TE-117 Borrow Region Wave and Velocity Impact Analysis

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Executive Summary

This report summarizes the hydrodynamic impact analysis for the TE-117 borrow region located in Lake Tambour in south Terrebonne Parish, LA. The aim of the analysis was to provide a numerical assessment of the potential impacts associated with the borrow area on the surrounding marsh system in terms of water velocity (i.e., current speed) and wave energy. The analysis was carried out using industry standard software modeling packages (MIKE 21, SWAN) in order to form a digital representation of the existing (pre-project) conditions. The existing conditions were modified by including the project borrow area using a worst-case fully built-out borrow layout (post-project). The numerical models were run for a variety of wind/wave scenarios for both the pre and post-project conditions. The results suggest that project impacts do not exceed 0.06 ft in terms of significant wave height (H_s) based on the SWAN model wave runs. Current velocity differences are less than 0.08 ft/s for the hydrodynamic scenario considered (winter period including the passage of extreme cold fronts). These differences are on the same order of magnitude as the practical accuracy limits for standard bathymetric measurements over soft-bottom topography and current velocity measurements in the marsh environment.

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Chapter 1

Introduction

1.1 Project Location and Description

The borrow area associated with the TE-117 marsh creation project is located in Lake Tambour above Terrebonne Bay in coastal Louisiana. This area has experienced rapid land loss and marsh fragmentation as a result of a variety of factors which have been well documented in the Louisiana Coastal Master Plan. An overview of the project location is given in Figure 1.1.

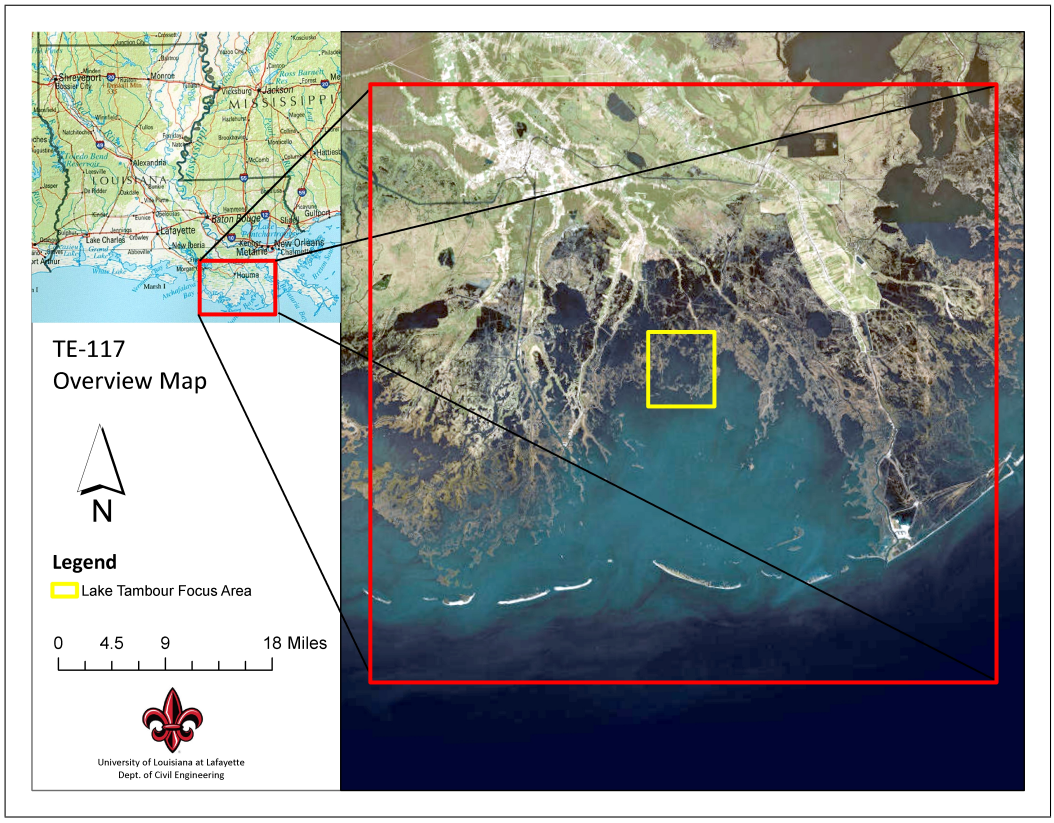

Figure 1.1: General Overview Map

1.2 Goal and Objectives

The overall goal of this effort is to provide a numerical assessment of the impact of the borrow region on surrounding marsh system in terms of wave energy and current velocity. This assessment is motivated by the fact that local wave energy and tidal exchange depends significantly on the bottom topography (i.e., bathymetry) and that alterations to the bathymetry can change the wave characteristics and tidal exchange patterns within a semi-enclosed marsh/open water environment. Given the complexity of the surrounding fragmented marsh system, and coastal Louisiana in general, advanced numerical modeling software packages (MIKE 21, SWAN) were required to conduct the analysis and to determine the overall project impacts. The specific objectives of our analysis are as follows:

1. To setup a two-dimensional wind-wave model including the borrow region and surrounding marsh areas.
2. To setup and calibrate a hydrodynamic model for water level and currents to encompass the project borrow site and surrounding regions.
3. To use the models to approximate the existing conditions in terms of wave heights and current speed and to provide a numerical assessment of the project impacts.

1.3 Scope

The overall scope of this project was to setup numerical models of the system and to conduct an impact assesment of the borrow area on the local wave energy and velocity characteristics adjacent to the project site (Figure 1.2). This includes the setup of a local SWAN (Simulating WAves Nearshore) model to analyze the project impacts on the wave spectrum and a detailed hydrodynamic model (MIKE 21) to approximate the water levels and velocity fields near the borrow region. The spectral wave model runs consist of 84 wind speed and direction combinations for both pre and post-project conditions for a grand total of 168 stationary simulation runs. The results are provided in graphical format at the end of this report and an overall summary of the analysis methodology, results, and an assessment of project impacts is also provided herein.

1.4 Outline

The report is organized as follows:

Chapter 1 The introduction is given in Chapter 1. It describes the fundamental terms used in this project. It motivates to study and understand the different techniques used in this work. This chapter also presents the outline of the objective of the report.

Chapter 2 It describes the collection, processing, and input of the data used to drive the numerical models.

Chapter 3 This chapter presents a description of the numerical models and their setup.

Chapter 4 The project impacts are summarized in Chapter 4 in addition to a discussion of uncertainties and an overall recap of the effort.

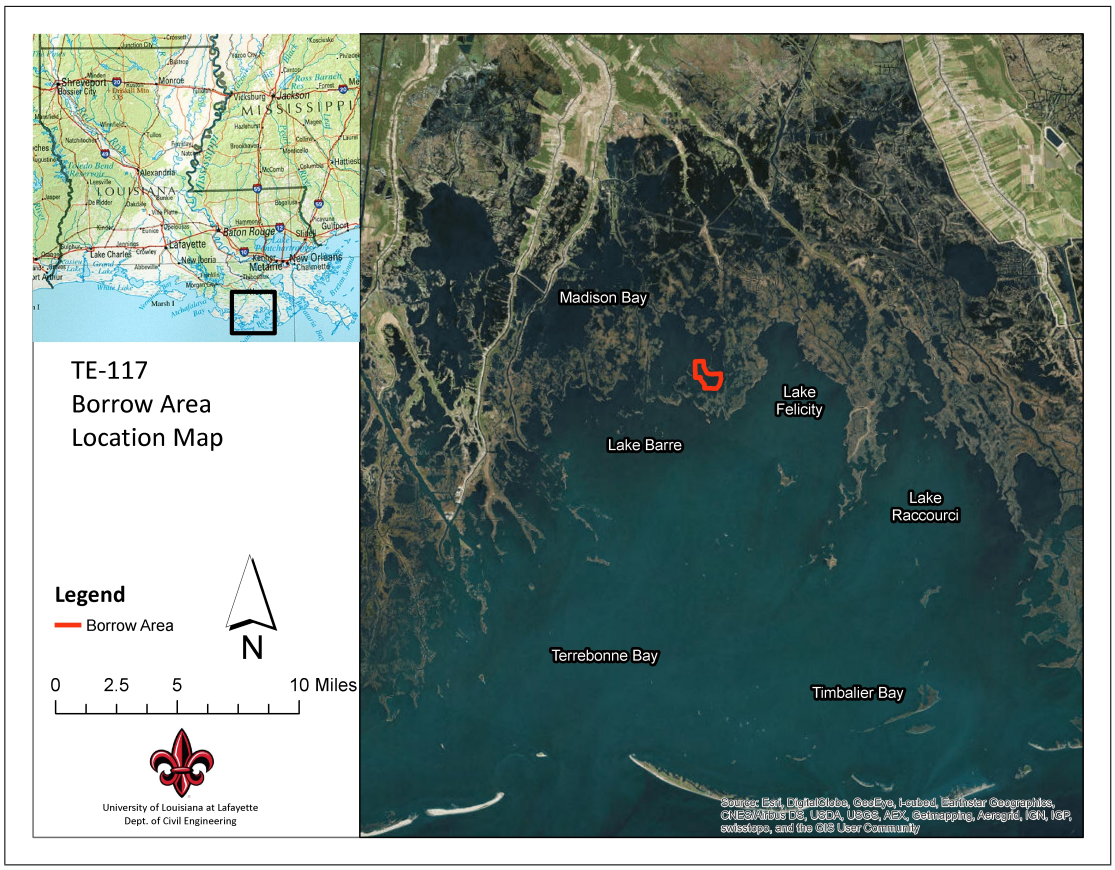

Figure 1.2: Borrow Area Location Map

Chapter 2

Data Gathering and Processing

2.1 Topographic Data

An essential element in any hydrodynamic study is the land and underwater topography (Figure 2.1). The topography input is usually given in the form of a digital elevation model (DEM) which is a generic electronic file which provides a numerical representation of ground heights. This study required the fusion of three DEM datasets including the LiDAR (Light Detection And Ranging), the USGS Gulf of Mexico topobathy dataset, and baseline profile survey data (obtained by Fenstermaker) to correct DEM discrepancies at the borrow site. The resulting DEM was then resampled to a coarser resolution for inclusion in the numerical models. The resampled DEM was then manually adjusted to re-establish marsh connectivity which was lost during the re-sampling procedure. Unless otherwise stated, all elevation data presented in this report are given relative to the North American Vertical Datum of 1988 (NAVD 88) geoid 99.

2.2 Water Level Data

Water level data was required in order to furnish the boundary conditions for the hydrodynamic model and to establish the mean high water depth which was used as the baseline for the wave modeling scenarios. Water levels were obtained from the Coastwide Reference Monitoring Network (CRMS) dataset as well as the National Oceanic Atmospheric Administration's (NOAA's) Tides and Currents (TaC) database.

2.3 Meteorological Data

Meteorological data was obtained from the NOAA TaC database as well as the offshore buoy program. Hourly wind speed and direction data from Grand Isle were subsequently

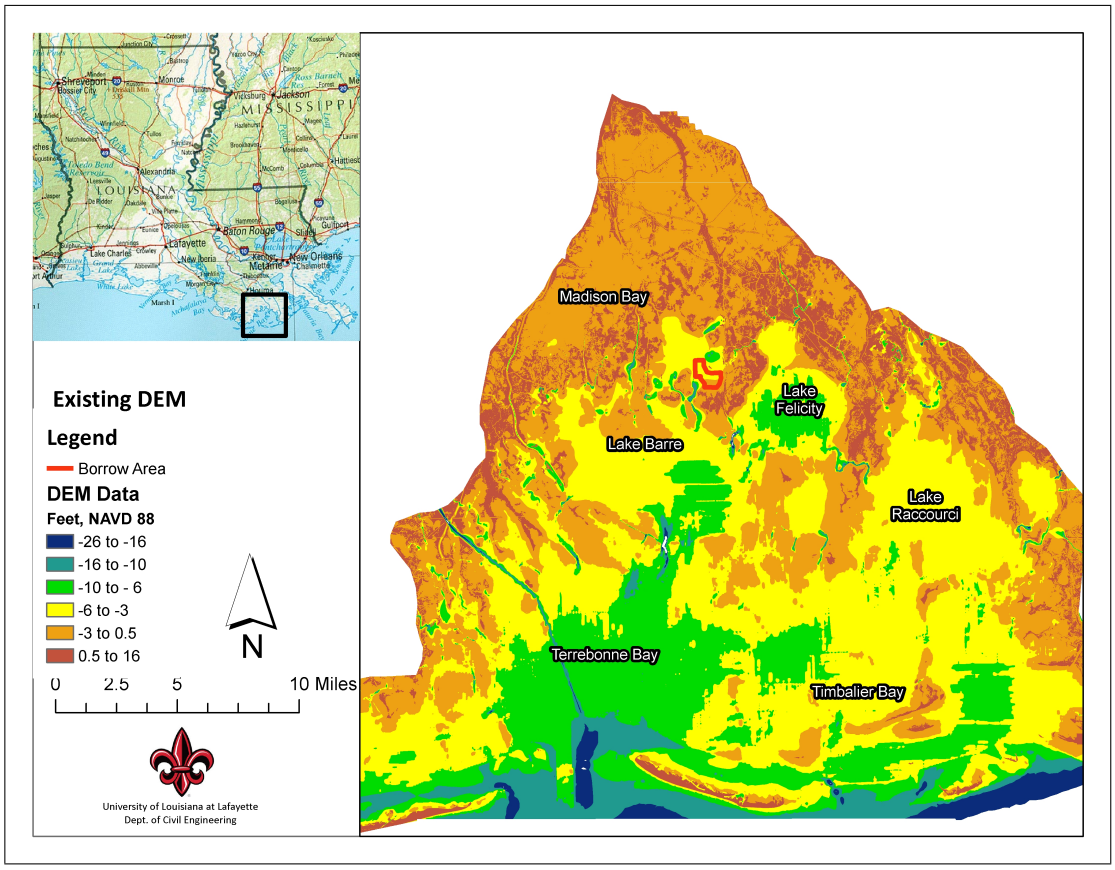

Figure 2.1: Bathymetry Data in Areas Surrounding the Borrow Region

processed to establish the wind frequency spectrum and the time series data required by the hydrodynamic model (Figure 2.2 and Figure 2.3).

Figure 2.2: Grand Isle Meteorological Station Relative to Lake Tambour Focus Area

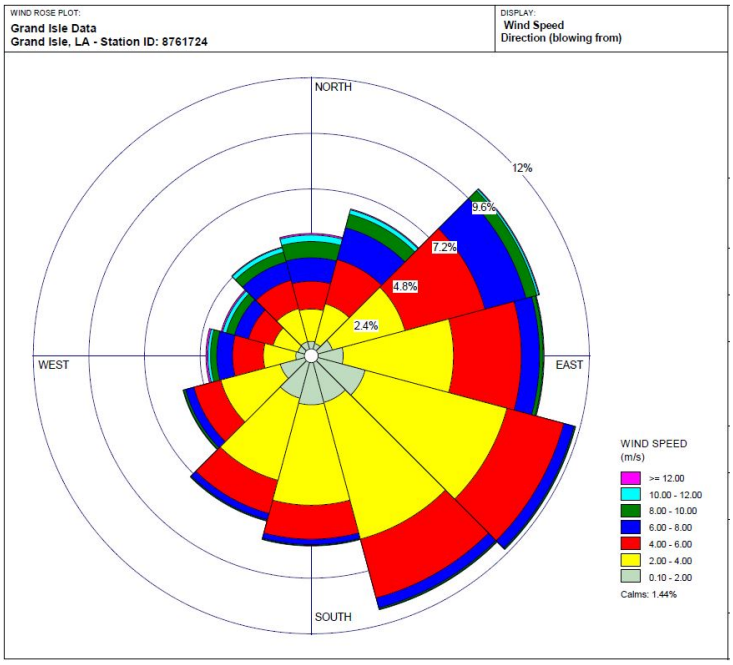

Figure 2.3: Wind Rose Summary - Grand Isle (2000-2017)

2.4 Wave Data

Wave measurements (significant wave height, H_s, direction, and wave peak period T_p) are required to construct the open water (swell) boundary conditions for numerical wave modeling studies. Although a number of site-specific monitoring efforts and research studies have been conducted within the Terrebonne Bay region in recent years, detailed wave measurements were not available within Lake Tambour at the time of this study. However, a review of the recent research efforts conducted in Terrebonne Bay (Table 2.1) as well as the offshore wave statistics at the CSI-06 monitoring station (Figure 2.4) provided valuable insight on the upper limit of the wave characteristics which could be expected within the Lake Tambour focus region (Figure 2.5).

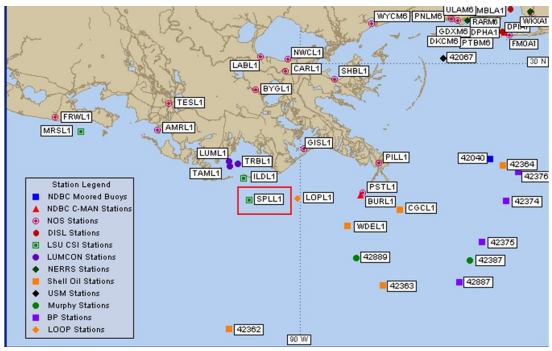

Figure 2.4: National Data Buoy Center Station - Red Highlighted Site is CSI-06

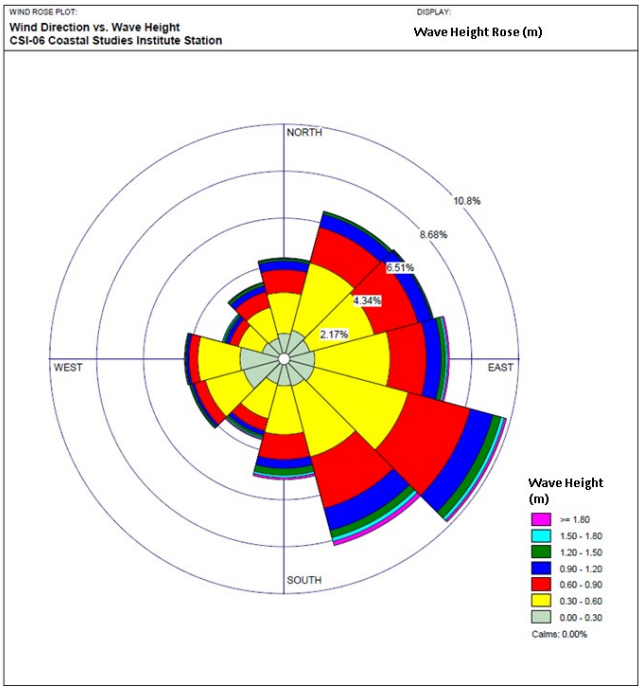

Figure 2.5: Wave Rose for CSI-06 (2009-2015)

Table 2.1: Summary of 2012 Wave Time Series Averages (Adapted from Parker, [5]) at a Site Located 7 Miles SW of Borrow Area in Terrebonne Bay (Standard Deviation in Parenthesis)

Period	H_s, **(ft)**	T_p **(s)**
12-13-2011 to 03-05-2012	0.36 (0.20)	2.99 (2.27).
03-05-2012 to 07-06-2012	0.46 (0.30)	2.92 (1.86).
07-06-2012 to 08-14-2012	0.33 (0.20)	2.46 (1.64).
12-13-2011 to 08-14-2012	0.39 (0.26)	2.86 (1.98).

2.5 Borrow Pit Design Data

The borrow pit layout data (provided by Fenstermaker) consisted of plan and profile sheets for two borrow pit configurations (Figures 2.6 and 2.7). The profile transects were used to make the local bathymetry adjustments within the borrow pit footprint. Two borrow pit configurations were provided and a composite configuration (taken as the spatial union of both footprints with the maximum depth) was used in the subsequent impact calculations.

Figure 2.6: Borrow Pit Configuration A

Figure 2.7: Borrow Pit Configuration B

Chapter 3

Numerical Modeling

3.1 Wave Analysis

Waves are a significant consideration when analyzing the impact of coastal restoration projects. Borrow activities (i.e., dredging) alter the underwater depth characteristics which can in turn alter the wave characteristics in the vicinity of the borrow site [1, 4]. The TE-117 borrow site is located in a fragmented marsh/bay system whose wave signal is primarily wind-driven. A spectral wave model (SWAN) was used to re-create the base wind/wave conditions within the vicinity of the borrow area.

The SWAN model is suitable for nearshore wave investigations since it captures the key physical processes involved with wave transformation within a shallow coastal environment. It solves the wave action balance equation in order to approximate the wave climate in the nearshore environment. The wave action balance equation is essentially a multidimensional scalar conservation law which represents the transport (advection terms) of wave energy and the subsequent amplification or damping of wave energy due to a variety of physical processes (reaction/source terms). Given the lack of detailed wave time series information within the project domain and the project execution time frame, the stationary (steady state) wave modeling option was chosen as the basis of the analysis.

The primary spectral wave model input and setup components include the underwater topography (bathymetry), physics parameters (e.g., bottom friction, wave interaction processes, frequency parameters), and the boundary conditions. Wave energy boundary conditions in general include side boundary conditions which account for wave characteristics at all open water boundaries as well as boundary forcing at the water surface due to wind effects.

3.1.1 SWAN Model

SWAN is a third generation wave model for obtaining realistic estimates of wave parameters in coastal areas, lakes and estuaries from given wind, bottom and current conditions. The model can be used on any scale relevant for wind-generated surface gravity waves. SWAN is based on the wave action balance equation with sources and sinks (3.1).

$$\frac{\partial N}{\partial t} + \frac{\partial c_x N}{\partial x} + \frac{\partial c_y N}{\partial y} + \frac{\partial c_\sigma N}{\partial \sigma} + \frac{\partial c_\theta N}{\partial \theta} = \frac{S_{tot}}{\sigma} \tag{3.1}$$

Here, N represents the action density spectrum and c represents the propagation velocities along the prescribed coordinate axes. The coordinate axes are x and y for geographical space, and σ and θ in frequency and directional space respectively. The right hand side of the equation includes the effects of wind-driven wave generation, dissipation, and nonlinear wave-wave interactions. Thus the action balance equation can be interpreted as a four-dimensional scalar conservation law (advection/reaction) with a reaction term (source) on the right hand side which takes into account atmospheric input, dissipation due to depth-induced wave breaking, bottom friction, and white-capping, triad and quadruplet nonlinear wave-wave interactions.

The SWAN model accounts for the following physics:

1. Wave propagation in time and space, shoaling, and refraction due to current and depth, frequency shifting due to currents and non-stationary depth.
2. Wave generation by wind.
3. Three- and four-wave interactions.
4. Whitecapping, bottom friction and depth-induced breaking.
5. Dissipation due to aquatic vegetation, turbulent flow and viscous fluid mud.
6. Wave-induced set-up.
7. Propagation from laboratory up to global scales.
8. Transmission through and reflection (specular and diffuse) against obstacles.
9. Diffraction.

3.1.2 Model Domain and Physics Parameters

The model domain was developed based on the composite bathymetry datasets discussed earlier in the report (Figure 3.1). Computational grids were generated for all scenarios using a Cartesian mesh with a square pixel resolution of 200 meters. The spectral directions

included the full circle for all simulations with a 10^0 resolution for a total of 36 directional bins. The discrete frequencies ranged from 0.05 to 1 Hz respectively. The JONSWAP bottom friction formulation was used with a bottom friction value of $C_{bf} = 0.019$ noting that this value is most likely conservative for the region given the shallow depths within Tambour Bay [2, 6]. All model simulations included the effects of triad interactions and default values were chosen for all other parameters.

3.1.3 Wave Model Boundary Conditions

The SWAN model simulations were run in stationary mode. However, a range of possible wind/wave combinations were developed to span the range of potential boundary conditions both at open boundaries (i.e., swell) and at the free surface (wind speed and direction). A total of 84 wind/directional scenarios were developed as the basis of the pre-post project comparative analysis. The wind boundary conditions were taken from the wind rose data compiled for Grand Isle, LA. The swell conditions were similarly developed based on the measurements published by the Coastal Studies Institute at the CSI-06 offshore platform. Strictly speaking in order to apply the offshore swell conditions, the model domain should extend far enough offshore so that the open water boundary at the downstream limit of the model domain is representative of the conditions at the monitoring gauge. For the purposes of the pre-post comparative analysis, a regional model was developed to incorporate Terrebonne Bay extending southward of the Timbalier Islands. The regional model was then used to perform a sensitivity analysis to investigate the significance of offshore swell components on Lake Tambour and more specifically whether the wave climate near the proposed borrow area is influenced by waves within the Gulf of Mexico. The regional model simulations suggested that the wave climate near the borrow area was not significantly influenced by offshore swell, but rather by the relatively large north-south open water fetch within Terrebonne Bay.

Due to the high computational cost of running the regional model over the boundary scenarios, a local model was developed for the Lake Tambour region. This local model inherited the same resolution and parameters of the larger regional model, but was significantly faster in wall clock simulation time - making it well suited for the overall project impact analysis. Given the lack of long term wave measurements inside of Terrebonne Bay and the fact that wave energy generally decreases with decreasing bathymetric depth, the wave boundary conditions for each respective wind speed and directional combination for the local model were taken directly from the CSI-06 offshore wave measurement spectra. Here, we point out that this selection most likely provides a more conservative estimate of the boundary condition at the south end of the local model. We also note that this boundary condition is applied by SWAN only when the characteristics (i.e., wind direc-

tion) are pointing into the domain (i.e., winds from the SW and SE quadrant), whereas the boundary condition is overwritten by conditions inside the model domain when the wind direction is pointing outward (i.e., winds blowing from the NE or NW quadrant) from the domain.

A marsh-inundating high tide elevation of 1.6 ft was used as the basis for the wave simulations. For comparison, the mean water level is 1.1 ft at the CRMS station nearest to the borrow area (CRMS0341-H01).

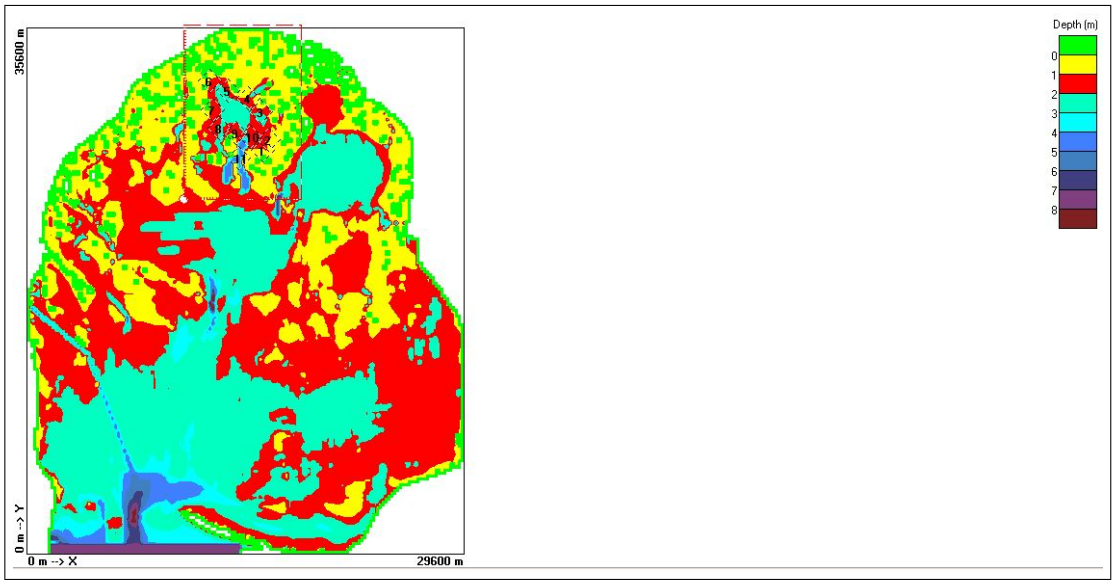

Figure 3.1: Regional SWAN Model Bathymetry Map. The Local Model Domain Outline is Shown by Dashed Lines.

3.2 Hydrodynamic Analysis

The main objective of the hydrodynamic analysis was to analyze the impact of the borrow area on wind and tide-induced currents at exposed shorelines within the Lake Tambour region. A two-dimensional full hydrodynamic model MIKE 21 by Danish Hydraulic Institute (DHI Inc.) was employed as the basis of the analysis.

3.2.1 MIKE 21 Model

MIKE 21 solves the depth-averaged equations of continuity and momentum (3.2). The model solves for current velocity and water surface elevation at locations distributed throughout the model domain and is well suited to analyze coastal systems featuring

complex shoreline configurations.

$$
\begin{aligned}
&\frac{\partial \zeta}{\partial t} + \frac{\partial p}{\partial x} + \frac{\partial q}{\partial y} = \frac{\partial d}{\partial t} \\
&\frac{\partial p}{\partial t} + \frac{\partial}{\partial x}(\frac{p^2}{h}) + \frac{\partial}{\partial y}(\frac{pq}{h}) + gh\frac{\partial \zeta}{\partial x} + \frac{gp\sqrt{p^2+q^2}}{C^2h^2} \\
&-\frac{1}{\rho_w}\left(\frac{\partial}{\partial x}(h\tau_{xx}) + \frac{\partial}{\partial y}(h\tau_{xy})\right) - \Omega_q - fVV_x + \frac{h}{\rho_w}\frac{\partial p_a}{\partial x} = 0 \\
&\frac{\partial q}{\partial t} + \frac{\partial}{\partial x}(\frac{pq}{h}) + \frac{\partial}{\partial y}(\frac{q^2}{h}) + gh\frac{\partial \zeta}{\partial y} + \frac{gq\sqrt{p^2+q^2}}{C^2h^2} \\
&-\frac{1}{\rho_w}\left(\frac{\partial}{\partial y}(h\tau_{yy}) + \frac{\partial}{\partial x}(h\tau_{xy})\right) - \Omega_p - fVV_y + \frac{h}{\rho_w}\frac{\partial p_a}{\partial y} = 0
\end{aligned}
\tag{3.2}
$$

The following symbols are used in the equations:

- $h(x, y, t)$ - water depth $(= \zeta - d)$ units in meters
- $d(x, y, t)$ - time varying bathymetric depth with units in meters
- $\zeta(x, y, t)$ - surface elevation in meters
- $p, q(x, y, t)$ - flux densities in x- and y-directions $(m^3/s/m)$, $(p, q) = (uh, vh)$ where (u, v) are depth averaged velocities in x- and y-directions
- $C(x, y)$ - Chezy resistance $(m^{1/2}/s)$
- g - acceleration due to gravity (m/s^2)
- $f(V)$ wind friction factor
- $V, V_x, V_y(x, y, t)$ - wind speed and components in x- and y- directions (m/s)
- $\Omega(x, y)$ - Coriolis parameter, latitude dependent (s^{-1})
- $p_a(x, y, t)$ - atmospheric pressure $(kg/m/s^2)$
- ρ_w - density of water (kg/m^3)
- x, y - space coordinates (m)
- t - time (s)
- $\tau_{xx}, \tau_{xy}, \tau_{yy}$ - components of effective shear stress

MIKE 21 takes into account the effects of tidal forcing at the open water boundaries, time-varying wind stress at the free surface, bottom friction, marsh wetting and drying cycles, and changes in underwater topography.

3.2.2 MIKE 21 Model Domain and Physics Parameters

The MIKE 21 model domain encompasses Lake Tambour and the areas northward in order to capture the tidal exchange near the borrow area (Figure 3.2). A rectangular grid was employed with a square pixel width of 63 meters in order to capture the narrower marsh canals surrounding the borrow site. Bathymetric corrections were applied to re-establish marsh connectivity accounting for sub-grid canals, and local bottom elevation adjustments were made at the borrow area based on Fenstermaker survey profiles. The model was setup with a constant Manning's n value of 0.025 applied uniformly throughout the model domain. The eddy viscosity parameter was set to 0.25 and wind speed and direction time series were taken from the Grand Isle meteorological station. Wetting and drying was turned on for all simulations.

3.2.3 MIKE 21 Boundary Conditions

The MIKE 21 model boundary conditions consisted of hourly water level time series obtained from the closest CRMS station. All water levels were adjusted to the common datum of NAVD 88 geoid 99 with an adjustment factor of +0.70ft applied to water levels given in geoid 012A. Rainfall and ET were not considered since their respective contribution to the local water levels and velocity fields in a semi-open coastal marsh system were expected to be small relative to the overall dominance of Gulf tides.

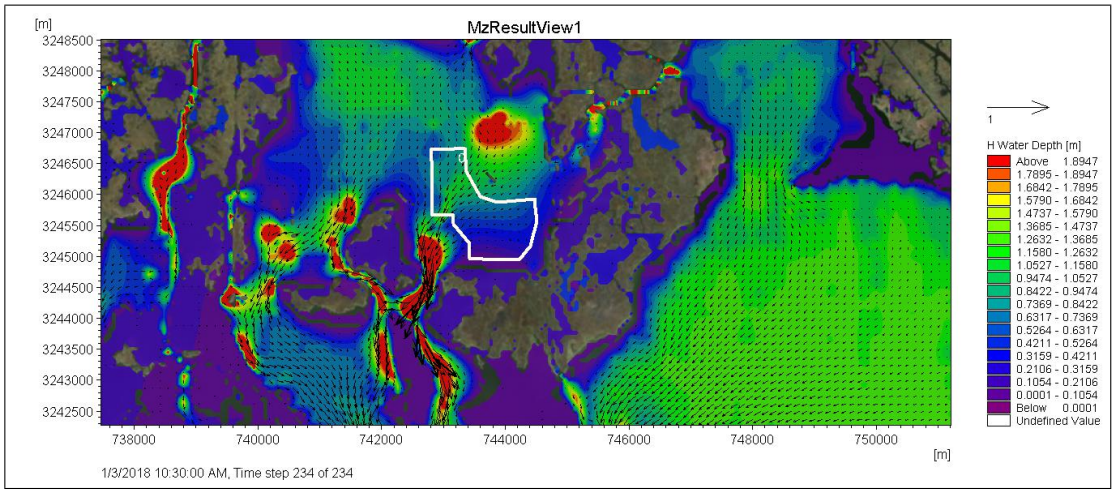

Figure 3.2: MIKE 21 Model Velocity Field Approximation.

3.2.4 MIKE 21 Model Calibration

The MIKE 21 model was calibrated against CRMS stations located within or very close to the model domain (Figures 3.3 through 3.6). The model calibration consisted of comparing

the model against CRMS hourly water level measurements. Note that detailed velocity measurements were not available at the time of the study. Overall, the model performed well compared to the measurements. The calibration period was taken to be the month of January 2018 which is representative of yearly low water conditions near the borrow area. Low water conditions represent an especially challenging target to model since bathymetric errors and frictional effects become more important with decreasing water depth.

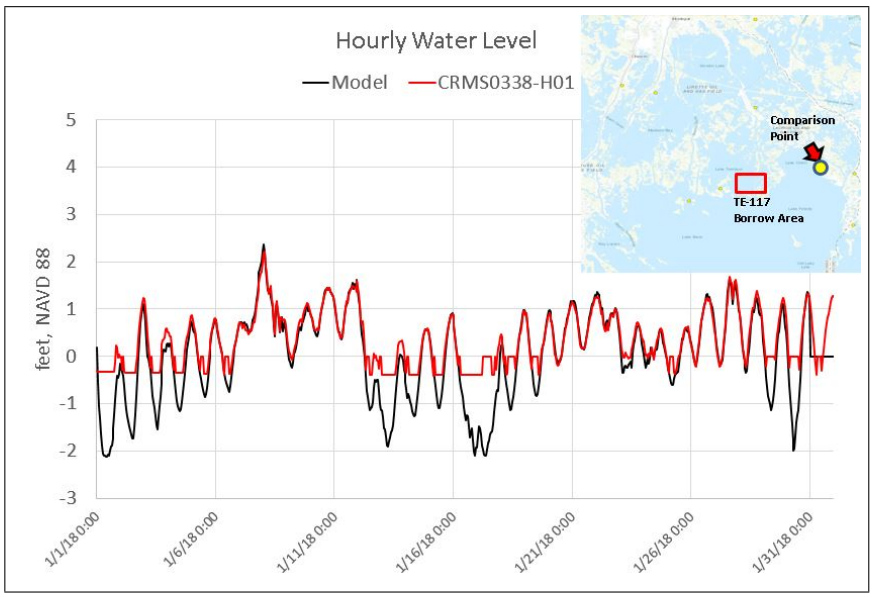

Figure 3.3: MIKE 21 Model vs. CRMS0338-H01 Hourly Water Level Comparison.

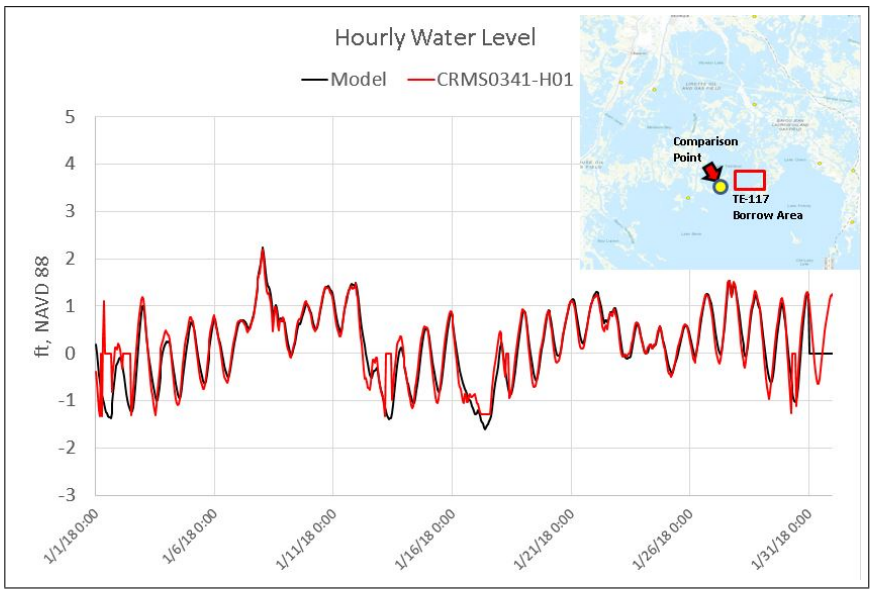

Figure 3.4: MIKE 21 Model vs. CRMS0341-H01 Hourly Water Level Comparison.

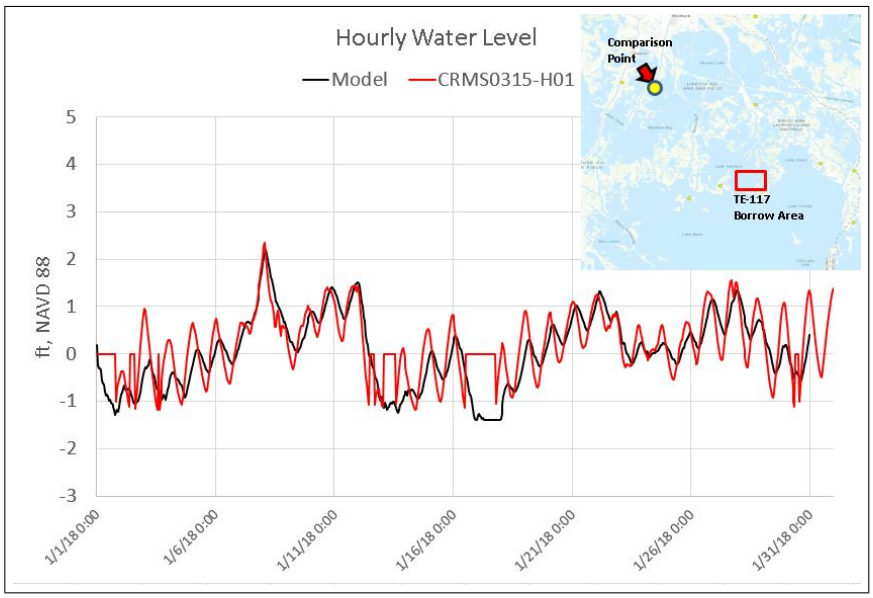

Figure 3.5: MIKE 21 Model vs. CRMS0315-H01 Hourly Water Level Comparison.

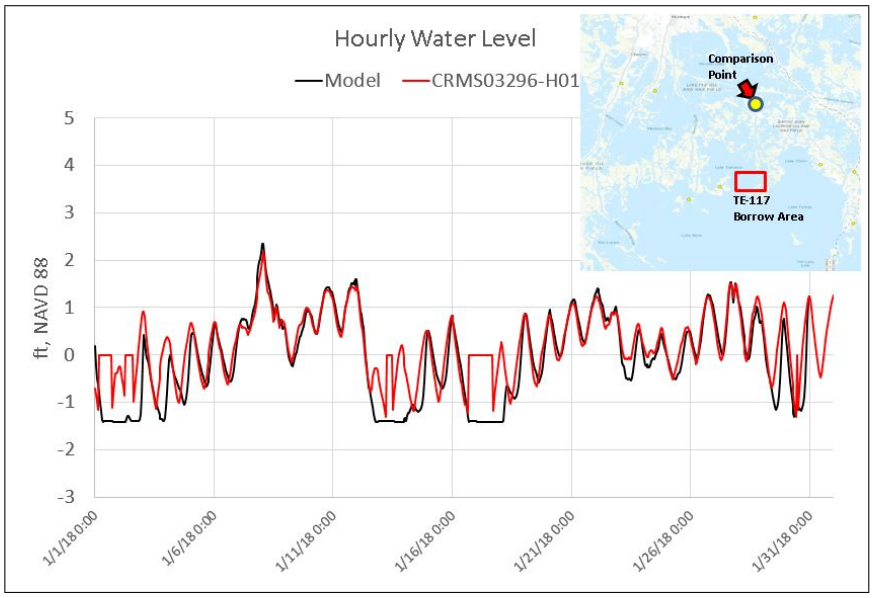

Figure 3.6: MIKE 21 Model vs. CRMS03296-H01 Hourly Water Level Comparison.

Chapter 4

Impact Assessment

4.1 Wave Impacts

A total of 84 wind speed/direction combination scenarios were simulated for the pre and post (borrow area) project scenarios in stationary mode. Each simulation provided an approximation of the significant wave height across the local model domain for pre and post-project conditions. The results from each simulation were then weighted according to the frequency of occurrence based on the Grand Isle wind rose dataset, and significant wave heights were averaged according to the relative wind/directional frequencies for a single composite pre and post project H_s layer [1]. The difference between the pre and post-project composite H_s layers was used as the basis of the impact assessment. The results suggest that the project would not increase the average significant wave heights by more than 0.07 ft within the vicinity of the borrow region. The greatest differences occurred immediately adjacent to the borrow region while exhibiting a steady decay in the wave height difference as one radiates outward from the project site (Figure 4.1).

4.2 Velocity and Stage Impacts

The calibrated MIKE 21 model was used as the baseline for the pre and post-project velocity and stage comparisons. The borrow region was implemented into the model by directly deepening the grid cells within the composite footprint of the two borrow area alternatives. The model was run over the calibration period (31 days) and provided a time-varying approximation of the hourly stages and velocities within and surrounding the project site. The hourly difference was calculated between the pre and post project scenarios for x-velocity, y-velocity, and water level. The final results were averaged arithmetically over the simulation period. The results suggest that the borrow region would not increase nearby tidal average velocities by more than 0.08 ft/sec, and water level

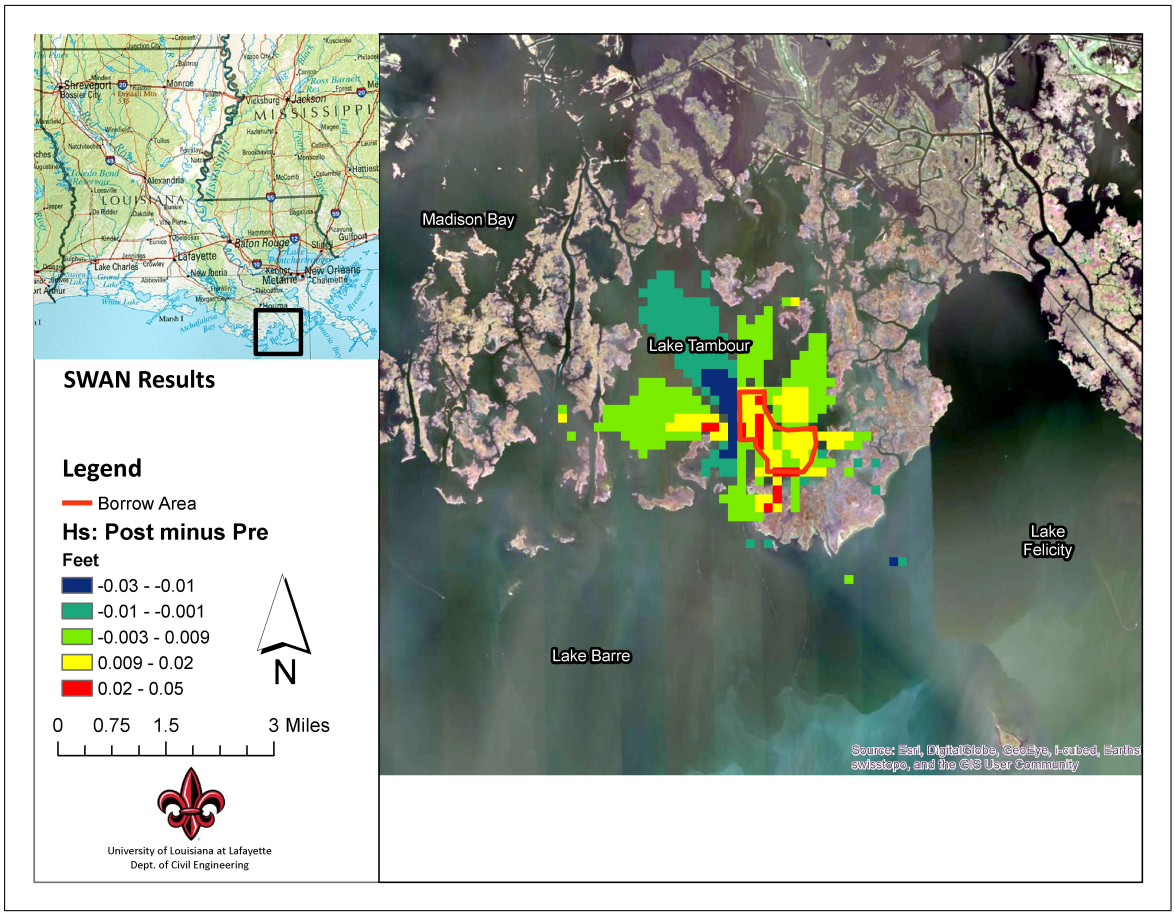

Figure 4.1: Significant Wave Height Difference Map.

deviations did not exceed 0.08 ft within the model domain (Figure 4.2). The maximum velocity increases occurred along the immediate perimeter of the borrow site. There was a slight lowering of the average water surface elevation near the tidal inlet located to the south and west of the borrow site owing to the fact that the borrow site is hydraulically connected to the submerged canal which passes through the inlet (Figure 4.3).

4.3 Modeling Uncertainties

Every numerical modeling study is subject to uncertainties with respect to data inputs, selection of parameters, and the choice of modeling tool and level of detail chosen. The main uncertainties associated with the wave modeling method used in this effort are attributable to a lack of detailed wave measurements within the Lake Tambour region and in particular within the proposed borrow region. We also point out that there were no detailed velocity measurements available (against which to compare MIKE 21) within the marsh canals or open water regions adjacent to Lake Tambour to supplement the CRMS water level measurements. We also note that spectral wave models such as SWAN are

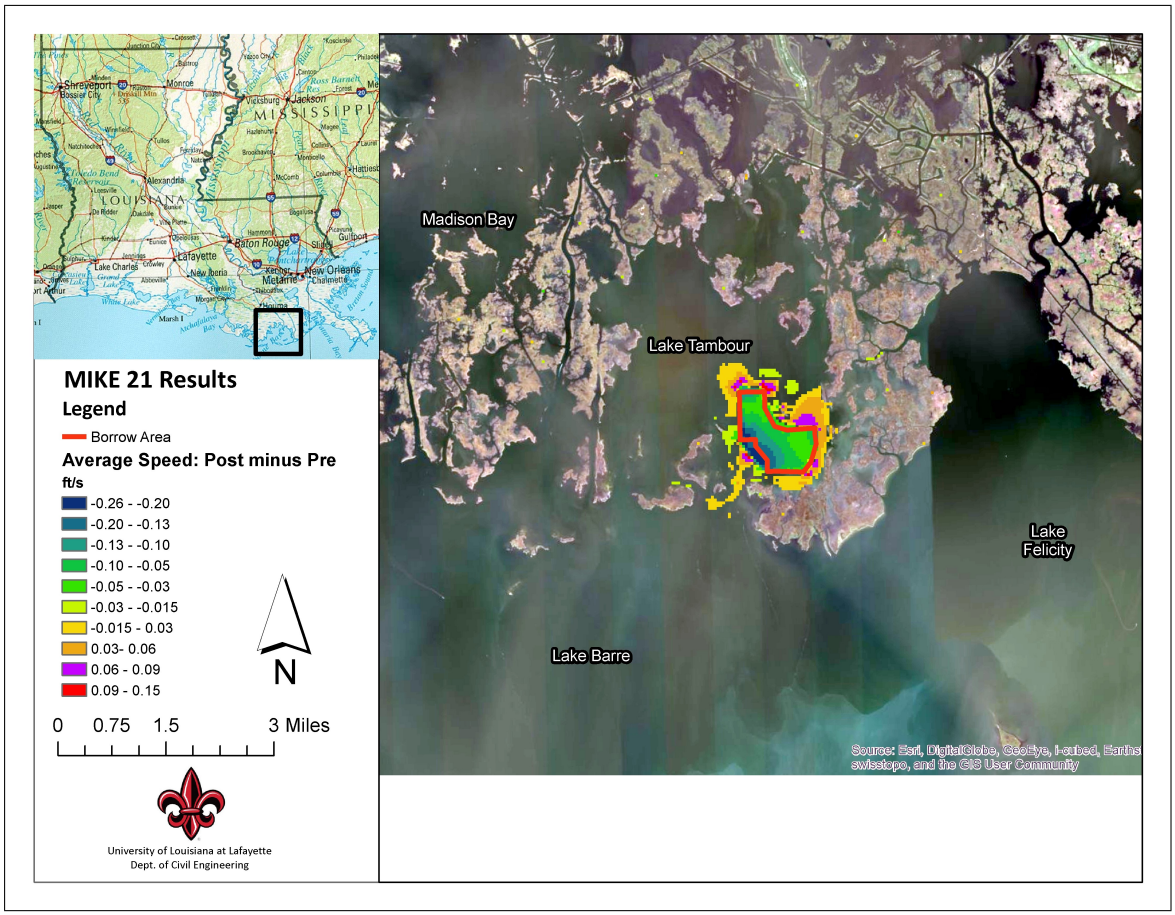

Figure 4.2: Current Speed Difference Map.

not able to directly simulate wave generated currents and this process has been identified as one of the potential contributing factors to the high rates of shoreline retreat occurring in the Terrebonne Bay system as a whole [3]. The simulations of wave-driven currents would require the use of a coupled hydrodynamic/nonstationary waves model with current enhancements provided via radiation stresses. Such an effort would require continuous current and wave measurements in the project vicinity to calibrate the models and the coupling scheme and this was well beyond the scope of the comparative analysis presented herein.

4.4 Summary and Conclusions

A detailed impact assessment was conducted for the borrow region associated with the TE-117 marsh creation project. The impact assessment included the setup and calibration of a detailed set of numerical models (SWAN, MIKE 21) encompassing the project site to provide a framework to compare the pre and post-project conditions in terms of significant wave height and tidal velocities along adjacent shorelines. The SWAN model was run in

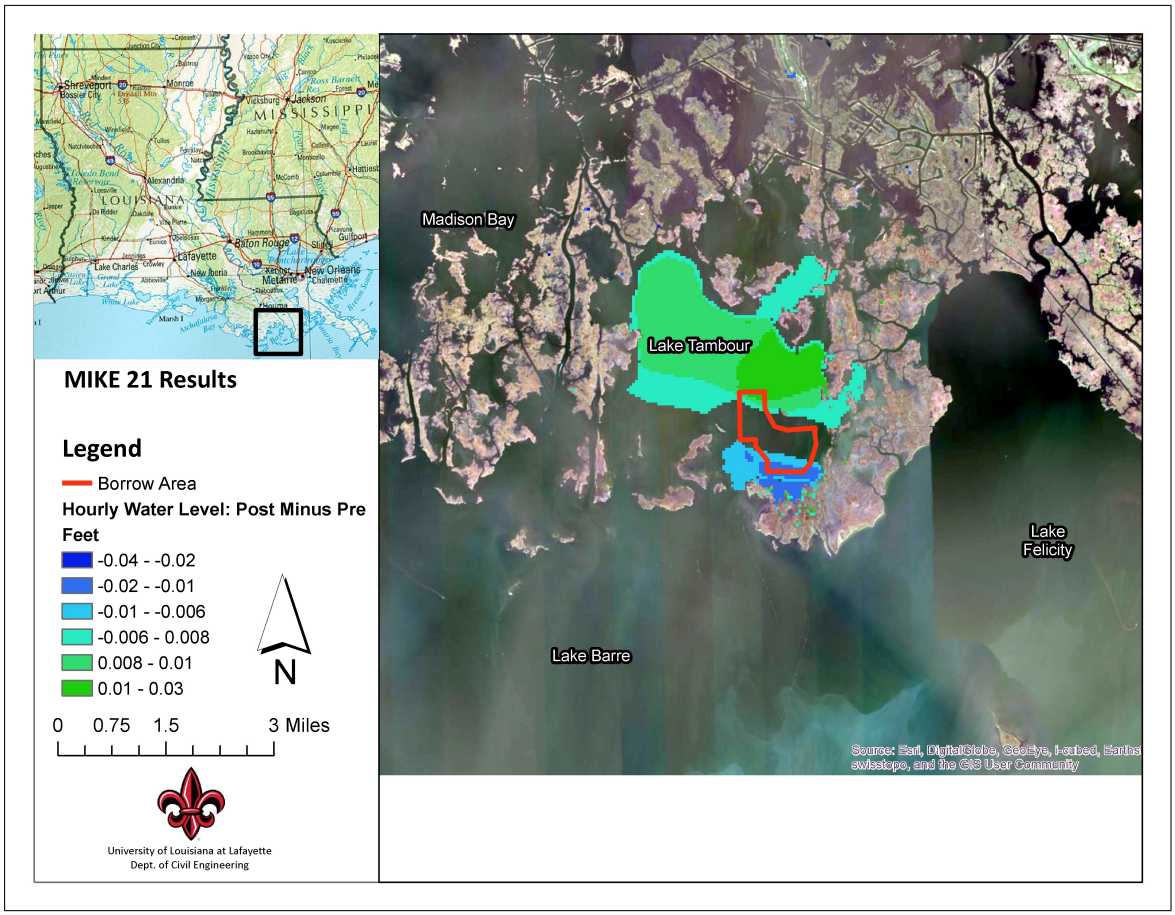

Figure 4.3: Water Level Difference Map.

stationary mode and considered 84 wind speed and direction combinations. The MIKE 21 model was run for a 31 day period over January 2018. The model results suggest that the average wave height increases did not exeed 0.06 ft and the average tidal velocities did not exeed 0.08 ft/sec. The water level variations as a result of changes in the drainage patterns did not exceed 0.03 feet anywhere within the Lake Tambour focus area. The impact values suggested by the model results are on the same order of magnitude as the practical error limits associated with measurements of underwater bathymetry and velocity in open water coastal environments.

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