APPENDIX

CRITICAL DATUMS

CRITICAL SITE DATUMS

DESIGN FLOOD ELEVATION: WATERFRONT

NOW-TERM (BASED ON 2030 1% AEP)

PARAMETER	**VALUE** (NAVD88)
2030 1% AEP WATER SURFACE ELEVATION	10.7 FT
2030 1% HMAX (WAVE HEIGHT)	3.0 FT
2030 1% HSIG (WAVE HEIGHT)	1.8 FT
DESIGN FLOOD ELEVATION (WSE+ HSIG WAVE CREST)	12.1 FT

NEAR-TERM (BASED ON 2050 1% AEP)

PARAMETER	**VALUE** (NAVD88)
2050 1% AEP WATER SURFACE ELEVATION	12.4 FT
2050 1% HMAX (WAVE HEIGHT)	3.5 FT
2050 1% HSIG (WAVE HEIGHT)	2.1 FT
DESIGN FLOOD ELEVATION (WSE+ HSIG WAVE CREST)	14.0 FT

LONG-TERM (BASED ON 2070 1% AEP)

PARAMETER	**VALUE** (NAVD88)
2070 1% AEP WATER SURFACE ELEVATION	14.1 FT
2070 1% HMAX (WAVE HEIGHT)	4.5 FT
2070 1% HSIG (WAVE HEIGHT)	2.6 FT
DESIGN FLOOD ELEVATION (WSE+ HSIG WAVE CREST)	16.2 FT

NOTES:

- All elevation values in NAVD88
- All data utilizing MC-FRM data as described on pg. 102

DESIGN FLOOD ELEVATION: CONLEY ST. I-93 UNDERPASS

NOW-TERM (BASED ON 2030 1% AEP)

PARAMETER	**VALUE** (NAVD88)
2030 1% AEP WATER SURFACE ELEVATION	10.7 FT
2030 1% HMAX (WAVE HEIGHT)	0 FT
2030 1% HSIG (WAVE HEIGHT)	0 FT
DESIGN FLOOD ELEVATION (WSE+ HSIG WAVE CREST)	10.7 FT

NEAR-TERM (BASED ON 2050 1% AEP)

PARAMETER	**VALUE** (NAVD88)
2050 1% AEP WATER SURFACE ELEVATION	12.4 FT
2050 1% HMAX (WAVE HEIGHT)	0 FT
2050 1% HSIG (WAVE HEIGHT)	0 FT
DESIGN FLOOD ELEVATION (WSE+ HSIG WAVE CREST)	12.4 FT

LONG-TERM (BASED ON 2070 1% AEP)

PARAMETER	**VALUE** (NAVD88)
2070 1% AEP WATER SURFACE ELEVATION	14.1 FT
2070 1% HMAX (WAVE HEIGHT)	1.5 FT
2070 1% HSIG (WAVE HEIGHT)	0.9 FT
DESIGN FLOOD ELEVATION (WSE+ HSIG WAVE CREST)	14.8 FT

CRITICAL SITE DATUMS

PRESENT-DAY TIDAL

DATUM	VALUE (NAVD88)
MLW	-5.16 FT
MTL	-0.42 FT
MHW	4.33 FT
HTL	6.80 FT

SEA LEVEL RISE ASSUMPTIONS

TIMEFRAME	VALUE (FT NAVD88)	VALUE (IN NAVD88)
2030	1.3 FT	15.6 IN
2050	2.5 FT	30 IN
2070	4.3 FT	51.6 IN

AVERAGE MONTHLY HIGH TIDE

TIMEFRAME	VALUE (NAVD88)
PRESENT	6.5 FT
2030	8.0 FT
2050	9.3 FT
2070	11.2 FT

NOTES:

- All elevation values in NAVD88
- Present-day MLW, MTL, MHW elevation values gathered from NOAA Station 8443970, Boston MA.
- Present-day HTL elevation value gathered from Neponset River Greenway Notice of Intent Plan Set.

2008 TIDAL

DATUM	VALUE (NAVD88)
MLLW	-5.30 FT
MLW	-4.95 FT
MTL	-0.20 FT
MHW	4.54 FT
MHHW	5.00 FT

2030 TIDAL

DATUM	VALUE (NAVD88)
MLLW	-3.80 FT
MLW	-3.90 FT
MTL	1.20 FT
MHW	6.10 FT
MHHW	6.50 FT

2050 TIDAL

DATUM	VALUE (NAVD88)
MLLW	-2.70 FT
MLW	-2.40 FT
MTL	2.50 FT
MHW	7.40 FT
MHHW	7.80 FT

2070 TIDAL

DATUM	VALUE (NAVD88)
MLLW	-1.00 FT
MLW	-0.70 FT
MTL	4.30 FT
MHW	9.30 FT
MHHW	9.70 FT

NOTES:

- All elevation values in NAVD88.

COASTAL MODELING

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TECHNICAL MEMORANDUM

Sent by Electronic Mail
DATE June 30, 2023 **JOB NO.** 2022-00242

TO Linh Pham, RLA
Senior Associate
Scape Landscape Architecture
linh@scapestudio.com

CC Laura Marett (Scape), Kirk Bosma (WHG), Grace Medley (WHG)

RE: Tenean Beach Flood Resiliency Design – Performance Modeling

Introduction

Woods Hole Group utilized the Massachusetts Coast Flood Risk (MC-FRM) to verify the performance and assess potential impacts associated with the proposed (schematic) coastal flood resiliency improvements at Tenean Beach in the Dorchester neighborhood of Boston, Massachusetts. The intent of the proposed design is to mitigate the Conley St flood pathway into the Dorchester neighborhood, providing protection up to a 2030 1% annual chance flood plus 1 foot of freeboard, at a minimum. This evaluation included influences of the proposed schematic design on flood pathways, flood extents, water surface elevations, and redirected flood waters to neighboring properties in a series of storms representative of coastal flood annual exceedance probabilities (AEPs) in the 2030 time horizon. The following technical memorandum serves to summarize the results of the performance modeling.

Proposed Coastal Flood Resiliency Improvements

Performance modeling involves virtual construction of the proposed design into the MC-FRM domain and additional sub-modeling grids, simulating select AEP storm scenarios within the model(s), and assessing hydrodynamic changes (water levels, extents, etc.) between existing and proposed conditions. For this project, the proposed schematic design combines an elevated waterfront park, elevated roadway, and flood wall, with a maximum continuous crest elevation of 14 feet NAVD88. Figure 1 presents the approximate alignment that was applied to the hydrodynamic modeling grid.

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Figure 1: Approximate design alignment contours applied to the modeling domain. The design was applied to the MC-FRM modeling mesh as a series of contours representing the 10ft NAVD88 contour line, the 12 ft NAVD88 contour line, and the 14 ft NAVD88 contour line as proposed by the design drawing.

MC-FRM Performance Modeling

The MC-FRM is a high-resolution, probabilistic flood risk model created specifically to assess physics-based, coastal forced, flooding conditions under present and future climate conditions for the entire coast of Massachusetts. The MC-FRM only considers overland coastal flooding – drainage infrastructure is not included. The model uses a two-way coupled version of the Advanced Circulation (ADCIRC) and Unstructured Simulating Waves Nearshore (UnSWAN) models to fully simulated a variety of storm conditions (e.g., tropical and extra-tropical cyclones, etc.). The MC-FRM incorporates the state standard sea level rise conditions over time as presented by Massachusetts Coastal Zone Management and Resilient MA (https://resilientma.mass.gov/changes/sea-level-rise). Storm intensification due to climate change is also incorporated within the MC-FRM in the 2050 and 2070 time horizons. The model has, and is currently, being used for numerous coastal planning and design projects throughout Massachusetts and is recommended by the Commonwealth of Massachusetts *Climate Resilience Design Standards* as the basis for resilient coastal design.

The MC-FRM provides a probabilistic distribution of water levels for locations throughout Massachusetts based on thousands of storms. From these thousands of storm events, individual storms corresponding closely to specific annual exceedance probability (AEP) water surface elevations can be selected to evaluate the performance of coastal flood resiliency projects. For this modeling effort, six representative storms, under two different climate horizons were simulated for existing conditions (existing elevations) and proposed conditions (with the proposed development constructed) within the MC-FRM framework.

The six specific storm AEP cases simulated and their respective peak stillwater levels at the project location are provided in Table 1.

Table 1. Peak water levels utilized for the performance modeling

Storm Event Case (Annual Exceedance Probability)	Return Period	Climate Horizon	Still Water Level at Tenean Beach (ft, NAVD88)
5%	20-year	2030	9.8
2%	50-year	2030	10.3
1%	100-year	2030	10.7
0.5%	200-year	2030	11.0-11.1
0.2%	500-year	2030	11.6
1%	100-year	2050	12.4

Flood Pathways Analysis

The proposed design's maximum crest alignment is at 14 feet NAVD88, and none of the storms considered produce high enough water surface elevations to exceed this elevation. As a result, the Conley St flood pathway is fully mitigated as a source of overland coastal flooding by the proposed design in these scenarios.

In the area west of I-93, between Dorchester Bay Basin and Neponset Circle, there are multiple 2030 AEPs in which the Conley St flood pathway is the only source of overland coastal flooding (Figure 2). These include the 2030 5%, 2%, and 1% AEPs (shown in shades of green). Based on the MC-FRM results, the proposed design will fully mitigate overland coastal flooding in this area at these AEPs. The risk of floodwater flanking the proposed design through underground drainage infrastructure in these events was not assessed.

There are additional coastal flood pathways into this area at lower AEPs in 2030 (and higher AEPs in 2050 and 2070). The MC-FRM resolves a significant flood pathway at the Morrissey Blvd/I-93 underpass just south of Dorchester Bay Basin (Figure 2). This pathway contributes to flooding in the area at 2030 0.5% (yellow) and lower AEPs (and 2050 2% and lower AEPs). However, the sub-area that floods from the Morrissey/I-93 pathway is separate from the sub-area that floods from the Conley St flood pathway at the 2030 0.5% (yellow) and 0.2% (orange) AEPs. At the 2030 0.1% AEP (pink), the two sub-areas join to a single larger floodplain. The proposed project will mitigate overland coastal flooding in the sub-area that floods from the Conley St flood pathway at the 2030 0.5% and 0.2% AEPs. The sub-area separately flooded by the Morrissey Blvd/I-93 pathway will remain at risk in these events. The risk of floodwater flanking the proposed design through underground drainage infrastructure in these events was not assessed.

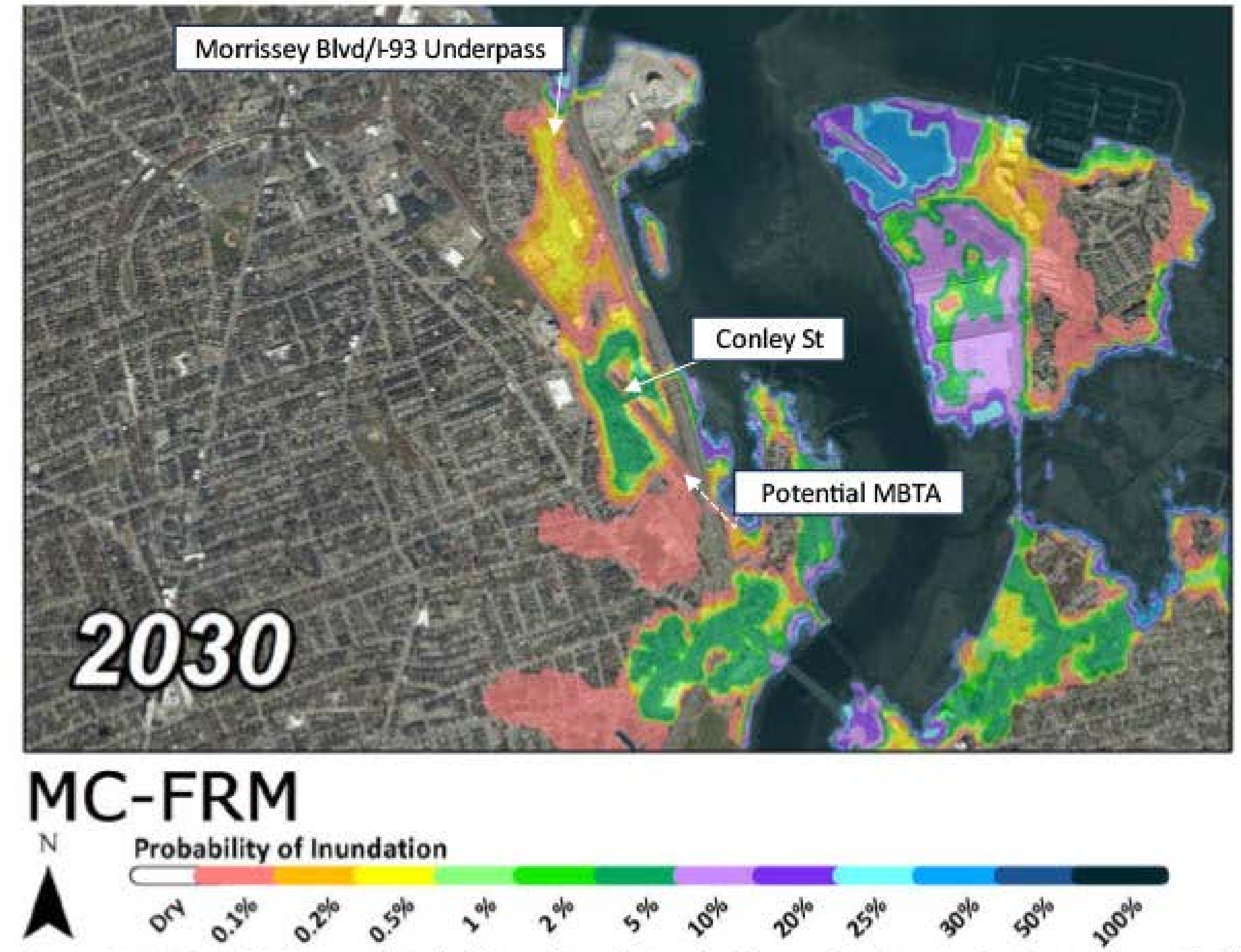

Figure 2: MC-FRM 2030 Annual Probability of Inundation (AEP) map showing Conley St, Morrissey Blvd/I-93 underpass, and potential MBTA flood pathways.

The MC-FRM does not resolve a narrow (approximately 5-10 feet wide) potential flood pathway at the MBTA Red Line maintenance yard on Conley Street (located on the far northern end of the existing concrete noise wall). At high enough water levels, flooding could potentially flank the noise wall on the east side of the rail right-of-way and flow over the rail line, into a narrow drainage ditch on the west side of the rail right-of-way, and north under the I-93 overpass into the sub-area fed by the Conley St flood pathway (Figure 2). Based on survey and LiDAR topographic data, the existing noise wall will block this flood pathway for events with a water surface elevation of up to about 11 feet NAVD88 (2030 0.5% AEP). For less frequent storms that begin to exceed that level, water may flank this noise wall. For example, at the 2030 0.2% water surface elevation (11.6 feet NAVD88) the potential flanking entry point would only be about 5 feet wide with maximum 0.1 feet to 0.6 feet of flood depth at the peak of the storm, limiting the volume of flooding that could potentially flank the proposed project through this pathway. Based on professional engineering judgement, the potential flooding through the MBTA pathway is unlikely to be sufficient to inundate the full sub-area protected by the proposed project up to the 0.2% AEP. With a water surface elevatoin around 13.0 feet NAVD88 (2050 0.5% AEP), this pathway is likely to be fully activated.

Results of Performance Modeling: Extent of Flooding

In a 1% AEP storm event in 2030, the Tenean Beach design meets the design intent of eliminating overland coastal flooding in the sub-area directly affected by the Conley St flood pathway (Figure 3).

Figure 3: Flood extents for the 1% AEP storm event under the 2030 climate horizon. The light blue indicates areas that are flooded in both existing and proposed conditions, whereas the dark blue regions indicate areas of avoided flooding due to the design alternative.

Flooding that occurs during the 2050 1% AEP storm event exceeds the threshold at which the Morrissey Blvd/I-93 flood pathway is activated. Due to the additional flooding coming from this pathway, there is an area of uncertainty in the flood extents due to the model's resolution, the ability to represent flow hydraulics through the MBTA Red Line underpasses at Morrissey Blvd, and limitations due LiDAR. This area of uncertainty is represented in Figure 4 as a hatched shading overlain on the flood extent.

Figure 4: Flood extents for the 1% AEP storm event under the 2050 climate horizon. The light blue indicates areas that are flooded in both existing and proposed conditions, whereas the dark blue regions indicate areas of avoided flooding due to the design alternative. The hatched area represents uncertainty in the extent of flooding.

Results of Performance Modeling: Water Surface Elevations

Part of this analysis involved using the MC-FRM results for water surface elevations (WSE) to provide WSE rasters before and after project implementation to inform a Benefit Cost Analysis conducted by TetraTech. The storms considered for this analysis were the five storms in 2030, where there is an independent project benefit in eliminating the flooding in the sub-area affected by the Conley St flood pathway. The results maps are shown in Figure 5 through Figure 9.

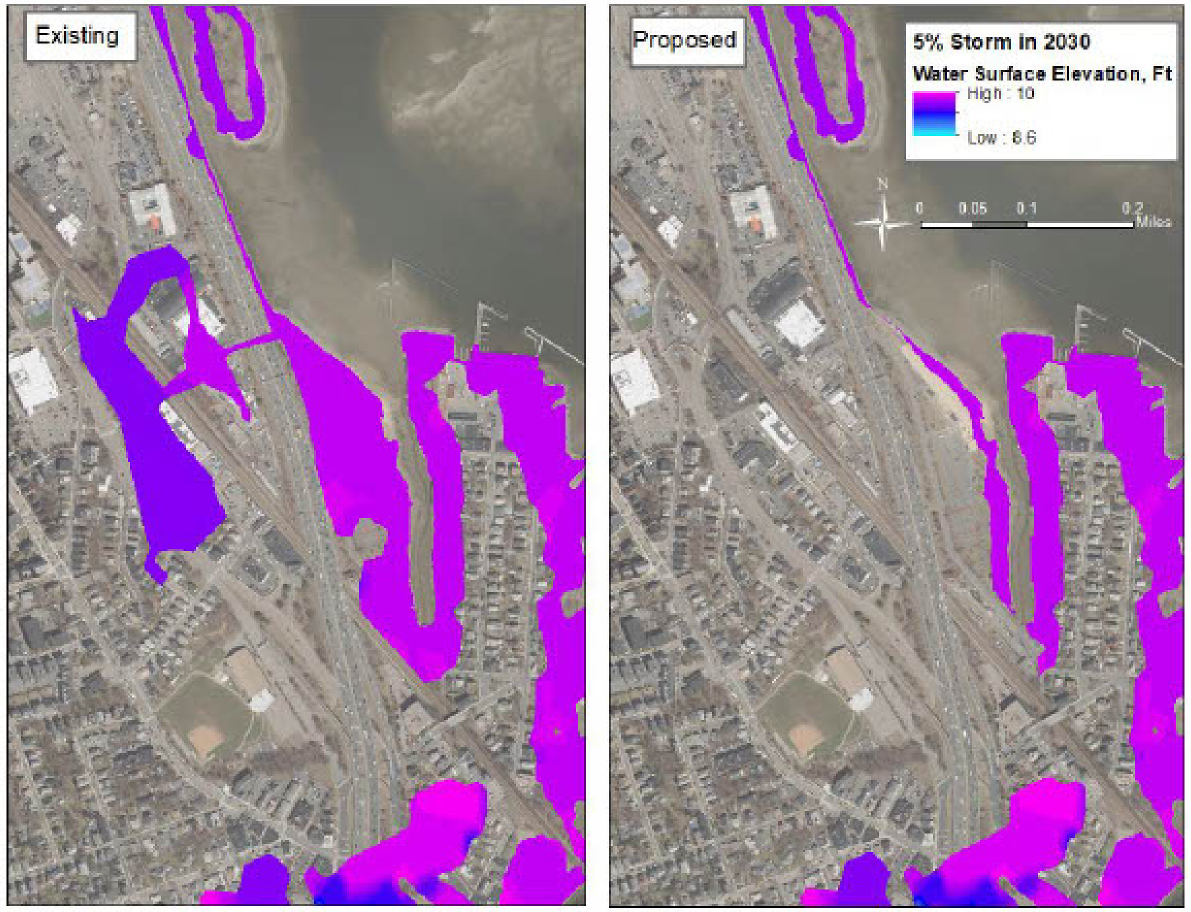

Figure 5: Water surface elevations for the 2030 5% AEP. The left panel represents existing conditions, without the project implemented, and the and the right panel represents proposed conditions, with the project implemented. Water surface elevations above Mean High Water (MHW) are shown in this figure, considering overland flooding only.

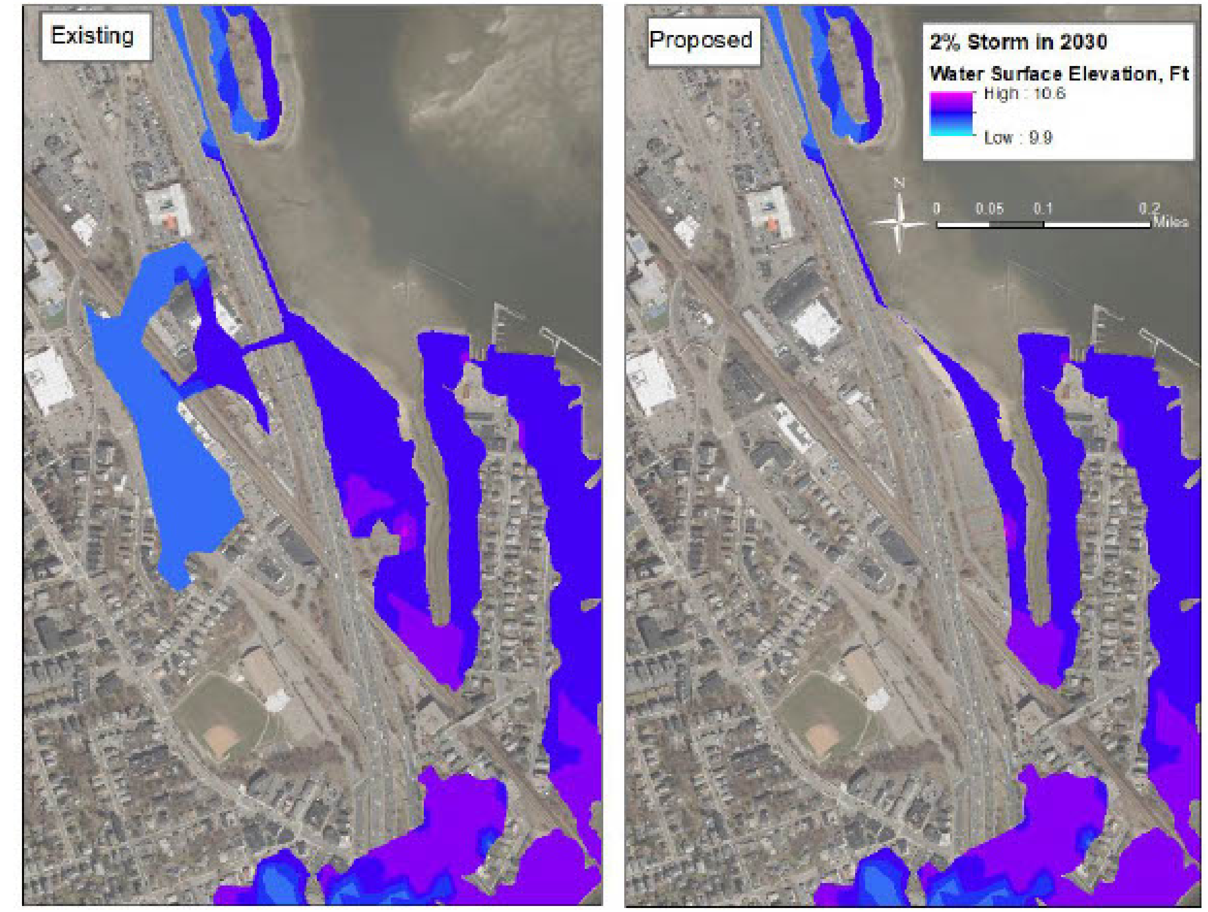

Figure 6: Water surface elevations for the 2030 2% AEP. The left panel represents existing conditions, without the project implemented, and the and the right panel represents proposed conditions, with the project implemented. Water surface elevations above Mean High Water (MHW) are shown in this figure, considering overland flooding only.

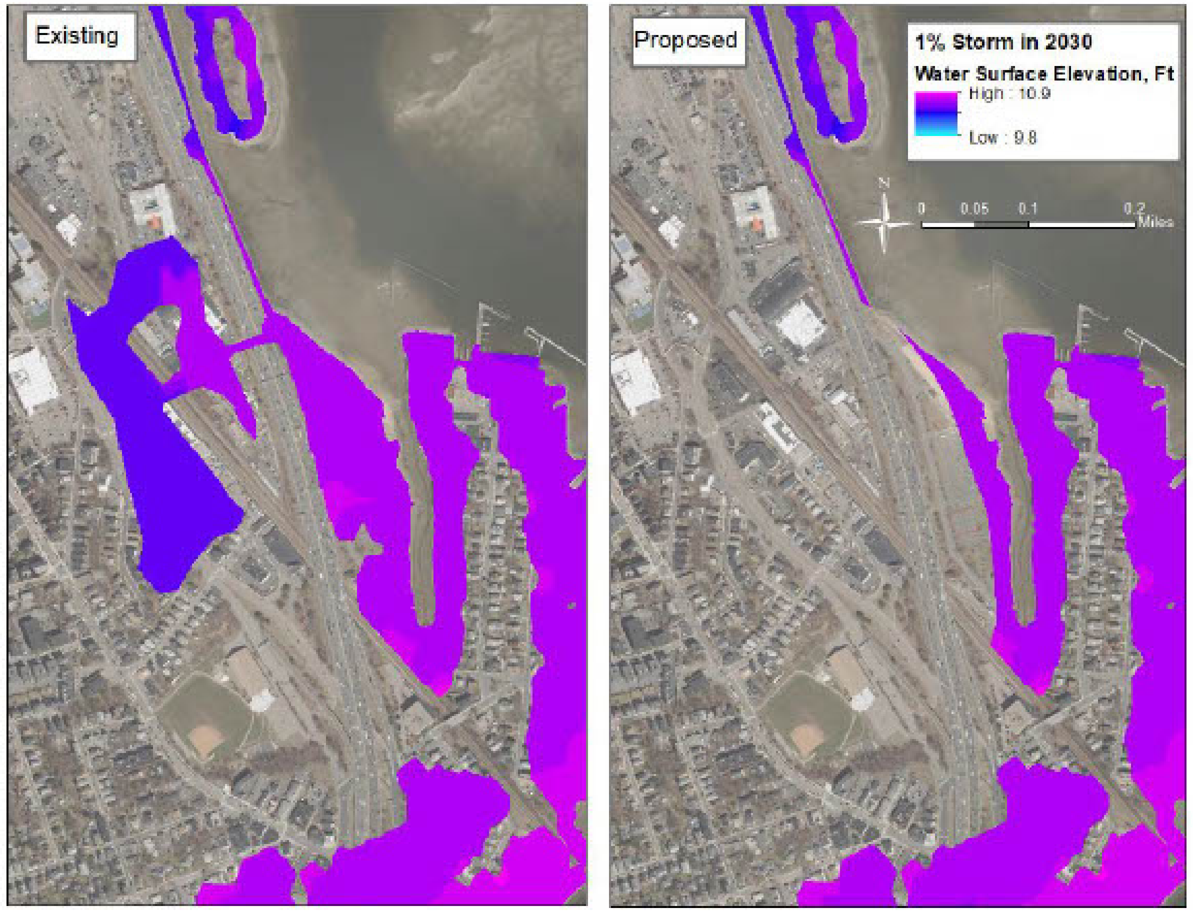

Figure 7: Water surface elevations for the 2030 1% AEP. The left panel represents existing conditions, without the project implemented, and the and the right panel represents proposed conditions, with the project implemented. Water surface elevations above Mean High Water (MHW) are shown in this figure, considering overland flooding only.

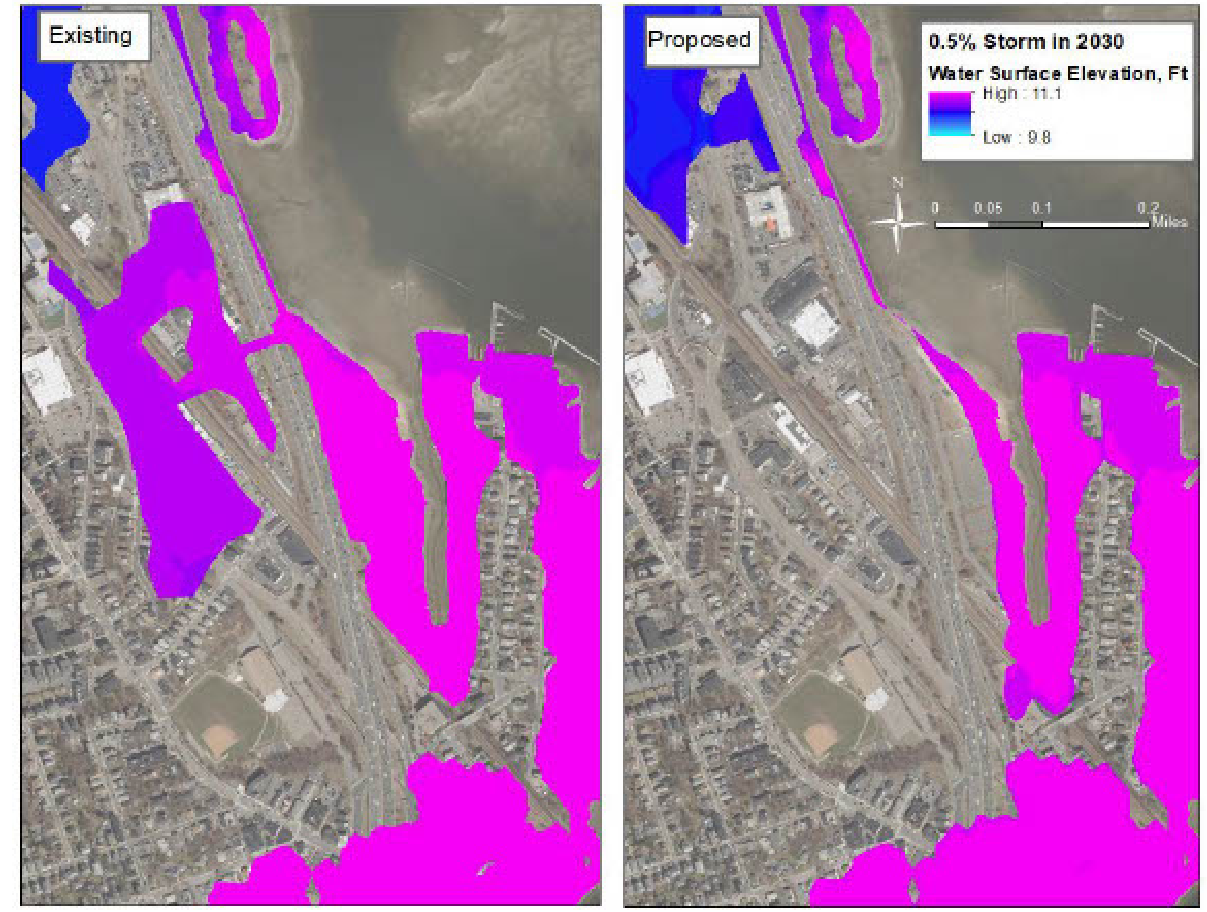

Figure 8: Water surface elevations for the 2030 0.5% AEP. The left panel represents existing conditions, without the project implemented, and the and the right panel represents proposed conditions, with the project implemented. Water surface elevations above Mean High Water (MHW) are shown in this figure, considering overland flooding only.

Figure 9: Water surface elevations for the 2030 0.2% AEP. The left panel represents existing conditions, without the project implemented, and the and the right panel represents proposed conditions, with the project implemented. Water surface elevations above MHW are shown in this figure, considering overland flooding only.

Results of Performance Modeling: Redirected Flood Waters

As flood waters flow inland and interact with infrastructure (both existing and proposed), various patterns and potential redirection of flow magnitudes, directions, and volumes can occur. Proposed infrastructure can function as a barrier to flow, which can potentially alter the flow patterns and modify flow velocities and flow volumes in the vicinity of these changes. Redirected flood waters that cause additional flooding to adjacent neighborhoods will be shown through modeled results as a localized increase in the water surface elevation in areas adjacent to the project implementation site. Impacts to neighboring properties in the form of redirected flood waters due to the placement of the design alignments was investigated for two storms, consisting of the 1% AEP event in 2030, and the 1% AEP event in 2050.

Modeled results indicate that during the most extreme of the storm scenarios simulated, there are no localized increases in water surface elevations, and therefore no redirected flood waters to the Port Norfolk neighborhoods. The assumption is made that results of flow redirection are the most extreme during the largest events, and if no difference is calculated in the largest of the events between existing and proposed water surface elevations, no differences will be observed in events of lesser magnitude.

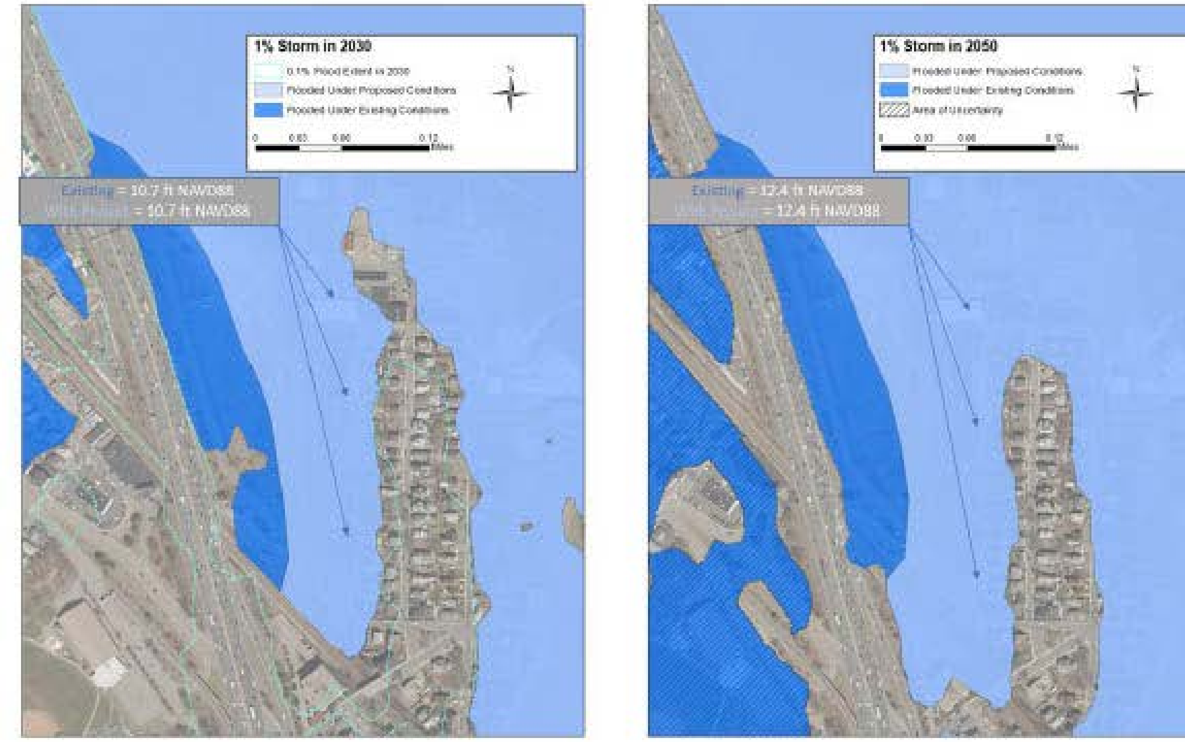

Figure 6: Flood extents, and water surface elevations, for the 1% AEP storm event under the 2030 (Left panel) and 2050 (Right panel) climate horizons, under existing and proposed conditions. The light blue indicates areas that are flooded with the project in place, whereas the dark blue regions indicate areas of the extent of flooding without the project in place. The hatched area in the right panel represents uncertainty in the extent of flooding that occurs when other flood pathways become dominant.

Conclusions

Based on the performance modeling results and analysis, key findings include:

- The proposed project effectively mitigates overland coastal flooding through the Conley St underpass.
- The proposed project meets the intended design goal of providing protection from overland coastal flooding up to a 2030 1% AEP.
- The proposed project does not redirect coastal floodwaters to the Port Norfolk neighborhood. Water surface elevations in the Port Norfolk area are the same with the project as in existing conditions.
- The proposed project eliminates flooding in the area inland of Conley St up to the 2030 0.5% AEP.
- At the 2030 0.2% AEP the proposed project may begin to be flanked by the MBTA flood pathway, but the flood volume is unlikely to be sufficient to inundate the full sub-area otherwise protected by the proposed project. Other resiliency improvements are required to mitigate this flood pathway.
- Other resiliency improvements are required to mitigate overland coastal flooding through the Morrissey Blvd/I-93 underpass. This flood pathway will activate at the 2030 0.5% AEP. In events with water surface elevations at or above the 2030 0.1% AEP, the degree to which this pathway will contribute flooding to the area otherwise protected by the proposed project is uncertain.

TECHNICAL MEMORANDUM

Sent by Electronic Mail
DATE June 30, 2023 **JOB NO.** 2022-00242

TO Linh Pham, RLA
Senior Associate
Scape Landscape Architecture
linh@scapestudio.com

CC Laura Marett (Scape), Kirk Bosma (WHG), Zach Stromer (WHG)

RE: Tenean Beach Flood Resiliency Design – Beach and Dune Cross-shore Modeling

Introduction

Tenean Beach, located in the Dorchester neighborhood of Boston, MA is a sandy beach situated at the confluence of the mouth of the Neponset River and Dorchester Bay. Tenean Beach has been identified by the Climate Ready Dorchester process as part of an area particularly at risk from climate change. Areas behind and adjacent to the beach were identified as being at risk of flood inundation during extreme coastal flood events with increasing risk due to expected future sea level rise. To provide resiliency benefits to the surrounding neighborhood and for the beach itself, a beach nourishment and dune enhancement element of the overall project has been designed.

The goal of raising the beach and dune with nourishment projects is to maintain a viable beach for recreational use under future sea level rise conditions, while also working in concert with the overall project's flood mitigation elements to reduce flooding under present and future storm conditions. As such, this project raises the elevation of the dune crest and beach berm and increases width of these beach elements to provide a more resilient beach setting and creates a usable beach even under future sea level rise conditions. Cross-shore wave and sediment transport modeling was conducted to understand the expected performance of the proposed project with respect to erosion during coastal storm events. Therefore, providing a measure of potential maintenance requirements with the beach nourishment portion of the overall resiliency mitigation approach.

While Tenean Beach was identified as being at risk due to flooding due to elevated water levels, wave-action is expected to be minimal, which means erosion and maintenance of the beach system may also be reduced. Located in a relatively narrow estuarine channel, and thus exposed to a short wave fetch length, Tenean Beach is fairly protected from wave action. Additionally, Tenean Beach is situated south-east of both Squantum Point and a wave fence at the Port Norfolk Yacht Club that shield Tenean Beach from larger waves during the predominantly nor'easter-driven coastal storm events. As wave-action is a critical component in driving beach erosion, Tenean Beach is expected to be relatively stable, experiencing only moderate erosion under regular conditions. For this reason, it can be expected that the proposed beach nourishment project will remain relatively stable and require infrequent replenishment.

Proposed Beach and Dune Improvements

The project proposes to expand and enhance the existing beach and construct a new beachgrass stabilized primary frontal dune with beach compatible sand. At its widest cross-section (Figure 1), the beach profile will rise from existing grade just above Mean High Water at a 10:1 slope to a 100 ft wide beach berm with a crest elevation of 7 ft NAVD88.

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The toe of the dune would be set at elevation 7 ft NAVD88, with a foreslope of 7:1, 20 ft wide crest at elevation 12 ft NAVD88, and backslope of 10:1. The dune will be stabilized with beachgrass.

Cross-shore Performance Modeling

In order to evaluate the conceptual design configurations of beach and dune nourishment at Tenean Beach, estimate service life, and to determine the protective level of the proposed design during high-energy storm events, a cross-shore sediment transport model (XBeach) was utilized. XBeach is an open-source numerical model developed to simulate wave, hydrodynamic and morphodynamic processes. It has been developed with support of various agencies including the US Army Corps of Engineers, Rijkswaterstaat and the EU, together with a consortium of UNESCO-IHE, Deltares (formerly WL|Delft Hydraulics), Delft University of Technology, and the University of Miami. The newest version of the model (XbeachX) was utilized for the purposes of this study. XBeach was originally designed to assess hurricane impacts on sandy beaches. However, with funding from the Dutch Public Works Department the model has been extended, applied, and validated for storm impacts on dune and urbanized coasts, and, with further support from the European Commission XBeach has been validated on a number of dissipative and reflective beaches throughout the EU.

To assess the proposed nourishment design at Tenean Beach a 1-Dimensional representation of the design was created based upon the most recently available survey and lidar data for the site. The proposed design was superimposed on the existing topography data to create a representative transect for the modeling. Figure 1 shows a plan view map of the 1D transect location simulated for this project.

Figure 1. Xbeach 1-D cross sectional transect assessed for Tenean Beach in Boston, MA

Boundary conditions including water levels and wave conditions were created to be applied at the offshore boundary of the Xbeach grid. Four different storm condition cases were utilized for this study. This included coastal storm events corresponding to 10yr, 20yr, 50yr, and 100yr return period storms under present day conditions (2008 centered tidal epoch). Wave and water level conditions were obtained from the Massachusetts Coast Flood Risk Model (MC-FRM) for representative storms. MC-FRM is a high-resolution flood risk dataset based upon the results of a probabilistic hydrodynamic modeling effort. From the MC-FRM ensemble discrete storm simulations were selected which corresponded to water levels representing the return period events.

The model output from each of the simulations conducted consists of wave height, water surface elevation, and velocity along the profile for each model output timestep, along with changes in the bottom profile showing areas of erosion and deposition. The final profile for each case was extracted from the model simulations for comparisons with the initial profile to determine possible impacts to the beach from storm conditions.

Results of Performance Modeling

Figures 2 and 3 show the results of the 10yr and 100yr storm condition cases simulated using the proposed design, respectively. The figures show the existing cross-shore profile (dotted black line), as well as the proposed design (solid black line). The red line in the figure shows the final eroded profile after the storm simulation. The figures also show the maximum water surface elevation that occurred during the storm, including the processes of wave-driven setup and wave run-up. Finally, the figure also shows the levels of mean high water (MHW) and mean low water (MLW) datums demonstrating the levels on the beach where water levels would fall during the different tidal phases.

The results show relatively limited erosion during both storm cases shown, corresponding to the relatively small waves in the project area. The 10yr event simulation resulted in slight erosion (lowering and retreating) of the beach berm with very minor erosion of the dune face. The 100yr event shows slightly deeper erosion of the beach berm with retreat of the dune crest of approximately 10 ft. Both figures show water levels during the storms not exceeding the dune crest, demonstrating the protection offered by the proposed design for near to mid-term climate change conditions. Under longer-term climate change conditions, other elements of the proposed mitigative design would provide flood protection capacity.

Wave run-up also does not exceed the dune crest in the evaluated cases showing that the proposed design protects from overtopping related flooding even during 100yr extreme events. The sand eroded during both evaluated cases is transported seaward from the nourishment but remains between the MHW and MLW datum lines (the intertidal zone). This sediment that is transported into the intertidal zone will remain part of the littoral cell (the coastal area where sediment transport occurs, as opposed to offshore areas where sediment transport is more isolated) being available both for possible shoreward transport during more quiescent summer conditions, as well as continuing to offer protective benefits in the form of enhanced wave breaking further offshore.

Therefore, even under large storm events (e.g., 100-year return period level), all of the added sediment remains in the intertidal zone lending to a wider useable beach that provides energy dissipation for the shoreline. This normal re-adjustment of material remains in an area that still provides recreational ability and a longer overall service life, even after large storm events. Maintenance of the beach is therefore expected to be minimal and no significant renourishment requirements are expected to occur even after storm events over the near to mid-term.

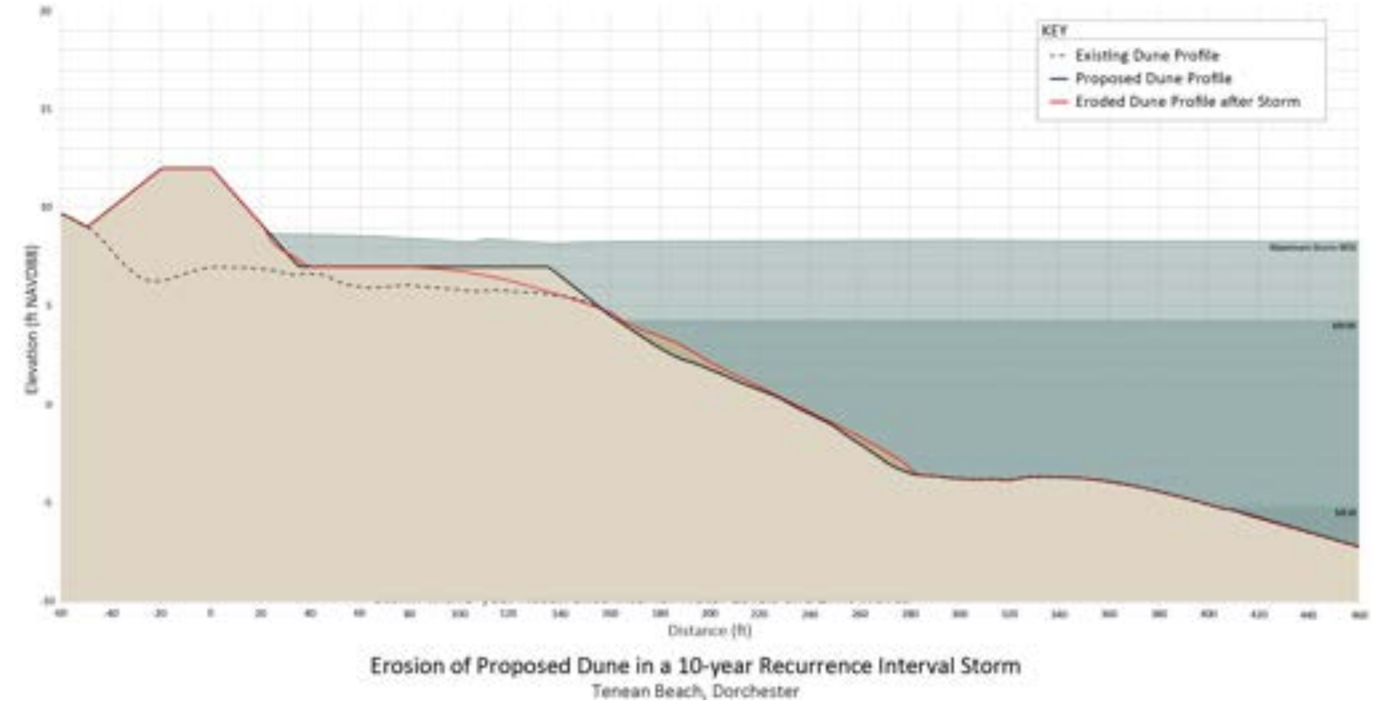

Figure 2. Xbeach 1-D model results for a 10-year recurrence interval coastal storm event. Solid black line represents the simulated proposed design. Dotted black line represents the existing conditions. Red line represents the eroded profile of the proposed design after the event.

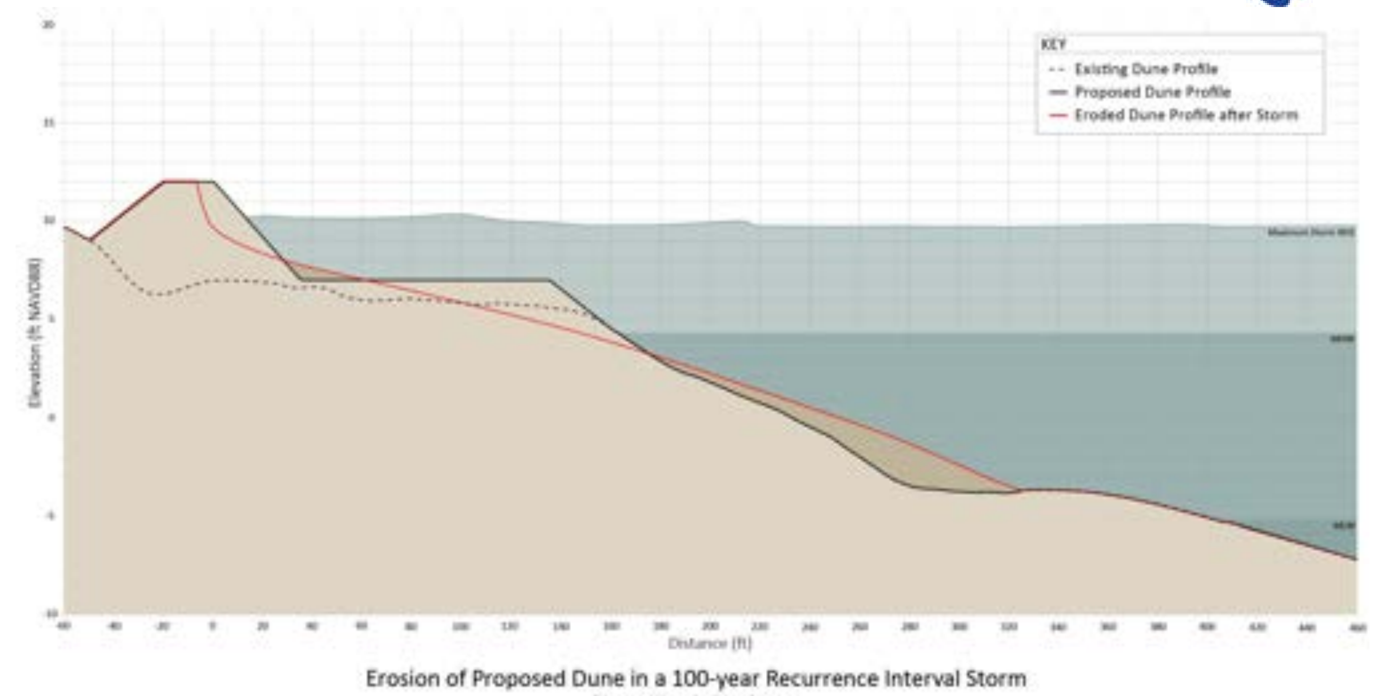

Figure 3. Xbeach 1-D model results for a 100-year recurrence interval coastal storm event. Solid black line represents the simulated proposed design. Dotted black line represents the existing conditions. Red line represents the eroded profile of the proposed design after the event.