Appendix 15A

Coastal Hazards Assessment

Final

WEST BASIN MUNICIPAL WATER DISTRICT OCEAN WATER DESALINATION PROJECT

Coastal Hazards Analysis

Prepared for
West Basin Municipal Water District

July 2019

ESA

Final

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EXECUTIVE SUMMARY

Project Background

Since rising sea-levels will increase the potential coastal flooding and flood hazards in the future, the West Basin Municipal Water District (District) conducted a site-specific coastal hazards analysis for the proposed desalination facility at the El Segundo Generating Station (ESGS) North and South Sites, which was included in the Draft EIR as Appendix 5. The results of that analysis are presented in Draft EIR Section 5.9.4, in the discussion of coastal flooding and tsunami impacts, and concluded that portions of the ESGS Site would be vulnerable to flooding from future coastal flood hazards, including from strong wave surge and tsunami inundation under future sea-level flood hazard conditions. Therefore, Mitigation Measure HYDRO-1 in EIR Section 5.9.4, requires the District to complete a Project-specific coastal engineering study for the final Project design, and would require the final Project engineering design to minimize conflicts with the applicable Coastal Act Sections 30235 (Construction altering natural shoreline) and 30253 (Safety, stability, pollution, energy conservation, visitors).

The California Coastal Commission (CCC) comments that the Draft EIR project description and analysis discuss the need for some unspecified type of coastal hazards shoreline protection, and that the Draft EIR fails to describe fully what would be needed and fails to adequately evaluate the severity of sea-level rise, increased storm energy, and coastal erosion. A site-specific study by Scott Jenkins (Draft EIR Appendix 5) was found by the CCC to have used sea-level rise projections and technical methods that were inconsistent with the current California state guidance. The CCC recommends that the Draft EIR be revised and noted that this type of proposed "critical infrastructure" facility is to be evaluated using high-risk sea-level rise projections and the "extreme risk aversion" scenario known as the "H++" scenario. The primary expectations and comments from the CCC included the following:

- Use the appropriate expected operating life for the proposed project, to be defined by the District (note the CCC recommends that the coastal analysis extend 100 years)
- Use the recent *2018 State Sea-Level Rise Guidance*, based on the findings from the 2017 *Rising Seas in California: An Update of Sea-Level Rise Science*, and consistent with prior guidance including the CCC's 2015 Sea-Level Rise Policy Guidance (updated 2018)
- Consider hazards resulting from an extreme coastal event with a 500-year return period. In this analysis, the return period is defined as the reciprocal (or inverse) of the annual exceedance probability.
- Use the medium-high risk aversion and extreme risk aversion (e.g., H++) sea-level rise projections over the expected operating life of the proposed project

- Summarize the available information on tsunamis, including the California Official Tsunami Inundation maps prepared for emergency evacuation planning, and the recent tsunami modeling and geodatabase prepared by American Society of Civil Engineers[1]

- Leverage the existing hazard mapping by ESA[2], USGS[3], and Terra Costa[4]

In response to these comments, West Basin completed this study, which is a supplemental coastal hazards assessment that considered these recommendations and essentially implemented Mitigation Measure HYDRO-1, by analyzing extreme wave runup for existing and future conditions, as well as reviewing available information on potential impacts from tsunami events.

The project site is located on the shore of Santa Monica Bay in the City of El Segundo, California. The site is owned by NRG and is currently used as an electrical power generating station. A multi-use bike path runs along the seaward edge of the project site, and is elevated approximately eight to ten feet above the beach. An existing coastal protection structure is located on the seaward slope of the bike path, which extends to the beach.

Coastal hazards were analyzed in the area as part of regional and site-specific studies. The AdaptLA project included regional coastal hazard mapping of extreme storm flooding and erosion with sea-level rise. Similarly, the USGS CoSMoS mapping presents projected flooding and erosion areas resulting from a range of extreme storms and sea-level rise scenarios. In both of these regional studies, the site appears to be exposed to storm flooding and potential erosion.

Process and Methods

The coastal hazards assessment was conducted using standard methods described in the 2005 *Federal Emergency Management Agency* (*FEMA) Guidelines for Coastal Flood Hazard Analysis and Mapping for the Pacific Coast of the United States*, the U.S. Army Corps of Engineers (USACE) *Shore Protection Manual*, and other technical analyses for coastal engineering. The coastal hazards assessment analyses comply with the recommendations of the 2018 CCC *Sea-Level Rise Policy Guidelines*, which describes specific needs to be included in the Coastal Development Permit (CDP) applications and presents recommendations on technical approaches for conducting wave runup and flooding analyses.

Waves and Water Levels

The wave runup analysis was performed using the composite slope method, which uses the deepwater wave conditions offshore of the site to “set up” the local water levels, and then steps

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[1] Note that the California Emergency Management Agency tsunami maps were prepared for evacuation planning only, and are based on the maximum credible tsunami, which is likely overly conservative for project design. Because of the lack of tsunami design guidelines in the United States, the ASCE recently updated their design guidance for considering tsunami forces in ASCE 7-16, and conducted extensive tsunami modeling that provides a detailed mapping of tsunami hazard inundation and runup elevations.

[2] Coastal Resilience: http://maps.coastalresilience.org/california/

[3] CoSMoS: http://data.pointblue.org/apps/ocof/cms/

[4] Climate Smart Cities, Trust for Public Land: https://dornsife.usc.edu/uscseagrant/adaptla/ (includes Coastal Resilience and CoSMoS data)

through the surf zone to identify the depth-limited wave condition that results in the greatest wave runup at the seaward edge of the project site. Wave runup was computed along three profiles at the project site for 69 annual maximum wave events.

Wave data was compiled from three primary sources: Coastal Data Information Program (CDIP) Monitoring and Prediction (MOP) System data, historic hindcast data of Walker et al. (1984), and the FEMA open coast flood study for the Pacific Coast. Corresponding tide data from the Santa Monica tide gauge was used to identify the tidal high water elevations occurring during the selected swell events. The data were reviewed and analyzed to develop a list of annual maximum wave and water level conditions that were used in the analysis.

Tsunamis

Existing and future hazards from tsunami inundation were evaluated using available existing information from the State of California (2009), prior work by Jenkins (2016; 2017) for the project site, and preliminary application of new guidance on tsunami inundation (ASCE 2017a).

Sea-Level Rise Scenarios

Five sea-level rise scenarios were developed for the study (Table ES-1). They are based on the *State of California Sea-Level Rise Guidance* prepared by California Ocean Protection Council (OPC) in 2018.[5], and serve to guide the understanding of a range of sea-level rise values and time horizons that can be related to site improvements, expected design life of structures, and adaptation phasing. The extreme risk aversion[6] projection of sea-level rise, which the state has required for analyzing critical infrastructure, and the medium-high risk aversion projection were used to bookend the possible timing of a given amount of sea-level rise. For a given time horizon scenario, the earlier year is consistent with extreme risk aversion scenario (more rapid sea-level rise) and the later year is based on the medium-high risk aversion scenario.

TABLE ES-1
SEA-LEVEL RISE SCENARIOS USED IN WAVE RUNUP ANALYSIS

Scenario	Existing	Mid-Century	Late-Century	Next-Century	Beyond 100 Years
Time Horizon	2019	2050 – 2060	2082 – 2100	2092 – 2120	2120+
Sea-Level Rise (feet)	0	2.6	6.8	8.5	14

The sea-level rise scenarios are also consistent with the *Sea-Level Rise Policy Guidance* developed by the California Coastal Commission (CCC) in 2015 and updated in 2018 to be consistent with updated sea-level rise projections.[7] Many of the analytical methods used in this

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[5] http://www.opc.ca.gov/webmaster/ftp/pdf/agenda_items/20180314/Item3_Exhibit-A_OPC_SLR_Guidance-rd3.pdf

[6] "Extreme risk aversion" describes the maximum expected sea-level rise, and is sometimes referred to as the "H++" scenario. Medium-High risk aversion refers to projections of sea-level rise that are lower than the H++ scenario, but similar to "high" sea-level rise scenarios in the prior state guidance circa 2013.

[7] https://documents.coastal.ca.gov/assets/slr/guidance/2018/0_Full_2018AdoptedSLRGuidanceUpdate.pdf

study are described in the *FEMA Coastal Flood Hazard Analysis and Mapping for the Pacific Coast of the United States* (FEMA 2005).

Findings and Conclusions

The primary finding of the study confirms that the extreme wave runup constrains the project site sometime between mid- and late-century time horizons. Wave overtopping during extreme events could pose a hazard to the infrastructure and operations, but may be accommodated by design decisions that account for high-velocity moving water associated with waves. Profiles of bore elevations were developed and presented, and may be used to develop planning-level siting of project infrastructure. The results can also be used during project design as an indication of how the project can be sited or adapted to higher sea-levels. The 100-year runup[8] elevation and landward extent was based on 69 annual maximum events computed using wave and water level data over a period of 115 years. The 115-year data set includes hindcasts[9] of the largest events of the century.

The project site is located within a tsunami design zone for existing and future conditions. Design guidance identifies the north portion of the site as being inundated due to tsunami with a runup extending to approximately the 23 feet NAVD[10] elevation contour; representing a depth of approximately three feet at the site. An analysis using the energy grade-line method found inundation depths at the site on the order of two to five feet for existing conditions, and increasing with sea-level rise.

Each sea-level rise model run considered a changing beach profile: i.e., the beach erodes with sea-level rise, but the rock revetment and trail are assumed to be maintained in place. The overall trend is that the beach narrows and the elevation decreases over time, exposing the site to larger waves in the future.

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[8] The 100 year runup refers to the potential elevation of runup with an average recurrence of once every 100 years and an annual probability of exceedance of 1%. The runup elevation is the addition of wave runup height to an ocean water elevation, often called “total water level.”

[9] A hindcast is a computed wave condition derived from historical weather charts.

[10] NAVD refers to the North American Vertical Datum of 1988, a fixed reference for elevations determined by geodetic leveling. The datum was derived from a general adjustment of the first-order terrestrial leveling nets of the United States, Canada, and Mexico.

1 INTRODUCTION

1.1 Problem Statement

Coastal flooding and erosion hazards put our natural and built assets at risk of damage and loss. Much of the damage along the California coast has occurred during intermittent extreme storm events, during which large swells coincide with elevated tidal water levels and result in major erosion and flooding. The frequency and intensity of damaging events are expected to increase with sea-level rise. Although hazard mapping products developed by ESA (e.g., Coastal Resilience), USGS (e.g., CoSMoS), and others represent the geographic areas that are vulnerable to existing and future flooding and erosion, they are informed by modeling that is conducted at a regional scale, and therefore these maps are limited in their applications to planning-level assessments. Permitting and design of a project require site-specific considerations of the coastal hazards, which can be more or less severe than shown by available regional hazard map products. The site-specific coastal hazards analysis is intended to describe the site's exposure to flooding and erosion over the expected life of the proposed project, and to assess when the site would be impacted by erosion hazards, still water flooding, and the extents of extreme wave runup.

This report describes a site-specific coastal hazards analysis that was completed for the proposed site of the West Basin Municipal Water District's Ocean Water Desalination Project in El Segundo, California. The project site is located on the shore of central Santa Monica Bay at an existing power plant. The Draft EIR assessed coastal hazards using available information from regional hazard mapping and the coastal hazard study prepared by Scott Jenkins (2016; 2017), included as Draft EIR Appendix 5. The Draft EIR also includes a mitigation measure that requires the completion of a site-specific coastal hazards analysis. Comments from the California Coastal Commission recommend filling technical gaps in the Final EIR that would need to be addressed during subsequent design phases, and prior to applying for a Coastal Development Permit (CDP), including:

- Considering higher amounts of sea-level rise based on the extreme risk aversion projection (e.g., H++), consistent with recommendations of recently updated guidance adopted by the State of California
- Assessing the 100- and 500-year wave runup extents
- Discussing potential impacts from tsunamis

Additional comments provided by the CCC are presented in the following section.

1.2 Background

During the environmental review phase of the project, the District completed a site-specific coastal hazards analysis (Scott Jenkins 2016; 2017) for the proposed desalination facility at the ESGS North and South Sites, which is included in the Draft EIR as Appendix 5. The results of that analysis are presented in Draft EIR Section 5.9.4, in the discussion of coastal flooding and tsunami impacts, and conclude that portions of the ESGS Site would be vulnerable to flooding from future coastal flood hazards, including from strong wave surge and tsunami inundation under future sea-level flood hazard conditions. Therefore, Mitigation Measure HYDRO-1 in EIR Section 5.9.4, requires the District to complete a Project-specific coastal engineering study for the final Project design, and requires the final Project engineering design to minimize conflicts with the applicable Coastal Act Sections 30235 (Construction altering natural shoreline) and 30253 (Safety, stability, pollution, energy conservation, visitors).

The CCC opines in its comments on the Draft EIR that the analysis fails to adequately evaluate the severity of sea-level rise, increased storm energy, and coastal erosion, and the project description fails to describe fully what type of coastal hazard shoreline protection would be required. The CCC recommends that the Draft EIR be revised and that this type of proposed "critical infrastructure" facility be evaluated using high-risk sea-level rise projections and the "extreme risk aversion" scenario known as the "H++" scenario. The primary expectations and comments from the CCC include the following:

- Use the appropriate expected operating life for the proposed project, to be defined by the District (note the CCC recommends that the coastal analysis extend 100 years)
- Use the recent 2018 State Sea-Level Rise Guidance, based on the findings from the 2017 Rising Seas in California: An Update of Sea-Level Rise Science, and consistent with prior guidance including the CCC's 2015 Sea-Level Rise Policy Guidance (updated 2018)
- Consider hazards resulting from an extreme coastal event with a 500-year return period
- Use the medium-high risk aversion and extreme risk aversion (e.g., H++) sea-level rise projections over the expected operating life of the proposed project, as well as a consideration of thresholds or tipping points for the site
- Summarize the available information on tsunamis, including the California Official Tsunami Inundation maps prepared for emergency evacuation planning, and the recent tsunami modeling and geodatabase prepared by American Society of Civil Engineers[11]

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[11] Note that the California Emergency Management Agency tsunami maps were prepared for evacuation planning only, and are based on the maximum credible tsunami, which is likely overly conservative for project design. Because of the lack of tsunami design guidelines in the United States, the ASCE recently updated their design guidance for considering tsunami forces in ASCE 7-16, and conducted extensive tsunami modeling that provides a detailed mapping of tsunami hazard inundation and runup elevations.

- Leverage the existing hazard mapping by ESA[12], USGS[13], and Terra Costa[14]

In response to these comments, West Basin completed this study, which is a supplemental coastal hazards assessment that considered these recommendations and essentially implemented Mitigation Measure HYDRO-1, by analyzing extreme wave runup for existing and future conditions, as well as reviewing available information on potential impacts from tsunami events.

1.3 Purpose and Scope of Study

The purpose of this study is to assess the vertical and horizontal extents of wave runup and coastal hazards at the project site for existing and future conditions with sea-level rise over the expected life of the development, which will be used for detailing the project planning and design, including initial site development and future adaptation. The study was completed in accordance with the following goal and objectives, developed in coordination with the District.

1.3.1 Study Goal

The overarching goal of the coastal hazards analysis is to inform the development of a desalination facility site plan and engineering/structural design that complies with the California Coastal Act with respect to minimizing conflicts with coastal hazards.

1.3.2 Study Objectives

The following study objectives were identified in coordination with the District:

1. Analyze the coastal hazards associated with sea-level rise impacts over the expected life of the project
2. Provide hazard extents that can be used to locate facilities outside of projected coastal flood hazard zones and inform planning of adaptation strategies that could manage the risk level through the expected life of the project
3. Identify time frames when adaptation actions are triggered

1.3.3 Linkage of Study to CEQA

The Draft EIR concludes that portions of the ESGS Site would be potentially vulnerable to flooding from future coastal flood hazards, including from strong wave surge and tsunami inundation under future sea-level flood hazard conditions. Therefore, Mitigation Measure HYDRO-1 in Draft EIR Section 5.9.4, requires the District to complete a Project-specific coastal engineering study for the final Project design, and requires the final Project engineering design to

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[12] Coastal Resilience: http://maps.coastalresilience.org/california/

[13] CoSMoS: http://data.pointblue.org/apps/ocof/cms/

[14] Climate Smart Cities, Trust for Public Land: https://dornsife.usc.edu/uscseagrant/adaptla/ (includes Coastal Resilience and CoSMoS data)

minimize conflicts with the applicable Coastal Act Sections 30235 (Construction altering natural shoreline) and 30253 (Safety, stability, pollution, energy conservation, visitors).

However, in response to comments received on the Draft EIR from State agencies and other interested stakeholders, West Basin prepared this supplemental Coastal Hazards Analysis; see Final EIR *Master Response: Supplemental Studies*.

1.3.4 Scope of Study

The scope of this study is focused on the completion of a coastal hazards analysis for the project that is consistent with the California state guidelines, and meets the expectations of the regulatory agencies, including the CCC. The analysis assesses the flooding and erosion impacts on the pre-project site for existing and future conditions, which is used to inform the project design. The technical analysis is based on a combination of existing information and new calculations to assess the potential exposure of the project to flooding and erosion.

Results that were developed for the regional AdaptLA study are used as a starting point, which utilizes the Coastal Resilience mapping tool developed by ESA, USGS's CoSMoS, and a mapping tool developed by Terra Costa/Scripps. The site-specific analysis consists of additional transect-based runup and erosion calculations using methods consistent with industry standards (e.g., FEMA, USACE, etc.) and CCC guidance.

The study addresses the concerns that the CCC letter identifies (described above) related to estimating the future coastal hazards at the site.

The primary steps of the study included:

- Site visit and project initiation, and a review of relevant studies
- Selection of sea-level rise scenarios
- Conduct a technical analysis to evaluate the coastal hazards for existing and future conditions
- Reporting

1.4 Report Structure

This report is structured as follows:

- **Section 2 – Project Setting:** An overview of the physical context of the project site, including its history and landscape. This section begins with a brief discussion of the project site, including elevations and site features, followed by a summary of the coastal hydrology and geomorphology, and finally a description of relevant climate change issues and sea-level rise scenarios used in the study.
- **Section 3 – Technical Analysis of Coastal Hazards:** The technical analysis methods and results for the coastal hazards assessment are described, including:

  - An overview of the technical approach that provides context of the parameters and methods.
  - A brief description of the still water level analysis used to estimate extreme still water level as a function of recurrence.
  - The approach to constructing a composite series of annual maximum wave and water level events to be applied to the wave runup analysis, including wave transformation and compilation of multiple data sources.
  - The analysis used to construct the nearshore profiles for existing and future conditions with sea-level rise.
  - The wave runup analysis, including a summary of method used and the results of the potential maximum wave runup and the landward extents calculations for existing and future conditions with sea-level rise.
  - A brief description of available information on tsunami hazards and approximate implications of sea-level rise on the hazards.
- **Section 4 – Conclusions:** This section summarizes the primary findings and conclusion of the study.

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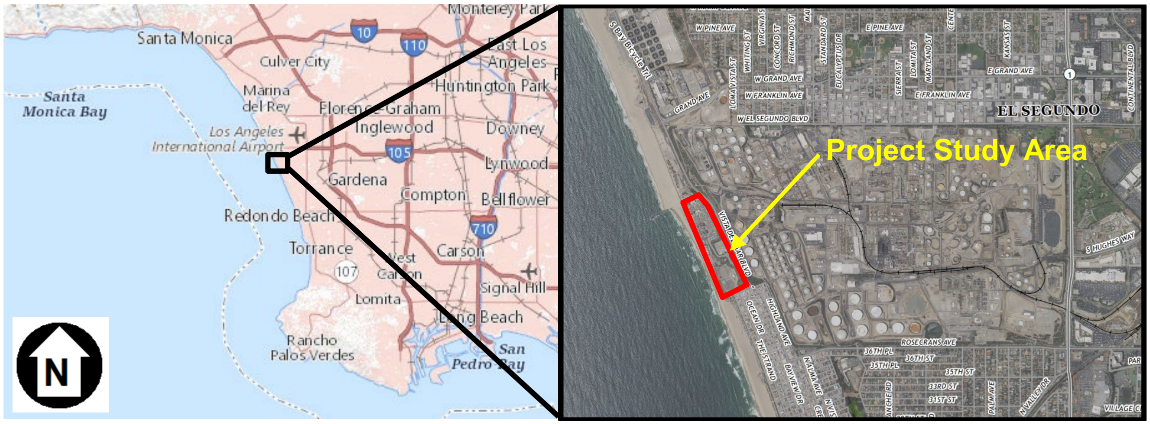
2 PROJECT SETTING

This section presents information on the physical context of the project site, including its history and landscape. This section begins with a brief discussion of the project site, including elevations and site features, followed by a summary of the coastal hydrology and geomorphology, and finally a description of relevant climate change issues and sea-level rise scenarios used in the study.

2.1 Study Area and Existing Site Conditions

2.1.1 Project Location and Vicinity

The project study area is located on the central portion of Santa Monica Bay in the City of El Segundo (Figure 1). The project study area is located immediately west of Vista del Mar, and is bounded by the City of Manhattan Beach to the south and Chevron facilities to the north.



West Basin MWD Ocean Water Desalination Project: Coastal Hazards Analysis / D170766.01

SOURCE: USGS

Figure 1
Project Location and Vicinity

2.1.2 Project Study Area

The project study area is focused on the El Segundo Generating Station (ESGS), which was originally constructed in the 1950s and expanded in the 1960s. The site is a flat parcel located adjacent to a narrow stretch of sandy beach, immediately south of the El Segundo Marine Terminal (ESMT) groin. Information on the history of the shore morphology and human interventions, including the site development and the ESMT groin, are presented in Section 2.2.4.

Primary Site Features

Figure 2 presents a map of the site, which shows some of the primary features that were considered in this study. Development of an ocean water desalination facility in a portion of the area currently being utilized for power generation is proposed by the District. The locations of the facilities and footprint are described in the March 2018 Draft EIR Section 3 (Project Description) and are approximately located in the northern two-thirds of the project site, which is lower and flatter than the southern portion of the site. The project site extends along approximately 2,500 feet of shore from north to south. Figure 2 shows the following features:

- *El Segundo Marine Terminal (ESMT) Groin*: A rubble and concrete groin constructed by Chevron U.S.A., Inc. in 1983 to prevent beach erosion and protect buried pipelines that transport oil to tankers offshore.

- *Bike Trail*: A multi-use pedestrian trail is located immediately west of the project site, and is owned and maintained by Los Angeles County.

- *Rock Revetment*: A quarry stone rock revetment is located along the seaward edge of the bike trail. Most of the rock revetment is visible and extends from the beach (approximately 12 to 15 feet NAVD) to elevations a few feet above the surface of the bike trail (approximately 19 to 22 feet NAVD) at an average slope of 2.6:1 (horizontal to vertical). The northern 300-400 feet of revetment appears to be buried by a constructed sand dune. According to the El Segundo General Plan (1980), the winter storms of 1978 necessitated the placement of 204,000 tons of rock revetment to prevent further erosion. An additional 3,000 tons of rock and 3,000 tons of sand were placed along the beach following the winter storms of 1980. Review of documents did not clearly indicate the presence of a rock revetment extending along the entire reach of the site, but it was assumed to exist. The analysis in this report assumes that the rock revetment is maintained over time by others.

- *Wall Barrier*: An architectural concrete wall approximately 1,700 feet in length is located between the ESGS and the bike trail from the northern edge of the project site. The wall was referred to as a “tsunami wall” by NRG staff, although there is no indication it is designed to meet specific coastal loading criteria. However, it is possible that it is intended to “break-away” when impacted by extreme coastal events, such as a tsunami or other wave action. The primary purpose of the wall was to mitigate temporary construction impacts to visual resources by users of the adjacent recreational beach.[15]

- *Fence Barrier*: A cyclone fence is located between the ESGS and the bike trail along the southernmost 800 feet of the project site.

- *Beach*: The beach located immediately west of the project site is relatively narrow compared to other beaches to the north and south. Based on review of aerial imagery in Google Earth and other sources, the beach width appears to be approximately 100 to 200 feet along most of the project site, but slightly wider in the vicinity of the ESMT groin.

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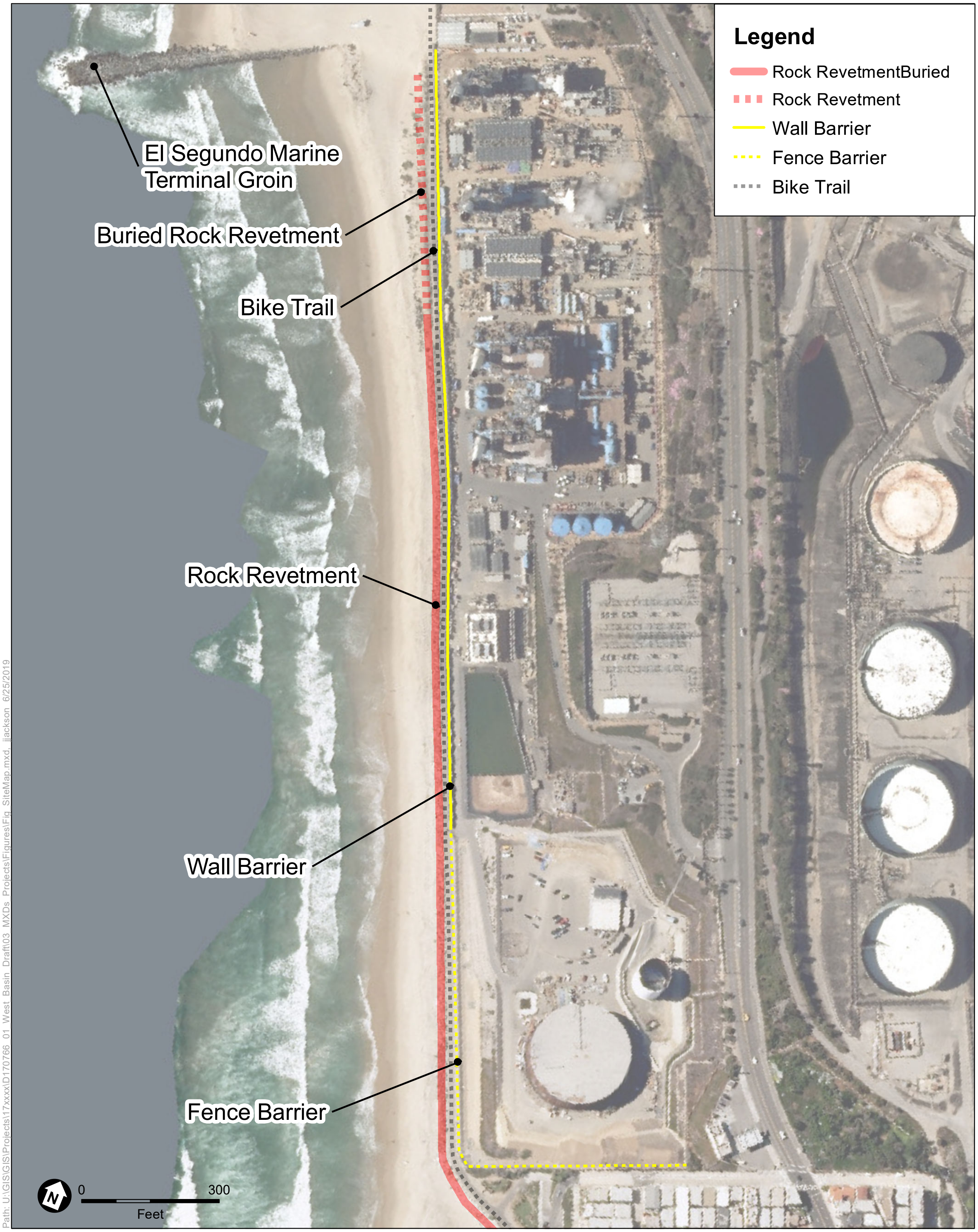
[15] https://www.energy.ca.gov/sitingcases/elsegundo/documents/2004-04-16_P-2_REV_PMPD.PDF



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SOURCE: LA County (2013 Imagery);

West Basin MWD Ocean Desalination Project Coastal Hazards Analysis / 170766.01

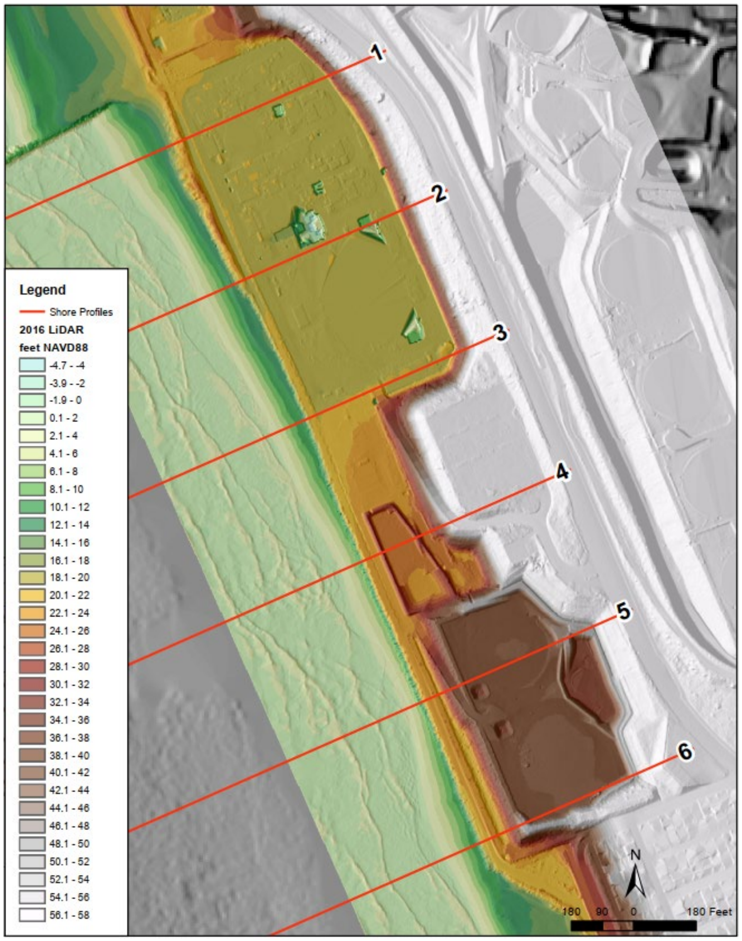
Figure 2
Map of Project Study Area

ESA

Site Elevations

The project site is located on a relatively flat, developed parcel immediately landward of a narrow beach. The northern portion of the project site is flat with elevation grades of approximately 19 to 20 feet NAVD[16]. The southern portion of the site includes a flat plateau area with an elevation of approximately 40 feet NAVD. At the landward edge of the site, the grades steeply upslope to Vista del Mar at an elevation of approximately 80 feet NAVD.

Figure 3 presents a topographic map of the project site that is based on LiDAR (Light Detection and Ranging) data collected in 2016 (USGS 2018). This data set was used as the basis for determining the site grades and beach characteristics for winter conditions. Six transects were initially identified for the study, but efforts were focused on Transects 1, 3, and 5, after initial investigations indicated only slight variations between adjacent transects.



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SOURCE: USGS (2018)

Figure 3
Topography of Study Area Based on 2016 LiDAR
(Red Lines Indicate Study Transects)

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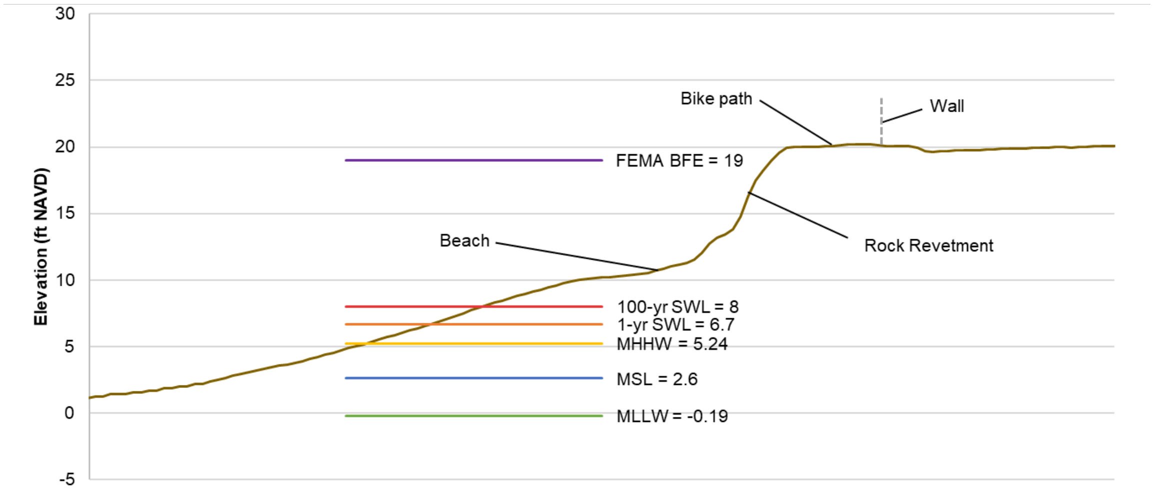
[16] NAVD refers to the North American Vertical Datum of 1988, a fixed reference for elevations determined by geodetic leveling. The datum was derived from a general adjustment of the first-order terrestrial leveling nets of the United States, Canada, and Mexico.

Figure 4 presents a cross-section of the ground surface elevation extracted from the LiDAR surface at Transect 3, and compares the grades to some of the coastal tidal datums and preliminary FEMA base flood elevation (BFE). Starting at the left side of the figure and moving right, the elevation profile extends approximately from low tide elevations, across the beach, up a steep rock revetment, across the bike path and into the project site. The horizontal colored lines represent tidal datums and a selection of extreme coastal water levels, which are described further in Section 2.2.



(BFE = base flood elevation; SWL = still water level; MHHW = mean higher high water; MSL = mean sea level; MLLW = mean lower low water)

West Basin MWD Ocean Water Desalination Project: Coastal Hazards Analysis / D170766.01

SOURCE: Topography from USGS (2018)

Figure 4
Typical Shore Profile Comparing Site Grades to Still Water Levels and FEMA Base Flood Elevation

The FEMA BFE is provided for reference, and has not yet been finalized. The effective FEMA Flood Insurance Rate Map (FIRM) for the area shows that the site is located adjacent to, but not within, a special flood hazard zone with no defined elevation. Although the preliminary FIRM has not yet become effective, the special flood hazard zone is mapped as a “VE” zone with elevation 19 feet NAVD. Here, “VE” refers to a velocity hazard zone with a defined elevation, which means these areas are subject to waves greater than three feet and other development restrictions to accommodate the force of moving water. As shown in this study, the preliminary FEMA BFE likely under-represents the flood hazards at the project site. These differences are described in Section 3.5.4.

Photographs of Project Area

Figure 5 presents a photograph of the shore facing north, which shows the location of the site relative to the bike trail, rock revetment, and the beach. This photograph was taken on October 30, 2018, and is assumed to represent summer-fall beach conditions when the beaches are typically at their seasonal maximum widths. The beach elevation was estimated to be approximately 10 to 12 feet NAVD based on visual observations relative to the trail elevation. Note the cyclone fence located in the right side of the photograph adjacent to the bike trail, and its transition to the wall barrier. The ESMT groin, which extends seaward from the beach, is visible in the distance.

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Figure 5
Photograph of Beach, Revetment, Bike Trail, and Fence/Wall Barrier Looking North on 10/30/18

Figure 6 presents a photograph of the shore facing south, which includes many of the features presented in the previous figure. This photograph was taken where the constructed dune transitions to exposed and visible rock revetment. Here, the beach is significantly wider than shown in Figure 5, and details of the wall barrier are shown.

West Basin MWD Ocean Water Desalination Project: Coastal Hazards Analysis / D170766.01

Figure 6
Photograph of Beach, Revetment, Bike Trail, and Wall Barrier Looking South on 10/30/18

Figure 7 presents a photograph of the ESMT groin located at the northern boundary of the project site. Based on visual observations alone, the ESMT groin affects the local beach morphology such that the beach on the north side is much wider than the south side of the groin. The history of the ESMT groin and its effects on the landscape are discussed further in Section 2.2.4. This location is also a popular surf spot, where waves peel around both ends of the groin and produce rideable surf for a wide range of conditions.

West Basin MWD Ocean Water Desalination Project: Coastal Hazards Analysis / D170766.01

Figure 7
Photograph Showing Difference in Beach Widths North and South of El Segundo Marine Terminal Groin on 10/30/18

Figure 8 presents a photograph of the northern portion of the project site landward of the wall barrier. The grades are relatively flat, but several industrial facilities are located throughout the site. This particular photograph is located near the existing seawater intake tunnels.

West Basin MWD Ocean Water Desalination Project: Coastal Hazards Analysis / D170766.01

Figure 8
Photograph of Site on Landward Side of Wall Barrier Looking North Near Intake Tunnels on 10/30/18

2.2 Coastal Hydrology and Geomorphology

This section summarizes the relevant information for the coastal water levels, waves, and geomorphology of the project site and vicinity.

2.2.1 Water Levels, Tides, and Datums

The tides in Santa Monica Bay exhibit mixed semi-diurnal characteristics, with two high tides and two low tides of unequal height occurring approximately every 24 hours. The tide range along the project site varies from approximately 3.5 feet during neap tides to over 7 feet during spring tides. Table 1 presents the published tidal datums for the Santa Monica tide gauge (NOAA NOS Station 9410840), located on the Santa Monica Pier about eight miles north of the project site. The mean higher high water (MHHW) elevation is calculated by averaging the higher high water height of each tidal day observed over the tidal epoch (a 19-year period of water level averaging known as the National Tidal Datum Epoch). Note that the maximum still water level of 8.3 feet NAVD was observed during the El Niño winter of 1982-1983, which is the storm of record for much of the California coast.

TABLE 1
PROJECT TIDAL DATUM BASED ON SANTA MONICA TIDE GAUGE (NOAA NOS STATION 9410840)

Datum	Elevation (feet NAVD)	Description
Max	8.31	Highest Observed Water Level (11/30/82)
HAT	7.08	Highest Astronomical Tide (12/2/90)
MHHW	5.24	Mean Higher-High Water
MHW	4.5	Mean High Water
MTL	2.62	Mean Tide Level
MSL	2.6	Mean Sea-Level
MLW	0.74	Mean Low Water
MLLW	-0.19	Mean Lower-Low Water
LAT	-2.16	Lowest Astronomical Tide (1/1/87)
Min	-3.03	Lowest Observed Water Level (12/17/33)

SOURCE: NOAA (https://tidesandcurrents.noaa.gov/datums.html?id=9410840)

2.2.2 Extreme Water Levels

Extreme still water levels are infrequent events that occur when the astronomical tidal waters are elevated due to low atmospheric pressure anomalies and other meteorological and climatic conditions, typically during severe winter storms, but also rare tropical storms. Extreme water levels in Santa Monica Bay have been reported by previous studies, including FEMA (2015) and ESA (2016), among others. Table 2 presents the results of an extreme value analysis conducted on the annual maximum record of still water levels measured at the Santa Monica tide gauge (see Section 3.2). The values of the estimated water levels presented in Table 2 are almost identical to those summarized in by FEMA (2015) as part of the Open Pacific Coast Flood Study. Note that the water levels measured during the major storms of the El Niño winter in 1982-1983 (maximum recorded is 8.3 feet) are similar to those with a 100- to 500-year return period (Seymour et al. 1984).

TABLE 2
EXTREME STILL WATER LEVEL RESULTS FOR SANTA MONICA TIDE GAUGE

Return Period (years)	X-Percent Annual Exceedance (%)	Still Water Level (feet NAVD) [a]
500	0.2	8.4
100	1	8.0
50	2	7.9
20	5	7.7
10	10	7.5
5	20	7.4
2	50	7.1

NOTES:

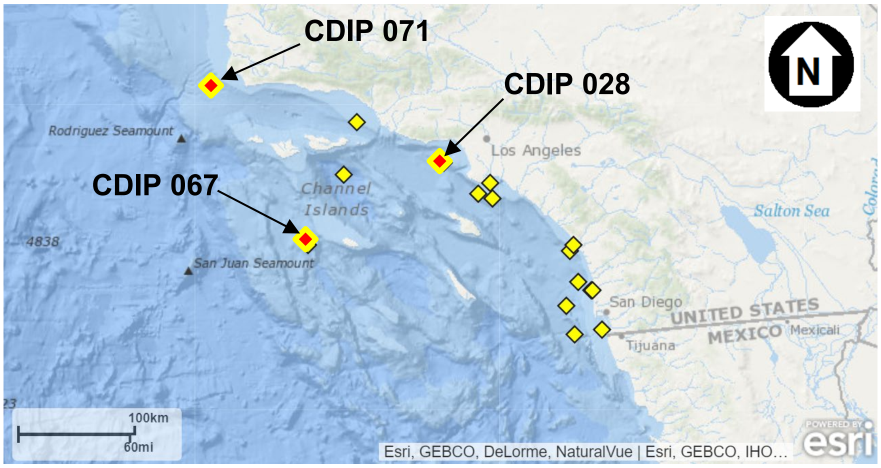
[a] Gumbel Maximum Likelihood Fit

2.2.3 Wave Climate

The wave climate of Southern California is characterized by intermittent long-period swells during the winter and summer months. During winter, large swells originating from storms in the North Pacific approach the Southern California region from the west and northwest directions. During summer and fall, swells originating from storms in the Southern Pacific dominate the wave climate, and approach the area from the southwest and south directions, often with wave periods greater than 20 seconds. Because wave power is proportional to the period, longer period wave events often result in the greatest coastal flood impacts and highest wave runup. South-facing shores of Southern California are also exposed to North Pacific tropical storm systems, which generally approach the region from the southeast. However, the San Clemente and Santa Catalina Islands create a wave shadow that shelters Santa Monica Bay from waves generated by most North Pacific tropical storms.

The wave climate of the project study area is greatly influenced by the nearshore bathymetry and the Channel Islands located offshore. Although the islands can block the offshore wave energy from reaching the shore of the project site, specific swell directions can penetrate to the Santa Monica Bay. Furthermore, the local bathymetry offshore of the project site tends to focus offshore swells originating from between 260 to 270 degrees, and as a result, long-period swells from these directions often double in height. This is discussed further in Section 3.3.

Figure 9 presents a map of the Southern California bight that indicates the locations of buoys operated by Scripps Institution of Oceanography (SIO) as part of their Coastal Data Information Program (CDIP). Three buoys are noted on the figure: CDIP 071 (Harvest buoy) located in deep water offshore of Point Conception, CDIP 067 located in deep water offshore of San Nicolas Island which is exposed to open ocean swells, and CDIP 028 located in nearshore conditions in Santa Monica Bay.

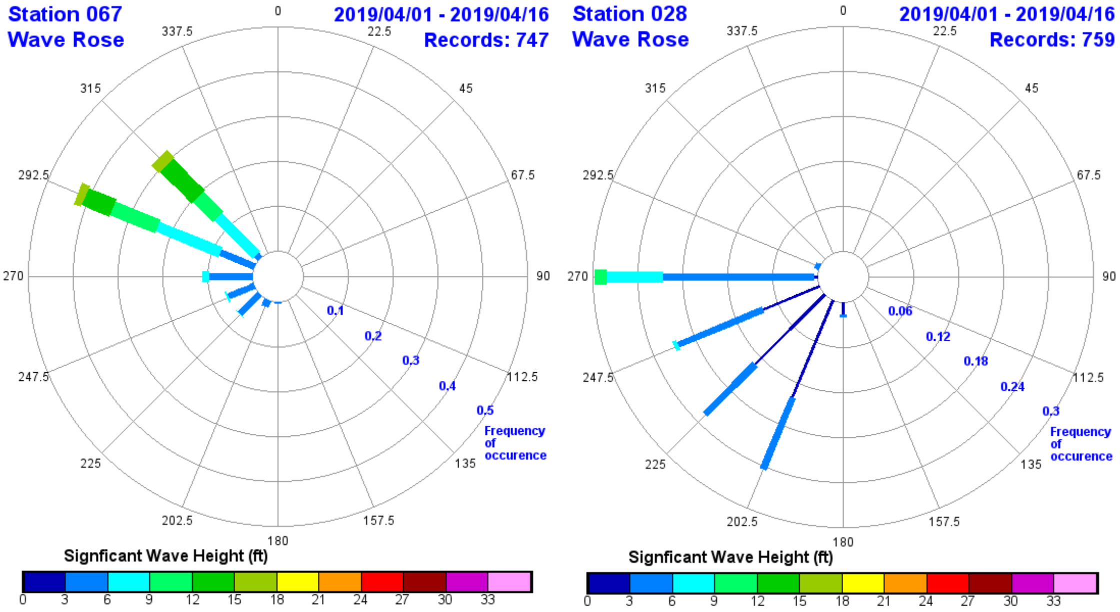


West Basin MWD Ocean Water Desalination Project: Coastal Hazards Analysis / D170766.01

SOURCE: NOAA National Data Buoy Center

Figure 9
Location of Wave Buoys Operated by Scripps in Southern California (Relevant Buoys Highlighted)

Figure 10 presents wave roses for CDIP buoys 067 (offshore) and 028 (nearshore) that describe the wave climate of Southern California in general and the Santa Monica Bay, respectively. The left panel shows the offshore wave conditions with predominant swell direction from the northwest. The largest waves also approach from the northwest directions. Closer to shore in Santa Monica Bay, the right panel indicates that the predominant wave direction shifts to the west and southwest, with the larges waves approaching from the west and west-southwest.



Deep Water

Santa Monica Bay

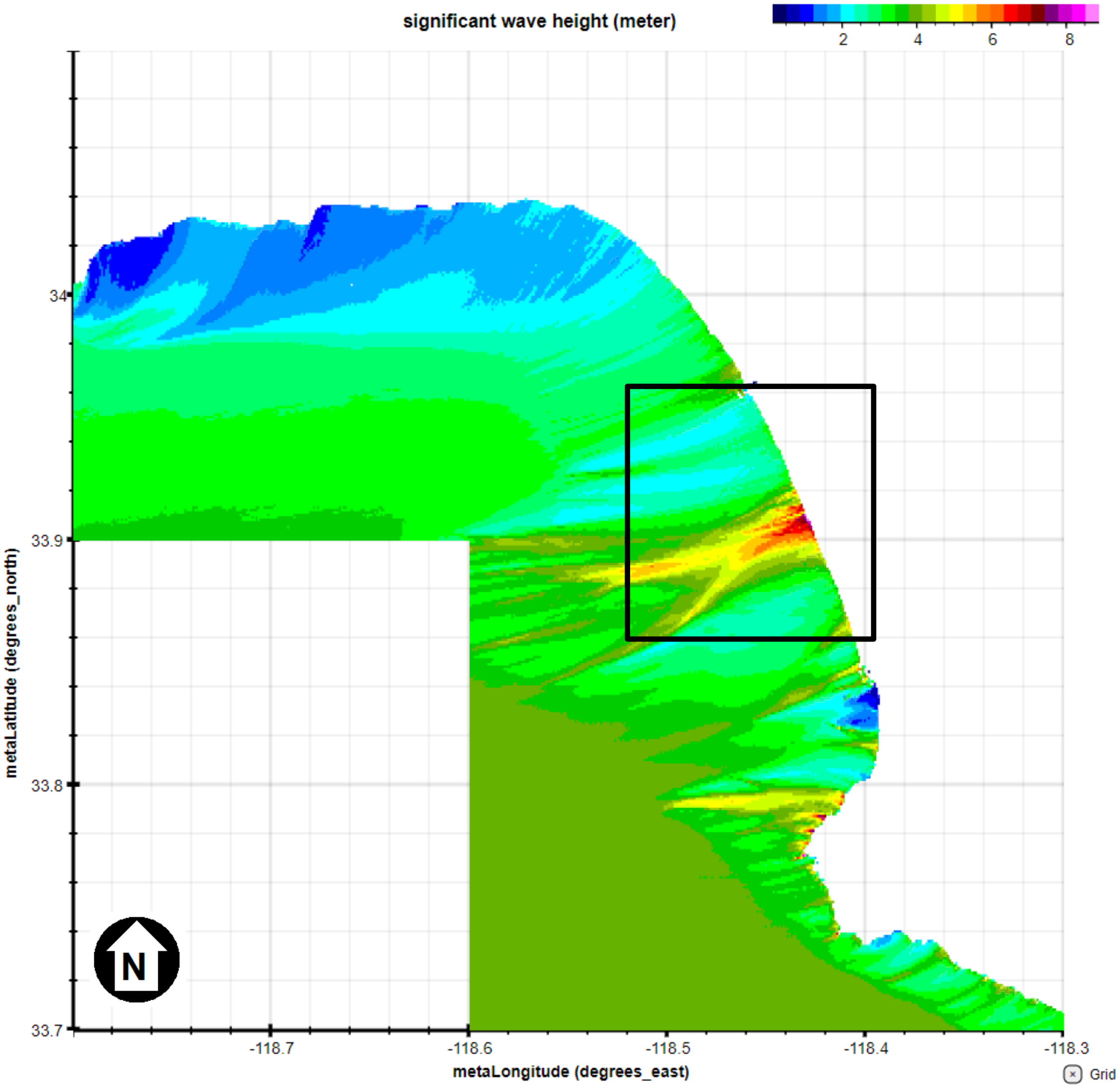
West Basin MWD Ocean Water Desalination Project: Coastal Hazards Analysis / D170766.01

SOURCE: CDIP

Figure 10
Wave Roses for San Nicolas Island (CDIP Sta. 067) and Santa Monica Bay (CDIP Sta. 028)

December 21, 2005 event

Figures 11 presents model output provided by CDIP showing wave heights for a wave event that occurred on December 21, 2005. This swell was a notable due to the very large wave conditions observed offshore of the project site. Deepwater wave conditions (offshore of Channel Islands) shown in Figure 11 were approximately 15 to 18 feet at 18 seconds coming from mean direction of 260-270 degrees. This is based on reviewing data from the Harvest buoy (CDIP 071); the San Nicolas Buoy (CDIP 067) was inactive during this event. Although the Harvest buoy is located offshore of Point Conception, it was assumed to be representative of the open ocean conditions and unrefracted swell. The CDIP model output indicated by the black box shows focusing of wave energy resulting in much greater wave heights near the project site. Figure 12 below presents information for the area in the black box.

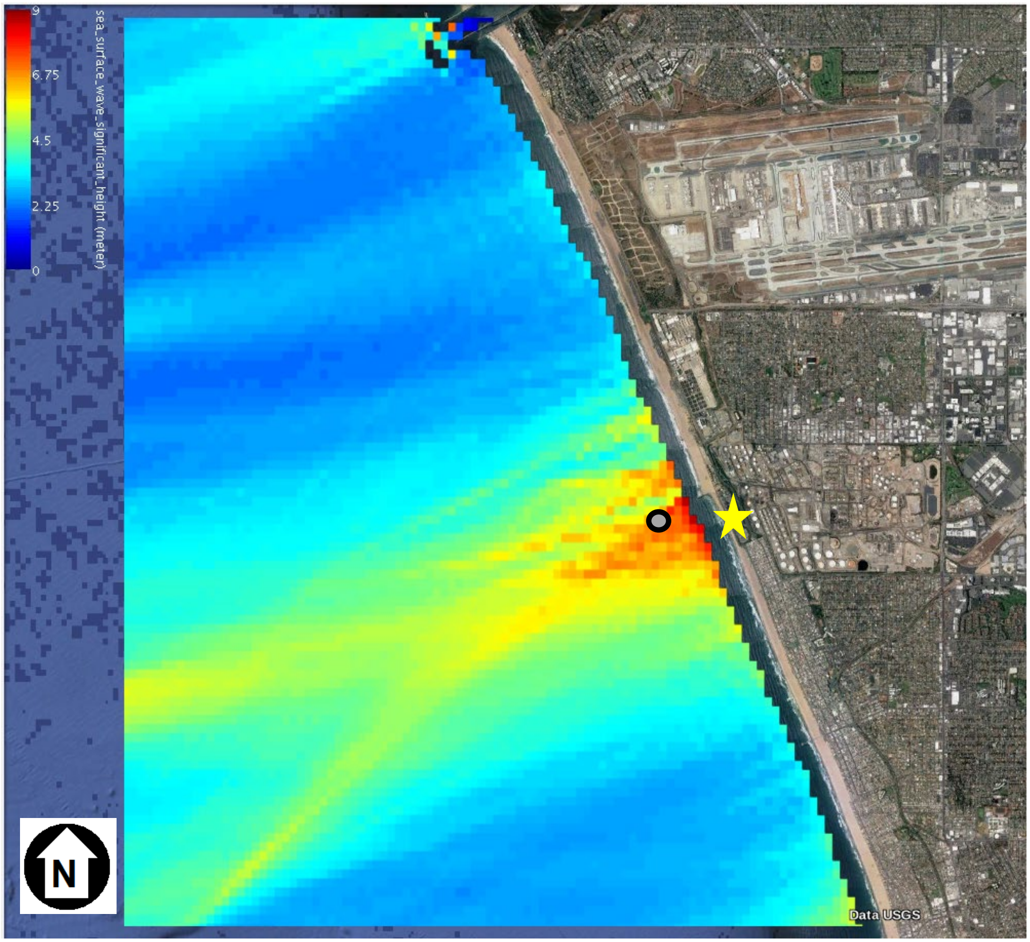


West Basin MWD Ocean Water Desalination Project: Coastal Hazards Analysis / D170766.01

SOURCE: CDIP

Figure 11
Wave height hindcast model output in Santa Monica Bay for December 21, 2005 event

Figure 12 presents a closer view of the wave heights that were modeled for the December 21, 2005 wave event. The star indicates the project site. Note that the wave heights increased from 15 to 18 feet (measured offshore) to almost 30 feet at the nearshore location shown by the red color. SIO staff indicated that since the waves are predicted at the 10-meter isobath, the estimate may be conservatively high if the waves are large enough to break in that location. However, this still indicates how long-period swells from specific directions amplify as they approach the project site.



West Basin MWD Ocean Water Desalination Project: Coastal Hazards Analysis / D170766.01

SOURCE: CDIP
NOTES: The star indicates the project site; the circle indicates approx. location of CDIP MOP L0587

Figure 12
Wave height hindcast model output offshore of project site for December 21, 2005 event

NRG staff described an incident in the 2000s in which a woman was injured when a wave broke over the bike path and knocked her against the wall, but were not able to offer any details. A brief article in the LA Weekly[17] described the surf conditions on this day and refers to a woman who broke her leg after being knocked into a wall by a wave: "Whatever the benchmark, everyone agrees that El Porto in Manhattan Beach is well over 20 feet by noon. A woman there breaks her leg when a wave smacks her against a wall while she's walking along a bike path."

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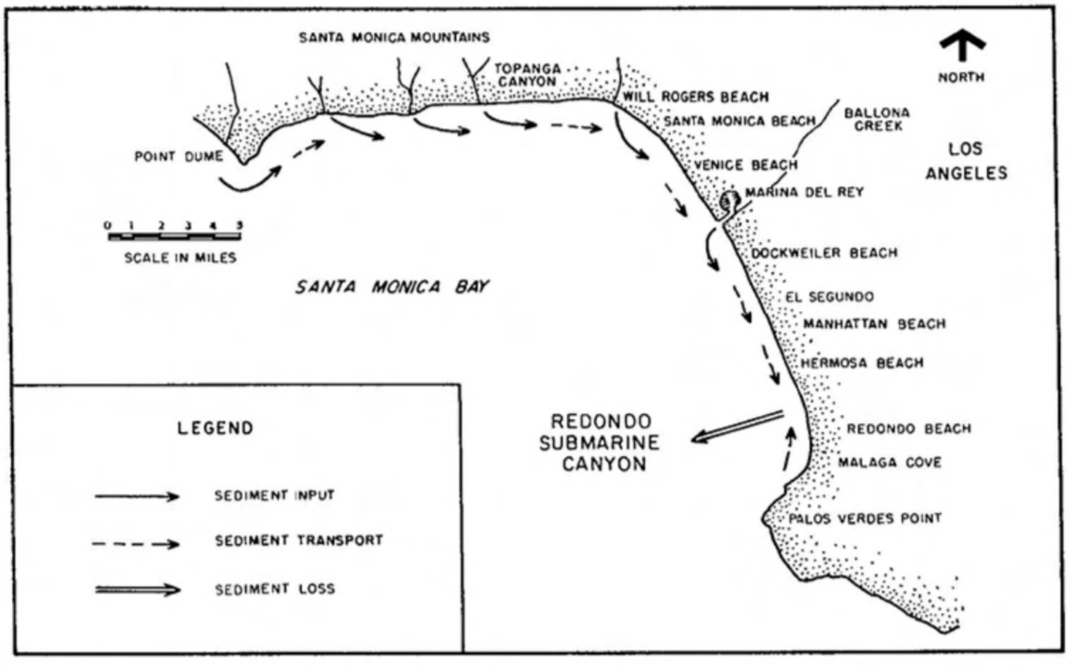
[17] https://www.laweekly.com/news/big-wednesday-2141346

2.2.4 Shore Morphology and Sediment Transport

This section provides an overview of the geomorphic considerations of the Santa Monica Bay shore, including the physical drivers of the sediment transport and the resulting morphology, as well as a succinct history of human interventions and how they have influenced the site conditions.

Overview of Santa Monica Bay Morphology & Sediment Transport

Figure 13 presents a schematic of the Santa Monica Bay littoral cell, for which the historic characteristics of the sediment dynamics have been summarized as lacking a major fluvial sediment source, having relatively high rates of littoral transport, and losing much of the sediment to an active sediment sink at the Redondo Submarine Canyon (Leidersdorf et al. 1994). These factors resulted in narrow beaches that typically ranged from 50 to 150 feet in width prior to human interventions. Fluvial contributions to Santa Monica Bay are limited to Ballona Creek and a number of small streams in the Santa Monica Mountains. The direction of net sediment transport to the east and south results from the predominantly westerly wave climate, but the direction can be reversed during south swells that occur in the summer, and occasionally under other conditions, such as during local storms events with south winds. The Coastal Regional Sediment Management Plan (CRSMP) for Los Angeles County reports an approximate longshore transport rate of 207,000 to 234,000 cubic yards per year along the shore of El Segundo, which is much higher than the general rate of 100,000 cubic yards per year along much of the Santa Monica Bay shore (USACE and CSMW 2012).



West Basin MWD Ocean Water Desalination Project: Coastal Hazards Analysis / D170766.01

SOURCE: Leidersdorf et al. (1994)

Figure 13
Schematic of Sediment Transport Pathways in the Santa Monica Bay Littoral Cell

Effects of Human Interventions and Structures at the Site

The beaches in the central and southern portions of Santa Monica Bay have been altered by human interventions since the late nineteenth century (Leidersdorf et al. 1994). Modifications to the shore include large-scale beach nourishment that artificially fills the beach seaward and construction of coastal structures, such as groins and breakwaters. These actions significantly altered the sediment dynamics of local reaches of shore. These interventions have resulted in widening beaches by hundreds of feet in some areas while causing other areas to erode. Construction of timber, rock and concrete groins have a general effect of widening beaches on the updrift (north) side and inducing erosion on the downdrift (south) side, as the predominant direction of sediment transport is from north to south.

A comprehensive timeline summary of interventions and significant coastal storms in Santa Monica Bay is presented by Leidersdorf et al. (1994). The following descriptions of interventions were selected as most relevant to the project site in El Segundo.

- Construction of the Hyperion sewage treatment facility in 1938 included excavation of over 15 million cubic yards of sand dunes in the project site, which was then placed along six miles of shore from El Segundo to the Santa Monica Pier (USACE and CSMW 2012). The placement occurred in two significant placements: 1.8 million cubic yards of fill were placed on Dockweiler Beach in 1938 and 13.9 million cubic yards of fill were placed along the shore from Venice to Dockweiler Beach from 1946 to 1948 (Leidersdorf et al. 1994). Figure 14 presents an oblique aerial photograph of the project site in 1952 after these major beach fill projects were completed. The image shows that the beach is several hundred feet wide during this period, and that the project site is relatively undeveloped aside from a railroad. Also shown in the image are two coastal structures: the open-pile Standard (Chevron) Oil Pier constructed in 1923, which has since been destroyed, and a 500-foot long groin at the El Segundo-Los Angeles boundary, which is currently buried in sand.

- Approximately 10 million cubic yards of sand were placed along the shore of Dockweiler Beach in the 1960s following the dredging of Marina del Rey (Leidersdorf et al. 1994).

- The El Segundo Generating Station (ESGS), originally constructed in 1954, was expanded and modernized in 1964.[18] Based on review of the aerial image presented in Figure 14 and the Google Earth image presented in Figure 15, it appears that the plant was developed by grading local materials seaward onto the back of the beach in front of the ESGS.

- In 1983, Chevron U.S.A., Inc. constructed a 900-foot long rock and concrete groin at the southern boundary of the El Segundo Refinery, which corresponds to the northern edge of the project site (CCC 1998). This groin is referred to as the El Segundo Marine Terminal (ESMT) groin. A CCC staff report prepared for an experimental surfing reef (CDP #E-98-15) describes the background of the ESMT groin, which was intended to prevent beach erosion and protect the pipelines that run between the offshore marine terminal and the onshore refinery. According to the CRSMP for Los Angeles County, 620,000 cubic yards of sand was dredged from an offshore source and placed on the beach to cover the pipelines that were exposed due to beach erosion that occurred during the 1983 storms. Leidersdorf et al. (1994) notes that 570,000 cubic yards were placed on the updrift (north) side of the structure to "hasten the attainment of a new state of equilibrium," and an additional 50,000 cubic yards were placed on the downdrift

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[18] https://scvhistory.com/scvhistory/sce_history.htm

(south) side to mitigate potential erosion. Emergency repairs to the groin were completed in 1986 following damages by storm waves. Conclusions made from analyzing survey data collected between 1983 and 1992 suggested that the ESMT groin had reduced the rate at which nourishment material was lost from the downdrift beaches, but that the structure deflected the sediment to the offshore region by inducing the formation of rip currents.

- Additional nourishment projects were completed in 1988 and 1989, totaling approximately 1 million cubic yards, but based on available information it is not clear if the sand was placed north or south of the ESMT groin, or on both sides.

West Basin MWD Ocean Water Desalination Project: Coastal Hazards Analysis / D170766.01

SOURCE: USC Libraries Special Collections, "Dick" Whittington Photography Collection, 1924-1987

Figure 14
Aerial View Facing North Over El Porto and Project Site in 1952

The CRSMP for Los Angeles County identifies the beach at El Segundo as a *beach erosion area of concern* (BECA), an erosion hot spot that has chronic problems that require constant attention, and which may benefit from modification of existing sand retention structures or placement of appropriate and approved structures (USACE and CSMW 2012). The CRSMP also recommends additional study to review the conditions to refine recommendations on appropriate strategies to address the localized high wave energy environment.

West Basin MWD Ocean Water Desalination Project: Coastal Hazards Analysis / D170766.01

SOURCE: Google Earth

Figure 15
Google Earth Oblique Aerial of the Project Site Shows that the ESGS was Developed Seaward from the Original Shoreline

2.2.5 Historic Storms and Documented Impacts

Coastal damages and impacts along the shore of Santa Monica Bay are typically a result of winter storms that include large waves and high water levels, although damages have also been caused by tropical storms (Walker et al. 1984; Flick 1998). The largest wave events in Southern California are strongly associated with the occurrence of an El Niño winter, which also result in sustained periods of elevated water levels through the winter (Seymour et al. 1984). Although nourishment has artificially widened the beaches of Santa Monica Bay, providing some level of protection to development, regional storm wave events caused erosion to beaches, damages to coastal structures, and flooding and damage to some of the seaward-most developed areas along the shore (Leidersdorf et al. 1994). Leidersdorf et al. (1994) included notable coastal storms in a timeline of the history of significant events for the beaches of Santa Monica Bay.

The storms of January 1983 are considered to be one of the most damaging events to impact the California coast on record (Flick 1998). The concurrent timing of peak high tides, effects of El Niño, storm surge, and large, long-period waves resulted in widespread flooding and erosion to the shores of Southern California. Figure 16 presents a set of photographs taken of the project study area and its vicinity shortly after the January 1983 storms. The top two photographs show rock and rubble strewn across the bike trail immediately seaward of the ESGS site, and sections of the bike trail collapsed onto the beach due to erosion of the fill. The images imply that a significant amount of wave action impacted the development and overtopped the bike trail into the project site. The middle two photographs provide context of the amount of beach erosion that occurred during the storm, where a vertical scarp on the order of six to ten feet was created along the back edge of the beach.

West Basin MWD Ocean Water Desalination Project: Coastal Hazards Analysis / D170766.01

SOURCE: Photographs by Brian McStotts, accessed online: https://forum.surfer.com/forum/ubbthreads.php?ubb=showflat&Number=2028706&page=2

Figure 16
Photographs Showing Erosion and Storm Damage at the Project Site in January 1983

The relatively warmer surface waters off California that occur during a strong El Niño could allow tropical cyclones (e.g., hurricanes) to move north in late summer and early fall to areas that would typically be unconducive to tropical systems (Seymour et al. 1984). Nine hurricanes made landfall in California during the period from 1900 to 1983, and five of the nine occurred at the onset of a strong El Niño – one of which was the storm of September 25, 1939, named the Great

1939 Long Beach Tropical Storm, or El Cordonazo. The September 1939 tropical storm is the only one to make landfall in California in the twentieth century (Chenoweth and Landsea 2004). The storm significantly damaged south-facing portions of the Los Angeles region, particularly Long Beach and its vicinity. The storm included a record amount of rainfall in Los Angeles, causing significant flooding. As part of a hindcast on extreme wave events, the significant wave heights were estimated to be about 27 feet with a period of 14 seconds and a direction of 205 degrees (Walker et al. 1984). The Palos Verdes headland likely sheltered much of Santa Monica Bay from the southerly direction of the waves.

A hurricane impacted San Diego and the coast north to Long Beach on October 2, 1858 (Chenoweth and Landsea 2004). Wind speeds on the order of 70 knots were estimated, which implies a category-1 hurricane, consistent with the types and extents of damages that occurred. Although reports on damages did not explicitly mention surge, ships were driven ashore, implying that the coast likely experienced large waves and flooding. Compared to the 1939 tropical storm, the potential damages from the 1858 hurricane were much greater and affected a larger area. Chenoweth and Landsea (2004) estimated that if a similar storm were to hit today, the damages could be on the order of several hundred million dollars.

2.3 Climate Change and Sea-Level Rise

This section presents a brief discussion on climate change and its effects on storm tracks, followed by a description of the sea-level rise scenarios that were selected for this study, and used in the technical analysis presented in Section 3.

2.3.1 Climate Change and Storm Tracks

Although climate change is expected to have significant effects on sea-level rise and global circulation patterns, its direct implications on individual storm tracks and wave energy affecting California is less understood. As summarized above, both extratropical and tropical storm events have historically impacted Southern California. There is some indication that climate change may increase the intensity of storms, but implications on the storm tracks are not clear. Modeling of projected storms and waves in the North Pacific that leverages output of the global circulation models show small or no increase in projected storm surge and wave activity through 2100 along the California coast (Bromirski et al. 2012; Erikson et al. 2015). Although the magnitude of changes in surges and waves appear to be limited, sea-level rise will greatly increase the damages to the coasts during extreme storms (Cayan et al. 2008).

2.3.2 Sea-Level Rise Scenarios

Background and Guidance Documents

Projections of global sea-level rise are well-documented and investigated, with recent research projecting sea-level rise on the order of 2 to 10 feet by 2100 in California (e.g., Cayan et al. 2008; Griggs et al. 2017). This research has been used to develop a series of policy guidance documents by the State of California that have recommended including specific amounts of sea-level rise in project planning and design, the most recent being the California Ocean Protection Council's (OPC) *State of California Sea-Level Rise Guidance* (OPC 2018). The OPC (2018) Guidance includes tables of projected relative sea-level rise at well-established tide gauges located along the coast of California through 2150 for a range of risk aversion scenarios, including low, medium-high, and extreme (e.g., H++). These projections were developed and summarized with the intention that local planning and design efforts would have a consistent and accepted basis for addressing future sea-level rise. Additional information on the sea-level rise policy and projections is located in Appendix A.

Technical methods and guidance for using the OPC (2018) projections in a coastal hazards analysis as part of the Coastal Development Permit application process are included in the *Sea-Level Rise Policy Guidance* developed by the California Coastal Commission (CCC), which was recently updated in 2018 (CCC 2018). The CCC (2018) Guidance provides a basis for selecting the time horizon and the risk level of the project, which are used to define the appropriate sea-level rise amounts, and recommends technical topics to be assessed, such as projected coastal flooding, wave runup, and coastal erosion associated with sea-level rise. Many of the analysis methods used to address the technical questions are described in the *FEMA Coastal Flood Hazard Analysis and Mapping for the Pacific Coast of the United States* (FEMA 2005). The work completed by ESA complies with state and federal guidance, and is considered as the industry standard.

Selected Scenarios

Five sea-level rise scenarios were developed for the study (Table 3). The sea-level rise scenarios are based on the OPC (2018) projections for the Santa Monica tide gauge. These scenarios were selected to relate site improvements, expected design life of structures, and adaptation phasing to a range of sea-level rise values and time horizons. The extreme risk aversion projection of sea-level rise, which the state has required for analyzing critical infrastructure, and the medium-high risk aversion projection were used to bookend the possible timing of a given amount of sea-level rise. For a given time horizon, the earlier year is consistent with extreme risk aversion scenario (more rapid sea-level rise) and the later year is based on the medium-high risk aversion scenario.

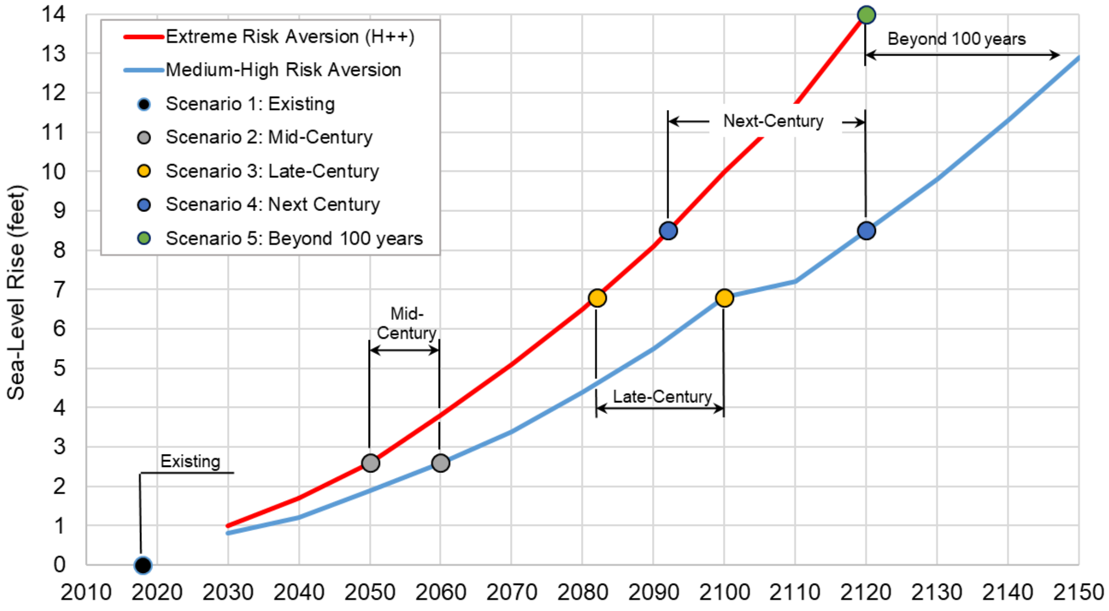
TABLE 3
SEA-LEVEL RISE SCENARIOS USED IN WAVE RUNUP ANALYSIS

Scenario	Existing	Mid-Century	Late-Century	Next-Century	Beyond 100 Years
Time Horizon	2019	2050 – 2060	2082 – 2100	2092 – 2120	2120+
Sea-Level Rise (feet)	0	2.6	6.8	8.5	14

Figure 17 presents the five selected sea-level rise scenarios graphically with the State's projections over time. The red curve represents the extreme risk aversion (i.e., for projects with low risk tolerance) projection of sea-level rise, which the state has required for analyzing critical infrastructure. The extreme risk aversion (also called "H++") is considered a "stand alone" worst-case scenario of unknown probability of occurrence: The probability cannot be estimated with confidence because the process driving the rapid sea-level rise (i.e., catastrophic collapse of land-based ice sheets into the ocean) is not well understood. The blue line represents sea-level rise projections for a medium-high risk aversion, which represents a low likelihood of occurrence within the associated timeframe, and provides a precautionary projection that should be used for less adaptive, vulnerable projects that will experience medium to high consequences as a result of underestimating sea-level rise, such as a coastal housing development (OPC 2018). The probability of sea-level rise exceeding the medium-high risk aversion projection is 0.005, or about 1 in 200 (OPC 2018).

The medium-high risk aversion should be used as a comparison to the extreme projection. Although tide gauge measurements on the west coast of the United States show zero or low rates of relative sea-level change since 1980 while sea-level rise is accelerating in other regions of the Pacific basin, factors associated with the Pacific Decadal Oscillation (PDO)[19] may be indicative of a regime shift that will cause a resumption to global rates or higher (Bromirski et al. 2012).

The *mid-century*, *late-century*, *next-century* and *beyond 100-years* time frames are selected to conform with planning and design time frames. The time frames relate to the project's expected life, as discussed in the next section. The range of sea-level rise for each time frame is provided to inform selection of design criteria and development of options to adapt to higher sea levels.



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SOURCE: OPC (2018)

Figure 17
Sea-Level Rise Scenarios for the Project are Based on the OPC (2018) Projections

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[19] The "Pacific Decadal Oscillation" (PDO) is a long-lived El Niño-like pattern of Pacific climate variability.

Expected Life of the Proposed Project

The project will have a design life of 30 to 40 years, which may be extended to a 50- to 100-year timeframe with future capital improvements and replacement and rehabilitation (R&R). Therefore, a **100-year study period** is selected based on the likely occupation of the site between 50 and 100 years. The time horizons used in the study were defined to approximately align with the expected timeframes of capital improvements, likely occurring in mid-century (approximately 2050-2060), late-century (approximately 2080-2100), or even later. The results of this study can be used to identify when adaptation actions would be triggered by considering “tipping points” of sea-level rise hazards at the site. Tipping points are those points in time and sea-level that result in serious consequences, requiring adaptive action (CCC 2018). Tipping points and triggers should be developed as part of the project design and related planning for adaptation to future sea-level rise.

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3 TECHNICAL ANALYSIS OF COASTAL HAZARDS

The technical analysis methods and results for the coastal hazards study are presented below. The following sections present:

- An overview of the technical approach that provides context of the parameters and methods,
- A brief description of the still water level analysis used to estimate extreme still water level as a function of recurrence,
- The approach to constructing a composite series of annual maximum wave and water level events to be applied to the wave runup analysis, including wave transformation and compilation of multiple data sources
- The analysis used to construct the nearshore profiles for existing and future conditions with sea-level rise
- The wave runup analysis, including a summary of method used and the results of the potential maximum wave runup and the landward extents calculations for existing and future conditions with sea-level rise
- A brief description of available information on tsunami hazards and approximate implications of sea-level rise on the hazards

3.1 Overview of Technical Approach

The technical approach applied to this study is based on guidance established by the USACE (1984; 2003) and FEMA (2005), and as recommended by the CCC (2018) for assessing the coastal hazards as part of the CDP application process. Estimating the extreme wave runup heights and landward extents at a specific site requires information on the tidal water elevations and storm surge, wave height and period offshore of the project site, and the shape of the shore, including the elevations through the nearshore, the surf zone, the beach, and the developed backshore.

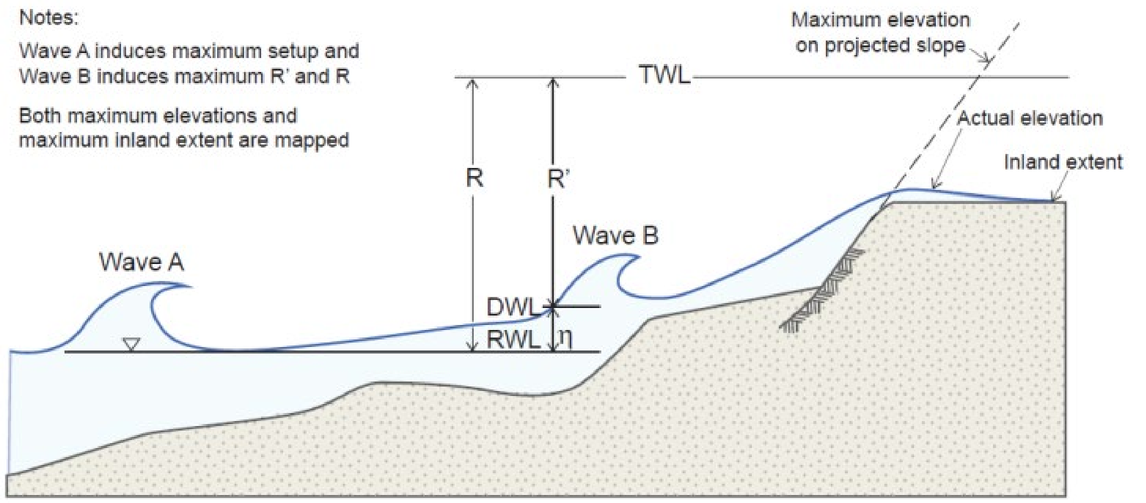
Figure 18 presents a definition sketch of the wave runup parameters from the *Technical Methods Manual (TMM) for Relating Future Coastal Conditions to Existing FEMA Flood Hazard Maps* prepared for the California Department of Water Resources and the California Ocean Science Trust (Battalio et al. 2016). The sketch illustrates the concepts that are used to determine the greatest wave runup hazards at a project site, consistent with the FEMA (2005) guidance:

1. Wave A represents the offshore wave conditions, which induces the maximum wave setup (i.e., a super-elevation of the water surface across the surf zone) that increases the depths above the reference water level (RWL). The RWL is similar to the still water level (SWL) that is often used in the literature to refer to the water level not affected by the incoming waves.

2. The relatively deeper water in the surf zone, referred to as the dynamic water level (DWL), allows depth-limited waves (Wave B) to propagate closer to shore.

3. Wave B breaks in the surf zone and induces the maximum runup on a projected backshore slope, shown as the dashed line. The potential maximum runup elevation, also called the total water level (TWL), is used to define the FEMA BFE. In subsequent discussion and figures, this potential elevation is also called *potential TWL*.

4. The actual wave runup (if greater than the backshore elevations) will overtop the barrier and rush landward to a location of maximum inland extent. This is another parameter that is mapped as a hazard zone by FEMA. In subsequent discussion and figures, this is called the *inland extent*.



TWL = Total water level = RWL + R

RWL = Reference water level ~ still water level

DWL = Dynamic water level, typicallly 2% exceedence ~ mean setup (aka "static") + 2x standard deviation

η = 2% setup at RWL shoreline, wave A

R = runup, including setup, above RWL, wave B typically on projected slope above back shore

R' = runup from wave B

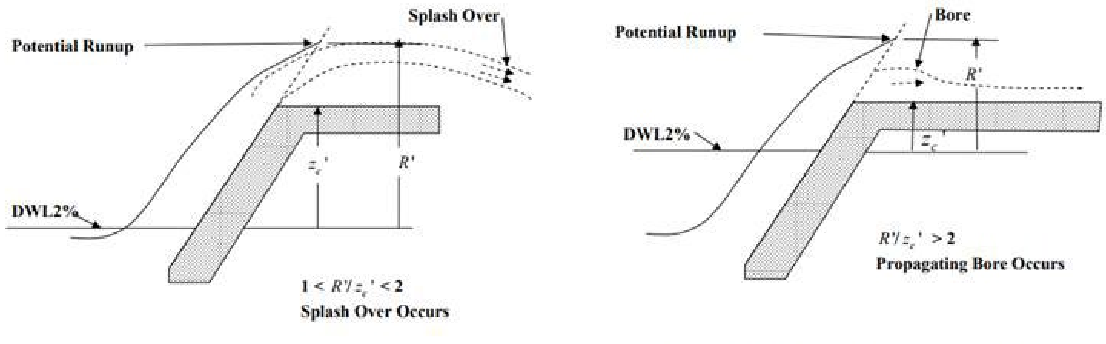
West Basin MWD Ocean Water Desalination Project: Coastal Hazards Analysis / D170766.01

SOURCE: Battalio et al. (2016)
NOTES: Maximum elevation on the projected slope is described as the potential maximum runup in this analysis

Figure 18
Definition Sketch of Wave Runup Parameters

The use of the two measures of wave runup extent, called here potential TWL and inland extent, is beneficial to inform flood plain management, planning and design. The *potential TWL* is indicative of how high a living or working space would need to be in order to avoid injury, presuming that fill or other obstruction may be located in the vicinity and cause the runup to extend higher. The *inland extent* is the landward limit of wave runup, thus defining the coastal flood plain. The height and extent of runup depends on the shore profile, which often changes with development. Providing the potential TWL and inland extent provide the potential vertical and horizontal dimensions of the wave runup hazard, where anything located within the space defined by these two dimensions may be subject to damage or injury during the flood event.

Figure 19 presents a sketch of the parameters of wave overtopping at a barrier from FEMA (2005), which are used in the computation of the landward extents of the wave runup. For this study, most of the overtopping conditions comprised bore overtopping (panel on right). The schematic illustrates how the bore elevation relates to the potential maximum wave runup.



a) Conditions for Splash Overtopping

b) Conditions for Bore Propagation Overtopping

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SOURCE: FEMA (2005)
NOTES: Potential runup is described as the potential maximum runup in this analysis. Potential runup is typically defined as the height above the reference water level, and corresponds to the potential TWL when the elevation of the reference water level is added

Figure 19
Definition Sketch of Wave Runup and Overtopping Parameters at Barrier

3.2 Still Water Level Analysis

A still water level analysis was completed to determine the extreme values of still water level as a function of return period. An extreme value analysis was conducted on the annual maximum water level data as recorded by the Santa Monica tide gauge. Figure 20 presents the annual maximum data (based on a water year spanning October 1 to September 30 of the following year) and several extreme value distributions that were fit to the data. The Gumbel Maximum Likelihood extreme value distribution was selected as the most-representative of the data, and compares well with similar analyses completed by NOAA and FEMA (2015).

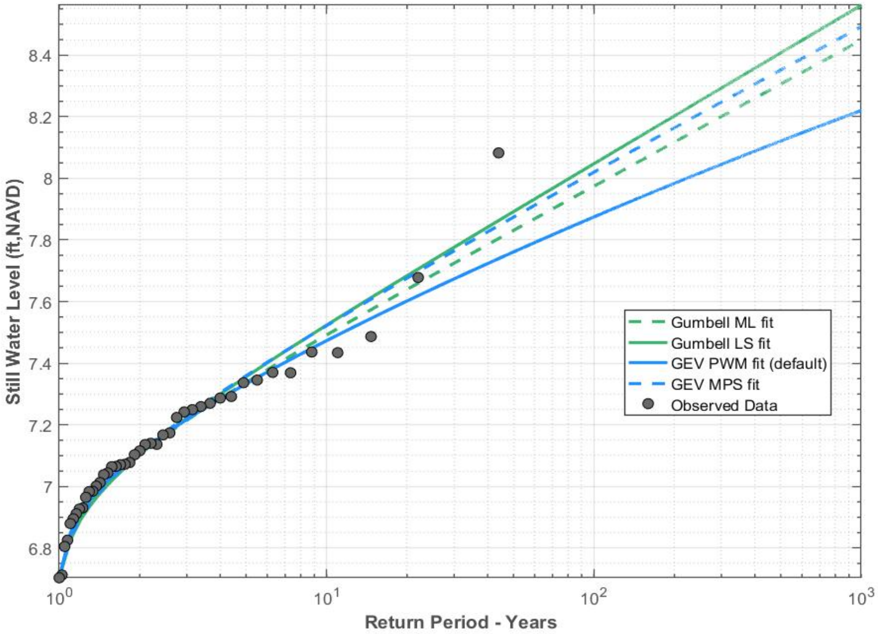

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Figure 20
Extreme Value Distributions fit to Annual Maximum Tide Data from Santa Monica Tide Gauge

Table 4 presents the tabulated values of the still water level as a function of return period or annual percent exceedance. The estimated values agree with a similar analysis by NOAA and have negligible differences with the FEMA tide frequency analysis (FEMA 2015).

TABLE 4
EXTREME STILL WATER LEVEL RESULTS FOR SANTA MONICA TIDE GAUGE (TABLE 2 REPEATED)

Return Period (years)	X-Percent Annual Exceedance (%)	Still Water Level (feet NAVD)[a]
500	0.2	8.4
100	1	8.0
50	2	7.9
20	5	7.7
10	10	7.5
5	20	7.4
2	50	7.1

NOTES:
[a] Gumbel Maximum Likelihood Fit

The wave runup analysis sought to use still water levels that were coincident with the extreme wave events. This was largely accomplished for the events from 1960 through 2017 for which tide measurements were available. For historical events, a high tide elevation corresponding to the date or month of the reported wave conditions was used, which may underrepresent the hazard for the historical conditions.

3.3 Wave Data Transformation & Compilation

The following sections summarize the sources of wave data, how that data was transformed to the project site, and how annual maximum wave events were selected for the analysis in Section 3.5.

3.3.1 CDIP Transformed Time Series

Nearshore wave characteristics, including the significant wave height, H_s, and peak wave period, T_p, were furnished by the Coastal Data Information Program (CDIP), Integrative Oceanography Division, operated by the Scripps Institution of Oceanography (SIO). Hourly wave height and period data were downloaded from the CDIP Monitoring and Prediction (MOP) System for station L0587, located immediately offshore of the project site at a water depth of 10 meters (see Figure 12). The MOP data is based on detailed spectral wave modeling and field data collection programs that have been developed into an efficient real-time conversion of offshore conditions to nearshore at virtual MOPs located up and down the coast (O'Reilly et al. 2016).

Figure 21 presents time series of the wave height and period near the project site from 2000 to 2017, as well as water levels and calculated parameters. The top panel shows the offshore and nearshore transformed wave height data, illustrating the variability introduced by the offshore wave period and direction due to refraction and other phenomena such as shadowing by the Channel Islands. The second panel shows the time series of peak wave period, which ranges from about five to 23 seconds. The third panel shows a time series of the wave runup height for the project site using an empirical equation developed for natural, gently sloping beaches (Stockdon et al. 2006), which typically resulted in wave runup heights of about five to over 15 feet. The fourth panel shows a time series of the still water level (SWL) measured at the Santa Monica tide gauge (NOAA NOS Station 9410840). The fifth and bottom panel shows a time series of the potential total water level (TWL), which represents the elevation of wave uprush.

The TWL shown in Figure 21 was calculated as the sum of the Stockdon wave runup and the coincident still water level. Because the Stockdon wave runup equation is intended for natural and gently sloping beaches, its results presented in Figure 21 are not within the range of the validity for conditions at the project site, including the relatively steep foreshore and nearshore morphology, narrow beach, and hardened backshore. However, the time series of TWL using the Stockdon wave runup was used to identify annual maximum[20] wave events and water level conditions to be used in the detailed wave runup analysis presented in Section 3.5. Note that the Stockdon wave runup method resulted in a maximum TWL of about 20 feet NAVD for the December 5, 2007 wave event.

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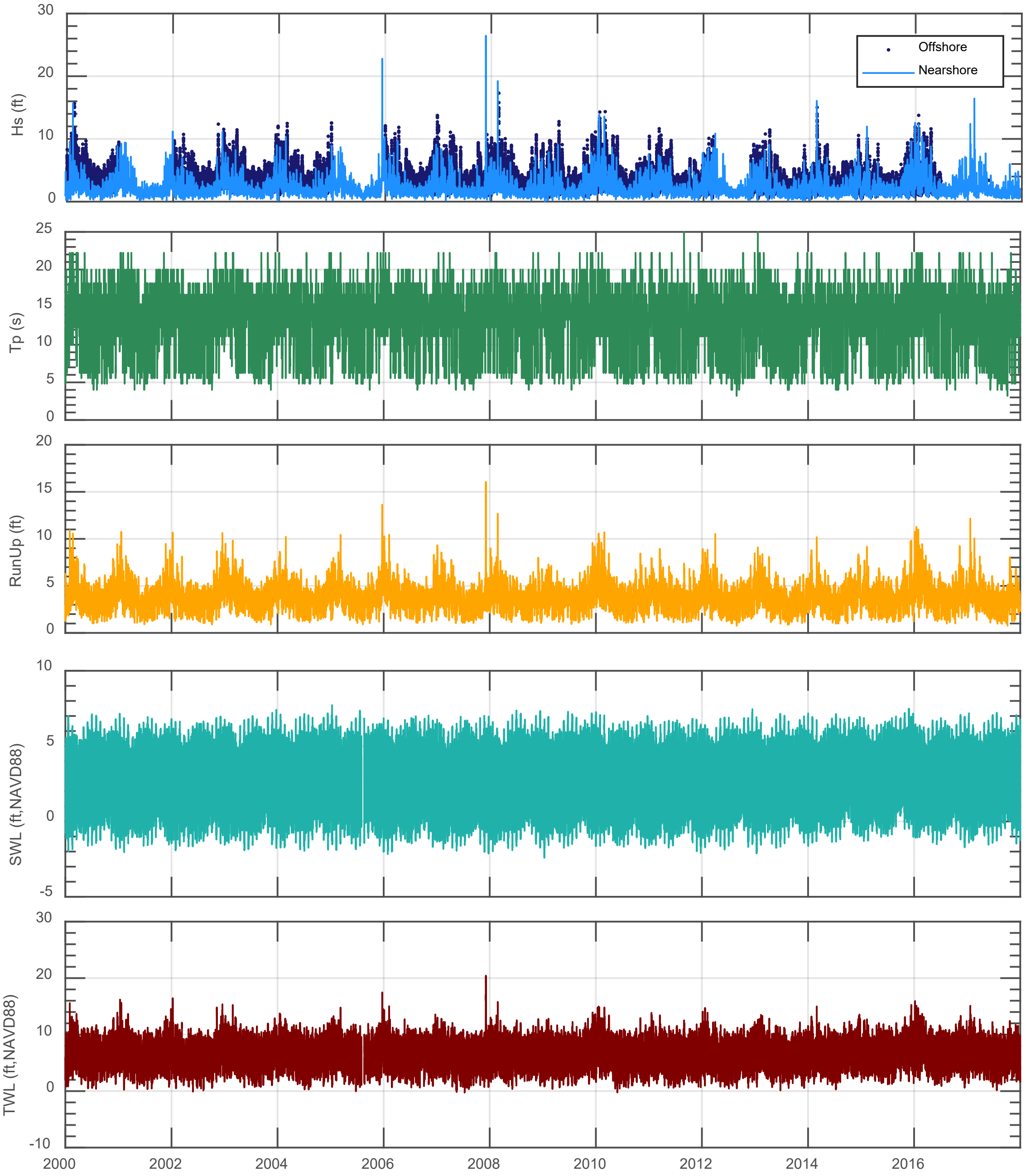
[20] Annual maximum in this report uses the water year, defined as the period from October 1 of one year to September 30 of the following year, and designated by the calendar year in which it ends.



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SOURCE: CDIP MOP L0587; NOAA NOS Sta. 9410840

NOTES: Runup computed using Stockdon et al. (2006)

Figure 21

Hourly Coincident Wave Height (H_s), Period (T_p), Runup, Still Water Level (SWL), and Total Water Level (TWL) between Year 2000 and 2017

3.3.2 Historical Hindcast Data

To extend the nearshore record of annual maximum events, a record of the maximum historical events in Southern California dating from 1904 to 1983 were reviewed, transformed from deepwater to the project site, and selected for use in the wave runup analysis.

Review of Hindcast Data

Wave hindcasts refer to the predictions of wave conditions for a past event, and are typically conducted by modeling historical observed wind conditions over a known location. The hindcast data compiled by Walker et al. (1984) were originally intended to update the standard coastal design criteria for Southern California after the damaging storms of 1983. The study found that the design wave height for a given recurrence interval had significantly increased, wave periods were much longer than previously considered, and the extreme wave conditions typically coincided with extreme water levels. The study included tables of the wave height, period, and direction for the most extreme storms that occurred in the 20th Century through 1983. These bulk parameters (i.e., significant wave height, period and direction) are representative of the deepwater conditions that affect the extents of Southern California, but not the conditions incident to specific reaches of shore. The wave period and direction have very significant effects on the wave conditions at a specific location on the shore of Southern California: longer wave periods tend to focus wave energy through underwater canyons and bathymetric-related effects by wave refraction, and some swell directions can be blocked by the Channel Islands. Therefore, to use the hindcast data in the wave runup analysis, the offshore conditions need to be transformed to the project site.

Transformation of Hindcast Data to Nearshore

The following process was used to transform the offshore bulk wave parameters to nearshore conditions offshore of the project site:

1. A wave energy frequency spectrum $S(f)$ was developed for the offshore wave height and period using the JONSWAP spectrum, as presented by Goda (1985) and shown by the equation

$$S(f) = \alpha H_{1/3}^{2} T_p^{-4} f^{-5} \exp\left[-1.25\left(T_p f\right)^{-4}\right] \gamma^{\exp\left[-\left(T_p f-1\right)^2/2\sigma^2\right]}, \qquad (1)$$

   where $S(f)$ is the spectral density as a function of frequency f, $H_{1/3}$ is the wave height that is the average of the highest of 1/3 of all waves (similar to the significant wave height, H_s), T_p is the peak wave period, γ is the peak enhancement factor, which controls the sharpness of the spectral peak, α is a function of the peak enhancement factor, and σ is a constant related to the peak frequency. The peak of the spectrum is typically narrower for swell than for storm seas (Goda 1985). A value of 8 was selected for the peak enhancement factor, resulting in a relatively sharp peak representative of well-developed swell. When additional information on seas (e.g., wind waves) was available, a second frequency spectrum was developed for the sea state using a value of 3.3 for the peak enhancement factor.

2. A directional wave spectrum was developed for the offshore swell conditions using a cosine-squared directional distribution presented by Goda (1985), and yielding a matrix of wave energy values as a function of frequency and direction in the form

$$S(f,\theta) = S(f)G(f,\theta), \tag{2}$$

   where $S(f,\theta)$ is the directional wave spectral density function, θ is the azimuth measured counterclockwise from the principal wave direction, and $G(f,\theta)$ is the directional distribution. A Mitsuyasu-type directional spreading function was used, shown by the equation

$$G(f;\theta) = G_0 \cos^{2s}\left(\frac{\theta}{2}\right), \tag{3}$$

   where G_0 is a constant, and s is a spreading parameter that relates the degree of energy spreading to the peak frequency (Goda 1985). The directional spread of storm seas is greater than the directional spread in swell (Goda 1985). This is because waves "self-organize" and become more coherent after propagating away from the high-wind generation zone, resulting in less energy spread across frequencies and direction. A value of 50 was selected for the spreading parameter to represent swell and a narrow direction spread. For the cases where sea state is included, a separate directional wave spectrum was developed using a value of 10 for the spreading parameter which results in a broader directional distribution appropriate for seas.

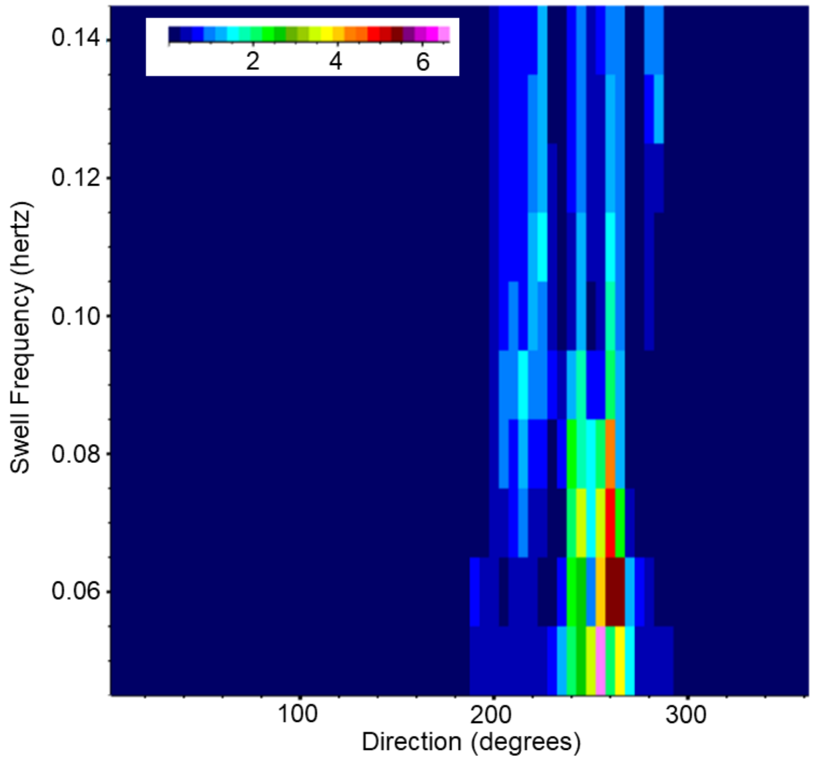
3. The nearshore spectral energy was computed by multiplying each offshore spectral energy value by its corresponding transformation coefficient and summing over all directions and frequencies, as shown by the equation

$$\hat{S} = \int_{f_{min}}^{f_{max}} \int_{-\pi}^{\pi} S(f,\theta)e_t(f,\theta)d\theta df, \tag{4}$$

   where $\hat{S}$ is the total nearshore spectral energy and $e_t(f,\theta)$ is the matrix of transformation coefficients as a function of frequency and direction. Transformation coefficients for the CDIP MOP System site location L0587, immediately offshore of the project site in water depth of 10 meters, were used for this analysis (Figure 22). For the cases where seas are included, the additional directional wave spectrum was transformed using the transformation coefficients for seas.

4. The nearshore transformed significant wave height, H_s, was computed as approximately four times the square root of the integrated directional wave spectrum and assumed that the wave height followed a Rayleigh distribution (Goda 1985). The peak period was selected as the frequency band with the greatest sum of energy over all directions. If information on seas was also included, the resulting H_s for swell and seas was combined using the Euclidean norm, or the root of sum of squares.

This transformation method summarized above was tested using other wave events from the current MOP record (2000-2018), which showed that it accurately converted offshore bulk wave parameters to nearshore wave characteristics. Some of the observed differences were attributed to local sea conditions, but the simplifying assumptions used to develop the frequency spectra and directional spreading are likely to contribute to the errors.



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SOURCE: CDIP MOP L0587
NOTES: Only wave refraction is included; A coefficient greater than 1.0 indicates wave amplification; 1.0 indicates no net refraction effect; values between 0 and 1.0 indicate reduction or no exposure; Direction refers to direction of offshore waves.

Figure 22
Wave Transformation Coefficients as a Function of Swell Frequency and Direction for Project Site

Selection of Hindcast Data

Annual maximum wave events occurring between 1904 and 1959 were selected from the transformed hindcast data. These data were selected as the maximum events over the first part of the twentieth century, and so they likely do not include more frequent wave events (such as 1- to 10-year recurrence). Although this data set included many more years from 1960 to 1983, a more recent wave hindcast completed by FEMA was used for this timeframe, which is described below.

3.3.3 FEMA Events from Coastal Flood Study

As part of FEMA's *Open Pacific Coast Flood Study*, a 50-year hourly offshore wave hindcast was developed for the period from 1960 to 2009 (FEMA 2015). The offshore wave hindcast was completed by modeling deepwater wave generation resulting from historic storms and wind fields over the Pacific Ocean. The deepwater wave conditions were transformed to nearshore using the SIO CDIP transformation coefficients described in Section 3.3.2 above. FEMA (2015) presents the annual maximum wave events at each location where wave runup is computed. Although runup was computed along a transect at the project site (Transect 67), the annual maximum wave event data is not provided. Therefore, we selected annual maximum wave event data from the adjacent transect located to the north (Transect 66) for the period from 1960 to 1999. Differences in wave characteristics between Transect 66 and Transect 67 are assumed to be negligible.

3.3.4 Compilation of Annual Maximum Data

Annual maximum event data were compiled and normalized so that all wave height and period data to be used in calculations was in the form of the unrefracted deepwater wave height and period. To accomplish this, the wave height-period events were deshoaled using a two-step process. The first step is completed by computing the wave length of each wave event at the 10-meter (32.8 feet) depth contour using the dispersion relation, shown by the equation

$$L = \frac{gT^2}{2\pi} \tanh\left(\frac{2\pi h}{L}\right) \tag{5}$$

where L is the wave length in feet, T is the wave period in seconds, h is the water depth in feet, and g is the acceleration of gravity assumed to be 32.2 feet per second squared. The second step is to deshoal the waves and obtain the unrefracted deepwater wave height, H_0', using the equation

$$H_0' = H\sqrt{\left[1 + \frac{4\pi h/L}{\sinh(4\pi h/L)}\right] \tanh\left(\frac{2\pi h}{L}\right)} \tag{6}$$

where H is the shoaled wave height in feet. The ratio H/H_0' is known as the shoaling coefficient, K_S (Goda 1985).

These steps are critical to the analysis because the wave runup methods and their components require using the unrefracted deepwater wave height to correct for potential overestimated wave heights for extreme events at the 10-meter depth contour using CDIP's transformation coefficients. Appendix B presents tabulated values of the deshoaled wave height, wave period, and coincident still water level for each annual maximum event used in the wave runup analysis.

3.4 Nearshore Profiles

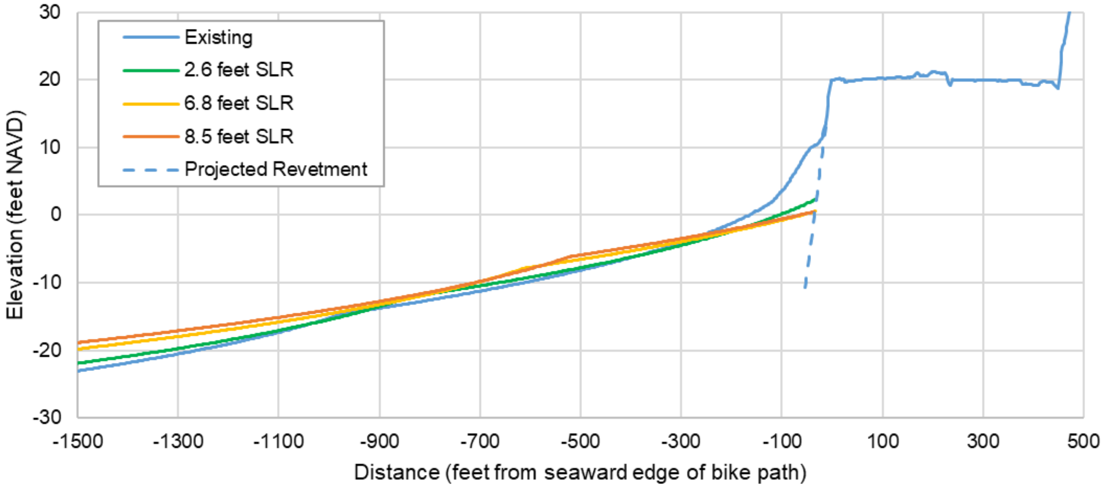
As shown in Figure 3 (Section 2.1.2), six elevation transects were constructed from offshore waters, across the surf zone, the beach, and the project site. Based on preliminary results that showed similar runup values and extents for adjacent transects, the number of transects was reduced to three. The nearshore profiles were constructed using three sets of data:

- LiDAR from 2016 represented the beach and uplands elevation (USGS 2018), which was assumed to be representative of a winter beach condition
- Nearshore survey conducted in 1962 that is shown on the design drawings for the tunnel intake/outfall structures for the ESGS upgrades (Southern California Edison Company 1964)
- Offshore bathymetry is from the Coastal California TopoBathy Merged Project (OCM Partners 2014).

Based on review of the 1962 nearshore survey, adjustment of elevations in the downdrift shadow of the ESMT groin (south of the groin) were made to reflect field observations by ESA in October 2018 and conclusions by Leidersdorf et al. (1994) that indicate the bed elevations in the surf zone establish a low-tide platform. During field observations, surfers were observed to be walking out toward the surf on the south side of the ESMT groin, and waves were peeling around the sand bar.

Profiles for the future conditions were computed using a Bruun-type transgression to account for the geomorphic response of the shore to sea-level rise. This approach assumes that the shore transgresses (i.e., raises vertically and shifts horizontally toward shore) as a function of the amount of sea-level rise and the slope of the profile from the depth of closure to the back-beach elevation. For this study, the depth of closure is defined as the most landward depth at which no significant change of a bottom profile occurs seaward of this location, and was selected to be approximately -34 feet NAVD, which is consistent with the AdaptLA project (ESA 2016) and based on the USACE *Coast of California Storm and Tidal Waves* Study for the Los Angeles region (USACE 2010). The slope of the profile was measured to be approximately 0.018, or about one foot vertically for every 53 feet horizontally. Therefore, the horizontal recession of the shore was computed to be 53 feet for every foot of sea-level rise. Note that this estimate did not account for background erosion rates, which would increase the amount of recession.

Figure 23 presents the existing and future profiles constructed for Transect 3 using the approach described above. The solid blue line represents the existing conditions profile. The dashed blue line represents a projection of the existing rock revetment, which is assumed to be maintained over time by others and would limit erosion of the fill beneath the bike trail and ESGS. The future condition profiles were adjusted and clipped where they intersected the projected revetment slope. The profile analysis shows that a loss of beach is possible with only 2.6 feet of sea-level rise, and then the rate of beach loss slows over time with additional sea-level rise (the beach is above the low water elevation of about 1 foot NAVD and seaward of the revetment). Local beach dynamics including the interaction of waves with the backshore coastal armoring were not considered, and would be expected to increase the local scour. Other considerations of the ESMT groin and beach nourishment actions could mitigate the beach loss.



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NOTE: Existing shore armoring is assumed to be maintained over time; full seaward extent of profile is not shown

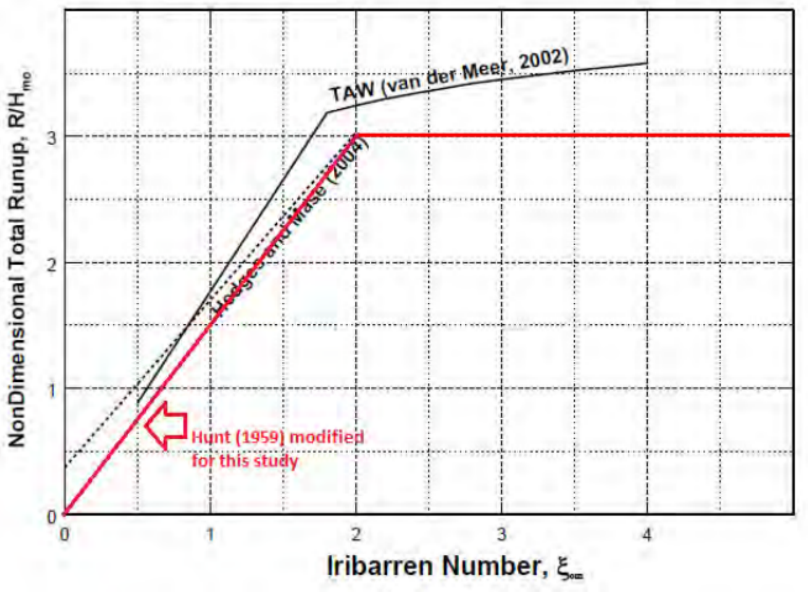
Figure 23
Shore Profiles for Existing and Future Conditions with Sea-Level Rise (SLR) (Transect 3 Shown)

3.5 Wave Runup Analysis

This section presents the wave runup analysis, including a brief overview of the methods used to compute the runup, followed by results of the maximum potential wave runup at the seaward edge of the project site, and finally a description of the landward extents of the wave runup.

3.5.1 Wave Runup Methods Used

The annual maximum wave event parameters (e.g., significant wave height, wave period, and coincident still water level) were used as inputs to a runup program that is valid for a wide range of profile configurations. This runup program, developed by ESA (previously Philip Williams and Associates, or PWA) and consistent with FEMA guidelines, was used to iteratively calculate the dynamic water surface profile along each representative shore profile, the nearshore depth-limited wave, and the runup elevation at the end of the profile. The dynamic water surface is the water level at the coast that is driven by sets of waves (or wave groups) that cause super-elevation of these water levels. Wave runup is computed using the method of Hunt (1959), which is based on the Iribarren number (also called the surf similarity parameter), a non-dimensional ratio of shore steepness to wave steepness. The runup is limited to a maximum of about three times the incident wave height, which is generally consistent with other methods that rely on the Iribarren number, as depicted in Figure 24. While there are a variety of runup equations, they provide a range of results and hence the simplest and direct was chosen (Hunt 1959).



Wave run-up relative to wave height is modeled as being proportional to the Iribarren Number, also known as the Surf Similarity Parameter, which is the ratio of the beach slope to the square root of wave steepness (relative slope steepness). Note that the wave run-up is limited above a value of three times the incident wave height.

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SOURCE: Modified from FEMA (2005)

Figure 24
Non-dimensional Wave Runup as a Function of Iribarren Number for Different Wave Runup Models (Hunt 1959 Used in this Study)

The program also uses the Direct Integration Method (DIM) to estimate the static and dynamic wave setup and resulting high dynamic water surface profile (FEMA 2005; Dean and Bender 2006; Stockdon et al. 2006). The methodology is consistent with the FEMA Guidelines for Pacific Coastal Flood Studies for barrier shores, where wave setup from larger waves breaking farther offshore and wave runup directly on barriers combine to generate the highest total water level and define the flood risk (FEMA 2005). This program also incorporates overland and structure surface roughness, which act as friction on the uprush of the waves, thus reducing the extent of wave runup. This method also uses a composite slope technique as described by Saville (1958), and outlined in the *Shore Protection Manual* (USACE 1984) and *Coastal Engineering Manual* (USACE 2003).

Figure 25 presents a schematic of the composite slope methodology and parameters. The largest waves incident to the site will set up the dynamic water level (shown as 2% water level), which then allows for smaller depth-limited waves to propagate further toward shore and result in the maximum wave runup at the shoreline. As described above, the process is iterative and requires stepping through the profile across the entire surf zone to the shoreline to find the maximum wave runup. See also Figure 18 for another schematic showing the wave setup and runup components of total water level.

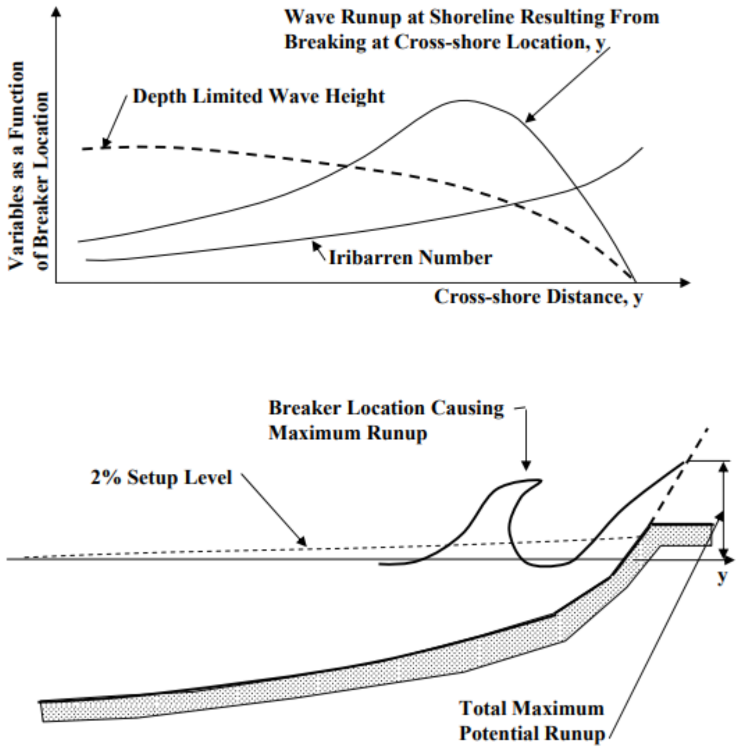

Figure D.4.5-10. Example Plot Showing the Variation of Surf Zone Parameters

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SOURCE: FEMA (2005)

Figure 25
Example of Composite Slope Parameters and Methodology:
Maximum Runup Caused by Intermediate Depth-Limited Wave

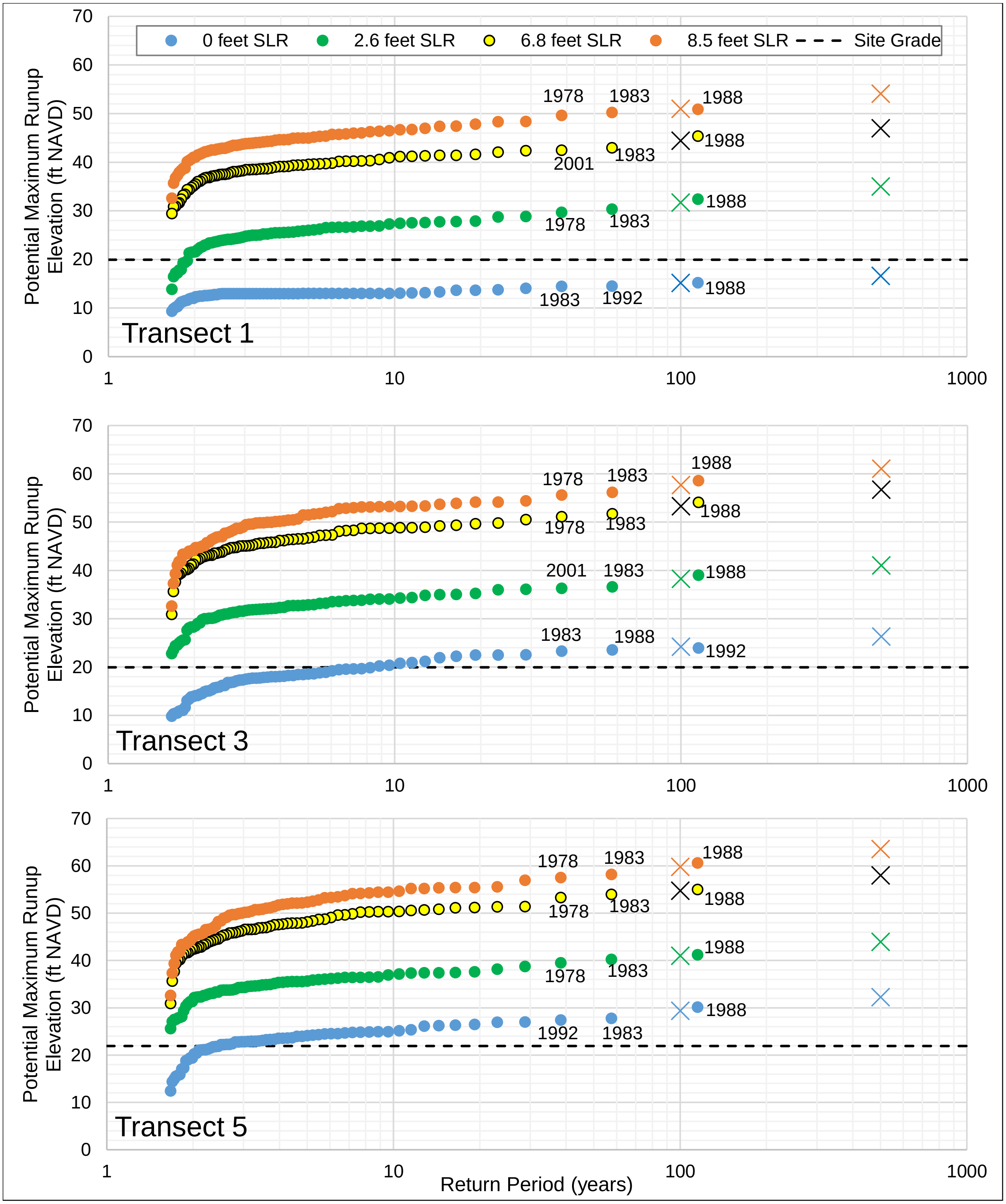
3.5.2 Potential Maximum Wave Runup

The potential maximum runup elevation, also referred to as the total water level (TWL), was computed using the methods described above for 69 annual maximum events. Figure 26 presents the potential maximum wave runup elevations for all 69 events (vertical axis) as a function of return period (horizontal axis) for existing and future conditions with sea-level rise at Transects 1, 3, and 5. Input water level and wave height and period are presented in Appendix B. In the figure, the results are presented as a function of the return period, or recurrence interval, along the horizontal axis. In this analysis, the return period is defined as the reciprocal (or inverse) of the annual exceedance probability. For example, a 100-year return period is an event that has a 1% chance of being exceeded in any given year, and a 500-year return period is an event that has a 0.2% chance of being exceeded in any given year.

The top panel of Figure 26 presents the results for Transect 1, the northernmost transect located closest to the ESMT groin where the existing beach is widest. The middle panel presents the results for Transect 3, which is largely representative of the flatter northern portion of the ESGS site. The bottom panel presents the results for Transect 5, the southernmost transect located where the site grades increase to approximately elevation 40 feet NAVD in the southern portion of the ESGS site. The dashed black line represents the elevation of the seaward edge of the bike trail; data points lying above the dashed black line indicate that the wave event overtops the barrier.

The data presented in Figure 26 represent the extreme value analysis for maximum “potential” wave runup at the barrier (see Figure 18). The crosses in each data set are the 100- and 500-year values of wave runup. The potential runup elevation is computed based on a projected slope on the seaward edge of the development, and is what the FEMA base flood elevation is typically based on. The computed runup height is highly dependent on slope: the steeper the slope, the higher the runup. For the purpose of this analysis, LiDAR data and aerial photos were used to provide a reasonable estimate for the slope of the rock revetment. As the dynamic water level (DWL; see Figure 18) increases to elevations close to the ground elevations of the backshore (approximately 20 feet NAVD), splash overtopping transitions to bore overtopping, which can propagate further into the site and cause greater damages due to its velocity and momentum. The landward extent of wave runup by overtopping is discussed more below in Section 3.5.3.

The maximum potential runup in Figure 26 is based on 69 individual annual maximum events, which occur over 115 years of data (this includes historic hindcast of the largest events of the century). Therefore, the runup elevation with a 100-year recurrence (1%-annual exceedance) was estimated from the available data by assuming that the 69 events are representative of a complete 115-year record. This implies that missing data will not significantly affect the extreme values. The results for existing conditions are comparable to FEMA calculations immediately north of the project site at FEMA transect LA0589 (FEMA 2015), for which an extreme value analysis was conducted for annual maximum wave runup computed using the Stockdon (2006) method. FEMA (2015) calculations at the ESGS project site used an alternative method for the extreme value analysis based on a peak-over-threshold approach, which introduces subjective selection of the threshold elevation used to define the frequency of exceedance.



Notes:
Dots represent modeled events and crosses denote estimated values for 100- and 500-year return periods.
Years for top three events are identified; wave and water level conditions for annual events are located in Appendix B.

Figure 26

Potential Maximum Wave Runup Elevations as a function of Return Period for Three Site Transects

Response-Based Methods

The method used to relate the maximum potential runup results presented in Figure 26 to the return period is known as a response-based approach, in which a statistical analysis is performed directly on the computed wave runup for the duration of the modeled storm events rather than determining the statistical relationships among various physical processes (FEMA 2005). This approach is a useful method for determining the response statistics when a sufficient duration of coincident data (i.e., forcing parameters) is available to develop a realistic time series of responses. The alternative is to use an event-based approach, where a variety of design events are selected for the forcing parameters (e.g., 1% wave and 1% water level) and used to determine the extreme values. Because this analysis used a response-based approach, the specific wave and water level conditions that would result in the 100- and 500-year events are not explicitly known, and in fact could result from several combinations of wave and water level conditions. To clarify the typical combinations of wave and water levels that result in the highest wave runup, Figure 26 includes the event year for the top three events computed at each transect and sea-level rise condition. Appendix B tabulates the wave and water level conditions for each of the annual maximum events modeled. The top events for each run include the years 1978, 1983, 1988, and 2001, each of which is characterized by a still water level of 6 feet NAVD or higher, wave height between 9.7 and 22 feet, and wave period between 17.5 and 23.3 seconds.

Effects of a Changing Nearshore Profile

Each sea-level rise case used the future conditions profile as described in Section 3.4. For these cases, the primary assumption is that the rock revetment and bike trail are assumed to be maintained in-place as the beach erodes with sea-level rise. The overall trend is that the beach elevation decreases over time, exposing the site to larger depth-limited waves in the future. The benefit of a wider beach can be inferred from the trend of the relatively lower wave runup heights computed at Profile 1, where the existing beach was wider than other locations modeled. This study does not include a comprehensive analysis that can evaluate the benefits of maintaining a beach, but overall the results suggest that it would be a concept worth considering that could help manage flood elevations, subject to further analysis.

Values of Extreme 100- and 500-year Events

Table 5 presents tabulated values of the estimated 100- and 500-year potential maximum wave runup for existing and future conditions with sea-level rise at Transects 1, 3, and 5. The 100- and 500-year values were determined using a logarithmic best-fit through the calculated data for return periods greater than the 10-year recurrence using an equation of the form:

$$TWL = A\log_{10}(R_T) + B, \tag{7}$$

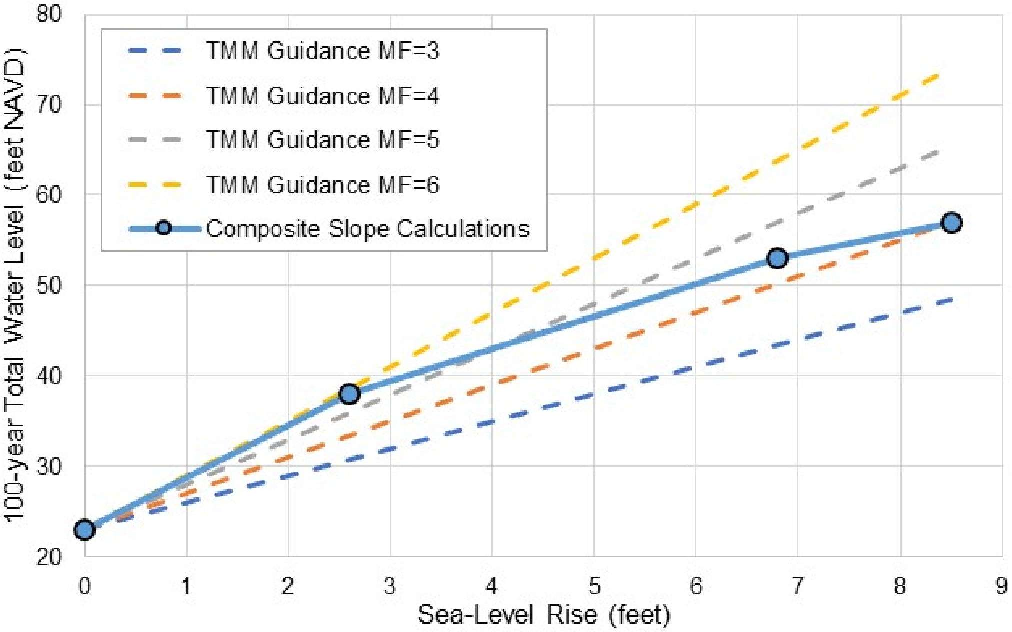
where TWL is the total water level as a function of return period, R_T is the recurrence interval or return period, and A and B are best-fit constants. The value of the 100-year total water level was less than the value of the maximum computed total water level corresponding to the 115-year recurrence interval, and so therefore is comparable to events that have historically occurred, while the 500-year estimate required projecting the logarithmic best-fit equation to the 500-year recurrence. The results in Table 5 show that the difference between the 100- and 500-year values is relatively small considering the relative likelihood of the two events. Because the potential maximum runup elevation calculations require many assumptions and steps, the difference in the values is likely smaller than the errors introduced by methods and assumptions. Furthermore, the approach is intended to yield results that are conservatively high.

TABLE 5
POTENTIAL MAXIMUM WAVE RUNUP ELEVATIONS FOR 100- AND 500-YEAR EVENTS (FEET NAVD)

Return Period (years)	0 feet SLR	2.6 feet SLR	6.8 feet SLR	8.5 feet SLR
Transect 1				
500-year	16.6	35.0	47.0	54.1
100-year	15.2	31.7	44.4	51.0
Transect 3				
500-year	26.3	41.1	56.7	61.1
100-year	24.2	38.2	53.3	57.7
Transect 5				
500-year	32.2	43.9	58.0	63.6
100-year	29.4	41.0	54.7	59.8

Comparison of Results to DWR Technical Methods Manual (TMM)

Comparison of the 100-year potential maximum runup elevation results presented in Figure 26 to a simplified method presented in the TMM (Battalio et al. 2016) show close agreement, which adds credibility and verification of the calculations made in this study. Figure 27 presents the 100-year total water level for the composite slope calculations (this study) as a function of sea-level rise and the 100-year total water level estimated using the TMM methods. The TMM method presents a simple equation that computes the future total water level by adding the amount of sea-level rise scaled by a morphology function (MF) that is to be selected by the user. The morphology function ranges from one, which is representative of an erodible shore and that results in a linear increase in TWL with sea-level rise, to values greater than four, which represent a non-erodible backshore that causes the wave runup height to amplify. The comparison of the methods in Figure 27 implies that the assumption that the existing rock revetment is maintained over time results in amplified wave runup that corresponds to a morphology function with a value between four and six. The reason that the morphology function is not constant over time is likely due to how the profile responds to sea-level rise. Recall in Section 3.4 that the geomorphic response of the profile was greatest for the first 2.6 feet of sea-level rise, and then did not continue to lower with additional sea-level rise. If other local interactions of the waves and the coastal armoring were considered, it is likely that the composite slope calculations for the higher amounts of sea-level rise would correspond to morphology function values closer to five or six. These values indicate that the runup at the site is highly sensitive to long-period swell, resulting in a very strong non-linear response to the progressively steeper profile.



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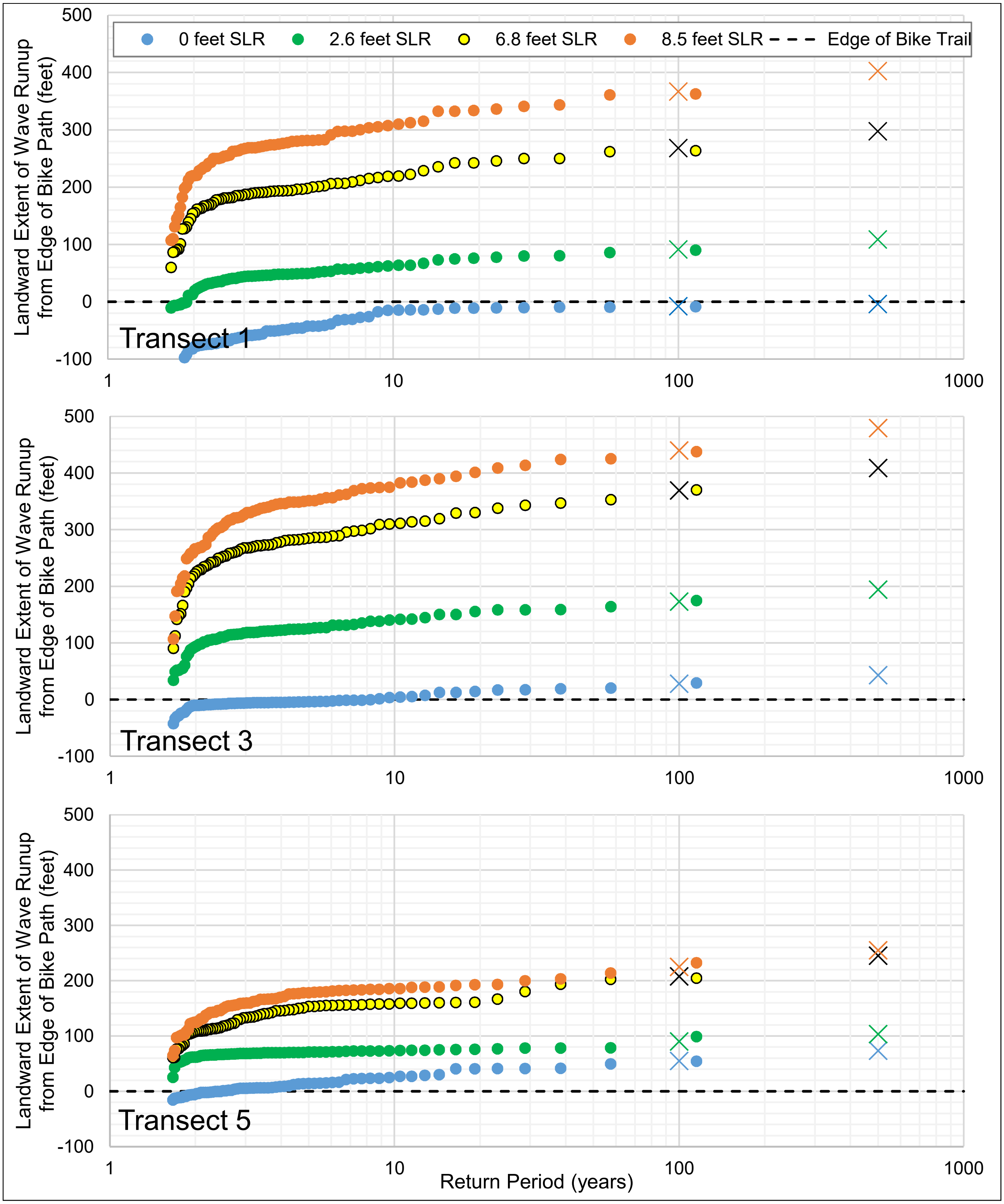
NOTES: TMM Guidance (Battalio et al. 2016) uses a *morphology function* (MF) to characterize the erodibility of the backshore (1 = erodible; 3-4+ = erosion resistant)

Figure 27
Comparison of 100-year TWL Calculations from Composite Slope Method to DWR Technical Methods Manual (TMM)

3.5.3 Landward Extents of Wave Hazards

A composite-slope methodology was used to estimate the landward extent of the extreme wave runup for 69 annual maximum events described above. Figure 28 presents the maximum landward extent of the wave runup for all 69 events as a function of return period for existing and future conditions with sea-level rise at Transects 1, 3, and 5. The top panel presents the results for Transect 1, the northernmost transect located closest to the ESMT groin where the existing beach is widest. The middle panel presents the results for Transect 3, which is largely representative of the flatter northern portion of the ESGS site. The bottom panel presents the results for Transect 5, the southernmost transect located where the site grades increase to approximately elevation 40 feet NAVD in the southern portion of the ESGS site. The “zero” line on the vertical axis shown by the dashed black line represents the seaward edge of the existing bike trail, and positive values are measured landward into the project site from that line.

Although the calculations assume that the existing vertical barrier wall is not present, a roughness factor of 0.6 was selected to represent the roughness of the rock armor and other features of the site, such as curbs, walls, and other irregularities that would disrupt the landward flow of water. Standard roughness values for application are presented in the various technical guidance (e.g., USACE 1984, USACE 2003, FEMA 2005). The assumption that the wall is not present is based on our understanding that the wall has not been structurally designed to withstand potential forces by wave action, and therefore has potential to fail during an extreme event. A roughness value of 0.6 is standard for the roughness of rock revetments, and is applicable for considering how the wave uprush may behave at the site. However, if the surface is kept smooth and open, waves will generally propagate further.



Notes:
Dots represent modeled events and crosses denote estimated values for 100- and 500-year return periods.

Figure 28

Landward Extents of Wave Runup as a function of Return Period for Three Site Transects

Table 6 presents tabulated values of the estimated 100- and 500-year maximum landward extents of wave runup for existing and future conditions with sea-level rise at Transects 1, 3, and 5. The 100- and 500-year values were determined using a logarithmic best-fit through the calculated data for return periods greater than the 10-year recurrence using Equation 7, presented above. As described in Section 5.3.2 for the potential maximum wave runup calculations, the difference between the 100- and 500-year values of landward extent is small considering the relative likelihood of the two events.

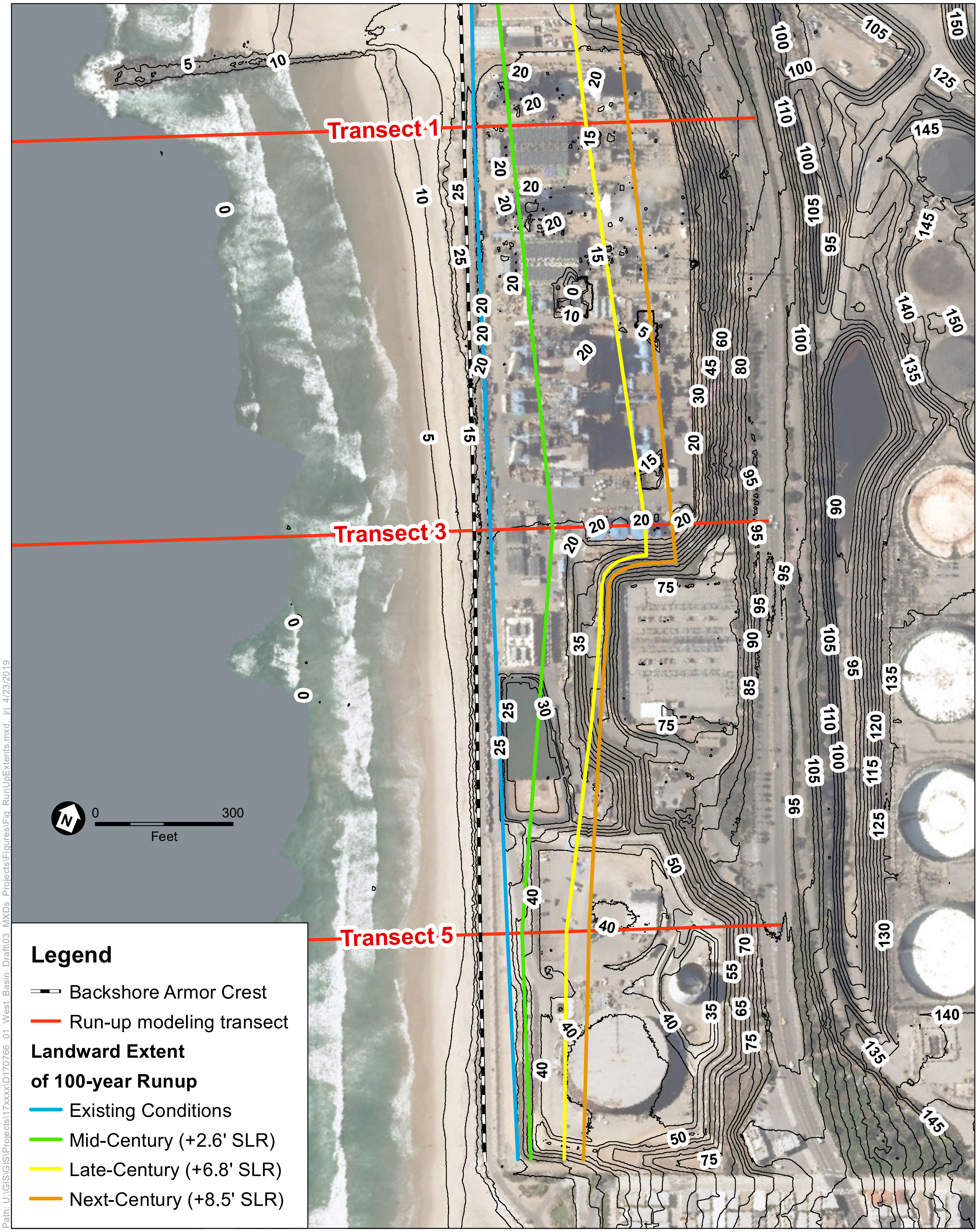
TABLE 6
LANDWARD EXTENTS OF WAVE RUNUP FOR 100- AND 500-YEAR EVENTS (FEET FROM BIKE PATH)

Return Period (years)	0 feet SLR	2.6 feet SLR	6.8 feet SLR	8.5 feet SLR
Transect 1				
500-year	-4	109	298	403
100-year	-8	92	269	367
Transect 3				
500-year	43	194	409	480
100-year	28	173	369	440
Transect 5				
500-year	73	103	245	254
100-year	55	90	207	225

Figure 29 presents a plan-view map that shows the 100-year landward extents of wave runup at the project site. These values increase with sea-level rise, and imply that the extreme coastal hazards will extend further into the site over time. Note that the existing FEMA FIRMs do not indicate flooding of the site for existing conditions. Based on review of the FEMA calculations, an empirical equation (e.g., Stockdon et al. 2006) was used that is intended for sandy beaches, and which is not able to consider the interaction of the waves with shore protection structures or steep backshore features. However, the FEMA study is a regional study, and the contractor may have had limited resources to adequately consider multiple methods that provide different answers, even though they are described in the FEMA guidelines.

Flooding Depths and Velocities

Water surface elevation and velocities of overtopping waves were computed for the wave overtopping bores resulting from wave runup exceeding the elevation of the bike trail. This analysis represents an extension of the wave runup calculations presented above, and is intended to help the project designers consider the approximate limits of wave hazards in the future with sea-level rise. Note that the project site is not currently mapped in a 100-year flood hazard zone by FEMA. The FEMA maps appear to under-represent the flood risk at the site, which is likely attributed to method uncertainty that is known to occur with regional studies: FEMA allows for map revisions based on more detailed and location-specific analysis, such as accomplished herein.



Path: U:\GIS\GIS\Projects\17xxxx\D170766_01_West_Basin_Draft\03_MXDs_Projects\Figures\Fig_RunUpExtents.mxd, jrj 4/23/2019

SOURCE: LA County (2013 Imagery);
NOAA CSC (2016 LiDAR Contours; ESA

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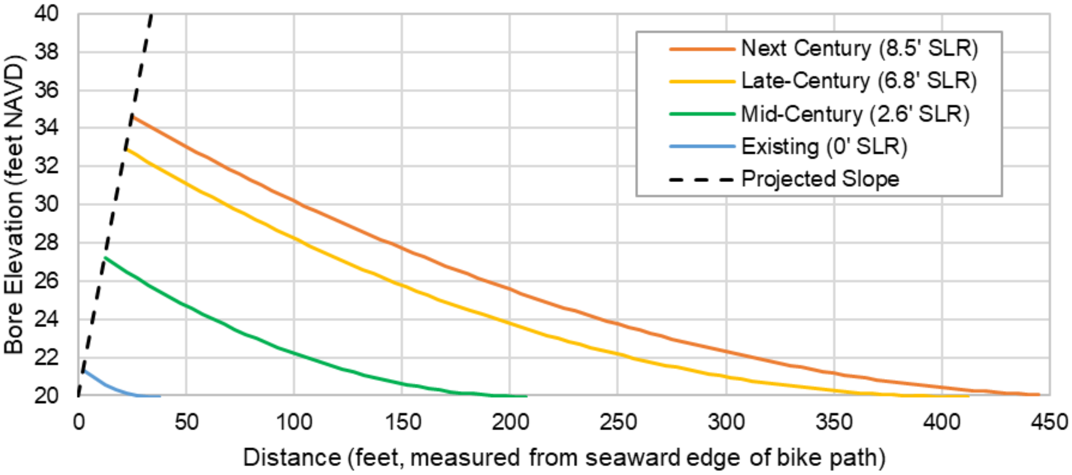
Figure 29

Plan View of Landward Extents of 100-year Wave Runup

Figure 30 presents the water surface elevation of bore height as a function of distance from the seaward edge of the bike trail (at the top of the existing rock revetment) at Transect 3. The plotted values are derived from the Potential TWL using the bore equation, resulting in a depth of water that decreases with distance landward. The event presented represents the 100-year recurrence, or 1% annual exceedance probability. Positive distance represents landward direction. These water surface profiles were computed using the formulation of the Cox-Machemehl equation as presented in FEMA (2005). Unique values of the scaling parameter were selected so that the landward extents would match those calculated using the composite slope runup method (see Table 6). The four curves in the chart (Figure 30) represent different amounts of sea-level rise from existing conditions to the next-century time horizons. Over time (and with increased amounts of sea-level rise), the runup elevation was shown to increase, as well as its landward limits or extents. Note that the existing ground elevation of the bike path at this profile location is approximately 20 feet NAVD, and assumed to be flush with the site grades landward of the bike path.



West Basin MWD Ocean Water Desalination Project: Coastal Hazards Analysis / D170766.01

Notes
Site grade 19.94 feet NAVD

Figure 30
Water Surface Elevation Profiles of 100-Year Wave Overtopping Bore at Transect 3 for Existing and Future Conditions with Sea-Level Rise

Figure 31 presents a comparison of the 100- and 500-year landward extents of the wave runup as a function of sea-level rise at Transect 3. The source data for the landward extents are shown in Figure 28 and tabulated in Table 6. The solid black circles and open squares represent the computed 100- and 500-year landward extents of wave runup, respectively. The solid and dashed lines are best-fit polynomials to the data points, and can be used to determine the landward extent of wave runup resulting from a given amount of sea-level rise.

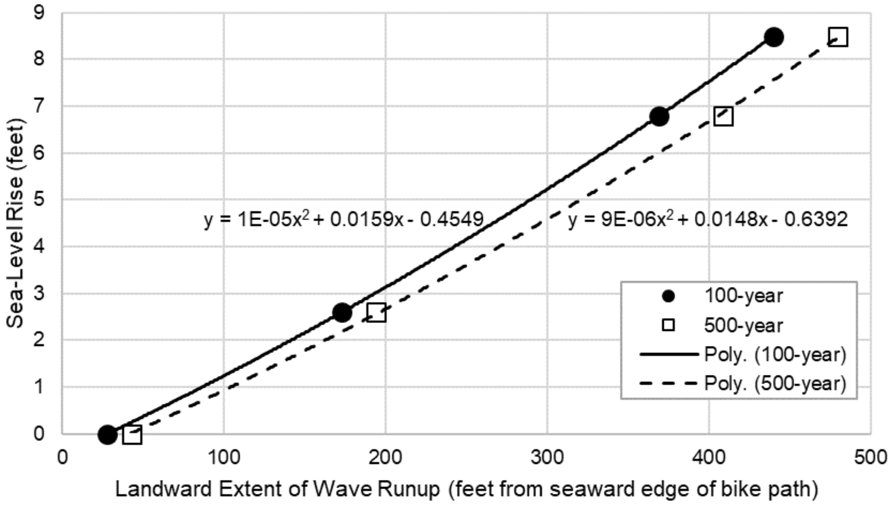


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Figure 31
Landward Extent of Wave Runup as a Function of Sea-Level Rise for 100- and 500-year Events at Site Transect 3

Table 7 summarizes the maximum landward extents of the wave runup and bore velocities based on methods presented in the FEMA (2005) guidelines for different time horizons and future sea-level rise amounts. The velocity was calculated using a method presented in FEMA (2005) that is based on the relative height of the potential wave runup and the elevation of the bike path. The FEMA (2005) guidelines recommend using this velocity for determining the limits of the wave momentum threshold of V^2h = 200 feet^3/second^2. Note that recent research suggests that a more appropriate limit is a value of V^2h = 100 feet^3/second^2.[21] This limit represents the landward extent of the "V zone," a special flood hazard zone that includes velocity and wave hazards, and which would require more stringent building requirements. For example, structures located within this zone would be required to be constructed on piles, with the lowest horizontal member elevated above the selected water profile presented in Figure 30. Elevating structures in a V zone should comply with FEMA building codes, and should use design approaches such as elevating critical infrastructure on piles with "break-away" walls that would allow flood waters to disperse in the event that the site floods. Constructing on fill is not an acceptable technique to elevate structures in a V zone because of the high erosion potential (FEMA 2005).

TABLE 7
LANDWARD EXTENTS OF BORE AND ASSOCIATED VELOCITIES FOR EXISTING AND FUTURE CONDITIONS

Time Horizon	Existing	Mid-Century (2050-2060)	Late-Century (2082-2100)	Next-Century (2092-2120)
Sea-Level Rise (feet)	0	2.6	6.8	8.5
Landward Extent of Wave Runup (feet, measured from bike path)	25	175	370	415
Velocity of Bore (feet per second)	25	27.3	36.5	38.8

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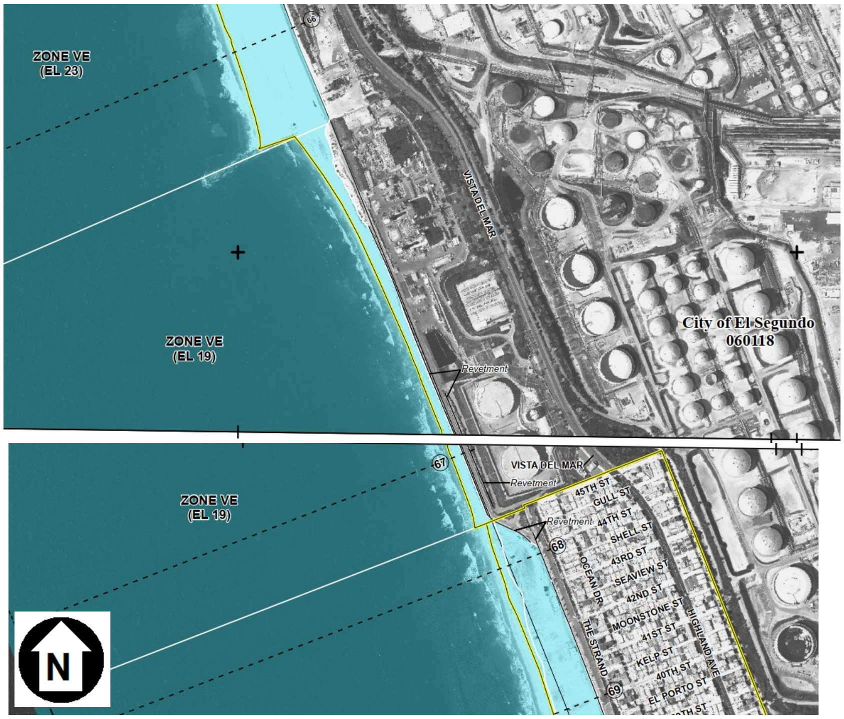
[21] Personal communication Bob Battalio, interpreted from Chock et al. (2011)

3.5.4 Summary and Comparison to Other Studies

The analyses presented above indicate that the extreme wave runup hazards constrain the project site over time. By mid-century (2050-2060) with 2.6 feet of sea-level rise, the extreme wave runup hazard extends approximately 200 feet into the site from the seaward edge of the bike trail. By late-century (2082-2100) with 6.8 feet of sea-level rise, the extreme wave runup hazard extents increase by an additional 200 feet to a total of over 400 feet into the site from the seaward edge of the bike trail. These results indicate that development at the project site should avoid or accommodate these hazards, and will likely be required to describe if and how it will adapt to higher sea-level over time. In this section, the results are briefly compared to other relevant studies for the project location.

FEMA Existing Conditions

The results of the 100-year potential maximum wave runup and landward extents for the existing conditions case are greater than calculated by FEMA (2015) and as mapped in the preliminary FEMA FIRM for the project site (Figure 32). The FEMA Contractor used a peak-over-threshold method, which introduces uncertainties on the event frequency and yields a result that is less than the adjacent transect to the north (Transect 66), where a standard extreme value analysis was used by ranking annual maximum events. The base flood elevation of 23 feet NAVD at the adjacent transect to the north (Transect 66) is comparable to the potential maximum runup values estimated in this study for the project site, adding credibility and verification of the calculations.



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SOURCE: FEMA

Figure 32
Preliminary FEMA Flood Insurance Rate Map Shows No Overtopping of Site

Coastal Resilience Future Mapping for AdaptLA

Hazard mapping of existing and future conditions along the shore of Santa Monica Bay was conducted for the AdaptLA project, completed as part of a vulnerability study for the City of Santa Monica (ESA 2016). Interactive mapping is hosted online as part of the Nature Conservancy's Coastal Resilience program.[22] Figure 33 presents a screenshot of the Coastal Resilience mapping at the project site considering approximately 3.0 feet of sea-level rise. The flood hazard that is shown in the map represents the approximate 100-year wave runup hazard extents, similar to what was analyzed in this study. The ESA (2016) work was conducted at a regional scale, and so does not consider the site-specific variability that affects detailed wave runup calculations, such as the variable topography at the project site. The ESA (2016) mapping presented in Figure 33 used a single transect to represent a "block" of shoreline that includes the entire project site and portions of the shore south of the project site. However, the result shown in Figure 33 for 3.0 feet of sea-level rise is generally comparable to the extents calculated in this study for the mid-century scenario with 2.6 feet of sea-level rise. This implies that the wave runup extents computed in ESA (2016) are lower in magnitude than those computed by this study, although the comparison indicates general agreement.

West Basin MWD Ocean Water Desalination Project: Coastal Hazards Analysis / D170766.01

SOURCE: AdaptLA / Coastal Resilience
https://maps.coastalresilience.org/california/#

Figure 33
Coastal Resilience Flood Hazard Map Showing 100-year Event with Three Feet of Sea-Level Rise

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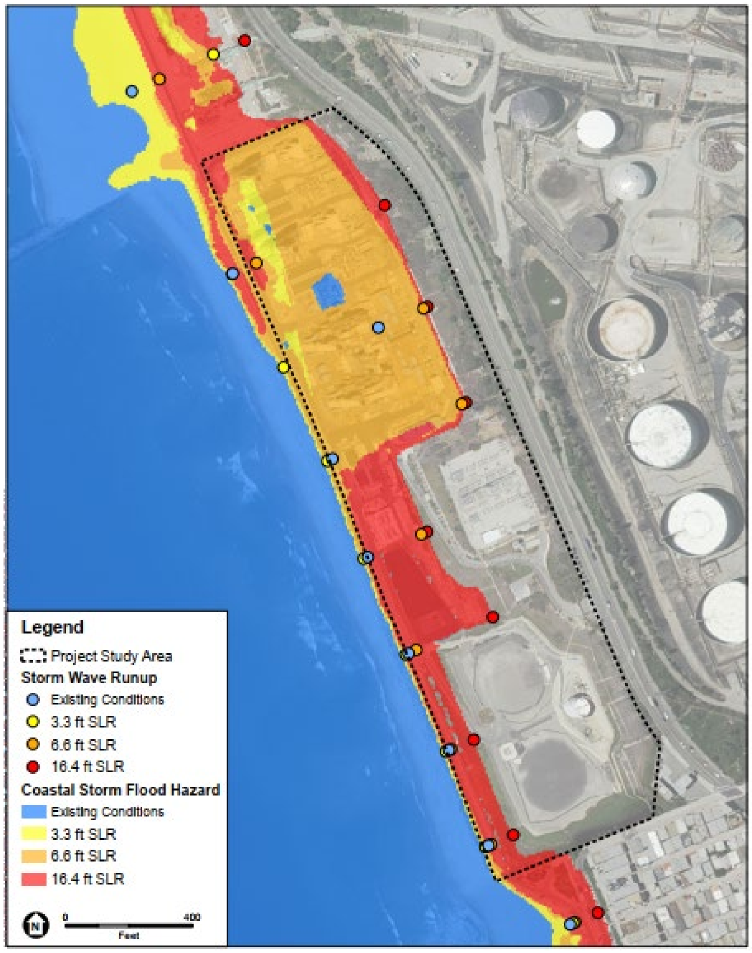
[22] https://maps.coastalresilience.org/california/#

USGS CoSMoS 3.0 Southern California

Hazard maps prepared as part of the Coastal Storm Modeling System (CoSMoS) by the U.S. Geological Survey (USGS) indicate the exposure of many sections of the California coast to flooding, waves, and erosion hazards for existing and future conditions with sea-level rise. The CoSMoS version 3.0 Phase 2 project included results of the regional sea-level rise hazard mapping along the shore of Los Angeles County (Barnard et al. 2018). Interactive mapping is hosted online as part of the Our Coast, Our Future (OCOF) project.[23] Figure 34 presents a plan-view image of the existing and future 100-year flooding hazards at the project site for the multiple sea-level rise scenarios: existing conditions (blue), 3.3 feet of sea-level rise (yellow), 6.6 feet of sea-level rise (orange), and 16.4 feet of sea-level rise (red). The areas shaded by the solid colors represent approximate flooding by extreme tidal elevations plus the effects of wave setup, and do not include the wave runup component. The approximate extents of wave runup are shown by the colored dots on the figure.



West Basin MWD Ocean Water Desalination Project: Coastal Hazards Analysis / D170766.01

SOURCE: USGS and Point Blue

Figure 34
Coastal Resilience Flood Hazard Map Showing 100-year Event with Three Feet of Sea-Level Rise

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[23] http://data.pointblue.org/apps/ocof/cms/

To develop these hazards, the technical approach by the USGS used a combination of two-dimensional hydrodynamic modeling of extreme tidal events (includes tidal and non-tidal residual components, but not waves) in Delft3d and one-dimensional simulations of wave setup and runup using XBeach (Erikson et al. 2017). The flood extents were determined by considering both the landward-most wet grid cells in the hydrodynamic model and the landward projection of the maximum wave setup calculated with XBeach (Erikson et al. 2017).

The mapping presented in Figure 34 is for the "hold the line" scenario, in which existing shore protection structures and the urban boundary are assumed to prevent erosion of the backshore (i.e., erosion of developed areas is not allowed). Although the CoSMoS hazard mapping is based on detailed modeling techniques, the results should be considered as approximate given its regional application, which required automated runs that included modeling of the entire Southern California shore and lacks site-specific information.

Direct comparison of the CoSMoS hazards to those presented in this study are approximate because the CoSMoS maps show the extents of projected dynamic water level (i.e., elevation of the 2-minute sustained wave setup on the extreme still water level) and this study presents the extents of the wave runup. For existing conditions and 3.3 feet of sea-level rise scenarios, the project site is not exposed to the hazards mapped by CoSMoS, but are exposed to the wave runup hazards presented in this study. However, for 6.6 feet of sea-level rise and greater, the hazards defined by the CoSMoS maps extend further than the wave runup limits computed in this study. The CoSMoS maps provide a tool for evaluating hazard exposure at a regional scale, which is useful for initial screening of potential hazards at a specific site. Additional technical analysis consistent with federal and state guidance, such as presented in this study, help refine the hazards for site-specific considerations of existing and future hazards.

Prior Coastal Hazards Analyses for the West Basin Ocean Desalination Project

The coastal hazards associated with extreme wave runup and tsunamis were analyzed previously for the project by Jenkins in 2016 and in 2017 (Draft EIR Appendix 5): The study found that the site is not subject to flooding hazards during extreme storms, but that the runup of a tsunami is more problematic for the site. See Section 3.6 for a review of Jenkins' tsunami projections. A major assumption of the studies was that the existing wall barrier would prevent future wave and tsunami runup from entering the site, although it is not clear if the wall was designed to withstand loadings by waves and tsunamis.

Hand calculations performed for existing conditions yield wave runup results of less than 0.5 feet and total water level of about 14.5 feet MLLW (14.3 feet NAVD)[24], which is lower than what has been projected by FEMA (Figure 32). However, this calculation was based only on the depth-limited wave height at the toe of the rock revetment, and does not account for larger waves breaking in intermediate locations in the surf zone. The computed runup was higher (total water

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[24] Note that Jenkins (2016) presents elevations at the site relative to mean lower-low water (MLLW), based on the Los Angeles tide gauges. Here, we present elevations approximately converted to the NAVD datum using a conversion of -0.19 feet from MLLW to NAVD for the Santa Monica tide gauge.

level of about 19.8 feet MLLW, 19.6 feet NAVD) using Coastal Evolution Model software developed by Jenkins and Wasyl (2005) that included greater erosion of the shore profile. The computed runup elevations suggest that the revetment and bike trail are not overtopped during the 100-year event, which is counter to historical observations (see Section 2.2.5).

The extreme event analyzed by Jenkins (2016) was based on the 100-year wave height offshore of the project coincident with a still water level of 2.62 feet MLLW (approximately equivalent to mean sea-level of 2.6 feet NAVD at Santa Monica tide gauge), which is not representative of a conservatively high event that is recommended by FEMA (2005). The selection of the combined extreme wave and water level in Jenkins (2016) assumed that the distributions of wave height and water levels are independent, which has been shown not to be the case for extreme events in California where elevated still water levels typically coincide with the largest wave events, especially during El Niño conditions (Seymour et al. 1984). Furthermore, all of the hazards analyzed were assumed to be blocked by the existing wall barrier along the perimeter of the project site, although there is no assessment of whether the wall is currently designed to withstand the potential loading by waves and tsunamis.

Future conditions considered sea-level rise amounts that were based on the projections of OPC (2013), which has now been superseded by OPC (2018). The Jenkins (2016) study considered up to 2.92 feet of sea-level rise by year 2065, resulting in future total water level of about 17.8 feet MLLW (17.6 feet NAVD) based on hand calculations, and about 20.9 to 23.4 feet MLLW (20.7 to 23.2 feet NAVD) using the software.

As an update to the initial Jenkins (2016) report, an additional sea-level rise scenario occurring at year 2100 was used to analyze the wave uprush and tsunami hazards per request of the California Coastal Commission (Jenkins 2017). The Jenkins (2017) updated study considered up to 5.5 feet of sea-level rise occurring at 2100, which resulted in a 100-year total water level of 20.2 feet NAVD and a maximum total water level of 26.0 feet NAVD. The assumption made by Jenkins (2017) that the extreme wave height and water level occur independently understates the projected total water level for a given recurrence interval, and the maximum event (reported as having an annual exceedance of 0.04%) is likely closer to the 100-year condition (1% annual exceedance) if the analysis considered that the waves and water levels are statistically jointly dependent (FEMA 2005; Garrity et al. 2007). Jenkins (2017) concluded that no overtopping of the bike trail or flooding of the project site was possible for a 100-year event with 5.5 feet of sea-level rise at 2100. For the maximum condition modeled, although the total water level would overtop at the bike trail, the existing wall would prevent inundation of the site during these conditions.

3.6 Tsunami Hazards

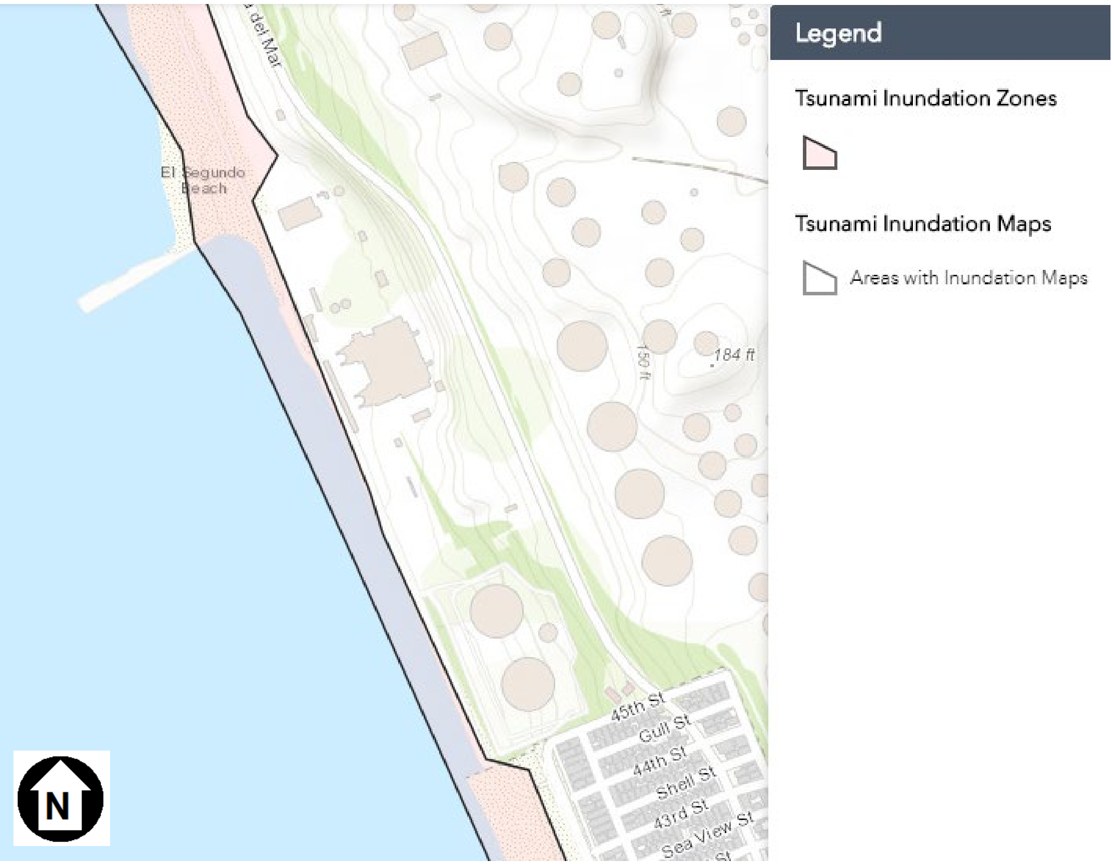
Based on available information and prior work, the project site is located in a tsunami inundation hazard zone. Analysis of tsunami hazards at the project site by Jenkins (2016; 2017) show that a 2-meter-high tsunami (or 6.6-foot) would inundate the site for existing and future conditions with sea-level rise. The following sections describe publicly available information on tsunami hazards that include the project site, including the California Official Tsunami Inundation Maps that show the site located landward of the tsunami hazards and more recent mapping by the American Society of Civil Engineers (ASCE) that shows the site within a tsunami inundation hazard zone.

3.6.1 Prior Coastal Hazards Analyses for the West Basin Ocean Desalination Project

Tsunami hazards for existing and future conditions were modeled by Jenkins (2016), which showed that a tsunami with an incident wave height of 2 meters (i.e., 6.6 feet) is expected to refract and focus its energy offshore of the project site, increasing the wave height to approximately 8 meters (i.e., 26.2 feet). The refracted tsunami would runup on the shore to elevations over 25 feet MLLW (24.8 feet NAVD) for existing conditions, and 28.8 feet MLLW (28.6 feet NAVD) for future conditions with 2.92 feet of sea-level rise. Jenkins (2016) suggests that the existing wall would prevent a tsunami from directly inundating the site, but that flows could enter the site from overtopping at the southern portion of the project site along the area that includes a cyclone fence and no wall. Jenkins (2017) describes that the tsunami hazard increases with the higher sea-level rise of 5.5 feet at 2100. The findings suggest that, under the future sea-level rise condition of 5.5 feet at 2100, a solitary wave tsunami with a height of 2 meters (i.e., 6.6 feet) would refract to 8 meters (i.e., 26.2 feet) as it approaches the project site, and would result in about 5.8 feet of overtopping at the bike bath, and 0.8 feet of overtopping of the existing wall barrier at the site, implying that the site is partially flooded. However, it is not known if the existing wall would withstand the anticipated loading of a tsunami. The study by Jenkins (2016 and 2017) did not address the structural performance of the wall.

3.6.2 California Official Tsunami Inundation Maps

The California Official Tsunami Inundation Map for the project site shows it located immediately landward of the tsunami inundation hazard area (Figure 35; State of California 2009). The California Geological Survey (CGS), California Office of Emergency Services (formerly California Emergency Management Agency), and the Tsunami Research Center at the University of Southern California developed a set of tsunami hazard maps for all populated areas at risk to tsunamis in California. The maps represent the tsunami hazards that result from a combination of the maximum considered tsunamis for each area that could be generated from a variety of near- and far-field tsunami sources (Wilson et al. 2008). The California Official Tsunami Inundation Maps that show the site located landward of the tsunami hazards: It is not known whether the existing wall was considered a barrier to tsunami runup. The maps include a disclaimer that states they are intended only for coastal evacuation planning and not for other regulatory purposes.



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SOURCE: California Geologic Survey Information Warehouse: https://maps.conservation.ca.gov/cgs/informationwarehouse/tsunami/

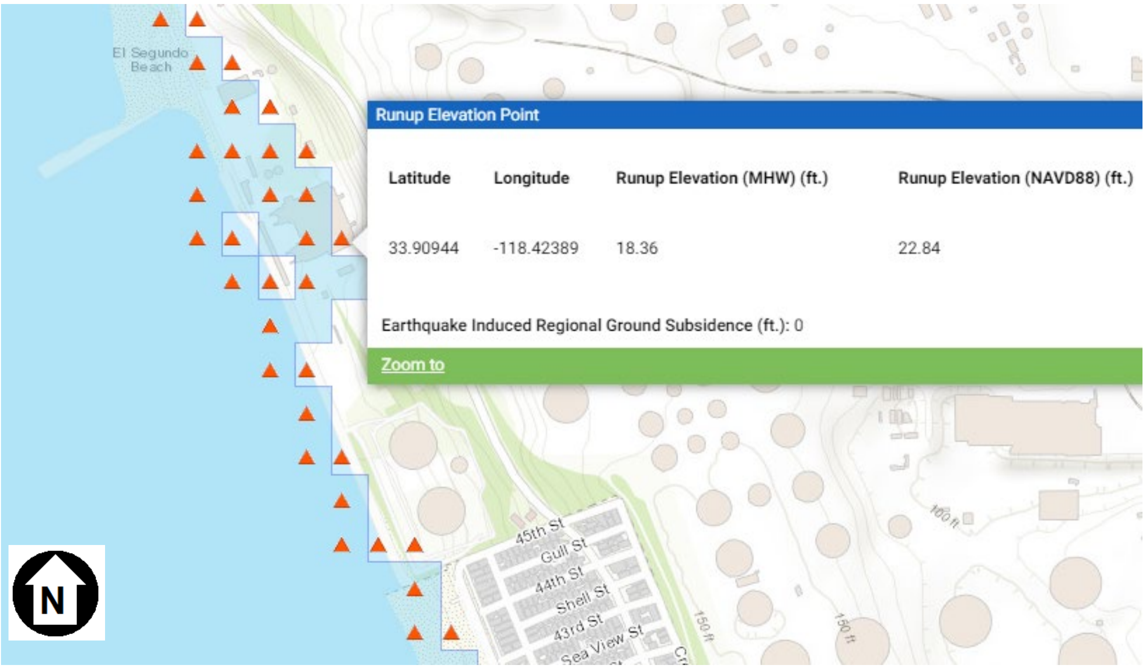
Figure 35
California Official Tsunami Inundation Map
Shows Site is not Inundated by Tsunami

3.6.3 Structural Design Considerations for Tsunami Hazards

The American Society of Civil Engineers (ASCE) recently updated the ASCE 7 design standard for determining the minimum design loads for buildings and other structures to include an entirely new chapter on tsunami design loads (ASCE 2017a). A new set of 2,500-year probabilistic tsunami design zone maps were produced for the five Pacific states of the U.S. for use with the ASCE design provisions (ASCE 2017b). An accompanying web-based tool includes the geocoded reference points of the offshore tsunami amplitude and period and the runup elevation associated with the inundation limit of tsunami hazards (ASCE 2017c). The tsunami hazard maps are not intended to be used for evacuation or emergency management planning; the maps are intended to be used to identify whether a project is located in a tsunami design zone, which would require the structural design to consider the minimum loadings identified by the tsunami design criteria described in the ASCE 7 design standard.

Figure 36 presents a screenshot of the web-based ASCE Tsunami Hazard Tool for the project site, showing that the 2,500-year tsunami inundates the northern portion of the site to approximately elevation 23 feet NAVD. Note that the tsunami runup height is computed relative to the mean high water level datum, as recommended by the ASCE design standard. The ASCE Tsunami

Hazard Tool indicates that the offshore tsunami height and period in the vicinity of Santa Monica Bay range from five to nine feet with a period of about 45 minutes (± 4 minutes), respectively. The offshore tsunami height is generally in agreement with the tsunami amplitude of 2 meters analyzed by Jenkins (2016; 2017). Although an event with a return period of 2,500-years has a relatively low likelihood of occurrence in comparison to the 100-year to 500-year flood hazards typically considered, the consequences of a tsunami are much greater and therefore current design guidance requires consideration of tsunamis for Risk Category III and IV structures located within the tsunami design zone. The 2,500-year event has an annual percent exceedance of 0.04%, and a 2% chance of exceedance over a period of 50 years.



Latitude	Longitude	Runup Elevation (MHW) (ft.)	Runup Elevation (NAVD88) (ft.)
33.90944	-118.42389	18.36	22.84

Earthquake Induced Regional Ground Subsidence (ft.): 0

SOURCE: ASCE Tsunami Hazard Tool, ASCE Tsunami Design Geodatabase Version 2016-1.0: https://asce7tsunami.online/

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Figure 36
ASCE Tsunami Hazard Tool Shows Project Site in Tsunami Design Zone

Appendix C presents additional information on the structural design criteria, including the design inundation depths and velocities for existing and future conditions with sea-level rise. These are preliminary values computed to inform project designers of the need to consider tsunami loads, but are not necessarily appropriate for design.

3.7 Nexus with Coastal Commission Guidelines

The following are the required steps as part of the CDP application process. This study addresses steps 1 and 2, and provides information that can be used to complete 3. Additional work will need to be done by the team to complete steps 4 and 5 prior to submitting a CDP application.

1. Establish the projected sea-level rise range for the proposed project
    a. Define Expected Project Life
    b. Determine Sea-Level Rise Range
2. Determine how physical impacts from sea-level rise may constrain the project site
3. Determine how the project may impact coastal resources, considering the influence of sea-level rise upon the landscape over time
4. Identify project alternatives that avoid resource impacts and minimize risks to the project
    a. Assess Design Constraints
    b. Identify Adaptation Options
    c. Utilize Adaptation Pathways
    d. Develop Project Modifications
    e. Plan for Monitoring
5. Finalize project design and submit CDP application

4 CONCLUSIONS

This section presents a summary of the main conclusions of the gathering of information and the analyses that were conducted. Based on the information presented above in this report, the following conclusions are made:

1. The primary finding of the study confirms that the future extreme wave runup with sea-level rise would constrain the project site sometime between the mid- and late-century time horizons, approximately by 2070. Wave overtopping during extreme events could pose a hazard to the infrastructure and operations, but may be accommodated by design decisions that account for high velocity moving water associated with waves. Profiles of bore elevations were developed and presented, and may be used to modify the project layout. The results can also be used during project design as an indication of how the project can be sited or adapted to higher sea-level.

2. The 115-year-long data set of high waves assembled for this study provides a good basis for the computed 100- and 500-year wave runup extents.

3. A 100-year timeframe is appropriate for this project based on review of California coastal policy (CCC 2018). The project will have a design life of 30 to 40 years, which may be extended to a 50- to 100-year timeframe with future capital improvements. Therefore, a 100-year study period was selected based on the likely occupation of the site between 50 and 100 years.

4. Wave hazards are expected to progress inland over time, with sea-level rise. The potential maximum wave runup elevation (potential total water level) at the seaward edge of the bike trail will increase around four to five times the amount of sea-level rise (Figure 27). The extent of wave runup inland from the seaward edge of the bike trail will increase approximately 50 feet for every foot of sea-level rise (Figure 31).

5. Each sea-level rise model run (for swell, not tsunami) considered a changing beach profile: i.e., the beach erodes with sea-level rise, but the rock revetment and trail are assumed to be maintained in place. The overall trend is that the beach would narrow and the elevation would decrease over time, exposing the site to larger waves in the future. The benefit of a wider beach is demonstrated by the relatively lower wave runup heights computed at Transect 1, where the existing beach is wider than at other locations modeled.

6. The 100-year wave runup results computed here are greater than those estimated by FEMA (2015) and Jenkins (2016; 2017), but less than CoSMoS 3.0, and similar to ESA's prior projections for AdaptLA. The site is unique and requires a site-specific analysis to address details missed by regional studies.

7. Design criteria could be established using the profiles of the water surface elevation of an overtopping bore as a function of distance for several time horizons (i.e., sea-level rise amounts). The site could be designed to locate facilities outside of the hazard area, such as

locating them farther inland or raising them to be above wave hazard zone, or otherwise designed to accommodate the loadings.

8. The northern portion of the site is mapped in a tsunami design zone (see Figure 36), which may affect modification of the site layout and design loadings. Preliminary calculations indicate potential design criteria within the inundation zone are depths on the order of two to five feet and velocities on the order of 10 to 12 feet per second. A preliminary analysis of the effects of sea-level rise indicates increases in inundation extents, depths, and velocities (Appendix C).

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Appendix A

Sea-Level Rise Policy and Projections

APPENDIX A
Sea-Level Rise Policy and Projections

This appendix provides additional information on the policy and projection of sea-level rise used to develop scenarios analyzed in the supplemental Coastal Hazards Analysis of the West Basin Municipal Water District Ocean Water Desalination Project. ESA summarized prior sea-level rise hazard mapping studies completed for the project location including how the studies account for sea-level rise. ESA also included a summary of State and Federal policy guidance and other relevant information.

1. Introduction

This appendix provides background information used for selecting sea-level rise amounts and time horizons based on different projections of sea-level rise over time as a function of greenhouse gas emissions. This memo also relates the sea-level rise scenarios used in prior work by ESA and the United States Geological Survey (USGS) to the recently updated California sea-level rise guidance.

2. Summary of Prior Sea-Level Rise Hazard Mapping Studies for the Project Location

ESA, USGS and Terra Costa have previously assessed the impacts of sea-level rise on the LA County coast. ESA conducted sea-level rise hazard mapping, including the erosion and flooding hazards, in collaboration with Los Angele County (ESA 2016). The USGS also recently released the Coastal Storm Modeling System (CoSMoS) 3.0 study (Phase 2), which includes similar hazard mapping along the Southern California coast, including the city of El Segundo. Although the methods used in the studies differ, ESA utilized the same input data (waves and water levels) produced for CoSMoS. Furthermore, both studies predict increased areas impacted by erosion and flooding with sea-level rise as compared to existing conditions. The approach in integrating sea-level rise policy differs, however, where the ESA studies present scenario-based hazard maps informed by the recommended sea-level rise policy guidance, and the USGS study presents results for a discrete range of sea-level rise amounts independent of time. How each of these studies incorporated sea-level rise is described in the following sections.

2.1 Los Angeles County Coastal Hazard Mapping by ESA

ESA worked with the City of Santa Monica to prepare coastal hazard maps with sea-level rise and perform a preliminary vulnerability assessment that could be included in the updated General

Plan and LUP/LCP and help focus local jurisdictions on specific additional studies (ESA 2016). The process involved several stakeholders and local science advisors. The sea-level rise scenarios were based on those presented in National Research Council's report *Sea-Level Rise for the Coasts of California, Oregon, and Washington* (NRC 2012). Based on ESA's interpretation of the new OPC (2018) guidance described in Section 3, the prior work is also consistent with the new sea-level rise projections of OPC (2018).

The planning horizons for the project were selected by the stakeholder process, which recommended presenting hazard data for the years 2030, 2050 and 2100. The selection of years was also consistent with state guidance at the time of the study (OPC 2013; see section 3.2). Table A-1 below lists the sea-level rise scenarios modeled for the County study. For the study, ESA examined hazard exposure and vulnerability under the Extreme SLR scenario by applying coastal hazard maps for 5.5 feet of sea-level rise at 2080, when sea-level rise amount occurs on the Extreme curve.

TABLE A-1
SEA-LEVEL RISE PROJECTIONS USED IN THE LOS ANGELES COUNTY COASTAL HAZARDS STUDY (ESA 2016)

Scenario	2030	2050	2100
Medium SLR*	0.5 feet	0.9 feet	3.1 feet
High SLR*	1.0 feet	2.0 feet	5.5 feet
Extreme SLR**	0.6 feet	2.0 feet	9.4 feet

*Based on projected (Medium scenario) and upper limit (High scenario) values for Los Angeles in Table 5.3 of NRC (2012)
**Based on 99.9th percentile for Representative Concentration Pathway 8.5 from Cayan et al. (2016)

ESA also produced a set of coastal hazard maps to include the effects that existing shore protection would have on the hazard extents. ESA developed a methodology for considering the protective nature of coastal structures, and assumed that the structures would be maintained throughout the forecasting period. This resulted in hazard areas that were reduced, but not eliminated, owing to overtopping of the structures that increases with the rise in sea-level.

2.2 CoSMoS Southern California 3.0

As part of the USGS effort to expand the CoSMoS along the west coast, the recent 3.0 Phase 2 study was completed for the Southern California coast (Barnard et al. 2015). Rather than computing the hazard extents for sea-level rise based on the current policy guidance, the CoSMoS approach computes the hazard extents for several discrete values of sea-level rise, independent of time. Sea-level rise amounts from 0 to 2 meters were used, at 0.25 meter increments. Table A-2 presents a conversion of the sea-level rise amounts from metric to English units.

TABLE A-2
METRIC-ENGLISH CONVERSION OF SEA-LEVEL RISE AMOUNTS SIMULATED BY COSMOS

Case	1	2	3	4	5	6	7	8	9
Meters	0	0.25	0.5	0.75	1	1.25	1.5	1.75	2
Feet	0	0.8	1.6	2.5	3.3	4.1	4.9	5.7	6.6

3. Sea-Level Rise Policy Guidance

The sections below present State and Federal guidance on sea-level rise.

3.1 State Guidance on Sea-Level Rise

The California Ocean Protection Council (OPC) first released a statewide sea-level rise guidance document in 2010 following Governor Schwarzenegger's executive order S-13-08. This interim guidance document informed and assisted state agencies to develop approaches for incorporating sea-level rise into planning decisions. The document was updated in 2013 (OPC 2013) after the NRC released its final report *Sea-Level Rise for the Coasts of California, Oregon, and Washington* (NRC 2012), which provided three projections of future sea-level rise associated with low, mid, and high greenhouse gas emissions scenarios, respectively.

The CCC adopted sea-level rise policy guidance in 2015, which was updated in 2018 (CCC 2018). The document recommends using a range of climate change scenarios (i.e., emissions scenarios) at multiple planning horizons for vulnerability and adaptation planning. The guidance presents a step-by-step process for addressing sea-level rise and adaptation planning in Coastal Development Permits (CCC 2018, p 21). This appendix focuses on the first step of the CCC recommended process: Establish the projected sea level rise range for the proposed project's planning horizon using the best available science. At the time of the CCC (2018) report, NRC (2012) was included in State policy by OPC (2013). Since then, California commissioned an update (Griggs et al. 2017) and released an update to the sea-level rise policy in March 2018. The CCC (2018) considers the Griggs et al. (2017) the best-available science and recommends using the OPC (2018) sea-level rise projections for low, medium-high, and extreme risk aversion scenarios for the high emissions (RCP 8.5). Additional information is provided in the following sections of this document.

3.1.1 Guidance on Climate Change and Sea-Level Rise Scenarios (Prior to 2018)

The accumulation of greenhouse gases in the Earth's atmosphere is causing and will continue to cause global warming and resultant climate change. For the coastal setting, the primary exposure will be an increase in mean sea-level rise due to thermal expansion of the ocean's waters and melting of ice sheets.

State planning guidance for coastal flood vulnerability assessments call for considering a range of emission scenarios (OPC 2013; CCC 2015). These scenarios bracket the likely ranges of future greenhouse gas emissions and ice sheet loss, two key determinants of climate whose future values cannot be precisely predicted. Scenario-based analysis promotes the understanding of impacts from a range of emission scenarios and identifies the amounts of climate change that would cause impacts.

The state guidance recommends using emission scenarios that represent low, medium, and high rates of climate change. Recent studies of current greenhouse gas emissions and projections of future loss of ice sheet indicate that the low scenario probably underrepresents future sea-level rise (Rahmstorf et al. 2012; Horton et al. 2014). Also, note that even if sea-level rise does not increase as fast as projected for the high scenario, sea-level rise is projected to continue beyond 2100 under all emission scenarios. The assumptions that form the basis for the NRC (2012) scenarios are as follows:

Low Emissions Scenario – The low scenario assumes population growth that peaks mid-century, high economic growth, and assumes a global economic shift to less energy-intensive industries, significant reduction in fossil fuel use, and development of clean technologies.

Medium Emissions Scenario – The medium scenario assumes population growth that peaks mid-century, high economic growth, and development of more efficient technologies, but also assumes that energy would be derived from a balance of sources (e.g., fossil-fuel, renewable sources), thereby reducing greenhouse gas emissions.

High Emissions Scenario – The high scenario assumes population growth that peaks mid-century, high economic growth, and development of more efficient technologies. The associated energy demands would be met primarily with fossil-fuel intensive sources.

Table A-3 presents sea-level rise projections for prior State guidance of OPC (2013) based on NRC (2012). The values for relative sea-level rise[1] at 2030, 2050 and 2100 for Los Angeles[2] are relative to 2000 and includes regional projections of both mean sea-level rise and vertical land motion of -1.5 millimeters per year for the San Andreas region south of Cape Mendocino.

TABLE A-3
OPC (2013) STATE GUIDANCE: SEA-LEVEL RISE PROJECTIONS FOR SOUTHERN CALIFORNIA

Scenario	2030	2050	2100
Low Range	0.2 feet	0.4 feet	1.5 feet
Mid Curve	0.5 feet	0.9 feet	3.1 feet
High Range	1.0 feet	2.0 feet	5.5 feet

Source: Table 5.3, NRC (2012)

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[1] The term "relative sea-level rise" indicates that the local effects of vertical land motion are included in the sea-level rise projection,

[2] Los Angeles relative sea-level rise amounts are in closest proximity to city of Santa Monica

3.1.2 Sea-Level Rise Guidance Update of 2018

The California Natural Resource Agency and OPC released 2018 guidance update (OPC 2018) to the 2013 State of California guidance document (OPC 2013). The updated guidance provides a synthesis of the best available science on sea-level rise in California, a step-by-step approach for state agencies and local governments to evaluate sea-level rise projections, and preferred coastal adaptation strategies. The key scientific basis for this update was developed by the working group of the California OPC Science Advisory Team titled *Rising Seas in California: An Update on Sea-Level Rise Science* (Griggs et al. 2017). The above mentioned studies and guidance documents are shown in Figure A-1 to illustrate the relationship between these documents.

Figure A-1
California Sea-level Rise Guidance Documents and Scientific Basis for Each

The 2018 guidance update includes the following key changes and additions to the OPC (2013) guidance:

- **For years before 2050, sea-level rise projections are provided only for the high emissions scenario (RCP 8.5).** The world is currently on the RCP 8.5 trajectory, and differences in sea-level rise projections under different scenarios are minor before 2050.

- **Includes new "extreme" sea-level rise projections associated with rapid melting of the West Antarctic ice sheet.**

- **Shifts from scenario-based (deterministic) projections to probabilistic projections of sea-level rise.** The guidance update recommends a range of probabilistic projections for decision makers to select given their acceptable level of risk aversion for a given project.

- **Provides estimated probabilities of when a particular sea-level rise amount will occur.** In addition to sea-level rise projections that are tied to risk acceptability, updated guidance provides information on the likelihood that sea-level rise will meet or exceed a specific height (1 foot increments from 1 to 10 feet) over various timescales.

The guidance update includes significant advances in the scientific understanding of sea-level rise. Compared to the ***scenario-based*** sea-level rise projections in the 2013 version of state guidance, the updated guidance incorporates ***probabilistic*** sea-level rise projections, which associate a likelihood of occurrence (or probability) with various sea-level rise heights and rates into the future and are directly tied to a range of emissions scenarios (described below). Using probabilistic sea-level rise projections is currently the most appropriate scientific approach for policy setting in California, providing decision makers with increased understanding of potential sea-level rise impacts and consequences. The guidance update also includes an extreme sea-level rise scenario that is based on rapid melting of the West Antarctic ice sheet.

The guidance update now provides a range of probabilistic projections of sea-level rise that are based on two Intergovernmental Panel on Climate Change (IPCC) emissions scenarios called representative concentration pathways (RCPs[3]), as well as a non-probabilistic projection associated with rapid West Antarctic ice sheet mass loss. These three climate scenarios are explained below:

RCP 2.6 *Scenario* – This scenario corresponds closely to the aspirational goals of the 2015 Paris Agreement, which calls for limiting mean global warming to 2 degrees Celsius and achieving net-zero greenhouse gas emissions in the second half of the century. This scenario is considered very challenging to achieve, and is analogous to the low emissions scenario in NRC (2012).

RCP 8.5 *Scenario* – This scenario is consistent with a future where there are no significant global efforts to limit or reduce emissions. This emission scenario is consistent with that used to develop the high emissions scenario in NRC (2012).

H++ Scenario – This extreme scenario was proposed by the OPC Science Advisory Team in response to recent scientific studies that have projected higher rates of sea-level rise due to the possibility of more rapid melting of ice sheets

Table A-4 presents the probabilistic projections of sea-level rise for Santa Monica with additional probabilities for the RCPs and the non-probabilistic H++ scenario (depicted in blue on the right-hand side). High emissions scenario represents RCP 8.5; low emissions scenario represents RCP 2.6. Because differences in sea-level rise projections under the various emissions scenarios are minor before 2050, the update only provides RCP 8.5 projections of sea-level rise up to 2050. **State-recommended projections for use in low, medium-high and extreme risk aversion decisions are outlined by dark blue boxes in Table A-4.** The State suggests that decision makers take a precautionary, risk-averse approach of using the medium-high sea-level rise

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[3] Named for the associated radiative forcing (heat trapping capacity of the atmosphere) level in 2100 relative to pre-industrial levels.

projections across the range of emissions scenarios for longer lasting projects with low adaptive capacity[4] and high consequences[5]. The State further recommends incorporating the H++ scenario in planning and adaptation strategies for projects that could result in threats to public health and safety, natural resources and critical infrastructure such as large power plants, wastewater treatment, and toxic storage sites. The probabilities included in Table A-4 do not represent the actual probabilities of occurrence of sea-level rise, but provide probabilities that the ensemble of climate models used to estimate the contributions of sea-level rise will predict a certain amount of sea-level rise (OPC 2018).

TABLE A-4
OPC (2018) STATE GUIDANCE: PROJECTED SEA-LEVEL RISE FOR SANTA MONICA IN FEET

		Probabilistic Projections (in feet) (based on Kopp et al. 2014)						*H++ scenario (Sweet et al. 2017) *Single scenario*
		MEDIAN	**LIKELY RANGE**			**1-IN-20 CHANCE**	**1-IN-200 CHANCE**	
		50% probability sea-level rise meets or exceeds...	*66% probability sea-level rise is between...*			*5% probability sea-level rise meets or exceeds...*	*0.5% probability sea-level rise meets or exceeds...*	
					Low Risk Aversion		**Medium - High Risk Aversion**	**Extreme Risk Aversion**
High emissions	2030	0.4	0.3	-	0.5	0.6	0.8	1
	2040	0.6	0.4	-	0.8	0.9	1.2	1.7
	2050	0.8	0.6	-	1.1	1.3	1.9	2.6
Low emissions	2060	0.9	0.6	-	1.2	1.5	2.3	
High emissions	2060	1.1	0.8	-	1.4	1.8	2.6	3.8
Low emissions	2070	1.0	0.7	-	1.4	1.9	3.0	
High emissions	2070	1.3	1.0	-	1.8	2.3	3.4	5.1
Low emissions	2080	1.2	0.8	-	1.7	2.3	3.8	
High emissions	2080	1.7	1.1	-	2.3	2.9	4.4	6.5
Low emissions	2090	1.3	0.8	-	2.0	2.7	4.6	
High emissions	2090	2.0	1.3	-	2.8	3.5	5.5	8.1
Low emissions	2100	1.5	0.9	-	2.3	3.1	5.5	
High emissions	2100	2.3	1.5	-	3.3	4.3	6.8	10.0
Low emissions	2110*	1.6	1.0	-	2.4	3.3	6.1	
High emissions	2110*	2.5	1.8	-	3.5	4.5	7.2	11.7
Low emissions	2120	1.7	1.0	-	2.7	3.8	7.3	
High emissions	2120	2.9	2.0	-	4.0	5.2	8.5	14.0
Low emissions	2130	1.9	1.1	-	3.0	4.2	8.3	
High emissions	2130	3.2	2.2	-	4.5	5.9	9.8	16.3
Low emissions	2140	2.0	1.1	-	3.2	4.7	9.4	
High emissions	2140	3.5	2.4	-	5.1	6.7	11.3	18.9
Low emissions	2150	2.2	1.1	-	3.6	5.3	10.8	
High emissions	2150	3.9	2.6	-	5.7	7.6	12.9	21.7

Source: OPC (2018)

The H++ projection is a single scenario and does not have an associated likelihood of occurrence as do the probabilistic projections. Probabilistic projections are with respect to a baseline of the

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[4] Adaptive capacity is the ability of a system or community to evolve in response to, or cope with the impacts of sea-level rise.

[5] Consequences are a measure of the impact resulting from sea level rise, typically quantitative.

year 2000, or more specifically the average relative sea level over 1991 - 2009. Probabilities are approximate, and were established by scientists using models and expert solicitation.

3.2 Federal Guidance

The US Army Corps of Engineers (USACE) issued circular EC 1100-2-8162 in December 2013, which provides guidance for the incorporation of direct and indirect physical effects of projected future sea-level rise (USACE 2013). This circular superseded all previous USACE-issued guidance on the subject, including the prior guidance issued (USACE 2011). According to the circular, planning studies and engineering designs should evaluate alternatives against a range of local sea-level rise projections defined by “low,” “intermediate” and “high” rates of local sea-level rise. The USACE circular suggests using three sea level curves (historic and NRC-I and NRC-III from NRC 1987) modified to reflect the increase in the present rate of global sea-level rise to 1.7 mm per year. USACE (2013) provided guidance on how to incorporate local vertical land motion into the “intermediate” and “high” projections of sea-level rise. Additional guidance can be found in USACE (2014).

In comparison to the State guidance described above, the USACE recommended curves are slightly lower for the respective emissions scenarios. Table A-5 presents a summary of the sea-level rise projections at 2030, 2060, and 2100 using the USACE (2013) guidance for values associated with Santa Monica.[6] For purposes of this study, we recommend using sea-level rise projections that comply with the State guidance.

TABLE A-5
SEA-LEVEL RISE PROJECTIONS FOR SANTA MONICA USING USACE (2013) GUIDANCE

Scenario	2030	2060	2100
Low	0.15 feet	0.30 feet	0.5 feet
Intermediate	0.44 feet	1.04 feet	2.08 feet
High	0.83 feet	2.32 feet	5.35 feet

Note: Values computed using methods described in USACE (2013) with parameters specific to Santa Monica area. See footnote #6 below.

3.3 Comparison and Combination of Federal and State Guidance

Figure A-2 presents a comparison of the updated OPC (2018) sea-level rise guidance to the federal USACE (2013) guidance. The solid, colored lines represent the projections of the new OPC (2018) guidance, and the dashed, colored lines represent the USACE (2013) sea-level rise scenarios for Santa Monica. Figure A-2 illustrates that the USACE (2013) high sea-level rise curve generally falls within the range of values for the medium-high risk aversion from the OPC (2018) guidance, while the USACE (2013) intermediate sea-level rise curve falls within the range of values for the low risk aversion from the OPC (2018). The low scenario for the USACE (2013)

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[6] Sea-level rise projections using the USACE (2013) guidance assume a project start at 2000 to facilitate comparison to State guidance; a subsidence rate of -1.5 mm/yr based on NRC (2012); and a historic sea-level rise rate of 1.53 mm/yr based on NOAA values for Santa Monica NOS station 9410840.

is lower than the recommended projections described by the current State guidance, and not recommended for evaluation in this study. However, the USACE often considers the USACE (2013) low curve for evaluating federal navigation channel dredging projects, and so could be used for project-specific purposes.

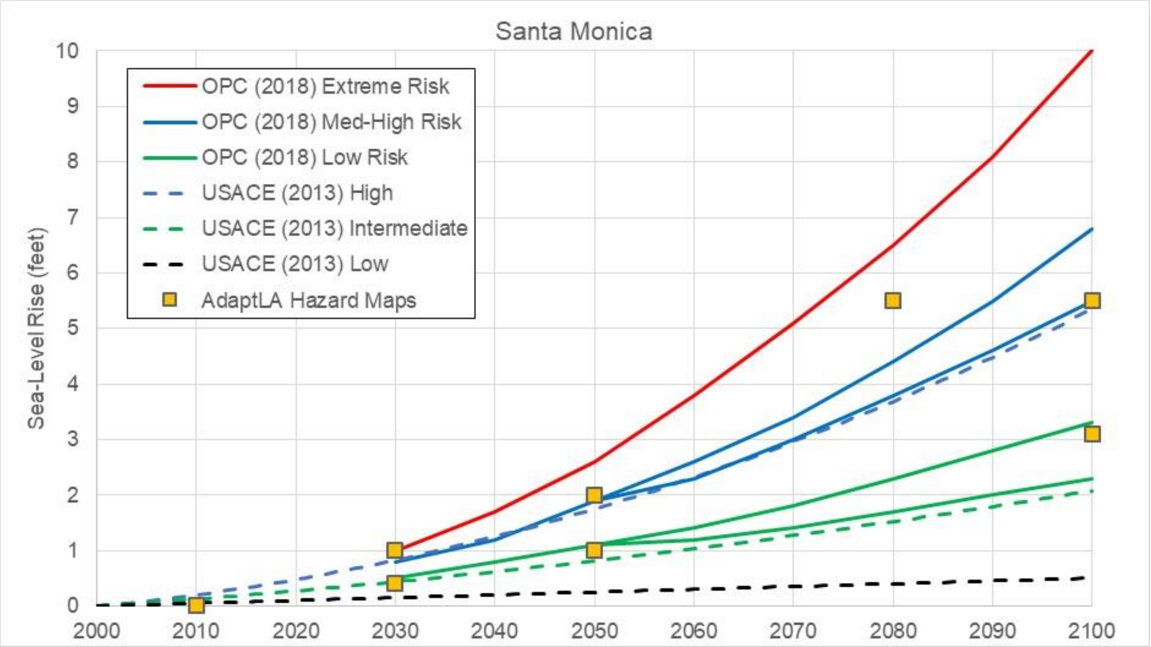

Figure A-2
Comparison of Federal (USACE 2013) and State (OPC 2018) Sea-Level Rise Projections

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Appendix B

Water Levels, Wave Heights and Periods for Annual Maximum Events

Table B-1: Tabulated values of still water level, deshoaled wave height, and wave period for annual maximum events used in wave runup analysis

Year	Date	SWL (ft NAVD)	H_0' (feet)	T_0 (sec)	Data Source
1904	9/10/1904	4.0	15.7	12.0	Hindcast - Walker et al. (1994)
1912	8/10/1912	4.1	13.7	11.8	Hindcast - Walker et al. (1994)
1915	1/28/1915	4.1	11.9	11.8	Hindcast - Walker et al. (1994)
1916	1/26/1916	4.1	11.6	9.6	Hindcast - Walker et al. (1994)
1926	2/1/1926	4.6	16.3	16.0	Hindcast - Walker et al. (1994)
1937	12/6/1937	5.2	13.0	16.4	Hindcast - Walker et al. (1994)
1939	9/15/1939	6.1	17.0	14.0	Hindcast - Walker et al. (1994)
1943	1/20/1943	5.5	4.3	11.0	Hindcast - Walker et al. (1994)
1952	3/13/1952	4.9	12.1	11.8	Hindcast - Walker et al. (1994)
1953	1/6/1953	4.2	19.8	19.2	Hindcast - Walker et al. (1994)
1958	4/1/1958	6.2	8.7	18.2	Hindcast - Walker et al. (1994)
1960	2/10/1960	5.2	11.3	15.9	FEMA (2015) at MOP LA0589
1961	3/25/1961	3.7	7.2	23.3	FEMA (2015) at MOP LA0589
1962	5/20/1962	5.4	6.7	19.2	FEMA (2015) at MOP LA0589
1963	2/10/1963	4.4	15.9	14.4	FEMA (2015) at MOP LA0589
1964	4/6/1964	6.3	7.4	19.2	FEMA (2015) at MOP LA0589
1965	6/15/1965	5.7	7.2	23.3	FEMA (2015) at MOP LA0589
1966	1/30/1966	4.5	9.4	17.5	FEMA (2015) at MOP LA0589
1967	5/25/1967	6.3	4.2	23.3	FEMA (2015) at MOP LA0589
1968	6/7/1968	5.7	9.4	17.5	FEMA (2015) at MOP LA0589
1969	3/21/1969	5.7	6.3	19.2	FEMA (2015) at MOP LA0589
1970	12/7/1969	6.4	8.4	17.5	FEMA (2015) at MOP LA0589
1971	2/23/1971	6.0	8.0	15.9	FEMA (2015) at MOP LA0589
1972	1/28/1972	6.0	4.9	19.2	FEMA (2015) at MOP LA0589
1973	11/17/1972	6.0	6.7	17.5	FEMA (2015) at MOP LA0589
1974	3/26/1974	5.0	10.9	17.5	FEMA (2015) at MOP LA0589
1975	4/25/1975	5.8	7.0	17.5	FEMA (2015) at MOP LA0589
1976	4/14/1976	5.8	7.2	15.9	FEMA (2015) at MOP LA0589
1977	7/29/1976	5.8	4.9	21.2	FEMA (2015) at MOP LA0589
1978	1/9/1978	7.0	9.7	17.5	FEMA (2015) at MOP LA0589
1979	5/8/1979	4.6	7.7	19.2	FEMA (2015) at MOP LA0589
1980	2/20/1980	5.7	16.2	15.9	FEMA (2015) at MOP LA0589
1981	1/22/1981	6.0	13.3	15.9	FEMA (2015) at MOP LA0589
1982	11/13/1981	6.0	5.8	15.9	FEMA (2015) at MOP LA0589
1983	3/1/1983	6.0	21.6	17.5	FEMA (2015) at MOP LA0589
1984	3/16/1984	5.8	5.0	21.2	FEMA (2015) at MOP LA0589
1985	11/25/1984	5.8	4.9	19.2	FEMA (2015) at MOP LA0589
1986	2/16/1986	4.0	17.7	15.9	FEMA (2015) at MOP LA0589
1987	1/12/1987	5.6	6.4	19.2	FEMA (2015) at MOP LA0589
1988	1/18/1988	6.8	22.0	15.9	FEMA (2015) at MOP LA0589
1989	3/25/1989	4.9	6.7	21.2	FEMA (2015) at MOP LA0589
1990	4/26/1990	6.8	3.9	21.2	FEMA (2015) at MOP LA0589
1991	5/30/1991	5.0	7.9	19.2	FEMA (2015) at MOP LA0589
1992	4/17/1992	6.6	4.5	23.3	FEMA (2015) at MOP LA0589
1993	2/8/1993	6.7	11.7	15.9	FEMA (2015) at MOP LA0589

Table B-1: Tabulated values of still water level, deshoaled wave height, and wave period for annual maximum events used in wave runup analysis (continued)

Year	Date	SWL (ft NAVD)	H_0' (feet)	T_0 (sec)	Data Source
1994	12/15/1993	6.1	8.3	17.5	FEMA (2015) at MOP LA0589
1995	6/15/1995	5.2	9.6	19.2	FEMA (2015) at MOP LA0589
1996	12/13/1995	3.8	13.0	15.9	FEMA (2015) at MOP LA0589
1997	2/18/1997	5.1	8.0	19.2	FEMA (2015) at MOP LA0589
1998	1/30/1998	6.1	13.2	17.5	FEMA (2015) at MOP LA0589
1999	5/15/1999	6.5	6.6	19.2	FEMA (2015) at MOP LA0589
2000	1/31/2000	4.8	7.8	20.0	CDIP MOP L0587
2001	1/11/2001	7.1	7.2	18.2	CDIP MOP L0587
2002	1/9/2002	5.8	9.8	18.2	CDIP MOP L0587
2003	12/17/2002	5.7	8.0	18.2	CDIP MOP L0587
2004	1/19/2004	6.5	6.4	15.4	CDIP MOP L0587
2005	3/10/2005	6.2	5.9	18.2	CDIP MOP L0587
2006	12/21/2005	3.8	19.7	16.7	CDIP MOP L0587
2007	12/22/2006	6.4	5.4	16.7	CDIP MOP L0587
2008	12/5/2007	5.3	19.8	18.2	CDIP MOP L0587
2009	2/8/2009	6.9	3.7	16.7	CDIP MOP L0587
2010	2/28/2010	6.5	8.9	15.4	CDIP MOP L0587
2011	1/19/2011	6.7	4.9	16.7	CDIP MOP L0587
2012	1/22/2012	6.4	4.7	20.0	CDIP MOP L0587
2013	2/10/2013	6.2	3.7	20.0	CDIP MOP L0587
2014	3/2/2014	5.3	14.1	14.3	CDIP MOP L0587
2015	12/20/2014	6.4	4.4	18.2	CDIP MOP L0587
2016	1/7/2016	6.4	9.7	16.7	CDIP MOP L0587
2017	1/22/2017	3.0	10.0	20.0	CDIP MOP L0587

Appendix C

Structural Design Considerations for Tsunami Hazards

APPENDIX C

Structural Design Considerations for Tsunami Hazards

This appendix provides additional information on the structural design criteria for consideration of tsunami hazards as part of the supplemental Coastal Hazards Analysis of the West Basin Municipal Water District Ocean Water Desalination Project.

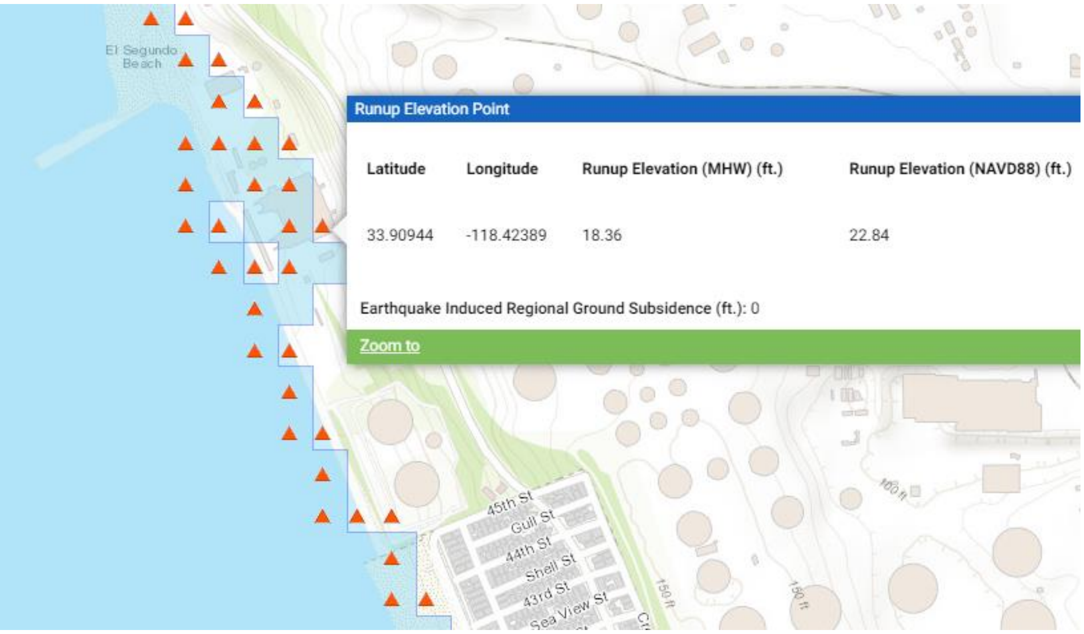
1. Introduction

The American Society of Civil Engineers (ASCE) recently updated the ASCE 7 design standard for determining the minimum design loads for buildings and other structures to include an entirely new chapter on tsunami design loads (ASCE 2017a). A new set of 2,500-year probabilistic tsunami design zone maps were produced for the five Pacific states of the U.S. for use with the ASCE design provisions (ASCE 2017b). An accompanying web-based tool includes the geocoded reference points of the offshore tsunami amplitude and period and the runup elevation associated with the inundation limit of tsunami hazards (ASCE 2017c). The tsunami hazard maps are intended to be used to identify whether a project is located in a tsunami design zone (and not for evacuation or emergency management planning), which would require the structural design to consider the minimum loadings identified by the tsunami design criteria described in the ASCE 7 design standard.

This appendix briefly describes the web-based tsunami hazard design zone and presents a first-cut application of the ASCE 7 design standard guidance for developing tsunami design criteria to be used during design of facilities located in a tsunami hazard design zone.

2. Web-Based Tsunami Hazard Design Zone

Figure C-1 presents a screenshot of the web-based ASCE Tsunami Hazard Tool for the project site, showing that the 2,500-year tsunami inundates the northern portion of the site to approximately elevation 23 feet NAVD. Note that the tsunami runup height is computed relative to the mean high water level datum, as recommended by the ASCE design standard. The ASCE Tsunami Hazard Tool indicates that the offshore tsunami height and period in the vicinity of Santa Monica Bay range from five to nine feet with a period of about 45 minutes (± 4 minutes), respectively. The offshore tsunami height is generally in agreement with the tsunami amplitude of 2 meters analyzed by Jenkins (2016; 2017). Although an event with a return period of 2,500-years has a relatively low likelihood of occurrence in comparison to the 100-year to 500-year flood hazards typically considered, the consequences of a tsunami are much greater and therefore current design guidance requires consideration of tsunamis for Risk Category III and IV structures located within the tsunami design zone. The 2,500-year event has an annual percent exceedance of 0.04%, and a 2% chance of exceedance over a period of 50 years.



Runup Elevation Point

Latitude	Longitude	Runup Elevation (MHW) (ft.)	Runup Elevation (NAVD88) (ft.)
33.90944	-118.42389	18.36	22.84

Earthquake Induced Regional Ground Subsidence (ft.): 0

West Basin MWD Ocean Water Desalination Project: Coastal Hazards Analysis / D170766.01

SOURCE: ASCE Tsunami Hazard Tool, ASCE Tsunami Design Geodatabase Version 2016-1.0: https://asce7tsunami.online/

Figure C-1
ASCE Tsunami Hazard Tool Shows Project Site in Tsunami Design Zone

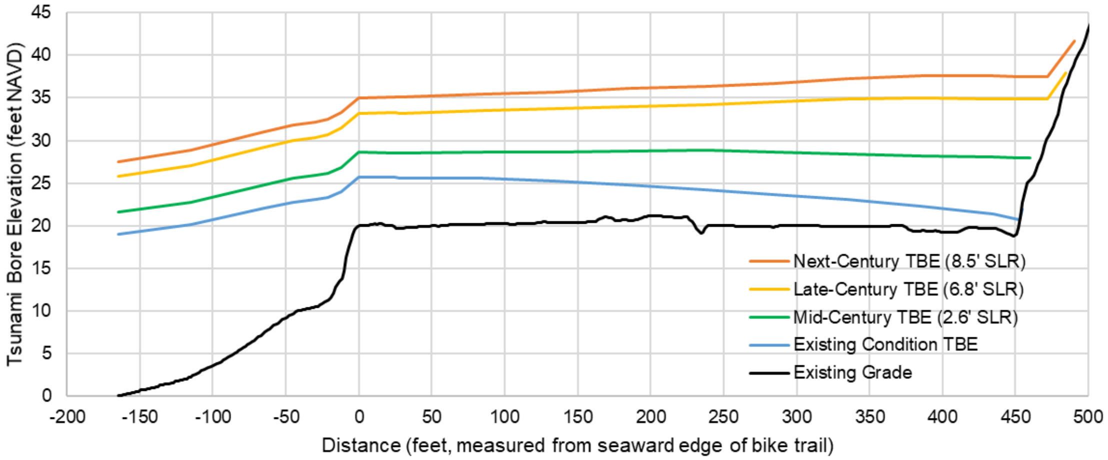
3. Development of Tsunami Design Criteria

Chapter 6 of the ASCE 7 design standard presents requirements for determining whether buildings and other structure located in a tsunami design zone shall be designed for “the effects of Maximum Considered Tsunami, including hydrostatic and hydrodynamic forces, waterborne debris accumulation and impact loads, subsidence, and scour effects…” (ASCE 2017a). The design inundation depth and flow velocity are two primary criteria used in the determination of design loads for structural design. The ASCE 7 design standard presents two types of analyses to develop the design inundation depth and flow velocity:

- Energy grade line analysis of maximum inundation depths and flow velocities
- Site-specific inundation and flow study using numerical modeling techniques (if required)

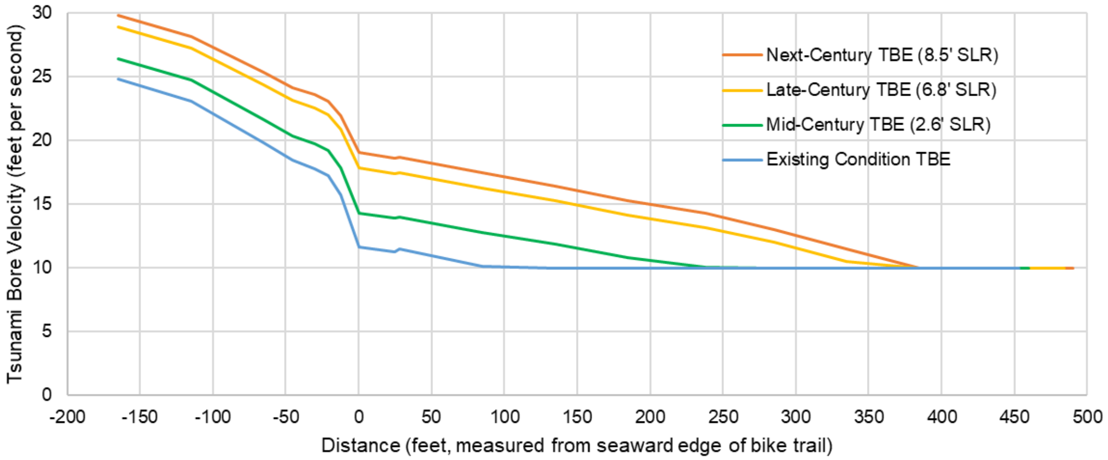
Selection of the energy grade line and/or site-specific analysis depends on the risk category of the building (e.g., risk category IV buildings and structures require both methods), and other site or tsunami characteristics that violate the assumptions of the energy grade line analysis. The information presented below is based only on application of an energy grade line analysis.

Figure C-2 and Figure C-3 present profiles of the design water surface elevation and velocities, respectively, resulting from a design tsunami event for existing and future conditions with sea-level rise. The 2016 edition of the ASCE 7 design standard outlines procedures to determine the design inundation depths and velocities along a transect across the site, based on the offshore tsunami characteristics and runup elevation in the ASCE Tsunami Hazard Tool. The design water surface elevation and velocities were computed using an energy grade-line method, as described in Section 6.6 of the ASCE 7 design standard (ASCE 2017a). Although the actual computed velocities were lower, the ASCE 7 design standard requires a minimum velocity of 10 feet per second to be used in the calculations. These are preliminary values computed to inform project designers of the need to consider tsunami loads, but are not necessarily appropriate for design.



West Basin MWD Ocean Water Desalination Project: Coastal Hazards Analysis / D170766.01

Figure C-2
Design Water Surface Elevation Profiles of Tsunami Bore at Transect 3 for Existing and Future Conditions with Sea-Level Rise



West Basin MWD Ocean Water Desalination Project: Coastal Hazards Analysis / D170766.01

Figure C-3
Design Velocity of Tsunami Bore at Transect 3 for Existing and Future Conditions with Sea-Level Rise

The calculations of the energy grade-line (not shown on figure for simplicity) and design water level for existing conditions are first made at the limit of runup, where the energy grade-line equals the water level, and then the analysis steps seaward across the site. The future cases with sea-level rise were analyzed by adding the sea-level rise to the seaward-most calculation point (located at 0 feet NAVD contour), and then stepping landward through the energy grade-line calculations until the runup limit is determined within a reasonable tolerance. It should be noted that the ASCE 7 design standard does not provide clear direction on incorporating the future sea-level rise into the energy grade-line calculation, and recommends adding the amount of sea-level rise to both the reference water level and the runup elevation. This approach recommended in the ASCE 7 design standard may be sufficient as an initial order of magnitude estimate, but the runup should be expected to respond non-linearly to changes in sea-level (Battalio et al. 2016). Therefore, for this analysis, only the reference water level was increased with sea-level rise, and the runup limits and elevation for future conditions were estimated from the energy grade-line calculations.

4. References

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Appendix 15B

Example Revised Site Plans

ESA

Memorandum

August 23, 2019

To:	Alejandra Cano, West Basin Municipal Water District	Ref. No.:	11187218
From:	Brian Leslie, Mark Donovan, PE, GHD	Tel:	949.585.5251
CC:			

Subject: **West Basin Ocean Water Desalination Project - Example Site Layouts Considering Coastal Hazards**

1. Introduction

The Coastal Hazards Analysis prepared by ESA in May 2019 concludes that portions of the ESGS Site would be potentially vulnerable to flooding from future unmitigated coastal flood hazards, including from strong wave surge and tsunami inundation under future sea level rise (SLR) scenarios. This memorandum provides two examples of how the West Basin's proposed Ocean Water Desalination Project (Project) could be designed on the North Site of the NRG property in El Segundo, California that would minimize conflicts with the applicable Coastal Act requirements until the years 2032 to 2075; sometime past mid-century but prior to late-century.

The Project would produce 20 million gallons per day (MGD) of potable water supply (Local Project). The proposed Project facilities, as analyzed in the Draft EIR, is shown in Figure 1.

2. Example Site Layouts Considering Coastal Hazards

Given the existing and projected future coastal hazards, two conceptual site layouts were developed to accommodate coastal hazards. The two layouts are anticipated to provide protection from flooding associated with (1) 100-yr return period wave hazards in the existing condition; and (2) 2.6' of SLR, which would provide protection until mid-to-late century (OPC 2018). The layouts are only conceptual and the considered adaptation strategies may be implemented individually or in various combinations.

2.1 Layout 1: Project Components Moved Inland Concept

Layout 1 would relocate the Local 20 MGD Project components that are most sensitive to flooding further inland on site (Figure 2). This includes the Electrical Substations/Electrical Buildings and Chemical Storage Area. The more robust components, namely the Reverse Osmosis and Pretreatment building, and the Intake Pump Station, are located on the seaward side of the property, but moved inland approximately 200 feet from the seaward edge of the bike trail.

Additionally, the Administration Building would be located on the western side of the property (seaward edge approximately 50 feet from bike trail) but would be elevated on piles to raise the first floor and provide floodable, at-grade parking underneath the building. The administration building's first floor freeboard is anticipated to be a minimum of 10 feet.

2.2 Layout 2: Elevated Project Site Concept

The Local 20 mgd Project could be positioned on a 4-foot raised pad to accommodate coastal flood hazards through mid- to late-century (Figure 3). The raised pad would be approximately 100 feet from the seaward edge of the bike path and could slope up at a 3:1' (H:V). The surface of the slope is anticipated to be roughened with landscaping or rock to reduce run-up potential up the slope during extreme events.

In addition to raising the site elevation, Project components that are most vulnerable to flooding were strategically located on the most landward portion of the site. The Chemical Storage Area and Electrical Substations/Electrical Buildings, in the locations specified, would be outside of the projected late century 100-year run-up limits.

3. Conclusions

Both relocation and design options outlined in this memo alleviate the vulnerability to unmitigated flooding as outlined in the ESA Coastal Hazards Analysis. They are both anticipated to provide protection from flooding associated with 100 year return period wave hazards in the existing condition and 2.6' of SLR (mid- to late-century). These layouts are examples only, and there are likely other design considerations that could be implemented to address vulnerabilities.

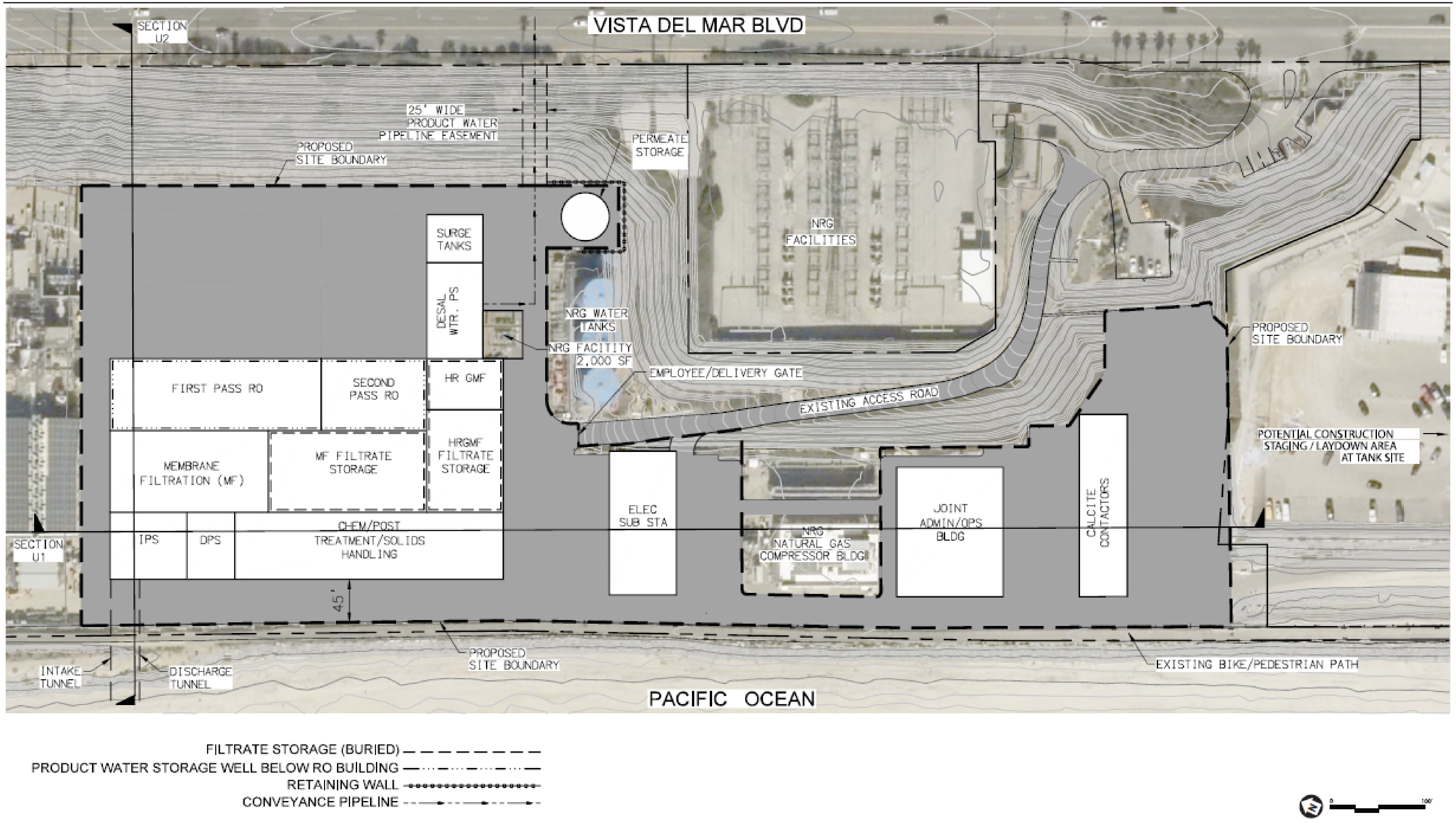

Figure 1. 20 MGD Project Facility Layout as Proposed in Draft EIR (ESA 2018)

FIGURE 2. LAYOUT 1 - SHIFTED INLAND CONCEPT - PLAN VIEW

FIGURE 3. LAYOUT 2 - ELEVATED PROJECT SITE CONCEPT - PLAN VIEW