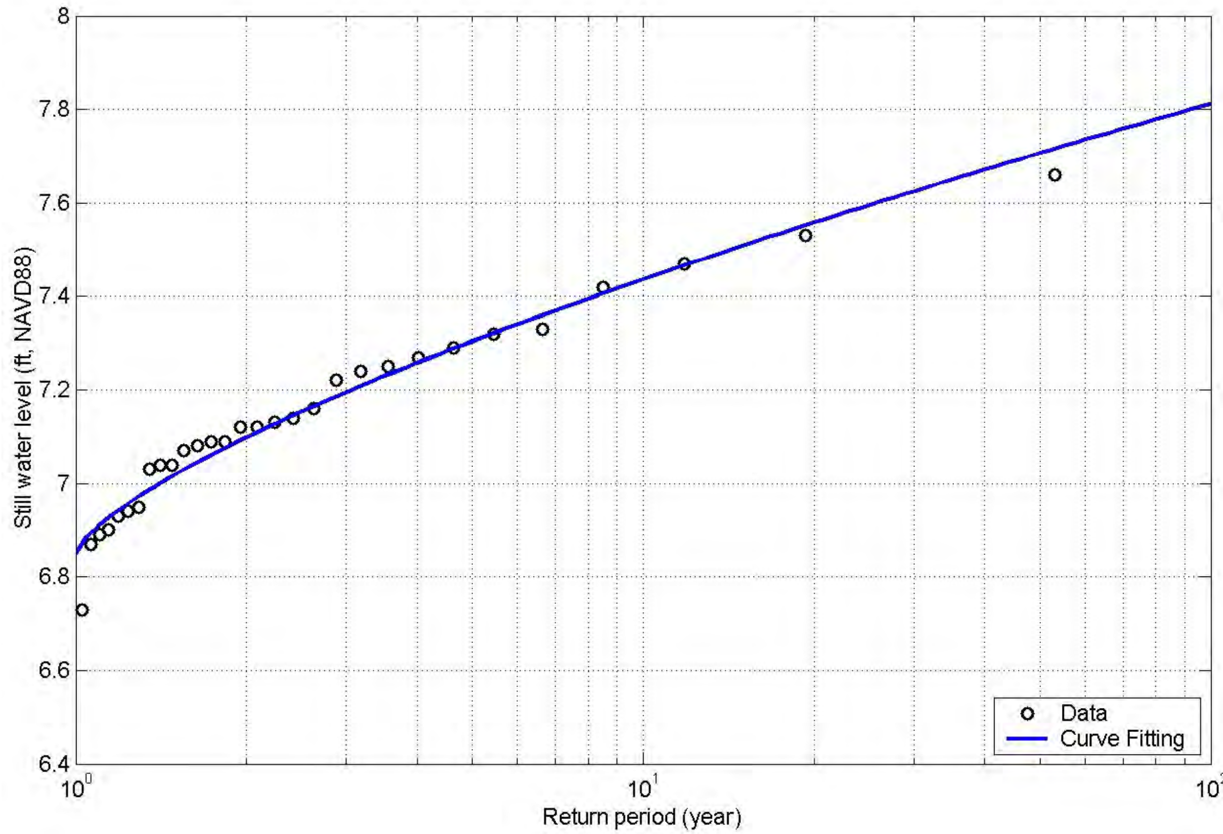

Figure 3. Return Frequency of Annual Maximum Still Water Levels

Table 2. Return Frequency of Annual Maximum Still Water Levels

Return period	Still water level (ft, NAVD88)
1-year	+6.8
10-year	+7.4
50-year	+7.7
100-year	+7.8

2.2 Sea Level Rise

The California Ocean Protection Council (OPC) adopted the 2018 update of the State of California Sea-Level Rise (SLR) Guidance, which provides science based guidance to help state and local governments analyze the risks associated with SLR and incorporate SLR into planning, permitting, and investing decisions. In this 2018 SLR Guidance, a range of potential SLR projections were developed for a subset of active tide gauges in California based on emission trajectories, acknowledging that projected SLR has a significant range of variation as a result of uncertainty in future greenhouse gas emissions and their geophysical effects, such as the rate of land ice melt. The probabilistic projections for the height of SLR over different time frames and emission scenarios for the Santa Barbara tide gauge, the closest gauge to the project site, are summarized in Table 3.

Table 3. Sea Level Rise Projections (Feet, from 2000)

Time Period		Likely Range (66% probability)	Medium-High Rise Aversion (0.5% probability)
2050	High Emissions	0.4 – 1.0	1.8
2070	Low Emissions	0.5 – 1.3	2.8
	High Emissions	0.7 – 1.7	3.3
2100	Low Emissions	0.6 – 2.0	5.3
	High Emissions	1.2 – 3.1	6.6

Adding the likely range of SLR to the existing SWL, the future annual maximum SWL are listed in Table 4. Depending on various greenhouse gas emission scenarios, the 1-year SWL will range from +7.2 to +7.8 feet, NAVD88 in 2050, from +7.5 to +8.5 feet, NAVD88 in 2070, and from +9.4 to +9.9 in 2100. The 100-year SWL will range from +8.2 to +8.8 feet, NAVD88 in 2050, +8.3 to +9.5 feet, NAVD88 in 2070, and from +8.4 to +10.9 feet, NAVD88 in 2100.

Table 4. Return Frequency of Annual Maximum SWLs with Likely Range SLR

Return period	Still water level (ft, NAVD88)		
	2050	2070	2100
1-year	+7.2 to +7.8	+7.3 to +8.5	+7.4 to +9.9
10-year	+7.8 to +8.4	+7.9 to +9.1	+8.0 to +10.5
50-year	+8.1 to +8.7	+8.2 to +9.4	+8.3 to +10.8
100-year	+8.2 to +8.8	+8.3 to +9.5	+8.4 to +10.9

2.3 Deep-Water Waves

Waves (ocean swell and wind waves) along the southern California coast are mainly produced by six basic meteorological weather patterns. These include extratropical storm swells in the Northern Hemisphere (north or northwest swell), wind swells generated by northwest winds in the outer coastal waters (wind swell), westerly (west sea) and southeasterly (southeast sea) local seas, storm swells of tropical storms and hurricanes off the Mexican coast, and southerly swells originating in the Southern Hemisphere (southerly swell).

Because of Point Conception and Point Mugu, Rincon Island is only exposed to waves coming from the southeast, clockwise to approximately the west, as shown in Figure 4. Furthermore, the offshore Channel Islands provide some sheltering from waves approaching from the Pacific Ocean within this exposure angle and reduce the energy of many ocean swells before they reach Santa Barbara Channel.

Figure 4. Rincon Island Exposure Angle to Pacific Storms

The NOAA National Data Buoy Center (NDBC) maintains a buoy station (NDBC 46053) inside Santa Barbara Channel. The location of this station is shown in Figure 5. Deployed at a water depth of approximately 1,300 feet, this buoy has collected the wind data and the wave data since 1994. Since this buoy is located within the Santa Barbara Channel, the sheltering effect of the offshore Channel Islands are already reflected in the measured data. The 27 years of wind data collected at NDBC 46053 was used in the analysis to represent the wind condition at Rincon Island. The collected wave data was used to represent the offshore deep-water wave condition before further propagating to Rincon Island, and the nearshore study area of this analysis.

Figure 6 shows the joint distribution of significant wave heights and wave directions based on wave data measured at the NDBC 46053 station. Approximately 31% of waves at this deep-water location come from west south-west (WSW), 53% of waves come from west, and 12% of waves come from west north-west (WNW). Waves coming from other directions are rare.

Figure 5. Location of NOAA NDBC 46053 Buoy Station

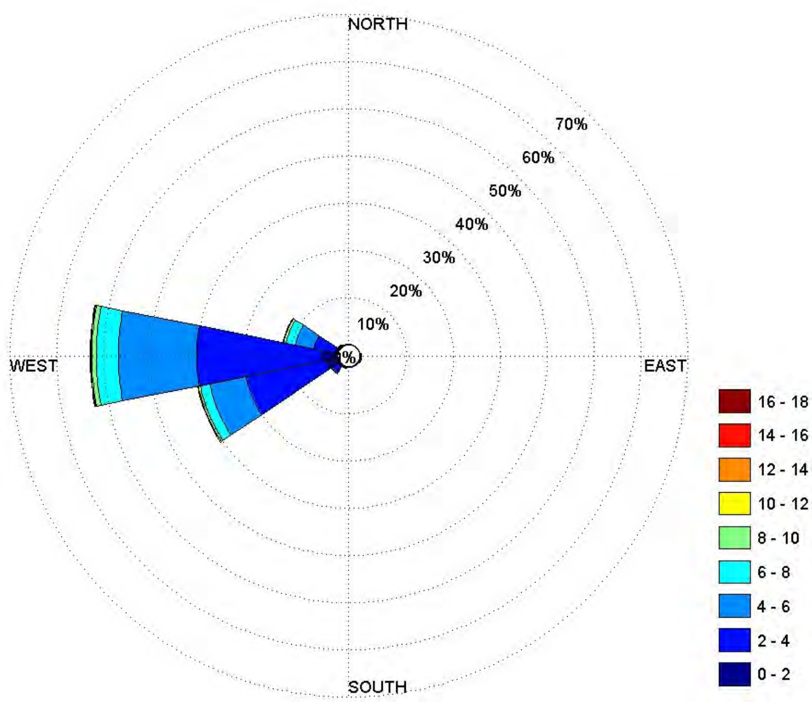

Figure 6. Joint Distribution of Deep-Water Wave Heights and Directions

The annual maximum values of the significant wave heights were derived from the wave data measured at the NDBC 46.53 station. A return frequency analysis of the annual maximum wave events was conducted. The annual maximum wave height data and the Weibull curve-fitting of the data are shown in Figure 7. As listed in Table 5, the 1-year wave event at this deep-water location has a significant wave height of 9.6 feet with a peak wave period of 11.5 seconds. The 100-year wave event has a wave height of 20.1 feet with a peak wave period of 20.2 seconds.

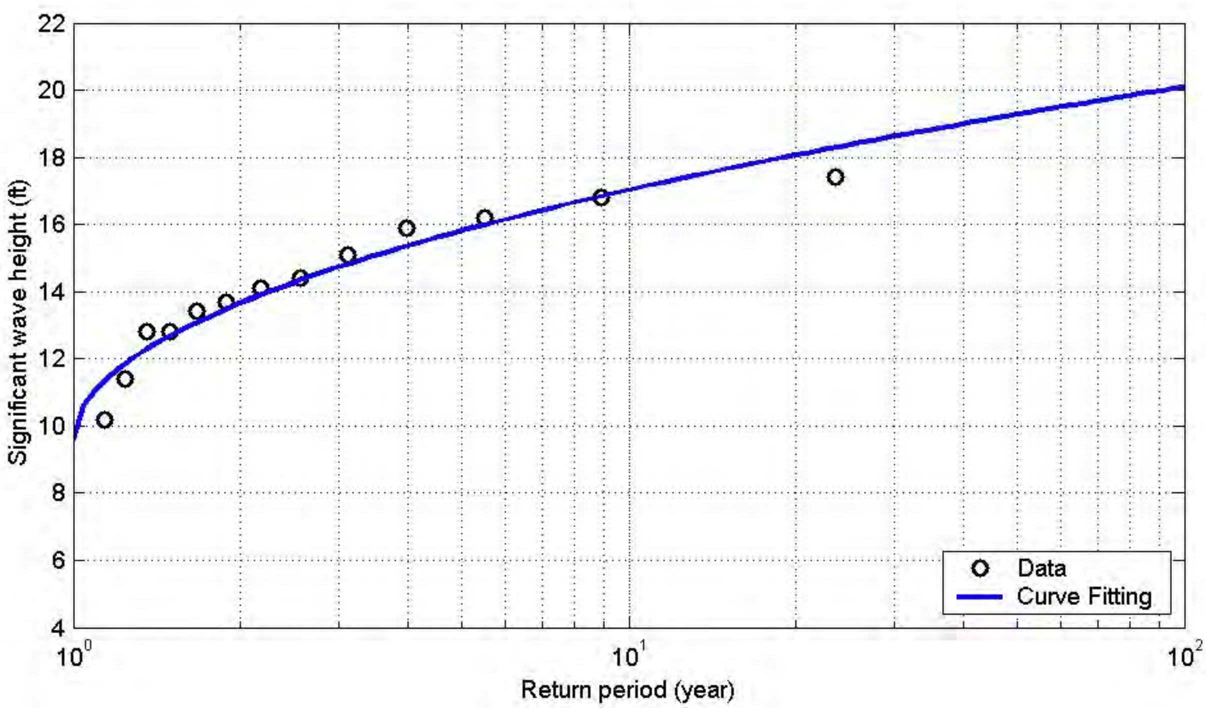

Figure 7. Return Frequency of Annual Maximum Deep-Water Wave Height

Table 5. Return Frequency of Annual Maximum Deep-Water Wave Height

Return period	Significant wave height (ft)	Peak wave period (second)
1-year	9.6	11.5
10-year	17.0	18.0
50-year	19.3	19.9
100-year	20.1	20.7

2.4 Wind

Figure 8 shows the joint distribution of hourly wind speeds and wind directions, or the so-called wind rose plot, based on the wind data measured at the NDBC 46053 station. It is noted that north winds occur for approximately 8% of the time, east winds for 14% of the time, south winds for 13% of the time, and west winds for 64% of the time.

The wind data collected at the NDBC 46.53 station was further divided into four directions: north, east, south, and west. The annual maximum wind speed was then determined for each of these four directions, based upon which a return frequency analysis of the annual wind events was conducted for each direction. The data and the curve-fitting of the annual maximum wind speeds are shown in Figure 9 through Figure 12 for these four directions, respectively. The wind speed of the wind events with various return periods are summarized in Table 6.

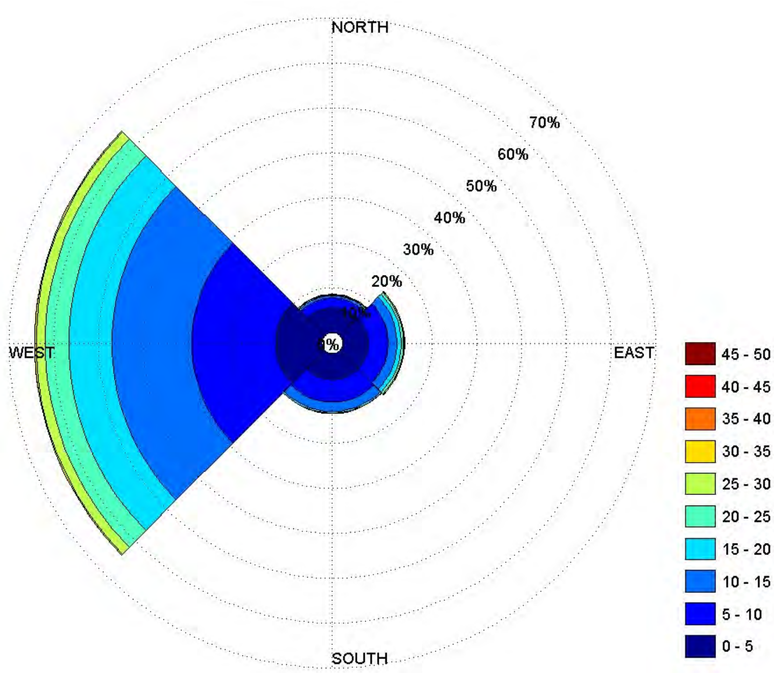

Figure 8. Joint Distribution of Wind Speeds and Directions (Wind Rose)

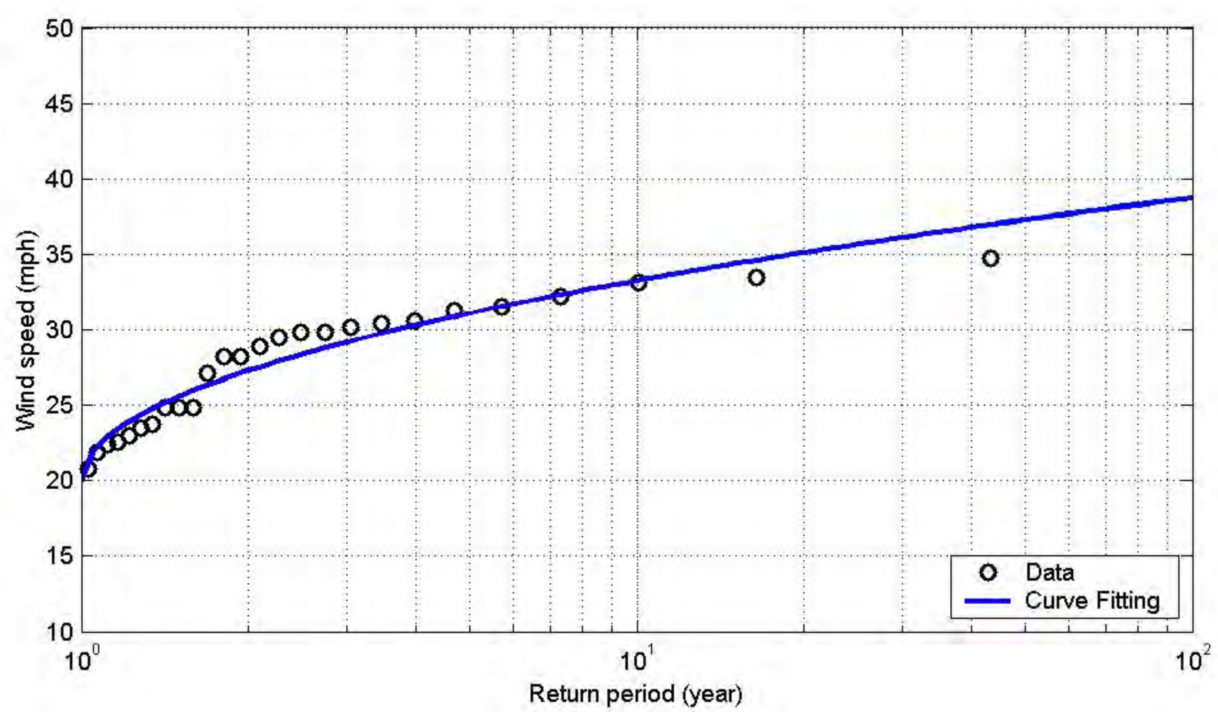

Figure 9. Return Frequency Analysis of Annual Maximum North Wind

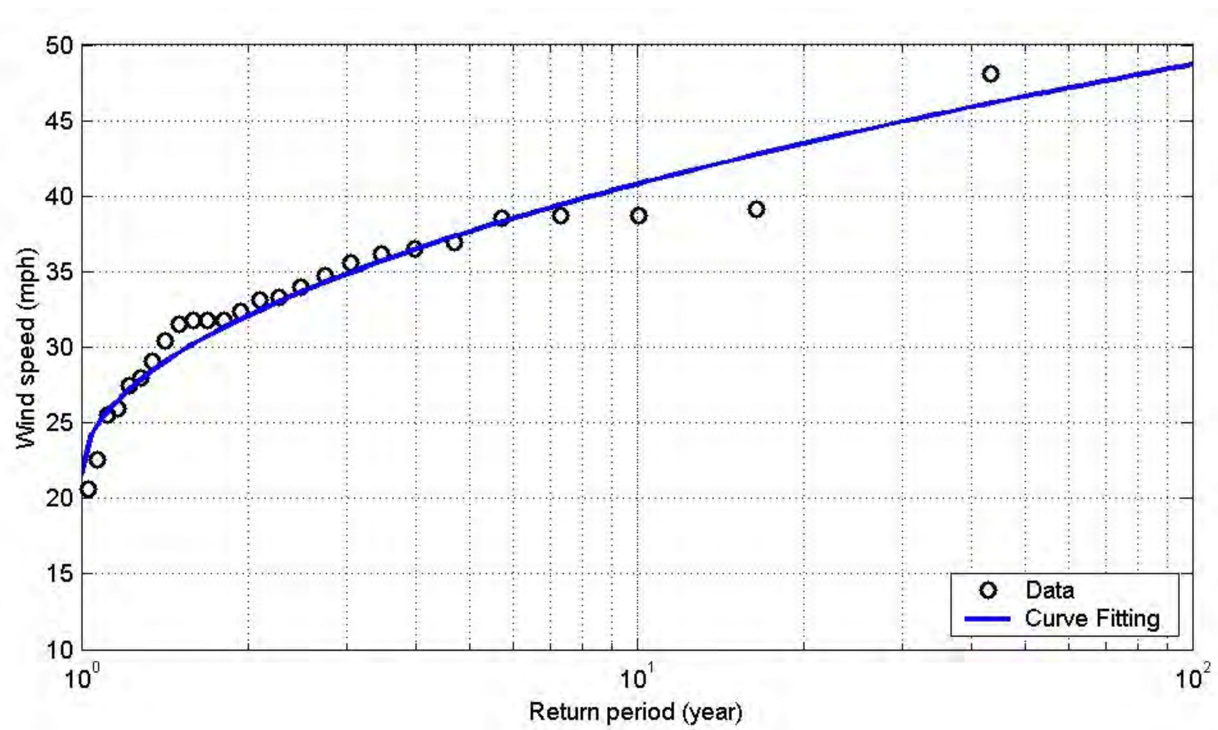

Figure 10. Return Frequency Analysis of Annual Maximum East Wind

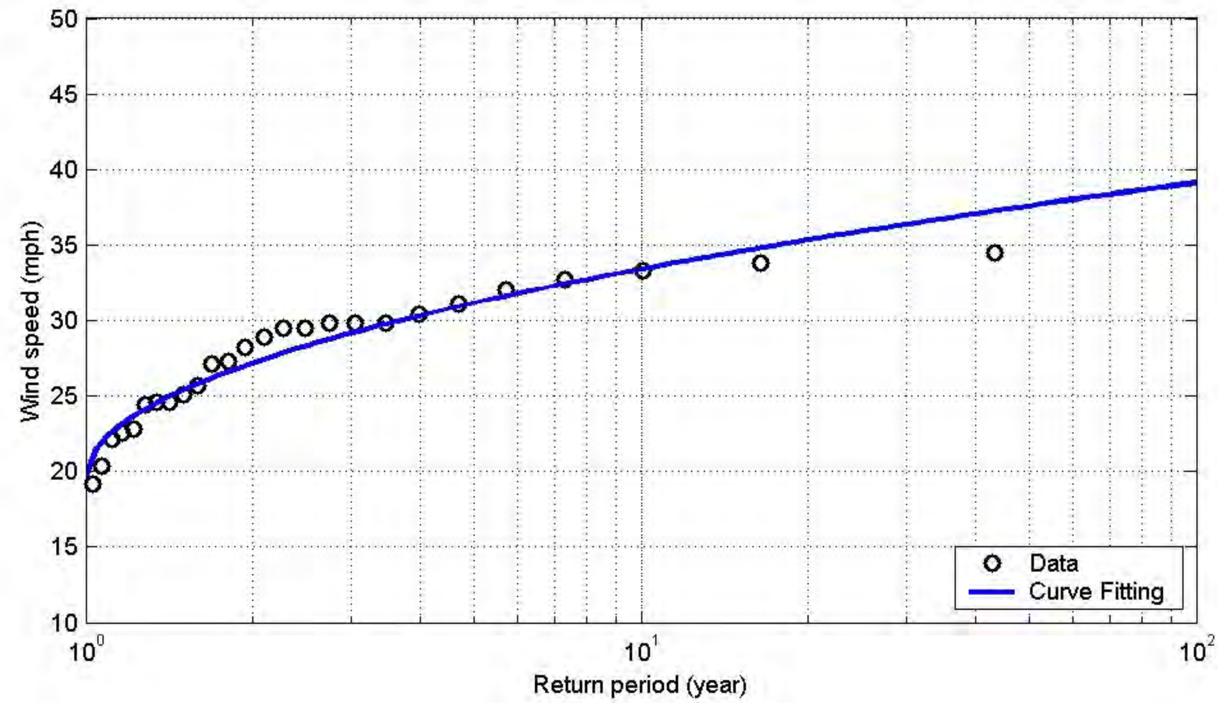

Figure 11. Return Frequency Analysis of Annual Maximum South Wind

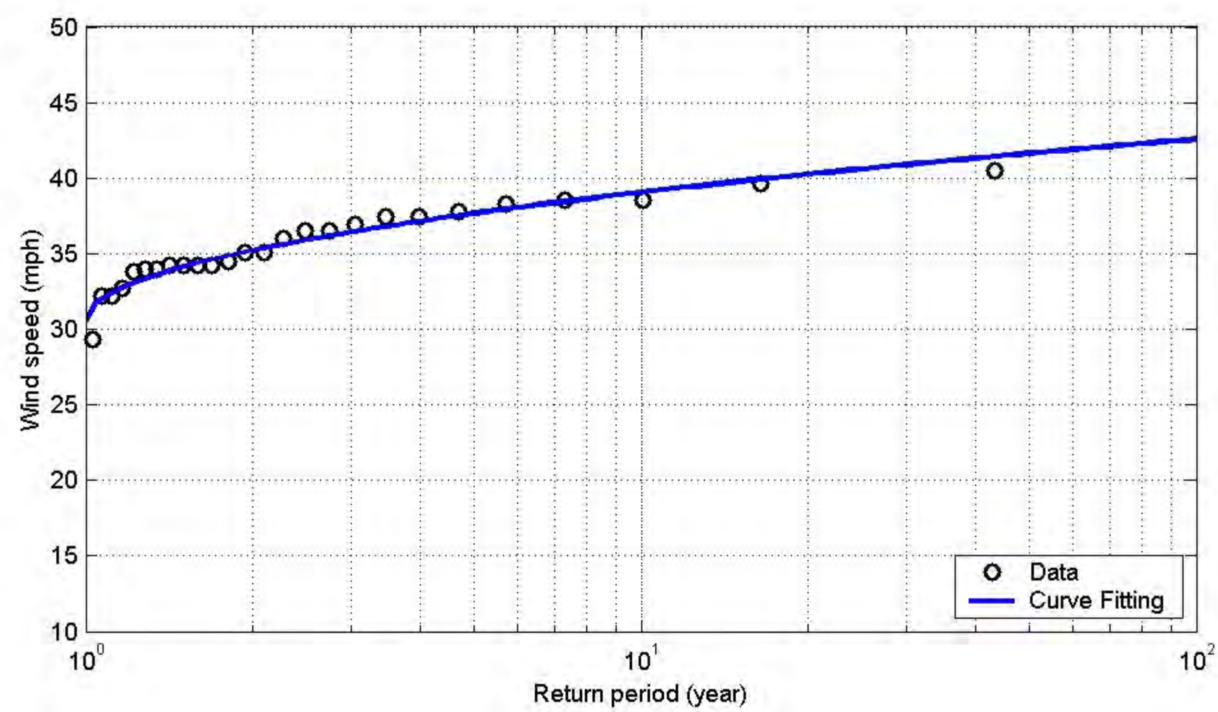

Figure 12. Return Frequency Analysis of Annual Maximum West Wind

Table 6. Return Frequency of Annual Maximum Winds

Return period	Wind speed (mph)			
	East	South	West	North
1-year	22	20	31	20
10-year	41	33	39	33
50-year	47	38	42	37
100-year	49	39	43	39

3 COASTAL ENGINEERING STUDY FOR ALTERNATIVE 2 – ISLAND REPURPOSING

3.1 Existing Condition of Rincon Island

A little over 2 acres in area, Rincon Island is an island made up of 160,000 cubic yards of dredged sand and gravel. This core is surrounded by 72,600 cubic yards of imported armor rock. Additionally, the seaside exterior is reinforced with 1,100 concrete tetrapods, weighing approximately 31 tons each. The layout of the Rincon Island facility is shown in Figure 13. A sketch of the cross-section along the main axis of the island is shown in Figure 14.

Photo by Driltek

Figure 13. Aerial View of Rincon Island

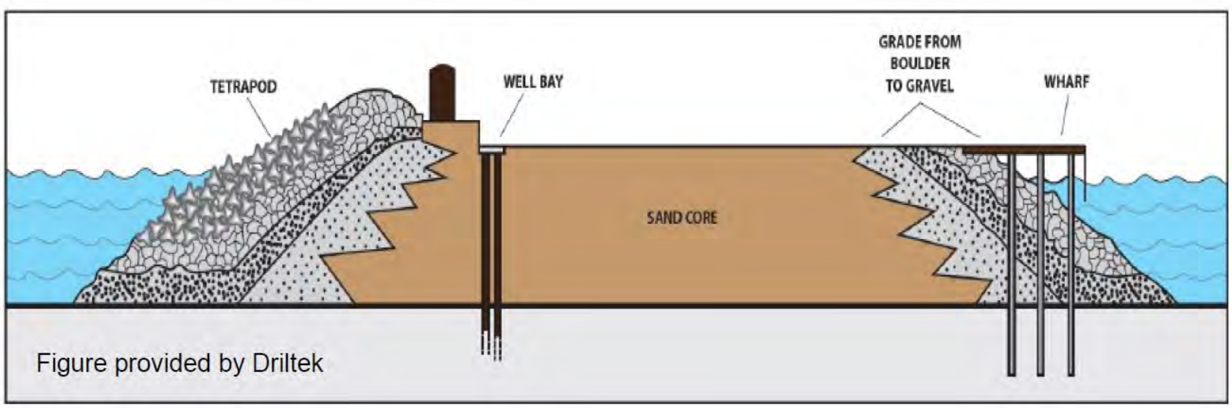

Figure 14. Sketch of Cross-Section of Rincon Island

3.2 Description of Alternative 2 – Island Repurposing

Alternative 2 would repurpose the island as a marine sanctuary. This alternative would include complete removal of the surface improvements on the island but would leave the rock and the sand core as habitat for marine life and birds. Under this alternative, the onshore facilities, the causeway, and the associated pipelines and power cables, would be removed after surface removal operations are completed on Rincon Island. The island will remain. The impact of the causeway removal on the nearshore processes is negligible because the size of the causeway piles is negligible compared to the wavelength and the scale of the nearshore area. Therefore, a coastal impact analysis was not conducted for this alternative. Instead, the analysis for this alternative focused on the coastal hazard on the island and the stability of the protective armor after considering potential future Sea Level Rise (SLR).

3.3 Rincon Island Topography

Longitude 123, Inc. (L123) and eTrac Inc. completed a hydrographic and Lidar survey of Rincon Island and adjacent nearshore region in March and April 2021. The topography of the island is shown in Figure 15. The typical section profile along the main axis of the island (seaside to leeside) is shown in Figure 16. Another section profile from north to south is shown in Figure 17. The comparison of the top elevations of the armor layers (revetments) and the island ground elevation between the existing (2021) condition and the as-build condition (Blume and James, 1959) are listed in Table 7.

Compared to the as-built condition, the top of the seaside revetment is more than five feet lower while the top of the north and southeast revetments is between one to two feet lower. The top of east wharf and the island ground elevations are slightly lower than the as-built condition. The general shape of the island and it's cross-section has not significantly changed from the as-built condition. As shown in Figure 16 and Figure 17, the side slope of the existing revetment is approximately 1.5H:1V, which remains unchanged from the as-built condition. The seaside difference could be due to a number of things that are outside the scope of this study. It could be as simple as the accuracy of the survey at that time with the tetrapods unique shape, but this study does not require a determination of the history of what has caused the change in elevation.

Table 7. Comparison of Rincon Island Elevations

Locations	Existing (2021) condition (ft, NAVD88)	As-built condition[1] (ft, NVAD88)
Top of seaward revetment	+35.5	+40.9
Top of north and SE revetment	+21.6 to +22.3	+23.9
Top of east wharf	+15.4	+15.9
Ground of island	+14.4 to +15.7	+15.9

Note: 1 – Elevations based on Blume and James (1959) and then converted to NAVD88 vertical datum

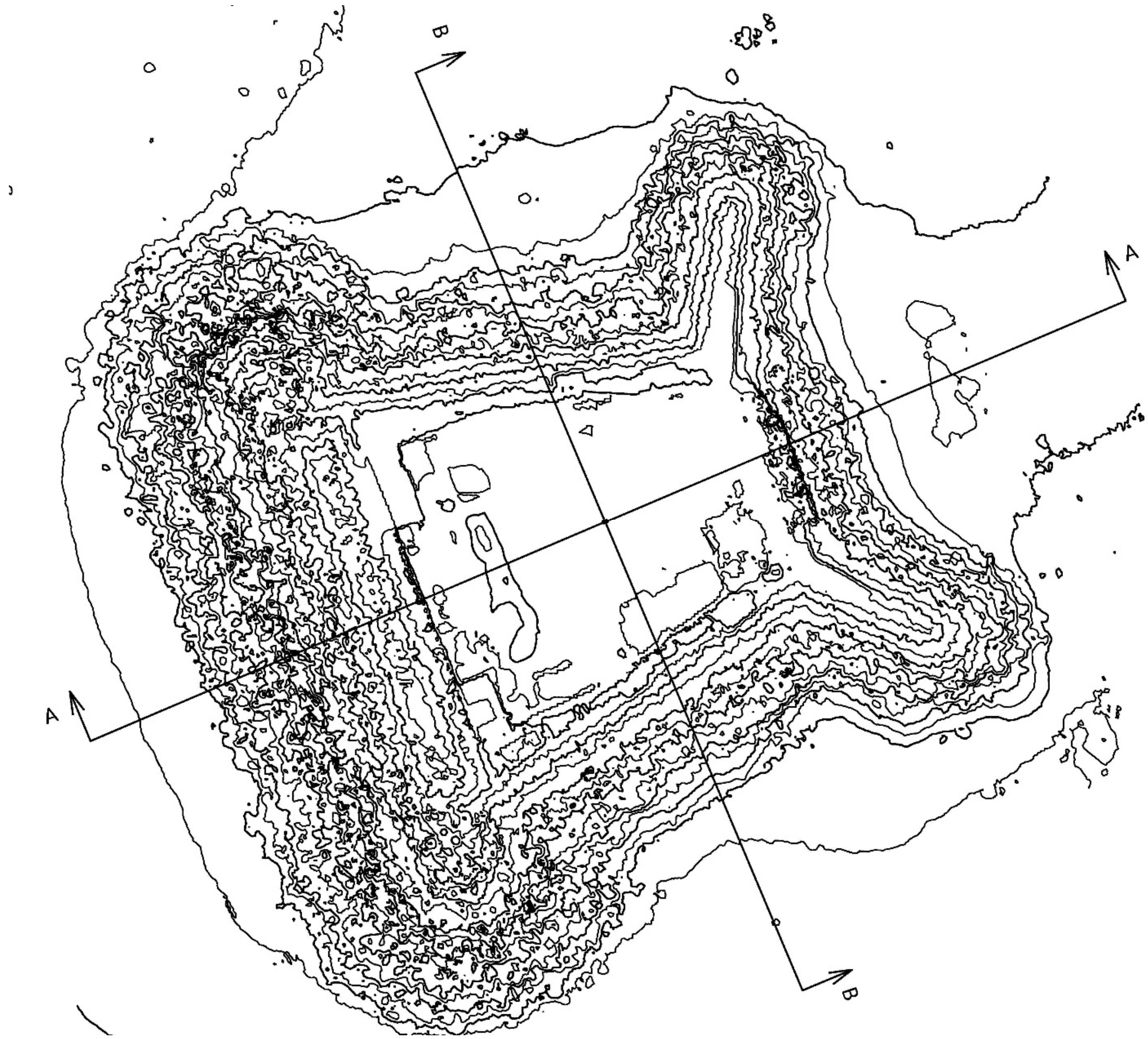

Figure 15. Existing Topography of Rincon Island (March/April 2021)

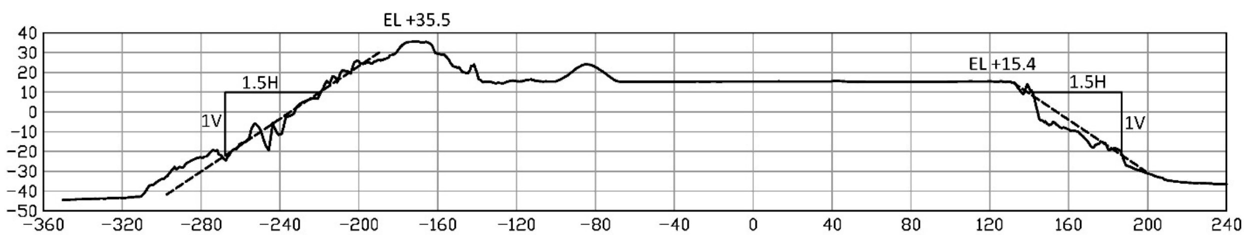

Figure 16. Rincon Island Typical Section A (Seaside to Leeside)

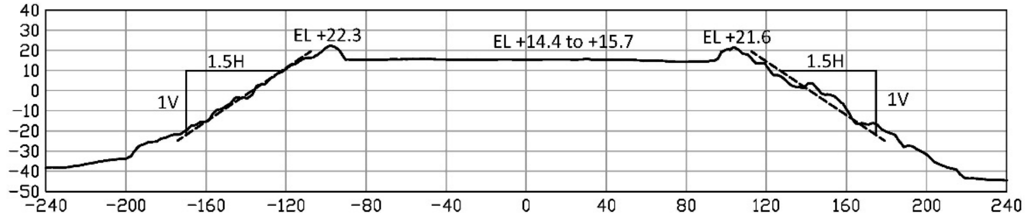

Figure 17. Rincon Island Typical Section B

3.4 Waves at Rincon Island

As discussed on Section 2.3, Santa Barbara Channel and Rincon Island are only exposed to ocean waves coming from the southeast, clockwise to approximately the west, and the offshore Channel Islands provide some further sheltering from waves approaching from the Pacific Ocean within this exposure angle. These ocean waves are usually generated by distant weather systems that propagate thousands of miles across oceans and seas. Wave data collected at the NDBC 46053 station, which is located within Santa Barbara Channel at a water depth of approximately 1,300 feet, was used to represent the offshore deep-water ocean wave conditions for the project site. As waves propagate from the deep water to nearshore coastal areas, they will be further altered by shoaling, refraction, and diffraction effects because of the variations in local bathymetry.

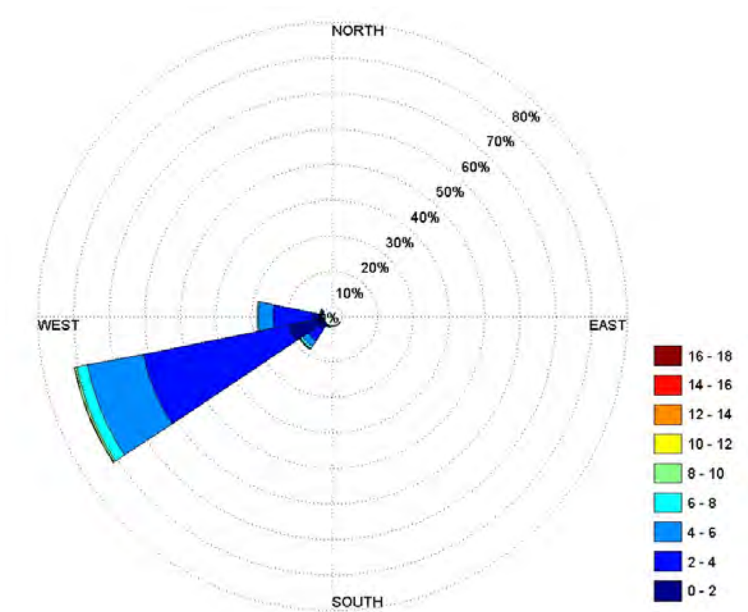

Figure 18. Joint Distribution of Wave Heights and Directions at Rincon Island

The ocean waves at Rincon Island, which is located at a water depth of approximately 48 feet, MLLW, were derived by propagating the deep-water waves using the wave shoaling and refraction method. The joint distribution of significant wave heights and wave directions at Rincon Island is shown in Figure 18. Because of the wave refraction effect, the directions of waves at Rincon Island have shifted towards to the shore-normal direction (SSW) at this location compared to the deep-water waves. While the majority (53%) of waves come from the west in deep water, 70% of waves at Rincon Island are from the WSW direction, 8% of waves from SW, and 18% from west.

Rincon Island was developed with an unusual plan shape in order to obtain optimum wave protection, as shown in Figure 19. Since 96% of the ocean waves approach the island from the SW direction clockwise to the west direction, only the seaside of the island is subject to the attacks from waves coming from the Pacific Ocean. The other three sides of the island are mainly subject to the actions of waves generated by local winds. It is noted that the ocean waves during storm events typically have much larger wave heights and much longer periods than the waves generated by local winds. Thus, the seaside of the island is subject to much more intense wave actions than the other three sides. That is why the unusual plan shape was selected and why 31-ton tetrapods were used along the seaside of the island.

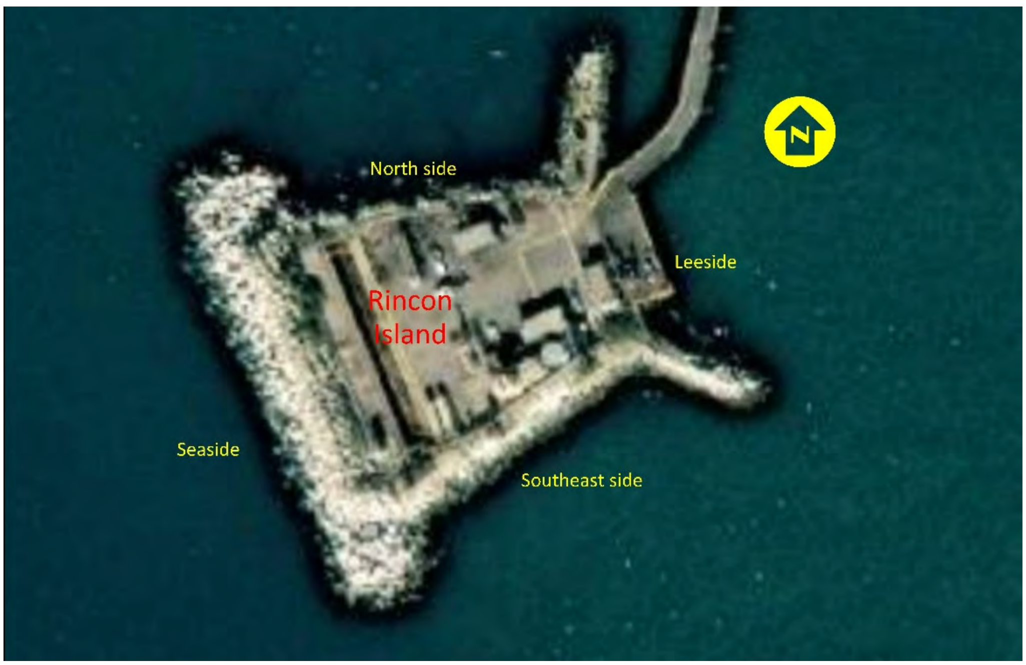

Figure 19. Aerial photo of Rincon Island

3.4.1 Waves at Seaside of Rincon Island

Based on the wave data computed at the island location (-48 feet, MLLW), the annual maximum values of the wave heights were derived. These annual maximum wave heights and the Weibull curve-fitting of the data are shown in Figure 20, and the wave heights for various return periods (years) are summarized in Table 8. At the seaside of the island, the significant wave heights for the 1-, 10-, 50-, and 100-year wave events are 6.9, 16.4, 19.3, and 20.4 feet respectively. These wave characteristics will be used to analyze the wave flood hazard from this seaside and the stability of the seaside revetement.

It is noted that a significant wave height of 14 feet was considered as a 14.4-year event in the original oceanographic studies ((Blume and James, 1959) for the Rincon Island's design. Based our analysis and current information, that wave height is approximately a 3.5-year wave event.

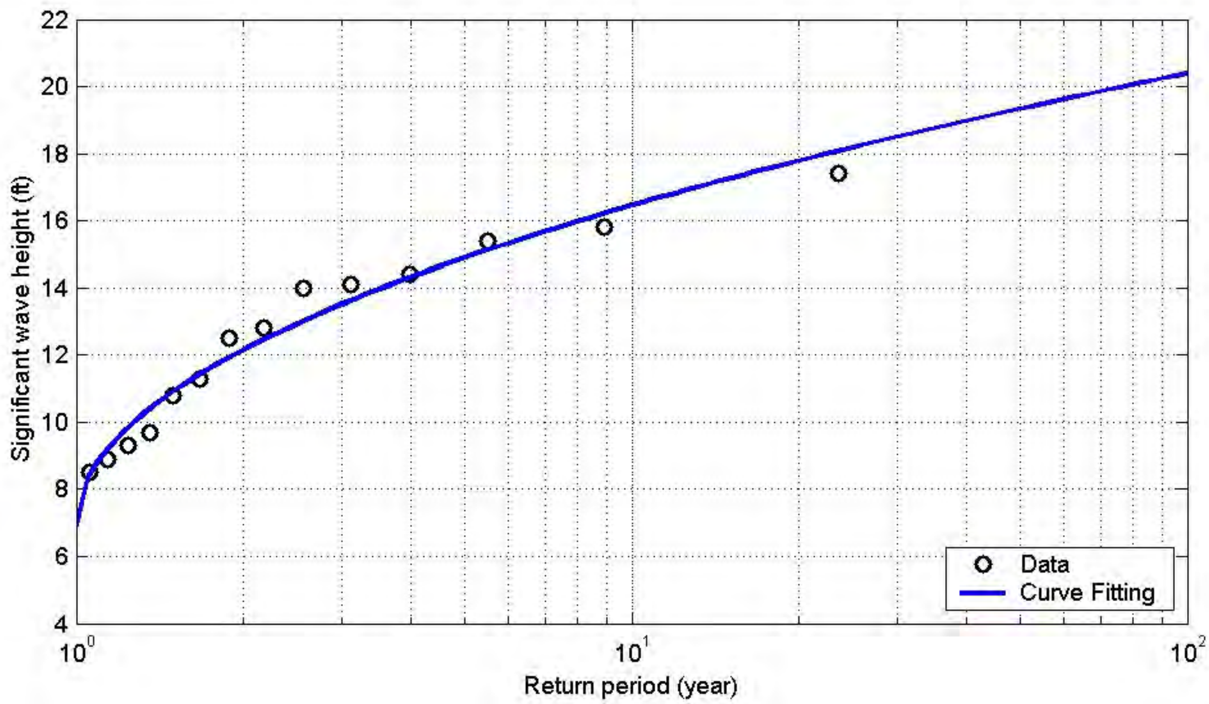

Figure 20. Return Frequency of Annual Maximum Wave Height at Seaside

Table 8. Return Frequency of Annual Maximum Wave Height at Seaside

Return period	Significant wave height (ft)	Peak wave period (second)
1-year	6.9	11.5
10-year	16.4	18.0
50-year	19.3	19.9
100-year	20.4	20.7

3.4.2 Wind Generated Waves at the Other Three Sides of Rincon Island

While the north side, leeside, and southeast side of Rincon Island are sheltered from attacks of waves generated by distant weather systems that propagate thousands of miles across the Pacific Ocean, these three sides are still subject to the actions of waves generated by local winds. The wave heights and periods of wind-waves at a given direction mainly depend on the wind speed, the fetch length, and the water depth along this direction. The fetch length is the length of water over which a given wind has blown without obstruction. The longest wind fetch lengths are approximately 2.2 miles for the north side of the island, 2.9 miles for the leeside, and 16 miles for the southeast side.

The wind-waves at these three sides of the island were computed using the wave prediction application within the Automated Coastal Engineering System (ACES), a module of the Coastal Engineering Design and Analysis System (CEDAS) software developed by the U.S. Army Corps of Engineers. ACES is a comprehensive set of software programs for applying a broad spectrum of coastal engineering design and analysis technologies, including applications for wave prediction, wave theory, wave transformation, structural design, wave runup, transmission and overtopping, littoral processes, and inlet processes. The methodologies included in the wave prediction application of ACES provide quick and simple estimates for wave growth over open-water and restricted fetches in deep and shallow water.

The significant wave heights and the peak wave periods of the wind-waves for various return periods were computed based on the annual maximum wind speed with corresponding return periods, as listed in Table 6. The results are listed in Table 9 for the three sides of Rincon Island that are sheltered from Pacific Ocean waves. These local wind-waves generated by the extreme winds have much lower wave heights with much shorter wave periods than the waves from the Pacific Ocean. These wave characteristics will be used to analyze the wave flood hazard from these three sides and the stability of the revetments at these three sides.

Table 9. Return Frequency of Annual Maximum Wind-Induced Wave Height

	North side			Leeside			Southeast side		
Return period	Wind spd (mph)	Hs (ft)	Tp (sec)	Wind spd (mph)	Hs (ft)	Tp (sec)	Wind spd (mph)	Hs (ft)	Tp (sec)
1-yr	20	1.0	1.9	22	1.2	2.2	20	2.8	3.6
10-year	33	1.8	2.4	41	2.8	2.9	33	5.4	4.6
50-year	37	2.1	2.6	47	3.4	3.1	38	6.5	5.0
100-year	39	2.6	2.6	49	3.6	3.2	39	6.7	5.0

Hs: Significant wave height; Tp: Peak wave period

3.5 Rincon Island Still Water Inundation

The still water levels (SWL) for various return periods are listed in Table 2 for the existing condition and in Table 4 for future conditions with SLR. The existing 100-year SWL is +7.8 feet, NAVD88. The 100-year SWL in 2100 is predicted to be between +8.4 to +10.9 feet, NAVD88, when considering the likely range of the future SLR. This will be lower than the top elevations of the existing perimeter of the island, which vary from +15.4 at the east wharf to +35.5 feet, NAVD88, at the seaside revetment. Even considering the highest SLR projection of 6.6 feet, which corresponds to the medium-high rise aversion (0.5% probability) with the high emissions scenario, the SWL in 2100 will be at least 1 foot lower than the perimeter of island. It is therefore concluded that Rincon Island will not be inundated by SWLs alone by 2100.

3.6 Wave Runup and Overtopping on Rincon Island

When waves propagate to a revetment, the waves will run up on the surface of revetment, resulting in flood elevations higher than the SWL. This uprush of water from wave action on the revetment is called wave runup. When the wave runup elevation exceeds the crest elevation of the revetment, waves will overtop the crest of the revetment and the overtopping water will then further propagate on the ground of the island. A wave runup and overtopping analysis was conducted to investigate the coastal flooding potential on Rincon Island.

The wave runup and wave overtopping on all four sides of Rincon Island were computed using the Wave Runup and Overtopping on Impermeable Structures application of ACES. This ACES application provides estimates of wave runup and overtopping on rough and smooth slope structures that are assumed to be impermeable. Runup heights and overtopping rates are estimated independently or jointly for monochromatic or irregular waves specified at the toe of the structure.

The wave runup and overtopping on the seaside revetment were computed based on the ocean wave condition at the toe of this revetment (Table 8). The wave runup and overtopping on the other three sides of island were computed based on the wind-generated waves at the toe of these revetments (Table 9). The results are summarized in Table 10. The wave runups on the seaside revetment are much higher than the three other sides. The much higher waves with much longer wave periods from the Pacific Ocean result in much higher wave runup on the seaside revetments compared to the runups generated on the three other sides by local wind-waves.

As listed in Table 10, the wave runup elevation on the seaside revetment is approximately at +18.8 feet, NAVD88 during the 1-year storm event and is at +36.1 feet, NAVD88 during the 10-year storm event. As listed in Table 7, the crest elevation of the seaside revetment is at approximately +35.5 feet, NAVD88. Therefore, waves are expected to overtop the seaside revetment during a 10-year or larger storm event. The overtopping flow rate is estimated to be 1.4 cubic feet per second per liner feet length (cfs/ft) of revetment during the 50-year storm event, and be 2.1 cfs/ft during the 100-year storm event. The 100-year wave runup elevations are at +10.9 feet, NAVD88 for the north revetment, +12.2 feet, NAVD88 for the leeside, and +16.4 feet, NAVD88 for the southeast revetment. These wave runup elevations are lower than the top elevations of the corresponding revetments. In other words, it is unlikely for waves to cause flooding on Rincon Island from the north side, leeside, and the south side of the island even during 100-year storm events.

A wave runup and overtopping analysis was also conducted for the year 2100 after considering a future SLR of 3.1 feet. As shown in Table 3, this is the SLR projected for 2100 for the most likely range (66% probability) with the high greenhouse gas emissions scenario. The results are listed in

Table 11. After considering a future SLR of 3.1 feet, it will be unlikely for waves to cause flooding on Rincon Island in 2100 from the north side, leeside, and the south side of the island during the 100-year storm events. However, waves will overtop the seaside revetment and cause flooding on Rincon Island in 2100 during 10-year or larger storm events.

As shown in Figure 12, the ground of Rincon Island generally slopes down towards the leeside of the island. As a result, the water that overtops from the seaside revetment during the 10-year or larger storm events will flow from the seaside to the leeside and then flow back to the Pacific Ocean. Because of the small overtopping flow rate, the flood water depth on the island is expected to be very small.

Table 10. Wave Runup on Rincon Island (Existing Condition)

Return period	Still water level (ft, NAVD88)	Hs (ft)	Tp (sec)	Wave runup (ft)	Wave runup elevation (ft, NAVD88)	Overtopping flow rate (cfs/ft)
Seaside (from Pacific storms)						
1-yr	6.8	6.9	11.5	12	18.8	0
10-year	7.4	16.4	18.0	28.7	36.1	0.4
50-year	7.7	19.3	19.9	33.9	41.6	1.4
100-year	7.8	20.4	20.7	35.9	43.7	2.1
North side (from local wind waves)						
1-yr	6.8	1.0	1.9	1.3	8.1	0
10-year	7.4	1.8	2.4	2.2	9.6	0
50-year	7.7	2.1	2.6	2.6	10.3	0
100-year	7.8	2.6	2.6	3.1	10.9	0
Leeside (from local wind waves)						
1-yr	6.8	1.2	2.2	1.6	8.4	0
10-year	7.4	2.8	2.9	3.4	10.8	0
50-year	7.7	3.4	3.1	4.1	11.8	0
100-year	7.8	3.6	3.2	4.4	12.2	0
Southeast side (from local wind waves)						
1-yr	6.8	2.8	3.6	3.8	10.6	0
10-year	7.4	5.4	4.6	7.0	14.4	0
50-year	7.7	6.5	5.0	8.4	16.1	0
100-year	7.8	6.7	5.0	8.6	16.4	0

Table 11. Wave Runup on Rincon Island in 2100 (with SLR = 3.1 feet)

Return period	Still water level (ft, NAVD88)	Hs (ft)	Tp (sec)	Wave runup (ft)	Wave runup elevation (ft, NAVD88)	Overtopping flow rate (cfs/ft)
Seaside (from Pacific storms)						
1-yr	9.9	6.9	11.5	12	21.9	0
10-year	10.5	16.4	18.0	28.7	39.2	0.9
50-year	10.8	19.3	19.9	33.9	44.7	2.5
100-year	10.9	20.4	20.7	35.9	46.8	3.4
North side (from local wind waves)						
1-yr	9.9	1.0	1.9	1.3	11.2	0
10-year	10.5	1.8	2.4	2.2	12.7	0
50-year	10.8	2.1	2.6	2.6	13.4	0
100-year	10.9	2.6	2.6	3.1	14	0
Leeside (from local wind waves)						
1-yr	9.9	1.2	2.2	1.6	11.5	0
10-year	10.5	2.8	2.9	3.4	13.9	0
50-year	10.8	3.4	3.1	4.1	14.9	0
100-year	10.9	3.6	3.2	4.4	15.3	0
Southeast side (from local wind waves)						
1-yr	9.9	2.8	3.6	3.8	13.7	0
10-year	10.5	5.4	4.6	7.0	17.5	0
50-year	10.8	6.5	5.0	8.4	19.2	0
100-year	10.9	6.7	5.0	8.6	19.5	0

3.7 Stability Assessment of Rincon Island Protective Armor Material

The sizes of armor rocks required for a stable revetment were estimated using the Structure Design application within ACES of the CEDAS software. The computed rock sizes were then compared to the existing protective (revetment) armor material of Rincon Island to assess the stability of the existing revetments. The side slope of the existing revetments is 1.5H:1V. This slope was used in the rock sizing analysis for various storm events.

The required rock size for the seaside revetment to remain stable is estimated to be 3.6 feet (3.8 tons in weight) for the 1-year storm event and 8.5 feet (51 tons) for the 10-year storm event. The required weight of individual units of armor material for the design (significant) wave height of 14 feet is approximately 32 tons, which is consistent with the existing 1,000 concrete tetrapods, each weighing approximately 31 tons, that have been placed on the seaside exterior of the island. However, this design wave, which was considered as a 14.4-year event in the original oceanographic studies (Blume and James, 1959), was estimated to be equivalent to a 3.5-year wave event based on our analysis. It is concluded that the existing seaside revetment is capable of withstanding a 3.5-year storm from the Pacific Ocean, but it may sustain damages and show considerable distressing under attack waves appreciably larger than a 3.5-year storm event. On the other hand, the historical extreme storms that occurred in the past 60 years appear to have not endanger the whole island. This indicates that Rincon Island may remain in place even when subject to rare occurrences of very large storm events.

The required weight of individual units of armor material on the other three sides of island are estimated to be 2 tons or less to make the revetments stable during a 100-year wind event. The size of the existing armor materials on these three sides are unknown, but the weight of individual units of armor material may be 16 tons for a design significant wave height of 12 feet based on Blume and James (1959). If this is true, the existing protective (revetment) armors on these three sides can withstand 100-year storm events.

The rock sizing analysis was also conducted for the future condition after considering SLR. However, the SLR is small compared to the existing water depth at the toe of the structures (at approximately -41’ to -48’ MLLW). As a result, the required rock sizes remain unchanged after including SLR in the water depth. The findings for the existing rock sizing also apply for the future condition with SLR.

4 COASTAL ENGINEERING STUDY FOR ALTERNATIVE 3 – PARTIAL DECOMMISSIONING

4.1 Description of Alternative 3 – Partial Decommissioning

Under Alternative 3, removal of surface facilities on Rincon Island would be conducted (inclusive of well bay and rig apron removal), but the asphalt covering would remain, and no further decommissioning would occur. Under this alternative, the onshore facilities and the causeway, along with associated pipelines and power cables, would be removed after surface removal operations are completed on Rincon Island.

4.2 Coastal Assessment

Since Rincon Island and the armor materials will remain in the same condition as Alternative 2; the findings for Alternative 2 will apply to Alternative 3.

5 COASTAL ENGINEERING STUDY FOR ALTERNATIVE 4 – COMPLETE DECOMMISSIONING

5.1 Description of Alternative 4 – Complete Decommissioning

This alternative involves the full removal of Rincon Island, the causeway, and all other associated infrastructure. Rincon Island has provided a certain wave sheltering effect to the nearshore region. Removal of the island may intensify wave energy and impact nearshore processes in some areas behind the island. The coastal analysis for this alternative is focused on the evaluation of project impacts on the nearshore processes including waves, nearshore circulation, sediment transport, and shoreline/beach evolution.

5.2 Project Impacts on Nearshore Waves

The nearshore wave condition was analyzed using the STWAVE model. Both the existing condition and Alternative 4 – Complete Decommission were modeled. By comparing the model results for these two scenarios, the impact of Alternative 4 on nearshore wave climate was assessed.

5.2.1 STWAVE Model Description

The STWAVE (STeady-state spectral WAVE) model was developed by U.S. Army Corps of Engineers for nearshore wave transformation (Smith et. al, 2001). STWAVE can be applied to quantify the change in wave parameters (wave height, period, direction and spectral shape) from offshore to the nearshore zone, where waves are strongly influenced by variations in bathymetry, water level, and current. STWAVE is capable of simulating wave shoaling, refraction, diffraction and breaking, wind-wave growth due to local sea breeze, and wave-wave interaction and whitecapping that redistribute and dissipate energy in a growing wave field. STWAVE solves the steady-state conservation of spectral wave action along backward traced wave rays with source/sink terms, and the governing equations are numerically solved using finite-difference methods on a Cartesian grid.

5.2.2 STWAVE Model Domain

The modeled domain in the STWAVE simulation covers a rectangular area of 2,100 meters (approximately 6,900 feet) cross-shore and 4,000 meters (approximately 13,100 feet) alongshore, with a cell size of 4 meters by 4 meters. The model domain is sufficiently large to cover the nearshore areas that may be impacted by Rincon Island or by Project Alternative 4. The model domain is shown in Figure 21. The onshore boundary of the model domain lies on the dry land. The offshore boundary is located along the approximate -60 feet, NAVD88 contour, which is approximately 1,600 feet seaward of Rincon Island.

Figure 21. STWAVE Model Domain

5.2.3 STWAVE Model Bathymetry

Contracted by Longitude 123 Inc, eTrac Inc. (eTrac) completed a hydrographic survey of Rincon Island on March 12 and 24, 2021. The survey area encompassed a corridor 1,000 feet on either side of the causeway and 1,500 feet around the Rincon Island structure. The resulting survey area is 1.2 miles long and 0.8 miles wide. Longitude 123 later collected Lidar data for Rincon Island and the dry areas adjacent to the causeway revetment, combined the Lidar data with the bathymetric data, and provided NV5 with a 2' by 2' gridded dataset (xyz points). This data set was used to represent the existing bathymetry of the areas covered by these surveys.

It is noted that these surveys only cover a small portion of the STWAVE model domain. For the model areas that are not covered in surveys, the USGS 1-meter DEM was used to represent the topography of the dry lands, and the NOAA Navigation Chart (Chart ID 18725) was used to develop the bathymetry of the nearshore areas. These three data sets were merged, processed, and converted to the same vertical datum - NAVD88. The existing bathymetry is shown in Figure 22 where the model boundaries are represented by the black rectangle.

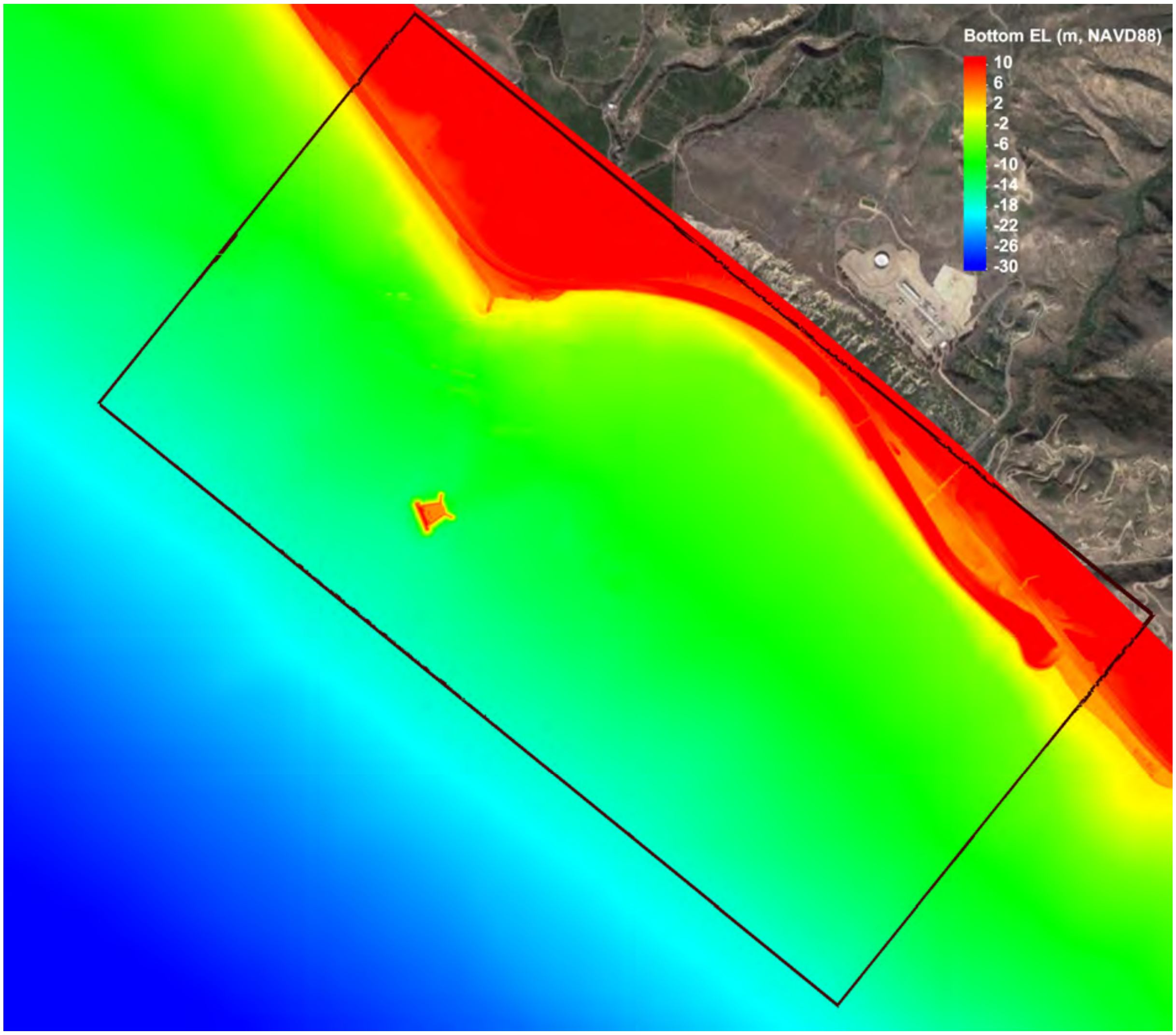

Figure 22. Bathymetry of STWAVE Model Domain, Existing Condition

Since there is no grading plan available for Alternative 4, the bathymetry for this alternative was developed by revising the existing bathymetry. The revision included removing the data points for Rincon Island and the data points for the causeway revetment so the bathymetry/topography at these locations are in line with adjacent contours. By looking at the aerial photos, the data points for the natural rocks near the causeway revetment were kept where possible. The bathymetry associated with Alternative 4 is shown in Figure 23.

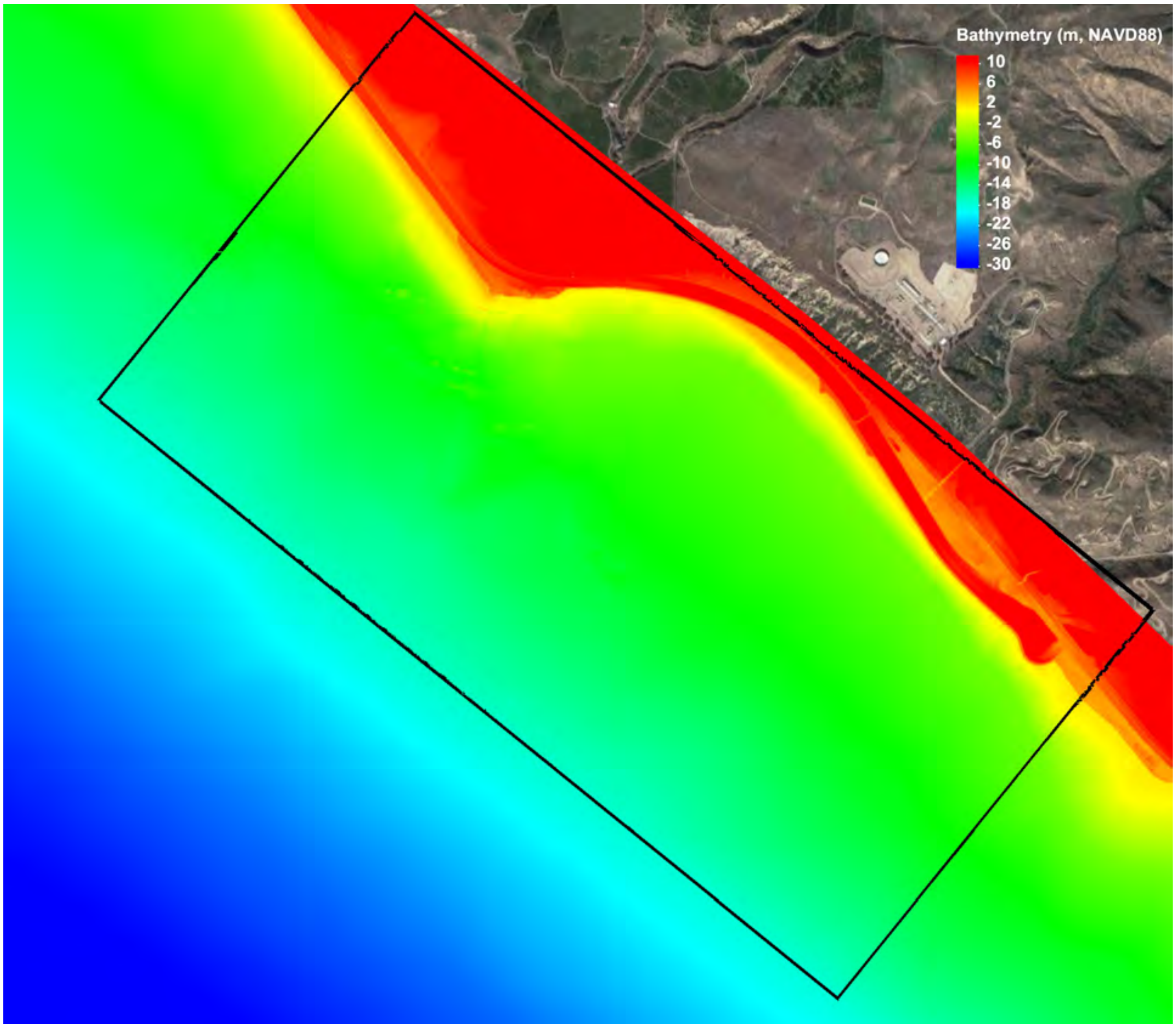

Figure 23. Bathymetry of STWAVE Model Domain, Alternative 4

5.2.4 STWAVE Model Events and Boundary Conditions

Extreme coastal storm events are typically responsible for the significant coastal hazards in the winter season such as storm-induced beach and shoreline erosion, flooding in coastal areas, and coastal structure damages. The stormed-induced beach erosion from these extreme events is considered temporary erosion as the lost sand may be brought back by waves in the next spring and summer seasons. The long-term change of beach and shoreline depends on the long-term wave climate. Therefore, our wave modeling analysis included both extreme storm events and the representative long-term wave climate of the study area.

The offshore boundary of the STWAVE model domain is located along the approximate -60 feet, NAVD88 contour, which is approximately 1,600 feet seaward of Rincon Island. The wave condition needs to be specified at this boundary for each modeled wave event. Fourteen years of wave data (wave height, wave period, and wave direction) has been measured at the NOAA NDBC

46053 station. These deep-water waves were propagated to the STWAVE offshore boundary (at -60ft, MLLW) using the wave shoaling and refraction method. The derived fourteen years of wave data was then further processed to determine the offshore boundary conditions for various STWAVE model scenarios.

The joint distribution of significant wave heights and wave directions at this boundary is shown in Figure 24 and listed in Table 12. It is noted that historical waves have approached this offshore boundary from the southwest direction during 6% of the time in the past 14 years, from the SSW direction during 67% of the time, and from the west direction during 24% of the time. The wave coming from the other directions only occurred for approximately 2% of the time. Figure 24 and Table 12 also show the percentages of various wave height increments for each direction. Since the prevailing wave direction is from SW to West, the long-term wave climate was represented by a synthetic series of 24 wave events in these prevailing wave directions. Each event is one combination of a given wave height with a prevailing wave direction, with the percentage of occurrence listed in Table 12. These 24 events, highlighted in yellow in Table 12, were included in the STWAVE model scenarios to represent the long-term wave climate.

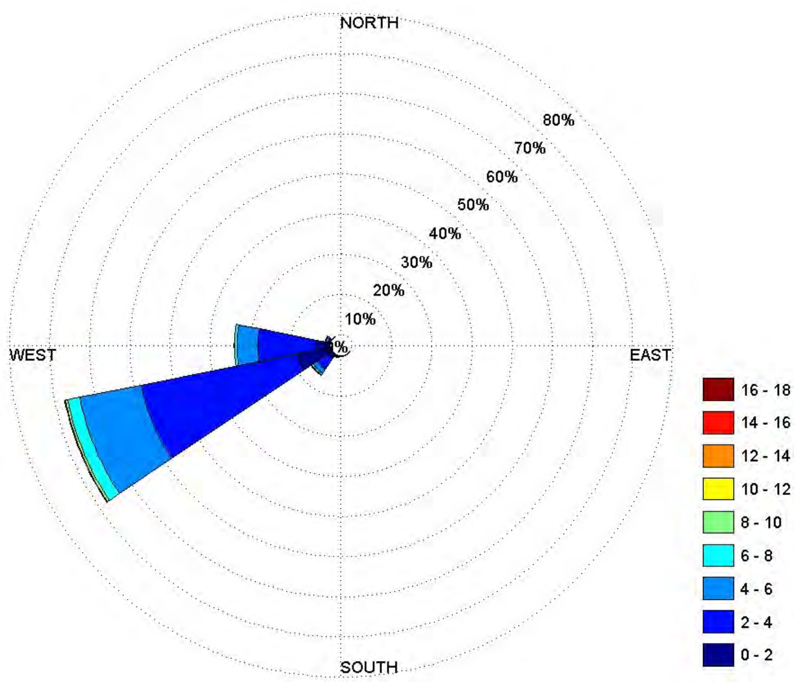

Figure 24. Joint Distribution of Wave Heights and Directions at STWAVE Offshore Boundary

Table 12. Joint Distribution of Wave Heights and Directions at STWAVE Offshore Boundary

Hs (ft)	Subtotal	SE	SSE	South	SSW	SW	WSW	West	WNW	NW
0 - 2	**16.27%**	0.007%	0.020%	0.149%	0.263%	1.356%	10.188%	4.204%	0.085%	
2 – 4	**56.75%**	0.012%	0.003%	0.014%	0.177%	3.142%	38.700%	14.136%	0.570%	0.001%
4 – 6	**20.78%**	0.001%	0.001%	0.003%	0.029%	1.146%	14.297%	4.721%	0.578%	
6 – 8	**3.97%**				0.007%	0.424%	2.795%	0.585%	0.154%	
8 -10	**0.61%**					0.104%	0.493%	0.015%	0.002%	
10 – 12	**0.18%**					0.045%	0.133%			
12 – 14	**0.05%**					0.014%	0.033%			
14 – 16	**0.01%**					0.003%	0.009%			
16 – 18	**0.00%**					0.001%				
18 -20	**0.00%**									
Subtotal	**98.6%**	**0.02%**	**0.02%**	**0.17%**	**0.48%**	**6.23%**	**66.65%**	**23.66%**	**1.39%**	**0.02%**

Based on the fourteen years of wave data computed at the STWAVE offshore boundary, the annual maximum values of wave heights were derived for these fourteen years. These annual maximum wave heights and the Weibull curve-fitting of the data are shown in Figure 25. The significant wave heights for various return periods (years) are summarized in Table 13. Combining wave heights of four (1-, 10-, 50-, and 100-year) storm events with three prevailing wave directions (SW, WSW, and west), twelve storm events were formulated for detailed STWAVE modeling study.

Table 13. Return Frequency of Annual Maximum Wave Height at STWAVE Boundary

Return period	Significant wave height (ft)
1-year	9.6
10-year	17.0
50-year	19.3
100-year	20.1

In total 36 wave events were included in detailed wave modeling with STWAVE. These included 24 events to represent the long-term wave climate, which will affect the alongshore sediment transport capacity and the long-term shoreline/beach evolution, and 12 events to represent the extreme storm events, which will cause temporal storm-induced beach/shoreline erosion, coastal flooding, and structure damages in the winter season. These 36 wave events were applied to both the STWAVE model for the existing condition and the model for Alternative 4.

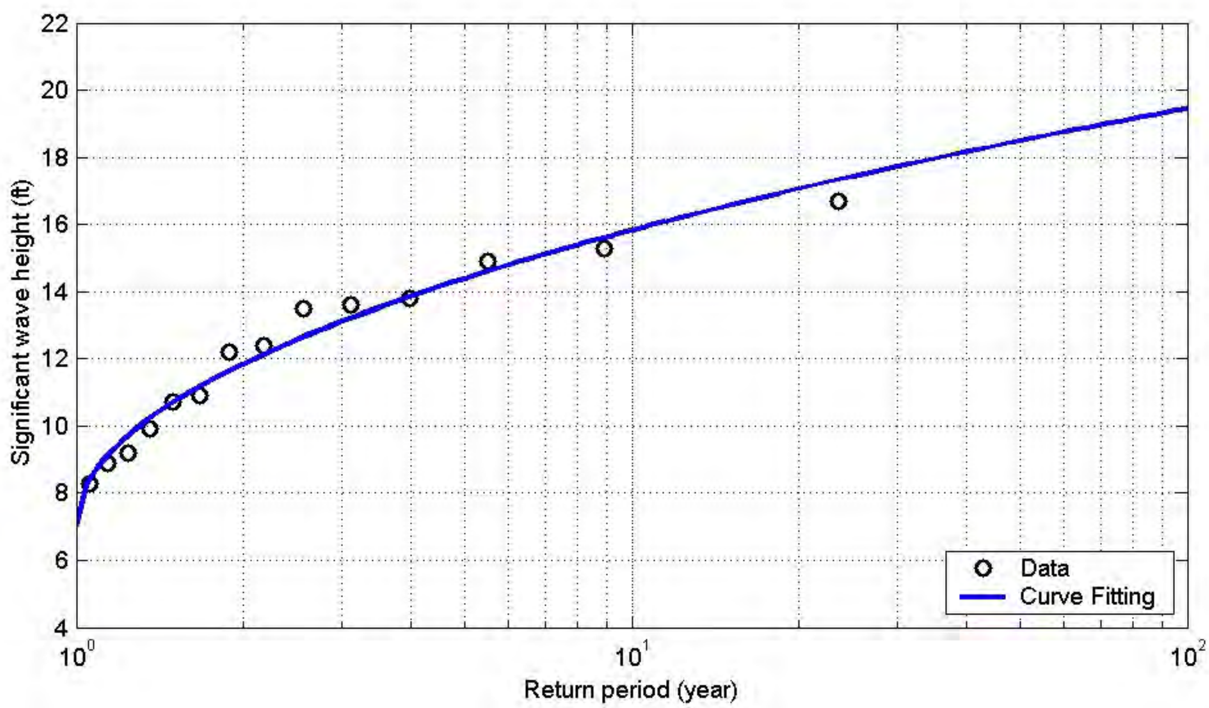

Figure 25. Return Frequency of Annual Maximum Wave Height at STWAVE Offshore Boundary

5.2.5 Wave Conditions for the Existing Condition

Figure 26 through Figure 28 show the spatial variations in significant wave heights in the study area when a 1-year storm event approaches from three prevailing directions (SW, WSW, and west), respectively. Figure 29 through Figure 31 show the wave climate when a 10-year storm event approaches from three prevailing directions. Figure 32 through Figure 34 show the wave climate for a 50-year storm event from three prevailing directions. Figure 35 through Figure 37 show the wave climate for the 100-year storm event from three prevailing directions.

As shown in these figures, the unusual plan shape of Rincon Island and the alignment of the seaside of the island have not only successfully provided wave protection to island but also provided appreciable wave sheltering effect for the nearshore region behind (leeside of) the island. While the wave-sheltered area varies with approaching wave directions, this sheltering effect can extend from Rincon Island to as far as the surf zone behind the island. It is also noted that the most decay of wave height occurs in the area immediately behind the island. The wave heights gradually recover with distance from the island due to the wave diffraction effect.

5.2.6 Wave Conditions for the Alternative 4 Condition

Figure 38 through Figure 49 show the spatial variations in significant wave heights in the study area for 12 extreme storm events, respectively. Same as for the existing condition, these events represent 12 scenarios when the 1-, 10-, 50, and 100-year storm events approaching from the three prevailing directions. With the full removal of Rincon Island, the wave heights behind the island will be increased and the wave climate in this area will be similar to the other adjacent areas that are not currently impacted by the island.

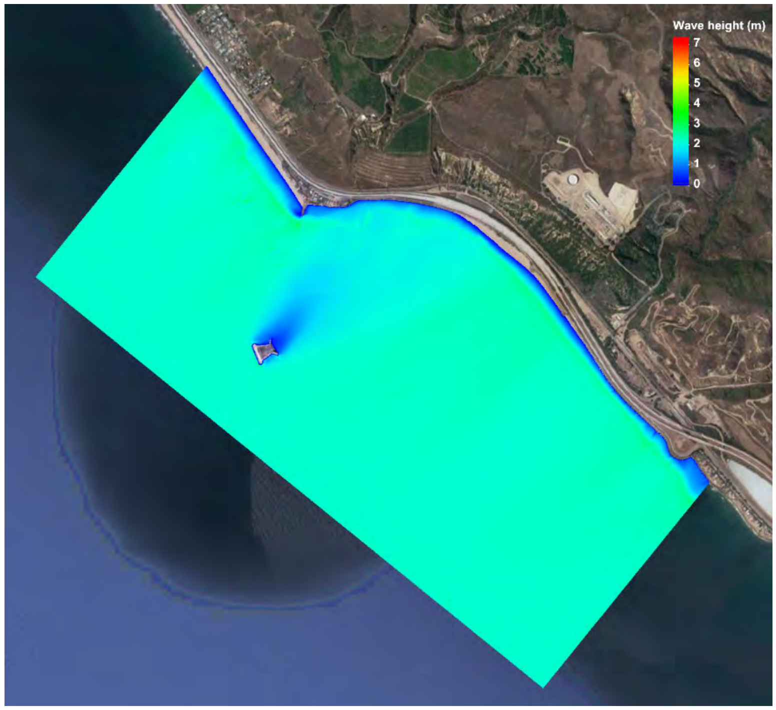

Figure 26. 1-Year Wave Height from SW, Existing Condition

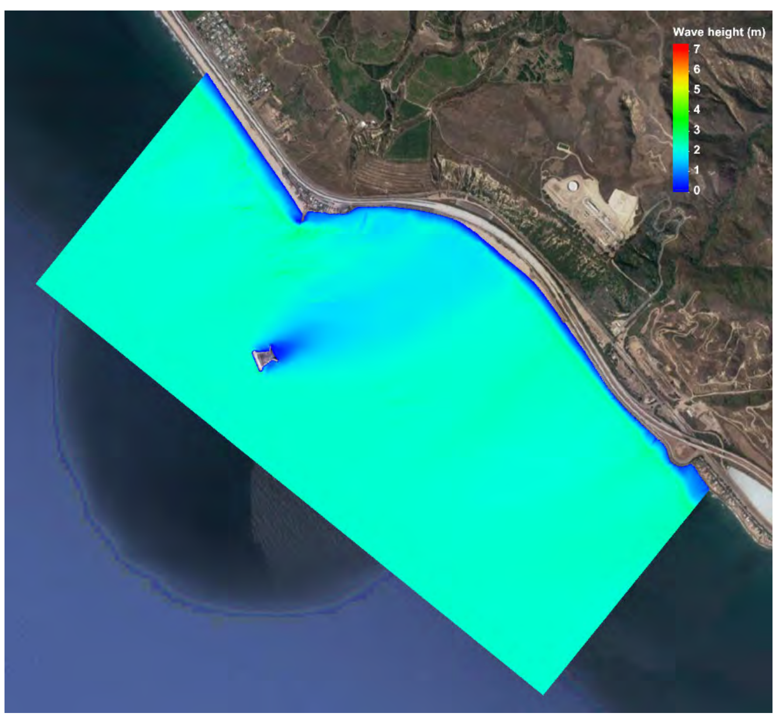

Figure 27. 1-Year Wave Height from WSW, Existing Condition

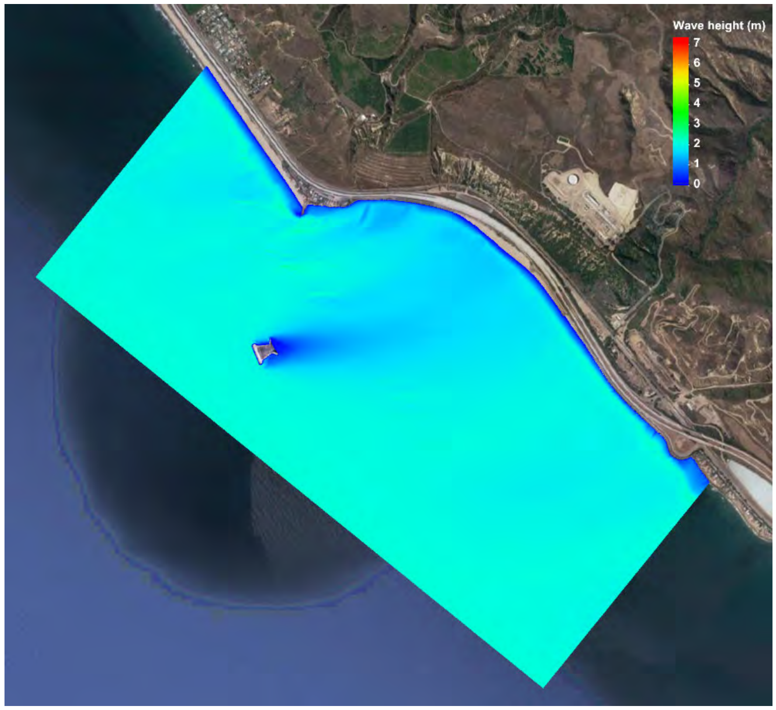

Figure 28. 1-Year Wave Height from West, Existing Condition

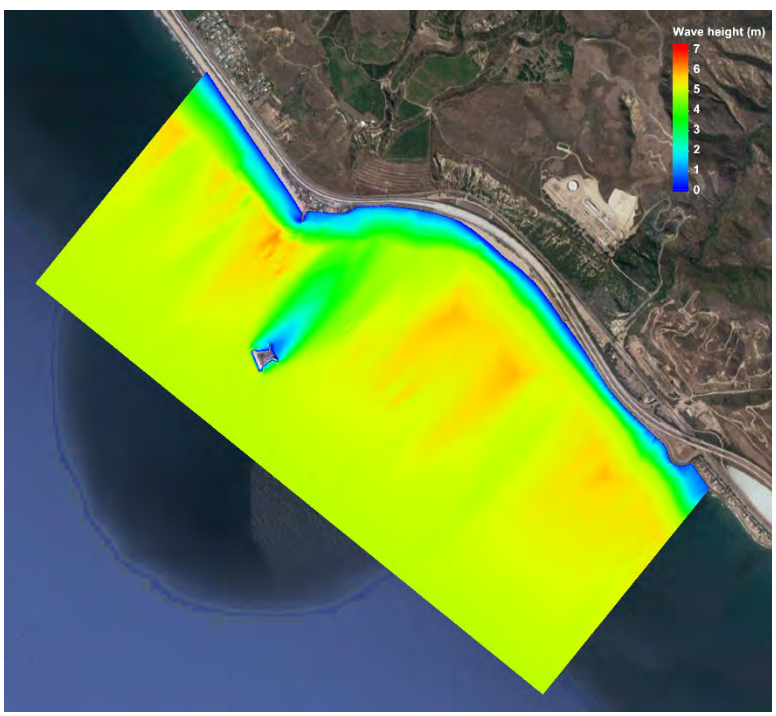

Figure 29. 10-Year Wave Height from SW, Existing Condition

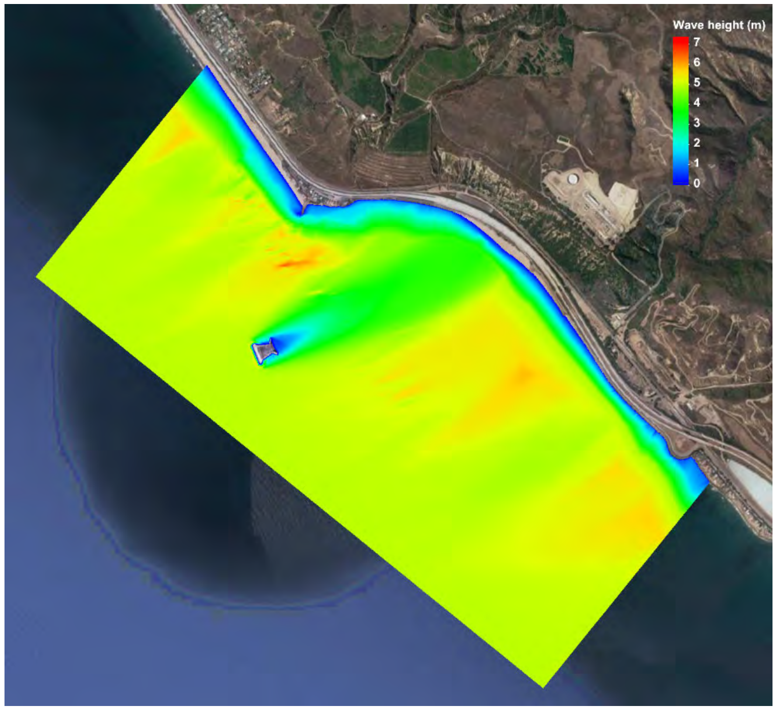

Figure 30. 10-Year Wave Height from WSW, Existing Condition

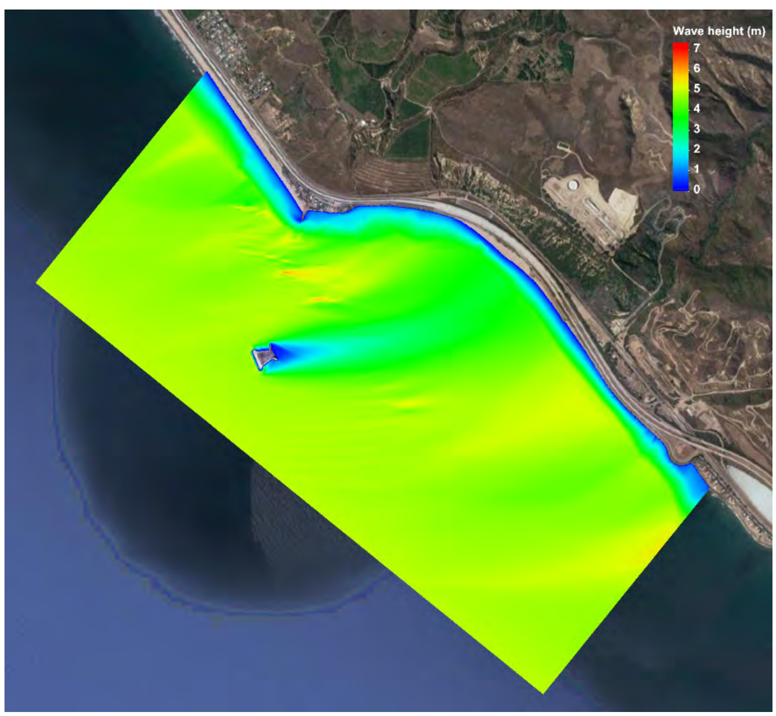

Figure 31. 10-Year Wave Height from West, Existing Condition

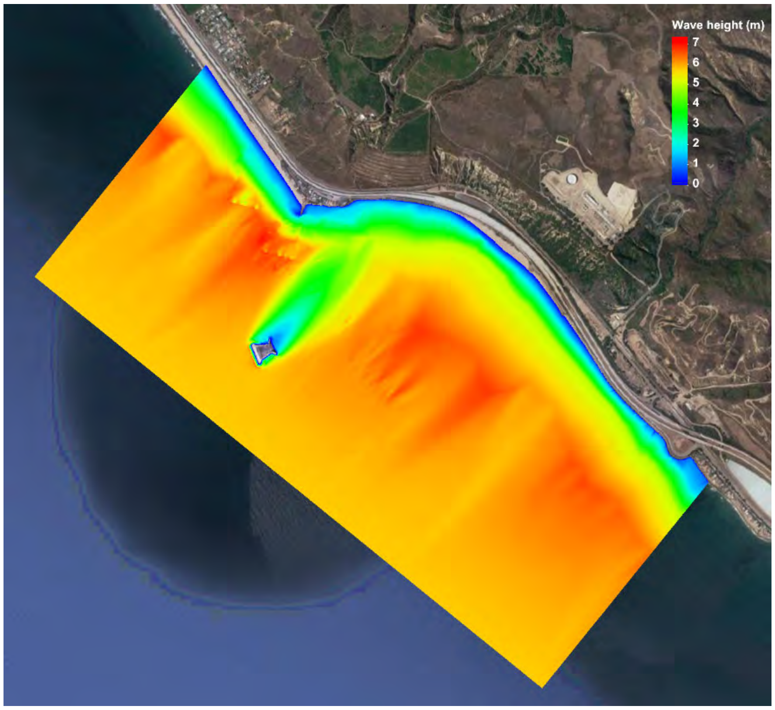

Figure 32. 50-Year Wave Height from SW, Existing Condition

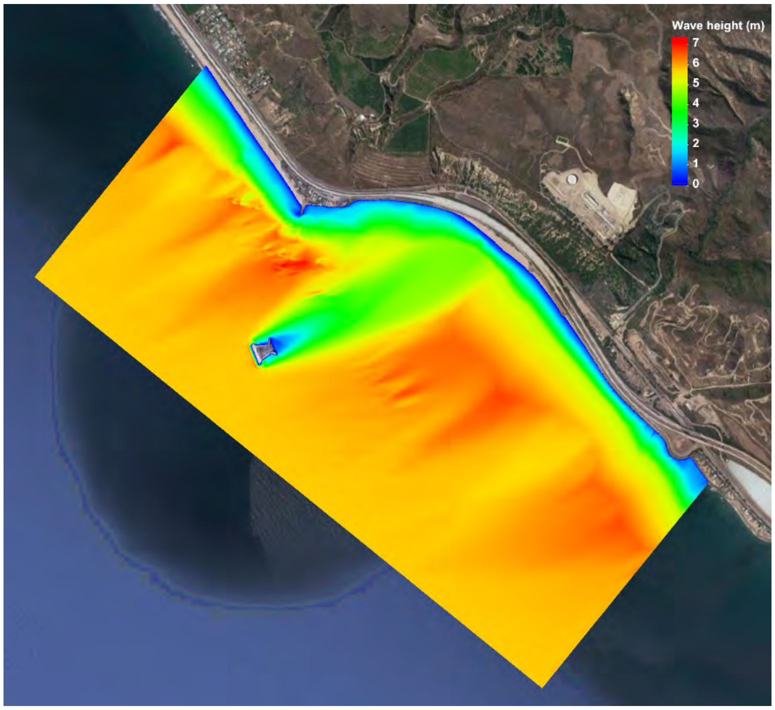

Figure 33. 50-Year Wave Height from WSW, Existing Condition

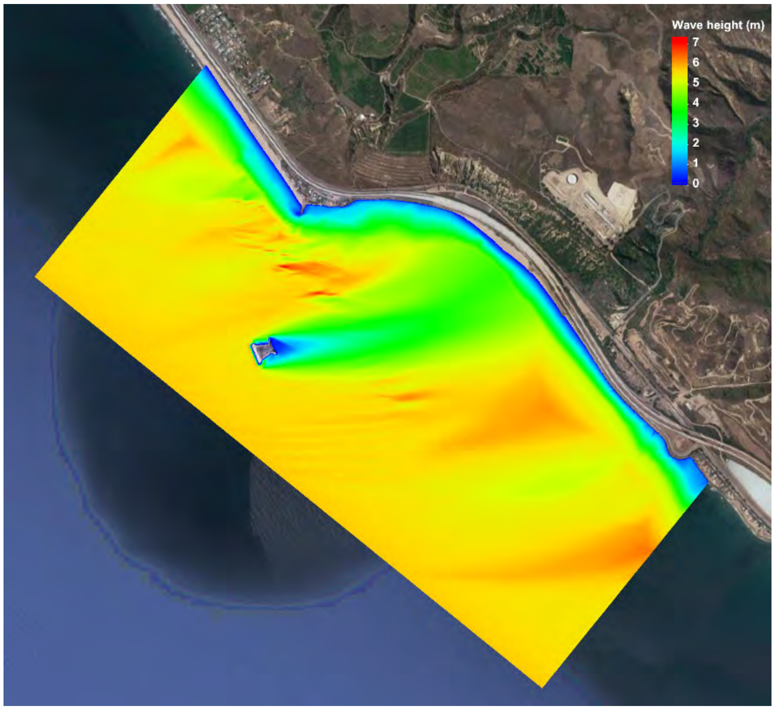

Figure 34. 50-Year Wave Height from West, Existing Condition

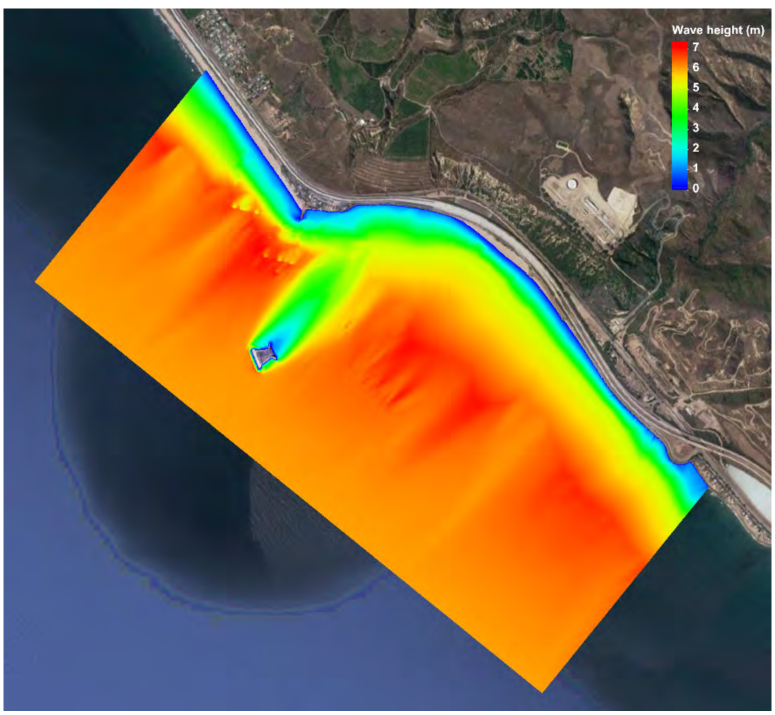

Figure 35. 100-Year Wave Height from SW, Existing Condition

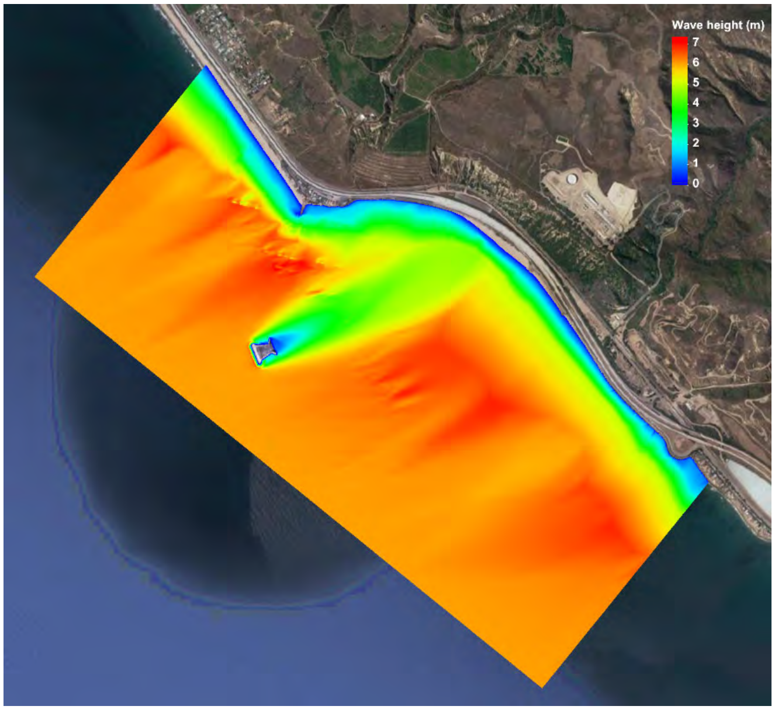

Figure 36. 100-Year Wave Height from WSW, Existing Condition

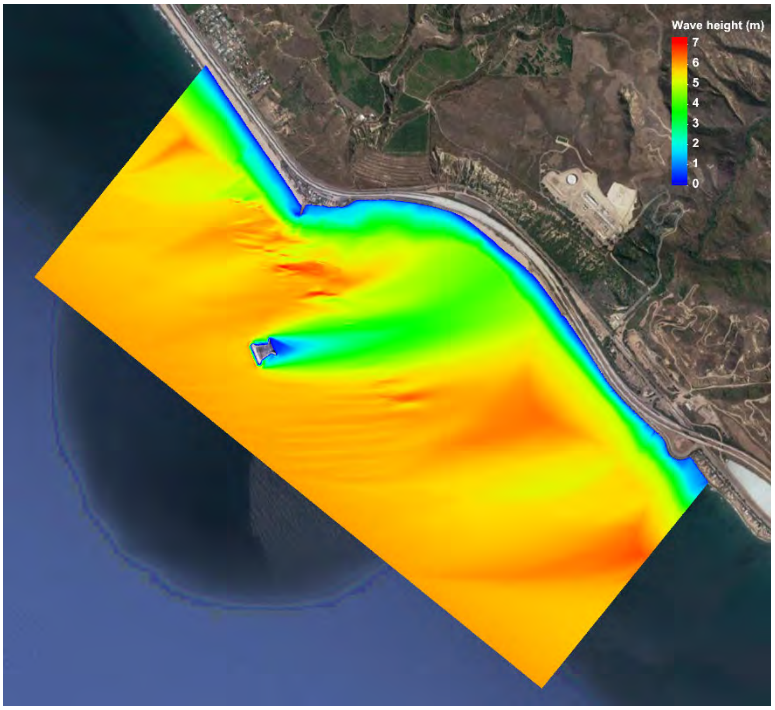

Figure 37. 100-Year Wave Height from West, Existing Condition

Figure 38. 1-Year Wave Height from SW, Alternative 4

Figure 39. 1-Year Wave Height from WSW, Alternative 4

Figure 40. 1-Year Wave Height from West, Alternative 4

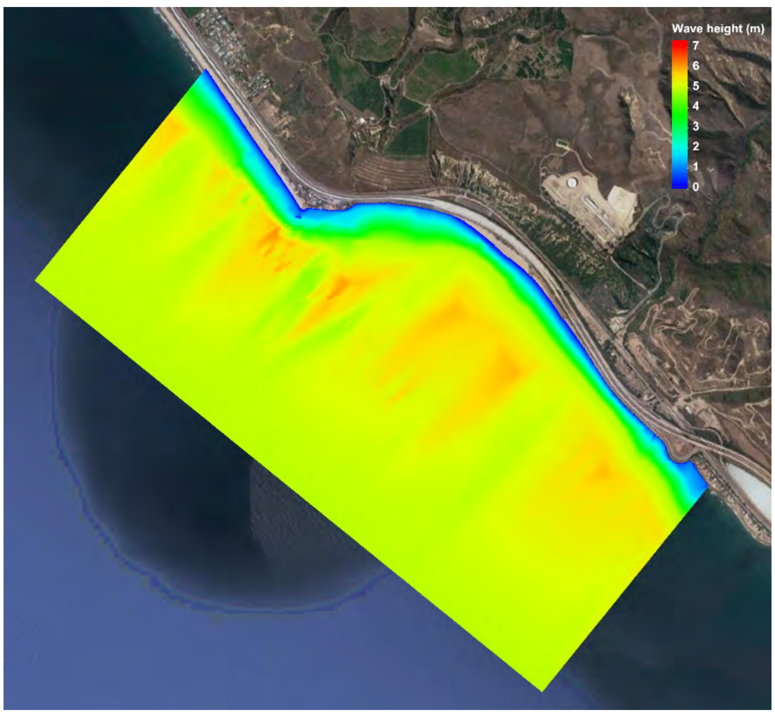

Figure 41. 10-Year Wave Height from SW, Alternative 4

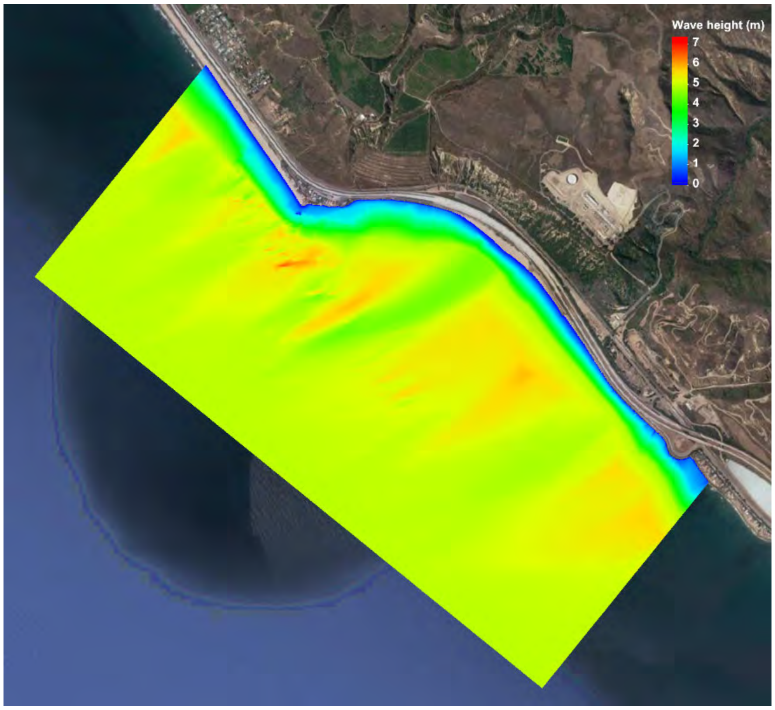

Figure 42. 10-Year Wave Height from WSW, Alternative 4

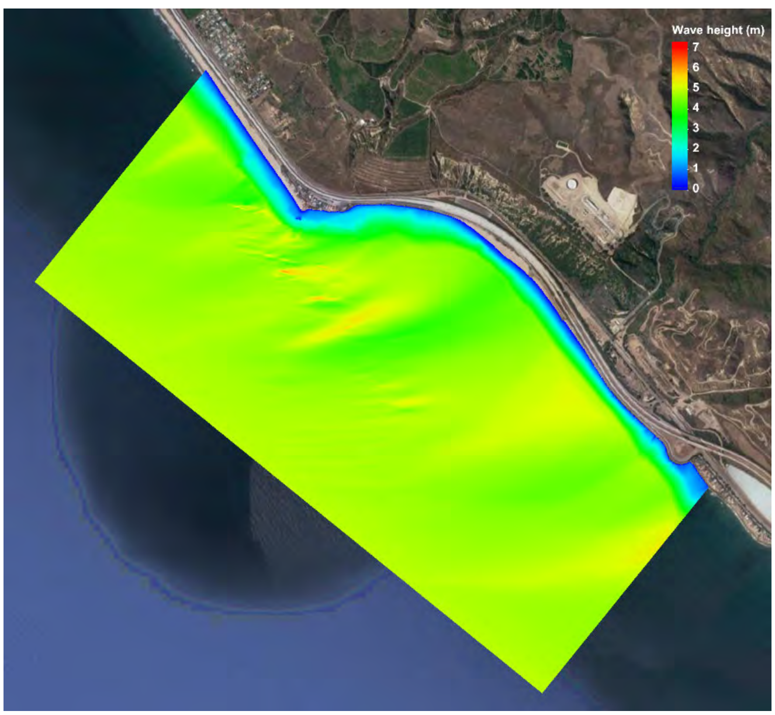

Figure 43. 10-Year Wave Height from West, Alternative 4

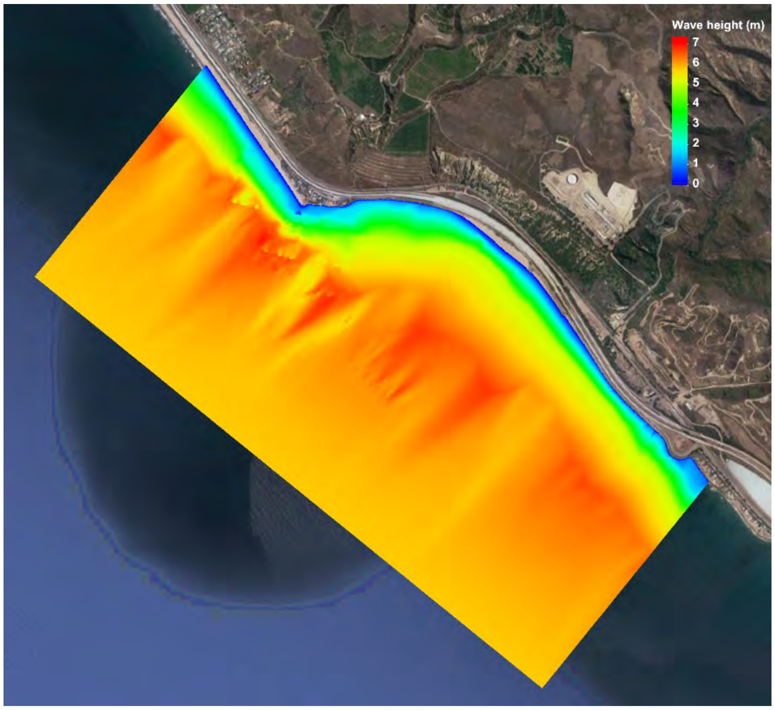

Figure 44. 50-Year Wave Height from SW, Alternative 4

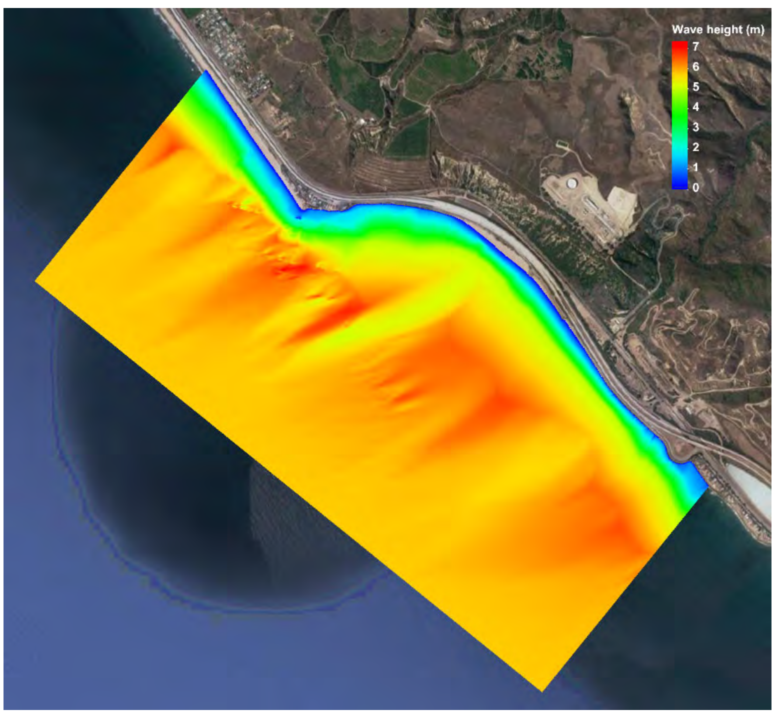

Figure 45. 50-Year Wave Height from WSW, Alternative 4

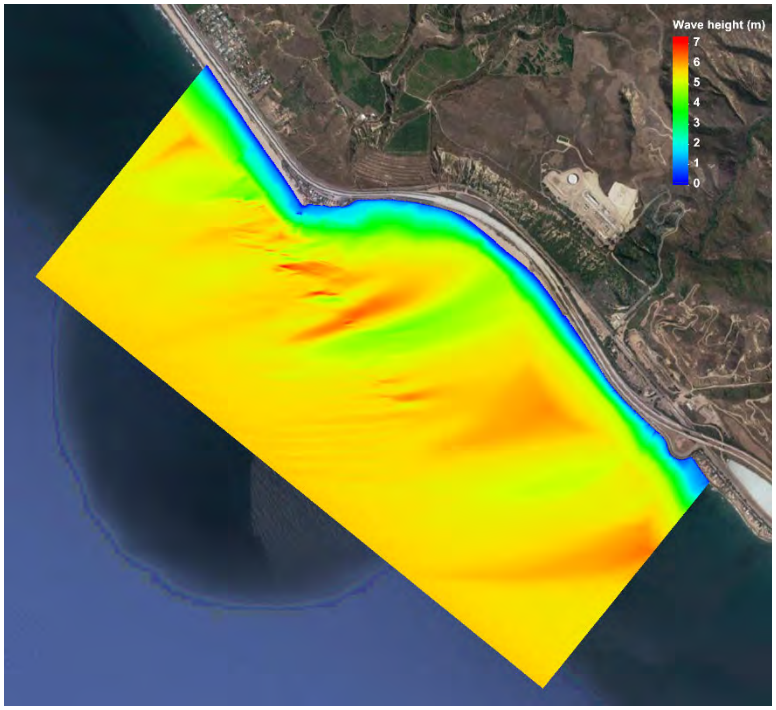

Figure 46. 50-Year Wave Height from West, Alternative 4

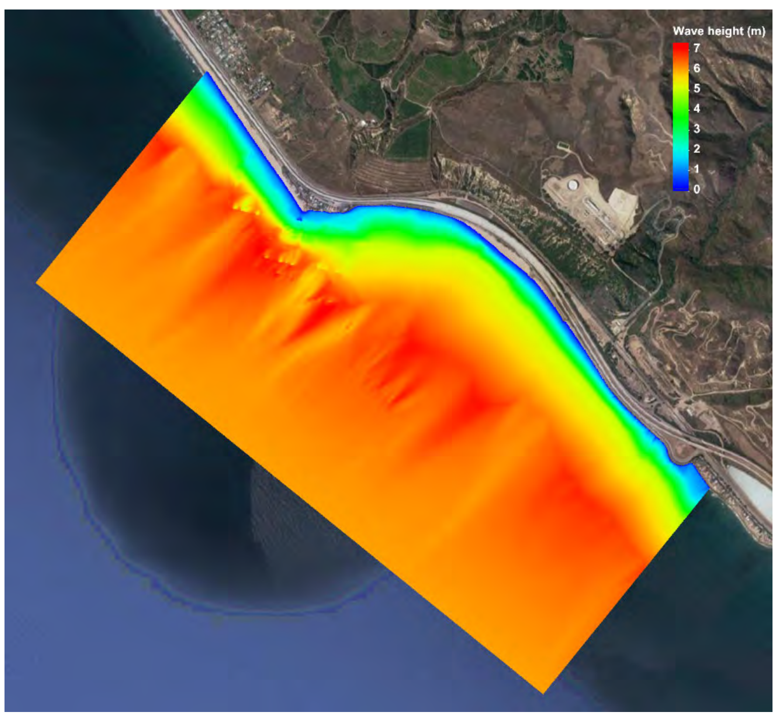

Figure 47. 100-Year Wave Height from SW, Alternative 4

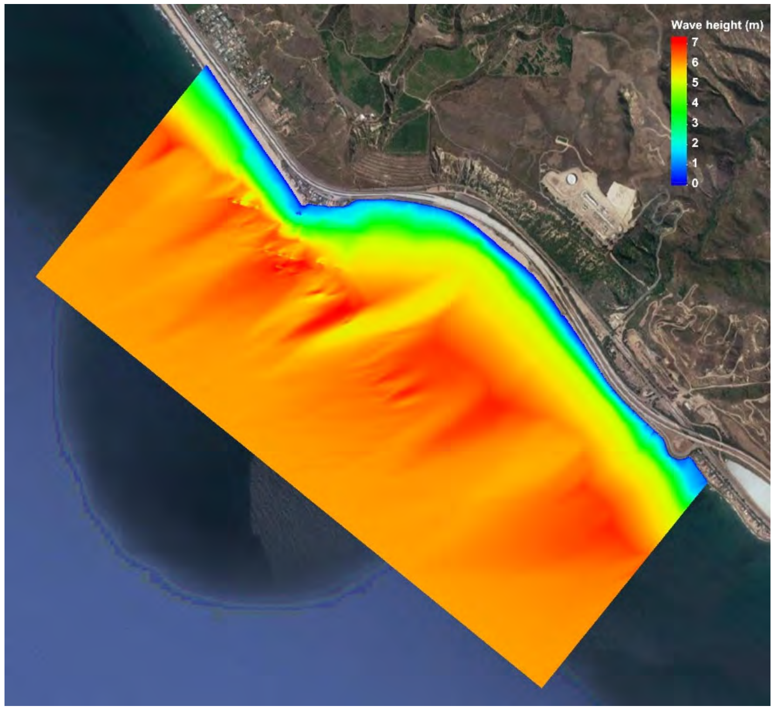

Figure 48. 100-Year Wave Height from WSW, Alternative 4

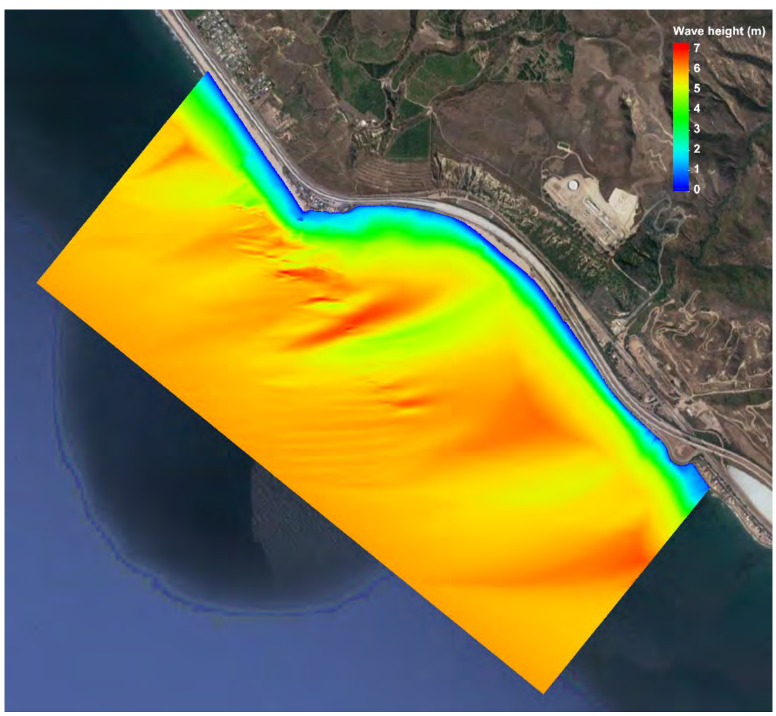

Figure 49. 100-Year Wave Height from West, Alternative 4

5.2.7 Assessment of Alternative 4's Impact on Nearshore Wave Climate

In order to quantify the impact of Alternative 4 on nearshore wave climate, the wave height profiles were compared between the existing condition and the Alternative 4 condition for 24 transects. The locations of these transects are shown in Figure 50, As examples, Figure 51 through Figure 63 shows the wave height profiles on impacted transects when a 100-year storm event approaches from the three prevailing directions. It is concluded that with the full removal of Rincon Island and the causeway revetment, Alternative 4 will increase the wave height and thus intensify the wave energy in the coastal area behind the island. The impacted area can be as long as 4,000 feet in the alongshore direction (between Transect 4 through Transect 18) during extreme storm events. The cross-shore extent of the impact can be from the island to the surf zone where wave breaking occurs. When a wave breaks, the wave height is a function of the water depth. Alternative 4 will have the most impact the wave climate immediately behind the island. This impact will decay with distance from the island.

Figure 50. Locations of Transects and Wave-Impacted Area of Alternative 4

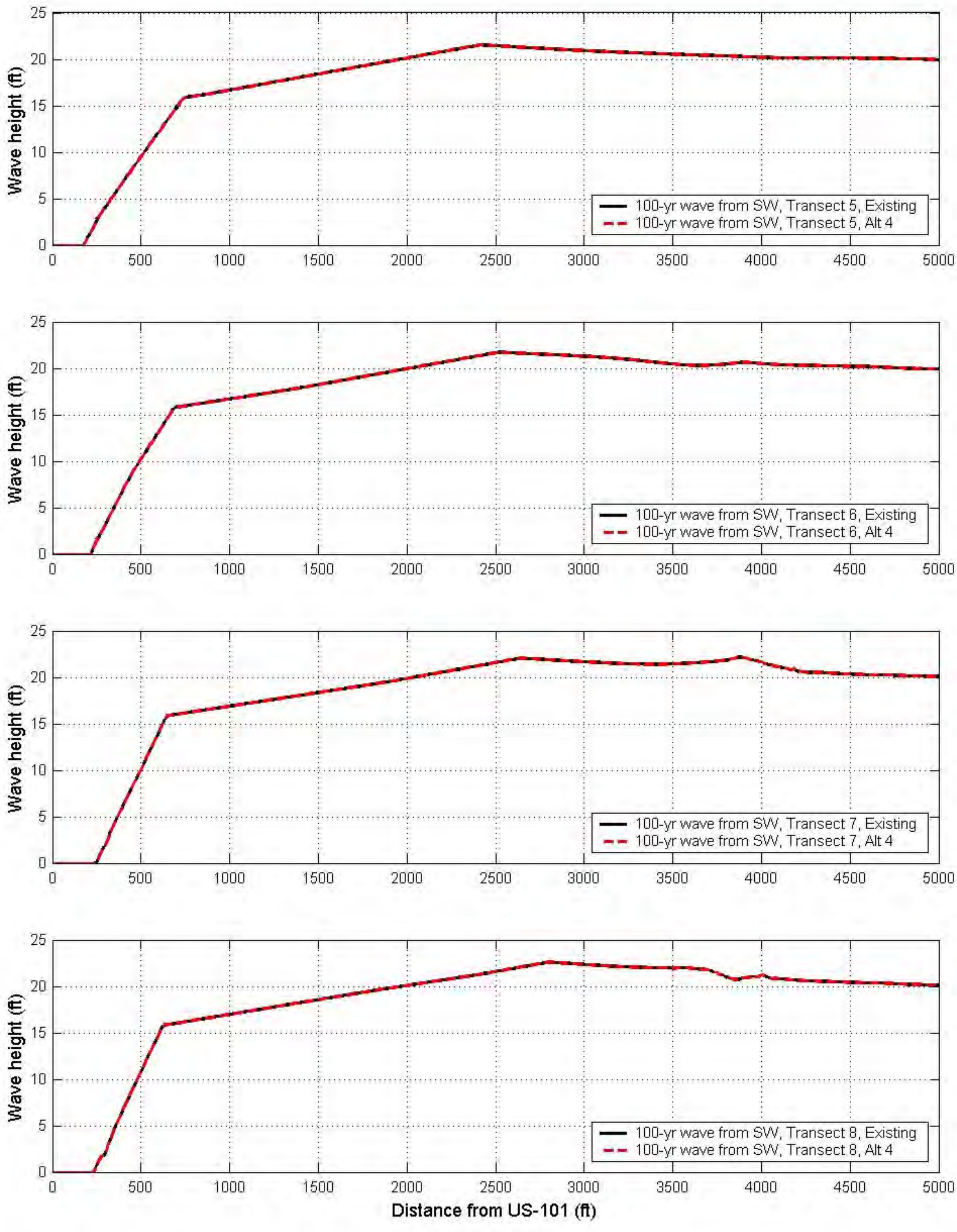

Figure 51. Comparison of 100-Year Wave Height between Existing Condition and Alternative 4 (Waves from SW, Transects 5-8)

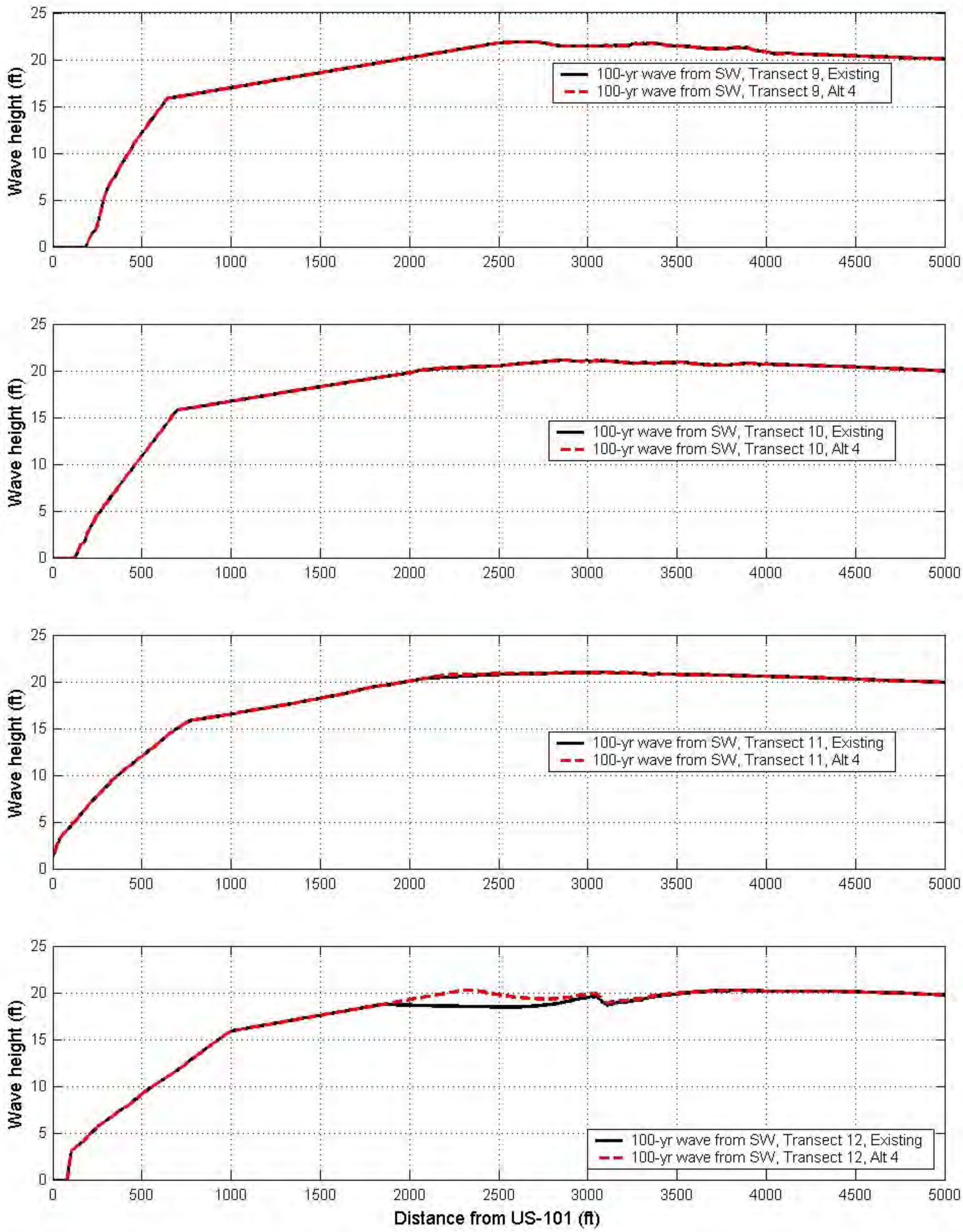

Figure 52. Comparison of 100-Year Wave Height between Existing Condition and Alternative 4 (Waves from SW, Transects 9-12)

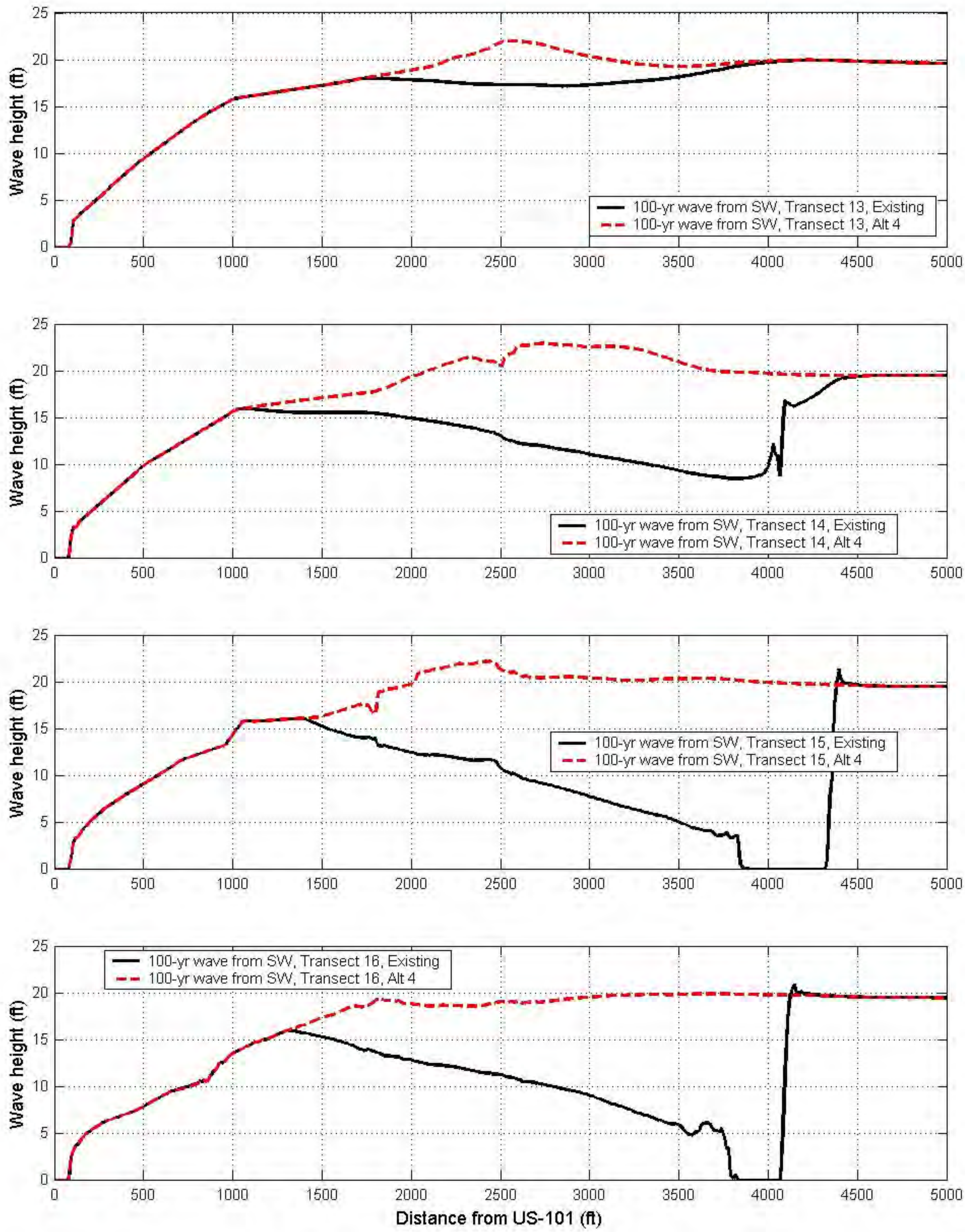

Figure 53. Comparison of 100-Year Wave Height between Existing Condition and Alternative 4 (Waves from SW, Transects 13-16)

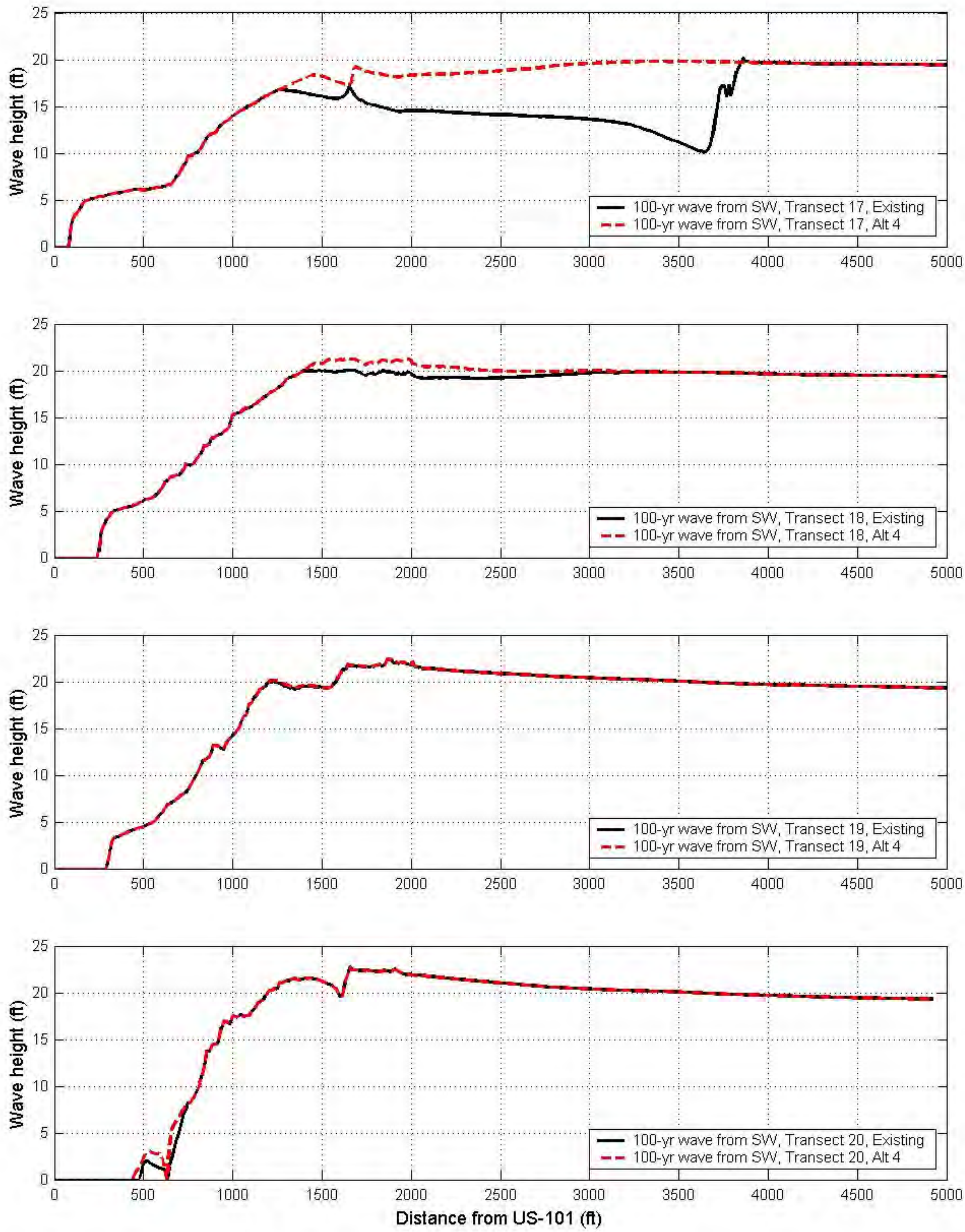

Figure 54. Comparison of 100-Year Wave Height between Existing Condition and Alternative 4 (Waves from SW, Transects 16-20)

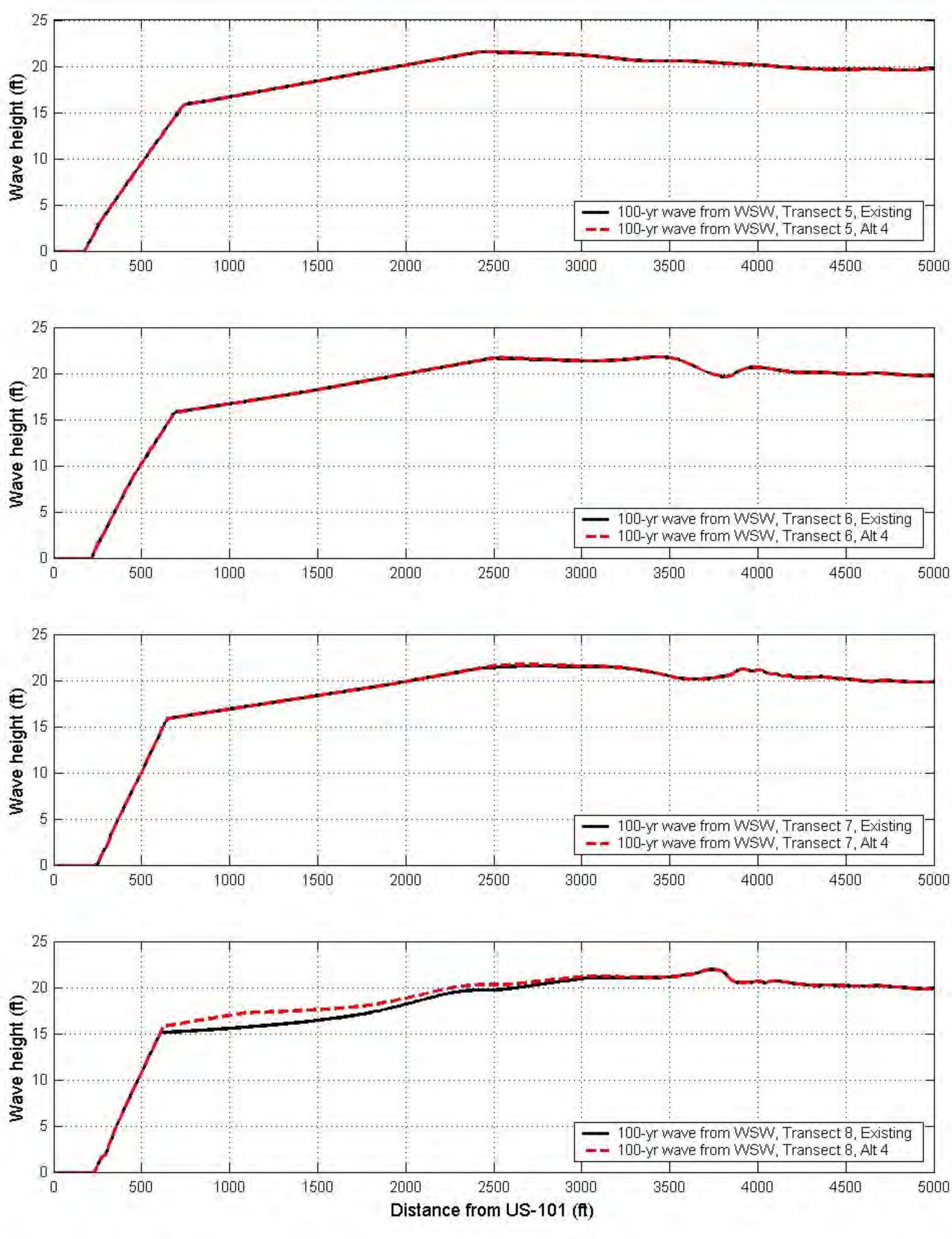

Figure 55. Comparison of 100-Year Wave Height between Existing Condition and Alternative 4 (Waves from WSW, Transects 5-8)

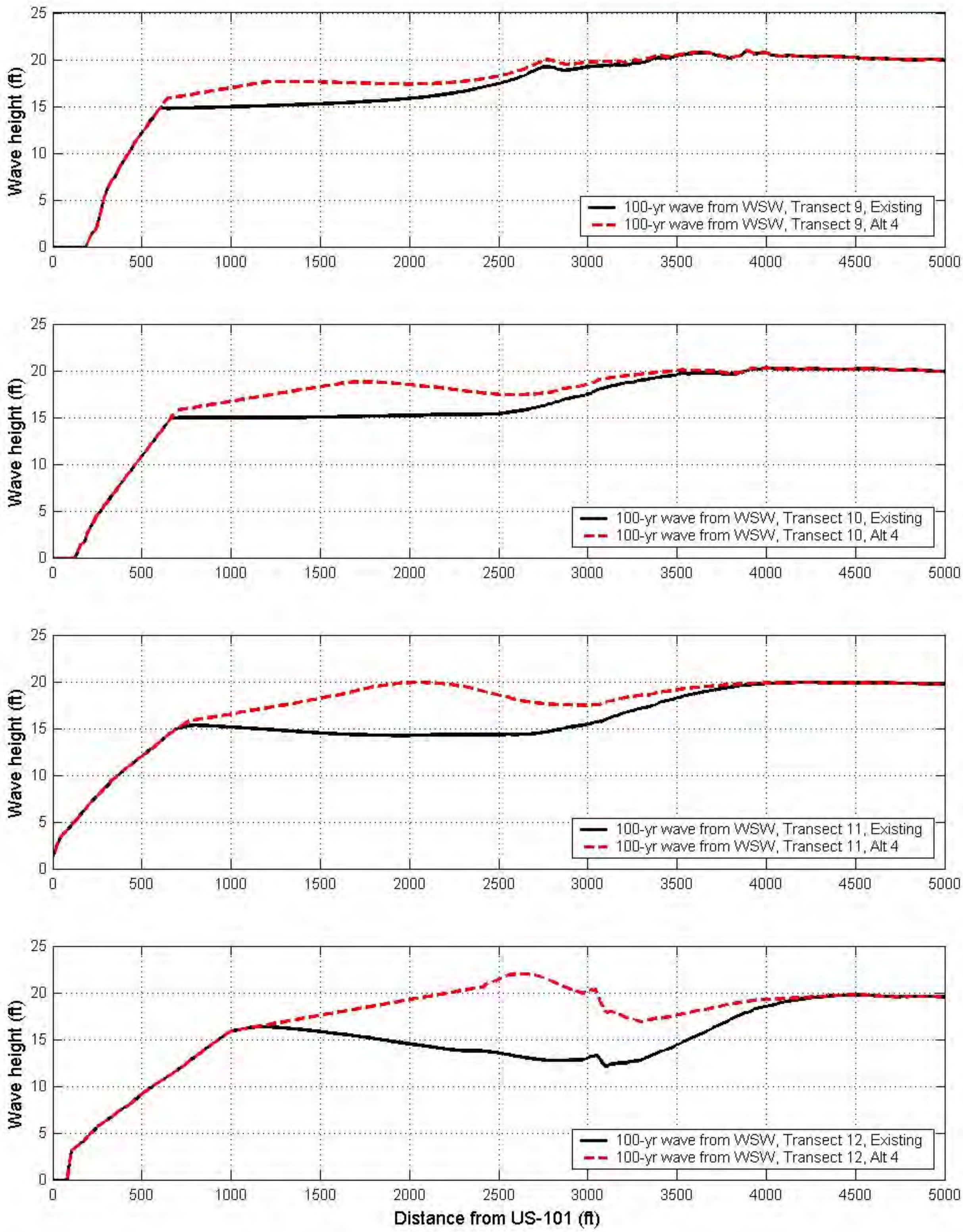

Figure 56. Comparison of 100-Year Wave Height between Existing Condition and Alternative 4 (Waves from WSW, Transects 9-12)

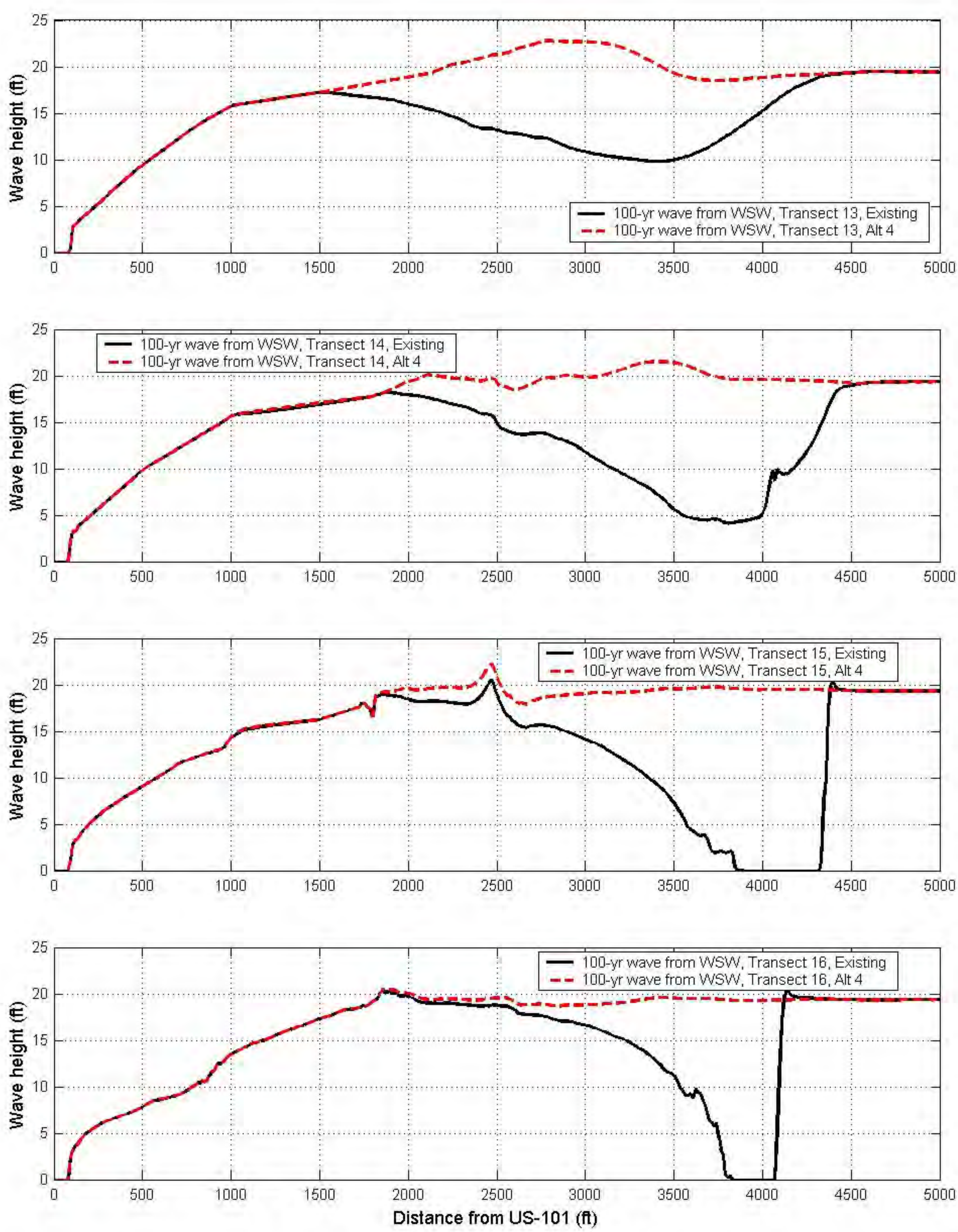

Figure 57. Comparison of 100-Year Wave Height between Existing Condition and Alternative 4 (Waves from WSW, Transects 13-16)

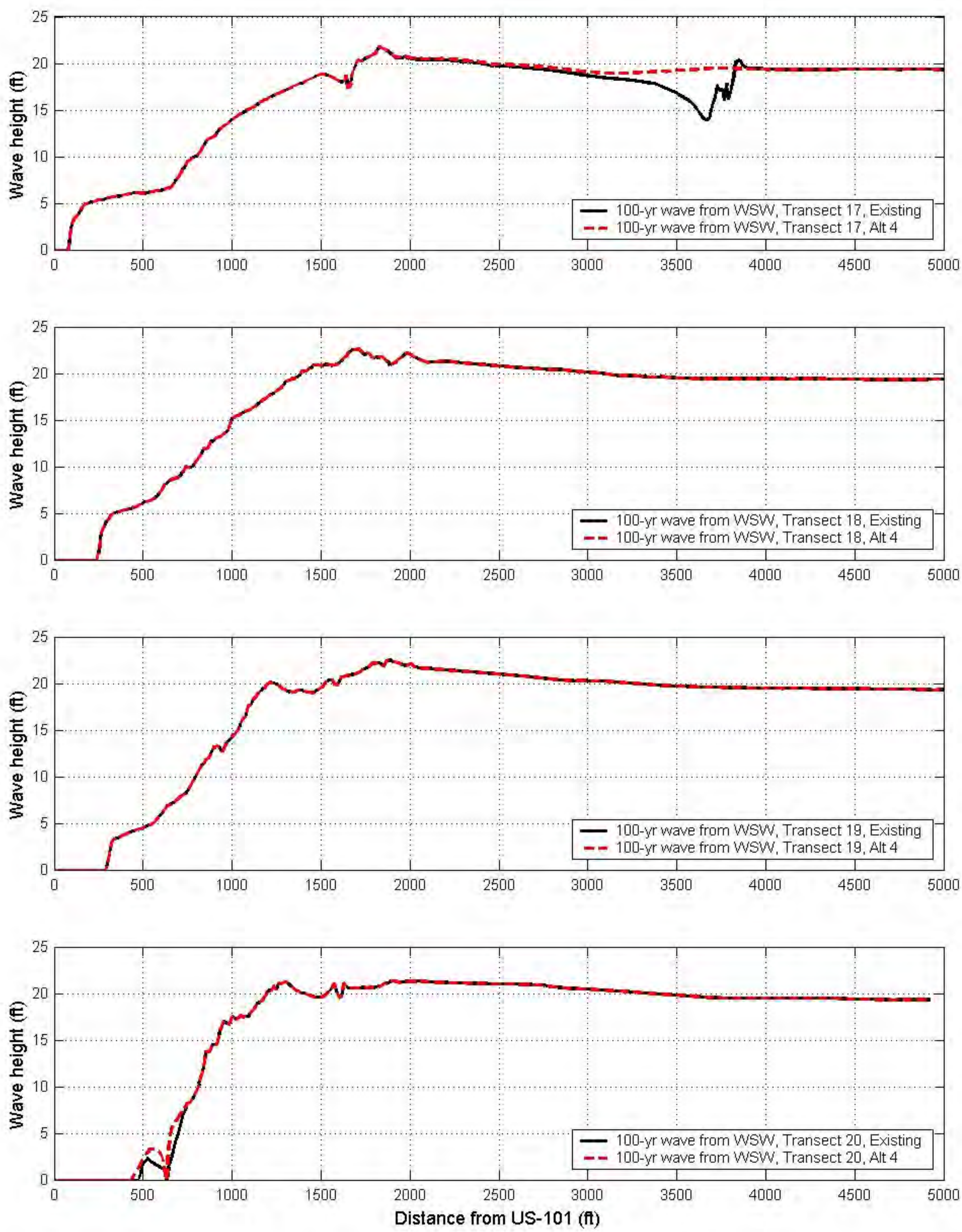

Figure 58. Comparison of 100-Year Wave Height between Existing Condition and Alternative 4 (Waves from WSW, Transects 17-20)

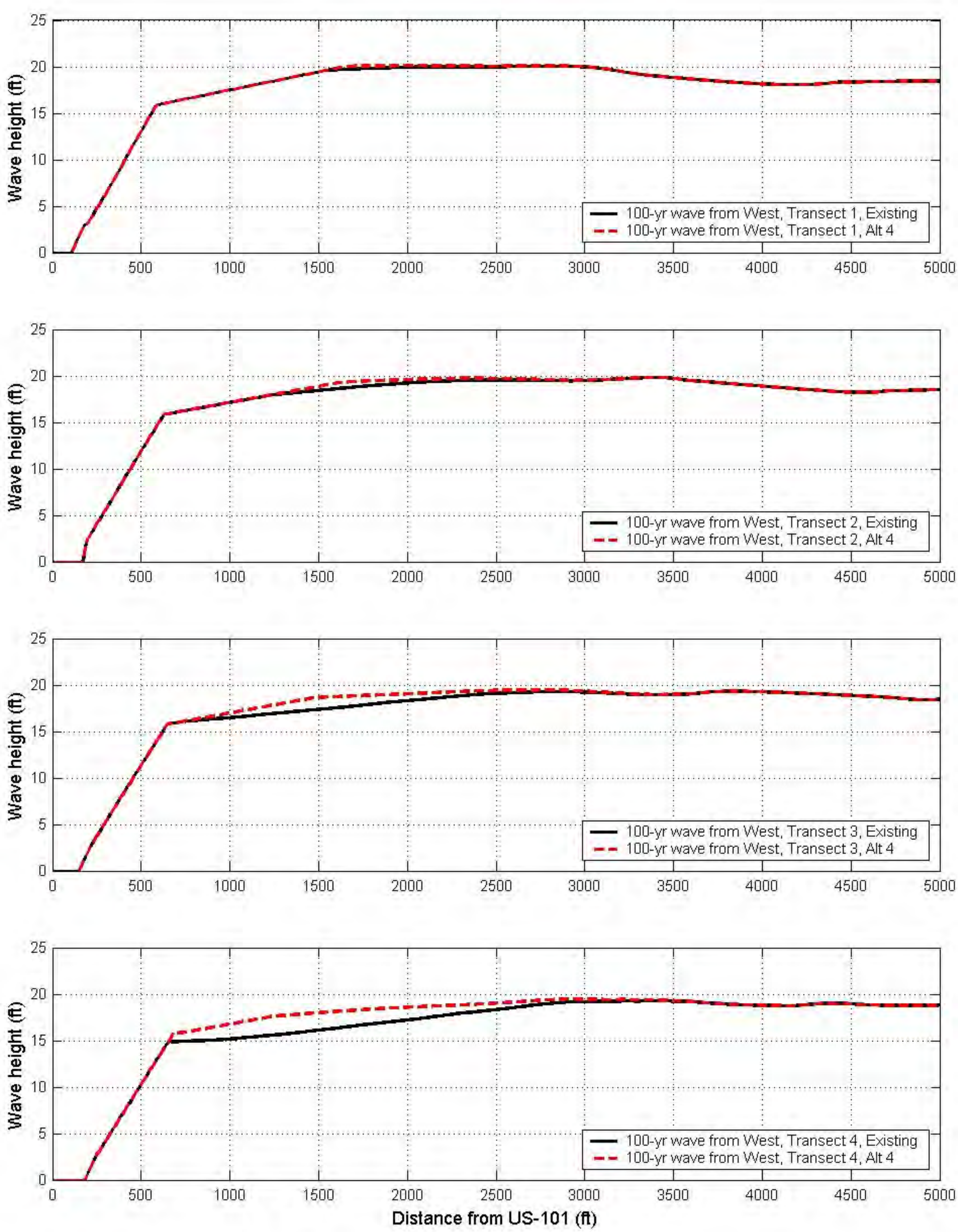

Figure 59. Comparison of 100-Year Wave Height between Existing Condition and Alternative 4 (Waves from West, Transects 1-4)

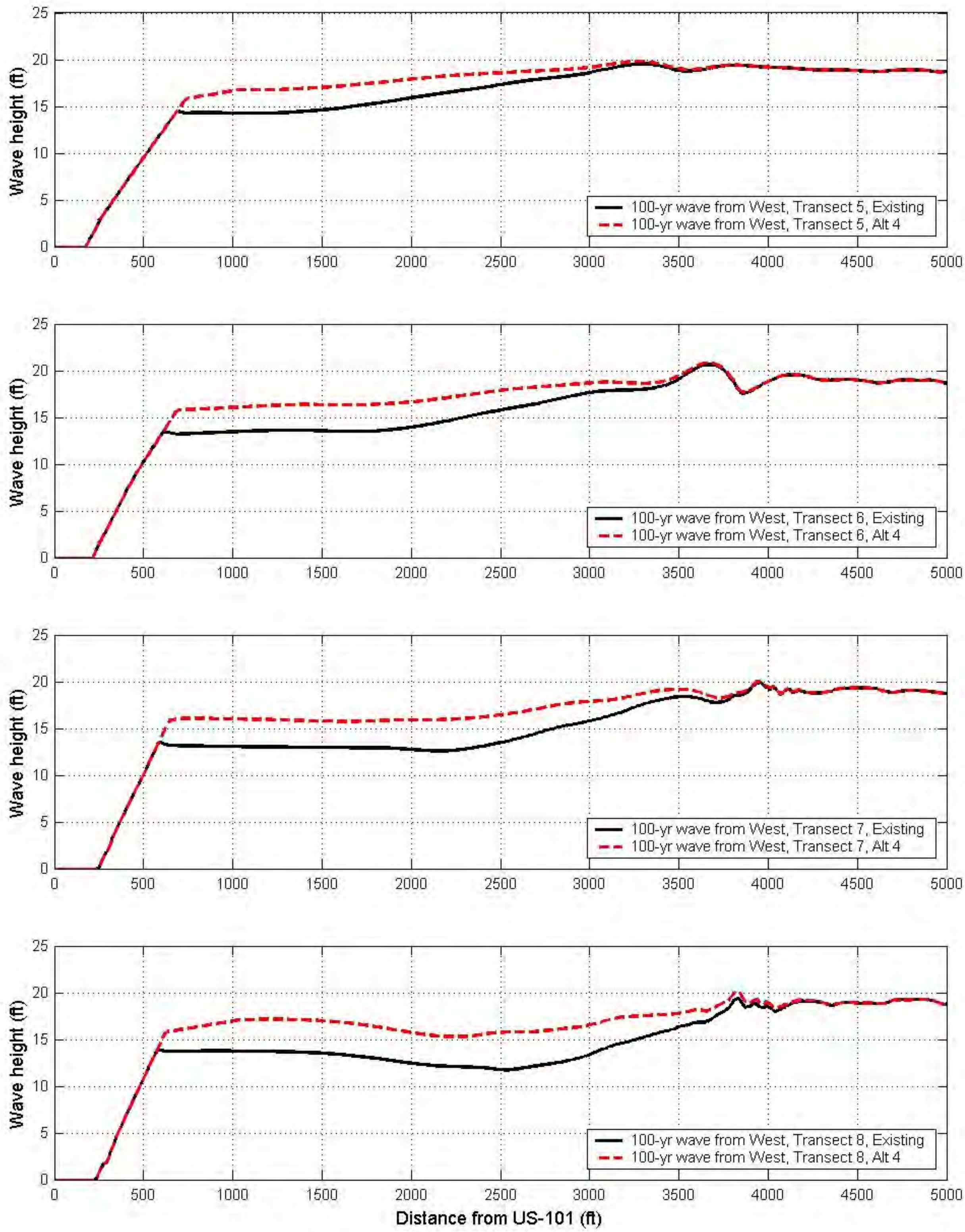

Figure 60. Comparison of 100-Year Wave Height between Existing Condition and Alternative 4 (Waves from West, Transects 5-8)

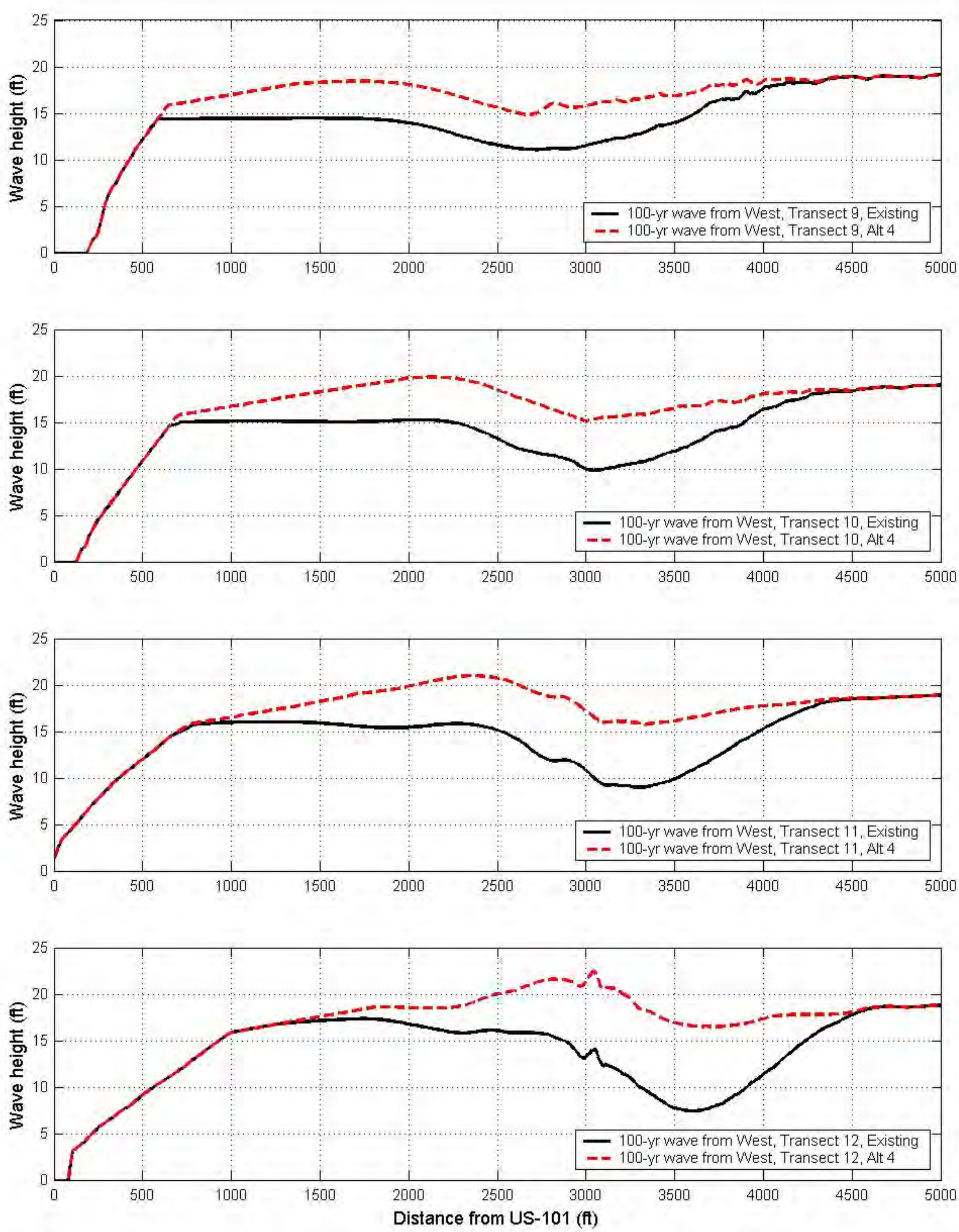

Figure 61. Comparison of 100-Year Wave Height between Existing Condition and Alternative 4 (Waves from West, Transects 9-12)

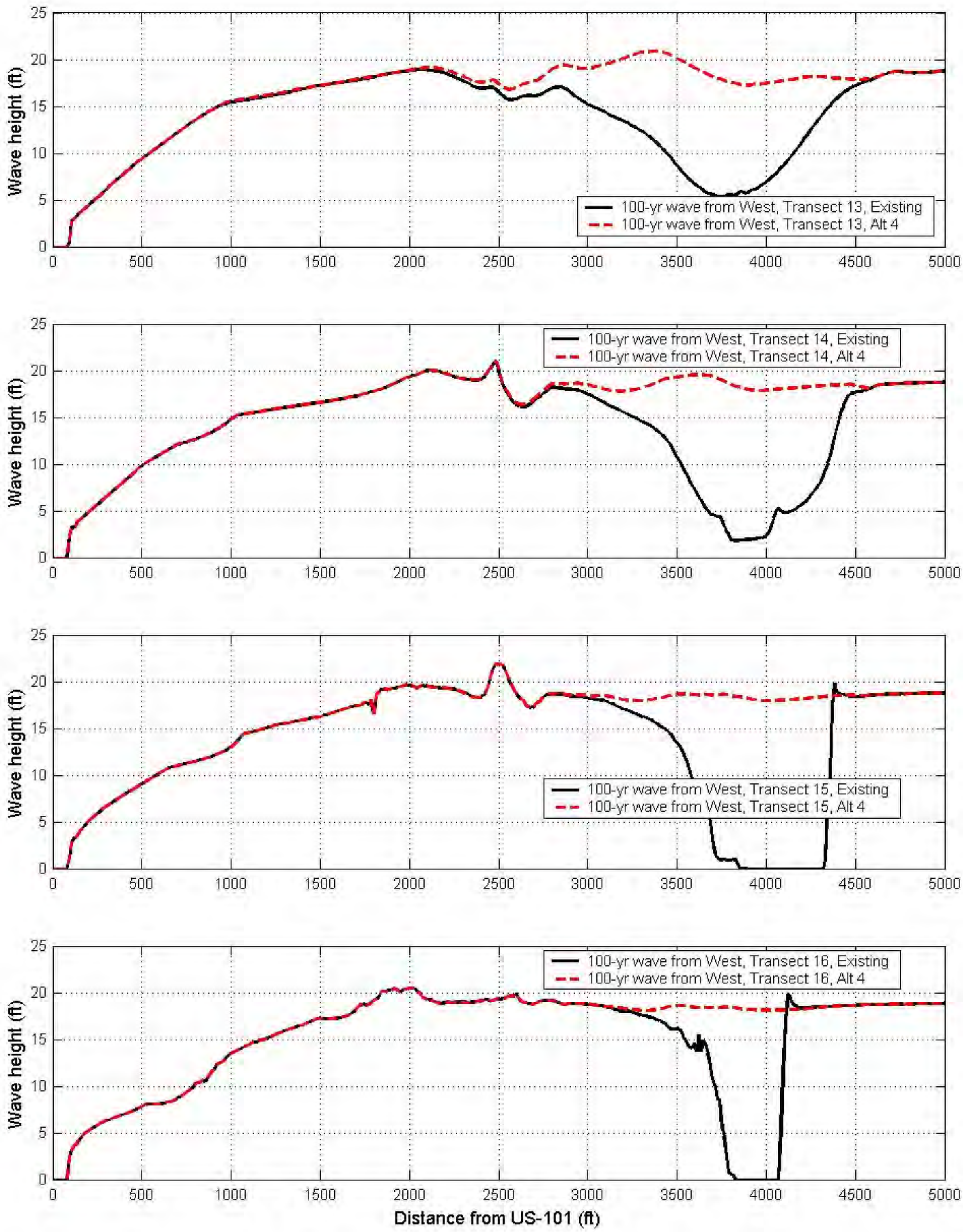

Figure 62. Comparison of 100-Year Wave Height between Existing Condition and Alternative 4 (Waves from West, Transects 13-16)

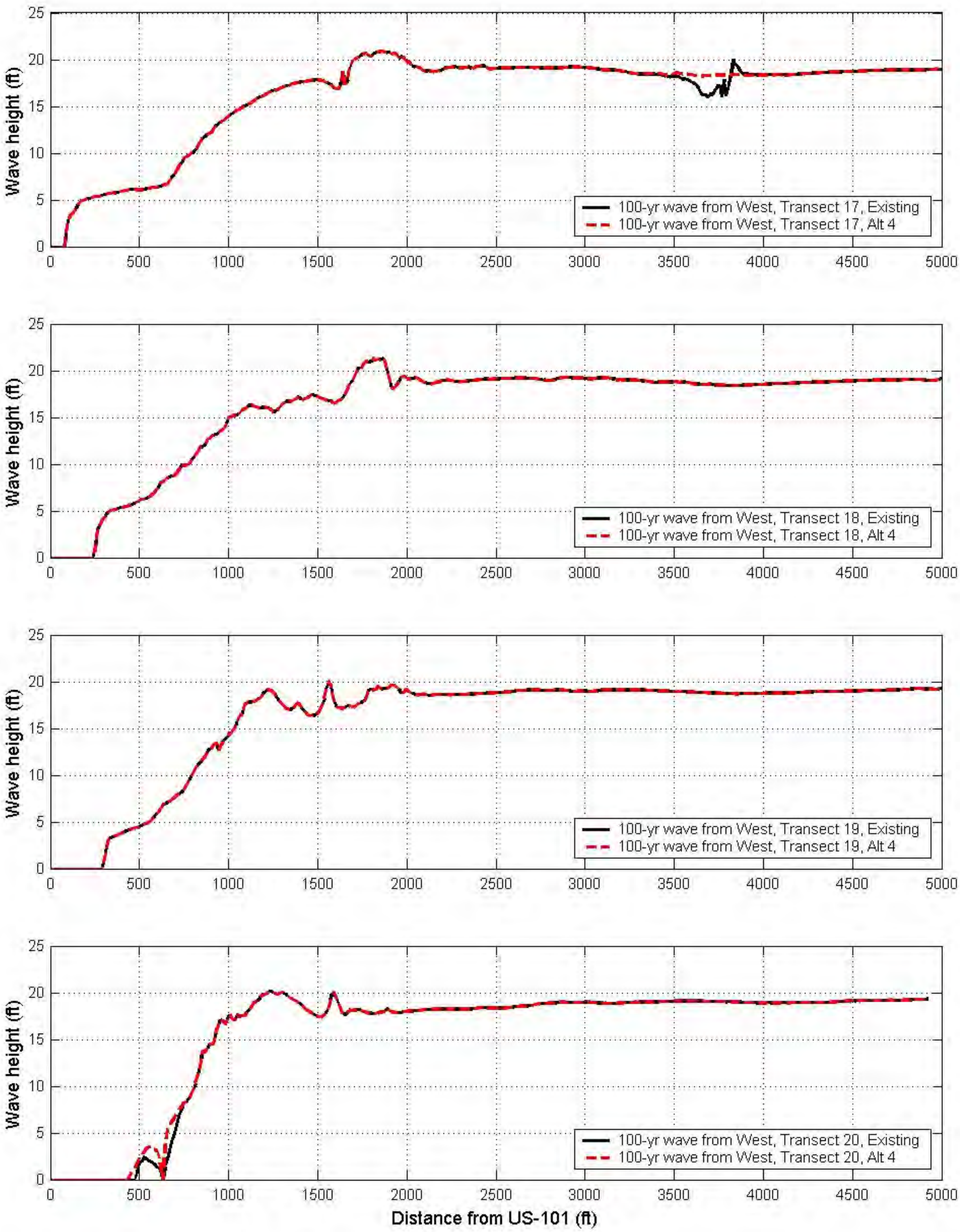

Figure 63. Comparison of 100-Year Wave Height between Existing Condition and Alternative 4 (Waves from West, Transects 17-20)

5.3 Project Impacts on Nearshore Circulation

Coastal and oceanographic currents that affect the water circulation patterns within the Santa Barbara Channel and the project area include offshore currents (currents existing offshore of the project area), alongshore currents (currents flowing parallel to the shoreline), and cross-shore currents (currents flowing perpendicular to the shoreline).

5.3.1 Impacts on Offshore Currents

The principal offshore currents are the California Current, the California Undercurrent, the Davidson Current, and the Southern California Countercurrent (also known as the Southern California Eddy). They consist of major large-scale coastal currents, constituting the mean seasonal oceanic circulation with induced tidal and event specific fluctuations on a temporal scale of 3 to 10 days (Hickey, 1979). Because the scales of these offshore currents are much larger than the size of Rincon Island, removal of Rincon Island will not have any impact on these currents.

5.3.2 Impacts on Alongshore Currents

Alongshore currents are wave-induced currents that move parallel to the shore. Alongshore currents form as waves sweep into the shoreline at an angle and push water down in one direction along the shoreline. They are generated by the shore-parallel component of the radiation stresses associated with the breaking process for obliquely incoming waves and by the surplus water which is carried across the surf zone towards the coastline. The direction of the alongshore current depends on the wave direction relative to the shoreline orientation. As discussed before, the waves come from the WSW and west for more than 90% of time. The alongshore currents induced by these waves will move along the coast of study area in a unidirectional direction from northwest to southeast (or from upcoast to downcoast). For the waves approaching from SW, which occurs in approximately 6% of the time, the alongshore currents may move either from upcoast to downcoast or from downcoast to upcoast depending on the orientation of local shorelines.

While the wave height can be reasonably well predicted with wave models such as STWAVE, the accuracy for the nearshore circulation model is still in an order of magnitude. As a result, it is difficult to quantify the project impact to the alongshore currents. But since Alternative 4 will increase the wave height and intensity wave energy in the coastal areas behind the island, the wave-induced alongshore currents are also expected to increase. The maximum alongshore current generally occurs within the surf zone. The length of the impacted area is expected be similar to the length of the wave-impacted area, which is approximately 4,000 feet in the alongshore direction.

5.3.3 Cross-Shore Currents

Cross-shore currents exist throughout the study area, particularly at times of increased wave activity. Cross-shore currents flow offshore near the seabed. They are driven by the cross-shore setup gradient. The offshore discharge of water is compensated by the onshore directed mass transport and roller transport in the upper part of the water column as waves propagate towards the shore.

Same as alongshore currents, the cross-shore currents are hard to be predicted accurately with numerical models. A higher wave usually produces a higher wave setup with a steeper cross-shore gradient. Alternative 4 will increase the wave height and intensity wave energy in the coastal areas behind the island. Therefore, the cross-shore currents are also expected to increase in these areas.

5.4 Project Impacts on Nearshore Sediment Transport

Sediment transport in the nearshore region is caused by the waves and particularly by the wave-induced alongshore and cross-shore currents. The alongshore sediment transport is typically responsible for long-term shoreline or beach evolution. The cross-shore sediment transport mainly impacts the seasonal variation of beaches and shoreline such as storm-induced erosion in the winter season and beach and recovery in the subsequent spring and summer seasons.

5.4.1 Alongshore Littoral Transport

The alongshore sediment transport is primarily due to the wave-induced alongshore currents. The alongshore sediment transport capacity was calculated in this analysis using the “CERC formula” (USACE, 1984) which is a function of the breaking wave height and wave angle relative to shoreline normal.

$$Q_l = K\left(\frac{\rho\sqrt{g}}{16\kappa(\rho_s-\rho)(1-n_p)}\right)H_b^{\ 2.5}\sin(2\alpha_b)$$

where Q_l is the volumetric alongshore sediment transport capacity, ρ_s is the density of sediment, ρ is the density of water, g is the acceleration of gravity, n_p is the sediment porosity and $n_p = 0.4$, H_b, α_b and κ are the breaking wave height, breaking wave angle relative to shoreline normal and the ratio of the wave height to the water depth at breaking, respectively, and K is a dimensionless coefficient which was recommended by the Shore Protection Manual (USACE, 1984) to be 0.39, if based on computations utilizing the significant wave height.

As discussed in Section 5.2.4, the long-term wave climate was represented by a synthetic series of 24 wave events, each with the percentage of occurrence derived from the 14 years of hourly wave data. These 24 wave events account for more than 97% of the waves that occur at the study area. The sediment transport capacity was calculated for each of these 24 events using the CERC formula. The wave breaking location and breaking wave characteristics, which are the main parameters in the CERC formula, were determined from the STWAVE model output data for each wave event. The average (annual) alongshore sediment transport capacity is the summation of the results for the 24 events times the corresponding percentage of occurrence.

It is noted that the STWAVE model domain is 4,000 meters long in the alongshore direction and consists of 1000 columns (transects). Based on their orientations, the shoreline in the study area was divided into 7 reaches, as shown in Figure 64. The alongshore sediment transport capacity was calculated for each of the 1,000 transects, and then was averaged for each reach. The estimated sediment transport capacity for each reach is shown in Figure 64. Both the existing condition and the results for Alternative 4 are shown in this figure.

The results indicate that the sediment moves alongshore from upcoast to downcoast for the entire shoreline but varies significantly from reach to reach due to the variations of shoreline orientations. The shorelines in Reaches 4 and 5 are almost parallel to the prevailing wave direction, resulting in extremely high alongshore sediment transport capacity in these two reaches. It is noted that the alongshore sediment transport capacity will increase by 40% for Reach 3, by 60% in Reach 4, and by more than 10% in Reach 5. The impacts to the other reaches are negligible. The length of these impact reaches is consistent with the impact to the wave climate.

Figure 64. Alternative 4 Impact to Alongshore Sediment Transport Capacity

It is noted that the results shown in Figure 64 are the alongshore sediment transport capacity, which is the maximum amount of sediment that can be carried by the alongshore currents. The actual alongshore sediment transport rate not only depends on the sediment transport capacity but also depends on the sediment influx from the upcoast and amount of sediment on the seabed. The shoreline in the study area is sand-starved. Because of this the actual alongshore sediment transport rate should be much less than the sediment transport capacity. It is also noted that the estimated alongshore sediment transport capacity or rate can be off by an order of magnitude between different methods.

5.4.2 Cross-Shore Sediment Transport

The cross-shore sediment transport is caused by cross-shore currents and wave motions. Sediment tends to move towards offshore during the stormy winter months, resulting in beach and shoreline erosion, and move back onshore when waves become milder in the spring and summer months. The cross-shore sediment transport rate cannot be well quantified. But due to the intensified wave energy and increased cross-shore currents, the cross-shore sediment transport rate is expected to increase for the areas where the wave climate will be impacted by Alternative 4.

5.5 Project Impacts on Shoreline/Beach Evolution

The shoreline or beach evolution is a direct consequence of alongshore and cross-shore sediment transport. The alongshore sediment transport impacts the long-term shoreline and beach evolution. The cross-shore sediment transport causes the seasonal fluctuations of the beaches and shorelines. The shoreline that is expected to be impacted by Alternative 4 is shown in Figure 65, which includes Reaches 3, 4, and 5 as shown in Figure 64. As discussed in previous sections, both the alongshore and cross-shore sediment transport rate will be increased after removal of Rincon Island, Alternative 4 may cause a long-term retreat of the beach and increase the magnitude of seasonal beach variation in Reach 3 and make sand even harder to be retained in Reaches 4 and 5. It is noted that almost the entire impacted shoreline is armored with revetments. The extreme waves already break offshore before propagating to these revetments. Alternative 4 is not likely to impact the stability of these armor rocks or cause any additional erosion for the shoreline that has already been armored with revetments.

5.6 Impacts of Removal of Causeway Revetment

The rock revetment at the land-end of the causeway is located in shallow water or the surf zone where large waves already break. Removal of this causeway revetment is unlikely to impact the overall wave climate, circulation pattern, or sediment transport capacity in the study area. However, this revetment intrudes into the ocean and thus actually acts as a short sand-retention structure (similar to a short groin). Since sand moves from upcoast to downcoast in this region, this revetment helps prevent sand in the surf zone from moving downcoast, and thus helps retain more sand on the upcoast. Removal of this revetment may cause more sand being moved from the beach that is immediately north of the causeway to the areas south of the causeway. However, because of the large sediment transport capacity, this extra amount of sand is not likely to be able to deposit in the south areas, and thus the impact to the beaches and shoreline in the south areas are expected to be insignificant.

Figure 65. Impacted Shoreline of Alternative 4

6 SUMMARY

A coastal engineering study was conducted to assist in the preparation of a Feasibility Study Report and the CEQA document, which will be performed by Padre Associates, Inc. (Padre), for the Rincon Island Decommissioning Project. This coastal engineering study assessed the coastal hazards on Rincon Island and the stability of the island protective armor materials for Alternative 2 – Island Repurposing and Alternative 3 – Partial Decommissioning; and analyzed the impacts of Alternative 4 - Complete Decommissioning on the coastal processes in adjacent areas. The findings and conclusions are summarized as follows:

6.1 Alternative 2 – Island Repurposing

- The existing Rincon Island, which is made up of dredged sand and gravel and is armored with rocks and cement tetrapods, will remain in this alternative. This alternative is not anticipated to cause any impact to coastal processes in adjacent areas.
- The top of protective armor (revetment) is at +35.5 feet. NAVD88 for the seaward revetment, +21.6 to +22.3 feet, NAVD88 for the north and southeast revetments, and +15.4 feet, NAVD88 for the east wharf. The ground elevation varies between +14.4 to +15.7 feet, NAVD88.
- Rincon Island is not anticipated to be inundated by the still water level in the year 2100 even considering the highest SLR projection of 6.6 feet.
- Under the existing condition, the seaside revetment of Rincon Island can be overtopped during a 10-year or larger storm events. But waves are unlikely overtop the north side, leeside, and southeast side of the island even during the 100-year storm event. This would also be true in year 2100 after considering a future likely SLR of 3.1 feet.
- The water that overtops the seaside revetment during the 10-year or larger storm events would flow from the seaside to leeside of island and then flow back to Pacific Ocean. Because of the small overtopping flow rate, the flood water depth on the island is expected to be small.
- The existing seaside revetment can withstand a 3.5-year storm from the Pacific Ocean. But it may sustain damages and show considerable distressing under attack from waves appreciable larger than a 3.5-year storm event. On the other hand, the historical extreme storms that occurred in the past 60 years appears to have not endanger the whole island. This indicates that Rincon Island may remain in place even when subject to the rare occurrences of very large storm events.
- The existing protective armors on north side, leeside, and southeast side of the island appears to be able to withstand the 100-year storm events.
- Future SLR should not impact the stability of the existing armor material because the SLR is small compared to the existing water depth at the toe of these revetments.

6.2 Alternative 3 – Partial Decommissioning

- Since Rincon Island and the armor materials would remain in the same condition as in Alternative 2, the findings for Alternative 2 will apply to Alternative 3.

6.3 Alternative 4 – Complete Decommissioning

- The nearshore wave condition was analyzed using the STWAVE model for both the existing condition and the Alternative 4 condition. In total 36 wave events were modeled. These included 24 events to represent the long-term wave climate and 12 events to represent extreme storm events.
- With the full removal of Rincon Island and the causeway revetment, Alternative 4 would increase the wave height and intensify the wave energy in the coastal area behind the island. The impacted area can be as long as 4,000 feet in the alongshore direction during extreme

storm events, as shown in Figure 50. The cross-shore extent of the impact can be from the island to the surf zone. Alternative 4 is anticipated to have the most impact on the wave climate immediately behind the island. This impact will decay with distance from the island.

- Alternative 4 is not anticipated to have any impact to the offshore currents. But it will increase the wave-induced alongshore currents and cross-shore currents in the areas where the wave climate is impacted by Alternative 4.
- Alternative 4 is anticipated to increase the alongshore sediment transport capacity by 40% for Reach 3, by 60% in Reach 4, and by more than 10% in Reach 5, as shown in Figure 64. The impact to the other reaches is negligible. Alternative 4 is also anticipated to increase the cross-shore sediment transport rate in the areas where the wave climate is impacted by Alternative 4.
- Alternative 4 may cause a long-term retreat of the beach and increase the magnitude of seasonal beach variation in Reach 3 and make sand even harder to be retained in Reaches 4 and 5. Alternative 4 is not likely to induce any erosion for the shoreline that has already been armored with revetments or impact the stability of these armor rocks.
- The rock revetment at the land-end of the causeway acts as a short sand-retention structure (similar to a short groin). Removal of this revetment, which is a part of Alternative 4, may cause more sand being moved from the beach that is immediately north of the causeway to the areas south of the causeway. But this extra amount of sand is not likely to be able to deposit in the south areas, and thus the impact to the beaches and shoreline in the south areas are expected to be insignificant.

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