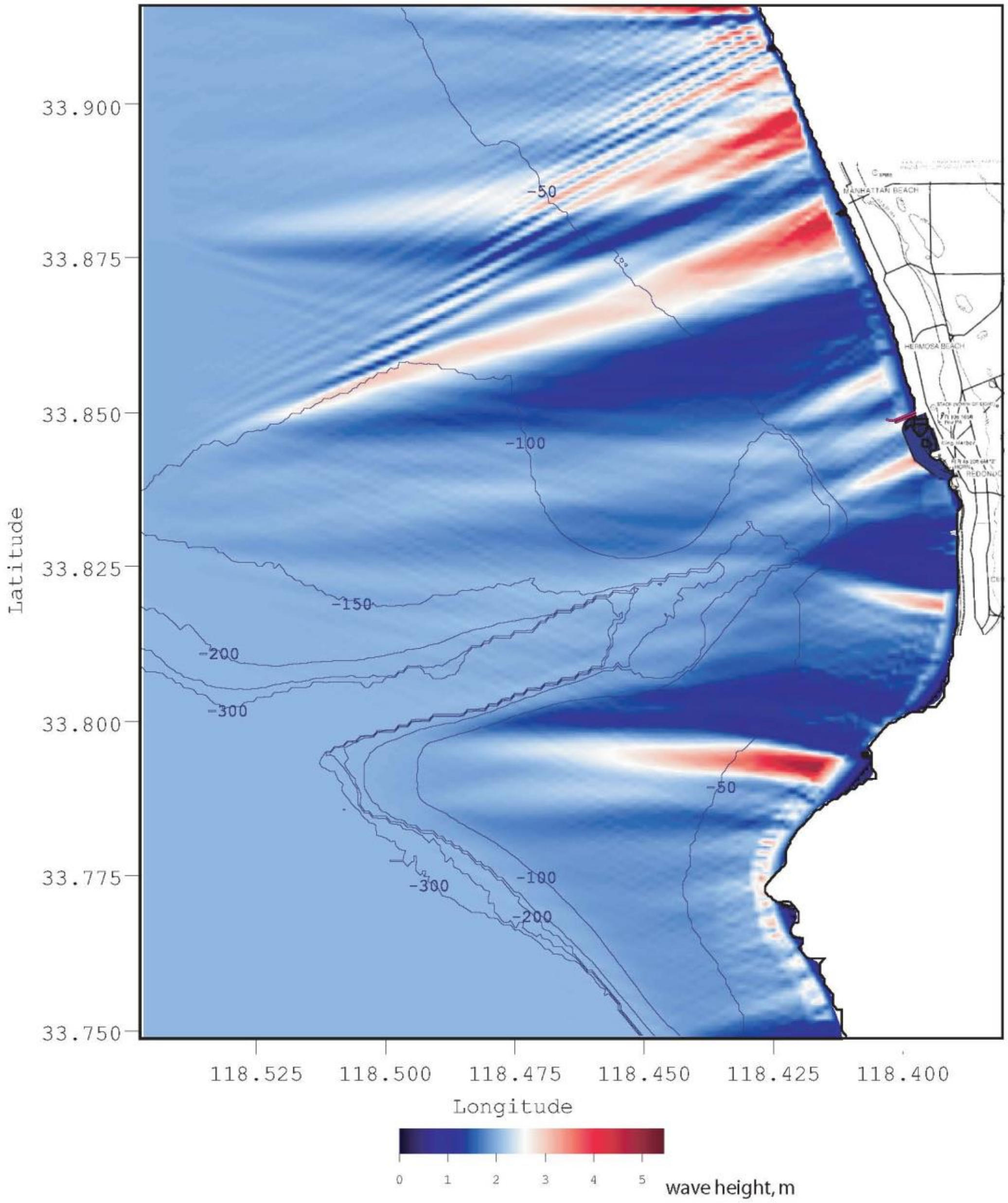
Technical Memorandum: Coastal Hazards Analysis of the West Basin Municipal Water District Ocean Water Desalination Project for Sea Levels at Year 2100



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20 February, 2017

Submitted to
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Executive Summary

This is an update to an antecedent study Jenkins (2016) in order to extend the analysis of that study to projected sea levels by year 2100. All the beach front facilities for the West Basin Desalination Project (which are at minimum elevations of +23 ft. NAVD) are safe from flooding or inundation by extreme event waves that are concurrent with extreme ocean water levels at the low range projection of sea level rise for 2100. However, at the high range of sea level rise projections for year 2100, there is a 0.04% chance that the maximum total water level events reach $TWL_{\max}$ = 26.02 ft. NAVD for the eroded beach conditions and $TWL_{\max}$ = 23.93 ft. NAVD for the accreted beach conditions. This would mean that the bike trail could be flooded by as much as 1 ft. to 3 ft. of overtopping from extreme wave run-up by year 2100, resulting in overtopping rates of Q' = 0.041 cfs/ft to 0.23 cfs/ft when extreme waves and extreme ocean water levels occur concurrently. At the ESGS North site, overtopping of the bike trail will be blocked by the NRG sea wall and by a perimeter wall (flanking weir gate), both of which have crest elevations at +28 ft. NAVD to +29 ft. NAVD. The perimeter wall is a new site feature proposed for the West Basin Desalination Project to prevent the bike trail over-pour flows from freely flowing around the southern flank of the NRG sea wall; thereby preventing flooding of the pad on which the desalination facility is proposed to be built, (which is at elevation +23 ft. NAVD). At the ESGS South site, the desalination facilities construction pad is proposed to be excavated below existing grade to + 23 ft. NAVD, but that site remains protected by the unexcavated portions of the existing land forms and vegetated berms which have crest elevations ranging from +30 ft NAVD. Hence the post-excavation land forms at the ESGS south site are sufficiently high to avoid flooding by the highest combinations of extreme waves and ocean water levels that may occur concurrently at 2100 sea levels.

On the other hand, Appendix-B of the *California Coastal Commision Sea Level Rise Policy Guidance* document (CCC, 2015) provides no specific guidance on the redline frequency for flooding or inundation. In the absence of such guidance we could adopt Federal Emergency Management Agency (FEMA) standards for flooding frequency and set redline planning frequency at the 100 year event (1% probability of recurrence). If we adopt the FEMA 1% standard, then the severity of overtopping and potential flooding of the project site is reduced to nil. For a 1% recurrence frequency, the highest total water levels only reach 1% TWL = 20.21 ft. NAVD for eroded beach conditions; whence both the bike trail and the ESGS sites experience no overtopping.

1) Introduction

Appendix-B of the *California Coastal Commision Sea Level Rise Guidance Policy Guidance* document (CCC, 2015) requires that coastal hazards analyses consider sea level rise impacts over the project lifetime. Precedence from antecedant desalination projects have typically used project lifspans of 50 years (SEIR, 2010), which was subsequently used in an antecedent coastal hazards study for the West Basin Desalination Project**,** (see Jenkins, 2016**).** However, the Chapte 6 guidance of (CCC, 2015) recommends 100 year planning horizons for critical infrastructure projects. The difficulty with implementing this recommendation follows from the fact that the NRC sea level projections (NRC, 2012) on which the the Appendix-B guidance is based, do not extend beyond year 2100. This makes an analysis of sea level impacts for a 100 year project life

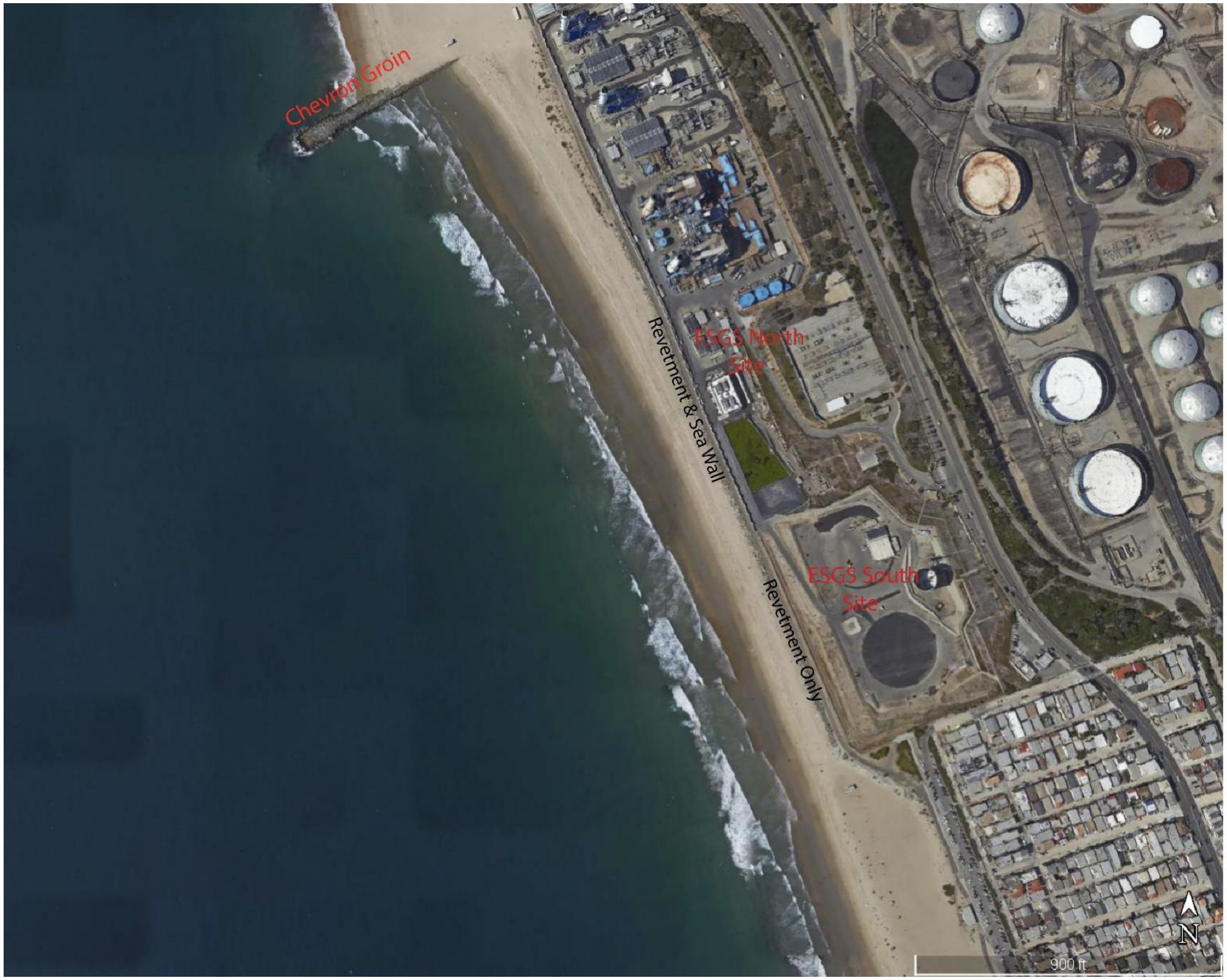

Figure 1: Aerial Image showing beach width variations south of the Chevron Groin. Note uniformly narrow beach in front of the bike trail revetment at the ESGS North and ESGS South sites.

Figure 2: Sea wall at the ESGS North Site, crest elevation =+ 28 ft. to + 29 ft. NAVD

Figure 3: Bike trail perched atop a rip-rap revetment at ESGS site; crest elevation Z = +22 ft to + 23 ft. NAVD

not possible with the West Basin Desalination Project. Furthermore, the Appendix-B guidance admits, "The uncertainty associated with any projections for sea level grows significantly as the time period increases and there are large uncertainties in projections for sea level rise in the year 2100 and beyond." But, Appendix-B guidance also states, "Since there has been little, if any, measureable rise in sea level since 2000 for most locations in California (Bromirski *et al.* 2011; NOAA 2013), there is little reason or justification for adjusting sea level rise projections from the year 2000 baseline to a more current date when analyzing projects with start dates prior to about Year 2015 or 2020". Therefore, the present analysis will use 2100 as the ultimate planning horizon for the West Basin Desalination Project based on this interpretation of Chapter 6 guidance for a critical infrastructure project.

The proposed desalination facility site is located at the existing 33-acre NRG El Segundo Generating Station (ESGS). On the ESGS property, (Figure 1) two project sites are being considered: 1) the ESGS North Site; and 2) the ESGS South Site. The ESGS North Site is an approximate 8-acre area located in the middle of the ESGS property which was the previous site for Units 3 & 4 that were recently decommissioned (December 2015). The ESGS North Site is bounded on the east by Vista Del Mar, on the west by the Marvin Braude Coastal Bike Trail, (Figure 3), and on the south by the ESGS South Site and on the north by newly commissioned Units 5, 6, and 7. Due to its previous use for Units 3 and 4, virtually the entire site is a level pad at approximate elevation Z = +23 ft NAVD. The important features with respect to a coastal hazards analysis site is the presence of a seawall, (Figure 2), immediately landward from the bike trail. The elevation of the crest of this seawall ranges from Z = +28 ft. NAVD at the north end rising slightly to Z = +29 ft. NAVD at the south end which is bounded by a fence along the boundary with the ESGS site. Other significant shoreline fortifications are the bike trail itself which is perched atop a rip-rap revetment at elevation Z = +22 ft NAVD at the north end of the sea wall and elevation Z = +23 ft NAVD at the south end of the sea wall. The revetment fortifies a low bluff that boarders the back beach.

The ESGS South Site is bounded on the east by an existing cutter oil tank which will remain in operation, on the west by the Marvin Braude Coastal Bike Trail, on the south by 45th Street and on the north by the northern edge of an elevated level pad that was the site of the previous fuel-oil tanks. The desalination facilities construction pad is proposed to be excavated below existing grade to + 23 ft. NAVD, but that site remains protected by the unexcavated portions of the remnant pad and existing land forms with crest elevations standing at +30 ft. NAVD at their lowest point (cf. APPENDIX-1). From these remnant landforms, vegetated slopes fall away to the west to a berm at Z = + 25 ft. NAVD. The berm then slopes down to the existing bike trail below whose road bed is at Z = +23 ft. NAVD. This slope was recently planted and landscaped as part of NRG's redevelopment project for Units 5, 6, and 7. Also as part of that redevelopment project, a land-scape berm at elevation Z = +25 ft. NAVD was constructed at the south boundary bordering on 45th Street.

2) Appropriate Sea Level Rise Projections

Appendix-B of CCC, (2015) permits either of two methods derived from the NRC report (NRC, 2012) for making sea level projections, 1) the *linear interpolation method*, and 2) the *best fit equation.* Sea level projection estimates using the "best-fit" equation are slightly less than estimations based on linear interpolation because the NRC's sea level curves are concave upward (sea level rise is expected to accelerate over the 21st Century). Therefore, we select the best-fit equation method for the sea level rise projections used in this study.

Since the West Basin Desalination Project is located well south of Cape Mendocino, the appropriate best fit equation for use in the DDP coastal hazards analysis is:

$$SLR = 0.0093t^2 + 0.7457t \quad \text{(upper-range projection)} \qquad (1)$$

$$SLR = 0.0038t^2 + 0.039t \quad \text{(lower-range projection)} \qquad (2)$$

Here, *SLR* is the sea level rise in centimeters (cm) and *t* is the time in years after the year 2000 baseline. Figure 4 plots the sea level rise projections from equations (1) & (2). For the critical infrastructure planning horizon at 2100, sea level rise is projected range from 1.37 ft to 5.50 ft. These values will be used in the calculations of extreme total water levels (TWL's) in the following sections.

3) Wave Run-up and Overtopping Statistical Analysis

This section uses the data bases described in the previous coastal hazards analysis by Jenkins (2016) to evaluate Steps-4 & 5 of a sea level rise/coastal hazards analysis as outlined in Apprendix-B of CCC(2015). We seek to quantify the probability of occurrences of *extremal total water levels* where the total water level (TWL) is the sum of the total run-up and the still water level (SWL). The total run-up, *R*, is a dynamic water level variation caused by wave shoaling and breaking, and is composed of three components: wave setup, $<\eta>$, dynamic wave setup, η_{rms} ; and incident wave run-up, R_{inc}. These run-up components are dependent on the extremal wave heights, which were evaluated from a composite 34-year wave record at the ESGS site assembled previously in Section-5 of Jenkins (2016). The composite 34-year wave record was obtained from the CDIP archival data for 1980-2010 (Figure 4.11 in Jenkins, 2016) was iteratively fit to Weibull (Type III) distributions with a range of *K-values* to find the best overall fit (highest correlation coefficient). A *K-value* of K = 1 was found to give an R-squared = 0.98, resulting in the extremal analysis curve shown in Figure 5. The red-line in Figure 5 is the Weibull Type III best fit and the crosses are the data points at the control point in 12 m water depth from refraction/diffraction analyses in Jenkins (2016), which produce the best fit distribution. The Weibull Type III best fit projects a maximum significant wave height of H_0' = 19.9 ft. with a probability of recurrence of 0.04% (return period = 2,500 yr); but such a wave has never been measured. The highest wave that was recovered from the refraction analysis in 12 m of water depth was due to the 18, January, 1988 storm (see cover Figure) with a significant wave height H_0' = 15.5 ft. and a probability of recurrence of 1.0% (return period = 100 yr). The extremal analysis curve in Figure 5 will be the computational basis of the extreme value analysis of wave setup, total run-up and total water level (TWL).

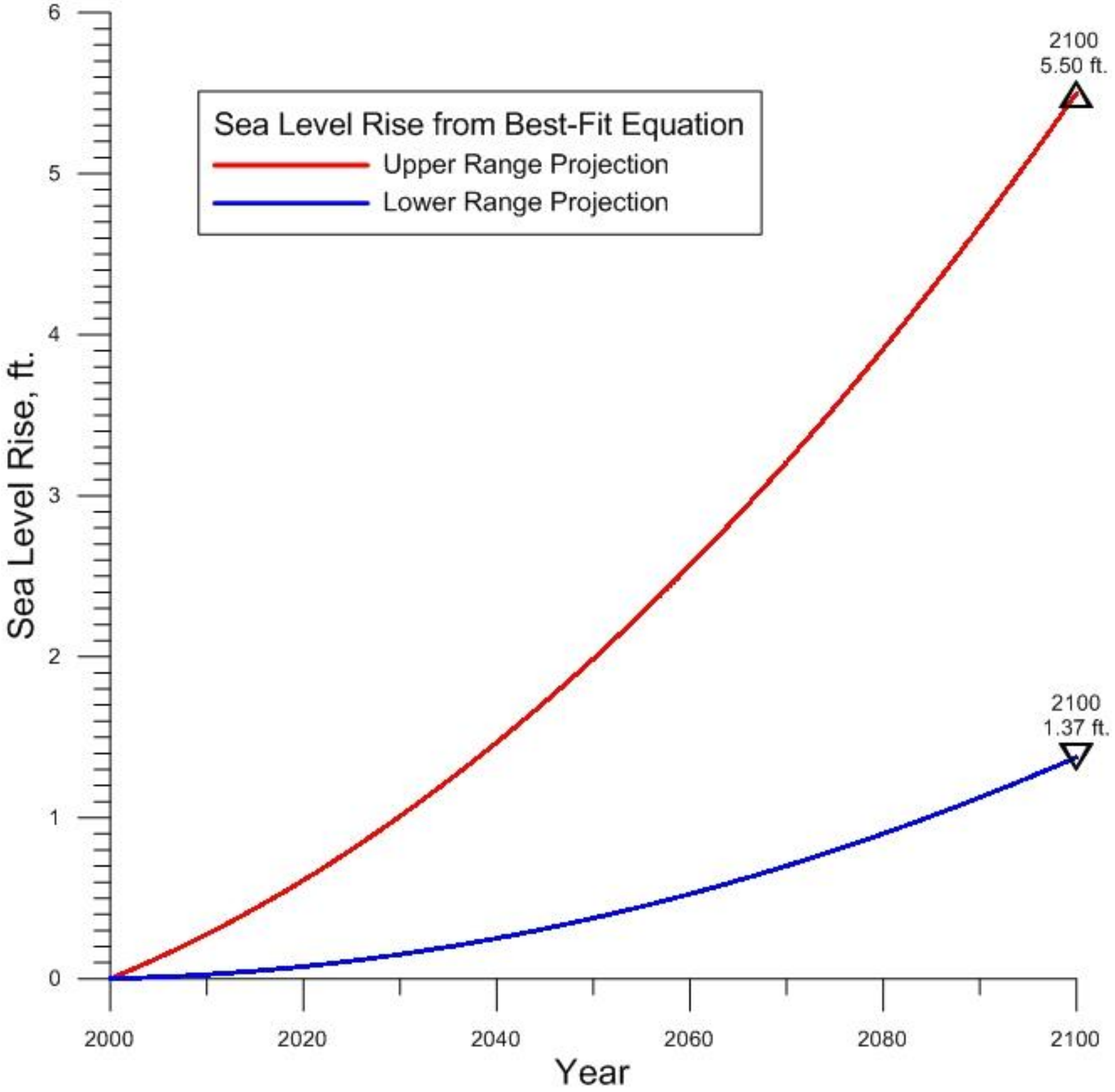

Figure 4: Range of sea level rise projections from the best-fit equation, (CCC, 2015, Appendix-B). 2070 and 2100 planning horizons indicated by symbols on the upper and lower range curves.

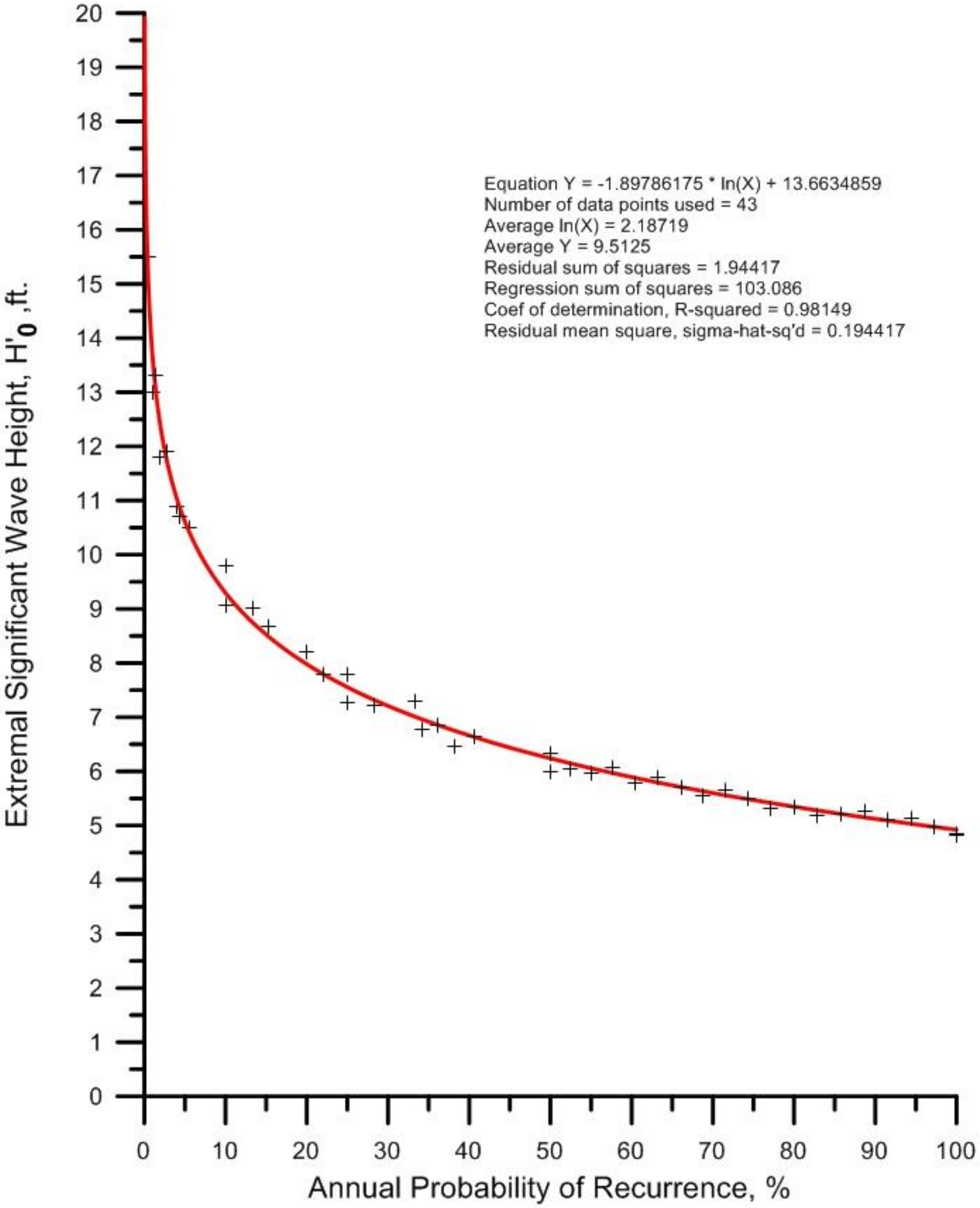

Figure 5: Probability of recurrence of design wave heights based on Weibull extremal analysis of significant wave heights at the ESGS site. Analysis based on Weibull Type III distribution applied to 12 m local water depth with K = 1.0. Recurrence Probability *P*(*H*) = 100%/*T*, where *T* = return period

We will begin by setting the still water level equal to present or future mean sea level, which will allow us to isolate the total run-up as an independent dynamic process whose probability is uniquely determined by the extremal wave height curve in Figure 5. We will then solve for *extremal total water levels* (TWL_{max}) by admitting to probability of occurrences of still water levels higher than mean sea level; which results in a joint probability analysis of occurrence of extremal wave heights concurrent with extreme ocean water levels.

Figures 6 - 8 give the annualized probability of recurrence of total run-up and its components of static wave setup, dynamic wave setup, and the total oscillatory swash component based on the extremal wave analysis curve in Figure 5 as applied to equations (16)- (22) in Jenkins (2016). For each component of total wave run-up, there are two sets of curves, representing eroded and accreted conditions at NRG El Segundo City Beach survey ranges in Figure 4.5 of Jenkins (2016). In all cases, the maximum water elevations are greater for the eroded beach conditions than for the accreted beach conditions. This is due to the fact that eroded beaches produce deeper local water depths at the toe of the rip-rap revetment that fronts the bike trail, and deeper local water depth result in higher bore heights and higher run-up elevations in the bar-berm section of the profile where waves are breaking and producing run-up. Inspection of Figure 8 indicates that maximum run-up is 15.4 ft. for the eroded beach conditions and 13.1 ft. for the accreted beach conditions, with a probability of recurrence of 0.04%.

The total run-up in Figure 8 is superimposed on the still water elevation to give the total water level. The annualized hydro period function of still-water level elevations at present sea level is plotted as the cyan colored line in Figure 9, based on the NOAA gage station #9410660 Los Angeles ocean water level data (surrogate for the ESGS site). Because both the Los Angeles NOAA tide gage and the West Basin Desalination Project are sited in locations with narrow continental shelfs of only about 4.5 km in width, it is reasonable to assume that the local tidal dynamics will not be altered by higher future sea levels (ie, sea level rise will not cause any new resonance or damping effects of the astronomic tides across the continental shelf). It is not known how ENSO or PDO climate cycles might be altered by global warming and higher sealevels, but for now it is resonable to assume that the hydroperiod function of still water elevations at future sealevels can be obtained by linear superposition of the present hydroperiod function in Figure 9 (cyan curve) and the sea level rise projections in Figure 4. By that approach, the hydro period function of still-water level elevations was obtained at 2100 sea level in Figure 9 (green and red curves). At the year 2100 planning horizon for critical infrastructure, low range projections in Figure 9 (green curve) indicate that mean sea level increases to MSL = +3.91 ft NAVD while extreme high water increases to EHW = +8.84 ft. NAVD, while mean higher high water increases to MHHW = + 6503 ft. NAVD. At the high range 2100 projections, (Figure 9, red curve) mean sea level increases to MSL = +8.04 ft. NAVD; extreme high water increases to an astonishing EHW = +12.97 ft. NAVD, and mean higher high water increases to MHHW = + 10.63 ft. NAVD. Inspection of Figure 9 indicates that recurrence probability for mean higher high water levels are $P(\text{MHHW}) = 13\%$ and $P(\text{MHW}) = 28\%$ for mean high water levels; while intuitively the recurrence probability for mean sea level is $P(\text{MSL}) = 100\%$. The extreme high water level event is a less than 1% event at $P(\text{EHW}) = 0.06\%$.

3.1) TOTAL WATER LEVEL ANALYSIS FOR EXTREMAL STILL WATER LEVELS

In this section we provide an analysis of total water levels due to extreme waves concurrent with extreme ocean water levels (extremal TWL's). The recurrence frequency (or return period) for these extremal TWL's is given by the joint probability of occurrence of extremal wave heights concurrent with extreme ocean water levels, or:

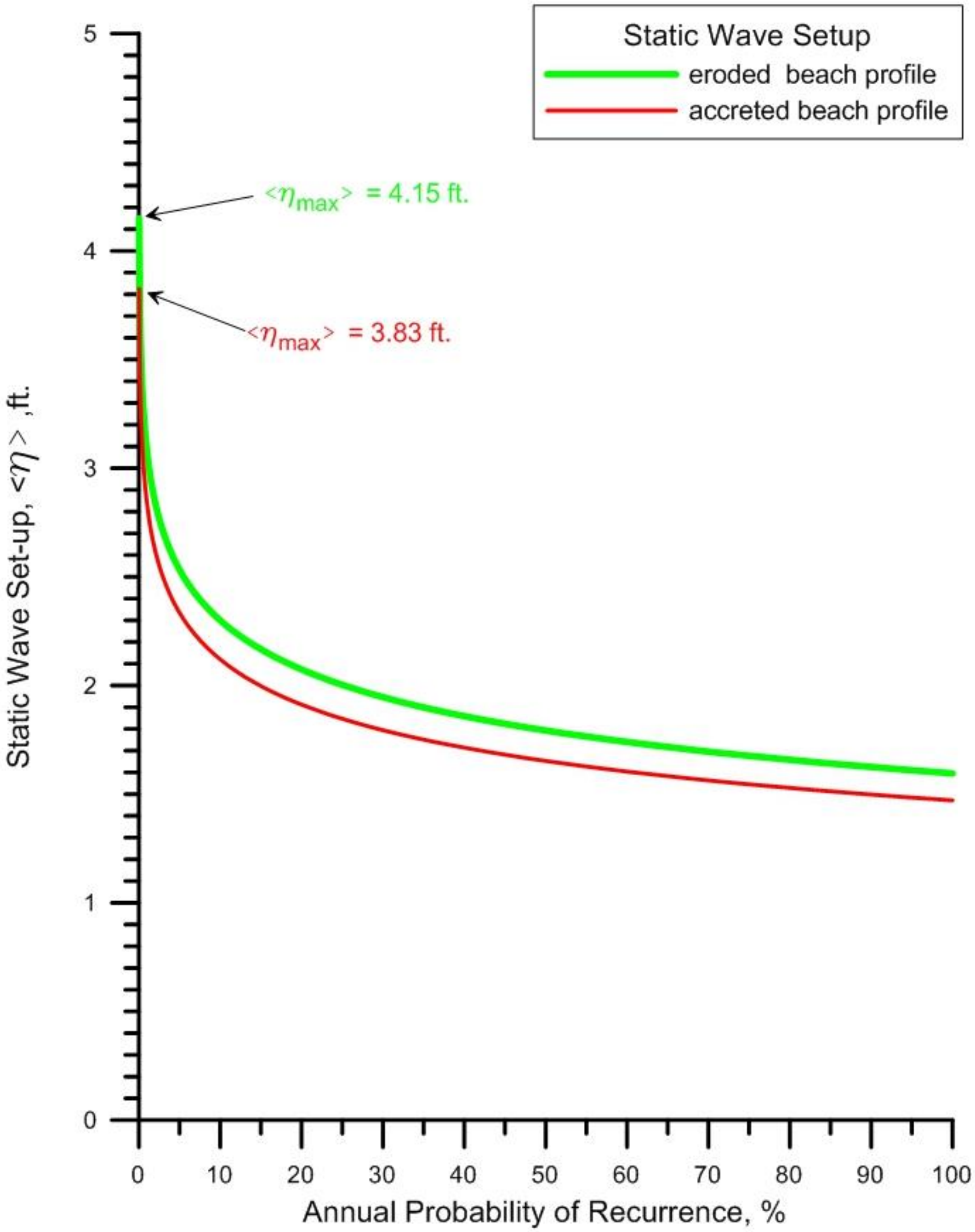

Figure 6: Probability of recurrence of static wave setup at El Segundo City Beach based on extremal design wave heights from Weibull Type III distribution (cf. Figure 5)

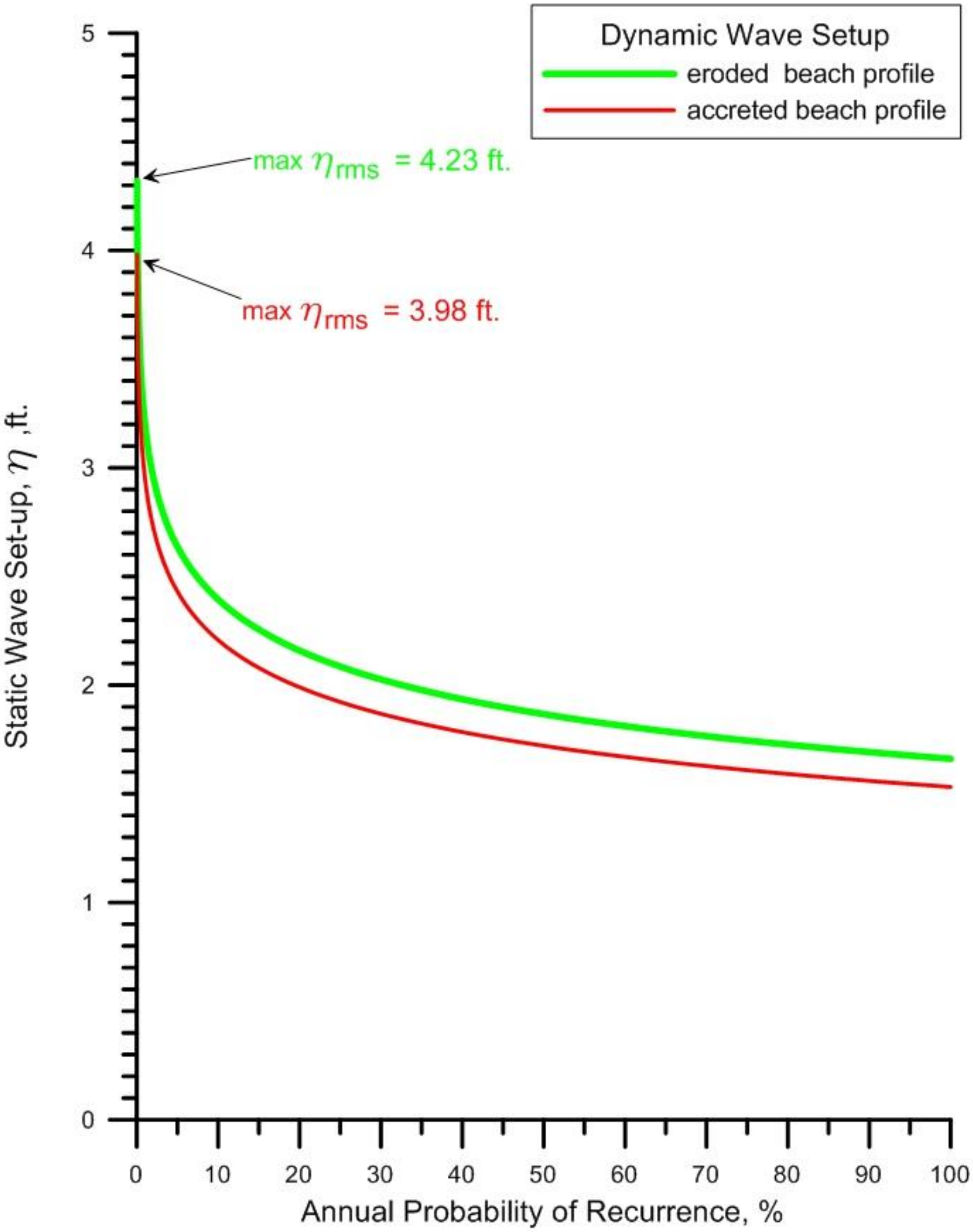

Figure 7: Annualized probability of recurrence of dynamic wave setup at El Segundo City Beach based on extremal design wave heights from Weibull Type III distribution (cf. Figure 5)

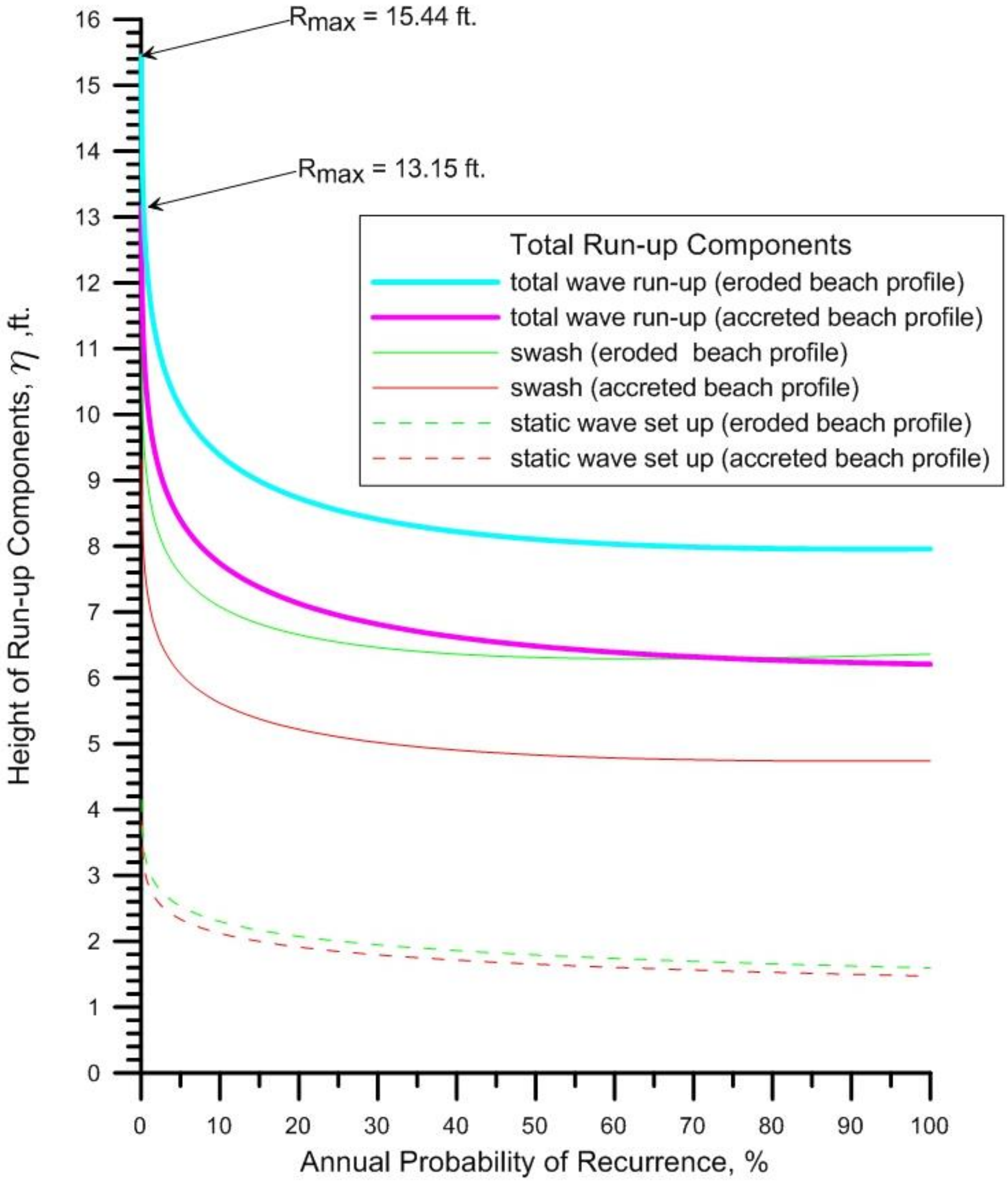

Figure 8: Annualized probability of recurrence of total wave run-up (and its components) at El Segundo City Beach based on extremal design wave heights from Weibull Type III distribution, (cf. Figure 5)

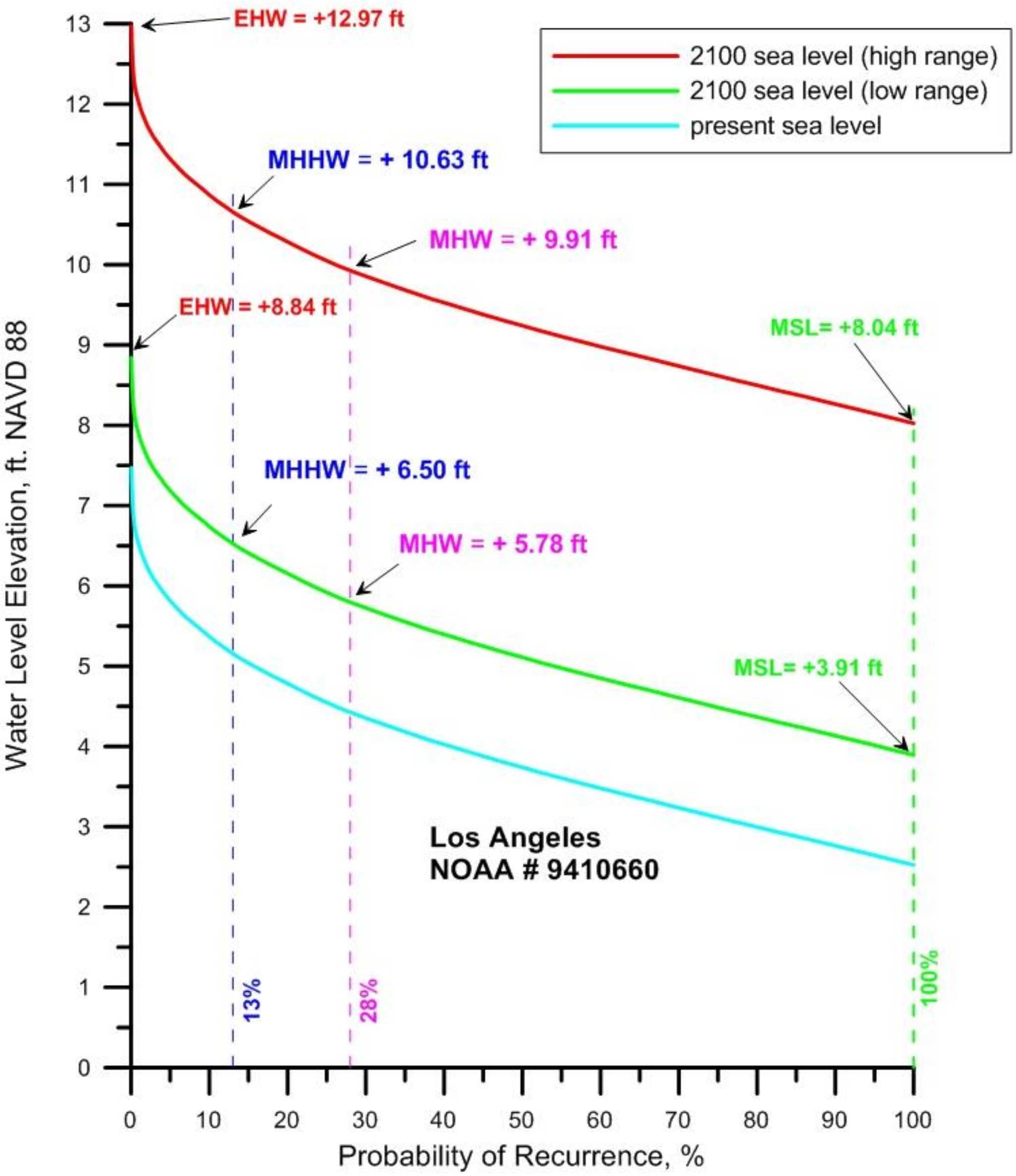

Figure 9: Hydro period function of still-water level elevations at 2100 sea level, based on ocean water level measurements at the Los Angeles gage station, NOAA #9410660, for the period of record 1924-2016. Tidal datums based on the 1983-2001 tidal epoch (latest datum analysis period).

$$P(TWL_{\max}) = P[R, Z_i] = P[R(H'_T] \bullet P_{i,j}(Z_i) \qquad (3)$$

where H'_T is the extremal significant wave height with return period of T years; $P_{i,j,}(Z_i)$ is the annualized probability of ocean water levels reaching an elevation of Z_i feet NAVD 88 from the hydro period function in Figure 9; $P[R(H'_T)]$ is the annualized probability of total run-up from the sum of equations (16) and (22) in Jenkins (2016), based on the probability of extremal wave heights with return frequency of once every T years, $P(H'_T)=1/T$, (cf. Figure 8). The total run-up calculations using extremal wave heights are based on the direct integration method (DIM) from Section 3 of Jenkins (2016).

Appendix-B of the *California Coastal Commision Sea Level Rise Policy Guidance* document (CCC, 2015) provides no specific guidance on the redline frequency for flooding or inundation. In the absence of such guidance we have adopted Federal Emergency Management Agency (FEMA) standards for flooding frequency and set redline planning frequency at the 100 year event (1% probability of recurrence). The 100 year wave event was the two day storm of 17-18 January, 1988, which produced deep water significant wave heights off El Segundo City Beach reaching 15.5 ft., approaching the beach from 270^0 with 15 second significant wave periods.

An analysis of extremal total water levels, (TWL's), based on the occurrence of extreme waves concurrent with extreme ocean water levels is found in Figures 10 & 11. For the low-range 2100 sea level projections, (Figure 11) the maximum total water level events (having a recurrence probability of 0.04%), reach $TWL_{\max}$ = 20.02 ft. NAVD for the eroded beach conditions and $TWL_{\max}$ = 17.72 ft. NAVD for the accreted beach conditions; again enforcing the original conclusions in Jenkins (2016) that all the beach front facilities for the West Basin Desalination Project (which are at elevation of at least +23 ft. NAVD) are safe from flooding or inundation by extreme event waves that are concurrent with extreme ocean water levels at the low range projection of sea level rise for 2100. But, for the high-range 2100 sea level projections, (Figure 11) the maximum total water level events could reach as high as $TWL_{\max}$ = 26.02 ft. NAVD for the eroded beach conditions, or $TWL_{\max}$ = 23.93 ft. NAVD for the accreted beach conditions. The joint probability of these extreme total water levels is very remote, $P(TWL_{\max})$ = 0.04%, because it relies on the highest observed wave in Figure 5 occurring simultaneously with the highest observed water level in Figure 9. Consequently there is only a 0.04% chance that the bike trail could be flooded by as much as 1 ft. to 3 ft. of overtopping from the highest possible wave run-up by year 2100, resulting in overtopping rates of Q' = 0.041 cfs/ft for accreted beach conditions, and Q' = 0.23 cfs/ft for eroded beach conditions, (Figure 12). However, the project sites are protected against these extreme overtopping events. At the ESGS North site, overtopping of the bike trail will be blocked by the NRG sea wall and by a perimeter wall (flanking weir gate), both of which have crest elevations at +28 ft. NAVD. The perimeter wall is a new site feature proposed for the West Basin Desalination Project to prevent the bike trail over-pour flows from freely flowing around the southern flank of the NRG sea wall; thereby preventing flooding of the pad on which the desalination facility is proposed to be built, (which is at elevation +23 ft. NAVD). At the ESGS South site, the desalination facilities construction pad is proposed to be excavated below existing grade to + 23 ft. NAVD, but that site remains

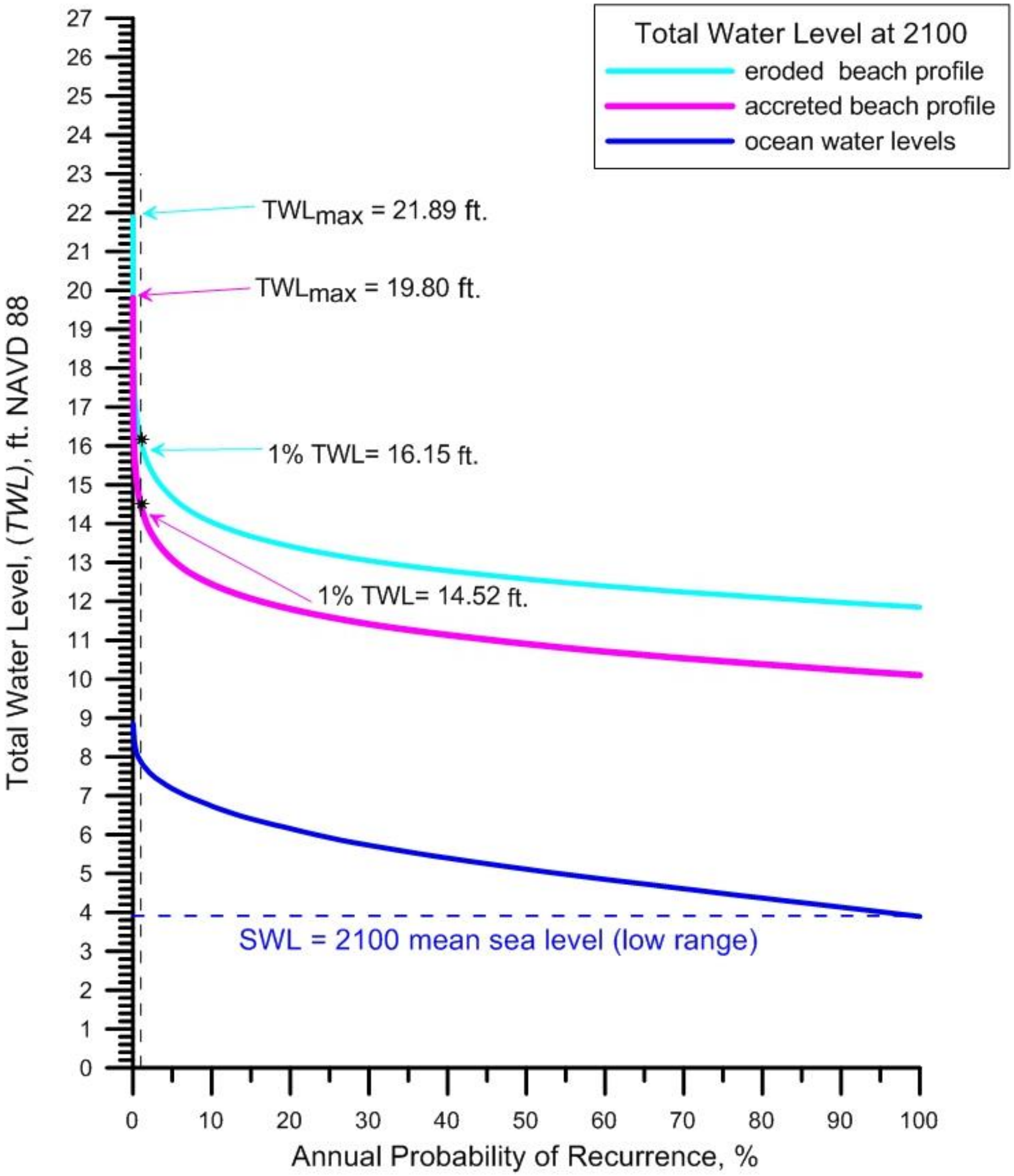

Figure 10: Annualized probability of recurrence of extremal total water level at El Segundo City Beach for based on extremal design wave heights from Weibull Type III distribution and still water levels set at extremal ocean water levels for 2100 sea level (low range prediction).
Probability of recurrence of TWLmax = 0.04%

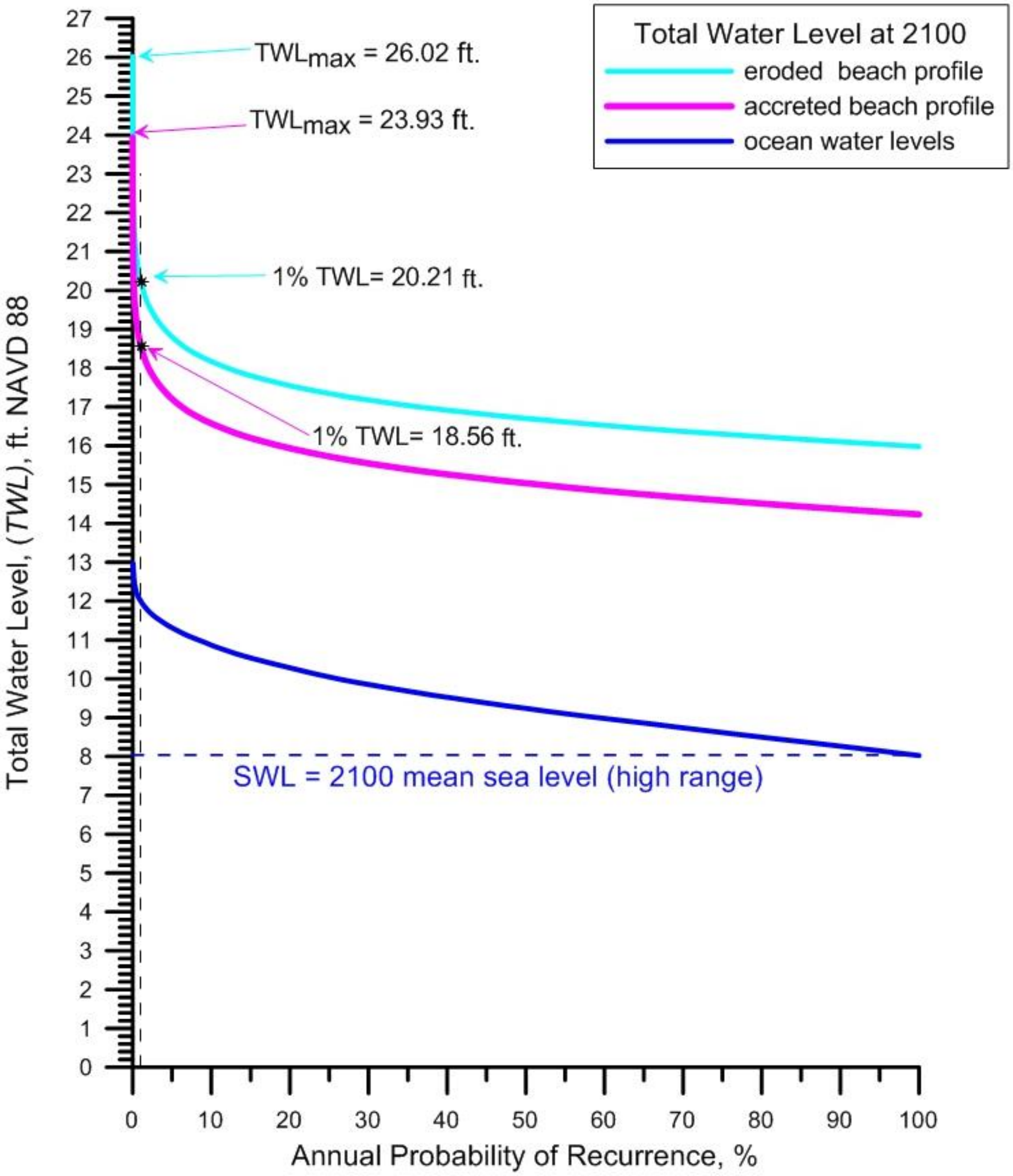

Figure 11: Annualized probability of recurrence of extremal total water level at El Segundo City Beach based on extremal design wave heights from Weibull Type III distribution and still water levels set at extremal ocean water levels for 2100 sea level (high range prediction).
Probability of recurrence of TWLmax = 0.04%

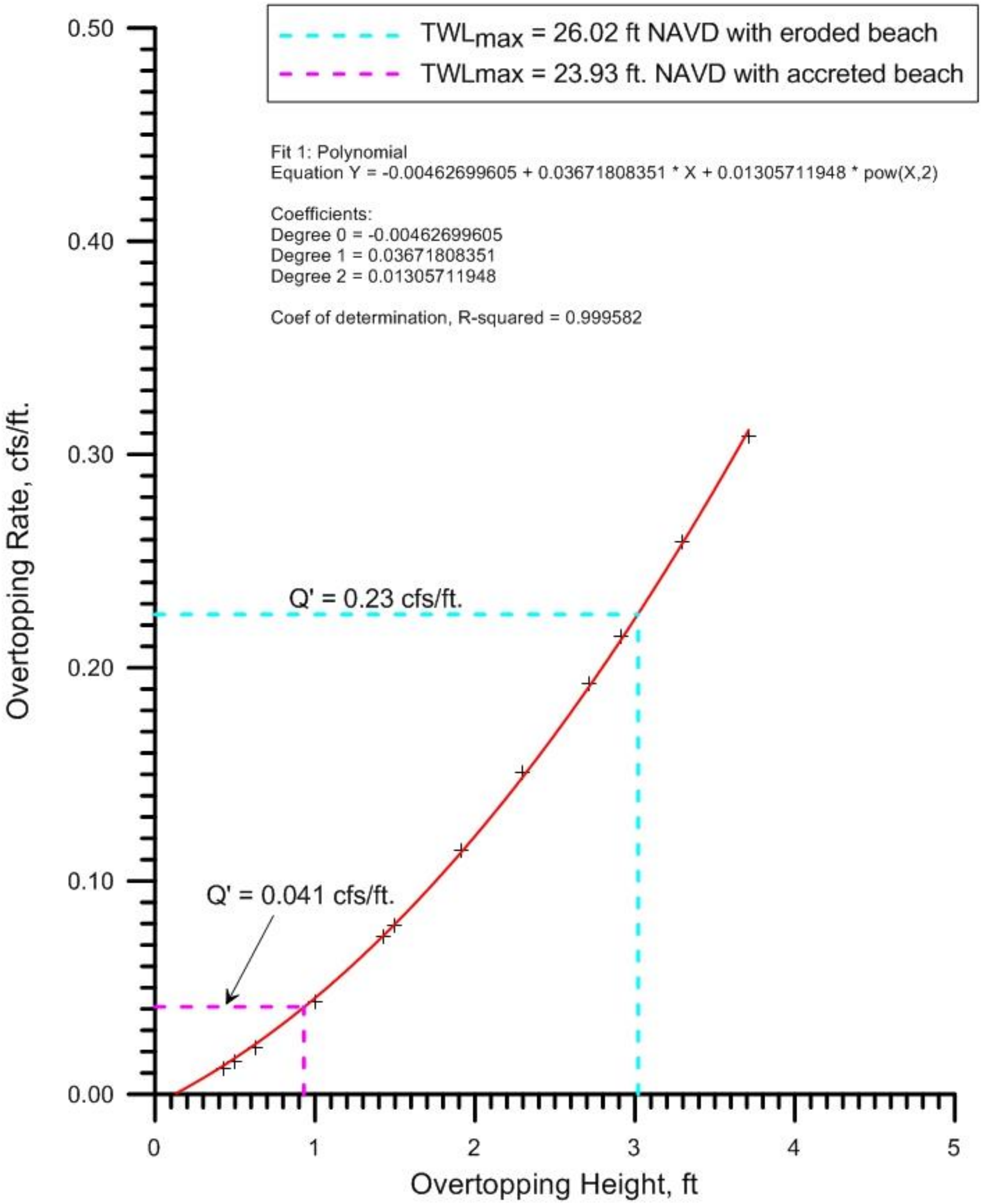

Figure 12: Overtopping rates of the Marvin Braude Coastal Bike Trail at the ESGS north and south sites as a function of overtopping height based on extremal total water levels for 2100 high-range projections of sea level Elevation of bike trail and ESGS construction pads = +23 ft. NAVD

protected by the unexcavated portions of the existing land forms and vegetated berms which are at elevations ranging from +26 ft to + 28 ft. Hence the post-excavation land forms at the ESGS south site are sufficiently high to avoid flooding by the highest combinations of extreme waves and ocean water levels that may occur concurrently at 2100 sea levels. However, the free board of the project site protections is more than sufficient considering that the FEMA design standard is for the 1% (100-year) event. Figure 11 teaches that for a 1% recurrence frequency, the highest total water levels only reach 1% TWL = 20.21 ft. NAVD for eroded beach conditions, while for accreted beach conditions, the 100-year event produces total water levels that only reach 1% TWL = 18.56 ft. Therefore no overtopping of the bike trail or flooding of the project site is possible for a 1% recurrence of high wave run-up concurrent with high ocean water levels for high-range projections of sea level rise at year 2100.

4) Tsunami Run-up and Inundation

Tsunami induced erosion, run-up, and overtopping were analyzed using the Chevron Groin bottom profiles (Figures 4.5 in Jenkins, 2016) and topographic slopes and elevations for the bike trail revetment, NRG sea wall and post-excavation remnant landforms and berms at the ESGS North and South sites. Tsunami induced TWL's were calculated assuming the low-range and high-range projections for sea level rise in year 2100 as plotted in Figure 4. The tsunami scenario is based on a 2m high solitary wave approaching the ESGS site from 165 degrees true, as could be anticipated for a catastrophic tsunami event arising from a major landside on the East side of San Clemente Island. Because the tsunami wave begins shoaling in much deeper water than typical storm-induced waves, it causes seabed scour and erosion to occur out to very deep water depths. The CEM software from Jenkins and Wasyl (2005) computes that seabed erosion occurs offshore to depths of -54 m MSL for this tsunami shoaling scenario; and the volume of eroded sediment can be as high as 10,863 m^3 per meter of shoreline. Therefore the TWL inundation calculations are based on eroded beach profiles and are given in Table 4.1. These tables indicate that the bike trail will be overtopped by several feet of tsunami run-up creating overtopping rates as high as Q' = 0.65 cfs/ft. at the high range projection of 2100 sea level, presenting an extreme hazard to pedestrian and bike traffic. Both the ESGS north and south sites are fully protected from tsunami overtopping for the low range projections of 2100 sea level. At the high range projections for year 2100, the NRG seawall at the ESGS north site will be partially overtopped at the sections that are under + 28.8 ft. NAVD, but the overtopping rates will be small, only Q' = 0.03 cfs/ft. Because a tsunami is a relatively brief, episodic event, these small overtopping rates should be manageable with an appropriately designed drainage system for desalination project's construction pad at the ESGS north sites. At the ESGS south site, the post-excavation land forms are sufficiently high to avoid flooding by tsunami run-up occurring the highest projected range of 2100 sea levels.

Table 4.1: Tsunami Total Water Level (*TWL*) and Overtopping Rates (Q') Analysis

	Bike Trail Elevation = +23 ft. NAVD	NRG Seawall ESGS north Elevation = +28 to +29 ft. NAVD	Vegetated Landforms ESGS south Elevation = +30 ft NAVD
TWL 2100 Sea Level Low Range Projection	24.7 ft. NAVD status = flooded	24.7 ft. NAVD status = dry	24.3 ft. NAVD status = dry
Overtopping 2100 Sea Level Low Range Projection	1.7 ft	0.0 ft	0.0 ft.
Q' 2100 Sea Level Low Range Projection	0.09 cfs/ft.	0.0 cfs/ft.	0.0 cfs/ft.
TWL @ 2100 Sea Level High Range Projection	28.8 ft. NAVD status = flooded	28.8 ft. NAVD status =partial flooding	28.4 ft. NAVD status = dry
Overtopping 2100 Sea Level High Range Projection	5.8 ft.	0.8 ft	0.0 ft
Q' 2100 Sea Level High Range Projection	0.65 cfs/ft.	0.03 cfs/ft.	0.0 cfs/ft.

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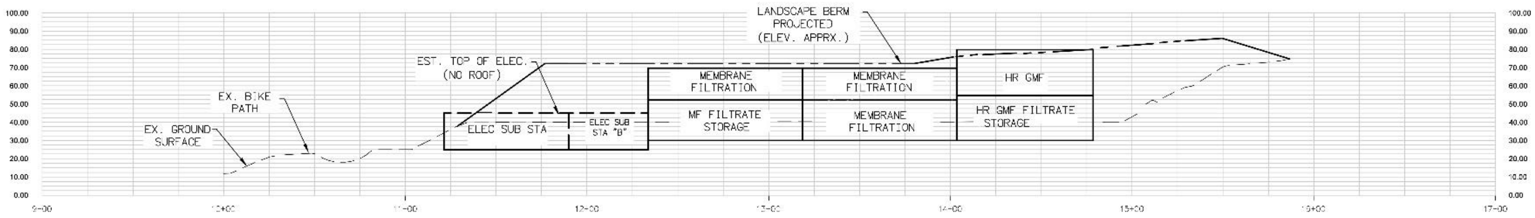
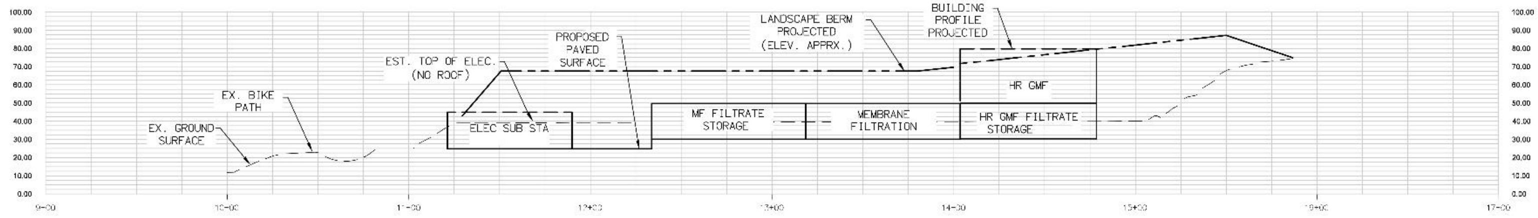


60 MGD REGIONAL PROJECT



20 MGD LOCAL PROJECT

Note: Facility locations and sizing are conceptual, subject to revision during final design and construction

Michael Baker INTERNATIONAL

0 80'

JN 134935 MAY 2016

WEST BASIN OCEAN WATER DESALINATION PROJECT

Section TS2 (ESGS South Site)

Exhibit 3-10

APPENDIX-1: Post-excavation cross sections of the ESGS South Site