Breton Landbridge Marsh Creation Project (BS-0038)

Numerical Modeling and Wave Impact Analysis

February 26, 2021

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Issue and revision record

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0	2/5/2021	Thomas Everett	Arpit Agarwal	Josh Carter	Technical Report for CPRA Review
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Executive summary

The following document summarizes the work completed by Mott MacDonald, LLC for CPRA under Contract No. 4400020242, Task #4, to support the Breton Landbridge Marsh Creation (West) project (BS-0038). The project intends to restore 423 acres of marshes and bank lines along the south side of Grand Lake in the Breton Basin (Plaquemines Parish, Louisiana).

Data collection and analysis was performed to understand the hydrodynamic conditions at the project site. Water surface elevation and wind data were collected from nearby gauges. An extremal analysis was performed on both data sets. The typical and extremal wind and water level conditions were used to force the numerical wind-wave generation model.

Wind-wave generation and transformation modeling was performed for the project vicinity to determine nearshore wave characteristics. The SWAN model was used to transform waves across Grand Lake. The model was run for an entire representative year to generate typical wave conditions along the project shoreline. Additional extremal wave scenarios were also used in modeling analysis. Two proposed alternative model setups were created for comparison with existing conditions. Alternative 1 comprised of the proposed BS-0038 borrow area and Alternative 2 assumed almost the entire Grand Lake to be used as a borrow source for future marsh creation projects. Waves generated using the existing bathymetric conditions model setup were compared against those generated using the project alternatives set up to analyze the effects of proposed borrow areas for marsh creation. The proposed borrow areas introduced negligible increases in wave energy near the project shoreline.

A shoreline change analysis was performed on the existing marshes along the Grand Lake. The project shoreline experience high erosion while the northern and western portions of the lake shoreline experienced low erosion. The typical wave conditions from 2016 to 2020 were found to cause moderate erosion at the project shoreline, but the high retreat rates were attributed to Hurricane Katrina. This analysis indicates that the typical wave conditions produce moderate erosion and that the marsh is susceptible to severe erosion during tropical events.

A wave impact analysis was performed along the project shoreline to understand the marsh edge vegetation's tolerance to wave impacts, and to develop a qualitative sense of the success of the proposed BS-0038 project in creating a thriving marsh edge. The results showed that most of the regular wave conditions fall in a favorable condition for marsh edge vegetation wave tolerance, but the less frequent, larger wave conditions exceed the tolerance threshold. A wave energy mitigation feature was presented and tested at the project site. It was found that the placement of artificial reef breakwaters along the project shoreline can reduce wave energy from a 20-year event up to 80%.

1 Introduction

The work descried in this report was conducted for the Coastal Protection and Restoration Authority (CPRA) by Mott MacDonald, LLC under Contract No. 4400020242, Task #4, to support the Breton Landbridge Marsh Creation (West) project (BS-0038).

The Breton Basin in Plaquemines Parish, Louisiana has been facing accelerated wetland loss due to multiple natural (storm activity) and manmade (levees along the Mississippi River, oil/gas related development) changes to the system. The wetlands that make up the Breton Basin complex serve as a critical defense feature against storm surge for the major port city of New Orleans. The Breton Landbridge Marsh Creation project (BS-0038) proposes to restore 423 acres of marshes and bank lines along the south side of Grand Lake. There will be 326 acres of marsh creation and 97 acres of marsh nourishment, respectively, via confined disposal in four disposal areas of sediment dredged from Grand Lake as shown in Figure 1. Three disposal areas will be fronted by constructing a lake-side berm and planted with appropriate vegetation on the lakeside slope for stability. An understanding of the local wave climate and its impact on the project elements is necessary for creating a successful and sustainable marsh creation project design.

The goal of this study is threefold: (1) evaluate the potential changes to wave climate within Grand Lake associated with proposed borrow area sites; (2) evaluate the impact of wave climate on the shoreline stability; and (3) propose potential alternatives to mitigate marsh edge erosion along the proposed marsh creation cells.

Figure 1. Project location and proposed marsh restoration plan. (*source: CPRA*)

Figure 2 shows the BS-0038 proposed marsh creation areas as well as future potential marsh creation projects. The proposed BS-0038 borrow area is approximately 2,260 ft by 3,450 ft with a bottom depth 23 ft below the existing lake bottom and a dredge side slope of 2H:1V. Additionally, there are three berm borrow areas that are 50 ft wide (at the bottom) with a bottom depth 10 ft below the existing lake bottom and a dredge side slope of 3H:1V. The berm borrow areas are 25 ft offset from the proposed MCA 1, 2, and 4 berms.

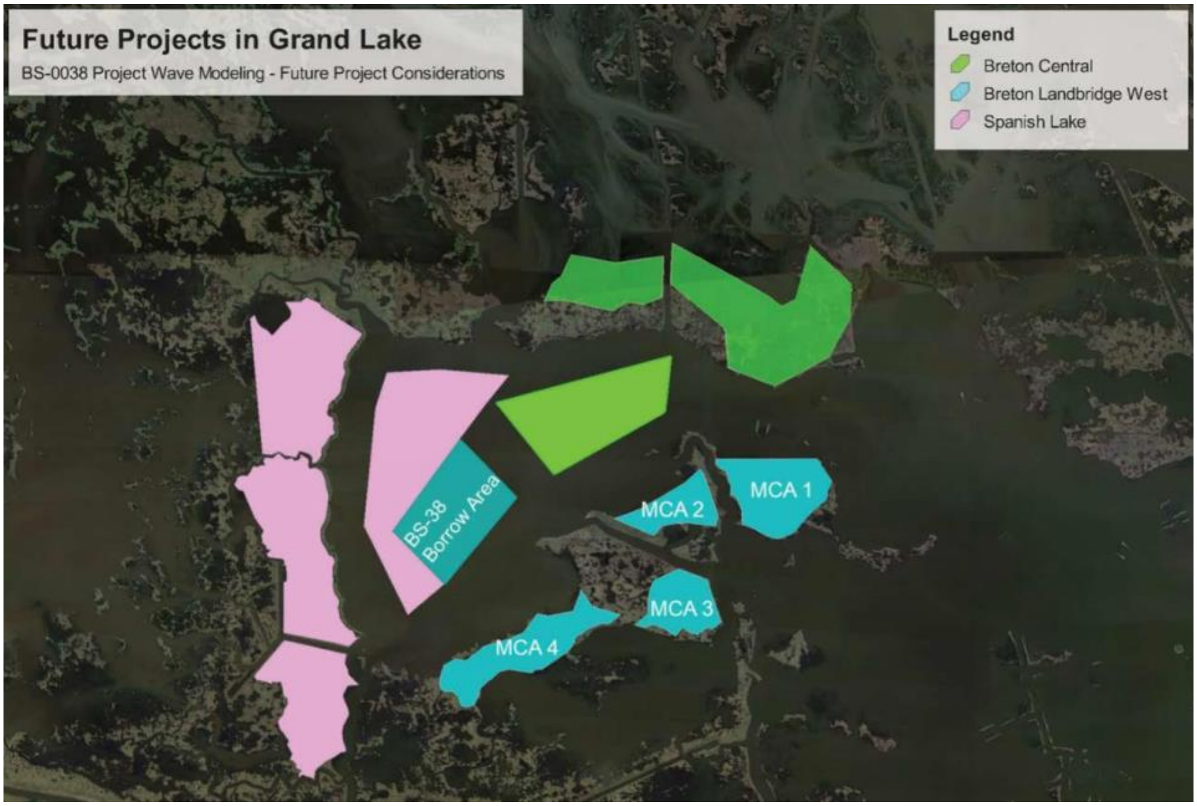

Figure 2. Future marsh creation projects in Grand Lake. (source: CPRA)

2 Environmental Conditions

This section discusses the environmental conditions observed at the Breton Landbridge project site. An analysis of water surface elevations and wind at the project site was conducted. These environmental conditions were used for the wave modeling analysis discussed in Section 3. Nearby gages collecting water surface elevation and wind data were researched to assess the availability and quality of data. Typical and extremal environmental conditions were evaluated and are discussed herein. Figure 3 shows the location of the gauges where data was collected with respect to the project site. In addition to wind and water level, bathymetry data were collected for use in the wave modeling analysis.

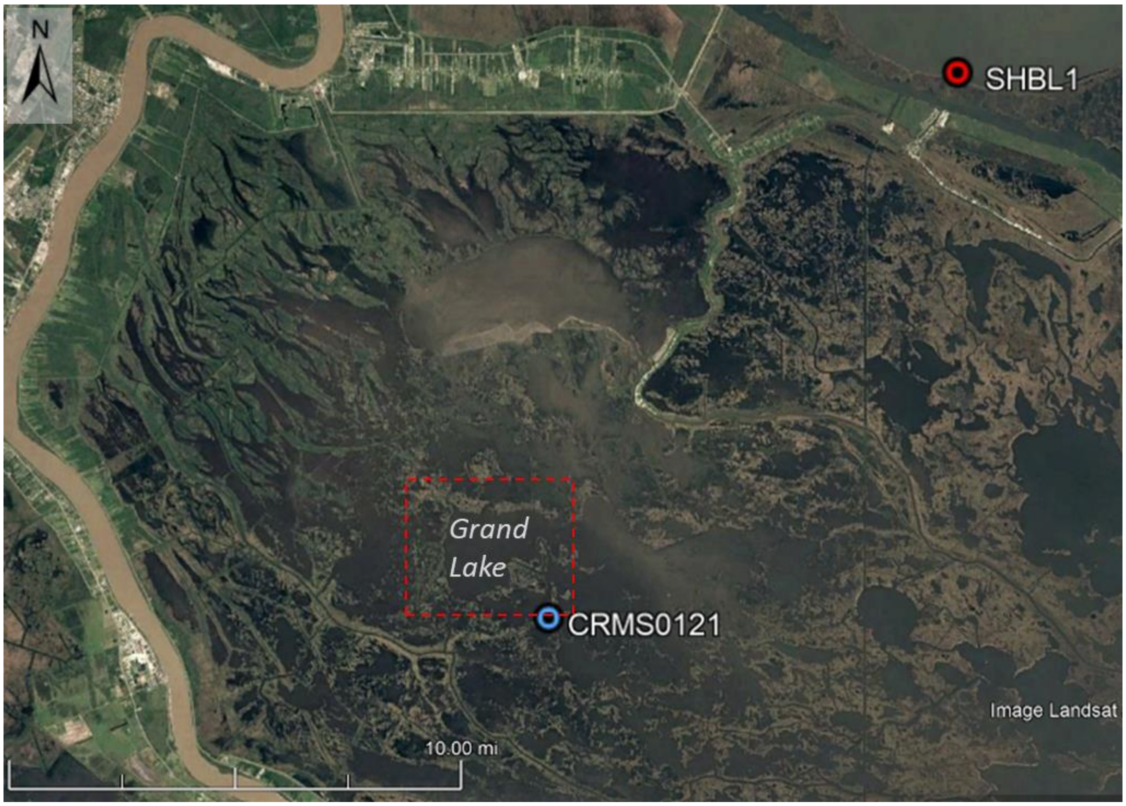

Figure 3. Gaging stations with respect to the project site.

2.1 Bathymetry

Bathymetry data was provided by Coastal Protection and Restoration Authority (CPRA). The data extends from the Mississippi River out towards Breton Sound which provides sufficient coverage for numerical modeling. The resolution of the bathymetry data is 3 m (9.8 ft) within Grand Lake complex and decreases to 100 m (328 ft) out toward Breton Sound. Figure 4 shows the bathymetry data in Grand Lake and surrounding areas.

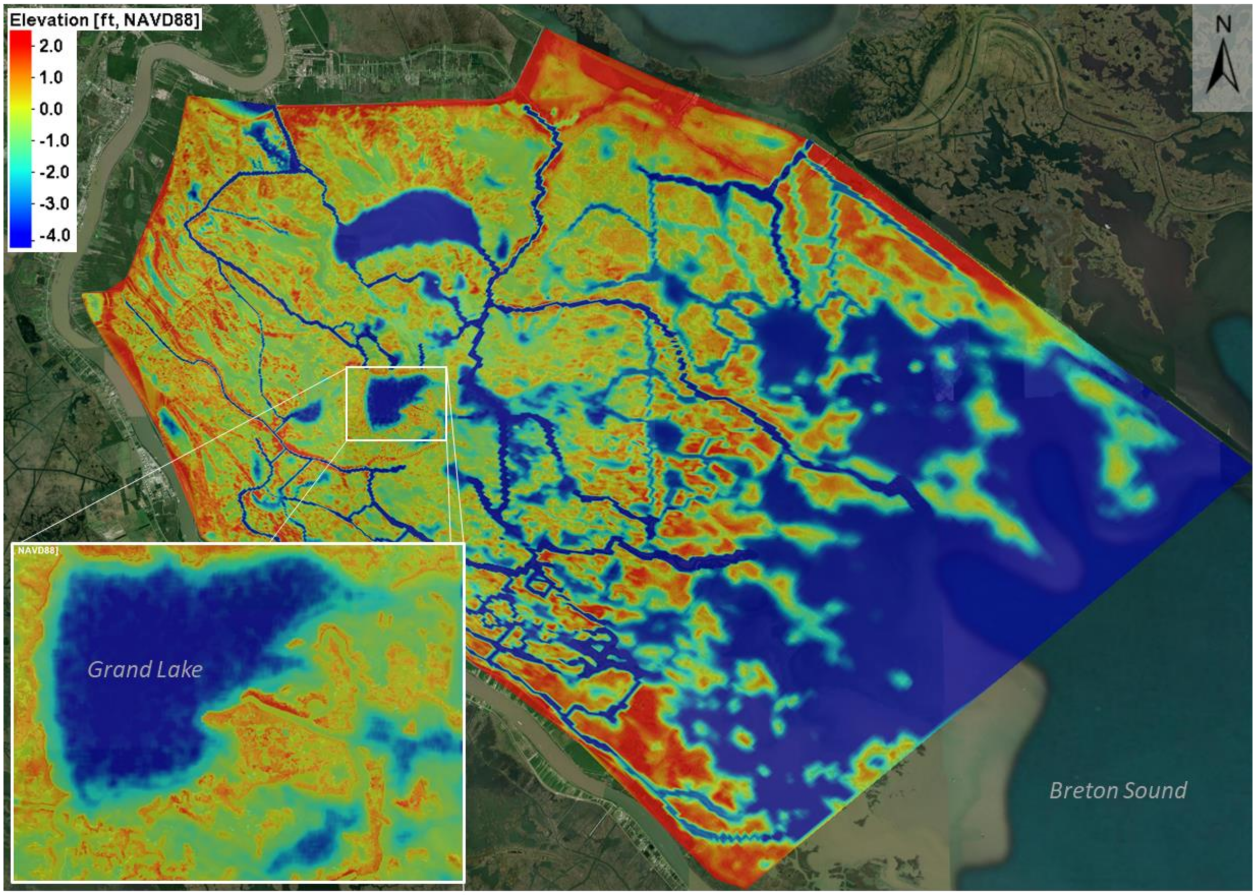

Figure 4. Grand Lake and surrounding wetlands bathymetry data collected by CPRA.

2.2 Water Surface Elevation

Water level data was obtained from the Coastwide Reference Monitoring System (CRMS) station CRMS0121. Hourly water level data was available from 2008 – 2020 with only a few minor data gaps. The data was used to establish datums at the project site, determine extremal water level values, and force the numerical wave model discussed in Section 3. The effects of Relative Sea Level Rise (RSLR) were considered in the analysis of the water levels. We used a RSLR rate of 7.4 mm/yr, provided by CPRA, which includes a combination of the SLR for the 1-m scenario and the local subsidence rate.

Using the measured water levels at the CRMS0121 site, the approximate values of mean higher high water (MHHW), mean lower low water (MLLW), and mean sea level (MSL) were determined and are summarized in Table 1. Figure 5 shows a cumulative distribution function (CDF) of the hindcast water levels. Based on this, the water level falls outside the range between MLLW and MHHW about 50% of the time, with the 90th percentile water level at about 1 foot above MHHW. The existing marsh, which is approximately at the MHHW elevation is overtopped about 35% of the time.

Table 1. Tidal datums based on measured water levels at the project site.

Tidal Datum	Elevation (ft. NAVD88)
MHHW	0.86
MSL	0.50
MLLW	0.12

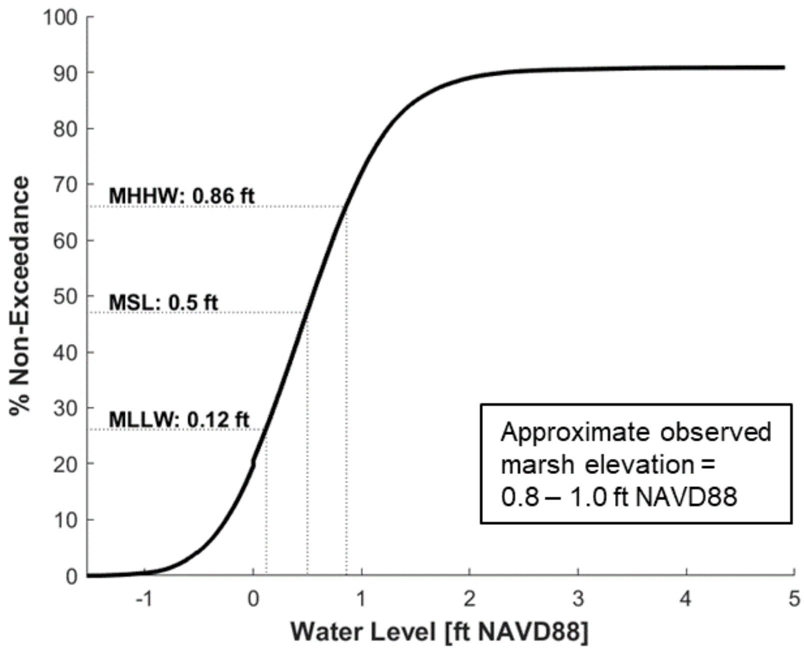

Figure 5. Cumulative Distribution Function of measured water levels at the project site for the period 2008-2020.

An extremal analysis using the annual max value approach was performed on the full record of the water level data. The extremal water level results summarized in Table 2 were used to force the wave model in Section 3. Note that the extremal values provided here included the effects of RSLR.

Table 2. Extremal water levels and their corresponding return period.

Return Period, Tr [yr]	WSEL [ft, NAVD88]
1	1.9
2	3.5
5	4.3
10	4.8
20	5.2

2.3 Wind

Wind data was obtained from the National Oceanic and Atmospheric Administration (NOAA) station SHBL1 at Shell Beach, Louisiana. Six-minute wind data was available from 2009 – 2020 with only a few minor data gaps. Figure 6 shows a wind rose for the available data at SHBL1. Inspection of the time series of wind speeds at SHBL1 indicates that wind speeds rarely exceeding 45 mph. When performing an extremal analysis, it is important to capture strong winds that are typically associated with higher return period storms, and typically these winds are not recorded by field gages. Therefore, a combination of wind data from SHBL1 and the National Hurricane Center (NHC) was used to determine the extremal wind speeds at the project site. The NHC has a database that includes hurricane storm tracks and windspeeds along the track for recorded historical hurricanes spanning from 1851-2014. Wind speeds within a 75 mi radius (representative of hurricanes that can pass through the project site) of Grand Lake were extracted for the analysis.

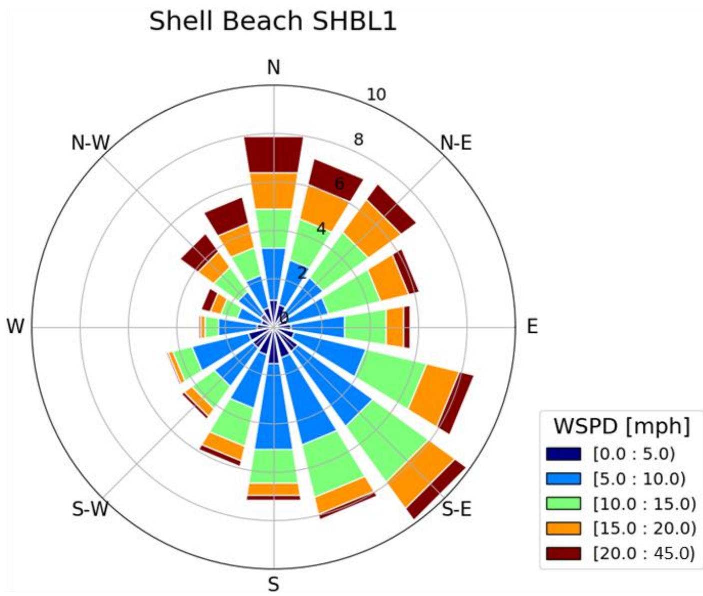

Figure 6. SHBL1 wind rose for 2009-2020.

An extremal analysis using the annual max value approach was performed on the wind data from SHBL1 and NHC. The extremal wind results summarized in Table 3 are used to force the wave model in Section 3.

Table 3. Extremal wind speeds and their corresponding return period.

Return Period, Tr [yr]	Wind [mph]	Source
1	37.1	SHBL1
2	37.2	SHBL1
5	59.4	NHC
10	77.8	NHC
20	95.1	NHC

2.4 Representative Year

A representative year was identified which best captures the long-term trends of the wind and water-level conditions at the project site. The representative year was determined by iteratively computing the root mean square error (rmse) value (statistical measure of how close the data are to the fitted regression line) of the joint distribution of wind speed and direction for a given 365-day period relative to the long-term distribution and identifying the period which gives the minimum rmse value. Since wind speed and direction are the primary forcing conditions for wave growth, these parameters were used to govern the establishment of the representative year. Once the representative year was selected, it was back checked against water level time series for the entire 10 year record and a rmse value of 0.2 ft was achieved signifying reasonable agreement. Using this method, the representative year for the Shell Beach NOAA gauge (SHBL1) winds was determined to be from April 11, 2015 00:00 to April 11, 2016 00:00 and is shown in Figure 7.

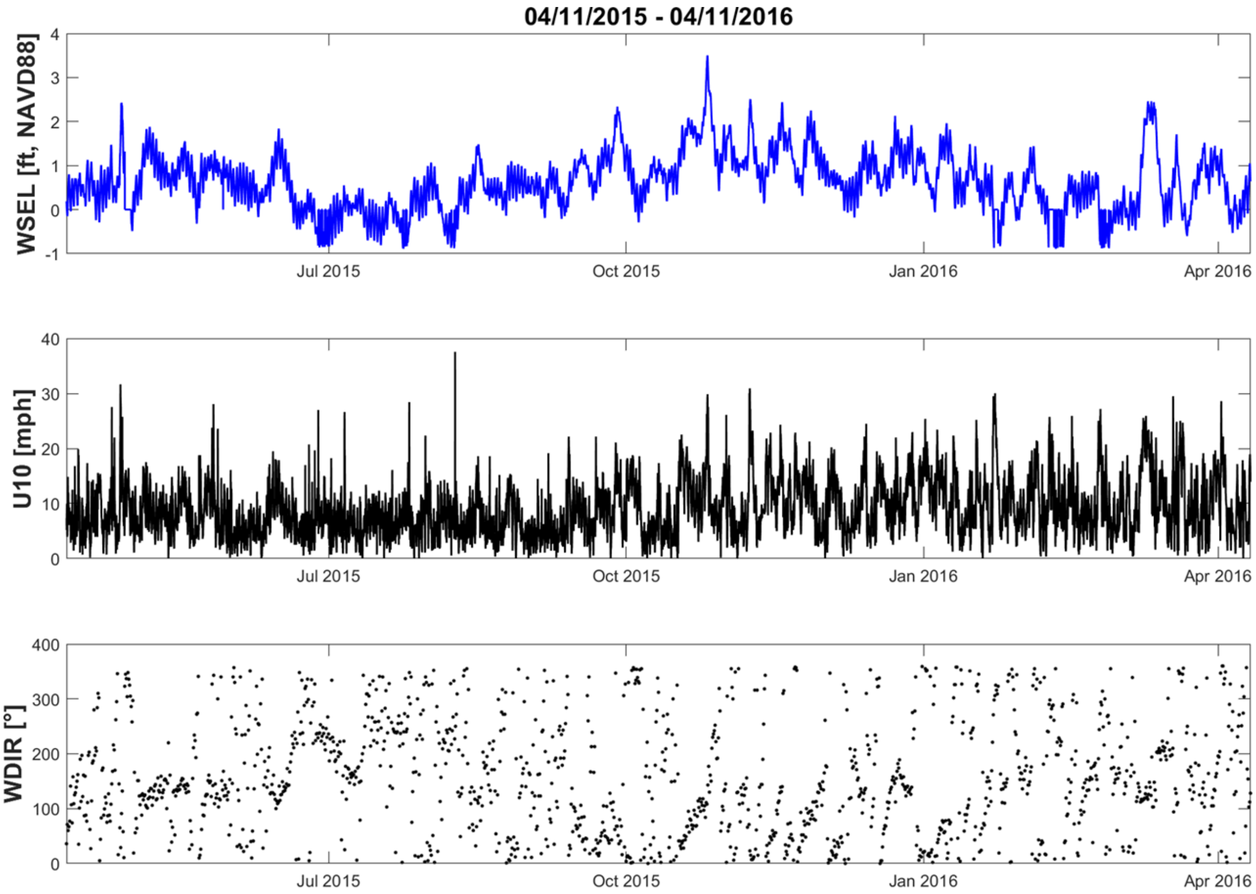

Figure 7. Representative year of wind and water levels at Grand Lake, LA (04/11/2015 – 04/11/2016).

3 Wave Modeling Analysis

Wind-wave generation and transformation modeling was performed in the project vicinity to determine wave characteristics along the Grand Lake shoreline. The modeling was conducted using SWAN (Simulating Waves Nearshore) numerical model. SWAN (Delft, 2014) is a 2-D, spectral (phase-averaged) wave transformation model that can be used to generate wind-waves and transform wave conditions to the nearshore project area.

3.1 Modeling Scenarios

The modeling scenarios considered for this analysis are shown in Table 4 and were finalized in consultation with CPRA. The representative year (Scenario 1) was modeled using the nonstationary mode of SWAN. A nonstationary run calls for a time series input of wind and water level and uses the hydrodynamics from the previous timestep as input into the current time step. We used nonstationary for the yearlong representative simulation as it is a continuous time series of wind and water level inputs. For the Biloxi Marsh CPRA project PO-0172 (Mott MacDonald, 2019), it was found that this is a more accurate approach for modeling typical wave conditions. For the extremal scenarios (Scenario 2 and 3), the stationary mode of SWAN was used since it calls for a single water level and wind value input, as shown in the extremal analysis (Section 2).

There are three bathymetric conditions considered for this analysis. The existing conditions (EX) are the current conditions at the project site, as shown in Figure 4. Alternative 1 (ALT 1) includes the proposed Borrow Area BS-38 and marsh creation lakeside berm borrow areas. Alternative 2 (ALT 2) includes a larger, lake borrow area (for potential future marsh creation projects in Grand Lake), as well as the lakeside berm, borrow areas. Figure 8 shows the bathymetric surfaces for Alternative 1 and 2 in the bottom left and right plots, respectively.

Each extremal scenario was run at two different water levels (MLLW and extremal water level) with extreme winds coming from four directions representing the largest fetches possible around the project locations, as shown in Table 4.

Table 4. Modeling scenarios

Scenario	Tr [yr]	Bathy	WSEL [ft, NAVD88]	WSPD [mph]	WDIR [°TN]
1	-	EX, ALT 1, ALT 2	Rep. yr. time series	Rep. yr. time series	Rep. yr. time series
2	1-YR	EX, ALT 1, ALT 2	0.12*, 1.9	37.1	45, 135, 225, 345
3	20-YR	EX, ALT 1, ALT 2	0.12*, 5.2	95.1	45, 135, 225, 345

(denotes MLLW)*

3.2 Modeling Grids

Two computational grids are used for the wave modeling analysis. The nonstationary modeling grid, used for the representative year simulation, uses a 15-meter (49 ft) fine resolution inside Grand Lake and a 150-meter (492 ft) coarse resolution outside of the lake. The white line in Figure 8 top plot shows the extent of the nonstationary grid. The stationary modeling grid, used for the extremal forcing scenarios, uses a 5-meter (16 ft) fine resolution in Grand Lake and 100-meter (328 ft) coarse resolution outside of the lake.

The Scenario 1 run which is a yearlong run is computationally expensive to execute. Further, based on the review of the wind conditions from Figure 6 and Figure 7 it was determined that locally generated wind waves will dominate the wave climate during the representative year simulation at the project site. Therefore, as shown by the white lines in Figure 8, the nonstationary grid extents were localized around the project site. The water level and wind forcing, shown in Figure 7, were implemented as spatially uniform condition across the entire non-stationary modeling grid domain. No wave boundary conditions were used for this simulation.

The stationary grid extends out to Breton Sound to fully capture the potential of extremal wave growth from offshore to the project site. Note that a sensitivity test was performed for the offshore extents of the stationary grid with and without wave forcing boundary conditions. The 25-yr wave height and peak period, extracted from an ADCIRC+SWAN model used for Mott MacDonald (2019), was tested at the offshore boundary. We found that excluding wave forcing boundary conditions, and the extents shown in Figure 8, were sufficient to capture the wave growth across the marsh between Breton Sound and Grand Lake. The stationary runs were therefore forced with extremal wind speeds, water levels, and wind direction as stated in Table 4 for Scenarios 2 and 3. The three bathymetric data sets described in Section 3.1 were interpolated onto the grids and shown in Figure 8.

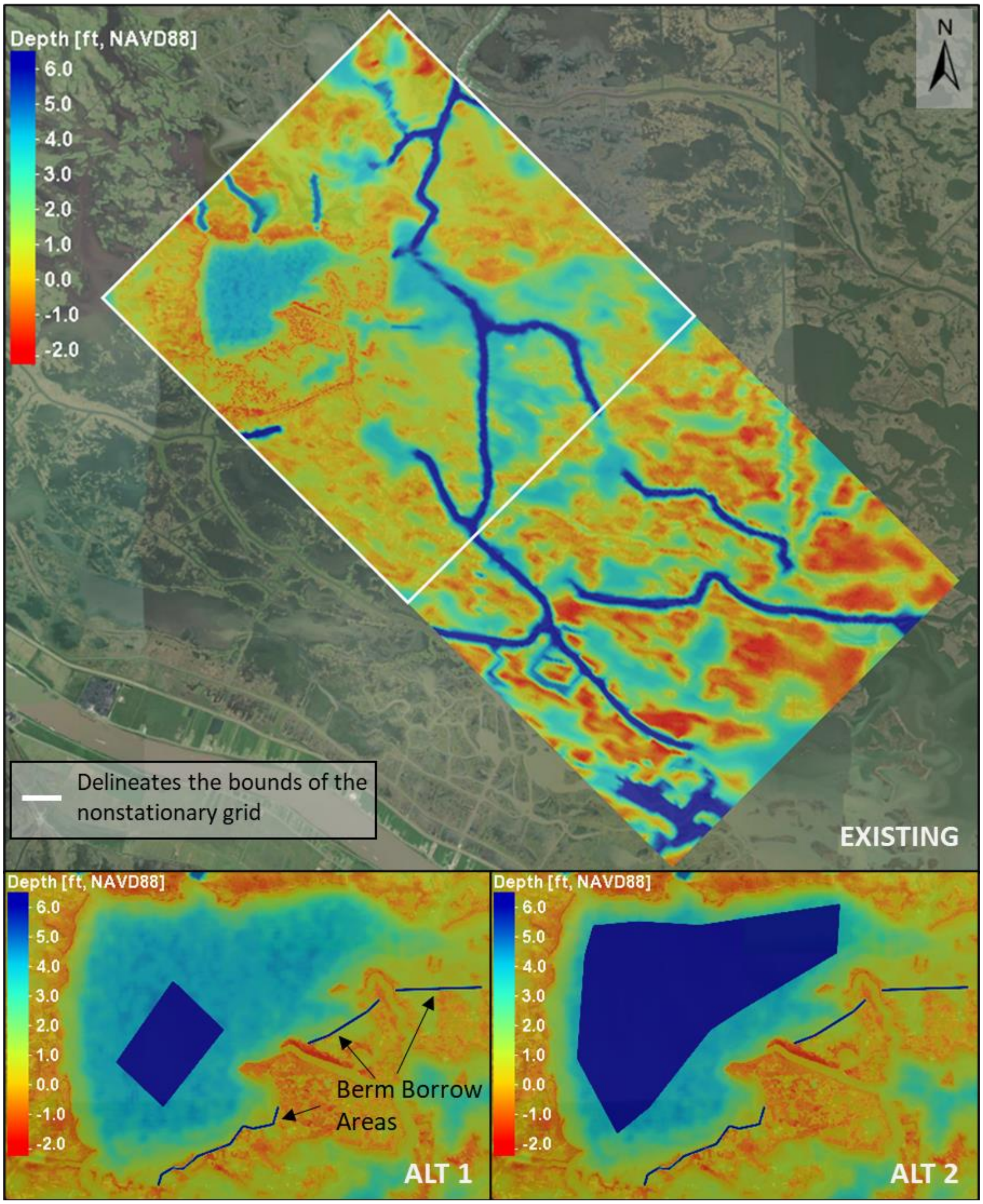

Figure 8. Bathymetric grids (top). Details are shown for proposed alternatives Alt 1 and 2.

3.3 Typical Conditions Results

The goal of the representative year (typical conditions) simulation was to quantify the changes in significant wave heights (Hs) along the Grand Lake marsh shoreline due to the proposed borrow areas in Alternatives 1 and 2. Wave results were extracted along the -2 ft NAVD88 contour at a 15 m (50 ft) spacing. To simplify the analysis, the observation points were grouped into shoreline regions as shown in Figure 9.

The max difference (increase from Existing to Alternative conditions) in Hs across each shoreline region at each time step was calculated and analyzed. Figure 10 shows a box and whisker plot for each shoreline region to highlight the distribution of Hs differences for the representative year (04/11/2015 – 04/11/2016). A box and whisker plot shows the spread and centers of a data set. Here, measures of the spread include the 9th and 91st percentiles (edge of whiskers), the 25th and 75th percentiles (edge of box) (Figure 10). The centers of the data set are represented by the mean ("+" sign) and median (straight line) (Figure 10).

The largest differences were observed along the northern and western portions of the lake. This is likely a result of the dominant southeasterly winds observed in Figure 6. The average difference in Hs was approximately 0.07 ft (0.8 inches) for both Alternative 1 and 2. Although the increase is about 15% from the Existing Hs, the magnitude is on the order of less than an inch and is not expected to cause any adverse effects to the existing marsh shoreline.

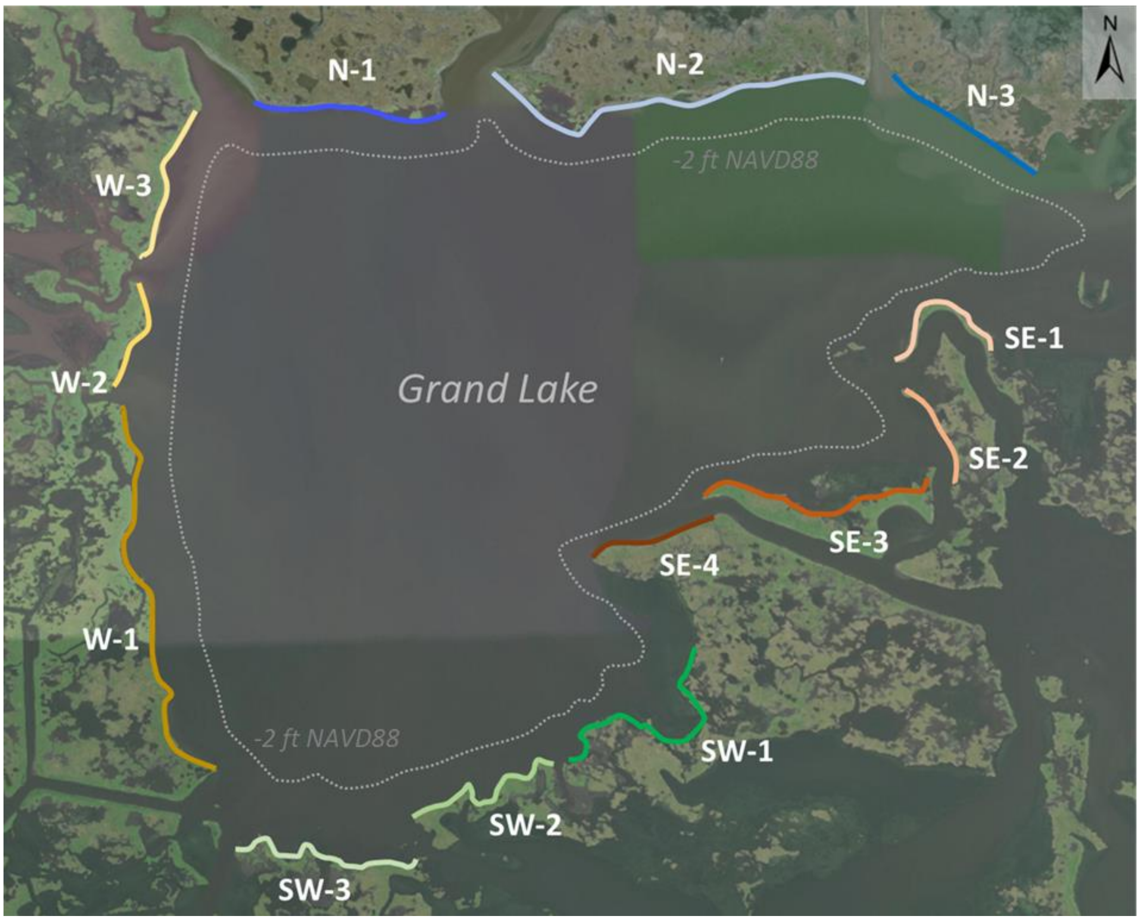

Figure 9. Shoreline regions for wave modeling analysis.

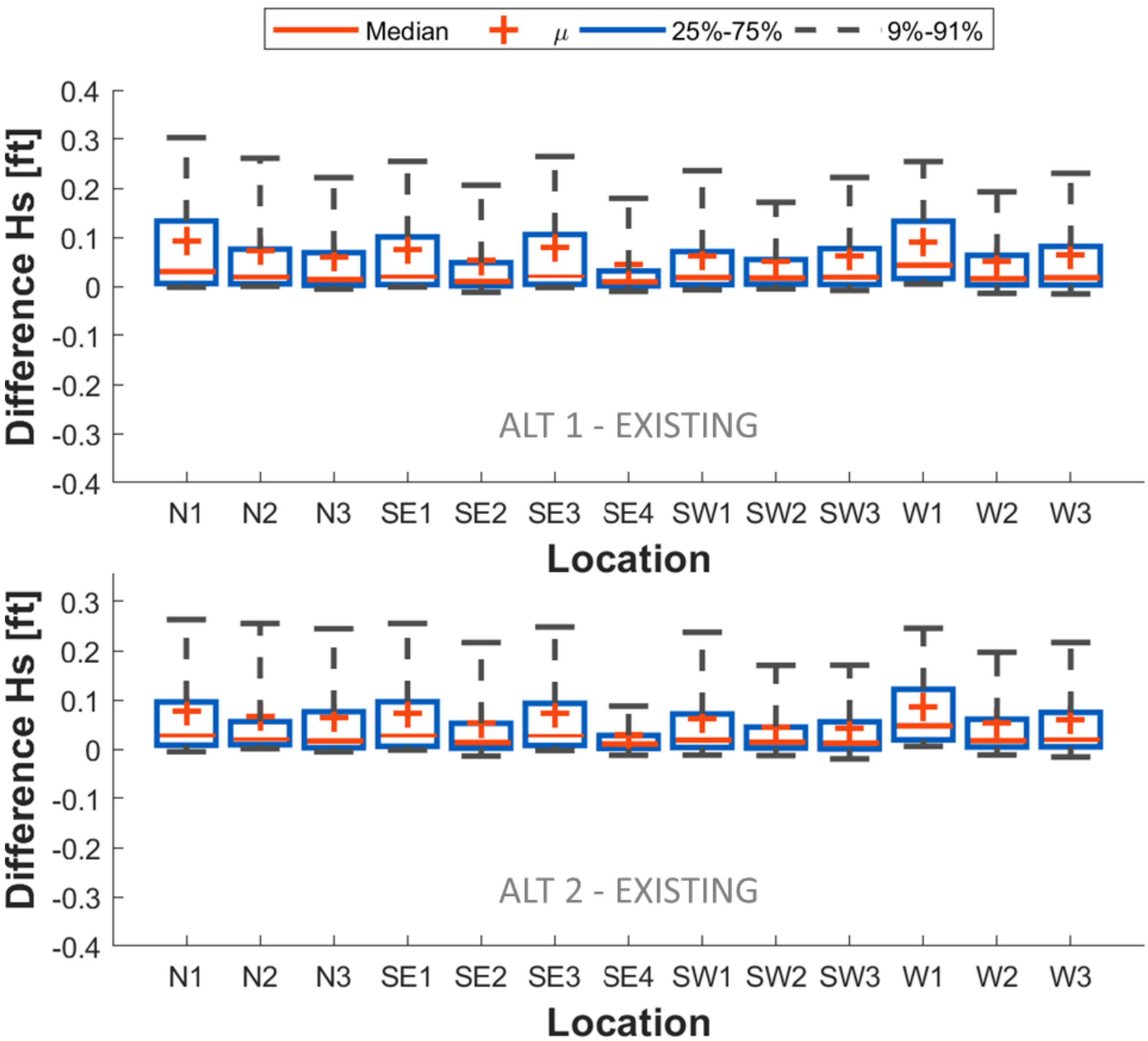

Figure 10. Distribution of Hs differences between Alt 1 and Existing (top) and Alt 2 and Existing (bottom) conditions. The average difference (μ) in Hs between 04/11/2015 – 04/11/2016 is approximately 0.07 ft (0.8 inches) for an average Existing Hs of 0.4-0.5 ft.

3.4 Extremal Conditions Results

The goal of the extremal conditions modeling effort was to quantify the changes in significant wave height (Hs) due to the proposed borrow areas in Alternative 1 and 2 for extreme events impacting the project site. The 1-yr and 20-yr return period conditions used to force the model are outlined in Table 4 - Scenario 2 and 3. Figure 11 shows the wave heights for Existing conditions impacted by a 20-yr storm coming at 345° wind direction. Wave heights up to 4 ft were observed in the middle of Grand Lake and up to approximately 2 ft near the project shoreline (Figure 11). Figure 12 shows the increase in Hs for Alternative 1 during the same 20-yr event. An increase in Hs is observed in the borrow area as fetch and depth increase across it. However, the increase is fairly local to the proposed borrow areas due to the depth limitations of wave growth and wave breaking outside of the deepened sections. Figure 13 shows the increase in Hs for Alternative 2 during a 20-yr event and similar trends to Alternative 1 were observed.

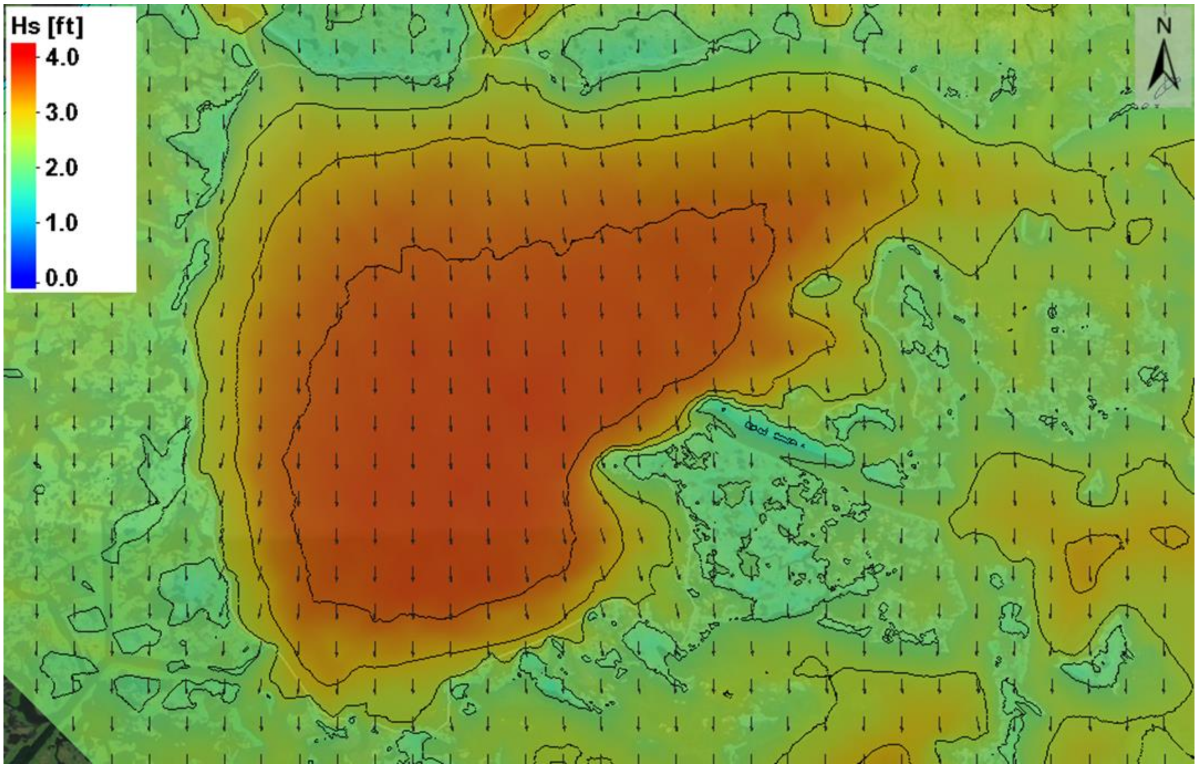

Figure 11. Existing conditions wave height [Hs] for 20-yr return period.

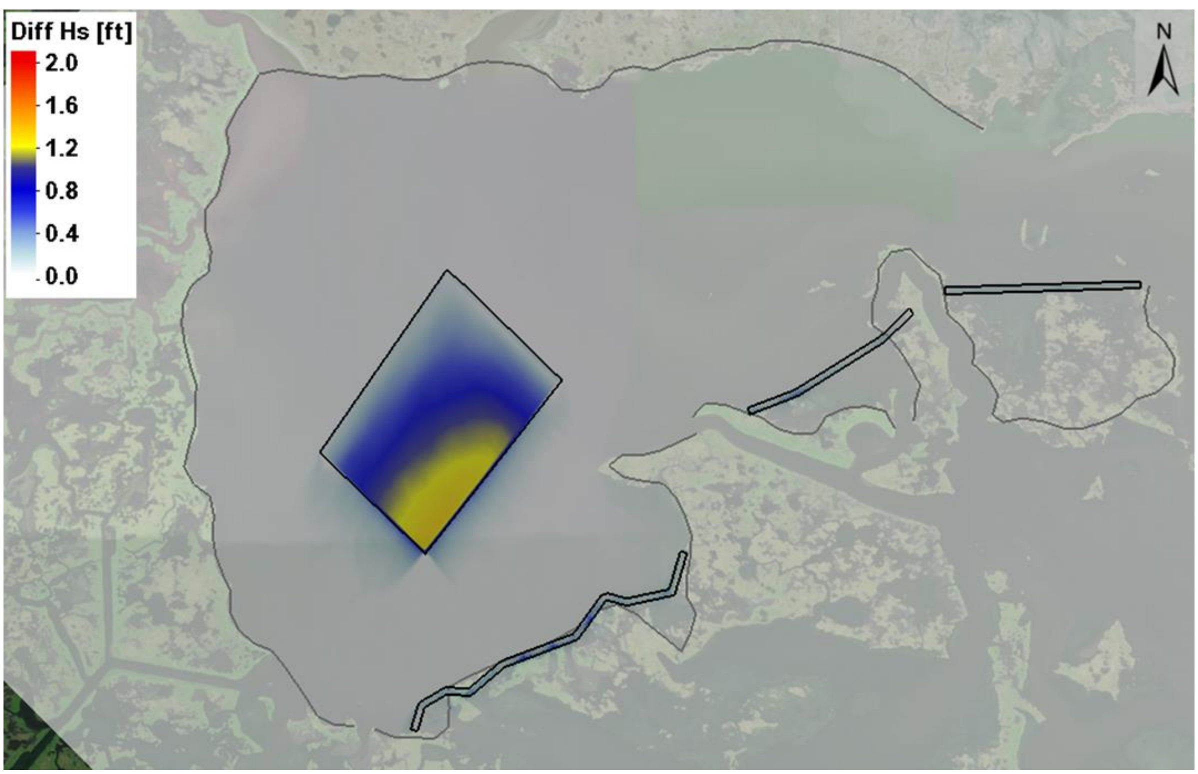

Figure 12. Increase in wave height for Alternative 1 during a 20-yr event.

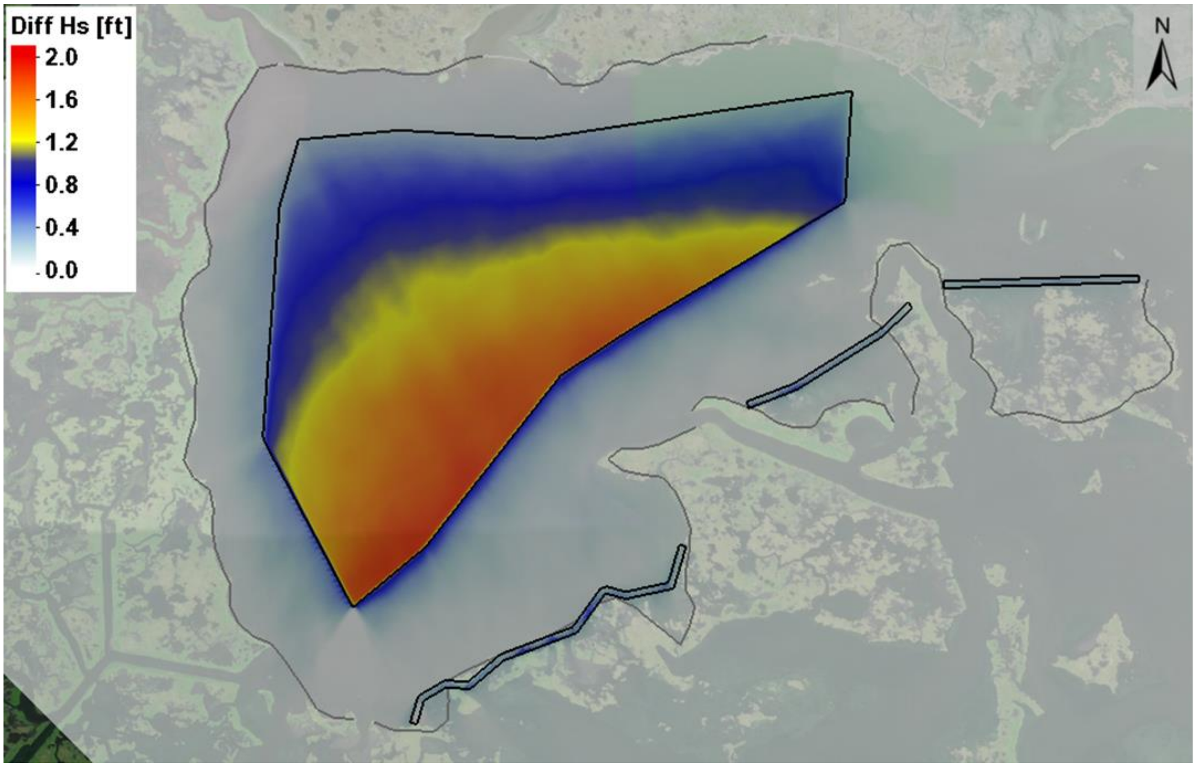

Figure 13. Increase in wave height for Alternative 2 during a 20-yr event at 345°.

To evaluate the impact of the proposed borrow areas on the project shoreline, wave results were extracted between the berm borrow area and the proposed marsh creation lakeside berms. Figure 14 shows differences in Hs at the lakeside berm of MCA 1, 2, and 4 (please refer to Figure 2) for a 1-yr extreme event. The individual boxes show the statistics for Hs differences considering all wind directions and water levels modeled. The average increase in Hs ranges from 0.05 – 0.1 ft from an existing Hs of 0.5 – 0.6 ft across the marsh creation areas for both Alternative 1 and 2. Figure 15 shows differences in Hs at the lakeside berm of MCA 1, 2, and 4 for a 20-yr event. The average increase in Hs ranges from 0.08 – 0.2 ft from an existing Hs of 1.4 – 1.5 ft across the marsh creation areas for both Alternative 1 and 2. In conclusion, the increase in wave heights due to the proposed borrow areas in Alternative 1 and 2 are not expected to add any negative impact to the project shoreline.

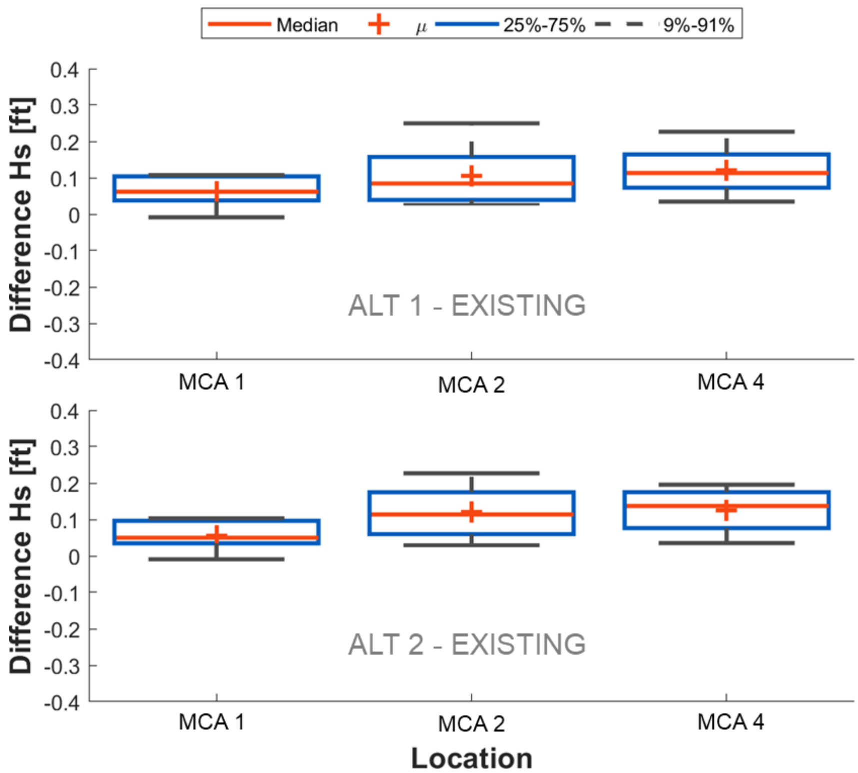

Figure 14. Differences in Hs at the lakeside berm of MCA 1, 2, and 4 for a 1-yr event.

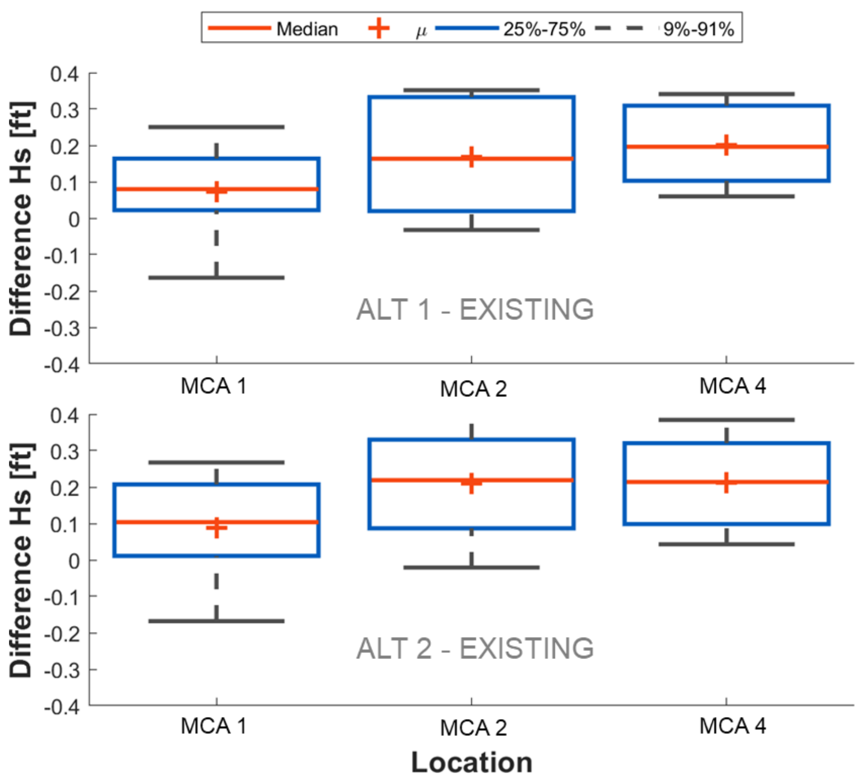

Figure 15. Differences in Hs at the lakeside berm of MCA 1, 2, and 4 for a 20-yr event.

4 Wave Impact Analysis

Wave impact analysis was conducted to determine the impact of wave heights on the existing marsh shoreline and determine if the wave climate is conducive for vegetation growth. An understanding of the wave conditions that will not adversely impact the colonization of vegetation helps to propose mitigation solutions that reduce the wave energy impacts.

4.1 Shoreline Change Rates

A shoreline change analysis was performed in Grand Lake to understand the existing shoreline change trends along the marsh shoreline. CoastSat (2019) was used to delineate the marsh shorelines. CoastSat is an open-source software toolkit written in Python that enables users to obtain time-series of shoreline position at any shoreline using publicly available satellite imagery. The Sentinel-2 (S-2) aerial imagery database was utilized for this study since it contains high-resolution aerials that can accurately represent the irregular marsh shoreline. However, the S-2 database only dates back to 2016 for this area and therefore the retreat rates calculated herein might not be representative of long-term trends and should be used for qualitative comparison of shoreline change rates among different segments of shorelines around the Grand Lake. The shoreline change rates shown in Figure 16 are obtained from the initial and final shoreline position between 2016 – 2020. Note that the retreat rates are smaller in the northern and western regions of Grand Lake and higher along the project shoreline in the southwest and southeast region.

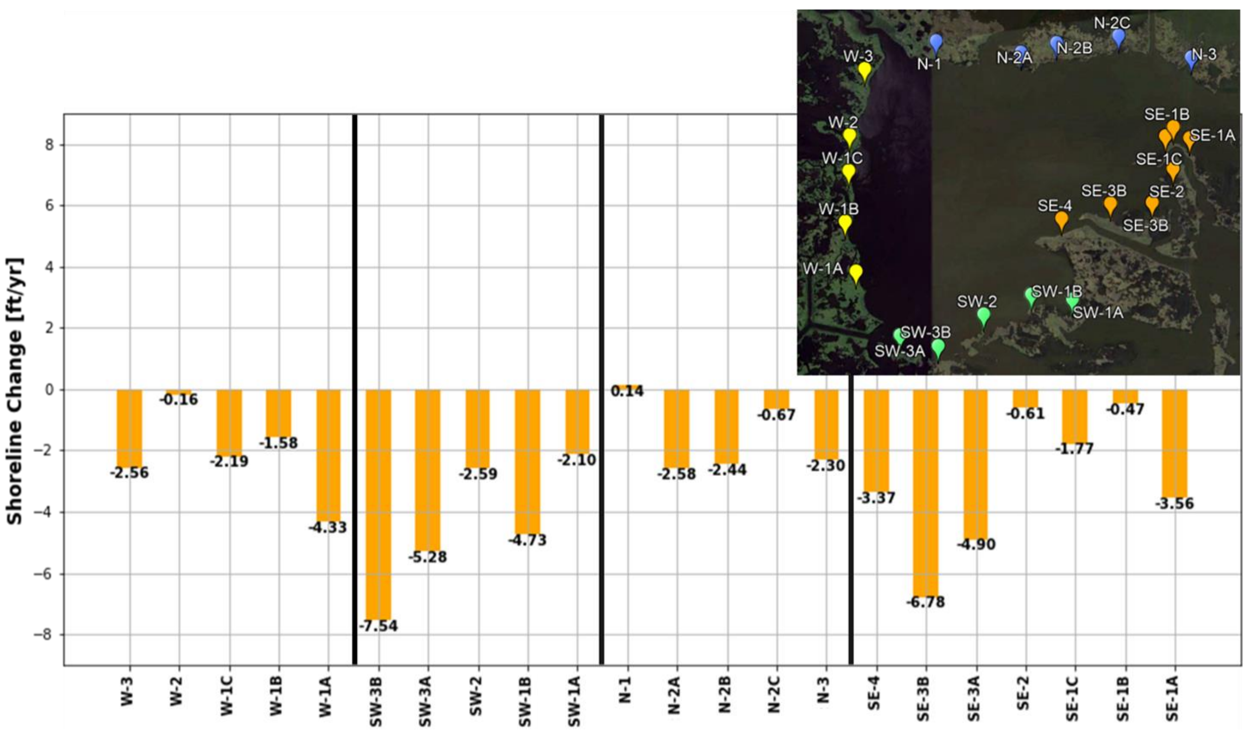

Figure 16. Grand Lake shoreline change rates from 2016 – 2020.

A closer look at the shoreline change rates along the project shoreline was performed to understand the cause of the erosion. A desktop analysis of shoreline positions (dating pre-2016) was performed in Google Earth. It was observed from the pre- and post-Hurricane Katrina

(August 2005) shorelines that the bulk of the shoreline retreat along the project shoreline occurred due to Hurricane Katrina (Figure 17). Notice that there is not much change between 1998 – 2004, and then a large retreat is observed between 2004 and 2005 shorelines (Figure 17). Again, post-Katrina between 2005 – 2015 shoreline change is minimal compared to that occurred during Katrina. The Hurricane Katrina track passed just east of Grand Lake, yielding strong winds from the north forcing waves on the southern shoreline. Therefore, it is important to protect the proposed marsh creation areas from an extremal event such as this. Note that hurricanes can cause strong winds in any direction along the project site, and could therefore produce similar large asymmetric erosion around the lake in the future.

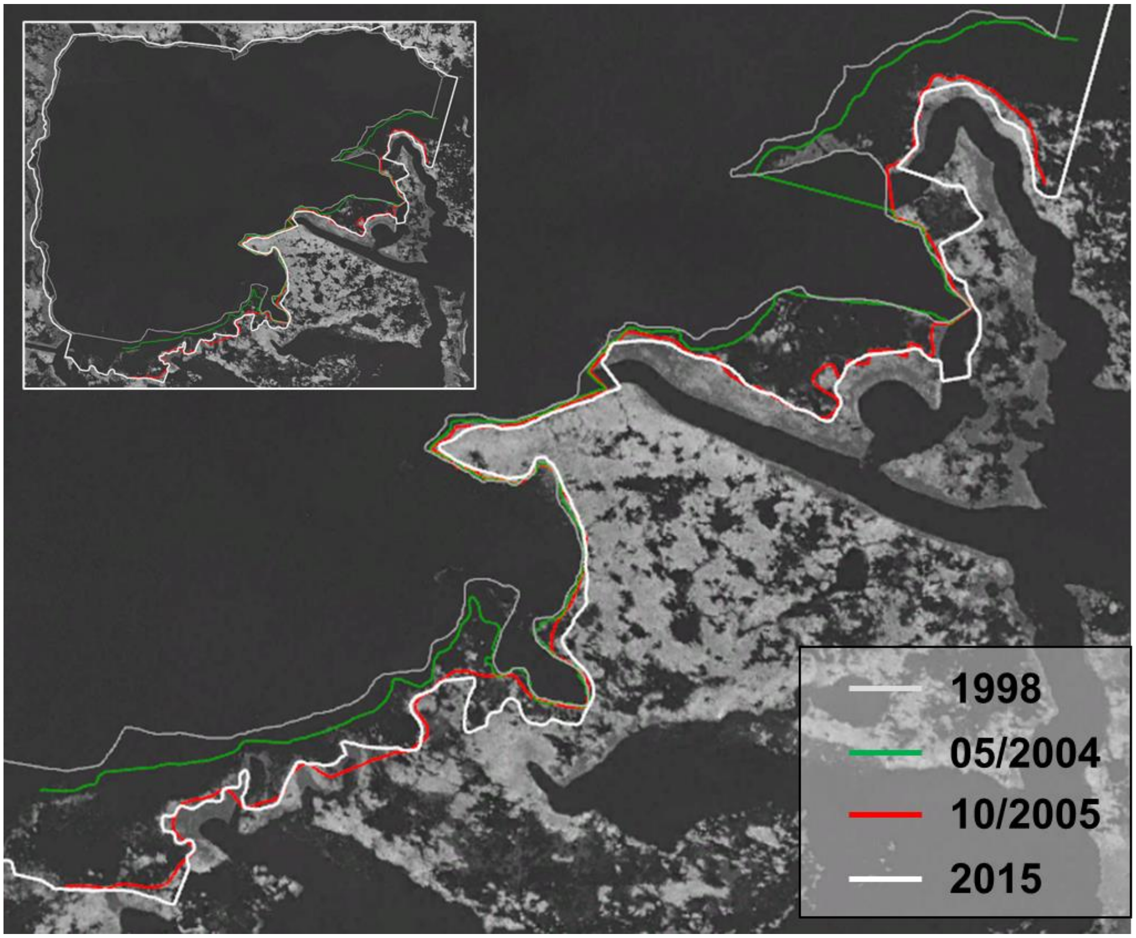

Figure 17. Hurricane Katrina induced shoreline retreat (Background aerial – 10/2005).

4.2 Wave Threshold for Marsh Vegetation

For the proposed marsh creation areas, it is important to understand whether vegetation can colonize on the lakeside containment berm. The lakeside containment berm is built to contain the material pumped into the marsh creation cell and to help protect the area from wave attack. Vegetation can help stabilize the berm soils which will allow more time for the marsh creation area to establish without the impact of wave energy. Roland and Douglass (2005) (R&D) performed a study to relate incident wave height to the presence of marsh vegetation. Note that the study was performed in Mississippi Sound and Mobile Bay for smooth cordgrass (*Spartina alterniflora*). Although the geology, morphology, and marsh vegetation in the R&D study might not directly reflect the vegetative conditions at the project site, the study allows a general insight to a framework relating coastal conditions (wave heights) to a measured ecological benefit (smooth cordgrass growth). Further, there are other environmental factors that influence vegetation growth (i.e. underlying soil properties and salinity) that are not accounted for in R&D.

The typical conditions wave results from the representative year simulation were plotted against the R&D curve (Figure 18). For the R&D curve, the area above the upper dashed line represents no presence of vegetation at the shoreline, the intermediate grey area between the dashed lines indicates wave levels at which eroding wetlands occurred, and the area below the lower dashed line predicts the colonization of wetland vegetation at the shoreline. The colored lines in Figure 18 show the distribution of waves for existing and alternatives under typical conditions against the R&D curve. There is no significant difference in the distribution of Hs between each alternative (Figure 18). For typical conditions in Grand Lake, the bulk of the waves were just below the erosive threshold for vegetation along different representative locations (Figure 19). The smallest waves and largest waves (which occur for less than 15% of the total modeled duration) in the distribution were found in the transitional, or erosive stage. The smallest waves, on the order of 0.2 ft, represent less than 10% of the representative year wave climate at the project shoreline. As observed in the Biloxi Marsh complex (Mott MacDonald, 2019), these small waves are not expected to impact the shoreline vegetation. In conclusion, the results show that most of the wave conditions fall in a favorable condition for vegetation growth in the project site, but the occasional larger wave condition during strong cold front events could disturb some vegetation.

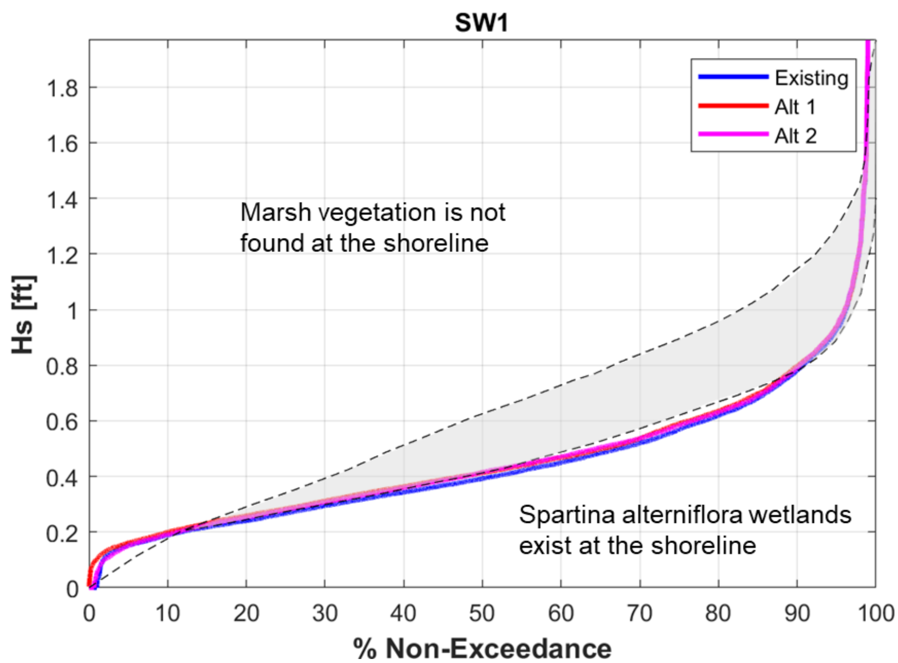

Figure 18. Representative year wave conditions at the project shoreline (SW-1) plotted against the R&D curve (dashed line).

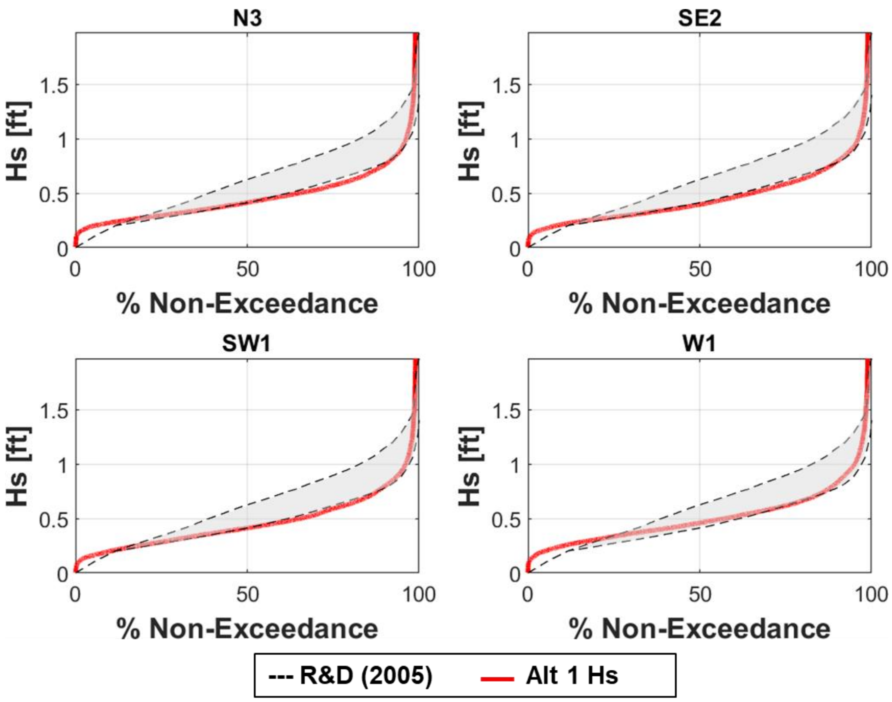

Figure 19. Representative year Alternative 1 wave conditions at representative locations in Grand Lake plotted against the R&D curve.

4.3 Wave Energy Mitigation

In Section 4.1, we observed that the primary cause of erosion along the project shoreline was from Hurricane Katrina, a high return period extremal event. Therefore, it is important to protect the marsh creation berm and surrounding project shoreline from such extreme events. Some potential mitigation solutions may include:

- Wider lakeside berm (to act as sacrificial berm while the newly created marsh stabilizes)
- Terraces (to break waves and therefore reduce the wave energy impacting the lakeside berm)
- Artificial Reef Units (to reduce transmitted waves and therefore reduce the wave energy impacting the lakeside berm)
    - Concrete Units (Wave Attenuation Devices [WAD], Reefballs, Oysterbreak, Shorejax)
    - Pile Supported Units (EcoBale, EcoSystems).

A method to predict wave transmission across artificial reef units was presented in the Biloxi Marsh Living Shoreline project (PO-0172) (Mott MacDonald, 2019). The method uses product-specific transmission coefficients for varying wave and water level conditions to accurately predict the waves on the protected side of the structure. In the PO-0172 study, Wave Attenuation Devices (WADs) were found to be one of the most cost-beneficial units (Mott MacDonald, 2019).

Here, we tested standard WAD units (Height = 6’-4” and Base width = 8’-5” with a 6” spacing between the units) arranged in a 1-row configuration along the -2 ft NAVD88 contour at our project shoreline to evaluate how it performs against extremal waves. The wave model was forced with 20-yr winds from 345° at MHHW water level. Note that MHHW was used since that is the typical elevation of the wetlands in this region and is one of the worst-case scenarios for wave impact on the marsh edge. Above MHHW, the wetlands become submerged and the relative impact of waves gets reduced. The max incident wave height (Hs_i) and corresponding transmitted wave (Hs_t) are plotted against the Roland and Douglass curve (Figure 20). An 80% reduction in Hs is observed at the -2 ft NAVD88 contour. Additionally, the transmitted Hs is significantly below the R&D curve which allows for vegetation to colonize the marsh edge.

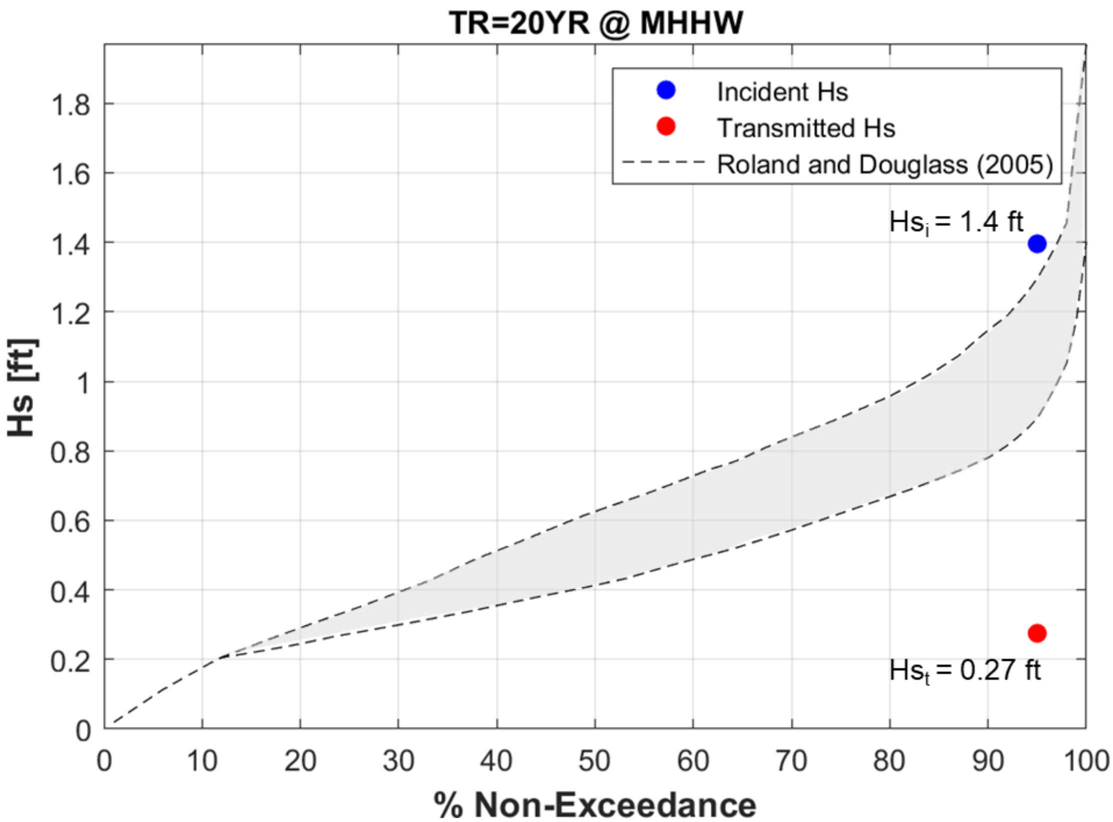

Figure 20. Wave transmission across 1-row of WAD units for a 20-yr event at MHHW water level. R&D curve included as a reference.

5 Conclusions

Based on the analysis shown in this report, the primary conclusions are summarized below:

- The increase in wave heights due to proposed borrow sites from Alternative 1 and 2 are small and are not expected to impact the project shoreline.
- The shoreline change analysis showed low retreat along the North and West portion of Grand Lake and higher retreat rates along the project shoreline (SE and SW shoreline). Most of the retreat along the project shoreline can be attributed to high energy extreme hurricane events.
- Marsh edge vegetation may be disturbed during larger cold fronts and could be damaged during extreme hurricane events.
- Placing artificial reef products at the project shoreline can reduce the wave height to within the marsh wave tolerance threshold. As an example, installing one row of WAD units reduces wave heights that impact the marsh edge by 80% for a 20-yr event.

6 References

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