BS-24
Terracing and Marsh Creation
South of Big Mar

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ALTERNATIVE FEATURES REPORT

Terracing and Marsh Creation South of Big Mar (BS-24)
Plaquemines Parish, Louisiana

April 2016

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PREFACE

The following Alternative Features Report is a revised draft resulting from the Preliminary Alternatives presentation held on Thursday, March, 11, 2015 at the NRCS Lafayette office. Since that presentation/meeting, several issues have been discussed with regards to site access and land rights, alternate project sites, and the availability of data with respect to the environmental conditions at the project site. Shortly after the March 11th meeting, it was determined that Cells 1, 2, and the western portion of 4 are inaccessible due to the shallow depth of cover over existing pipelines; thus preventing access with barge mounted construction equipment. Based on the recommendations outlined in the geotechnical report, it has been determined that the cross-sectional geometry of the terraces required to maintain an acceptable range of stability, will prevent the use of traditional marsh machines for construction. This is due to the reach limitations of the equipment. Barge mounted draglines with workable reaches in excess of 100 linear feet will likely be required to construct the proposed terraces. This equipment drafts approximately 4 to 6 feet of water and will not be able to cross the pipelines traversing the project area. As a result, Cells 1 and 2 have been removed from the project in their entirety, and a new cell (Cell 2B) has been proposed as a viable alternative. Approximately two-thirds of Cell 4 is currently accessible and terraces are still proposed for this area. Relocating the terraces to site 2B required additional topographic and bathymetric data to be collected in the area, as well as an additional geotechnical investigation. After months of planning and permitting, this work was completed between the months of September 2015 and February 2016. Any reference to "additional surveying or geotechnical investigation" in this report is referring to the work completed during this time. In general, the results of the additional surveys and geotechnical investigation yielded results that were similar to the conditions of the original survey and geotechnical work completed for project.

LHA also performed a magnetometer survey of the proposed terrace Cell 2B as well as the proposed access route from Lake Lery, through the BS-24 marsh creation cell, and into the proposed access route. One undefined magnetic anomaly was discovered during the process of completing this work, but LHA field personnel were unable to identify the object. The magnetic signal was very strong; however, it was localized and did not resemble a pipeline. The object is located near the northeast corner of Cell 2B and should not interfere with any of the project features. The anomaly will be shown on project drawings such that the construction contractor is aware of its presence and is able to avoid the object.

In addition to eliminating a large portion of the original terrace cells, the presence of the referenced pipelines will prohibit site access from the north and west, thus requiring the construction contractor to access the sites from the east. The BS-16 project (currently under construction) consists of reestablishing the Lake Lery rim along the western and southern shoreline. The newly constructed lake rim will have to be temporarily excavated to allow the BS-24 project contractor to access the site. Once all work is complete, the contractor may restore the lake rim to pre-project condition. This aspect of the project is still under discussion with the project team. The long term effects of cutting and rebuilding this earthen feature have not been thoroughly explored. The exact location where the rim will be cut will have to be determined by NRCS and LHA once the BS-16 project has been completed and as-built conditions assessed.

During the March 11, 2015 meeting, the availability and accuracy of site specific data was questioned by all parties in attendance with regards to “healthy marsh elevation”, Mean High Water elevation, etc. A brief discussion with CPRA personnel in attendance revealed that CPRA was currently in the process of updating all of their monitoring stations to the current geoid model, but it was unclear as to when this new data would become available. Recently (February 2016),

LHA noticed that the online data for the nearby monitoring station, CRMS0117, has been updated to Geoid 12A and shows the average marsh elevation to be at +0.8' NAVD88. Originally NRCS/USFWS directed LHA to consider marsh elevation to be +1.0' NAVD 88, and all of the assumptions and calculations in this report are indicative of the +1.0' elevation. Reducing the target elevation to +0.80' NAVD88 may result in a reduction of spoil material to be placed in the marsh creation area and terraces, and possibly reduce the overall construction cost of the project. Currently LHA is proceeding with the assumption that the target marsh elevation for the BS-24 project is still +1.0' NAVD88, unless directed otherwise by the NRCS.

ALTERNATIVES DESIGN REPORT
(BS-24) TERRACING AND MARSH SOUTH OF BIG MAR

PROJECT OVERVIEW

The Louisiana coast is comprised of various types of marshes and swamps and is considered to be one of the largest wetland areas in the United States. However, the coastal marshes of Louisiana are continually changing and evolving as a result of man-made alterations to the landscape, natural disasters, and other natural processes. Located in southeastern Louisiana, the BS-24 project site is situated in the Breton Sound region of Plaquemines Parish, approximately sixteen miles southeast of New Orleans.

Figure 1.1 – Project location

Over the last half-century, this area has undergone significant hydrologic and ecological changes resulting in excessive land loss and loss of habitat. Through the Coastal Wetlands Planning, Protection, and Restoration Act (CWPPRA), the Natural Resources Conservation Service (NRCS) is proposing to construct approximately 65,000 linear feet of shallow water

earthen terraces and create approximately 334 acres of intermediate marsh in the Breton Sound region, south of Big Mar and west of Lake Lery. Over the last 80 years, approximately 14,300 acres of vegetated marsh have converted into open water lakes as a result of scouring caused by wave action, subsidence and sea-level rise (referred to herein as relative sea-level rise (RSLR)), and tropical storms. The proposed terraces will not only create a platform for vegetation growth within the marsh, but also reduce wave fetch in these large open water areas. Terraces will also reduce the flow velocity of water entering the project site from the Caernarvon Diversion structure, resulting in increased sediment deposits within the area. The 334 acres of marsh created by this project will establish a healthy marsh platform conducive to facilitating the growth of submerged aquatic vegetation (SAVs) and other marsh vegetation. This marsh area will also help reinforce the western rim of Lake Lery.

PROJECT SITE CHARACTERISTICS

The project area is comprised mostly of coastal fresh to intermediate marshes, and vegetation consistent with each type. Based on the geotechnical investigation report prepared by GeoEngineers, Inc., the underlying soils in the project area generally consist of layers of very soft peat and organic clays ranging between depths of 6 to 18 feet. Since construction activities will be limited to these soils, any discussion of deeper soil layers has been intentionally omitted from this report. These soft organic soils have extremely high moisture contents, are highly compressible, and will play a significant role in the design of the earthen terraces and marsh creation site discussed later in this report. For additional information regarding the soil strata, reference the *"BS-24 Terracing and Marsh Creation South of Big Mar"* geotechnical report and *"Addendum 1"*, prepared by GeoEngineers, Inc., dated September 23, 2014 and February 12, 2016, respectively. Both documents are included in Appendix E.

The hydrologic characteristics of the project area are somewhat consistent with coastal marshes, with portions of the area being subject to tidal and salinity fluctuations. However, water levels and salinities in the immediate vicinity of the BS-24 site are also influenced significantly by the Caernarvon Diversion structure, which was designed to divert water from the Mississippi River into, and through, the BS-24 project area. The BS-24 project site, like the rest of the Gulf coast, is susceptible to tropical storms and hurricanes, which have proven to be most detrimental by converting these marshes into open water. According to the BS-24 project data sheet, Hurricane Katrina (2005) converted approximately 39 square miles of vegetated marsh in the project area to open water bodies.

Southeast Louisiana has a predominant south-southeast wind direction[1] which contributes to significant wave generation in large, open bodies of water within the coastal marshes and provides a continuous source of scour and erosion in these areas. Waves cause scour to occur along the shorelines, which lead to increased land and vegetation loss. Relative Sea-Level Rise (RSLR) is also a factor contributing to the degradation of the wetlands along the Louisiana coast, including the Breton Sound region. RSLR rates vary across the State, with areas of southeast Louisiana having the highest rates (ranging from 0 to 35 mm/yr). Based on the studies performed by the Subsidence Advisory Panel for the Louisiana CPRA Master Plan[2], RSLR rates in the Breton Sound region are estimated to range between 3 to 10 mm/yr as depicted by Figure 1.2 below. However, recent studies of the Caernarvon Freshwater Diversion project, located approximately 4.5 miles north of the BS-24 site, imply that the amount of sediment deposited in area as result of

[1] According to the "*Caernarvon-Lake Lery Lake Rim Restoration Project (BS-16) Borrow Site Impact Analysis*" prepared by FTN Associates, Ltd. (2011), the predominant wind direction is SSE (North azimuth of approximately 170°. This document is included herein; see Appendix H.

[2] RSLR rates were obtained from the *"Recommendations for Anticipated Sea-Level Rise Impacts on Louisiana Coastal Resources During Project Planning and Design"* published by the Coastal Protection and Restoration Authority of Louisiana, LACES Division, 24 January 2012.

the diversion will likely offset the effects of RSLR. Based on the findings of this study, the NRCS, USFWS, and CPRA has requested that RSLR rates not be incorporated in the marsh platform elevation determination.

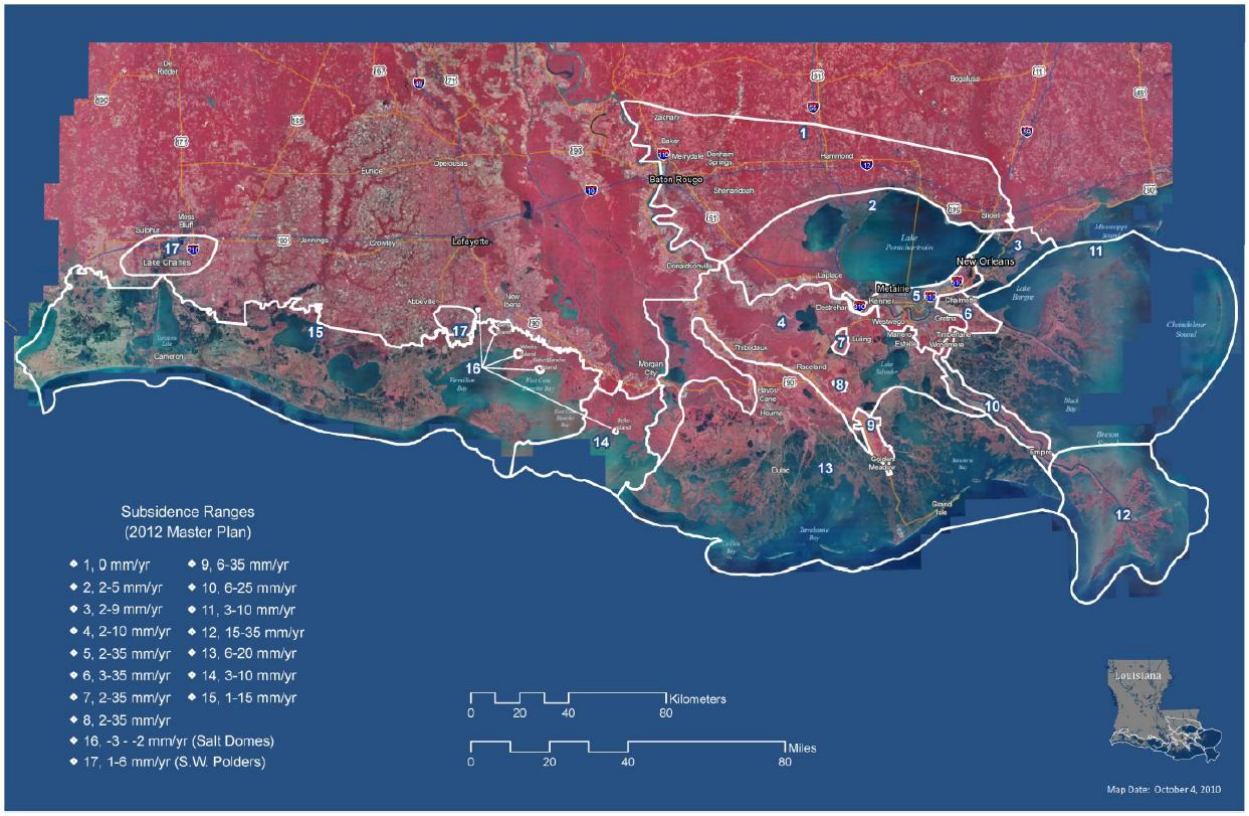


Figure 1.2 – Estimated subsidence rates from the 2012 Louisiana Master Plan

DESIGN METHODOLOGY AND DATA REVIEW

The NRCS initially provided various technical documents to Lonnie G. Harper & Associates, Inc. (LHA) pertinent to the BS-24 project for review. LHA will be using the data provided by the NRCS as a basis for all design assumptions and considerations, which will be discussed in greater detail herein. The following sections will summarize LHA's understanding and interpretation of the data provided, as well as outline some issues that may need to be discussed with the NRCS and associated agencies to develop a better understanding of the project and its goals.

Survey Data and Survey Control:

Initially, LHA was provided with topographic/bathymetric survey data (referred to as "data" herein) of the project site(s). The NRCS staff has collected data throughout the marsh creation site and terrace fields using standard Real Time Kinematic (RTK) surveying equipment and methodologies. LHA's understanding is that all data collected by the NRCS was referenced to the control monument "BS16-SM-02". Based on the data sheet provided for the "BS16-SM-02" monument, the vertical position for this monument is referenced to Geoid12A and Geoid03 as well as geodetic datum NAD 83 and NAVD88. In contrast, the data provided for the marsh creation site borrow area, located in Lake Lery, appears to have been collected based on control monuments BS30a-SM-02 and BS16-SM-01. According to the survey report prepared by T. Baker Smith for the BS-16 project, these monuments were used as the basis for all data collected, both of which were referenced to Geoid 03, and having ellipsoid heights of -25.584 meters and -25.425 meters, respectively. Further discussion with NRCS personnel revealed that these monuments were damaged and/or destroyed; therefore, BS16-SM-02 was established with Geoids 12A and 03 orthometric heights (elevations), enabling this monument to be used with data sets referenced to each geoid model.

Subsequent surveys performed by LHA to collect additional topographic and bathymetric data were also collected using RTK surveying equipment and methodologies and referenced to the BS16-SM-02 monument. All data collected by NRCS and LHA are referenced to the same control monument and geoid model, thus resulting in consistent field data. At this time, the data collected by T. Baker Smith is inconsistent with the other data sets, but it is our understanding that as-built data of the BS-16 will be provided at a later date, from which we can extract any relevant data needed for the BS-24 project relative to Geoid 12A.

Lastly, in reviewing the *"Draft Project Information Sheet for Wetland Value Assessment (WVA)"* prepared by U.S. Fish and Wildlife Service (Refer to Appendix G), it was discovered that specific construction elevations [at year 20] for the project features have already been identified for this project. The document states, *"…[terraces] would be constructed to an elevation of [+]2.0 feet NAVD88, geoid 99"* and *"dredged material would be pumped into containment dikes to achieve a target marsh elevation of 1.8 ft NAVD88, geoid 99…"* The elevations specified by this report are referenced to a geoid model that is inconsistent with the data collected by T. Baker Smith and NRCS, and will create significant inconsistencies within the project design. Furthermore, the marsh creation site elevation specified in the WVA is inconsistent with the +1.0' elevation outlined in LHA's scope of services provided by NRCS. Based on the discussions held during the preliminary alternatives presentation between LHA, NRCS, CPRA, and USFWS, target elevations will be based on current marsh elevations referenced to the current geoid. Target elevations will be discussed in greater detail later in this report.

<u>Geotechnical Data:</u>

The NRCS has provided a geotechnical investigation report, prepared by GeoEngineers, Inc., (refer to Appendix E.) containing information on soil properties at the project site, estimates of settlement and consolidation within the soil masses used for this project, and narratives containing design recommendations relative to the BS-24 project. During the Alternative Features design phase of this project, LHA requested that an additional soil investigation be performed in the new terrace cell (Cell 2B), and the report resulting from of that investigation, titled Addendum 1, has also been included in Appendix E. LHA has reviewed both reports and is of the opinion that the quantity and quality of the data is adequate for this type of project and that no additional information is needed at this time. However, LHA will be consulting with GeoEngineers, Inc.

throughout the design phase of the project to confirm feature designs and also provide additional analysis when required. Any subsequent reports or analysis following this report, will be included in the final design report for the project.

Tidal Data:

Section 6.1.1.1 of the "*Scope of Work"* document provided to LHA by NRCS states that *"the contractor (LHA) shall determine the mean high and mean low tide for the spring/summer months and consider that information for the design of the intertidal marsh platform and for terrace dimensions."* LHA has been directed by NRCS and USFWS to assume that the target elevation is +1.0 feet for the marsh creation fill area and +2.0 feet (1 foot above MHW) for the terraces (both referenced to NAVD88, Geiod12A). Based on the updated CRMS0117 data, the average marsh elevation and ninetieth percent (90th%) water elevation were determined to be +0.80 feet and +0.96 feet, respectively. Both referenced to NAVD 88 Geoid12A. These values are approximately equal to the original assumed elevation of +1.0 NAVD88 and do not warrant modifying. Should NRCS and USFWS feel that adjustments to the target elevations are needed, then LHA will incorporate these adjusted elevations into the project.

Furthermore, LHA reviewed the water stage data[3] collected by CRMS0117 station between the months of October 2013 through February 2016; all of which is referenced to a NAVD88, Geoid 12A elevation. The available data implies that this area does not experience daily tidal fluctuations, but remains at a relatively constant elevation throughout a 24-hour period. LHA has averaged the stage data for each year and the results are presented in the table below. High and

[3] Stage data obtained from the CRMS0117 station was recorded at inconsistent intervals ranging from two hours between readings up to six hours in some instances. Although intervals are not consistent, the amount of data analyzed should provide sufficient information to determine average water levels within the project area.

Low water elevations are also included. Only data referenced to Geoid 12A has been included in the evaluation.

Table 1.1 – CRMS0117 Stage Data			
Year of Observation	**Average Water Level**	**High Elevation**	**Low Elevation**
2013 (Oct.-Dec.)	0.80	1.91	-0.03
2014 (12 months)	0.39	1.73	-0.51
2015 (12 months)	0.52	3.51	-0.52
2016 (Jan.- Feb.)	0.39	1.58	-0.59

*All elevations referenced above are in terms of feet, NAVD 88, Geoid 12A

Missing and Incomplete Data:

In the "*Scoping Meeting Report"* prepared by LHA and dated January 2015 (Refer to Appendix F), LHA requested that the NRCS provide additional data relative to the BS-24 and adjacent BS-16 projects for review such that relevant information could be incorporated into the BS-24 project design. To date, LHA is awaiting the delivery of the items listed below:

1. Provide as-built drawings and/or survey data of the restored lake rim (west end) and borrow area "A" from the BS-16 project (when it becomes available); and,
2. Applicable Land Rights agreements for the project area to insure planned project features and access routes/methods are permitted across, or adjacent to, known pipelines in the project area.

Marsh Creation Site – Site Access and General Design Requirements

As stated previously, one of the key features of the BS-24 project is the creation of approximately 334 acres of intermediate marsh within the Breton Sound wetland complex. The

target marsh creation area (MCA) is shown in the figure below based on the georeferenced shape file (file name BS-24_features (*.shx)) provided by NRCS.

Figure 1.3 – 334 Acre Marsh Creation Site

This area consists of mostly open water areas, with average depths of about two feet. The remaining areas are made of up broken marsh, floating vegetation, and remnants of the Lake Lery rim. The CWPPRA project BS-16 currently under construction will restore the Lake Lery rim along the western and southern shorelines. As a result, access to the MCA with marine based construction equipment will be prohibited from the east. In addition, the existing pipelines approximately two miles to the north and west, will prohibit access from these areas. Therefore, the only viable means of accessing the MCA and terrace cells is to excavate an access channel

through the newly constructed lake rim and then restore it upon completion of the BS-24 project. Since meeting with the NRCS and other agencies in March 2015 meeting, LHA has recommended that the lake rim be cut between Sta 28+00 and Sta 30+00 (from BS-16 construction drawings). This location was chosen to prevent impacting the geotextile reinforcement planned in the adjacent areas. Should geotextile reinforcement be installed in this area through a BS-16 contract modification, then additional consultations with the geotechnical consultant may be required to determine the effects of cutting through the reinforcement material.

An additional concern of LHA is maintaining the integrity of the lake rim after the lake rim has been restored and the efforts required to achieve the required construction template. Typically the integrity of fill material diminishes significantly after it has been handled multiple times, especially considering the high organic and moisture contents of the native material. Given these conditions, sheet piling will likely be the most effective method of closing the lake rim to facilitate the marsh creation work in the area. This issue will need to be shared with the geotechnical consultant and explored in greater detail as the project progresses.

Due to the remote location of the project sites and sensitivity of the area, LHA has proposed an official access route for this project to minimize the environmental impacts caused by flotation dredging. The proposed access route extends from the current BS-16 access route through the lake rim and MCA, and into the two terrace cells. Flotation dredging will be required throughout the proposed route in order to get barge mounted construction equipment to the sites. Access route spoil material shall be side cast from the route in the lake area or used to construct nearby earthen features of the BS-24 project.

The MCA will be isolated from the surrounding waters by constructing a containment levee/dike around the perimeter. At this time, LHA is intending to incorporate portions of the

newly constructed lake rim into the containment system for the marsh creation work; however, this will be re-evaluated as the as-built data from the BS-16 project becomes available. The containment dike will consist of spoil material being placed and maintained at an elevation of +5.25 feet NAVD 88, with side slopes varying from 3H:1V to 5H:1V and a top width of at least 5 feet. All spoil material used to construct the dikes initially shall be excavated from inside the marsh creation area, adjacent to the dike. Any maintenance lifts placed on the perimeter containment dike should come from a borrow source outside of the MCA. The use of hydraulically dredged material should be avoided. Any excavations shall not exceed elevation -10.0 feet NAVD 88 and a cut slope of 3H:1V. Due to the poor soil conditions, it is recommended that dikes be constructed in a minimum of two lifts, with the first lift not to exceed elevation +2.5 feet NAVD 88 and allowed to settle for a minimum of 60 days prior to placing subsequent lifts. The geotechnical report recommends a minimum berm width of 25 feet between the dike and borrow area to prevent slope failures from occurring, and to provide sufficient work space for the dike construction. However, NRCS has recommended that an additional 10 feet wide buffer zone be incorporated between the dike toe and edge of borrow canal; increasing the total width of the berm to 35 feet. These spatial limitations are a result of assuming the containment dikes will be constructed using a marsh machine and accounts for the overburden pressure exerted by the machine on the berm. Should the dike be constructed using a barge mounted dragline, then the 10 feet wide buffer can likely be relaxed. The 25 feet wide berm width could also be reduced pending the results of further slope stability analysis, which will be evaluated during the next design phase of the project and included in subsequent design reports. Reference Appendix A for a sample cross section of the proposed containment dike and borrow area. The geotechnical report also

discusses the benefits of using geotextile reinforcement which is discussed in detail under the alternatives section of this report.

Spoil Placement:

Spoil material will be hydraulically dredged and pumped from a pre-determined borrow area located in Lake Lery, approximately one-half mile east of the site, and discharged into the marsh creation cell(s). Based on the *Scope of Services, Section 6.1.2.3*, the target marsh elevation is +1.0 feet NAVD88, Geoid 12A at year 20. According to the settlement analysis provided in the geotechnical report, it is estimated that an initial fill elevation of +3.25 feet with a tolerance of +0.5 feet of overbuild will be required to obtain the +1.0 feet elevation at year 20. This proposed fill height accounts for the estimated consolidation settlement as outlined in the geotechnical report, and does not include elastic settlement which will occur instantaneously during construction. The estimated elastic settlement value will be used to derive construction quantities for spoil placement. Settlement calculations are included in Appendix D and are based on the recommendations provided in the geotechnical investigation report. Based on a fill elevation of +3.25 feet NAVD 88 and an average water bottom elevation of approximately -0.72 feet NAVD 88, LHA estimates that approximately 3.8 million cubic yards of dredge spoil, including the volume needed to backfill the initial borrow areas, will be required to meet the goals of this project, assuming a cut-to-fill ratio of 1.5 as recommended by the geotechnical report. The recommended cut-to-fill ratios provided in the geotechnical report range from 1.3 to 1.5, the latter of which was selected for this analysis to provide a more conservative value and cost estimate.

Marsh Creation Alternatives:

Due to the nature of the marsh creation work, there are few alternatives for design as the acreage of the site is fixed and the soil properties are fairly consistent throughout the project area.

It seems the only relevant design alternatives will consist of the following: subdividing the 334 acre marsh creation area into smaller cells, varying the locations and/or type of the dewatering structures, or incorporating the use of geotextile reinforcement into the containment dike design. Utilizing subdivided marsh creation cells throughout the area may aid in the constructability of the work, enabling the contractor to focus on smaller areas at a given time. However, there will be additional construction expenses resulting from the construction of additional containment dikes within the 334 acre area. Further discussion of this aspect with the NRCS personnel resulted in leaving this option open to the construction contractor as part of their construction means and methods. Dewatering structures will be located along the western side of the MCA at frequent intervals to adequately convey the excess runoff from within the cell(s) based on the size of the dredge being used by the construction contractor. Therefore, the construction contractor shall be responsible for the dewatering system design and location(s).

Lastly, the use of geotextile reinforcement in the containment dike design is a potential alternative. Based on the recommendations in the geotechnical report, the use of geotextile reinforcement will reduce the volume of spoil required to construct the interior marsh containment dikes by approximately thirty-five percent. LHA is proposing the use of geotextile reinforcement on the interior marsh containment dikes as an alternative design for the MCA, and the incremental costs associated with this is included in the cost estimate provided in Appendix C. The use of geotextiles will have little to no benefit if used along the lake rim containment dike, as illustrated by Appendix E.[4] Its use in this area will alleviate a 20 feet wide setback requirement between the dike and marsh cell; however, the geometric cross-section of the dike will not be reduced. The possible use of geotextile reinforcement along the shoreline will be determined by the BS-16

[4] Appendix E contains Figure 5 from the geotechnical investigation report prepared by GeoEngineers, Inc.

project, as this consideration was included in the report without knowing if, or where, geotextile reinforcement would be used in the BS-16 project. Based on the minimal use of reinforcement shown in the BS-16 project drawings, it is evident that geotextile reinforcement is not a viable alternative for the eastern containment dike (lake rim). At this time LHA is not recommending the use of geotextile reinforcement for any of the containment dikes, but may elect to include it on the interior dike design if its use results in a constructability advantage and/or a net decrease in the construction cost.

Anticipated Problems and Concerns:

Based on the information gathered to date, LHA's main concern with the marsh creation site is the physical location of the eastern containment dike relative to the newly constructed lake rim rehabilitation. The structural integrity of the lake rim at the time of construction (BS-24) is unknown. All design alternatives referenced herein are based on the assumption that the as-built conditions of the BS-16 features will be as predicted in the geotechnical reports. If the BS-16 features do not perform as anticipated, modifications to the BS-24 features may be required. Regardless of the responses provided by the geotechnical consultant, LHA feels that the final design location cannot be determined until the as-built data of the lake rim has been provided.

Furthermore, the BS-16 project is currently experiencing significant erosion along the newly constructed lake rim caused by wave action in the lake. Although the BS-24 project is not adjoined to the lake itself, similar situations could arise in the surrounding marshes. This may require the use of temporary breakwaters to be placed adjacent to the project features to dampen the wave action. Lastly, there is some concern in reference to the borrow area associated with the BS-16 and BS-24 projects. If there is not an adequate volume of dredge material available, the borrow area may have to be increased. If that occurs, LHA will rely on guidance/direction from

the NRCS and other agencies to help determine the most favorable location of the borrow area to lessen the environmental and fisheries impacts. At this time LHA anticipates that a sufficient volume of borrow material will be present at the time of construction. This issue will be revisited upon receipt of the BS-16 as-built drawings, which will help determine the volume available for construction.

AUXILIARY DISPOSAL AREA FOR HYDRAULICALLY DREDGE MATERIAL

If the MCA does not require the full estimated dredge quantity to specified in the construction contract, the contractor will need to dispose of the remaining spoil material in order to satisfy the contract quantities. LHA is proposing a disposal site in terrace cell 2B, near the MCA as a potential disposal area. See Figure 1.4. LHA has selected this location due to the likelihood of the regulatory agencies requiring the spoil to be contained and the presence of proposed project features. Containment levees/dikes can be constructed between the newly constructed terraces, creating an area with perimeter protection, preventing sediment from being discharged into an uncontained area. LHA does not anticipate this feature will be required, therefore no costs are reflected in the construction cost estimate provided in Appendix C.

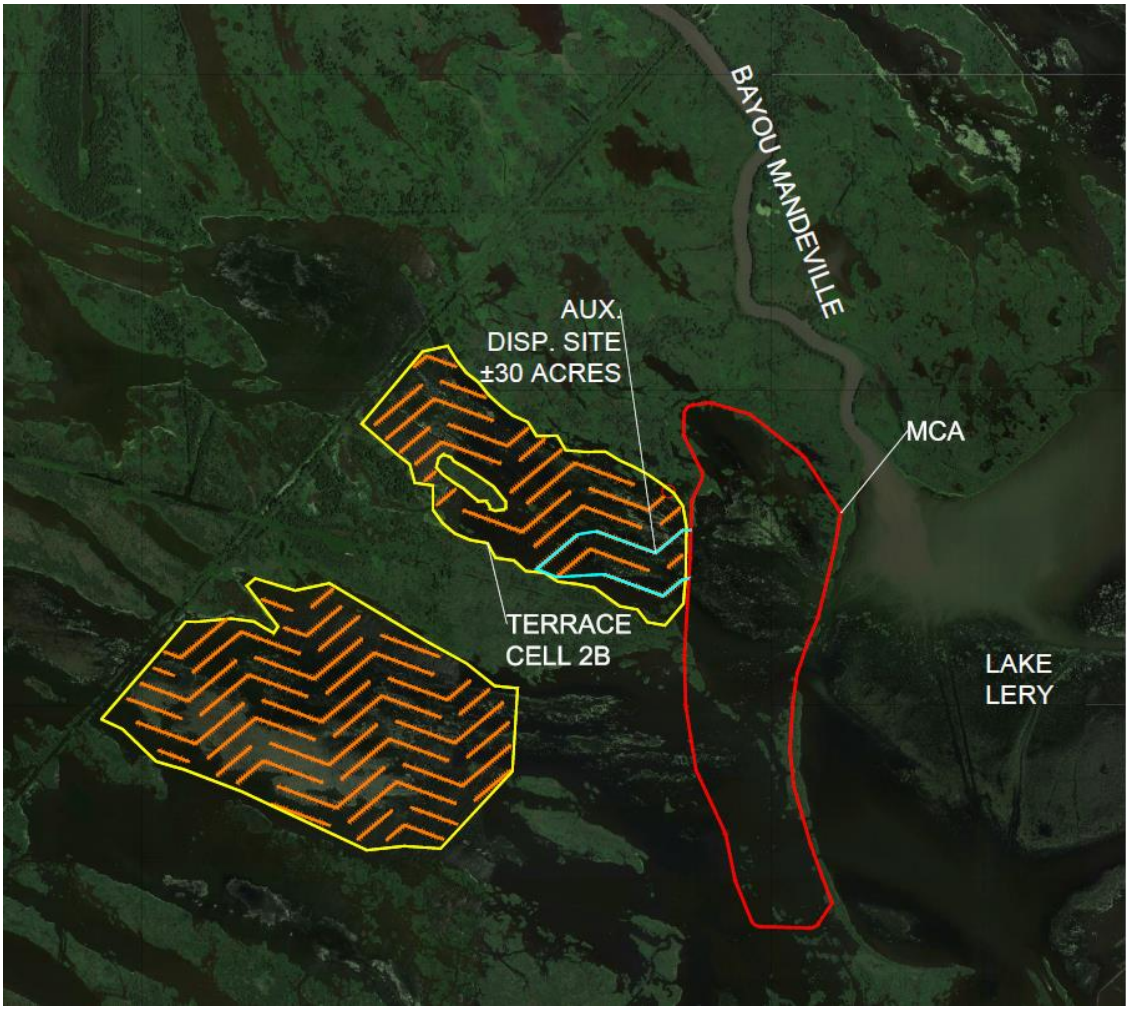


Figure 1.4– 30 Acre Auxiliary Disposal Site

TERRACES – GENERAL DESIGN REQUIREMENTS

In addition to the marsh creation work associated with the BS-24 project, this project will also consist of constructing approximately 65,000 linear feet of shallow water earthen terraces in the open water areas west of Lake Lery. See Figure 1.5 below for terrace field locations. Like the marsh creation site described previously, this area consists of mostly open water areas, with average water depths of about two feet, and with the remaining areas made up of broken marsh and floating vegetation. Terrace cells 1, 2, and the western portion of cell 4 have been eliminated due to the pipelines preventing site access with construction equipment. To compensate for these

areas, a new cell (cell 2B) has been proposed for terrace construction. In recent months, additional surveying and geotechnical work was completed in cell 2B to obtain the necessary data to determine site characteristics and terrace construction requirements in the area.

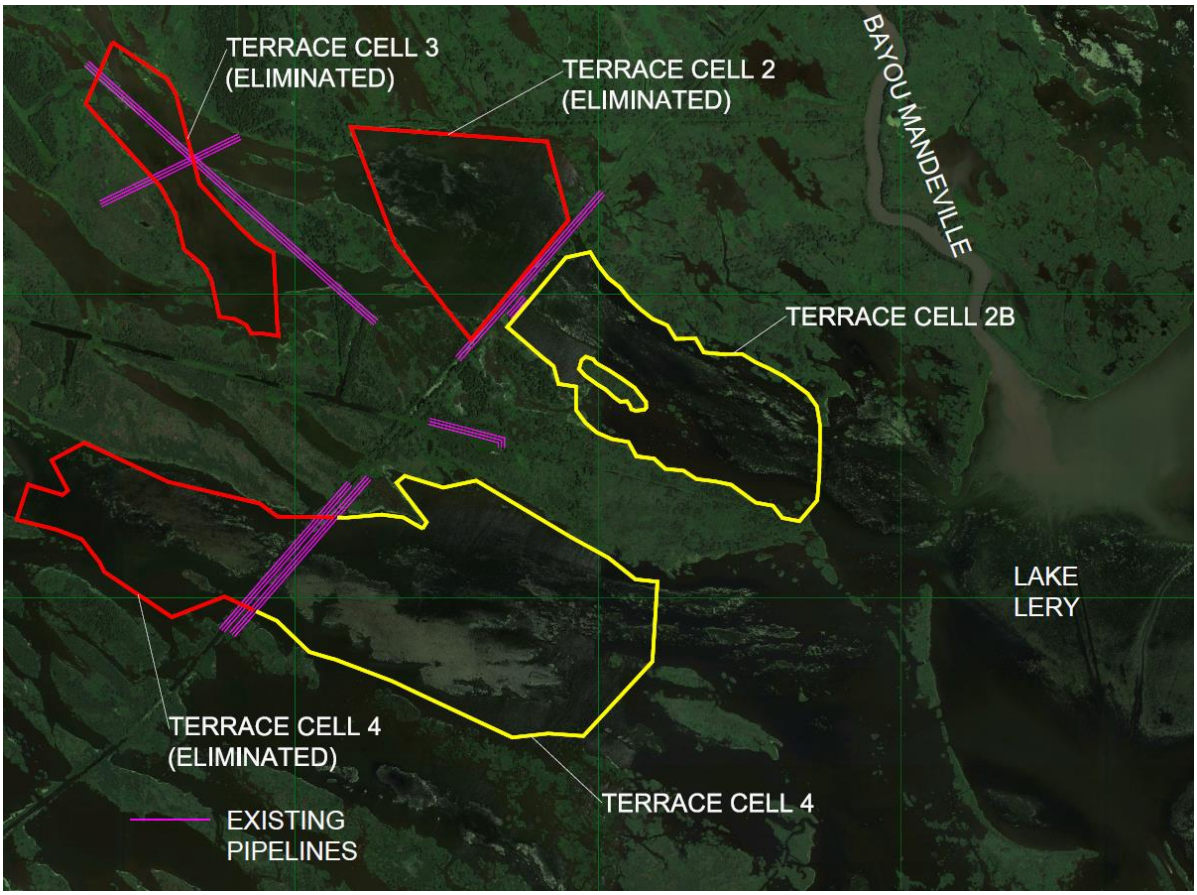


Figure 1.5 – Terrace Field Locations

The purpose of the earthen terraces is to reduce wave fetch within the open water bodies, to dissipate water velocities flowing through the project area, and to encourage sediment deposition and marsh accretion. Wave fetch is a function of wind speed and direction, water depth, and the straight-line distance between adjacent bank lines on a given water body. The greater the distance between bank lines and the deeper the water, the more susceptible the area becomes to excessive wave heights and scour potential. The presence of terraces provides breaks in the water surface, helping reduce the wave intensity and scour effects. As these terraces are spaced closer

to each other, these benefits are increase. Two limiting conditions for minimizing terrace spacing are construction equipment maneuverability and the availability of borrow material. Based on the proposed terrace cross-sectional geometry, the anticipated material settlement, and additional allowances for possible erosion during construction, LHA recommends a spacing of 300 feet for the terraces. In addition to providing sufficient borrow material for terrace construction, this width will allow adequate maneuvering space for construction equipment. Planting the terraces with native marsh grasses is also very important to the longevity and effectiveness of the terraces. LHA is of the understanding that the NRCS will plant the terraces independently of the construction contract; therefore, planting requirements are not included herein. However, LHA has been made aware that significant erosion is occurring on the BS-16 project and that the NRCS is considering to use hydro-seed to help stabilize the soil material and facilitate vegetative growth on the associated project features. LHA may incorporate this item into the BS-24 project as the design progresses.

These earthen terraces will be constructed of native soil material excavated from the adjacent borrow areas. As previously highlighted, the native soils are highly compressible and have a high moisture content, both of which increase the soil's potential to consolidate over time. Therefore, settlement and slope stability will govern the cross-section design of the terraces. Based on the recommendations outlined in the geotechnical report and the requests of USFWS, the terraces will have a top width of fifteen (15) feet, with slopes of 5 horizontal:1 vertical (5H:1V). Borrow areas will be located adjacent to each side of the terrace and shall have a maximum cut slope of 3H: 1V, with a thirty-five (35) feet wide berm separating them. Reference Appendix B for proposed terrace and borrow area cross-sections and terrace layout. Similar to the berm requirements associated with the MCA, this berm width may also be reduced significantly based

on the use of barge mounted equipment. Further evaluation of this feature will be conducted in subsequent design submittals.

LHA's scope of services includes designing terraces to meet a top elevation of +2.0 feet NAVD 88 at year 20; therefore, the constructed elevation must account for all anticipated settlement. As outlined earlier in this report, RSLR will not be incorporated in the design height. The geotechnical report identifies three separate types of settlement that will occur over the twenty-year design life of the terraces that must be added together to determine the total settlement. Based on the values specified in the report, the estimated total settlement is tabulated in Table 1.1.

Table 1.2 - Estimated Settlement Values	
Estimated Shrinkage Settlement*	12"
Estimated Construction Settlement*	Not included as it occurs instantaneously during construction per geotechnical report
Estimated Consolidation Settlement*	9"-21"; (21" used for this report)
Estimated Total Settlement	33" or 2.75 feet

*Values obtained from "BS-24 Terracing and Marsh Creation South of Big Mar" geotechnical report, prepared by GeoEngineers, Inc., dated September 23, 2014, Page 9, Table 2. (Refer to Appendix E.)

With a target elevation of +2.0 feet NAVD88 (at year 20) and an estimated settlement of 2.75 feet during that time period, the constructed elevation of each terrace shall be +4.75 feet NAVD 88. Based on the +4.75 feet top elevation, specified side slopes, and an average water bottom elevation of approximately -1.04 feet NAVD 88, the volume per linear foot required for construction is estimated to be approximately 14.0 cubic yards, including a 1.5 cut to fill ratio. Assuming that 65,000 linear feet of terraces are constructed during this project, an estimated 0.96 million cubic yards of excavated dredge material will be required for terrace construction. With the proposed

terrace spacing of 300 feet, approximately 2.5 million cubic yards of borrow material is available for construction. This provides adequate material for terrace construction including possible losses due to erosion occurring during construction. The terraces associated with this project will likely need to be constructed in two or more lifts and require 1-2 years to construct, assuming no tropical storms occur during construction. Based on the discussions held at the preliminary alternatives meeting, it is evident that the 65,000 linear feet quantity cannot be increased by more than twenty-five percent (25%) based on cost and quantity. Therefore, LHA is proceeding with the intent to maximize the available space in the designated terrace cells by spacing the terraces at 300 feet center-to-center. Total linear footage may be slightly more or less than the specified 65,000 feet.

Terrace Alternatives:

For the purpose of this project, the alternatives are numerous with respect to terrace orientation and spacing; however, LHA has prepared two baseline terrace configurations for consideration. Option 1 consists of traditional chevron pattern (commonly referred to as "duck-wing") spaced at 300 feet center-to center, with borrow areas on both sides. See Figure 1.6.

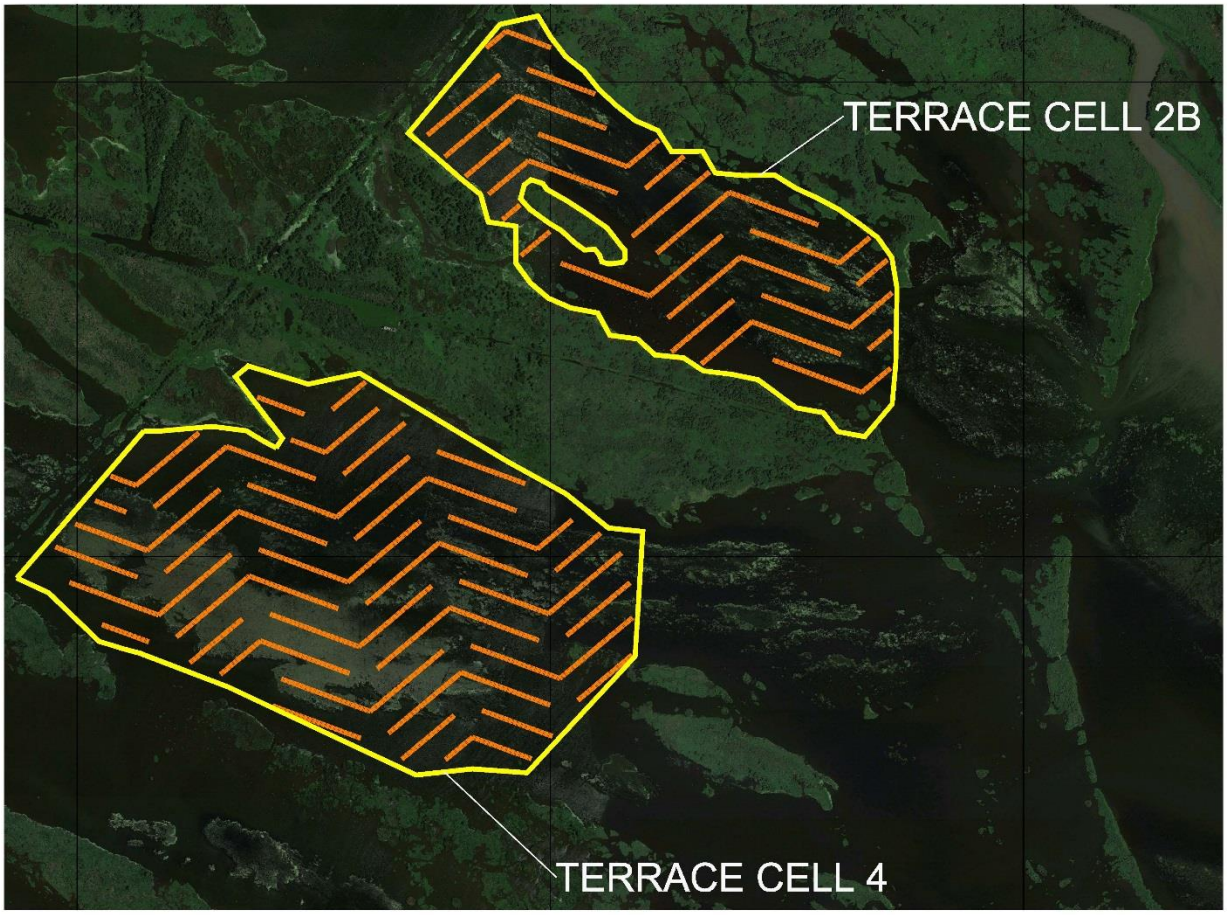


Figure 1.6 – Chevron Pattern at 300 ft spacing.

The terraces are oriented perpendicular to the predominant wind direction, having a general alignment bearing S80° 00’00”W/N80°00’00”E, and the physical geometry of the terraces is consistent with the description in the preceding section. Based on this configuration, LHA has determined that there is sufficient space to construct approximately 69,000 linear feet of terraces in the allotted areas. This is a preliminary layout and is subject to change slightly due to availability of borrow material, spatial limitations, etc.

Option 2 consists of a modified chevron pattern with the same general cross-section as Option 1. See Figure 1.7.

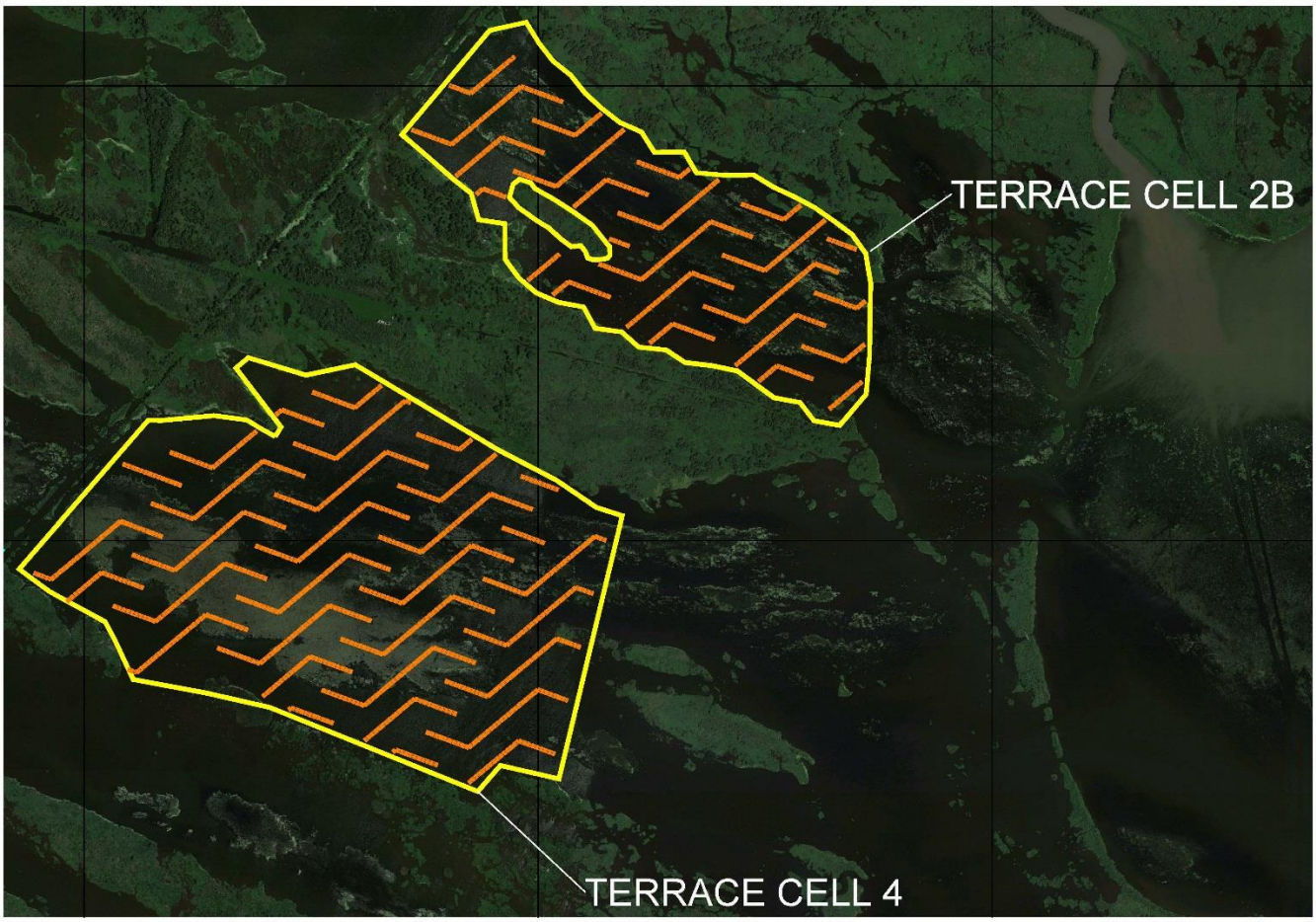


Figure 1.7 – Modified Chevron Pattern at 300 ft spacing.

Using the configuration of Option 2 and same 300 feet spacing, results in approximately 69,000 linear feet also. Based on these comparisons, it is evident that either option will yield approximately the same acreage of terraces. However, Option 1 will likely provide for easier navigation between the terraces with a barge and construction equipment and less incidental dredging. Both scenarios are oriented perpendicular to the predominant wind direction, and LHA does not recommend making any significant alterations to the alignment of the terraces with respect to wind direction. Complete layouts of Options 1 & 2 with 300 feet spacing are included in Appendix B.

Anticipated Problems and Concerns:

The only foreseeable problem LHA anticipates with the terrace construction is with respect the constructability of the terraces due to their relatively large size. Based on the geometry of the terraces, berm and borrow area requirements, and the quality of the soil material, it only seems practical for contractors to use a large dragline mounted on a spud barge to construct these terraces. It is highly likely that a dragline will need 200 feet of boom to be able to reach the center of each terrace from the borrow area without encroaching on to the proposed berm. The workable reach of a dragline is measured horizontally from the center of the machine outward to the end of the boom, with the boom at an angle of 40 degrees from vertical. (e.g. 200 x sin(40) =128.5 feet of reach) Lesser boom lengths will likely reduce the machine's effectiveness to complete the work, unless the berm width can be reduced significantly as mentioned in previous sections. Very few contractors in this geographical region possess a dragline with this reach capability; therefore, the amount of potential contractors will be minimal for this work. The use of a dragline and spud barge will likely require additional incidental dredging to navigate through the terrace field. This aspect is unavoidable and poses no real concern from a design standpoint; however, all potential dredge areas will need to be shown in the environmental permit application.

CONSTRUCTION BUDGET

LHA has prepared a preliminary construction budget based on the target fill heights referenced herein. Based on the remote location, access restrictions, and the constructability of the project features, LHA has estimated the total construction cost to be approximately $29.6 million, which includes a twenty-five percent contingency. (The unit cost items for the marsh creation work are based on the bid proposal associated with the BS-16 project and should be relevant for this project.) The unit price for the terrace construction is based on an estimated $3.00

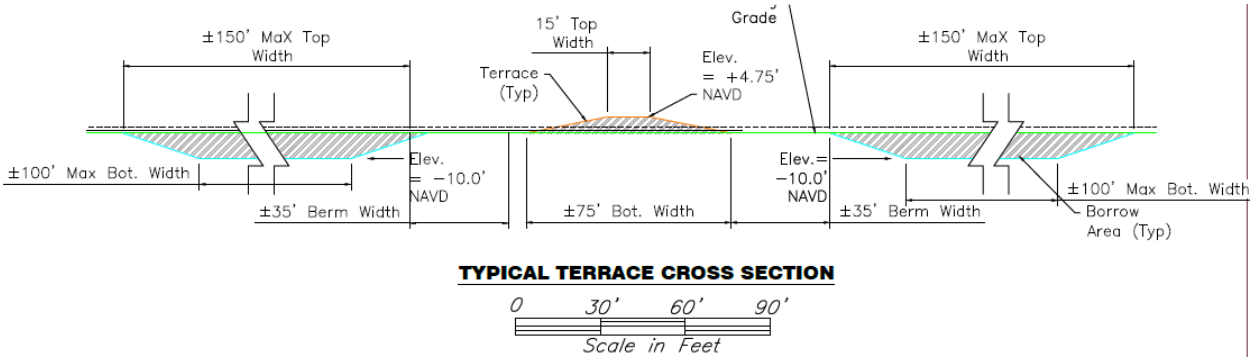
per cubic yard of material, which is fairly conservative based on the current market price of crude oil. Due to the reduction in oil field work, contractors are offering much lower prices than in recent years. If the price of oil stays low, it is likely the terrace construction cost could be reduced by nearly fifty-percent. These unit costs will fluctuate with the economy as time progresses, and the construction estimate will be updated as the project develops.

RECOMMENDATIONS AND CONCLUSIONS

After reviewing all available geotechnical data, data provided by the NRCS and the data collected by LHA, and considering the general scope of work and significance of the BS-24 project, LHA recommends the following.

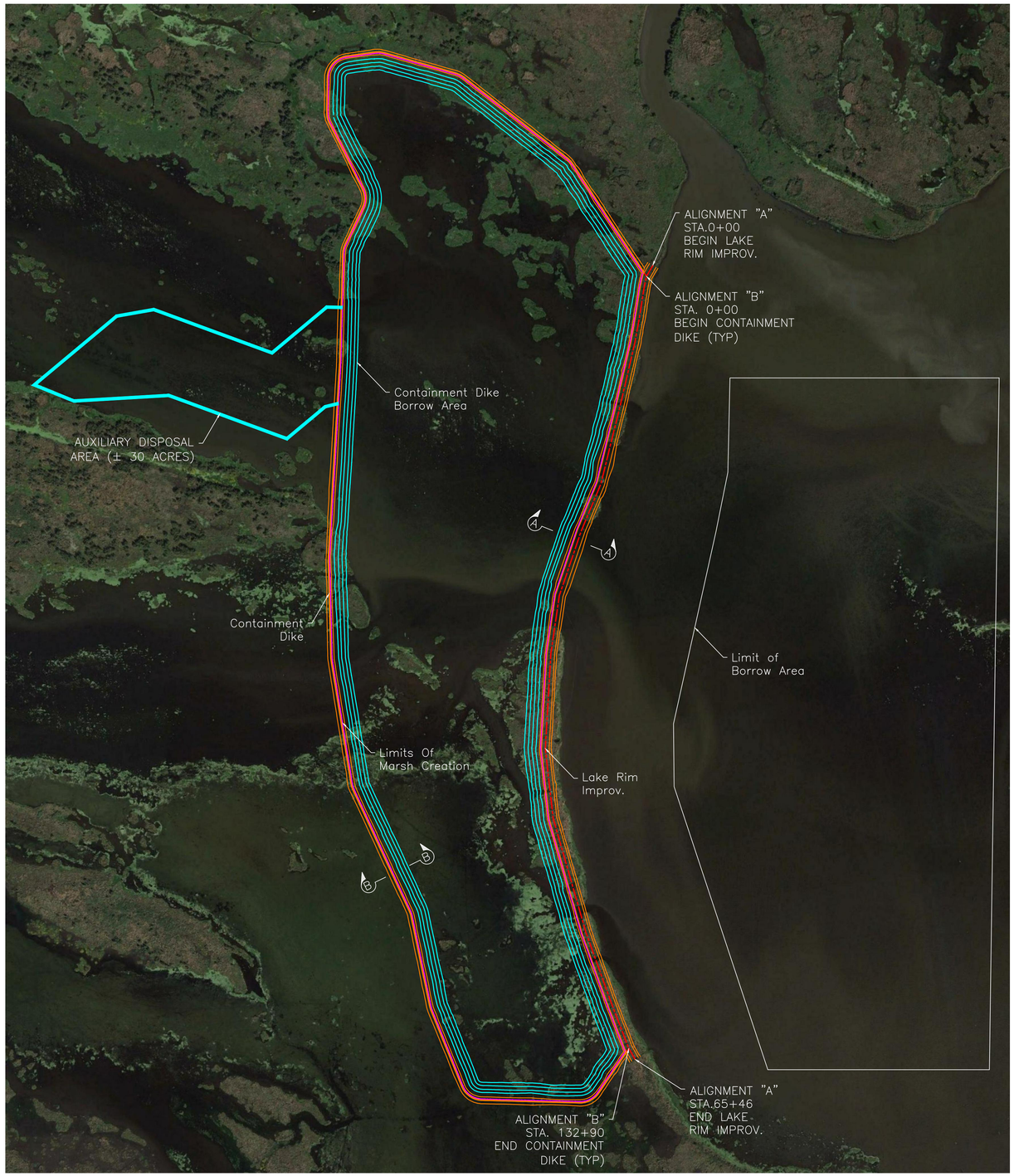
1. Marsh Creation: LHA is also of the opinion that the use of geotextile reinforcement within the containment dike will be problematic from an installation standpoint and will provide a minimal net cost savings, if any, to the BS-24 project. Based on the data presented herein, LHA recommends constructing the containment dikes to the lines and grades previously described, with the constructed marsh fill height set at +3.25 feet NAVD 88 +0.5 feet for overbuild. Dewatering structures will be sized and placed by the construction contractor to accommodate the expected runoff volume created by their dredging operations. Dewatering systems should discharge runoff on the west side of the marsh creation cell(s).
2. Terrace Construction: LHA recommends Option 1, which consists of the chevron pattern terraces, spaced at 300 feet center-to-center, on the basis that they will be efficient at reducing wave fetch due to tighter spacing, increase sedimentation within the watershed, provide a greater amount of surface area to facilitate vegetation growth, allow for easier navigation and possibly reduce the amount of incidental dredging required. Terraces

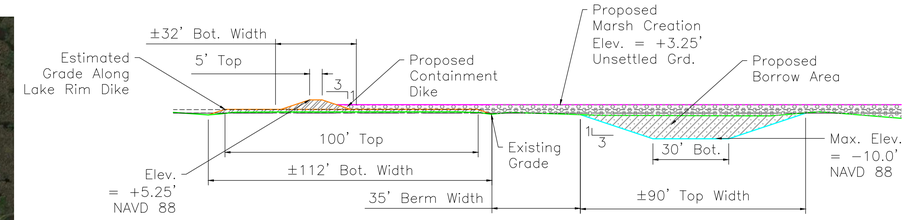
should be built to have a top width of fifteen feet, side slopes of 5H:1V, and crest elevation of + 4.75 feet NAVD 88.



In summary, LHA is of the opinion that all project features discussed within this report will meet or exceed the expectations of the NRCS and goals of the project based on the data described herein. Despite the few concerns listed, LHA feels that the design phase of this project will progress in a timely manner, assuming all requested data can be provided.

APPENDIX A
MARSH CREATION SITE ALTERNATIVES





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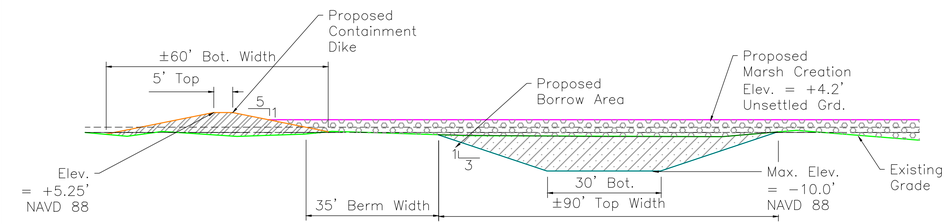

SECTION "B-B" (ALT. #1 - NON-REINFORCED DIKE)

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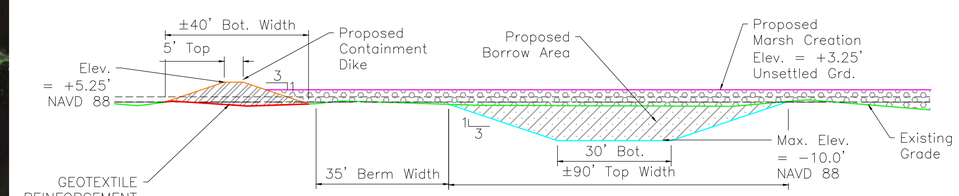
Scale in Feet



SECTION "B-B" (ALT. #2 - REINFORCED DIKE)

0 20' 40' 60'
Scale in Feet

Approximate total volume required for Alternate No. 1 = 3,757,040 CUBIC YARDS
Approximate total volume required for Alternate No. 2 = 3,810,500 CUBIC YARDS

Auxiliary disposal area is configured such that the proposed terraces serve as portions of the containment dikes needed to contain the excess dredge spoil. Additional dikes needed to enclose the area shall be constructed in accordance with "Section B–B" as shown above.

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0 500' 1,000' 1,500'
Hor. Scale in Feet

		Date
Designed	Chris Wheat	04/21/16
Drawn	Aaron Harper	04/21/16
Checked	Leonard Harper	04/21/16
Approved	Lonnie Harper	04/21/16

MARSH CREATION OPTION ALTERNATES
BS–24 TERRACING AND MARSH CREATION SOUTH OF BIG MAR

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Plaquemines Parish, Louisiana

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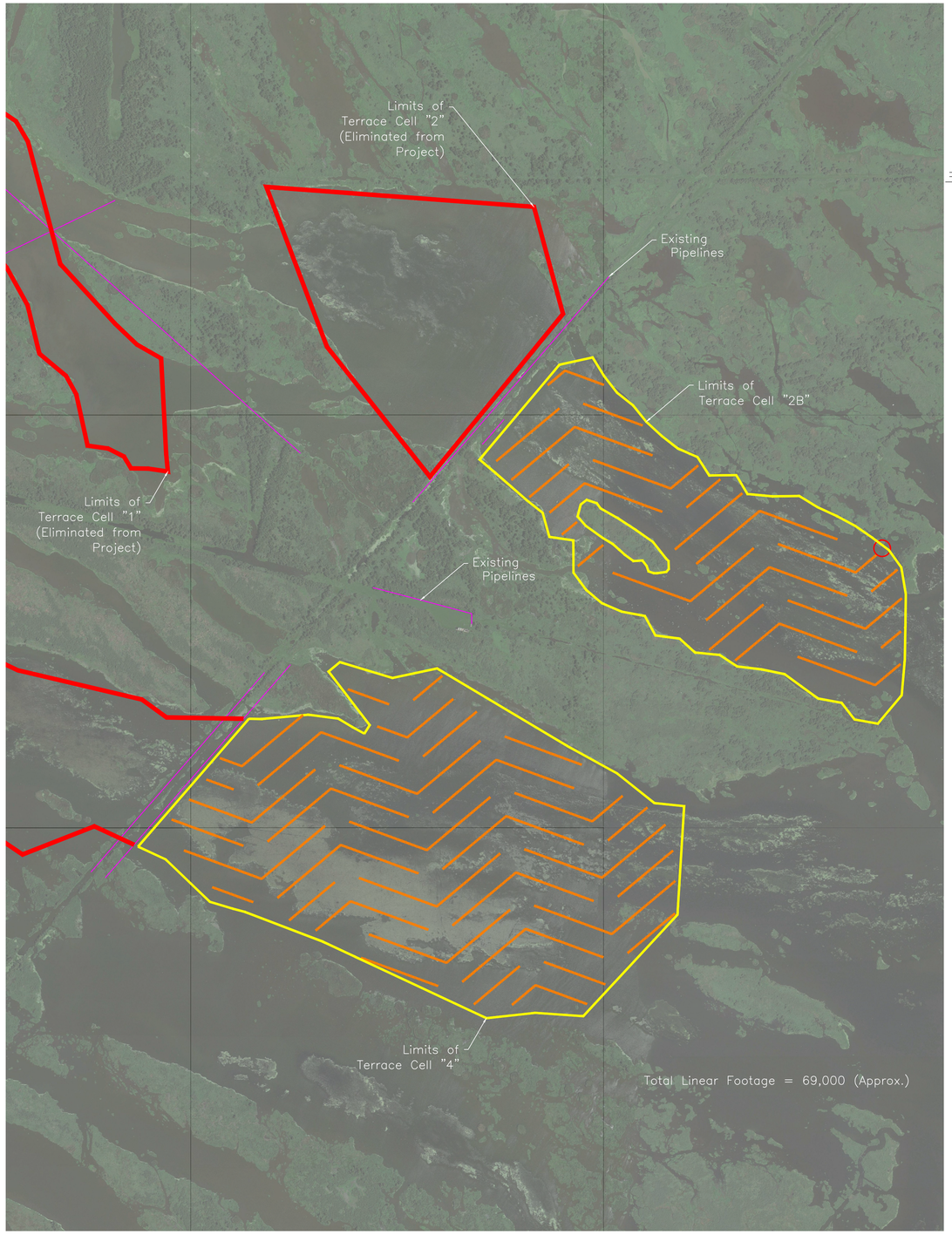
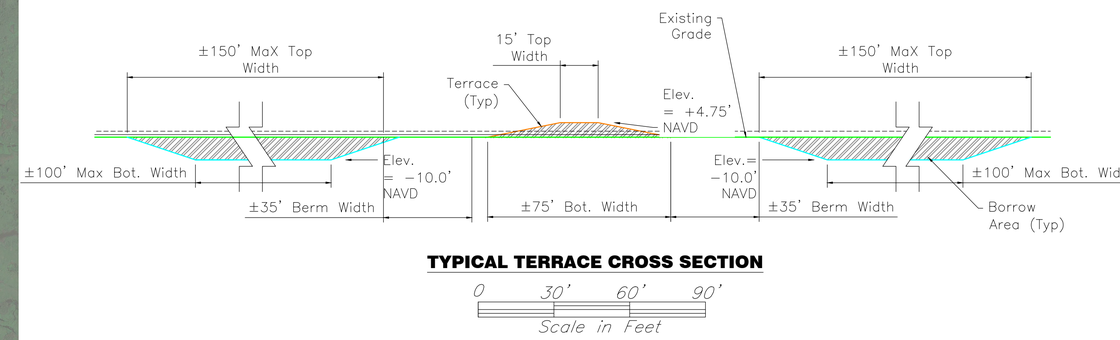
Sheet 01 of 01

APPENDIX B
TERRACE SITE ALTERNATIVES

Option 1 – 3 Pages

Option 2 – 3 Pages





TYPICAL TERRACE CROSS SECTION

0 30' 60' 90'
Scale in Feet

0 800' 1,600' 2,400'
Hor. Scale in Feet

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TERRACE CELLS OPTION "1" & TYPICAL SECTION
BS-24 TERRACING AND MARSH CREATION SOUTH OF BIG MAR
Page 01 of 03

Plaquemines Parish, Louisiana

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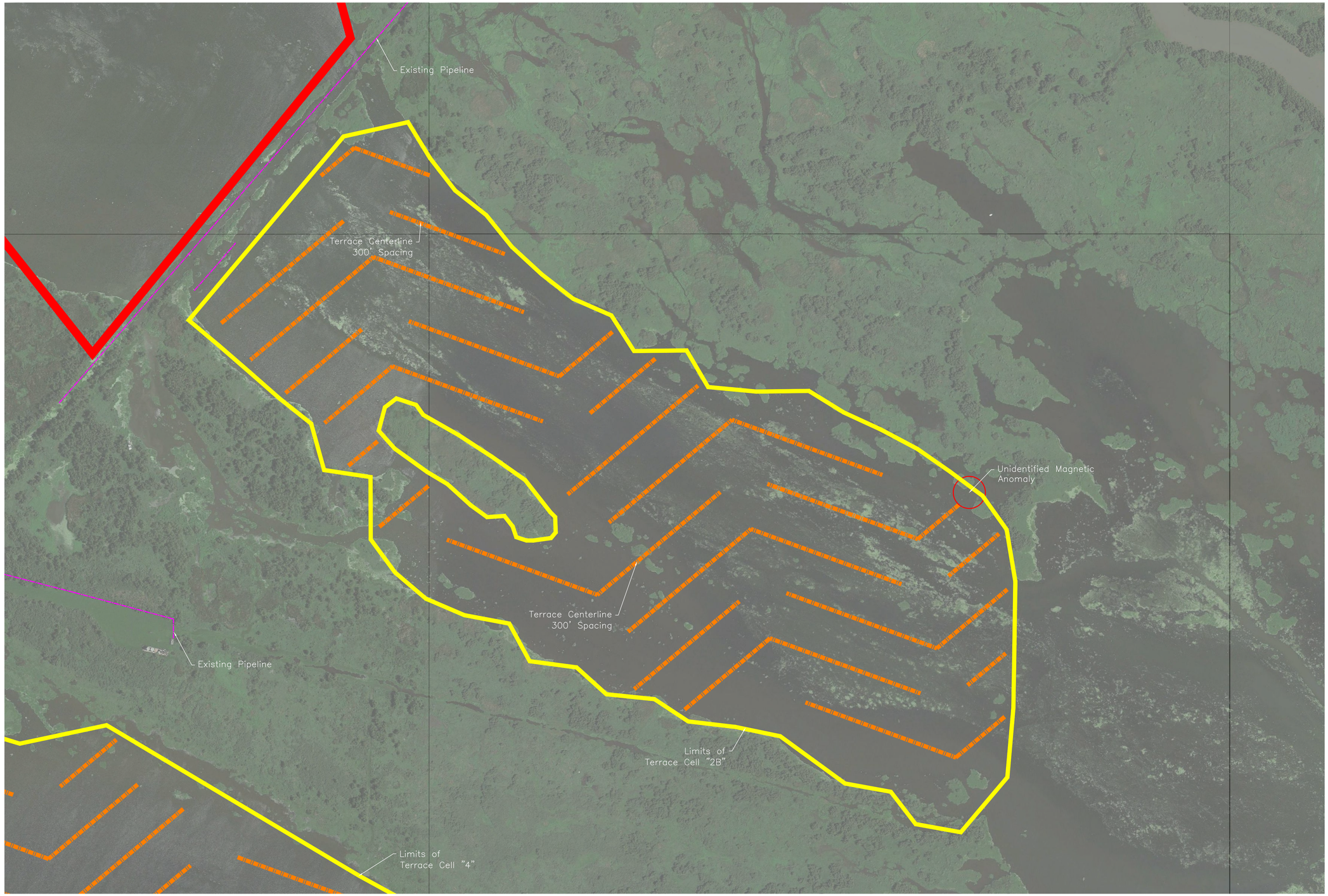

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0 300' 600' 900'
Hor. Scale in Feet

Note: Borrow areas not shown for clarity.

		Date
Designed	Chris Wheat	04/21/16
Drawn	Aaron Harper	04/21/16
Checked	Leonard Harper	04/21/16
Approved	Lonnie Harper	04/21/16

TERRACE CELL "2B" OPTION "1"
BS-24 TERRACING AND MARSH CREATION SOUTH OF BIG MAR
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Plaquemines Parish, Louisiana

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Drawing No.

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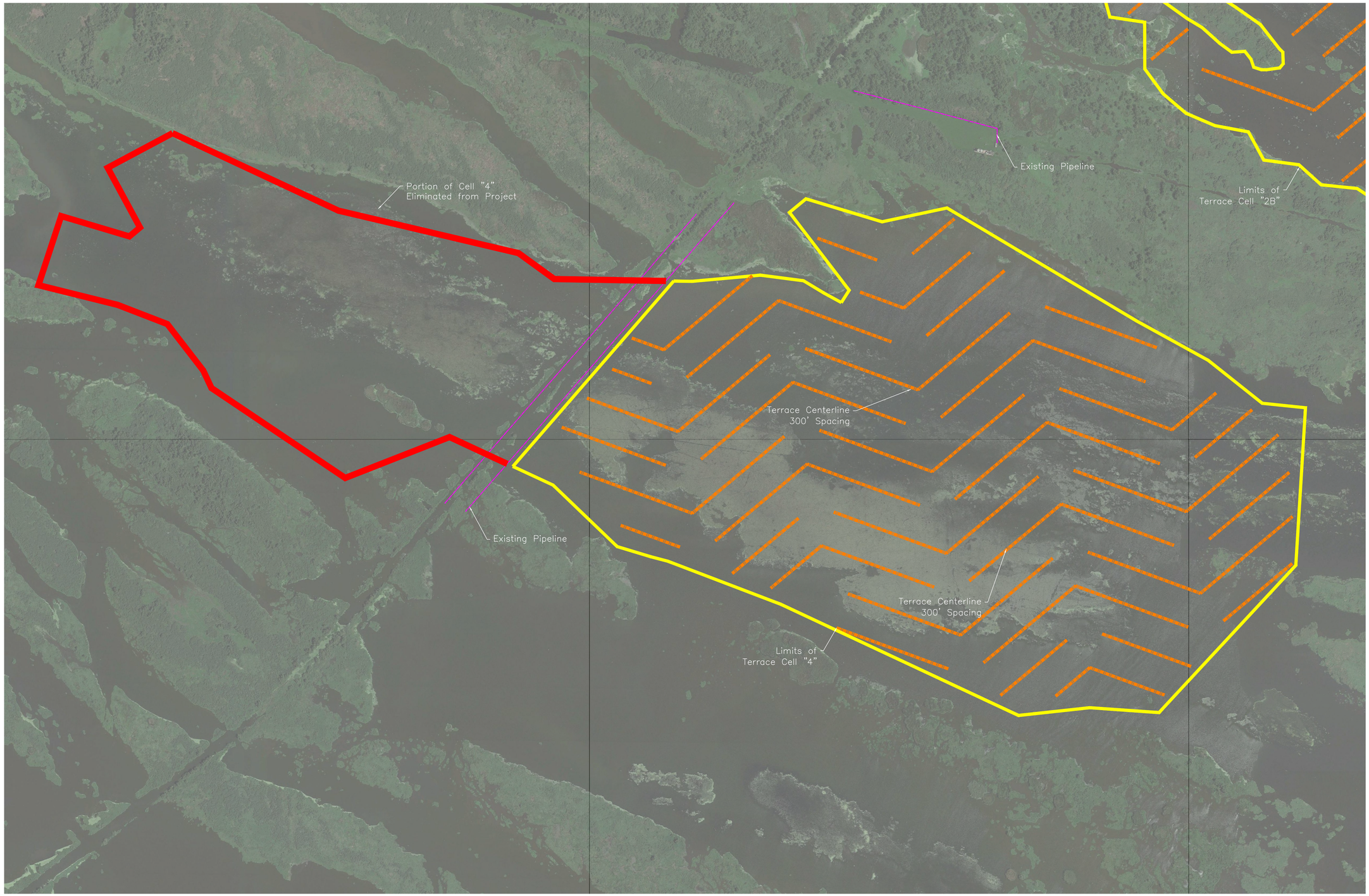

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0 400' 800' 1,200'
Hor. Scale in Feet

Note: Borrow areas not shown for clarity.

		Date
Designed	Chris Wheat	04/21/16
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Checked	Leonard Harper	04/21/16
Approved	Lonnie Harper	04/21/16

TERRACE CELL "4" OPTION "1"
BS-24 TERRACING AND MARSH CREATION SOUTH OF BIG MAR
Page 03 of 03

Plaquemines Parish, Louisiana

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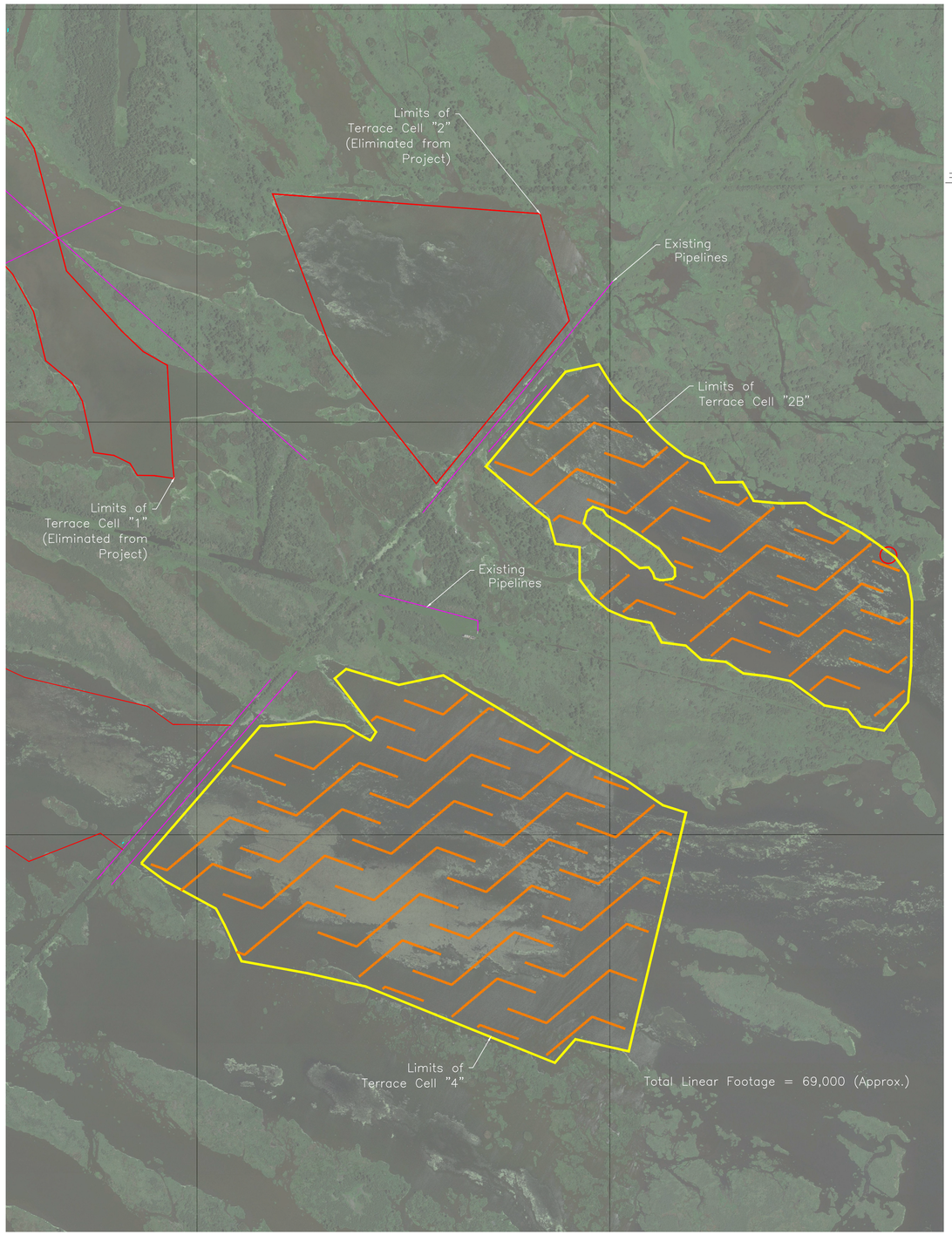
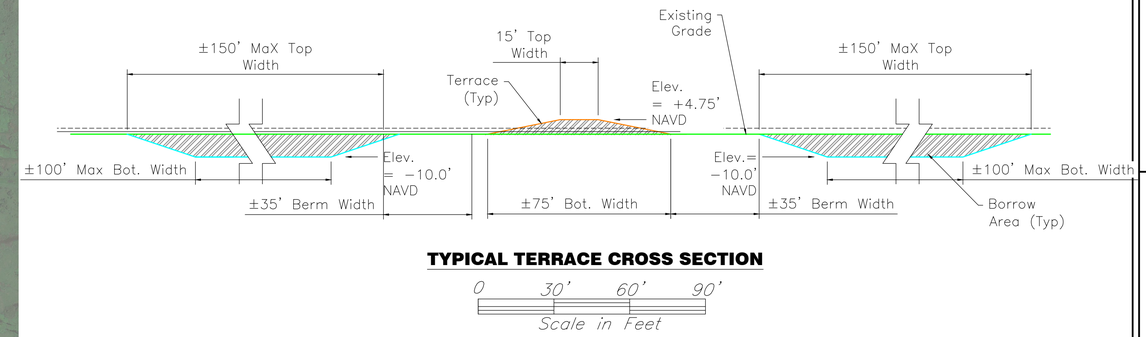
Sheet 03 of 03





TYPICAL TERRACE CROSS SECTION

0 30' 60' 90'
Scale in Feet

0 800' 1,600' 2,400'
Hor. Scale in Feet

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TERRACE CELLS OPTION "2" & TYPICAL SECTION
BS-24 TERRACING AND MARSH CREATION SOUTH OF BIG MAR

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Plaquemines Parish, Louisiana

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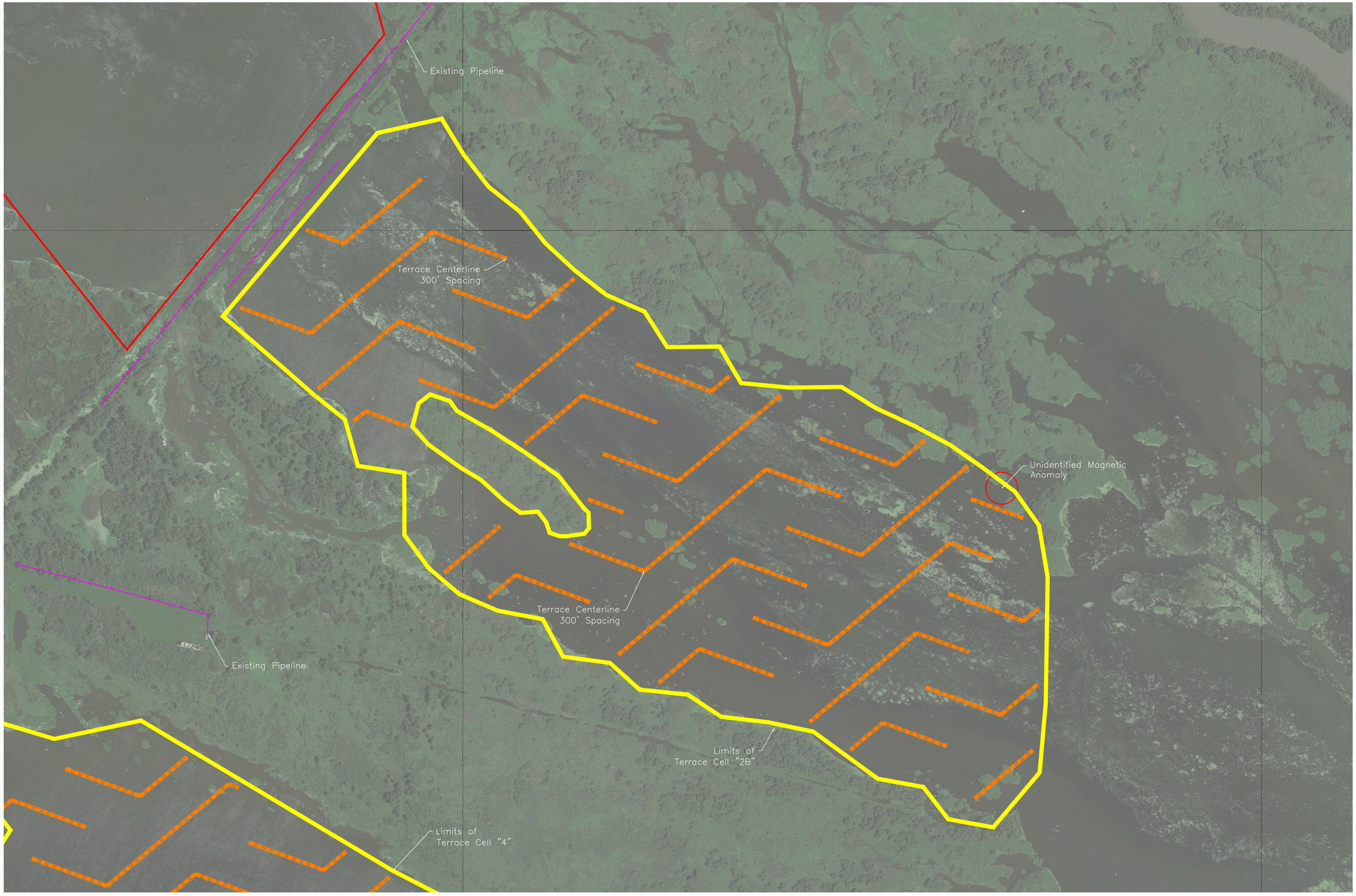
Sheet 01 of 03



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0 300' 600' 900'
Hor. Scale in Feet

Note: Borrow areas not shown for clarity.

		Date
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Drawn	Aaron Harper	04/21/16
Checked	Leonard Harper	04/21/16
Approved	Lonnie Harper	04/21/16

BS-24 TERRACING AND MARSH CREATION SOUTH OF BIG MAR
TERRACE CELL "2B"
Page 02 of 03
Plaquemines Parish, Louisiana

NRCS
Natural Resources Conservation Service
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File No.
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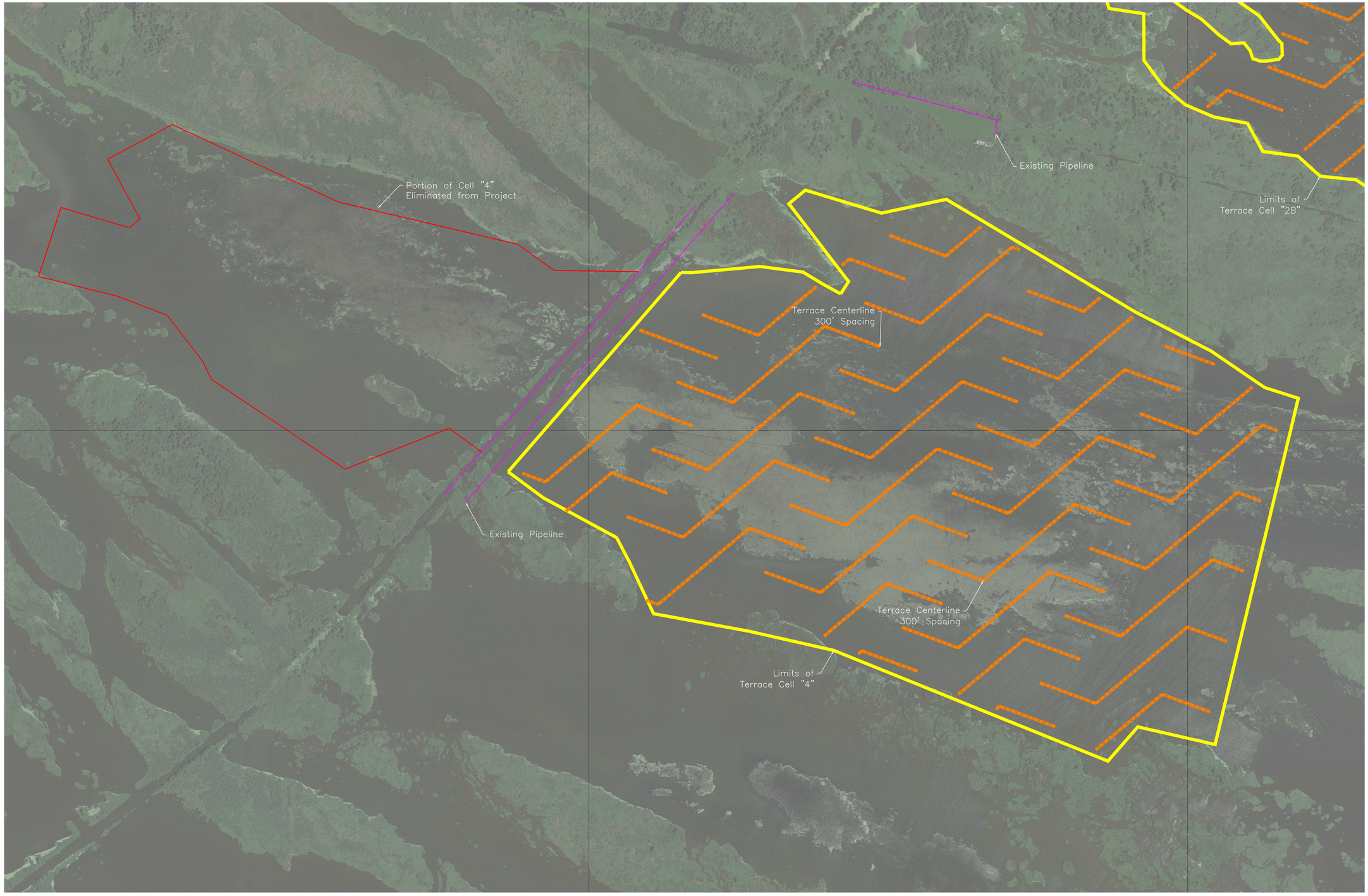
Sheet 02 of 03



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0 400' 800' 1,200'
Hor. Scale in Feet

Note: Borrow areas not shown for clarity.

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Checked	Leonard Harper	04/21/16
Approved	Lonnie Harper	04/21/16

BS-24 TERRACING AND TERRACE CELL "4" MARSH CREATION SOUTH OF BIG MAR

Page 03 of 03

Plaquemines Parish, Louisiana

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Sheet 03 of 03

APPENDIX C
PRELIMINARY CONSTRUCTION COST ANALYSIS

BS-24 Terracing and Marsh Creation South of Big Mar
Preliminary Estimated Construction Cost Analysis
Marsh Creation w/o Geotextile Reinforcement, Terrace Option 1 (Recommended)

Description of Work	Est. Quantity		Unit Cost	Extended Cost
General Conditions	N/A		$689,230.25	$689,230
Mobilization	1		$1,034,403.50	$1,034,404
Access Dredging	250,000	yd^3	$2.00	$500,000
Constr. Staking	N/A		$350,000.00	$350,000
Terrace Construction	69,000	L.F.	$41.93	$2,893,170
Perimeter Containment Dike	6,500	L.F.	$45.67	$296,855
Interior Marsh Containment Dike	13,500	L.F.	$34.67	$468,045
Marsh Creation	3,800,000	yd^3	$4.10	$15,580,000
De-watering Strs	N/A		$300,000.00	$300,000
QC/QA Surveys	N/A		$300,000.00	$300,000
Demobilization	1		$1,251,868.00	$1,251,868
			Subtotal	**$23,663,572**
			Contingency (25%)	$5,915,893
			Estimate Total Construction Cost	**$29,579,465**

*Unit prices listed herein are based on the average bid prices from various recent project of similar work and work environments or verbal quotes from experienced contractors.

**Varying the configuration and spacing of the terraces will have a minimal effect on the estimated cost, however increasing/decreasing the total linear footage will have a significant impact on the cost. This estimate is based on the assumption of constructing 69,000 linear feet of terraces, regardless of spacing or orientation.

***Access dredging quantities are estimated based on current survey data.

Mobilization/Demobilization cost calculated as 10% of total work items. (5% Mob. ; 5% Demob.)

General conditions calculated as 3% of all pay items inlcuding mobilization/demobilzation.

BS-24 Terracing and Marsh Creation South of Big Mar
Preliminary Estimated Construction Cost Analysis
Marsh Creation w/ Geotextile Reinforcement & Terrace Option 1

Description of Work	Est. Quantity		Unit Cost	Extended Cost
General Conditions	N/A		$708,522.33	$708,522
Mobilization	1		$1,034,633.00	$1,034,633
Access Dredging	250,000	yd^3	$2.00	$500,000
Constr. Staking	N/A		$350,000.00	$350,000
Terrace Construction	69,000	L.F.	$41.93	$2,893,170
Perimeter Containment Dike	6,500	L.F.	$45.67	$296,855
Interior Marsh Containment Dike	13,500	L.F.	$35.01	$472,635
Geotextile Reinforcement	69,000	yd^2	$9.25	$638,250
Marsh Creation	3,800,000	yd^3	$4.10	$15,580,000
De-watering Strs	N/A		$300,000.00	$300,000
QC/QA Surveys	N/A		$300,000.00	$300,000
Demobilization	1		$1,251,868.00	$1,251,868
			Subtotal	**$24,325,933**
			Contingency (25%)	$6,081,483
			Estimate Total Construction Cost	**$30,407,417**

*Unit prices listed herein are based on the average bid prices from various recent project of similar work and work environments or verbal quotes from experienced contractors.

**Varying the configuration and spacing of the terraces will have a minimal effect on the estimated cost, however increasing/decreasing the total linear footage will have a significant impact on the cost. This estimate is based on the assumption of constructing 69,000 linear feet of terraces, regardless of spacing or orientation.

***Access dredging quantities are estimated based on current survey data.

Mobilization/Demobilization cost calculated as 10% of total work items. (5% Mob. ; 5% Demob.)

General conditions calculated as 3% of all pay items inlcuding mobilization/demobilzation.

BS-24 Terracing and Marsh Creation South of Big Mar
Preliminary Estimated Construction Cost Analysis
Marsh Creation w/o Geotextile Reinforcement, Terrace Option 2

Description of Work	Est. Quantity		Unit Cost	Extended Cost
General Conditions	N/A		$695,530.25	$695,530
Mobilization	1		$1,044,403.50	$1,044,404
Access Dredging	350,000	yd^3	$2.00	$700,000
Constr. Staking	N/A		$350,000.00	$350,000
Terrace Construction	69,000	L.F.	$41.93	$2,893,170
Perimeter Containment Dike	6,500	L.F.	$45.67	$296,855
Interior Marsh Containment Dike	13,500	L.F.	$34.67	$468,045
Marsh Creation	3,800,000	yd^3	$4.10	$15,580,000
De-watering Strs	N/A		$300,000.00	$300,000
QC/QA Surveys	N/A		$300,000.00	$300,000
Demobilization	1		$1,251,868.00	$1,251,868
			Subtotal	**$23,879,872**
			Contingency (25%)	$5,969,968
			Estimate Total Construction Cost	**$29,849,840**

*Unit prices listed herein are based on the average bid prices from various recent project of similar work and work environments or verbal quotes from experienced contractors.

**Varying the configuration and spacing of the terraces will have a minimal effect on the estimated cost, however increasing/decreasing the total linear footage will have a significant impact on the cost. This estimate is based on the assumption of constructing 69,000 linear feet of terraces, regardless of spacing or orientation.

***Access dredging quantities are estimated based on current survey data.

Mobilization/Demobilization cost calculated as 10% of total work items. (5% Mob. ; 5% Demob.)

General conditions calculated as 3% of all pay items inlcuding mobilization/demobilzation.

BS-24 Terracing and Marsh Creation South of Big Mar
Preliminary Estimated Construction Cost Analysis
Marsh Creation w/ Geotextile Reinforcement & Terrace Option 2

Description of Work	Est. Quantity		Unit Cost	Extended Cost
General Conditions	N/A		$714,822.33	$714,822
Mobilization	1		$1,044,633.00	$1,044,633
Access Dredging	350,000	yd^3	$2.00	$700,000
Constr. Staking	N/A		$350,000.00	$350,000
Terrace Construction	69,000	L.F.	$41.93	$2,893,170
Perimeter Containment Dike	6,500	L.F.	$45.67	$296,855
Interior Marsh Containment Dike	13,500	L.F.	$35.01	$472,635
Geotextile Reinforcement	69,000	yd^2	$9.25	$638,250
Marsh Creation	3,800,000	yd^3	$4.10	$15,580,000
De-watering Strs	N/A		$300,000.00	$300,000
QC/QA Surveys	N/A		$300,000.00	$300,000
Demobilization	1		$1,251,868.00	$1,251,868
			Subtotal	**$24,542,233**
			Contingency (25%)	$6,135,558
			Estimate Total Construction Cost	**$30,677,792**

*Unit prices listed herein are based on the average bid prices from various recent project of similar work and work environments or verbal quotes from experienced contractors.

**Varying the configuration and spacing of the terraces will have a minimal effect on the estimated cost, however increasing/decreasing the total linear footage will have a significant impact on the cost. This estimate is based on the assumption of constructing 69,000 linear feet of terraces, regardless of spacing or orientation.

***Access dredging quantities are estimated based on current survey data.

Mobilization/Demobilization cost calculated as 10% of total work items. (5% Mob. ; 5% Demob.)

General conditions calculated as 3% of all pay items inlcuding mobilization/demobilzation.

APPENDIX D
SETTLEMENT CALCULATIONS

Lonnie G. Harper & Associates, Inc.
CIVIL ENGINEERING AND LAND SURVEYING CONSULTANTS

PROJECT NAME _____ PROJECT NUMBER 20___ - ____
AUTHOR _____ PAGE___ OF_____
COMMENTS _____ SCALE _____

MARSH CREATION FILL CALCULATION

* ASSUME TARGET ELEVATION IS +1.0' NAVD88 *

FROM FIG F-2 GEOTECH REPORT

INITIAL FILL ELEV	@ YR 20
3.5'	1.21'
3.0'	0.84'

INTERPOLATE TO FIND FILL HEIGHT FOR ELEV 1.0' @ YR 20

$$\frac{(1.21 - 0.84)}{(3.5 - 3.0)} = \frac{(1.21 - 1.0)}{(3.5 - x)}$$

= X = 3.35' = CONSOLIDATION SETTLEMENT

FROM PG 10 OF GEOTECH, TOTAL SETTLEMENT WILL BE CONSOLIDATION SETTLEMENT ~~PLUS ELASTIC SETTLEMENT~~

~~FROM TABLE 3, PG 10 ELASTIC SETTLEMENT = 5.5 in. (AVG)~~

~~TOTAL FILL HEIGHT~~

~~= 3.35' + (5.5/12) = 3.81' NAVD88~~

~~+ 6.5 mm/yr for RSLR @ 20 yrs~~

~~= 4.25' NAVD88~~

* ELASTIC SETTLEMENT & RSLR EXCLUDED FROM CALCULATION PER NRCS CORRESPONDENCE DATED APRIL 4, 2016.

TEL: 337.905.1079 2746 HWY 384, BELL CITY, LA 70630 FAX: 337.905.1076

APPENDIX E
GEOTECHNICAL INVESTIGATION REPORT

Only relevant portions of the geotechnical report are included herein.

Geotechnical Engineering Services

BS-24 Terracing and Marsh Creation
South of Big Mar
Plaquemines Parish, Louisiana

for

US Department of Agriculture
Natural Resources Conservation Service

September 23, 2014

GeoEngineers
Earth Science + Technology

Geotechnical Engineering Services

BS-24 Terracing and Marsh Creation
South of Big Mar
Plaquemines Parish, Louisiana

for
US Department of Agriculture
Natural Resources Conservation Service

September 23, 2014

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Baton Rouge, Louisiana 70809
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Geotechnical Engineering Services

BS-24 Terracing and Marsh Creation
South of Big Mar
Plaquemines Parish, Louisiana
File No. 10883-020-01

September 23, 2014

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Natural Resources Conservation Service
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VT:DSE:lb

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GeoEngineers

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INTRODUCTION

This report presents the results of GeoEngineers, Inc.'s (GeoEngineers) geotechnical engineering services for the Terracing and Marsh Creation South of Big Mar Project (BS-24) located in Plaquemines Parish, Louisiana. Our services have been completed under United States Department of Agriculture - Natural Resources Conservation Service (NRCS) contract AG-7217-C-10-0003, task order AG-7217-D-14-0034, dated May 5, 2014. The project is located south of Big Mar, and west of Lake Lery, as shown in Figure 1. Relevant site features are shown in Figure 2.

All elevations described in this report, including figures and appendices, are referenced to the North American Vertical Datum of 1988 (NAVD 88), Geoid 12A.

PROJECT UNDERSTANDING

Our understanding of the project is based on the Scope of Services for Geotechnical Investigation dated March 31, 2014, communications with NRCS, an April 23, 2014 site visit with NRCS representatives, and our May 2, 2014 proposal.

GeoEngineers understands that the primary goal of this project is to create approximately 65,000 linear feet of earthen terraces in shallow open water areas within the Caernarvon Diversion outfall area. The earthen terraces will reduce wave fetch in open water areas and promote conditions conducive to growth of marsh vegetation and submerged aquatic vegetation. Approximately 334 acres of marsh creation is also proposed to re-establish the western shoreline of Lake Lery in association with the Lake Lery West Shoreline Restoration and Marsh Creation project (BS-16).

The earthen terrace component of the project will most likely be constructed with marsh buggy long reach excavators. The marsh creation area will be designed as a traditional marsh creation area utilizing earthen dikes to contain fill material hydraulically dredged and pumped from a borrow area in Lake Lery.

PURPOSE AND SCOPE OF SERVICES

The purpose of our services is to perform geotechnical analysis as a basis for recommendations for design and construction of the proposed project features. Our specific scope of services included the following:

1. Visited the site to observe field conditions and better understand the project conditions.
2. Contacted Louisiana "One-Call" to notify them of our intent to perform soil borings at this site and to clear the boring locations of potential underground utilities.
3. Performed a field investigation that included:
    a. Fifteen undisturbed soil borings: three soil borings to a depth of 30 feet below mudline in the marsh creation area and twelve soil borings to a depth of 30 feet below mudline in the planned earthen terrace fields.
    b. Two borehole vane shear tests per boring at the three marsh boring locations and an additional six vane shear tests at the earthen terrace borings.

4. Performed laboratory testing on select soil specimens. The laboratory testing program included strength, unit weight, moisture content, Atterberg limit, organic content, fiber content, grain size, specific gravity, and consolidation testing.
5. Evaluated subsurface data and identified appropriate design profiles representing different sections along the project alignment.
6. Completed the following evaluations for each design profile as appropriate:
    a. Earthen Terraces:
        i. Evaluated stability of terraces with a 15-foot top width and with a lower borrow area excavation limit of elevation -10 feet (El. -10 feet) adjacent to the terraces. The side slopes for a stable terrace configuration were 5H:1V.
        ii. Evaluated constructed terrace top elevations of +2 feet, +3 feet, +4 feet and +5 feet. Note that after determining a stable elevation, GeoEngineers did not run lower elevations, since they will be more stable;
        iii. Performed settlement analyses for stable terrace configuration determined in stability analyses. Initial settlement at construction and settlement at 0.5, 1, 3, 5, 10 and 20 years after construction were estimated; and
        iv. Completed bearing capacity analyses for all elevations and stable terrace configurations determined from the slope stability and settlement analyses. Note that once a stable bearing capacity has been determined at some elevation, GeoEngineers did not run bearing capacity for lower elevation terraces;
    b. Updates to the January 21, 2011 Caernarvon/Lake Lery Shoreline Restoration (BS-16) report:
        i. Updated the elastic construction settlement of foundation soils in the marsh fill area; and
        ii. Updated the settlement curves for Groups 12 through 16.

    The March 31, 2014 NRCS requested scope of services identified the following.

    A survey datum adjustment has been made since the completion of the BS-16 geotechnical investigation. Elevations in that report were referenced to NAVD 88, Geoid99. An update of the geoid model in the project area to Geoid12A has been completed, which has resulted in the elevations shown in the BS-16 report being 0.325' above their Geoid12A elevation.

    The NRCS scope of services required GeoEngineers to reproduce Table 4 (Elastic Construction Settlement of Foundation Soils in Marsh Fill Area 2) and Appendix G, Figures G-1 through G-5 (Groups 12 through 16) from that report, with all elevations adjusted down by 0.325-foot:

    c. Dredged fill placed in the marsh creation area:
        i. Evaluated self-weight consolidation over time (0 - 20 years) for the dredge fill material considering the proposed construction method, using self-weight consolidation data from the BS-16 project, and the Primary consolidation, Secondary compression, and Desiccation of Dredged Fill (PSDDF) model;

ii. Evaluated settlement over time (0 - 20 years) for the foundation material on which the marsh fill material will be placed considering the proposed construction method;

iii. Evaluated total marsh fill settlement over time (0 - 20 years) considering the proposed construction method; and

iv. Developed curves for each marsh fill area boring location showing the combined total expected settlement vs. time. Curves are based on a range of initial marsh fill elevations beginning with El. +2 feet and increasing in 0.5-foot increments to El. +4.5 feet. The time scale includes initial marsh fill placement; end of construction; intervals of 0.5, 1, 3, 5, and 10 years after initial placement; and ultimate settlement (20 years after initial placement);

d. Earthen containment dikes:

i. Determined the maximum construction elevation considering desired marsh elevation and expected fill properties;

ii. Evaluated acceptable side slopes with and without geotextile reinforcement;

iii. Determined acceptable crown width;

iv. Determined minimum berm width and geotextile requirements (if any) assuming a borrow channel bottom of El. -10 feet;

v. Estimated settlement of containment dike during a approximate one-year construction period;

vi. Performed bearing capacity analyses;

vii. Determined factor of safety for the resistance of the containment dike to horizontal sliding due to force exerted on the dike by the dredge slurry. Containment dike configurations were approved by NRCS prior to analysis; and

viii. Provided required setback distance for the dike to be located on the top of the lake rim embankment.

7. Provided an estimate for cut to fill ratio for containment dike, earthen terrace and marsh creation area fill.

8. Provided general construction recommendations.

9. Prepared a report of findings, including recommended earthen containment dike and terrace geometry, estimated marsh settlement, and fill to cut ratios.

FIELD EXPLORATION

Field exploration was performed from May 8, 2014 to May 13, 2014, during which 15 soil borings were completed to a depth of 30 feet below existing mudline using an airboat-mounted drill rig, including 3 soil borings (BHMC-1 through BHMC-3) in the marsh creation area and 12 (BHT-1 through BHT-12) for earthen terraces. All borings were sampled continuously for the top 20 feet, and then at 5-foot centers to the boring completion depths. Surveyed mudline elevations at the soil boring

locations provided by NRCS varied from El. -0.82 to El. -1.76 feet. Soil boring locations are shown in Figure 2 and detailed soil boring logs are included in Appendix A.

Borehole sampling was conducted in general accordance with applicable ASTM specifications. High-quality, undisturbed, cohesive and semi-cohesive soil (clay/clayey silt) specimens suitable for laboratory strength testing were obtained using a 30-inch-long, 3-inch outside diameter, thin-walled steel Shelby tube sampler. At each soil boring, the sampler was hydraulically pushed into the ground a distance not exceeding 24 inches per specimen using an Osterberg piston sampler. Soil borings were grouted upon completion in accordance with Louisiana requirements.

Immediately upon recovery, each sample was classified in the field by a GeoEngineers field representative based on soil exposed on either end of the Shelby tube. Each Shelby tube was then sealed and stored/transported in a vertical position. Shelby tubes were secured bottom down during transportation to minimize sample disturbance.

Upon completion of each soil boring in the marsh creation area and select borings for the earthen terrace, the drill rig was repositioned adjacent (±2 feet) to the completed boring and a GEONOR H-10 vane borer instrument was used to perform field vane shear tests at various depths in general accordance with ASTM D 2573. The test consisted of placing a four-blade vane in the in-situ soil and rotating it from aboard the drill rig to determine the torque required to shear a cylindrical soil surface with the vane. The resulting torque was used to calculate the in-situ soil undrained shear strength.

LABORATORY TESTING

Intact semi-cohesive and cohesive samples were subjected to laboratory miniature vane (mini vane) shear testing prior to extrusion. Upon extrusion, each sample was examined to confirm or modify field classifications. Representative samples were selected for laboratory testing consisting of moisture content, dry unit weight, unconfined compression, unconsolidated undrained compression, organic content, fiber content, grain size analysis, consolidation testing and Atterberg limits. The test results are presented on the boring logs and figures included in Appendix A and Appendix B, respectively.

No new self-weight consolidation tests or settling column tests were performed on samples obtained for this project. Instead, self-weight consolidation and settling column test results from BS-16 project were considered in analyses for this project.

SITE CONDITIONS

Project Location

The project is located in Plaquemines Parish, Louisiana south of Big Mar and west of Lake Lery, as shown in Figure 1.

Surface Conditions

On April 23, 2014, representatives of GeoEngineers and NRCS toured the project area by airboat. Based on our observations and discussions with the NRCS representatives during the visit and observations during the site investigation, we offer the following information regarding site conditions.

Water depths ranged from approximately 1.5 to 2.5 feet at soil boring locations BHMC-1-30 through BHMC-3-30 and BHT-1-30 through BHT-12-30 at the time of drilling. Weather, wind, and tides can substantially affect water levels. Wind can make the open water rough and make it difficult to operate equipment that is sensitive to wave action.

The surrounding area is generally undeveloped but there are pipelines and other features that were noted during our field visit and drilling. Land adjacent to canals is typically elevated relative to the surrounding area and supports growth of trees, shrubs, and marsh grasses. Wildlife flourishes in these marsh lands and was often seen during our site visit and field investigation.

The Caernarvon Diversion structure, designed to release water from the Mississippi River influences this area. When the diversion structure is open, water from the structure flows to, and through, the project area.

Subsurface Conditions

The subsurface conditions discussed below are based on the soil borings completed for this project and survey information provided by the NRCS. No artifacts or material other than that noted on the soil boring logs was observed by GeoEngineers during our field investigation, or during laboratory testing; however, GeoEngineers personnel are not trained in recognition of such items.

Subsurface profiles based on our soil borings for the earthen terrace and in the marsh creation area are shown in Figures 3A and 3B, respectively. Although undetected anomalies, (sand layers, logs, etc.) beyond the soil borings may exist, the generalized subsurface conditions can be described as follows.

Earthen Terrace Area

As shown in the subsurface profiles (A-A', B-B', C-C' and D-D') in Figure 3A, the proposed earth terrace area soil predominantly consists of layers of very soft peat and organic clay in the upper 6 to 18 feet. The thickness and depth of these deposits varied in each soil boring. Beneath the peat and organic clay, all the soil borings encountered a clay layer that varied from high moisture fat clay to silty clay, and in many cases the clay contained silt and sand seams or layers. At soil borings BHT-2-30, BHT-8-30, BHT-9-30 and BHT-10-30, a layer of granular soil consisting of sand and/or clayey sand with varying amounts of silt and clay was encountered 22 feet, or deeper below the mudline and extended to the respective soil boring completion depths.

Appendix C contains the assumed design profiles (shear strength, unit weight, and moisture content) for the 12 earthen terrace soil borings, based on laboratory and field testing results. As presented in these profiles, peat moisture content ranges from about 270% to about 1,250%, and organic clay moisture content ranges from about 80% to about 550%. These high moisture, highly compressible, organic materials were generally in the upper 6 to 18 feet across the marsh area where earthen terraces will be constructed. In the layers below these organic deposits, average clay moisture contents vary from about 20% to about 120%.

Soil boring logs are provided in Appendix A. Appendix B contains laboratory data, and Appendix C presents the design soil properties vs. elevation based on field and laboratory test results.

Marsh Creation Area

As shown on Figure 3B, the marsh creation area soil borings encountered similar soils as those encountered on the western shoreline of Lake Lery, provided previously in the BS-16 report dated January 21, 2011. The top 2 to 22 feet below mudline was very soft peat and organic clay. Beneath the peat and organic clay, all the soil borings encountered a clay layer that varied from high moisture fat clay to silty clay, and in many cases the clay contained silt and sand seams or layers. Shells were encountered in a few soil samples at BHMC-2-30.

As presented in the profiles in Appendix C, peat moisture content in the proposed marsh creation area ranges from about 300% to about 800%, and organic clay moisture content ranges from about 115% to about 220%. In the clay layers below these organic deposits, average moisture contents vary from about 35% to about 100%.

Detailed soil boring logs are provided in Appendix A. Appendix B contains laboratory data, and Appendix C presents the design soil properties vs. elevation based on the field and laboratory investigation.

CONCLUSIONS AND RECOMMENDATIONS

General

Soil conditions for this project resemble the BS-16 project. Based on the investigation results, the proposed improvement area is generally suitable for the construction of proposed earthen terraces, containment dike and marsh creation. The results of the slope stability and settlement analyses are presented in tables below. Details of the analysis methods are presented in Appendices D through F for slope stability, bearing capacity and settlement for the various project features.

Earthen Terrace Slope Stability and Bearing Capacity

GeoEngineers evaluated slope stability and bearing capacity for the earthen terraces with a crown elevation of +5 feet, 5 horizontal to 1 vertical (5H:1V) side slopes and a 15-foot crown width. The borrow excavation was assumed to be excavated to El. -10.0 feet with a 3H:1V cut slope. The slope stability failure modes evaluated are shown on Figure 4 and recommended sections are shown on Figure 5. In general, the earthen terraces built to El. +5 feet have an adequate factor of safety for slope stability except at BHT-6-30 where a maximum crown elevation of El. +4.0 feet is recommended for single lift construction.

As evidenced by the results presented below soil conditions vary across the site, and there are areas that are expected to require two-lift construction. GeoEngineers recommends the NRCS consider a two-lift construction for all terraces and interior containment dikes to 1) help manage other problem areas that may be identified during construction, and 2) to avoid the difficult problem of delineating and tracking areas with different construction requirements. The first lift should be constructed to the full base width of the completed terrace, to El. +2.5 ft, and allowed to sit for a minimum of 60 days, prior to placing the next lift to the full design elevation.

A second option for these conditions may be to use geotextile reinforcement. However, a reinforcement option has not been evaluated for the terrace. Table 1 below summarizes the slope stability factor of safety results for the earthen terraces without reinforcement.

Table 1. Earthen Terrace Slope Stability Analysis Results – Without Reinforcement

Boring ID	Terrace Dimension				Bench Width (feet)	Slope Stability FOS				Global Bearing FOS
						Condition			Appendix D Figure #	
	Crown Elevation (feet)	Crown Width (feet)	Side Slopes (H:V)	Mudline Elevation (feet)		1	2	3		
BHT-1	+5	15	5:1	-0.92	25	2.25	1.57	1.77	D-1	2.19
BHT-2	+5	15	5:1	-1.12	25	1.85	1.77	1.40	D-2	2.57
BHT-3	+5	15	5:1	-1.26	25	1.83	1.44	1.33	D-3	1.55
BHT-4	+5	15	5:1	-0.96	25	1.95	1.55	1.50	D-4	1.65
BHT-5	+5	15	5:1	-1.02	25	2.39	1.59	1.72	D-5	3.04
BHT-6	+5	15	5:1	-1.26	25	2.40	1.16	1.14	D-6	-
BHT-6	+4	15	5:1	-1.26	25	1.94	1.42	1.43	D-7	2.19
BHT-7	+5	15	5:1	-1.42	25	1.86	1.55	1.57	D-8	1.92
BHT-8	+5	15	5:1	-1.52	25	1.89	1.42	1.47	D-9	1.60
BHT-9	+5	15	5:1	-1.72	25	2.79	1.92	1.91	D-10	2.31
BHT-10	+5	15	5:1	-1.72	25	2.28	1.55	1.57	D-11	1.98
BHT-11	+5	15	5:1	-0.82	25	2.14	1.47	1.65	D-12	1.89
BHT-12	+5	15	5:1	-1.22	25	2.18	1.54	1.41	D-13	2.15

Condition 1 –Marsh to Excavation

Condition 2 –Terrace to Excavation

Condition 3 –Terrace to Marsh

A bench width of 25 feet was modeled for the earthen terrace to provide sufficient space for marsh buggy excavator access and also increase terrace stability. The factor of safety given in Table 1 includes an assumed load of 260 pounds per square foot (psf) from a marsh buggy excavator during construction in situations where the excavator load reduces the factor of safety.

Earthen terrace geometries that have flatter side slopes and/or wider benches than the section shown in Figure 5 will be more stable. Higher crown elevations, shorter benches, or a deeper access channel will have to be re-evaluated for stability. No geotextile reinforcement was necessary to achieve stability for all earthen terraces. However at BHT-6-30, the terrace should be constructed in lifts for an El. +5 feet crown with the first lift limited to El. +2.5 feet.

Earthen terrace configurations from Table 1 were also checked against global bearing failure and found to be stable. Appendix D contains results of the most critical slope stability section for each completed earthen terrace evaluation and the bearing evaluation.

Earthen Terrace Settlement

GeoEngineers evaluated settlement for the earthen terraces constructed for crown elevations of +2, +3, +4 and +5 feet. Table 2 provides a summary of the settlement estimates. Appendix E (Figures E-1 though E-13) contains graphical and tabular summaries of settlement.

Settlement for earthen terraces has three components; 1) consolidation of underlying soil due to the additional loading imposed by the earthen terrace; 2) immediate construction (elastic) settlement of soil during construction; and 3) shrinkage within the terrace earthen fill. All three components must be added to obtain the total settlement.

Construction, or elastic, settlement is the result of immediate compression of the underlying soils during placement of fill (i.e. during construction). Elastic settlement has been estimated as 20% of the long term consolidation settlement. This estimated number is educated guess based on professional judgment. It is difficult to distinguish construction settlement from consolidation settlement because they both occur during construction and there is little, or no, data that GeoEngineers is aware of for coastal Louisiana organic soil. Construction settlement will be offset by fill placement during construction and is not likely to be directly observed. It will, however, increase the fill quantity required to reach the design elevation and should be considered for fill quantity estimates.

Settlement or shrinkage of fill materials is likely to be significant for the earthen terraces. Shrinkage of terrace fill is a function of many variables, including fill material, construction practices, weather, and fill height. There are also off-setting effects. For example, as fill loses water and shrinks, it becomes lighter and smaller reducing the amount of consolidation settlement of the underlying soils as compared to the full initial load. Shrinkage will not be uniform; the exterior of the terrace, especially at higher elevations, is expected to shrink more than the interior, especially near the water level. This is a very difficult number to predict, but GeoEngineers recommends estimating shrinkage settlement as 20% of the earthen terrace height above the mean water design level. We have assumed that soil El. -10 feet will be utilized to construct the earthen terrace. Soil to El. -10 feet typically has a considerable amount of organics with high moisture content (generally greater than 250%). Hence, GeoEngineers assumed 20% volume shrinkage in addition to the estimated consolidation and construction settlement.

For example, based on a mean water elevation of 0 feet and an earthen terrace elevation of 5 feet at soil boring location BHT-1-30, GeoEngineers recommends allowing for 1 foot (12 inches) of elevation loss due to shrinkage, in addition to consolidation settlement. It is expected that shrinkage will occur within 3-6 months after construction depending upon the season. Dry and sunny weather will speed the shrinkage process, while wet and cloudy weather will slow the process. Shrinkage due to drying will also vary within the fill; fill exposed to sun and air at the exterior of the terrace will dry more than fill near the center of the dike near the water level (which is likely to remain moist after draining excess water during initial excavation from a submerged condition).

TABLE 2. EARTHEN TERRACE SETTLEMENT ESTIMATES

Boring ID.	Crown Elevation[3] (feet)	Estimated Shrinkage Settlement[1] (inches)	Estimated Construction Settlement[2] (inches)	Estimated Foundation Soil Consolidation Settlement (inches)				
				6 Mo.	1 Yr.	3 Yrs.	10 Yrs.	Long-term (20 Years)
BHT-1	+5	12	3	11	12	14	14	14
	+2	5	2	7	7	8	9	9
BHT-2	+5	12	2	9	9	9	9	9
	+2	5	1	6	6	6	6	6
BHT-3	+5	12	3	10	11	12	13	13
	+2	5	2	6	7	7	8	8
BHT-4	+5	12	4	18	18	19	20	20
	+2	5	2	11	12	12	12	12
BHT-5	+5	12	2	8	9	11	11	11
	+2	5	1	5	6	6	6	6
BHT-6	+5	12	4	17	19	20	21	21
	+2	5	3	11	12	12	13	13
BHT-7	+5	12	3	14	16	17	17	17
	+2	5	2	9	9	10	10	10
BHT-8	+5	12	4	11	12	14	17	19
	+2	5	2	7	8	9	10	11
BHT-9	+5	12	3	11	12	13	14	14
	+2	5	2	8	8	9	9	9
BHT-10	+5	12	3	14	15	16	17	17
	+2	5	2	8	9	9	10	10
BHT-11	+5	12	4	11	14	16	17	18
	+2	5	2	8	9	10	11	11
BHT-12	+5	12	4	15	16	17	19	19
	+2	5	2	10	10	11	11	12

(1) Shrinkage settlement = (Initial construction elevation-Assumed water elevation)*20%; Water at El. 0 feet, NAVD88 Geoid 12A.

(2) Estimated construction settlement is not included in the estimated consolidation settlement.

(3) Crown elevation at end of earthen terrace construction.

Marsh Creation

Settlement

The existing marsh mudline surface was taken as the surveyed mudline elevation at each soil boring, and the water level was assumed to be at El. 0.0 feet. The marsh creation target elevation is estimated to be El. +1 foot and the target year for achieving this elevation is yet to be determined by NRCS (could range from target year 3 to target year 20).

The thickness of dredged material in a contained area is reduced by primary consolidation, secondary consolidation, and desiccation. The consolidation settlement and time rate of settlement analyses for the marsh creation area were performed using the PSDDF program. The self-weight

consolidation and settling column test results from BS-16 project were used to determine input parameters for the dredged fill materials.

A significant characteristic of hydraulic fill is that, initially, more of the hydraulic fill is above the water table (often 50% or more); however, as the fill consolidates and foundation soils compress, the fill submerges. The mass of the solids within the fill remains constant, so as the fill settles/consolidates and more of the mass becomes submerged (becomes buoyant), the stress (weight) of the fill on the underlying soils decreases relative to the time the fill was initially placed.

Elastic settlement will occur during placement of dredged fill material and is expected to be approximately 20% of the primary consolidation settlement of the foundation material under the initial fill load. The total settlement will be the consolidation settlement plus the elastic settlement. However, the elastic settlement will not be recognized because it will be immediately offset during construction as more material is placed. The main influence of elastic settlement will be to increase fill quantity estimates.

The sum of the dredge fill settlement and the underlying soil settlement was used to determine the total settlement that will be realized at the surface of the dredge fill area after filling is complete. Figures F-1 through F-3 in Appendix F provide both graphical and tabular summaries of marsh elevation versus time for a 20-year period for varying initial marsh fill elevations based on the combined settlement of the dredged fill and underlying soil. In Table 3 below, the estimated elastic settlement for each marsh fill scenario is provided. Elastic construction settlement should be added to the total dredged fill thickness for purposes of quantity estimates.

TABLE 3. ELASTIC CONSTRUCTION SETTLEMENT OF FOUNDATION SOILS IN MARSH FILL AREA

Boring ID	Initial Marsh Fill Elevation (Feet NAVD 88)					
	2.0	2.5	3.0	3.5	4.0	4.5
Estimated Elastic Construction Settlement (inches)						
BHMC-1	5	5	5	6	6	6
BHMC-2	4	5	5	5	5	5
BHMC-3	5	5	6	6	6	7

GeoEngineers approached marsh fill settlement a little differently for this project than for the BS-16 project. The key difference in how GeoEngineers estimated the settlement for this report is that we tried to account for the settlement occurring within the hydraulic fill during the construction period (60 days) in the PSDDF model. To account for this scenario, we applied multiple lifts to the dredged fill during the 60 day construction period. Although the estimated initial unit weight of the slurry is approximately 75 pounds per cubic foot (pcf) based on self-weight consolidation test results, we assumed that the fill consolidates as construction happens. In other words, we assume that the dredged fill placed between 0 to 15 days is more consolidated by end of construction (60 days) than that placed from 45 to 60 days. Unit weight was calculated using a specific gravity of 2.66 and from an average of void ratio values obtained from PSDDF for the combination of each fill lift at the end of 60 days. This unit weight was used to compute the load from the marsh fill at the end of construction and estimate the foundation settlement over time.

The graphs previously provided in the BS-16 report have been revised and will be provided as a separate attachment.

Containment Dike Slope Stability and Bearing Capacity

Slope Stability Along Shoreline

Slope stability analyses were performed for a containment dike constructed on an earthen embankment and an adjacent excavation access channel to determine the minimum required horizontal distance from the excavation access channel to the embankment, and verify side slope requirements.

Earthen embankment sections were analyzed with a 15-foot berm from the embankment toe to the excavation access channel cut slope (Figure 5). The excavation access channel was assumed to be excavated to El. -10.0 feet with a 3H:1V cut slope. The results of our analysis indicate that side slopes of 3H:1V for the embankment and the containment dike will provide a factor of safety greater than 1.2 for all sections on the east side of the marsh creation area along the shoreline. However, to maintain embankment stability with the containment dike placed on top, the containment dike will have to be placed at a minimum of 20 feet back from the marsh-side (west side) embankment slope crest as shown in Figure 5. Table 4 shows the factors of safety with and without the 20-foot set-back. Table 4 does not take reinforcement into consideration; however, it is understood that the BS-16 project is moving toward construction with the geotextile reinforcement to be installed under the earthen berm.

TABLE 4. SUMMARY OF EARTHEN EMBANKMENT AND CONTAINMENT DIKE STABILITY WITHOUT REINFORCEMENT

Boring ID	End of Construction Containment Dike Configuration				FOS without Reinforcement				Global Bearing FOS
	Crown Elevation (feet)	Crown Width (feet)	Side Slopes (H:V)	Bench Width (feet)	Condition 1	Condition 2	Condition 3	Appendix D Figure #	
BHMC-1	+6	5	3:1	0	3.79	-	0.90	-	-
BHMC-1	+6	5	3:1	20	3.79	1.73	1.32	D-14	1.56
BHMC-2	+6	5	3:1	0	2.30	-	1.09	-	-
BHMC-2	+6	5	3:1	20	2.29	1.87	1.54	D-15	1.67
BHMC-3	+6	5	3:1	0	3.92	-	0.95	-	-
BHMC-3	+6	5	3:1	20	3.89	2.00	1.49	D-16	1.44

Condition 1 – Embankment to Excavation

Condition 2 – Dike to Excavation

Condition 3 – Dike to Marsh

If geotextile reinforcement with a tensile strength at 5% strain of 250 pounds per inch or more is used, the containment dike will be stable without the 20 feet set-back (Figure 5). The geotextile must be placed so that the tensile strength is aligned perpendicular to the embankment alignment (i.e. shoreline). Seams perpendicular to the embankment should be avoided or sewn in a manner that maintains strength.

TABLE 5. SUMMARY OF EARTHEN EMBANKMENT AND CONTAINMENT DIKE STABILITY WITH REINFORCEMENT

Boring Id.	End of Construction Containment Dike Configuration				FOS with Reinforcement				Global Bearing FOS
	Crown Elevation (feet)	Crown Width (feet)	Side Slopes (H:V)	Berm Width (feet)	Condition			Appendix D Figure #	
					1	2	3		
BHMC-1	+6	5	3:1	0	4.48	1.92	1.40	D-17	2.77
BHMC-2	+6	5	3:1	0	2.71	2.50	1.25	D-18	2.90
BHMC-3	+6	5	3:1	0	4.53	2.37	1.28	D-19	2.54

Condition 1 – Embankment to Excavation

Condition 2 – Dike to Excavation

Condition 3 – Dike to Marsh

Slope Stability Interior Marsh

Containment dike stability was evaluated for locations along the interior marsh with and without a geotextile based on single-lift construction. Evaluations show that containment dikes constructed without a geotextile to El. +5 feet at BHMC-1-30 and El. +5.5 feet at BHMC-2-30 and BHMC-3-30 with 5H:1V slopes have a stability factor of safety more than 1.2. The excavation access channel was assumed to be excavated to El. -10.0 feet with a 3H:1V cut slope. A 25-foot berm between the toe of the containment dike and the excavation channel cut slope was considered for the evaluations. The stability evaluations take in to account a 260 psf load from a typical marsh buggy excavator for construction of the dikes.

GeoEngineers also reviewed interior marsh containment dike stability with regard to the BS-16 project, even though it was not specifically part of this scope of services. Specifically, soil borings BHMC-16-30 and BHMC-18-30 from the BS-16 project indicated significantly weaker existing soil profiles than BHMC-1 through BHMC-3 for this BS-24 project, but they are all in the same general vicinity where interior marsh containment dikes may be constructed. These two BS-16 borings do not have the same factors of safety as the BS-24 soil borings, and will require staged construction to achieve the same containment dike geometry and elevation (El. +5 ft to El +5.5 ft with 5H:1V side slopes). Given the potential for variability between soil boring locations, as supported by these two BS-16 soil borings, GeoEngineers recommends staged construction for all dikes and terraces. The first lift should be constructed to the full base width of the completed dike, to El. +2.5 ft, and allowed to sit for a minimum of 60 days prior to placing the next lift.

TABLE 6. SUMMARY OF CONTAINMENT DIKE STABILITY WITHOUT REINFORCEMENT

Boring Id.	End of Construction Containment Dike Configuration				FOS without Reinforcement				Global Bearing FOS
	Crown Elevation (feet)	Crown Width (feet)	Side Slopes (H:V)	Berm Width (feet)	Condition			Appendix D Figure #	
					1	2	3		
BHMC-1	+5	5	5:1	25	1.60	1.72	1.33	D-20	1.83
BHMC-2	+5.5	5	5:1	25	1.89	1.64	1.41	D-21	1.73
BHMC-3	+5.5	5	5:1	25	1.85	1.72	1.26	D-22	1.53

Condition 1 – Marsh to Excavation

Condition 2 – Dike to Excavation

Condition 3 – Dike to Marsh

When geotextile reinforcement was provided, containment dikes constructed to El. +6 feet with 3H:1V side slopes had a factor of safety above 1.2. As with the unreinforced option a 25-foot berm and marsh buggy load to 260 psf were included where appropriate.

TABLE 7. SUMMARY OF CONTAINMENT DIKE STABILITY WITH REINFORCEMENT

Boring Id.	End of Construction Containment Dike Configuration				FOS with Reinforcement				Global Bearing FOS
	Crown Elevation (feet)	Crown Width (feet)	Side Slopes (H:V)	Berm Width (feet)	Condition			Appendix D Figure #	
					1	2	3		
BHMC-1	+6	5	3:1	25	1.58	1.46	1.40	D-23	2.78
BHMC-2	+6	5	3:1	25	1.96	1.62	1.27	D-24	2.90
BHMC-3	+6	5	3:1	25	1.88	1.83	1.28	D-25	2.56

Condition 1 – Marsh to Excavation

Condition 2 – Dike to Excavation

Condition 3 – Dike to Marsh

Sliding

GeoEngineers evaluated the factor of safety for containment dike sections shown in Figure 5 for sliding. The critical period when sliding failure might occur for the containment dikes is when the dikes are at an elevation of +5 feet (includes 1-foot containment dike settlement before marsh fill is placed) and marsh fill is at an elevation of +5 feet (assume an extreme rain event). The evaluation did not include any reinforcement for the containment dikes. The results indicate that the containment dikes will have a minimum factor of safety of 1.5 as seen in the table below:

TABLE 8. SUMMARY OF CONTAINMENT DIKE STABILITY IN SLIDING

Boring Id.	Containment Dike Crown and Bottom Elevation			Marsh Fill Elevation (feet)	FOS Sliding	
	Crown Elevation (feet)	Bottom Elevation Along Shoreline (feet)	Bottom Elevation Interior Marsh (feet)		Along Shoreline	Interior Marsh
BHMC-1	+5	+1.5	-0.96	+5	>1.5	>1.5
BHMC-2	+5	+1.5	-1.76	+5	>1.5	>1.5
BHMC-3	+5	+1.5	-1.26	+5	>1.5	>1.5

Settlement

GeoEngineers performed settlement analyses for the earthen embankment/containment dike sections along shoreline and containment dikes in the interior marsh based on Terzaghi's one-dimensional linear consolidation. Settlement parameters were developed using consolidation test results. Published correlations and correlations based on test data from this project and similar projects were used to develop settlement parameters for soil without a consolidation test.

In addition to consolidation settlement, the foundation soil will undergo elastic settlement. Estimates of elastic settlement, which occur during earth fill placement for the containment dike, are about 20% of the long-term consolidation settlement. The elastic settlement for each boring performed in the marsh creation area is shown in Tables 9 and 10. The total settlement will be the consolidation settlement plus the construction (immediate elastic) settlement. However, the construction settlement will not be recognized because more earthen fill will be placed to achieve the required end-of-construction elevation during construction.

All settlements were based on the appropriate geometry for a containment dike with earthen fill varying from El. +5 to +6 feet. Tables 9 through 12 provide a summary of settlement estimates for both construction activities and consolidation settlement. Time rate of settlement versus elevation over a 20-year period is shown for each marsh creation area soil boring in Figures E-14a to E-14d through E-17a to E-17d in Appendix E.

Containment dikes are typically maintained and hydraulic fill is likely to be placed within the dikes soon after dike construction; therefore, we have not included shrinkage in our estimates. However, if NRCS would like to include a shrinkage allowance, 10% to 20% of the dike fill height above water may be used, similar to the method used to estimate shrinkage for the terraces. A reduced percentage, such as 10%, may be appropriate, if the dikes will only be exposed to drying without hydraulic fill for a short period of time, and a larger number may be appropriate for a longer wait between dike construction and hydraulic fill placement.

TABLE 9. EARTHEN EMBANKMENT/CONTAINMENT DIKE SETTLEMENT ESTIMATES ALONG SHORELINE WITHOUT REINFORCEMENT

Boring ID.	Crown Elevation[2] (feet)	Estimated Construction Settlement[1] (inches)	Estimated Settlement (inches)				
			Foundation Soil Consolidation Settlement				
			6 months	1 Year	3 Years	10 Years	Long-term (20 Years)
BHMC-1	+6	3	13	14	15	15	15
BHMC-2	+6	2	7	8	8	8	8
BHMC-3	+6	3	12	12	13	14	15

(1) Estimated construction settlement is not included in the estimated consolidation settlement.

(2) Crown elevation at the end of construction of containment dike.

TABLE 10. EARTHEN EMBANKMENT/CONTAINMENT DIKE SETTLEMENT ESTIMATES ALONG SHORELINE WITH REINFORCEMENT

Boring ID.	Crown Elevation[2] (feet)	Estimated Construction Settlement[1] (inches))	Estimated Settlement (inches)				
			Foundation Soil Consolidation Settlement				
			6 months	1 Year	3 Years	10 Years	Long-term (20 Years)
BHMC-1	+6	3	13	14	16	16	16
BHMC-2	+6	2	8	9	10	10	10
BHMC-3	+6	3	12	13	14	15	15

(1) Estimated construction settlement is not included in the estimated consolidation settlement.

(2) Crown elevation at end of construction of containment dike.

TABLE 11. CONTAINMENT DIKE SETTLEMENT ESTIMATES INTERIOR MARSH WITHOUT REINFORCEMENT

Boring ID.	Crown Elevation[2] (feet)	Estimated Construction Settlement[1] (inches)	Estimated Settlement (inches)				
			Foundation Soil Consolidation Settlement				
			6 months	1 Year	3 Years	10 Years	Long-term (20 Years)
BHMC-1	+5	3	13	14	15	16	16
BHMC-2	+5.5	2	7	7	8	8	8
BHMC-3	+5.5	3	12	13	15	16	16

(1) Estimated construction settlement is not included in the estimated consolidation settlement.

(2) Crown elevation at end of construction of containment dike.

TABLE 12. CONTAINMENT DIKE SETTLEMENT ESTIMATES INTERIOR MARSH WITH REINFORCEMENT

Boring ID.	Crown Elevation[2] (feet)	Estimated Construction Settlement[1] (inches)	Estimated Settlement (inches)				
			Foundation Soil Consolidation Settlement				
			6 months	1 Year	3 Years	10 Years	Long-term (20 Years)
BHMC-1	+6	3	13	14	16	16	16
BHMC-2	+6	1	6	7	7	7	7
BHMC-3	+6	3	12	13	14	15	15

(1) Estimated construction settlement is not included in the estimated consolidation settlement.

(2) Crown elevation at end of construction of containment dike.

Hydraulic Dredging Cut to Fill Ratio

The cut to fill ratio evaluation was based on index properties, self-weight consolidation and settling column test results from BS-16 project which are included in Appendix G. Based on these values, and an assumed construction period longer than 60 days, we calculated a cut to fill ratio equal to about 0.7 using the methodology presented in Appendix G. In other words, for every 1.4 cubic yards (CY) placed in the marsh site, 1 CY will be cut from the dredging areas; however, please consider our observations in the next paragraph for quantity estimates. These calculations are applicable only to hydraulically filled marsh creation areas; mechanically dredged areas will be different.

It must be understood that these cut to fill ratios calculated in Appendix G are not the same as the ratio of as-constructed in-place cut volume to in-place fill volume ratio that has been observed for completed coastal restoration projects in South Louisiana. Typically, it takes approximately 1.3 to 1.5 CY of in-place hydraulically removed borrow material to fill 1.0 CY in the placement area. This number can vary significantly depending upon the material being dredged, placement area size, containment, pumping rates and other factors. Typically coarser fill materials (sands) placed in larger fill areas with good containment require less cut to fill the desired area.

CONSTRUCTION CONSIDERATIONS

Based on the site work and evaluations completed for this project, the following are offered with respect to construction.

- Based on our stability evaluations, two-lift construction is recommended for unreinforced earthen terraces and interior containment dikes. The first lift should be constructed to El +2.5 feet over the full width of the final design terrace or dike section. Construction should be planned so that the time gap between the end of first lift and the start of second lift is at least 60 days. This will allow the soil to consolidate and gain strength after which the additional fill can be placed. We expect the second lift will be able to be placed to the full design elevation; however, if stability problems are encountered, an intermediate second lift may be required, followed by a third lift.
- For construction of the earthen terrace and containment dikes in the interior marsh, a minimum of 25 feet bench must be provided between the toe of the dike and the excavation cut slope. Marsh buggy excavators used to construct the earthen terrace and containment dikes must stay at least 5 feet away from the edge of the excavation cut slope. To maintain excavation overall embankment stability, we recommend that the marsh buggies remain as close to the dike toe as practical.

- The surficial soil at this site is predominantly peat and organic clay; both highly organic soil. These materials will be more difficult to use for construction purposes when compared to clay, silt, or sand; however, a pilot study with similar soil, completed by the NRCS suggest that these materials can be used successfully. The NRCS should be aware that contractors are likely to try to excavate clay from beneath these organic soils, which will require a different evaluation by GeoEngineers to correctly model deeper excavations and heavier fill materials for dikes and terraces. Heavier fill is also likely to settle more, and cause more displacement of shallow organic material (i.e. mud waves).
- Water levels can significantly affect construction and dike/terrace stability. High water levels may increase erosion, while low water levels reduce fill buoyancy and can cause failures.
- GeoEngineers does not have any pipeline maps for the region, but based on the site visit on April 23, 2014 with the NRCS representatives, we spotted pipeline markers in the project vicinity. Precautions must be taken to prevent pipeline damage during construction.
- There are property owner restrictions on the type of equipment that can access the site. Contractors may need to take extra precaution while performing the work to reduce impacts to local wildlife.

LIMITATIONS

We have prepared this report for the exclusive use of the USDA-NRCS in support of design of the proposed BS-24 Terracing and Marsh Creation South of Big Mar located in Plaquemines Parish, Louisiana.

Within the limitations of scope, schedule and budget, our services have been executed in accordance with generally accepted practices in the field of geotechnical engineering in this area at the time this report was prepared. No warranty or other conditions, expressed or implied, should be understood.

Please refer to Appendix H titled "Report Limitations and Guidelines for Use" for additional information pertaining to use of this report.

FIGURES

GeoEngineers

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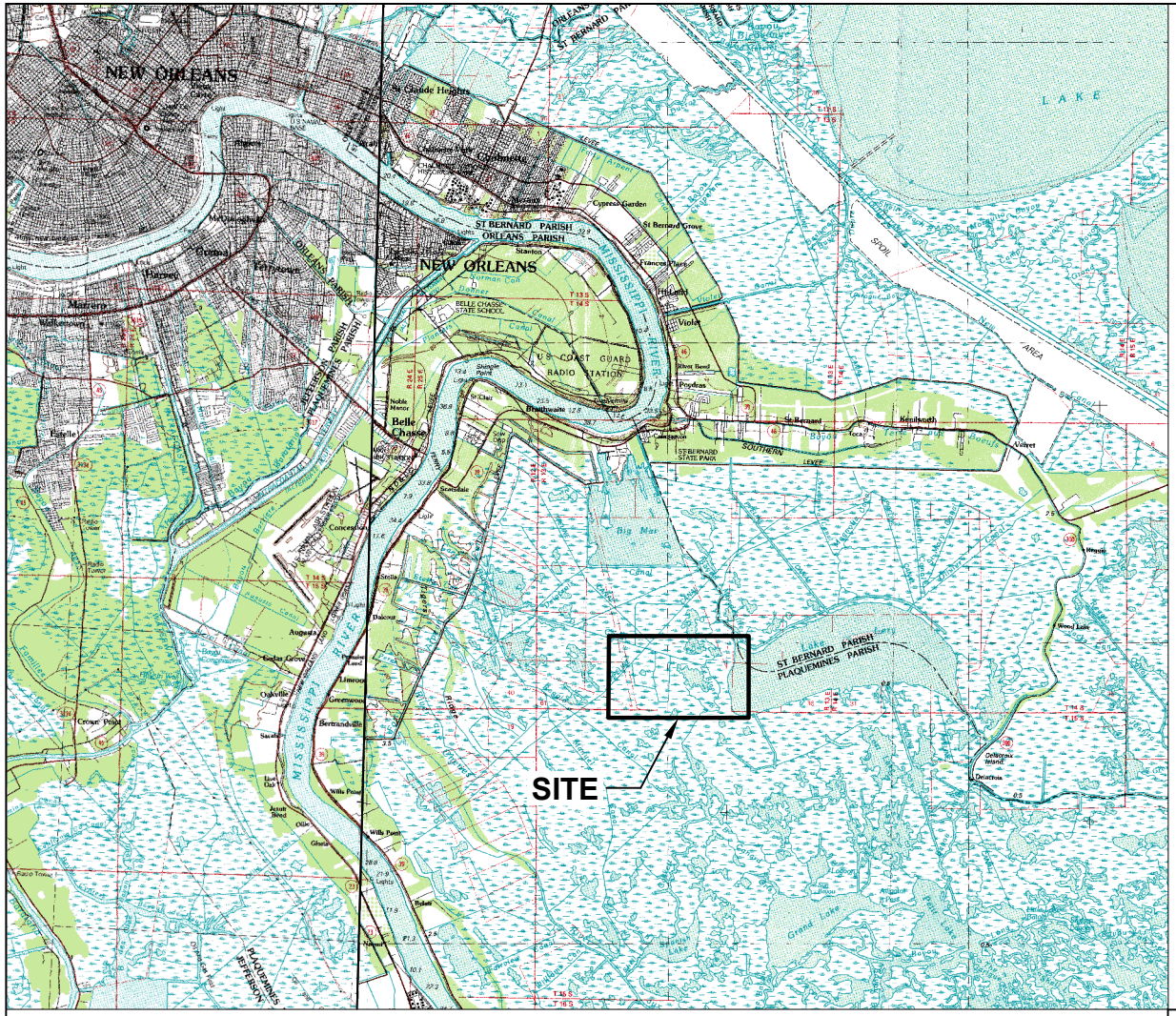
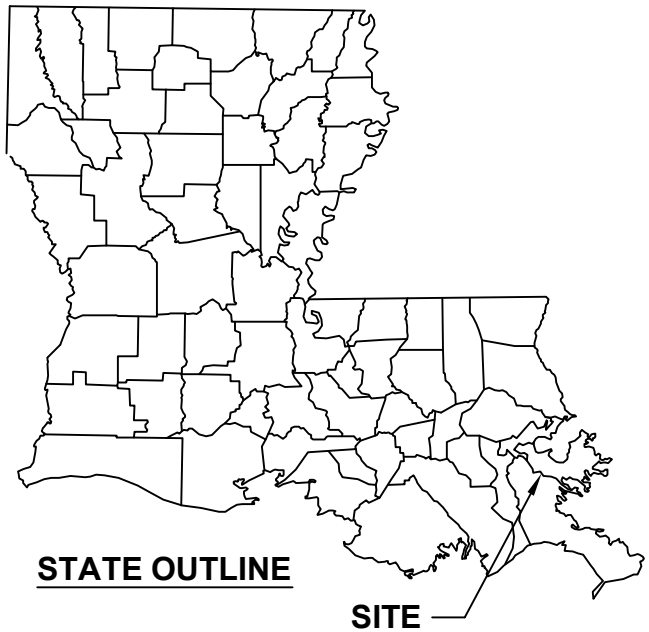
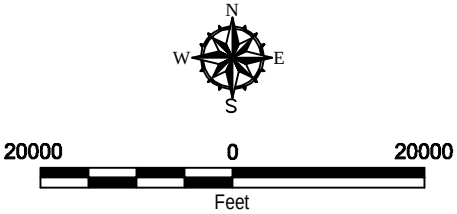
VT：KMC







Notes:
1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. can not guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

Reference: Topographic image taken from USGS, DRG-100k Template, Quad Black Bay & Gulfport, Dated 9/22/2005

VICINITY MAP

NRCS - BS-24 Terracing and Marsh Creation
South of Big Mar
Plaquemines Parish, Louisiana

GEOENGINEERS

Figure 1

DPS : KMC

BOREHOLE DETAILS			
BORING #	LATITUDE	LONGITUDE	DEPTH (FT)
BHMC-01-30	N29° 48' 06.61"	W89° 52' 51.44"	30'
BHMC-02-30	N29° 47' 46.78"	W89° 52' 55.77"	30'
BHMC-03-30	N29° 47' 11.82"	W89° 52' 52.62"	30'
BHT-01-30	N29° 48' 46.28"	W89° 55' 01.54"	30'
BHT-02-30	N29° 48' 26.48"	W89° 54' 51.56"	30'
BHT-03-30	N29° 48' 36.36"	W89° 54' 13.85"	30'
BHT-04-30	N29° 48' 25.79"	W89° 53' 57.71"	30'
BHT-05-30	N29° 47' 44.56"	W89° 55' 23.96"	30'
BHT-06-30	N29° 47' 37.72"	W89° 54' 51.97"	30'
BHT-07-30	N29° 47' 29.68"	W89° 54' 24.25"	30'
BHT-08-30	N29° 47' 37.51"	W89° 54' 00.58"	30'
BHT-09-30	N29° 47' 12.63"	W89° 54' 06.07"	30'
BHT-10-30	N29° 47' 16.70"	W89° 53' 32.55"	30'
BHT-11-30	N29° 47' 06.80"	W89° 54' 40.43"	30'
BHT-12-30	N29° 46' 53.98"	W89° 54' 16.43"	30'

LEGEND

BHT-01-30 — Approximate Soil Borehole Location

BHLR-01-50 — Approximate Location of Previously Completed Soil Boring for BS-16 Project

Access Route

Cross Section

N W E S

2000 0 2000
Feet

Notes:
1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. can not guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

Reference: Aerial image was taken from Google Earth Pro., Licensed to GeoEngineers Inc., Imagery dated: 3/5/2013

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SOIL BORING LOCATION PLAN

NRCS - BS-24 Terracing and Marsh Creation
South of Big Mar
Plaquemines Parish, Louisiana

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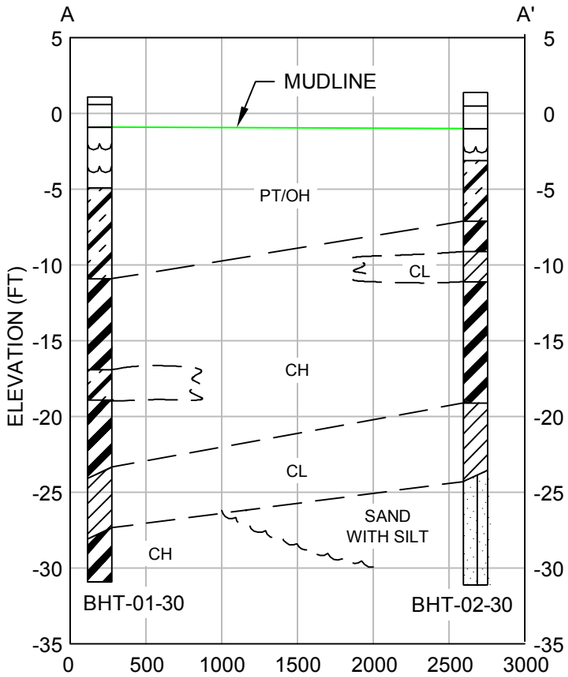
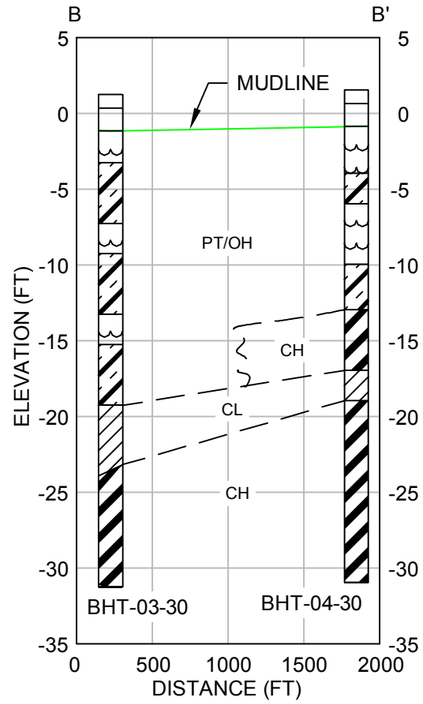
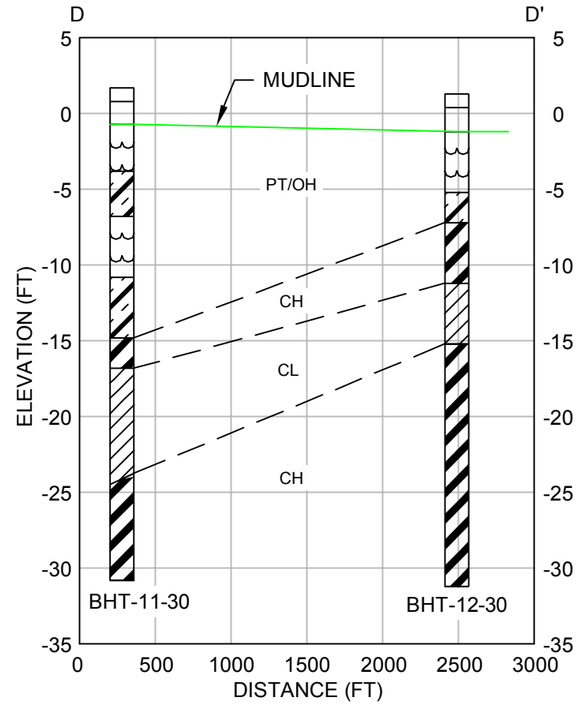
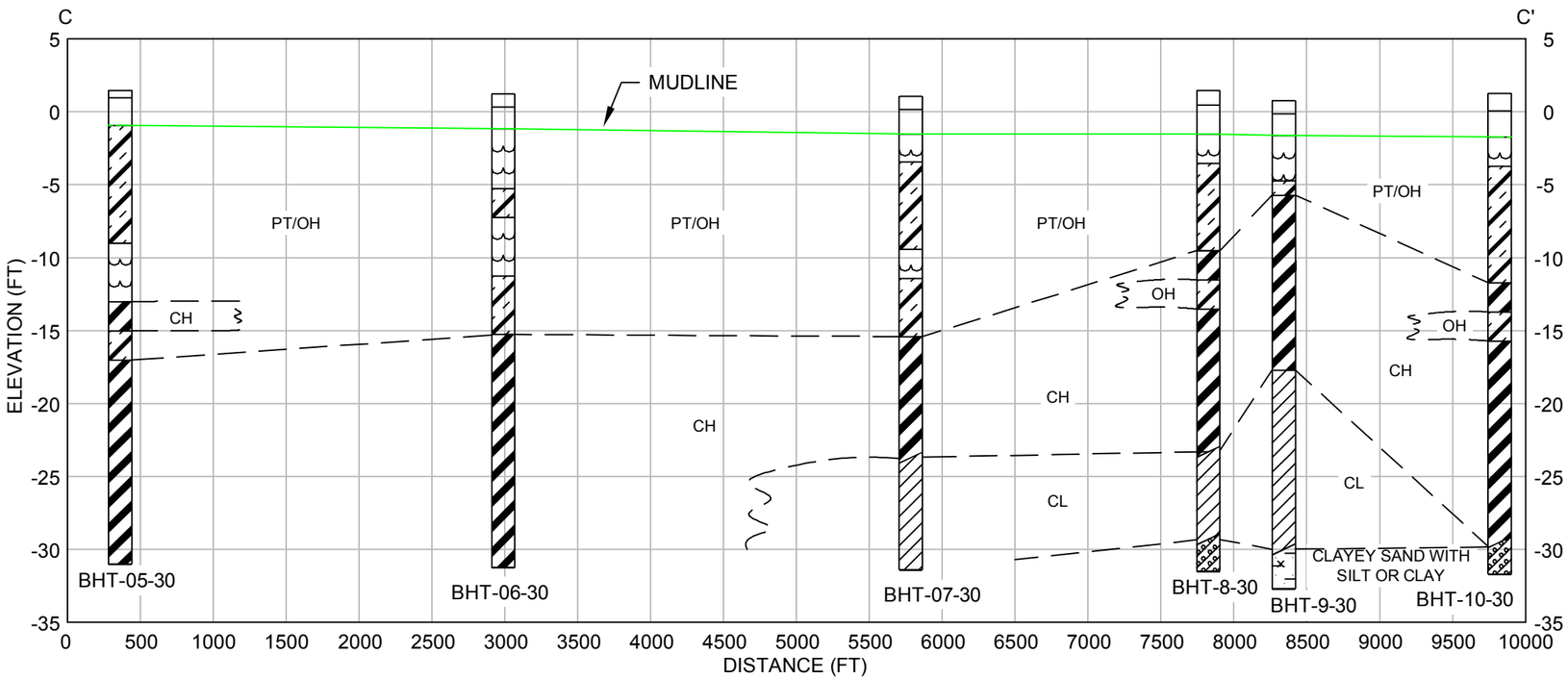
Figure 2









LEGEND

- SAND WITH SILT
- SILTY CLAY
- PEAT
- CLAY
- CLAYEY SAND
- ORGANIC CLAY
- CLAYEY SAND WITH SILT

Notes:
1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. can not guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

TERRACE SUBSURFACE PROFILES
A-A', B-B', C-C' AND D-D'

NRCS - BS-24 Terracing and Marsh Creation
Plaquemines Parish, Louisiana

GEOENGINEERS

Figure 3A

DPS : KMC

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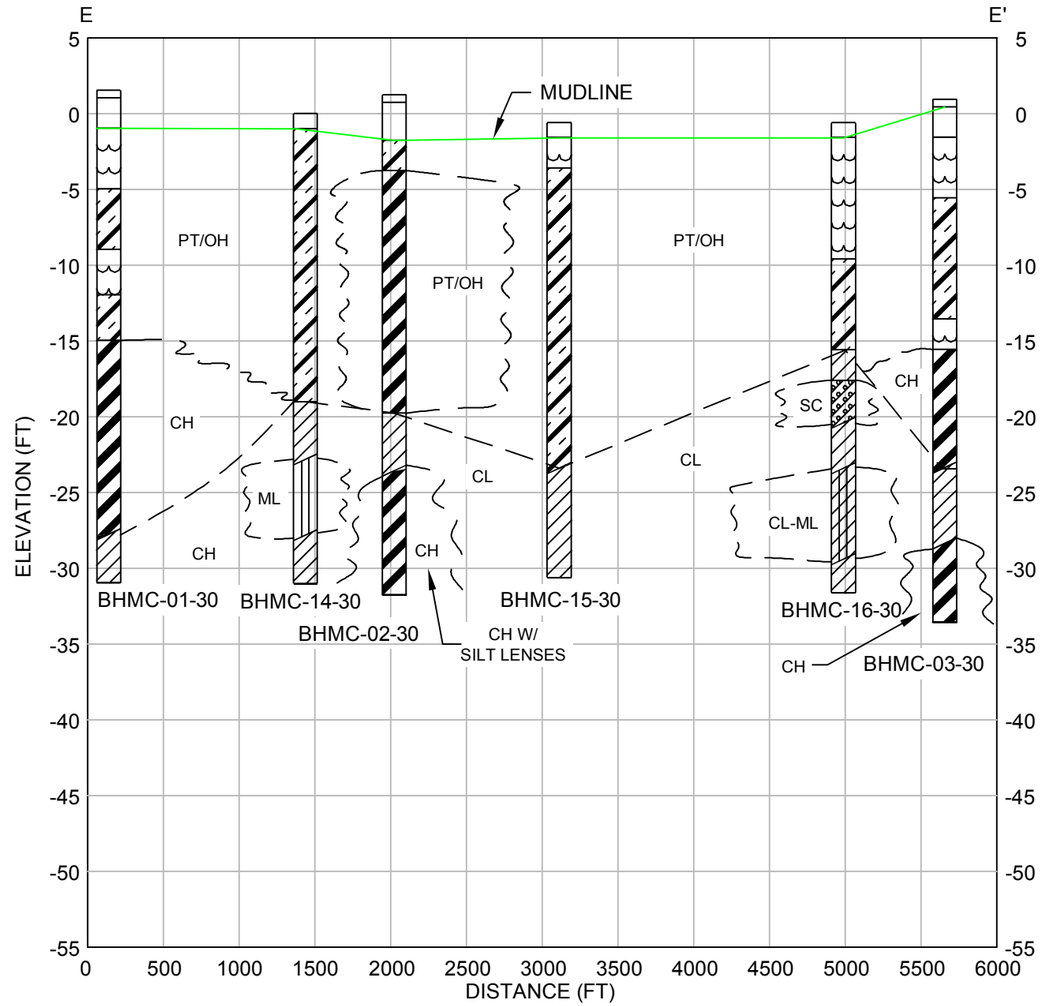
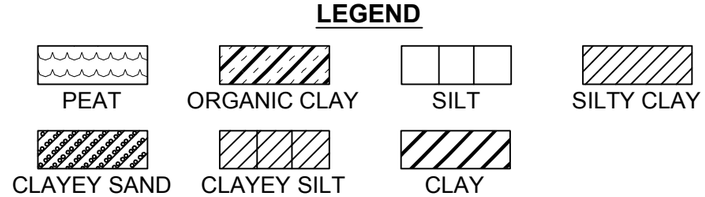


NOTES:

1. BHMC-1-30, BHMC-2-30, BHMC-3-30 CURRENT PROJECT
2. BHMC-14-30, BHMC-15-30, BHMC-16-30 CAERNARVON OUTFALL/LAKE LERY WEST SHORELINE RESTORATION PROJECT (BS-16).

LEGEND



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MARSH CREATION AREA
SUBSURFACE PROFILE E-E'

NRCS - BS-24 Terracing and Marsh Creation
Plaquemines Parish, Louisiana

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Figure 3B

DPS : KMC

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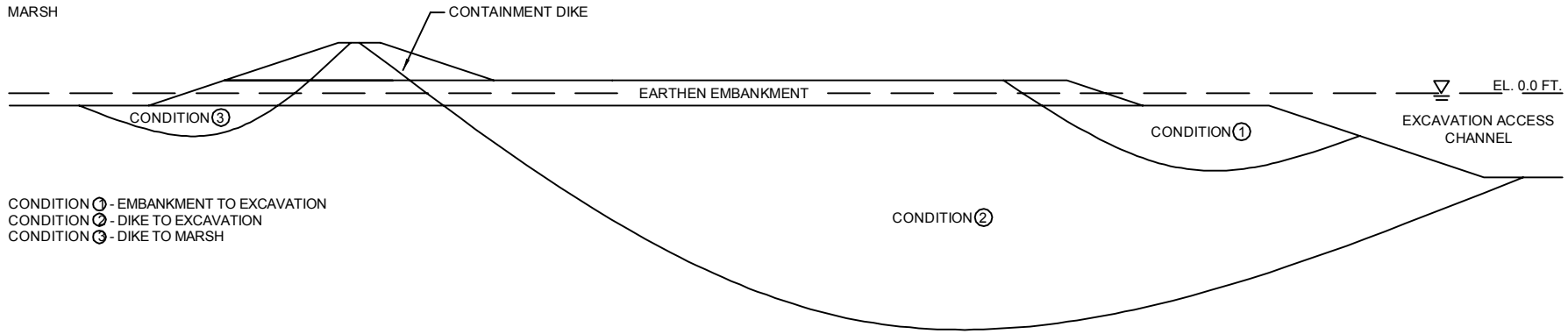
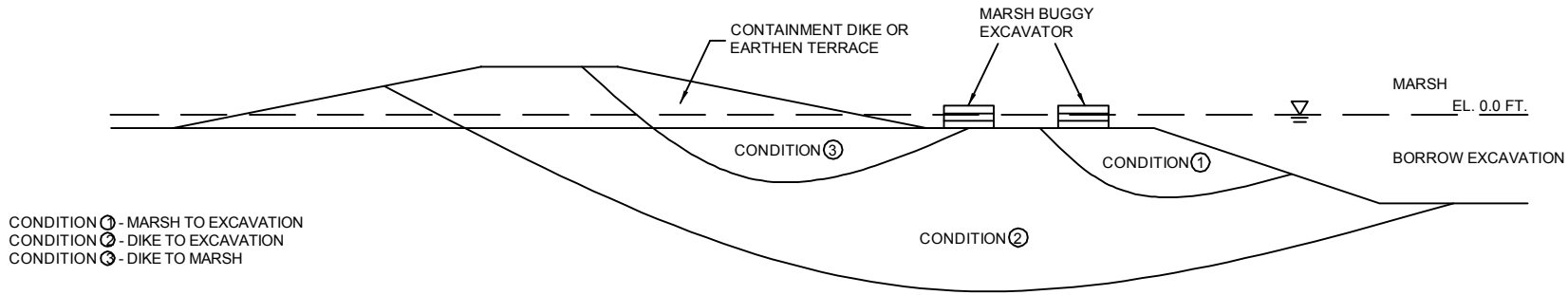
EARTHEN EMBANKMENT/CONTAINMENT DIKE ALONG SHORELINE



CONTAINMENT DIKE AND EARTHEN TERRACE INTERIOR MARSH



SCALE

20 0 20

Feet

Notes:
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2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. can not guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

EARTHEN EMBANKMENT/CONTAINMENT DIKE TERRACE SLOPE STABILITY CRITICAL FAILURE SURFACES

NRCS - BS-24 Terracing and Marsh Creation
South of Big Mar
Plaquemines Parish, Louisiana

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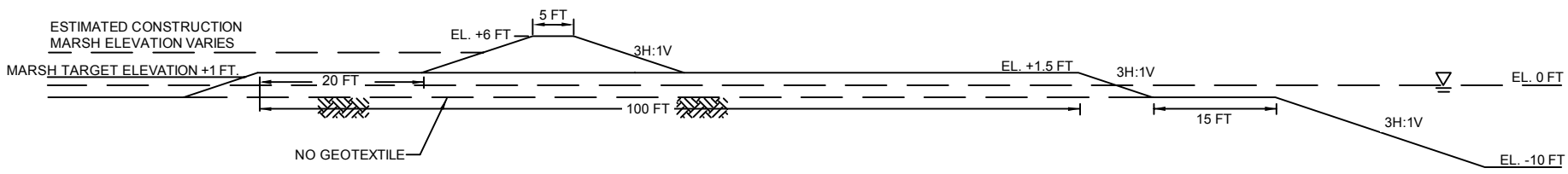
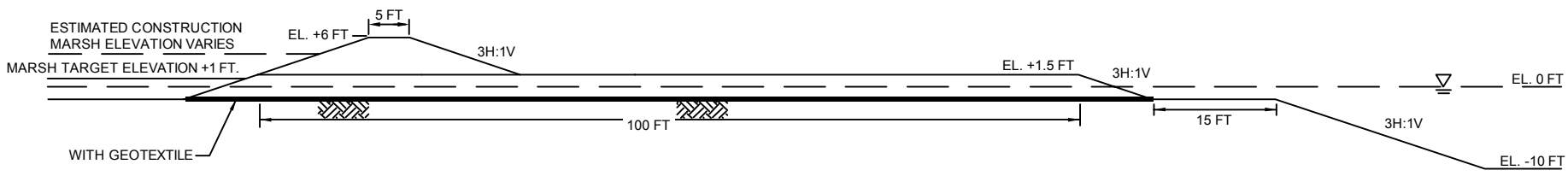
Figure 4

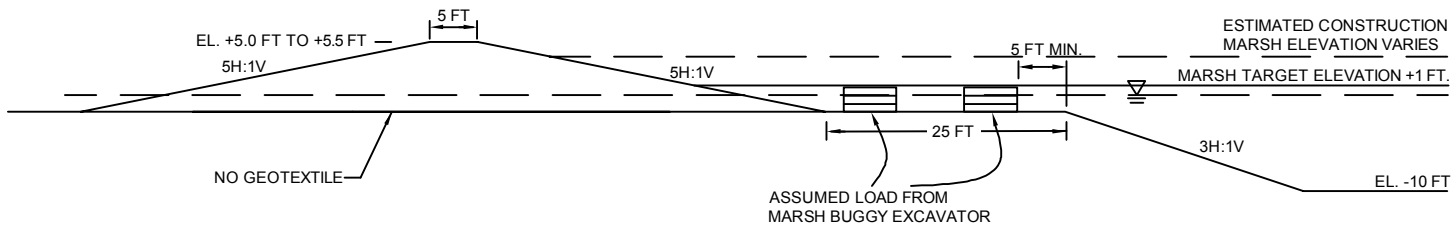
EARTHEN EMBANKMENT/CONTAINMENT DIKE ALONG SHORELINE WITHOUT REINFORCEMENT



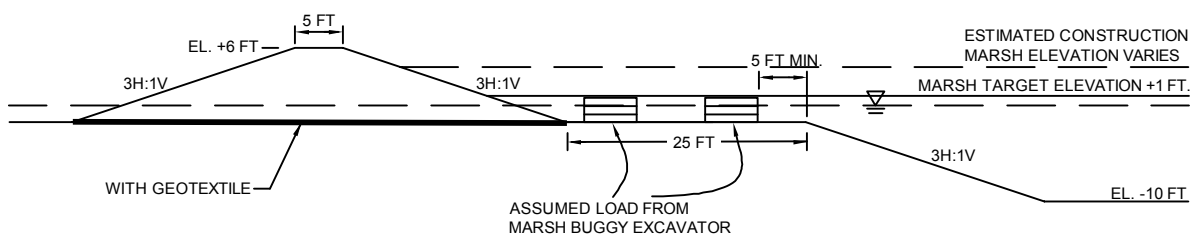
EARTHEN EMBANKMENT/CONTAINMENT DIKE ALONG SHORELINE WITH REINFORCEMENT



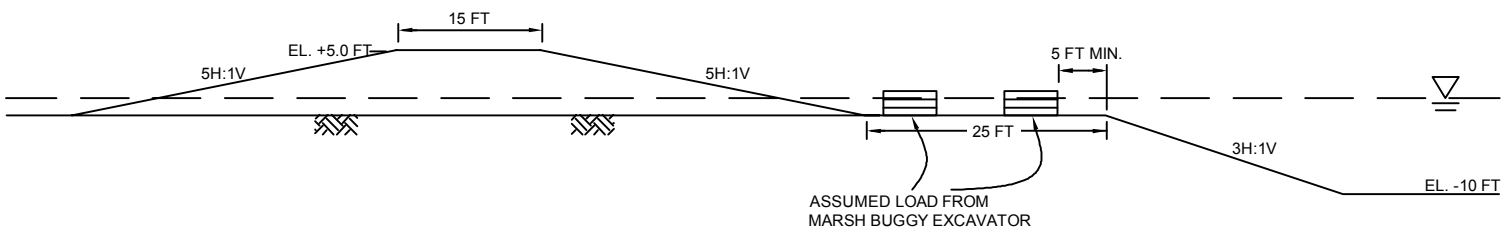
CONTAINMENT DIKE INTERIOR MARSH WITHOUT REINFORCEMENT



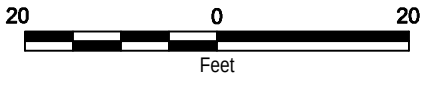
CONTAINMENT DIKE INTERIOR MARSH WITH REINFORCEMENT



EARTHEN TERRACE



SCALE



Notes:
1. Crown elevations provided are for maximum construction elevations.
2. The locations of all features shown are approximate.
3. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. can not guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

EARTHEN EMBANKMENT/CONTAINMENT DIKE AND EARTHEN TERRACE DETAILS

NRCS - BS-24 Terracing and Marsh Creation
South of Big Mar
Plaquemines Parish, Louisiana

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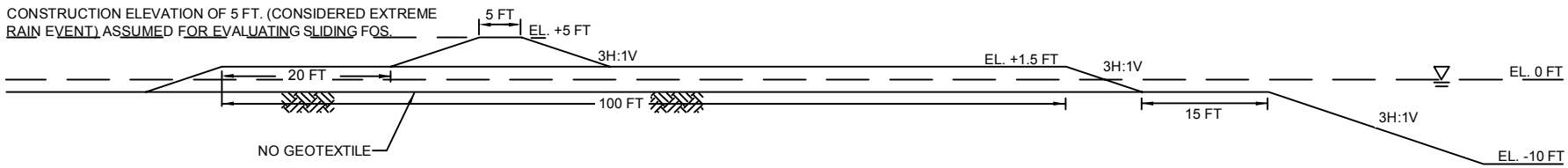
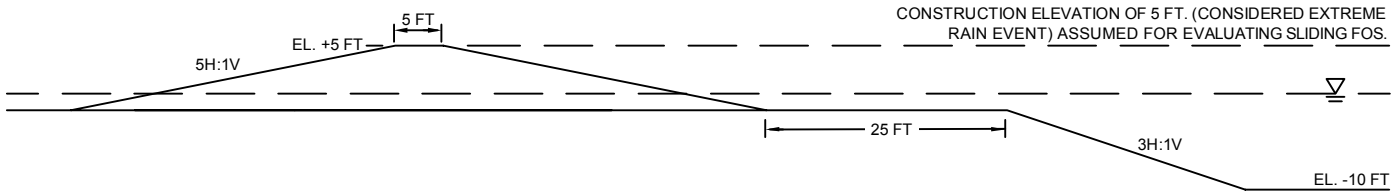
Figure 5

EARTHEN EMBANKMENT/CONTAINMENT DIKE ALONG SHORELINE WITHOUT REINFORCEMENT



CONTAINMENT DIKE INTERIOR MARSH WITHOUT REINFORCEMENT



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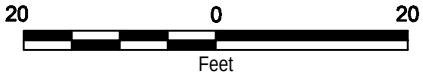

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EARTHEN EMBANKMENT/CONTAINMENT DIKE DETAILS FOR SLIDING FACTOR OF SAFETY

NRCS - BS-24 Terracing and Marsh Creation
South of Big Mar
Plaquemines Parish, Louisiana

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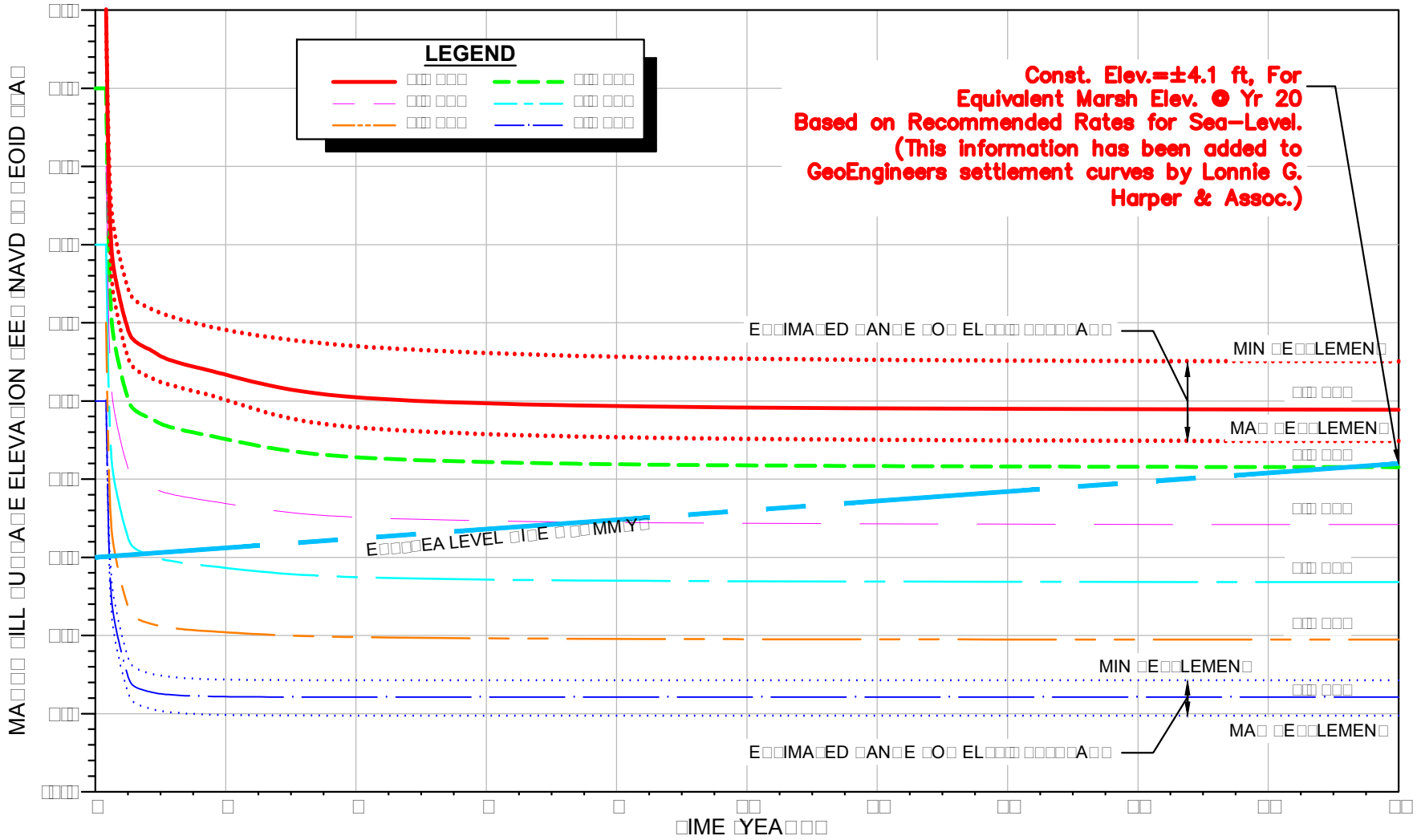
Figure 6

APPENDICES

GeoEngineers



MA ILL U A E ELEVA ION EE							
ON U ION DAY	DAY	DAY	YEA	YEA	YEA	YEA	YEA

SETTLEMENT VS. TIME
AVERAGE FOR ALL MARSH SOIL BORINGS

N B rr d M r r
r L

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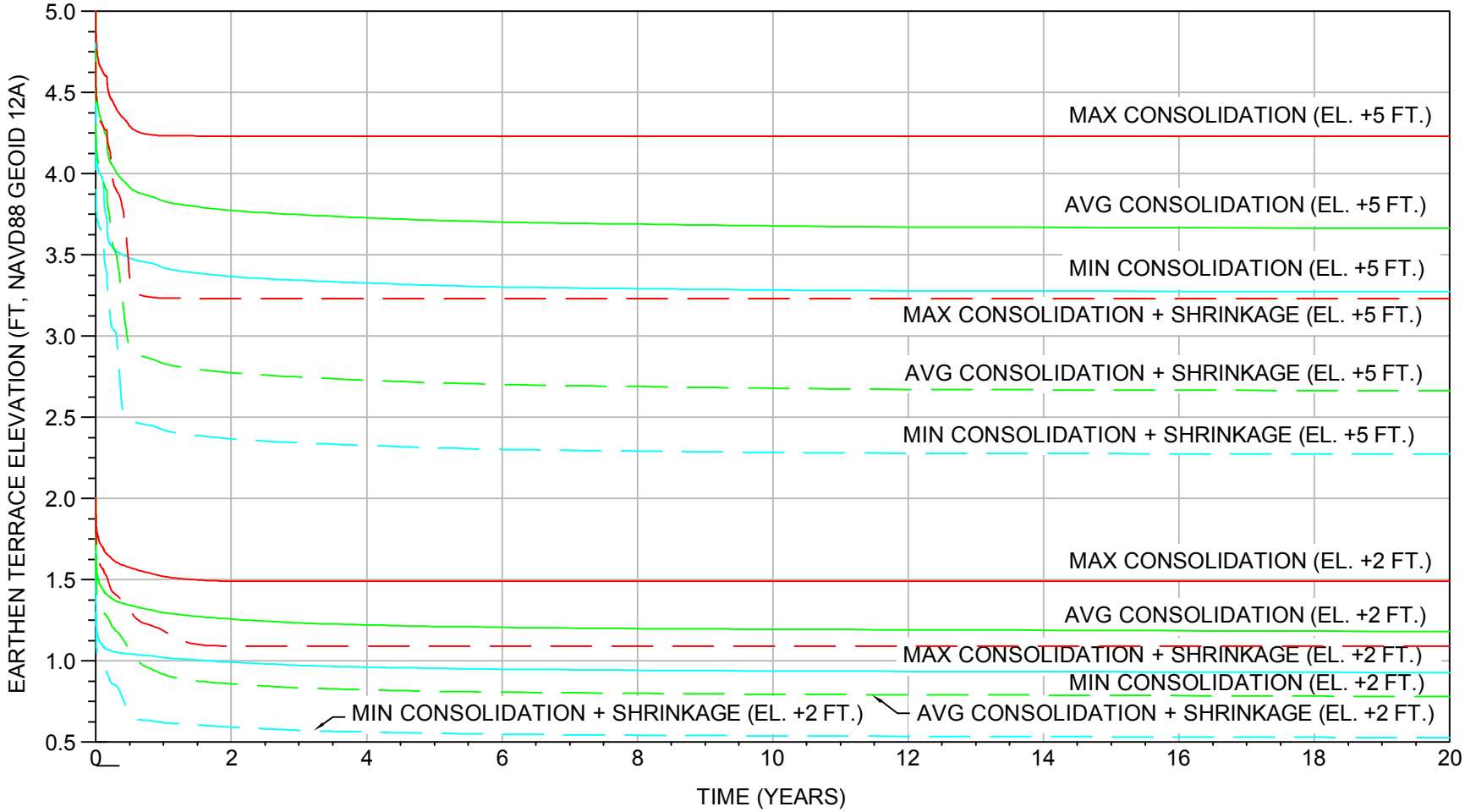
Figure F-1



EARTHEN TERRACE ELEVATION (FEET NAVD88) CONSOLIDATION (CONSOLIDATION + SHRINKAGE)						
0 DAYS	6 MONTHS	1 YEAR	3 YEAR	5 YEAR	10 YEAR	LONG TERM
2.0 MAX	1.6 (1.3)	1.5 (1.2)	1.5 (1.1)	1.5 (1.1)	1.5 (1.1)	1.5 (1.1)
2.0 AVG	1.3 (1.1)	1.3 (0.9)	1.2 (0.8)	1.2 (0.8)	1.2 (0.8)	1.2 (0.8)
2.0 MIN	1.0 (0.6)	1.0 (0.6)	1.0 (0.6)	1.0 (0.6)	0.9 (0.5)	0.9 (0.5)
5.0 MAX	4.3 (3.3)	4.2 (3.2)	4.2 (3.2)	4.2 (3.2)	4.2 (3.2)	4.2 (3.2)
5.0 AVG	3.9 (2.9)	3.8 (2.8)	3.8 (2.8)	3.7 (2.7)	3.7 (2.7)	3.7 (2.7)
5.0 MIN	3.5 (2.5)	3.4 (2.4)	3.3 (2.3)	3.3 (2.3)	3.3 (2.3)	3.3 (2.3)

SETTLEMENT VS. TIME
AVERAGE FOR ALL
EARTHEN TERRACE SOIL BORINGS

NRCS - BS-24 Terracing and Marsh Creation
South of Big Mar
Plaquemines Parish, Louisiana

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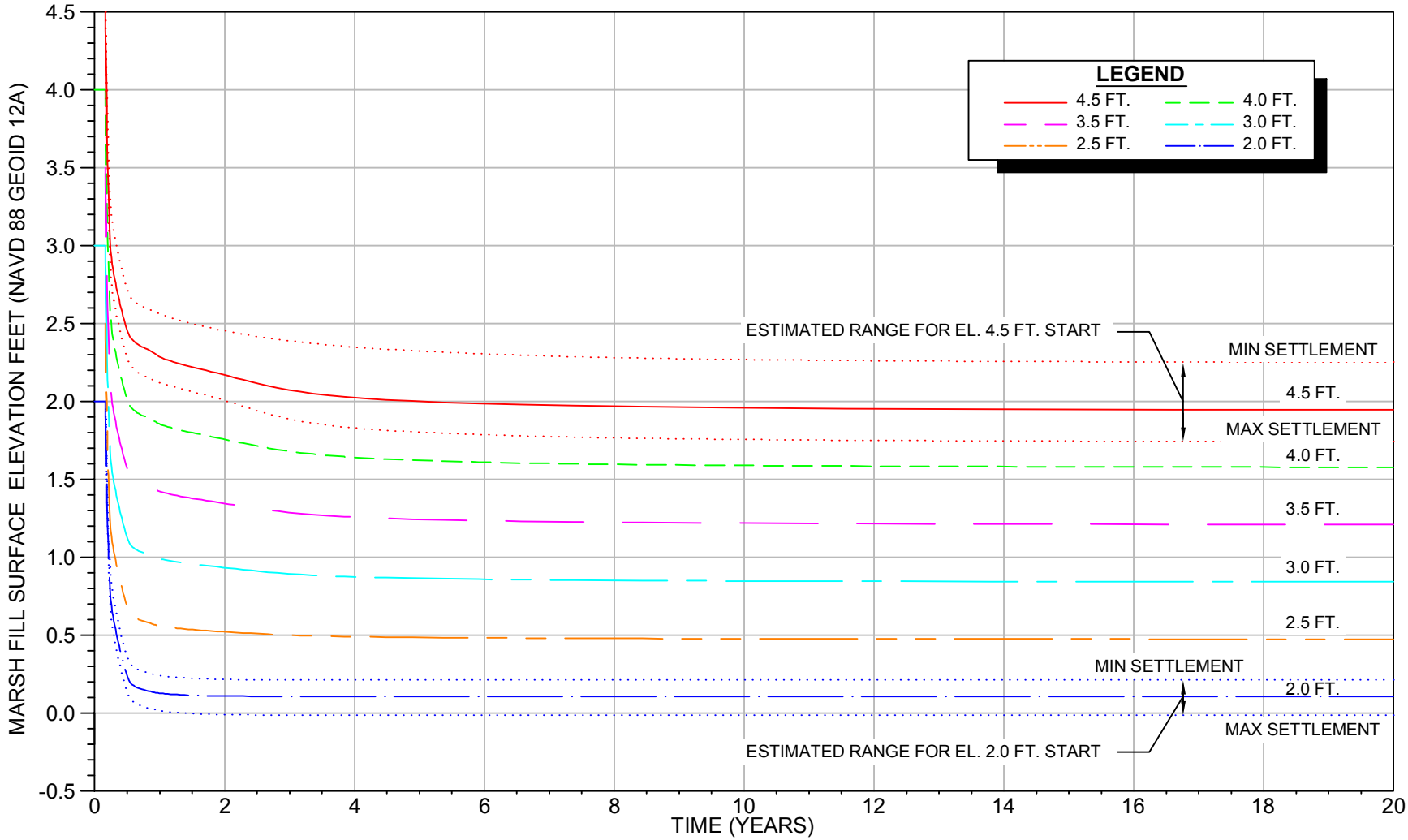
Figure E-1



MARSH FILL SURFACE ELEVATION (FEET)							
CONSTRUCTION 0 - 60 DAYS	75 DAYS	180 DAYS	1 YEAR	3 YEAR	5 YEAR	10 YEAR	20 YEAR
4.5	3.04	2.47	2.28	2.05	1.98	1.95	1.94
4.0	2.59	2.02	1.85	1.66	1.61	1.58	1.58
3.5	2.15	1.58	1.42	1.27	1.23	1.21	1.21
3.0	1.70	1.14	0.99	0.88	0.86	0.84	0.84
2.5	1.25	0.69	0.56	0.50	0.48	0.47	0.47
2.0	0.81	0.25	0.13	0.11	0.11	0.11	0.11

SETTLEMENT VS. TIME
AVERAGE FOR ALL MARSH SOIL BORINGS

NRCS - BS-24 Terracing and Marsh Creation
Plaquemines Parish, Louisiana

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Figure F-1

APPENDIX G
Marsh Creation Fill to Cut Ratio

Calculation Checksheet

Project No. 10883-020-01 Project Title: BS-24 Terracing and Marsh Creation

Deliverable Title: Fill to Cut Ratio

Calculations Description: Estimated the fill to cut ratio based on empirical correlations provided in PSDDF manual, and ASCE journal March/April 2005 P. 56 and information provided for self-weight consolidation and settling column test results in BS-16 Lake Lery West Shoreline Protection project.

Originator: CLE Checked by: VT Date: July 29, 2014

Checking method (describe): Verified parameters and checked analyses

Comments: The fill to cut ratio evaluation was based on settling column and self-weight consolidation tests results, which are included in Appendix I-C, and design guidance in the United States Army Corps of Engineers (USACE) publication EM-1110-2-5027.

project Lake Lery W. Marsh Creation project no. 10883-007-01

by EE date 07/18/14 sheet 1 of 2 checked by VT

Fill to Cut Ratio

LL = 116 PL = 34 PI = 82

$e_{SL} = .0515\ PI + 1.26$ Journal ASCE MARCH/APRIL 2005 p. 56 for e_{SL} = saturation limit

$e_{SL} = .0515(82) + 1.26$

$e_{SL_1} = 5.483$

$e_{SL} = .056(PI) + 1.0$ PSDPF Manual p. 33 Eq. 4

$e_{SL} = .056(82) + 1.0$

$e_{SL_2} = 5.592$

$w_c = 119.04$ SG = 2.66

$e_i = \frac{w_c SG}{S_D}$ $S_D = 1.0$ for 100% saturation

$e_i = \frac{1.1904(2.66)}{1.0} = 3.166$

use* $e_o = e_{SL2} = 5.592$

use $V_i = 1.0$

$V_F = V_i\left[\frac{e_o - e_i}{1 + e_i} + 1\right]$

$V_F = 1.0\left[\frac{5.592 - 3.166}{6.592} + 1\right]$

$V_F = 1.36$

Fill to cut ratio = 1.37 Say 1.4

* Note: plot of previous data (22 comparisons) shows this relationship: $e_o \cong e_{SL}$

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APPENDIX H
Report Limitations and Guidelines for Use

APPENDIX H
REPORT LIMITATIONS AND GUIDELINES FOR USE

This appendix provides information to help you manage your risks with respect to the use of this report.

Geotechnical Services Are Performed for Specific Purposes, Persons and Projects

This report has been prepared for US Department of Agriculture/Natural Resources Conservation Service and their authorized agents and regulatory agencies. The information contained herein is not applicable to other sites.

GeoEngineers structures our services to meet the specific needs of our clients. No party other than US Department of Agriculture/Natural Resources Conservation Service may rely on the product of our services unless we agree to such reliance in advance and in writing. This is to provide our firm with reasonable protection against open-ended liability claims by third parties with whom there would otherwise be no contractual limits to their actions. Within the limitations of scope, schedule and budget, our services have been executed in accordance with our Agreement with the Client and generally accepted geotechnical practices in this area at the time this report was prepared. Use of this report is not recommended for any purpose or project except the one originally contemplated.

A Geotechnical Engineering or Geologic Report Is Based on a Unique Set of Project-Specific Factors

This report has been prepared for the BS-24 Terracing and Marsh Creation South of Big Mar project in Plaquemines Parish, Louisiana. GeoEngineers considered a number of unique, project-specific factors when establishing the scope of services for this project and report. Unless GeoEngineers specifically indicates otherwise, it is important not to rely on this report if it was:

- not prepared for you,
- not prepared for your project,
- not prepared for the specific site explored, or
- completed before important project changes were made.

For example, changes that can affect the applicability of this report include those that affect:

- the function of the proposed structure;
- elevation, configuration, location, orientation or weight of the proposed structure;
- composition of the design team; or
- project ownership.

If important changes are made after the date of this report, we recommend that GeoEngineers be given the opportunity to review our interpretations and recommendations. Based on that review, we can provide written modifications or confirmation, as appropriate.

Subsurface Conditions Can Change

This geotechnical or geologic report is based on conditions that existed at the time the study was performed. The findings and conclusions of this report may be affected by the passage of time, by man-made events such as construction on or adjacent to the site, or by natural events such as floods, earthquakes, slope instability or groundwater fluctuations. If more than a few months have passed since issuance of our report or work product, or if any of the described events may have occurred, please contact GeoEngineers before applying this report for its intended purpose so that we may evaluate whether changed conditions affect the continued reliability or applicability of our conclusions and recommendations.

Most Geotechnical and Geologic Findings Are Professional Opinions

Our interpretations of subsurface conditions are based on field observations from widely spaced sampling locations at the site. Site exploration identifies the specific subsurface conditions only at those points where subsurface tests are conducted or samples are taken. GeoEngineers reviewed field and laboratory data and then applied our professional judgment to render an informed opinion about subsurface conditions throughout the site. Actual subsurface conditions may differ, sometimes significantly, from those indicated in this report. Our report, conclusions and interpretations should not be construed as a warranty of the subsurface conditions.

Geotechnical Engineering Report Recommendations Are Not Final

The construction recommendations included in this report are preliminary and should not be considered final. GeoEngineers' recommendations can be finalized only by observing actual subsurface conditions revealed during construction. GeoEngineers is unable to assume responsibility for the recommendations in this report without performing construction observation.

We recommend that you allow sufficient monitoring, testing and consultation during construction by GeoEngineers to confirm that the conditions encountered are consistent with those indicated by the explorations, to provide recommendations for design changes if the conditions revealed during the work differ from those anticipated, and to evaluate whether earthwork activities are completed in accordance with our recommendations. Retaining GeoEngineers for construction observation for this project is the most effective method of managing the risks associated with unanticipated conditions.

A Geotechnical Engineering or Geologic Report Could Be Subject to Misinterpretation

Misinterpretation of this report by members of the design team or by contractors can result in costly problems. GeoEngineers can help reduce the risks of misinterpretation by conferring with appropriate members of the design team after submitting the report, reviewing pertinent elements of the design team's plans and specifications, participating in pre-bid and preconstruction conferences, and providing construction observation.

Do Not Redraw the Exploration Logs

Geotechnical engineers and geologists prepare final boring and testing logs based upon their interpretation of field logs and laboratory data. The logs included in a geotechnical engineering or geologic report should never be redrawn for inclusion in architectural or other design drawings.

Photographic or electronic reproduction is acceptable, but separating logs from the report can create a risk of misinterpretation.

Give Contractors a Complete Report and Guidance

To help prevent costly problems associated with unanticipated subsurface conditions, we recommend giving contractors the complete geotechnical engineering or geologic report, but preface it with a clearly written letter of transmittal. In that letter, advise contractors that the report's accuracy is limited. In addition, encourage them to confer with GeoEngineers and/or to conduct additional study to obtain the specific types of information they need or prefer.

Contractors Are Responsible for Site Safety on Their Own Construction Projects

Our geotechnical recommendations are not intended to direct the contractor's procedures, methods, schedule or management of the work site. The contractor is solely responsible for job site safety and for managing construction operations to minimize risks to on-site personnel and adjacent properties.

Read These Provisions Closely

It is important to recognize that the geoscience practices (geotechnical engineering, geology and environmental science) are less exact than other engineering and natural science disciplines. Without this understanding, there may be expectations that could lead to disappointments, claims and disputes. GeoEngineers includes these explanatory "limitations" provisions in our reports to help reduce such risks. Please confer with GeoEngineers if you need to know more how these "Report Limitations and Guidelines for Use" apply to your project or site.

Biological Pollutants

GeoEngineers' Scope of Work specifically excludes the investigation, detection, prevention or assessment of the presence of Biological Pollutants. Accordingly, this report does not include any interpretations, recommendations, findings or conclusions regarding the detecting, assessing, preventing or abating of Biological Pollutants, and no conclusions or inferences should be drawn regarding Biological Pollutants as they may relate to this project. The term "Biological Pollutants" includes, but is not limited to, molds, fungi, spores, bacteria and viruses, and/or any of their byproducts.

A Client that desires these specialized services is advised to obtain them from a consultant who offers services in this specialized field.

Have we delivered World Class Client Service?

Please let us know by visiting **www.geoengineers.com/feedback**.

GeoEngineers

Geotechnical Engineering Services Addendum No. 1

BS-24 Terracing and Marsh Creation
South of Big Mar
Plaquemines Parish, Louisiana

for

Lonnie G. Harper & Associates

February 12, 2016

GeoEngineers
Earth Science + Technology

PRELIMINARY

Geotechnical Engineering Services
Addendum No. 1

BS-24 Terracing and Marsh Creation
South of Big Mar
Plaquemines Parish, Louisiana

for
Lonnie G. Harper & Associates, Inc.

February 12, 2016

GeoEngineers

11955 Lakeland Park Boulevard, Suite 100
Baton Rouge, Louisiana 70809
225.293.2460

Geotechnical Engineering Services
Addendum No. 1

BS-24 Terracing and Marsh Creation
South of Big Mar
Plaquemines Parish, Louisiana
File No. 10883-020-02

February 12, 2016

Prepared for:

Lonnie G. Harper & Associates
2746 Highway 384
Bell City, LA 70630

Attention: Mr. Chris Wheat, PE

Prepared by:

GeoEngineers, Inc.
11955 Lakeland Park Boulevard, Suite 100
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PRELIMINARY

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PRELIMINARY

David S. Eley, PE
Principal

JMP:DSE:lb

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PRELIMINARY

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Surface Conditions 3
Subsurface Conditions 3
Earthen Terrace Area 4

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General 4
Earthen Terrace Slope Stability and Bearing Capacity 4
Earthen Terrace Settlement 5

CONSTRUCTION CONSIDERATIONS **7**

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PRELIMINARY

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PRELIMINARY

INTRODUCTION

This report presents the results of GeoEngineers, Inc.'s (GeoEngineers) geotechnical engineering services for the Terracing and Marsh Creation South of Big Mar Project (BS-24) located in Plaquemines Parish, Louisiana. Our services have been completed under contract with Lonnie G. Harper & Associates, Inc. (LGH) task order AG-7217-D-13-0001, dated May 8, 2015. The project is located south of Big Mar, and west of Lake Lery, as shown on Figure 1. Relevant site features are shown on Figure 2.

All elevations described in this report, including figures and appendices, are referenced to the North American Vertical Datum of 1988 (NAVD 88), Geoid 12A.

PROJECT UNDERSTANDING

Our understanding of the project is based on the Scope of Services for Geotechnical Investigation, defined scope of work by LGH dated May 8, 2015 and revised August 8, 2015, and our August 19, 2015 proposal.

GeoEngineers understands the primary goal of this project is to create earthen terraces in shallow open water areas within the Caernarvon Diversion outfall area. The earthen terraces will reduce wave fetch in open water areas and promote conditions conducive to growth of marsh vegetation and submerged aquatic vegetation. Approximately 334 acres of marsh creation is also proposed to re-establish the western shoreline of Lake Lery in association with the Lake Lery West Shoreline Restoration and Marsh Creation project (BS-16).

The earthen terrace component of the project will most likely be constructed with marsh buggy long reach excavators. The marsh creation area will be designed as a traditional marsh creation area utilizing earthen dikes to contain fill material hydraulically dredged and pumped from a borrow area in Lake Lery.

PURPOSE AND SCOPE OF SERVICES

GeoEngineers completed a geotechnical investigation and engineering evaluations for the BS-24 project in 2014. However, LGH and NRCS realized construction access to Terrace Cells 1 and 2 are blocked by a pipeline that cuts through the project area. Terrace Cell 2 was relocated closer to Lake Lery in an accessible area that did not have existing geotechnical explorations. This document focuses on the new Terrace Cell 2 location. Our specific scope of services included the following:

1. Visited the site to observe field conditions and better understand the project conditions.
2. Contacted Louisiana "One-Call" to notify them of our intent to perform soil borings at this site and to clear the boring locations of potential underground utilities.
3. 3.Performed a field investigation that including two (2) undisturbed soil borings to a depth of 30 feet below the mudline in the new Terrace Cell 2 location.
4. Performed laboratory testing on select soil specimens.
5. Evaluated subsurface data and identified appropriate design profiles representing different sections along the project alignment.

PRELIMINARY

6. Completed the following evaluations for each design profile as appropriate:
    a. Earthen Terraces:
        i. Evaluated stability of terraces with a 15-foot top width and with a lower borrow area excavation limit of elevation -10 feet (El. -10 feet) adjacent to the terraces. The side slopes for a stable terrace configuration were 5 horizontal feet to each vertical foot (5H:1V).
        ii. Evaluated constructed terrace top elevations of +2 feet, +3 feet, +4 feet and +5 feet. Note that after determining a stable elevation, GeoEngineers did not run lower elevations, since they will be more stable;
        iii. Performed settlement analyses for stable terrace configuration determined in stability analyses. Initial settlement at construction and settlement at 0.5, 1, 3, 5, 10 and 20 years after construction were estimated;
        iv. Completed bearing capacity analyses for stable terrace configurations determined from the slope stability analysis. Note that once a stable bearing capacity was determined, GeoEngineers did not run bearing capacity for lower elevation terraces; and
        v. Provided general construction and maintenance recommendations.
7. Submitted a list of equipment used and names of personnel involved in the drilling activities and a package including all field soil boring logs and notes.
8. Prepared this report of geotechnical findings and analysis results.

FIELD EXPLORATION

Field exploration was performed on December 21, 2015. Two soil borings were completed to a depth of 30 feet below existing mudline using an airboat-mounted drill rig. Each soil boring was sampled continuously for the top 20 feet, and then at 5-foot centers to the boring completion depths. Soil boring locations are shown on Figure 2 and detailed soil boring logs are included in Appendix A.

Borehole sampling was conducted in general accordance with applicable ASTM specifications. High-quality, undisturbed, cohesive and semi-cohesive soil (clay/clayey silt) specimens suitable for laboratory strength testing were obtained using a 30-inch-long, 3-inch outside diameter, thin-walled steel Shelby tube sampler.

At each soil boring, the sampler was hydraulically pushed into the ground a distance not exceeding 24 inches per specimen using an Osterberg piston sampler. Soil borings were grouted upon completion in accordance with Louisiana requirements.

Immediately upon recovery, each sample was classified in the field by a GeoEngineers field representative based on soil exposed on either end of the Shelby tube. Each Shelby tube was then sealed and stored/transported in a vertical position. Shelby tubes were secured bottom down during transportation to minimize sample disturbance.

Vane shear tests using a GEONOR H-10 vane borer instrument were attempted in general accordance with ASTM D 2573. We were unable to establish torque readings in the very soft subsurface soils and

PRELIMINARY

suspect the equipment was not functioning correctly. As there are no test results to report, we will not discuss field vane use any further in this document.

LABORATORY TESTING

Intact semi-cohesive and cohesive samples were subjected to laboratory miniature vane (mini vane) shear testing prior to extrusion. Upon extrusion, each sample was examined to confirm or modify field classifications. Representative samples were selected for laboratory testing consisting of moisture content, unit weight, unconsolidated undrained compression, organic content, fiber content, grain size analysis, consolidation testing and Atterberg limits. The test results are presented on the boring logs and figures included in Appendix A and Appendix B, respectively.

SITE CONDITIONS

Project Location

The project is located in Plaquemines Parish, Louisiana south of Big Mar and west of Lake Lery, as shown on Figure 1.

Surface Conditions

Water depths ranged from approximately 1.5 to 2.5 feet at soil boring locations BHT-13-30 and BHT-14-30 at the time of drilling. Weather, wind, and tides can substantially affect water levels. Wind can make the open water rough and make it difficult to operate equipment that is sensitive to wave action.

The surrounding area is generally undeveloped but pipelines and other features were noted during our field visit and drilling. Land adjacent to canals is typically elevated relative to the surrounding area and supports growth of trees, shrubs, and marsh grasses. Wildlife flourishes in these marsh lands and was often seen during our site visit and field investigation.

The Caernarvon Diversion structure, designed to release water from the Mississippi River influences this area. When the diversion structure is open, water from the river flows through structure to, and through, the project area.

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Subsurface Conditions

The subsurface conditions discussed below are based on the soil borings completed for this project and survey information provided by the LGH. No artifacts or material other than that noted on the soil boring logs was observed by GeoEngineers during our field investigation, or during laboratory testing; however, GeoEngineers personnel are not trained to recognize such items.

A subsurface profile was created based on a combination of terrace soil borings BHT-3-30 and BHT-4-30 from the original investigation at the site, BHT-13-30 and BHT-14-30 from this investigation, and BHMC-2-30 from the original investigation and is shown on Figure 3. Although undetected anomalies, (sand layers, logs, etc.) beyond the soil borings may exist, the generalized subsurface conditions can be described as follows.

Earthen Terrace Area

As shown in the subsurface profile on Figure 3, the proposed earth terrace area soil predominantly consists of layers of very soft peat and organic clay in the upper 3 to 18 feet. The thickness and depth of these deposits varied in each soil boring. Below the near-surface organic layer, soil boring BHT-13-30 encountered a transitional zone of inorganic and organic clay between 14 and 18 feet below mudline, followed by silt with sand layers and lenses. We were unable to retrieve a sample from the 23 to 25 feet below mudline sample interval, which sometimes occurs when attempting to collect non-plastic material in a Shelby tube, so we have assumed the silt layer continues to about 25 feet below mudline. From about 25 feet below mudline to the termination depth of soil boring BHT-13-30, we encountered clayey sand.

Alternating layers of silt and silty clay were encountered below the near surface organic deposits at BHT-14-30 from about 12 feet below mudline to about 18 feet below mudline, followed by very soft clay with silt pockets to about 23 feet below mudline, after which loose sand was encountered to the termination depth of the boring.

Appendix C contains design profiles (shear strength, unit weight, and moisture content) based on laboratory testing results for earthen terrace soil borings BHT-13-30 and -14-30. In these profiles, peat moisture content ranges from about 350% to about 900%, and organic clay moisture content ranges from about 100% to about 375%. These high moisture, highly compressible organic materials were found in the upper 12 to 18 feet in the two new borings, which is generally consistent with the 3 to 15 feet observed in our original investigation for the marsh area where earthen terraces will be constructed. In the layers below these organic deposits, moisture contents vary from about 20% to about 120%.

Soil boring logs are provided in Appendix A. Appendix B contains laboratory test results, and Appendix C presents the design soil properties vs. elevation based on field and laboratory test results.

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CONCLUSIONS AND RECOMMENDATIONS

General

Soil conditions for this project are generally similar to those encountered in our previous BS-24 investigation. Based on our engineering evaluations, the proposed improvement area is generally suitable for earthen terrace construction. The results of the slope stability and settlement analyses are presented in tables below. Details of the analysis methods are presented in Appendix D for slope stability and bearing capacity and Appendix E for earthen terrace settlement.

Earthen Terrace Slope Stability and Bearing Capacity

GeoEngineers evaluated slope stability and bearing capacity for the earthen terraces with a crown elevation of +5 feet, 5 horizontal to 1 vertical (5H:1V) side slopes and a 15-foot crown width. The borrow excavation was assumed to be excavated to El. -10.0 feet with a 3H:1V cut slope.

The slope stability failure modes evaluated are shown on Figure 4 and the recommended section is shown on Figure 5. In general, earthen terraces built to El. +5 feet have an adequate factor of safety for slope stability.

As evidenced by the results presented below, soil conditions vary across the site. Table 1 summarizes the slope stability factor of safety results for the earthen terraces without reinforcement.

Table 1. Earthen Terrace Slope Stability Analysis Results – Without Reinforcement

Boring ID	Terrace Dimension				Bench Width (feet)	Slope Stability FOS				Global Bearing FOS
						Condition			Appendix D Figure #	
	Crown Elevation (feet)	Crown Width (feet)	Side Slopes (H:V)	Mudline Elevation (feet)		1	2	3		
BHT-13	+5	15	5:1	-2.0 assumed	25	1.78	1.38	1.30	D-26	1.92
BHT-14	+5	15	5:1	-2.0 assumed	25	2.03	1.78	1.56	D-27	1.95

Condition 1 –Marsh to Excavation
Condition 2 –Terrace to Excavation
Condition 3 –Terrace to Marsh

A bench width of 25 feet was modeled for the earthen terrace to provide sufficient space for marsh buggy excavator access and improve terrace stability. The factor of safety given in Table 1 includes an assumed load of 260 pounds per square foot (psf) under each marsh buggy pontoon during construction in situations where the excavator load reduces the factor of safety.

Earthen terrace geometries that have flatter side slopes and/or wider benches than the section shown on Figure 5 will be more stable. Higher crown elevations, shorter benches, or a deeper borrow channel will have to be re-evaluated for stability. No geotextile reinforcement was necessary to achieve stability for earthen terraces.

Earthen terrace configurations from Table 1 were also checked against global bearing failure and found to be stable. Appendix D contains results of the most critical slope stability section for each completed earthen terrace evaluation and the bearing evaluation.

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Earthen Terrace Settlement

GeoEngineers evaluated settlement for the earthen terraces constructed for crown elevations of +2, +3, +4 and +5 feet. Table 2 provides a summary of the settlement estimates. Appendix E (Figures E-18 and E-19) contains graphical and tabular summaries of settlement.

Settlement for earthen terraces has three components; 1) consolidation of underlying soil due to the additional loading imposed by the earthen terrace; 2) immediate construction (elastic) settlement of soil during construction; and 3) shrinkage within the terrace earthen fill. All three components must be added to obtain the total settlement.

Construction, or elastic, settlement is the result of immediate compression of the underlying soils during placement of fill (i.e. during construction).

Elastic settlement has been estimated as 20% of the long term consolidation settlement. This estimated number is educated guess based on professional judgment. It is difficult to distinguish construction settlement from consolidation settlement because they both occur during construction and there is little, or no, data that GeoEngineers is aware of for coastal Louisiana organic soil. Construction settlement will be offset by fill placement during construction and is not likely to be directly observed. It will, however, increase the fill quantity required to reach the design elevation and should be considered for fill quantity estimates.

Settlement or shrinkage of fill materials is likely to be significant for the earthen terraces. Shrinkage of terrace fill is a function of many variables, including fill material, construction practices, weather, and fill height. There are also off-setting effects. For example, as fill loses water and shrinks, it becomes lighter and smaller reducing the amount of consolidation settlement of the underlying soils as compared to the full initial load. Shrinkage will not be uniform; the exterior of the terrace, especially at higher elevations, is expected to shrink more than the interior, especially near the water level. This is a very difficult number to predict, but GeoEngineers recommends estimating shrinkage settlement as 20% of the earthen terrace height above the mean water design level. We have assumed that soil between El. 0 feet and El. -10 feet will be utilized to construct the earthen terrace. Soil to El. -10 feet typically has a considerable amount of organics with high moisture content (generally greater than 250%). Hence, GeoEngineers assumed 20% volume shrinkage in addition to the estimated consolidation and construction settlement. GeoEngineers conducted experiments wherein we exposed core samples of various types to the open air while keeping the sample bottom in water. We observed that organic clay indeed experiences significant shrinkage, as we expected. However, observed shrinkage in peat soils was small, presumably because capillary action along the fibers carried moisture to the top of the sample and maintained sufficient moisture to sustain the sample volume. Because the foundation soils within the top 10 feet of the terrace area are a mix of organic clay and peat, we have assumed a shrinkage will be significant.

Based on a mean water elevation of 0 feet and an earthen terrace elevation of +5 feet, GeoEngineers recommends allowing for up to 1 foot (12 inches) of elevation loss due to shrinkage, in addition to consolidation settlement. It is expected that shrinkage will occur within 3 to 6 months after construction depending upon the season. Dry and sunny weather will speed the shrinkage process, while wet and cloudy weather will slow the process. Shrinkage due to drying will also vary within the fill; fill exposed to sun and air at the exterior of the terrace will dry more than fill near the center of the dike near the water level (which is likely to remain moist after draining excess water during initial excavation from a submerged condition).

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TABLE 2. EARTHEN TERRACE SETTLEMENT ESTIMATES

Boring ID.	Crown Elevation [3] (feet)	Estimated Shrinkage Settlement [1](inches)	Estimated Construction Settlement[2] (inches)	Estimated Foundation Soil Consolidation Settlement (inches)				
				6 Mo.	1 Yr.	3 Yrs.	10 Yrs.	Long-term (20 Years)
BHT-13	+2	5	1 ¾	7	8	8	8	8
	+3	7	2 ¼	9	10	11	11	11
	+4	10	2 ½	11	11	12	13	13
	+5	12	2 ¾	12	13	14	14	14
BHT-14	+2	5	1 ¾	8	9	9	9	9
	+3	7	2 ½	12	12	13	13	13
	+4	10	3 ¼	15	15	16	16	16
	+5	12	3 ¾	17	18	18	18	18

(1) Shrinkage settlement = (Initial construction elevation-Assumed water elevation)*20%; Water at El. 0 feet.
(2) Estimated construction settlement is not included in the estimated consolidation settlement.
(3) Crown elevation at end of earthen terrace construction.

PRELIMINARY

CONSTRUCTION CONSIDERATIONS

Based on the site work and evaluations completed for this project, the following are offered with respect to construction.

- For construction of the earthen terrace, a minimum bench width of 25 feet must be provided between the toe of the terrace and the excavation cut slope. To maintain excavation and overall embankment stability, we recommend marsh buggies remain as close to the toe as practical without disturbing the terrace fill.
- Surficial soil at this site is predominantly peat and organic clay; both highly organic soil. These materials will be more difficult to use for construction purposes when compared to clay, silt, or sand; however, a pilot study with similar soil, completed by the NRCS suggests these materials can be used successfully. LGH should be aware that contractors are likely to try to excavate clay from beneath these organic soils, which will require a different evaluation by GeoEngineers to correctly model deeper excavations and heavier fill materials for dikes and terraces. Heavier fill is also likely to settle more, and cause more displacement of shallow organic material (i.e. mud waves).
- Water levels can significantly affect construction and terrace stability. High water levels may increase erosion, while low water levels reduce fill buoyancy and can cause failures.
- Pipeline markers were observed in the project vicinity. Precautions must be taken to prevent pipeline damage during construction.
- There are property owner restrictions on the type of equipment that can access the site. Contractors may need to take extra precaution while performing the work to reduce impacts to local wildlife.

LIMITATIONS

We have prepared this report for the exclusive use of Lonnie G. Harper & Associates, Inc. in support of design of the proposed BS-24 Terracing and Marsh Creation South of Big Mar located in Plaquemines Parish, Louisiana.

Within the limitations of scope, schedule and budget, our services have been executed in accordance with generally accepted practices in the field of geotechnical engineering in this area at the time this report was prepared. No warranty or other conditions, expressed or implied, should be understood.

Please refer to Appendix F titled "Report Limitations and Guidelines for Use" for additional information pertaining to use of this report.

PRELIMINARY

FIGURES

GeoEngineers

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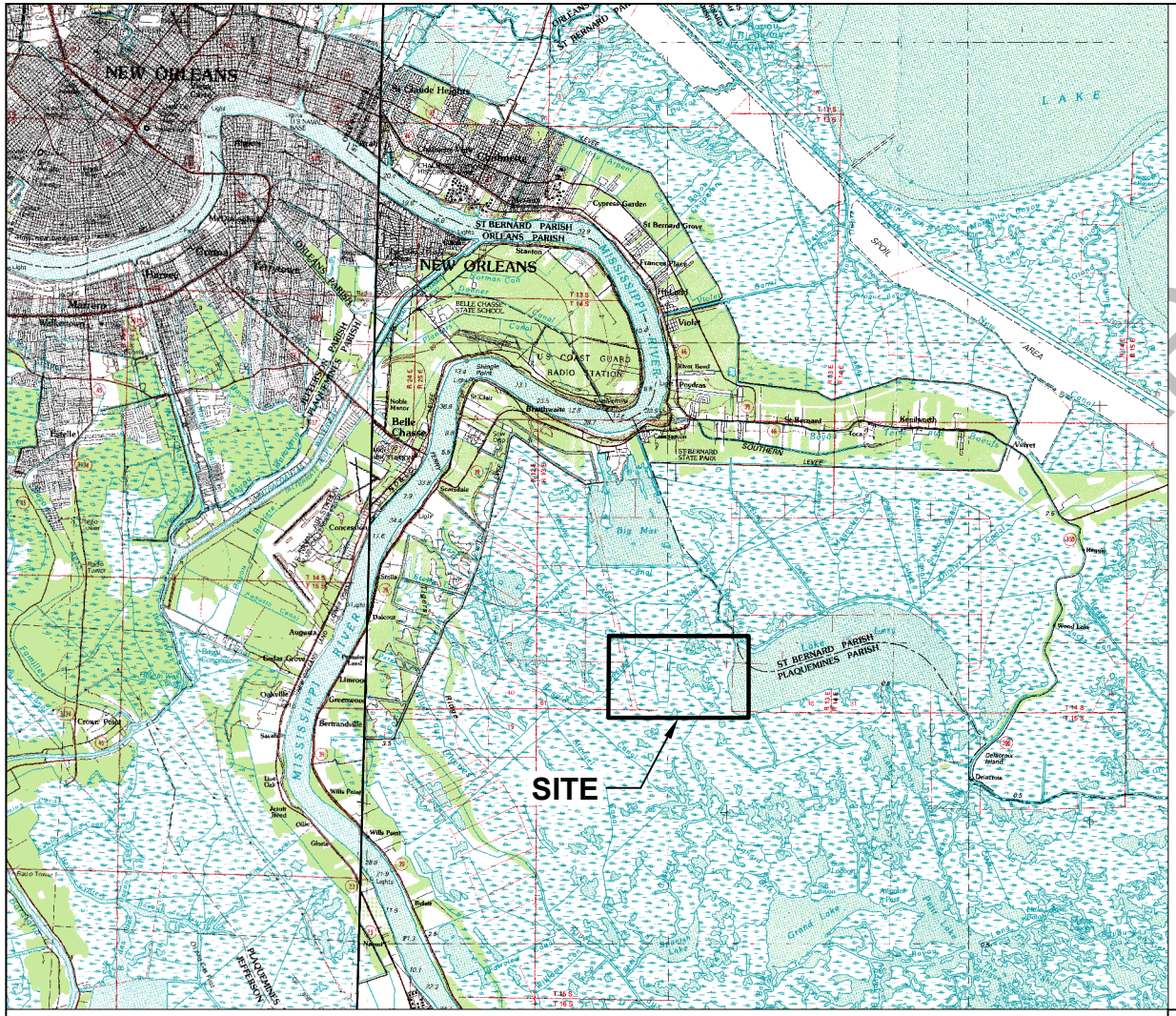

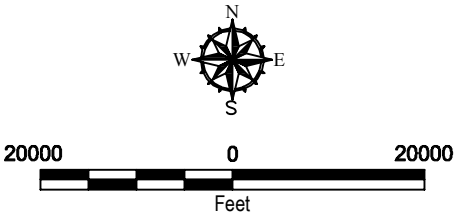

Notes:
1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. can not guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

Reference: Topographic image taken from USGS, DRG-100k Template, Quad Black Bay & Gulfport, Dated 9/22/2005

VICINITY MAP

USDA NRCS - BS-24 Terracing and Marsh Creation
Additional Geotechnical Services
Plaquemines Parish, Louisiana

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Figure 1

BOREHOLE DETAILS			
BORING #	LATITUDE	LONGITUDE	DEPTH (FT)
BHT-13-30	N29° 48' 06.3"	W89° 53' 41.8"	30'
BHT-14-30	N29° 47' 51.6"	W89° 53' 16.4"	30'

LEGEND

- BHT-13-30 — Approximate Soil Borehole Location
- BHT-01-30 — Previously Completed BS-24 Borings
- BHLR-01-50 — Approximate Location of Previously Completed Soil Boring for BS-16 Project
- Access Route
- Cross Section

N W E S

2000 0 2000
Feet

Notes:
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Reference: Aerial image was taken from Google Earth Pro., Licensed to GeoEngineers Inc., Imagery dated: 3/5/2013

SOIL BORING LOCATION PLAN

USDA NRCS - BS-24 Terracing and Marsh Creation
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Figure 2

DPS : KMC

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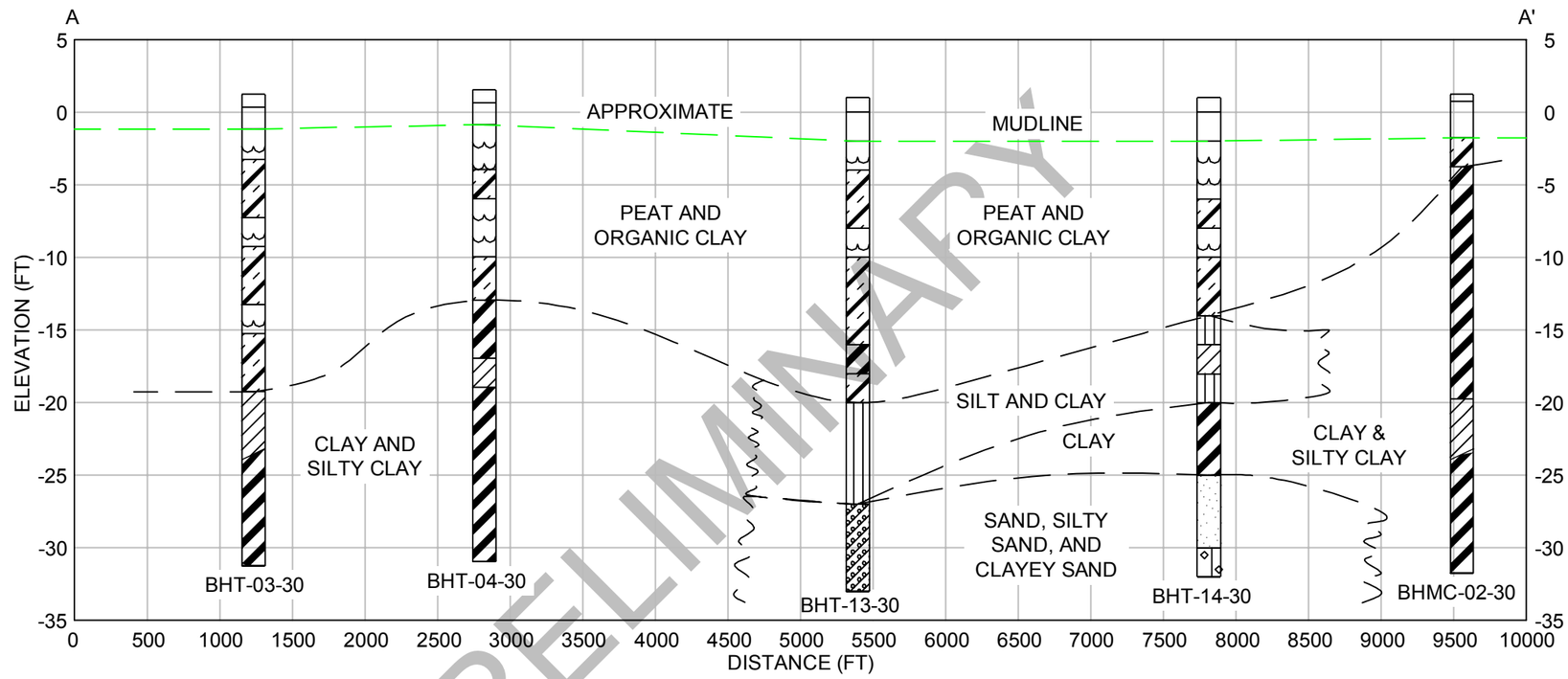
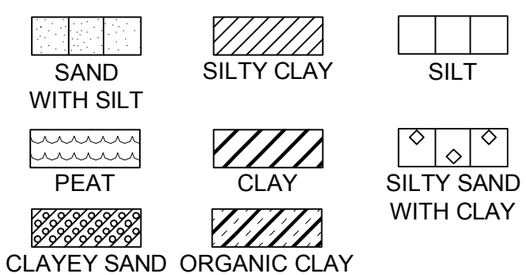


PRELIMINARY

LEGEND



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TERRACE SUBSURFACE PROFILE

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Figure 3

DPS : KMC

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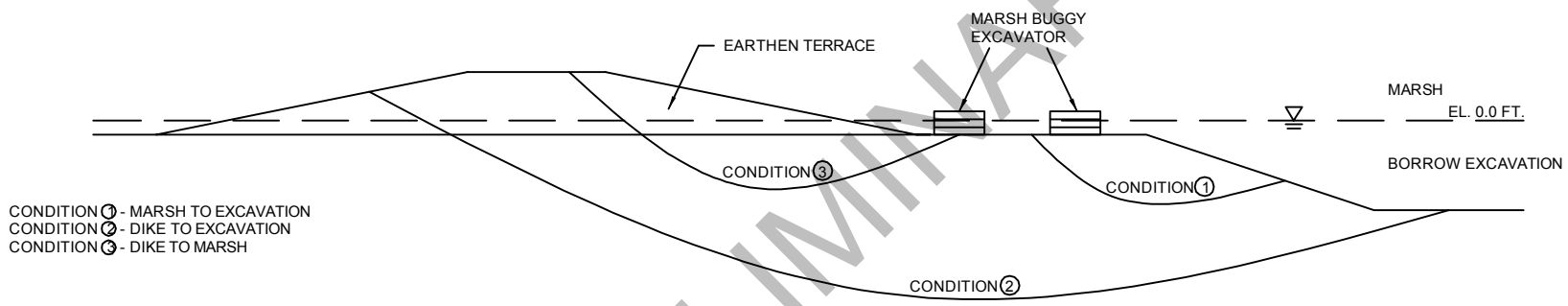
EARTHEN TERRACE INTERIOR MARSH



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SCALE

20 0 20

Feet

Notes:
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SLOPE STABILITY FAILURE SURFACES

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Plaquemines Parish, Louisiana

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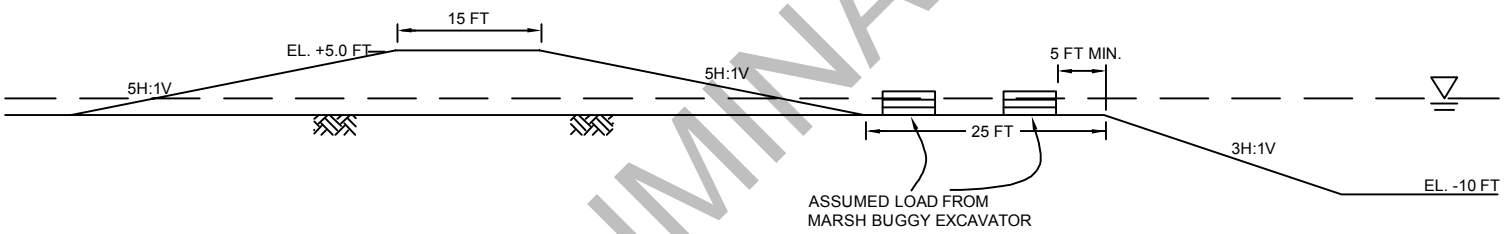
Figure 4

EARTHEN TERRACE WITHOUT REINFORCEMENT



PRELIMINARY

SCALE

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Feet

Notes:
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EARTHEN TERRACE DETAILS

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Additional Geotechnical Services
Plaquemines Parish, Louisiana

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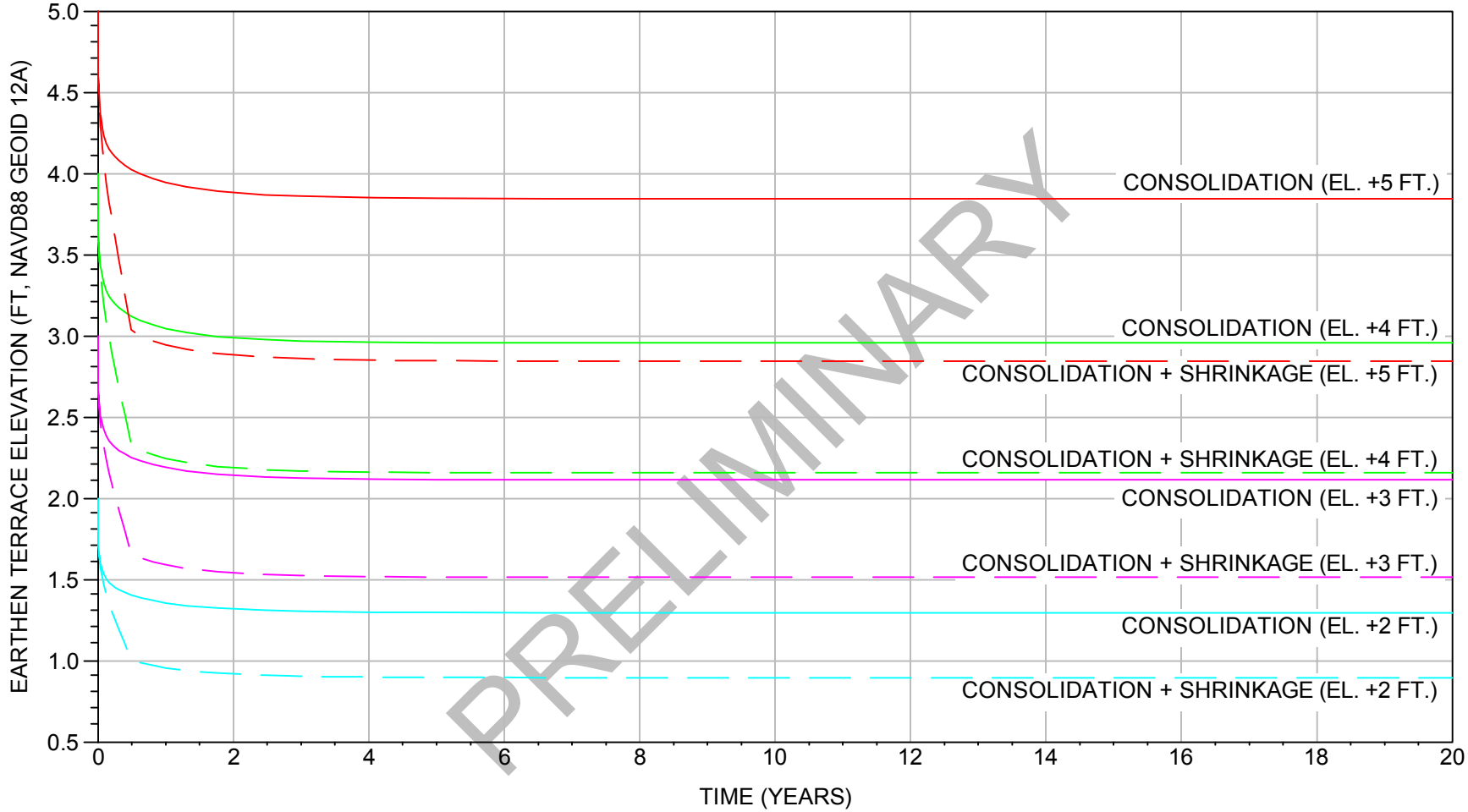
Figure 5

APPENDIX E
Settlement Analyses Earth Terraces

PRELIMINARY



EARTHEN TERRACE ELEVATION (FEET NAVD88) CONSOLIDATION (CONSOLIDATION + SHRINKAGE)						
0 DAYS	6 MONTHS	1 YEAR	3 YEAR	5 YEAR	10 YEAR	LONG TERM
2.0	1.4 (1.0)	1.4 (1.0)	1.3 (0.9)	1.3 (0.9)	1.3 (0.9)	1.3 (0.9)
3.0	2.3 (1.7)	2.2 (1.6)	2.2 (1.6)	2.1 (1.5)	2.1 (1.5)	2.1 (1.5)
4.0	3.1 (2.3)	3.1 (2.3)	3.0 (2.2)	3.0 (2.2)	3.0 (2.2)	3.0 (2.2)
5.0	4.0 (3.0)	4.0 (3.0)	3.9 (2.9)	3.9 (2.9)	3.9 (2.9)	3.9 (2.9)

CONSTRUCTION SETTLEMENT (FEET)
0.1
0.2
0.2
0.2

Notes: 1. Construction settlement must be added for quantity estimates.

EARTHEN TERRACE ELEVATION VS. TIME
BHT-13-30

USDA NRCS - BS-24 Terracing and Marsh Creation
Additional Geotechnical Services
Plaquemines Parish, Louisiana

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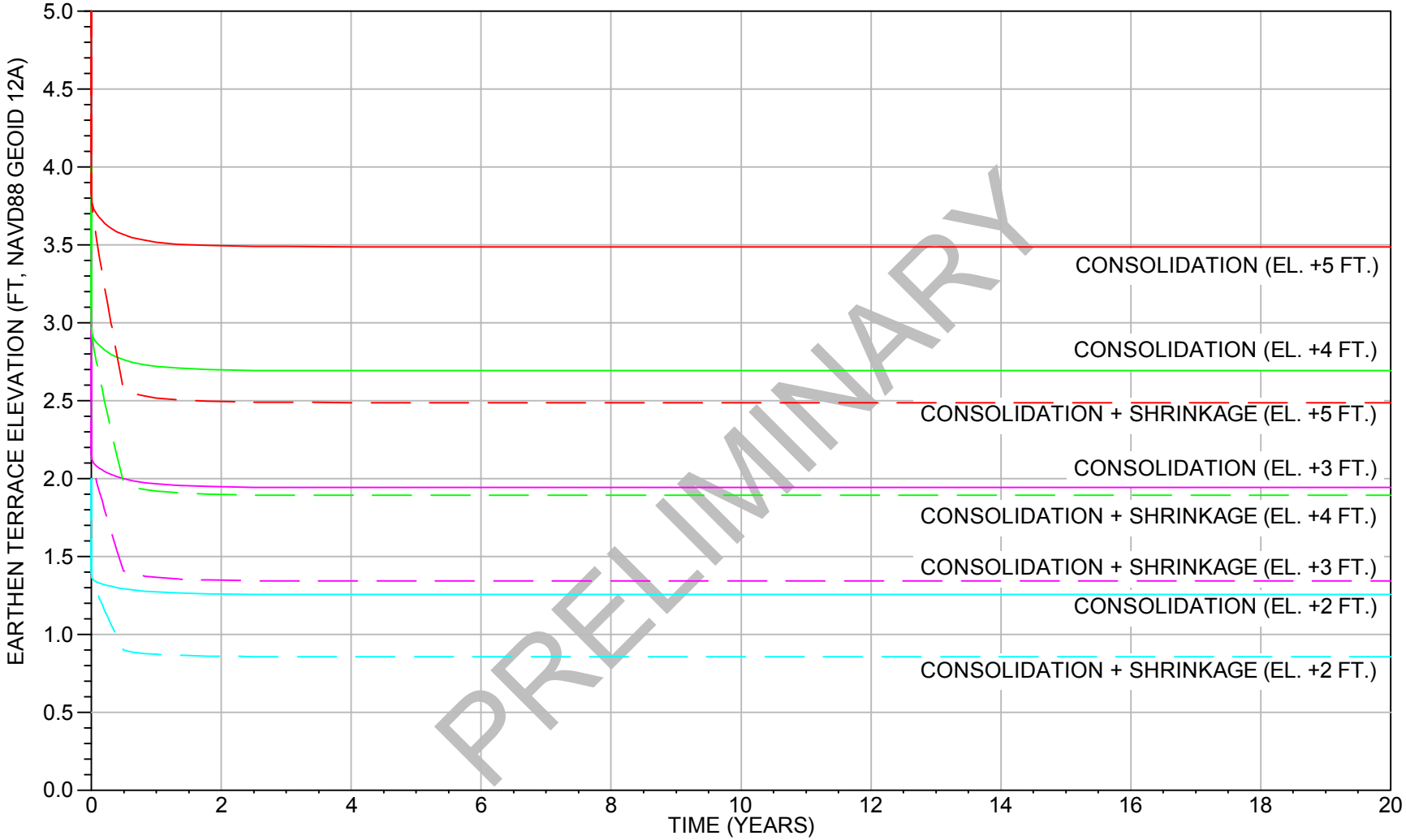
Figure E-18



EARTHEN TERRACE ELEVATION (FEET NAVD88) CONSOLIDATION (CONSOLIDATION + SHRINKAGE)						
0 DAYS	6 MONTHS	1 YEAR	3 YEAR	5 YEAR	10 YEAR	LONG TERM
2.0	1.3 (0.9)	1.3 (0.9)	1.3 (0.9)	1.3 (0.9)	1.3 (0.9)	1.3 (0.9)
3.0	2.0 (1.4)	2.0 (1.4)	1.9 (1.3)	1.9 (1.3)	1.9 (1.3)	1.9 (1.3)
4.0	2.8 (2.0)	2.7 (1.9)	2.7 (1.9)	2.7 (1.9)	2.7 (1.9)	2.7 (1.9)
5.0	3.6 (2.6)	3.5 (2.5)	3.5 (2.5)	3.5 (2.5)	3.5 (2.5)	3.5 (2.5)

CONSTRUCTION SETTLEMENT (FEET)
0.2
0.2
0.3
0.3

Notes: 1. Construction settlement must be added for quantity estimates.

EARTHEN TERRACE ELEVATION VS. TIME
BHT-14-30

USDA NRCS - BS-24 Terracing and Marsh Creation
Additional Geotechnical Services
Plaquemines Parish, Louisiana

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Figure E-19

APPENDIX F
Report Limitations and Guidelines for Use

PRELIMINARY

APPENDIX F
REPORT LIMITATIONS AND GUIDELINES FOR USE

This appendix provides information to help you manage your risks with respect to the use of this report.

Geotechnical Services Are Performed for Specific Purposes, Persons and Projects

This report has been prepared for US Department of Agriculture/Natural Resources Conservation Service and their authorized agents and regulatory agencies. The information contained herein is not applicable to other sites.

GeoEngineers structures our services to meet the specific needs of our clients. No party other than US Department of Agriculture/Natural Resources Conservation Service may rely on the product of our services unless we agree to such reliance in advance and in writing. This is to provide our firm with reasonable protection against open-ended liability claims by third parties with whom there would otherwise be no contractual limits to their actions. Within the limitations of scope, schedule and budget, our services have been executed in accordance with our Agreement with the Client and generally accepted geotechnical practices in this area at the time this report was prepared. Use of this report is not recommended for any purpose or project except the one originally contemplated.

A Geotechnical Engineering or Geologic Report Is Based on a Unique Set of Project-Specific Factors

This report has been prepared for the BS-24 Terracing and Marsh Creation South of Big Mar project in Plaquemines Parish, Louisiana. GeoEngineers considered a number of unique, project-specific factors when establishing the scope of services for this project and report. Unless GeoEngineers specifically indicates otherwise, it is important not to rely on this report if it was:

- not prepared for you,
- not prepared for your project,
- not prepared for the specific site explored, or
- completed before important project changes were made.

For example, changes that can affect the applicability of this report include those that affect:

- the function of the proposed structure;
- elevation, configuration, location, orientation or weight of the proposed structure;
- composition of the design team; or
- project ownership.

If important changes are made after the date of this report, we recommend that GeoEngineers be given the opportunity to review our interpretations and recommendations. Based on that review, we can provide written modifications or confirmation, as appropriate.

PRELIMINARY

Subsurface Conditions Can Change

This geotechnical or geologic report is based on conditions that existed at the time the study was performed. The findings and conclusions of this report may be affected by the passage of time, by man-made events such as construction on or adjacent to the site, or by natural events such as floods, earthquakes, slope instability or groundwater fluctuations. If more than a few months have passed since issuance of our report or work product, or if any of the described events may have occurred, please contact GeoEngineers before applying this report for its intended purpose so that we may evaluate whether changed conditions affect the continued reliability or applicability of our conclusions and recommendations.

Most Geotechnical and Geologic Findings Are Professional Opinions

Our interpretations of subsurface conditions are based on field observations from widely spaced sampling locations at the site. Site exploration identifies the specific subsurface conditions only at those points where subsurface tests are conducted or samples are taken. GeoEngineers reviewed field and laboratory data and then applied our professional judgment to render an informed opinion about subsurface conditions throughout the site. Actual subsurface conditions may differ, sometimes significantly, from those indicated in this report. Our report, conclusions and interpretations should not be construed as a warranty of the subsurface conditions.

Geotechnical Engineering Report Recommendations Are Not Final

The construction recommendations included in this report are preliminary and should not be considered final. GeoEngineers' recommendations can be finalized only by observing actual subsurface conditions revealed during construction. GeoEngineers is unable to assume responsibility for the recommendations in this report without performing construction observation.

We recommend that you allow sufficient monitoring, testing and consultation during construction by GeoEngineers to confirm that the conditions encountered are consistent with those indicated by the explorations, to provide recommendations for design changes if the conditions revealed during the work differ from those anticipated, and to evaluate whether earthwork activities are completed in accordance with our recommendations. Retaining GeoEngineers for construction observation for this project is the most effective method of managing the risks associated with unanticipated conditions.

A Geotechnical Engineering or Geologic Report Could Be Subject to Misinterpretation

Misinterpretation of this report by members of the design team or by contractors can result in costly problems. GeoEngineers can help reduce the risks of misinterpretation by conferring with appropriate members of the design team after submitting the report, reviewing pertinent elements of the design team's plans and specifications, participating in pre-bid and preconstruction conferences, and providing construction observation.

Do Not Redraw the Exploration Logs

Geotechnical engineers and geologists prepare final boring and testing logs based upon their interpretation of field logs and laboratory data. The logs included in a geotechnical engineering or geologic report should never be redrawn for inclusion in architectural or other design drawings. Photographic or electronic reproduction is acceptable, but separating logs from the report can create a risk of misinterpretation.

PRELIMINARY

Give Contractors a Complete Report and Guidance

To help prevent costly problems associated with unanticipated subsurface conditions, we recommend giving contractors the complete geotechnical engineering or geologic report, but preface it with a clearly written letter of transmittal. In that letter, advise contractors that the report's accuracy is limited. In addition, encourage them to confer with GeoEngineers and/or to conduct additional study to obtain the specific types of information they need or prefer.

Contractors Are Responsible for Site Safety on Their Own Construction Projects

Our geotechnical recommendations are not intended to direct the contractor's procedures, methods, schedule or management of the work site. The contractor is solely responsible for job site safety and for managing construction operations to minimize risks to on-site personnel and adjacent properties.

Read These Provisions Closely

It is important to recognize that the geoscience practices (geotechnical engineering, geology and environmental science) are less exact than other engineering and natural science disciplines. Without this understanding, there may be expectations that could lead to disappointments, claims and disputes. GeoEngineers includes these explanatory "limitations" provisions in our reports to help reduce such risks. Please confer with GeoEngineers if you need to know more how these "Report Limitations and Guidelines for Use" apply to your project or site.

Biological Pollutants

GeoEngineers' Scope of Work specifically excludes the investigation, detection, prevention or assessment of the presence of Biological Pollutants. Accordingly, this report does not include any interpretations, recommendations, findings or conclusions regarding the detecting, assessing, preventing or abating of Biological Pollutants, and no conclusions or inferences should be drawn regarding Biological Pollutants as they may relate to this project. The term "Biological Pollutants" includes, but is not limited to, molds, fungi, spores, bacteria and viruses, and/or any of their byproducts.

A Client that desires these specialized services is advised to obtain them from a consultant who offers services in this specialized field.

PRELIMINARY

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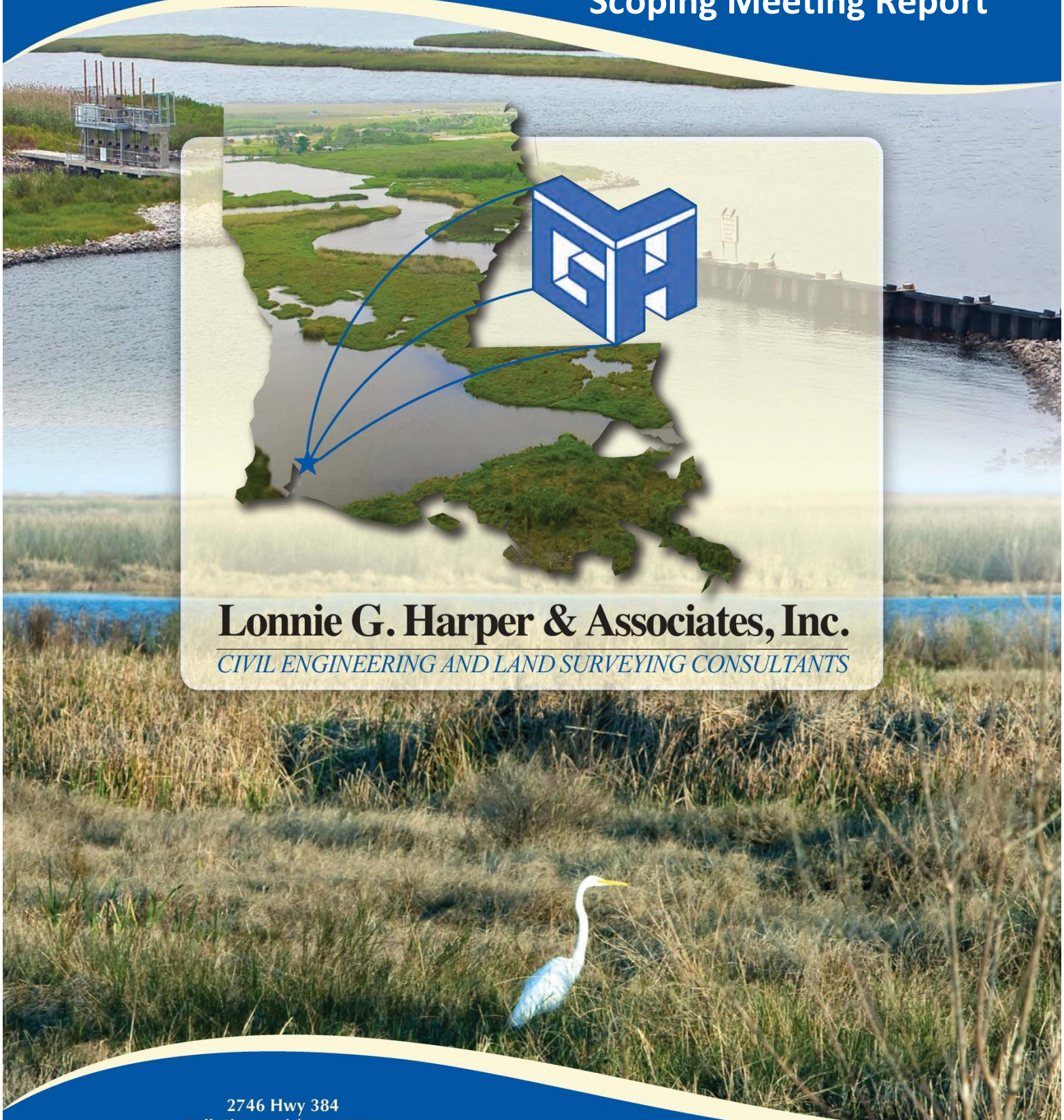
APPENDIX F
SCOPING MEETING REPORT

Scoping Meeting Report Appendices Intentionally Omitted

Natural Resources Conservation Service

BS-24 Terracing and Marsh Creation South of Big Mar - Scoping Meeting Report



Lonnie G. Harper & Associates, Inc.

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2015

PRELIMINARY SCOPING MEETING REPORT

Terracing and Marsh Creation South of Big Mar (BS-24)
Plaquemines Parish, Louisiana

January 2015

Prepared for:

Natural Resources Conservation Service
3737 Government Street
Alexandria, La 71302

Attention: Ms. Vicki Supler, Contracting Officer

Prepared by:

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Principal

Lonnie G. Harper & Associates, Inc.
CIVIL ENGINEERING AND LAND SURVEYING CONSULTANTS

SCOPING REPORT: (BS-24) TERRACING AND MARSH CREATION PROJECT

PROJECT OVERVIEW AND UNDERSTANDING

Lonnie G. Harper & Associates, Inc. (LGH) has been requested to provide a proposal for professional design services based on the scope of work outlined in the *"Scope of Services for Design Services"*[1] dated December 2014, as provided by the Natural Resources Conservation Service (NRCS) for the BS-24 Terracing and Marsh Creation project. This project consists of constructing approximately 65,000 linear feet of shallow water earthen terraces and the creation of approximately 334 acres of marsh in the Caernarvon Diversion outfall area, west of Lake Lery. The terraces are intended to reduce wave fetch within the large open water bodies, as well as promote the growth of submerged aquatic vegetation (SAVs) and marsh vegetation and to capture suspended sediments with the watershed. The 334 acre marsh creation area will be constructed using hydraulically dredged and pumped spoil material from an existing borrow area on the western end of Lake Lery. The marsh creation area will utilize traditional earthen containment dikes to contain the dredged material and to facilitate drainage of the area.

PROJECT DATA REVIEW

The NRCS has provided LGH with the following documentation relative to the BS-24 project for review which will be incorporated into the design phase(s) as necessary.

1. BS-16 and BS-24 Fact Sheets and Maps;
2. BS-24 Project Information Sheet for Wetland Value Assessment (WVA) dated 10/10/2012;
3. Preliminary cost estimates;
4. BS-24 Project features (shape file);
5. Magnetometer survey report collected by T. Baker Smith dated 06/02/2014;
6. Topographical/bathymetric data collected by NRCS dated 02/21/2014 thru 05/17/2014;
7. Updated project control monument (BS16-SM-02) data sheet;
8. BS-24 Project geotechnical investigation report completed by GeoEngineers, Inc., dated 09/23/2014;
9. Soil borings from USACE;
10. Borrow Site Impact Analysis report by FTN Associates, Ltd., dated 05/05/2011;
11. CWPPRA Standard Operating Procedures (SOP), dated August 2014;
12. Right of Entry letters from Delacroix Corporation and Mr. Lester Evans, both dated 09/13/2013;
13. Design Technical Specification for Architect-Engineer Design Services

Upon further review of the abovementioned documents, the NRCS provided the following documentation at the request of LGH.

14. BS-16 geotechnical investigation reports completed by GeoEngineers, Inc., dated 07/02/2010, 01/21/2011, 07/01/2011, 07/21/2011, and 09/30/2011;
15. BS-16 survey data, report, and plans completed by T. Baker Smith, dated 01/12/2011.

After reviewing the data provided by the NRCS and further discussions held with NRCS personnel during the scoping meeting on January 15, 2015, LGH has determined the following items will need to be provided by NRCS as soon as possible.

[1] *"Scope of Services for Design Services"* has been included in Appendix A for reference.

Survey/Project Site Data

1. Provide a copy of the BS-16 bid documents (plans and specifications) for reference.
2. Provide geographical boundaries of borrow area "A" in the form of a georeferenced shape file (*.shx) or actual survey data (comma delimited ASCII format) defining the limits of excavation.
3. Provide the magnetometer survey data (point number, northing, easting, elevation, description) of the BS-24 and BS-16 project sites in comma delimited, ASCII format.
4. Provide adjusted topographic/bathymetric survey data of borrow areas referenced to GEOID12A.
5. Provide as-built drawings and/or survey data of the restored lake rim (west end) and borrow area "A" from the BS-16 project (when they become available but prior to commencement of the 95% design phase).
6. Applicable Land Rights agreements from the pipeline companies with infrastructure in the project area.
7. A copy of the environmental permit drawings and applicable agency correspondence outlining the terms and conditions of the environmental permits associated with the BS-16 project.
8. NOTE: Any survey data provided shall be referenced to the following: Horizontal Datum – NAD83, Vertical Datum – NAVD 88, **GEOID12A.** .

Geotechnical Data

1. LGH is unaware of any missing data necessary for the design phase(s) of the BS-24 project; therefore no additional information is needed at this time.

LGH believes all information listed above is readily available, or will become available during the BS-16 construction phase, and should not require any significant additional expenditure.

SCOPE OF SERVICES - SUMMARY

Preliminary Design (30% Design) Phase: (Reference Appendix A, Section 6.1 and all sub-sections)

Project Feature Alternatives: Upon approval of this proposal by the NRCS and receipt of a Notice to Proceed, LGH will begin the 30% Design Phase of the BS-24 project. Based on the proposal request provided by NRCS and the discussions held at the scoping meeting on January 15, 2015, the 30% Design phase will consist of developing the project features; along with multiple alternatives (minimum of two) and an in-depth review of the documentation originally provided by the NRCS. LGH will establish the basic layout/size of the project based on the information provided and advise the NRCS on potential conflicts with existing infrastructure, existing hydraulic features, land rights, etc. LGH will present the design features with alternatives to the NRCS, CPRA, and USFWS (referred to as "Agencies"), along with preliminary construction cost estimates for each scenario. LGH will provide recommendations for the best suitable alternative for the project and address any questions or concerns posed by the Agencies responsible for the BS-24 project. After the alternatives have been presented to the Agencies, they will direct LGH on which design alternative to pursue for this project. After making their selection, the NRCS will authorize LGH to commence the Project Feature Design.

Project Feature Design: Upon approval of the Feature Alternative, LGH will begin developing the selected alternative project. This phase will focus on the actual design of the project features;

incorporating the project goals and objectives, along with comments or recommendations provided by the Agencies. The Project Feature Design will provide preliminary schematics and material quantities of the design features along with proposed alignments, elevations, cross-sections, etc. All documentation shall be presented to the Agencies in the form of a Preliminary Project Feature Design Report presentation, after which the Agencies will provide their comments and recommendations.

30% Design: After reviewing the Preliminary Project Feature Design Report, the NRCS will provide comments to LGH to be incorporated into the 30% Design Report. NRCS will also provide additional information such as land ownership documentation, potential oyster lease impacts, cultural resources assessments, monitoring, and administrative cost estimates, and updated information regarding project benefits; all of which shall be incorporated in the 30% Design Report. The 30% Design Report shall be prepared as outlined in the CWPPRA Standard Operating Procedures. Once completed, LGH will submit the report to the NRCS for review and commentary. The 30% Design Report will then be presented to the Agencies by LGH at the 30% Design meeting. Any comments received from the NRCS, will be incorporated into the report and re-submitted to NRCS as final deliverables.

Design Phase (95% Design): (Reference Appendix A, Section 6.2 and all sub-sections)

95% Design: Once the final 30% Design Report has been distributed to the NRCS and associated agencies for review and concurrence, LGH will then move into the 95% Design Phase of the project. This phase will focus on the final preparation of construction drawings and specifications; as well as, assessing the constructability of the project and estimated construction costs. LGH will participate in progress meetings, as needed, to keep the NRCS abreast of any issues encountered, pending deadlines, and progress of the design. LGH will submit a Preliminary 95% Design Report to the NRCS for their review and commentary, which will be incorporated into the final draft of the report. The preliminary report will include details of the project, description of any data collected by LGH, all calculations, detailed description of any variations from the Phase 0, draft construction drawings and specifications, and an updated construction cost estimate.

LGH will present the design to the NRCS and associated agencies at the 95% design meeting, after which LGH will be prepared to address any questions or concerns pertaining to the project design. After official comments from the NRCS on the Preliminary 95% report have been received, LGH will prepare the final draft of the report, construction drawings and specifications, and other deliverables, which will be submitted to the NRCS, so that funding can be secured for the construction phase of the BS-24 project.

Construction Phase (Construction Support): (Reference Appendix A, Section 7.0 and all sub-sections)

During the public bidding process, LGH will be required to attend a pre-bid meeting and site showing. The design engineer, along with any other required LGH personnel, shall attend both meetings to assist the NRCS in addressing any questions which may arise from potential bidders. Following the bid process, LGH will be required (as needed) to assist the NRCS in the evaluation of proposals from prospective bidders, highlighting the strengths, weaknesses, constructability, etc. of each proposal. LGH will play the role of an advisor in the process of selecting a contractor but shall not participate in the overall ranking of proposals as outlined in Section 7.2 of Appendix A.

During the construction phase of the project, LGH shall attend several conferences to assist the NRCS in addressing questions posed by the construction contractor. It is anticipated there will be a total of

twelve (12) conferences throughout the construction phase of the project. LGH will also review all applicable submittals provided by the construction contractor for compliance with the construction documents, constructability, approval/disapproval, etc. Also included in LGH's scope of work is to assist the NRCS with the preparation of any construction contract modifications. Modifications may require additional engineering drawings, specifications, data collection, etc. which shall be performed by LGH. All work performed by LGH to complete a modification shall be done so in accordance with Section 7.5 of Appendix A. In addition to the previous items, LGH will provide general assistance and communication, as well as attend pre-final and final inspections as stipulated by Sections 7.6 and 7.7 of Appendix A.

TIMELINE

After reviewing the proposed scope of work and discussing the projected timeline (with NRCS personnel) for the design phases of the BS-24 project; it has been recommended by all parties that the 2015 Timeline (provided by NRCS) be adhered to through the 30% Design Phase. Due to close proximity and relationship of the BS-24 and BS-16 projects, it is imperative that the BS-24 timeline be re-evaluated at the end of the 30% Design Phase; incorporating the progress of the BS-16 project. As mentioned previously, borrow area "A" is a feature associated with both projects and modifications to the size and/or location of the borrow area may be required after the BS-16 project is complete. The BS-16 as-built drawings/survey will also play a vital role in the 95% Design Phase of the BS-24 project, thus likely requiring an extension of the timeline into 2016.

LGH has slightly altered the suggested 2015 Timeline provided by NRCS through the 30% Design Phase as shown in Appendix B.

PERMITS

The responsibility of LGH to obtain and/or renew any permits necessary to complete the design phase of the BS-24 project has been clarified to mean that LGH will prepare the necessary environmental permit drawings (coastal use permit and USACE permits) for the project. The NRCS will be responsible for submitting the permit application and drawings to the associated regulatory agencies and provide any additional correspondence needed to obtain these permits. It is our understanding that LGH will not be responsible for the following items, which are commonly associated with the environmental permitting process:

- Acquisition of land rights
- Wetland Delineation
- Water Bottom Assessment (oyster fisheries resources)
- Hydrologic and Hydraulic (H&H) Impact Analysis
- Storm Surge Analysis/Impacts
- DOTD Permits
- U.S. Coast Guard Permits

LGH does not anticipate any additional permits will be required to complete the design phase of the BS-24 project.

LIMITATIONS ON AUTHORITY OF THE DESIGNER

LGH has reviewed Section 8.0 of Appendix A, and understands completely the terms and conditions of the Designer's responsibility and authority pertaining to the BS-24 project.

APPENDIX G
WETLAND VALUE ASSESSMENT (WVA)

[CWPPRA

Terracing and Marsh Creation South of Big Mar

Candidate Project
for the
Twenty Second Priority Project List
of the
Coastal Wetlands Planning, Protection and Restoration Act

Proposed by

U. S. Fish and Wildlife Service

Draft Project Information Sheet
for
Wetland Value Assessment (WVA)

October 10, 2012

Project Name: Terracing and Marsh Creation South of Big Mar

Sponsoring Agency - U. S. Fish and Wildlife Service
Contact: Angela_Trahan@fws.gov; 337-291-3137

Project Location/Area

The project area is located in the Breton Sound Basin (Region 2) in Plaquemines Parish. The 334 acre marsh creation area is located along the western shoreline of Lake Lery, and the three terrace fields encompassing approximately 1,000 acres are located in the large open water areas to the west of the marsh creation area and south of Big Mar and Delacroix Canal.

Problem

From 1932 to 1990, the Caernarvon Mapping Unit lost 14,240 acres of its marsh. Prior to Hurricane Katrina, the greatest lost documented occurred between 1956 and 1974 and coincided with Hurricane Betsy and extensive canal building. Hurricane Katrina in 2005 devastated the area resulting in substantial marsh loss. According to USGS Open File Report (2006-1274), approximately 39 square miles of marsh around the upper and central portions of Breton Sound were converted to open water by ripping of the marsh or by marsh submergence. One of the most significant restoration tools used in this basin is the Caernarvon Freshwater Diversion project which has a diversion capacity of up to 8,000 cfs, but has been operated at less than 2,000 cfs. In recent years, the operational plan of the Caernarvon Freshwater Diversion has proposed higher water discharge rates during the winter and spring to address hurricane impacts.

Although Caernarvon is being operated primarily as a freshwater diversion, Lake Pontchartrain Basin Foundation (LPBF 2011) has documented significant wetland growth in the Big Mar area of the Caernarvon Delta since 2004. Wetland growth appears to be accreting annually at a more rapid rate as the platform has reached the emergent threshold to support marsh vegetation. In 2005, Hurricane Katrina pushed marsh balls from the surrounding marsh, including the proposed project area, into the southwest portion of Big Mar Pond. The result is the formation of a proto-delta that acts as a sediment trap. The rate of wetland expansion in the Big Mar Pond after 2004 is 14 times (1400%) greater than before with an estimated annual rate of approximately 80 acres per year. LPBF estimated that 40% of Big Mar Pond is emergent wetlands. Once Big Mar reaches its capacity the potential for wetland accretion will move further down the basin. The proto-delta is a good indication that terracing within the large open water areas south of Big Mar would facilitate sediment trapping and potentially emergent marsh growth. Further, research by Snedden (2006) indicates that the diversion supplies over 100,000 tons of sediment per year. This amount can be increased to over 500,000 tons per year by diverting river water during high and, especially, rising river stages. Sheet flow across the marsh occurs when the diversion is operated at 3,500 cfs and greater. The PULSES study also determined that under high flow conditions (6,500 cfs) 30% of the flow is discharged over the marsh (Day et al, 2003).

The Information from Caernarvon Freshwater Diversion Project Report (2006) offers the following information relative to sediment distribution prior to Hurricane Katrina. Since that Report the landscape has significantly changed (i.e., delta formation in Big Mar and continued

expansion of large open water areas to the south), and sediment distribution has likely changed as a result.

> Dr. John Day and Dr. Jim Cowan supplied a summary of research at Caernarvon from a variety of researchers at LSU and ULL. …Sediment distribution within the estuary is primarily down the main channels of Bayou Terre aux Boeufs and Reggio Canal/River aux Chene until the water level reaches marsh level. Sheet flow then contributes about 10-20% of the sediment load to the marsh. Short-term deposition follows expected seasonal and spatial trends with the greatest deposition occurring in spring and during high river stages and closest to the estuary head.
>
> Sediment studies indicate that the upper Breton Sound marshes are sustainable and the long-term deposition is around 2.6-3 mm/year. Of the suspended sediment load in the Caernarvon outfall about 40% stays in Big Mar, 25% travels down Bayou Mandeville toward Lake Lery, <u>about 24% exits to the marshes south of Big Mar, and 11% flows down Delacroix canal toward Reggio and Manual canals</u>.

A number of projects have been proposed in the Caernarvon outfall area through programs such as CWPPRA, LCA, and Supplemental WRDA funding, with only a few being constructed or authorized for construction including:

- Caernarvon Freshwater Diversion Project (BS-08) – Freshwater diversion with up to an 8,000 cfs capacity.

- Caernarvon Diversion Outfall Management project (BS-03a) - A combination of culverts, plugs and spoil bank restoration allows water from the channels to flow into the marsh interior and be retained in the marsh for a longer period of time.

- South Lake Lery Shoreline and Marsh Restoration (BS-16) – located along the southern and western shoreline of Lake Lery, and expected to be constructed in spring of 2013.

- The Supplemental 4 Caernarvon project would direct 250 cubic feet per second (cfs) into the 40 Arpent Canal to influence areas to the east, and is expected to be awarded in September 2013.

- St. Bernard Parish CIAP Project – The Parish is currently seeking engineering and construction contract work to facilitate project development.

- Braithwaite Migitation Area – 30 acre marsh creation project to mitigate for Braithwaite levee repairs.

- LPBF Cypress Plantings – cypress trees were planted in 2010-2011 on newly formed delta within Big Mar.

Without restoration, this region will continue to see the coalescence of water bodies and higher wave generated erosion rates, and a greater influence associated with the open brackish Black Bay system especially during periods of reduced Caernarvon flow. Reestablishment of the Breton Sound marshes is dependent on both the maintenance and reconstruction of the marsh framework as well as optimizing the flow and sediments delivered by the Caernarvon Freshwater Diversion. The 2011 BS-03a Monitoring Report (Moore et al 2011) recommended marsh creation and terracing within large open water areas as a restoration plan to combat marsh loss in the area.

Historic Land Change Data

In 1932, this unit had 73,730 acres of marsh. A major cause of loss in this unit has been storm related, as hurricanes drove higher saline waters into the fresh/intermediate northern portion. Altered hydrology, caused by numerous canals, has exacerbated the storm-related loss and caused greater tidal scour and saltwater intrusion. Even the massive amounts of sediment deposited in the 1920's could not prevent loss once the river levee was repaired. On the southern edges of the unit, wind related erosion has been and continues to be fairly extensive. Between 1932 and 1990, a total of 14,240 acres of marsh were lost in this unit. The greatest land loss (6,560 acres) occurred from 1956-1974 and coincided with Hurricane Betsy and extensive canal building. About 3,320 acres were lost from 1932-1956, and 3,380 acres were lost from 1974-1983. From 1983- 1990, the loss was reduced to only 980 acres (LCWCRTF 1999).

Subsidence is high in the Caernarvon Mapping Unit, 2.1-3.5 ft/century, (LCWCRTF 1999), Using an average of 2.8 ft/century, the project area would experience 0.56 feet of subsidence in 20 years based on that data. However, sediment input from the diversion is believed to offset RSLR (LDNR 2006). Studies done in the Caernarvon area pre-Hurricane Katrina indicate that deposition in the marsh is 0.84 feet over 20 years, assuming the mineral component alone would influence open water bottom elevations it is estimated that half of that, or 0.42 feet over 20 years (personal communication with Erick Swenson), would deposit within the open water areas.

Goal

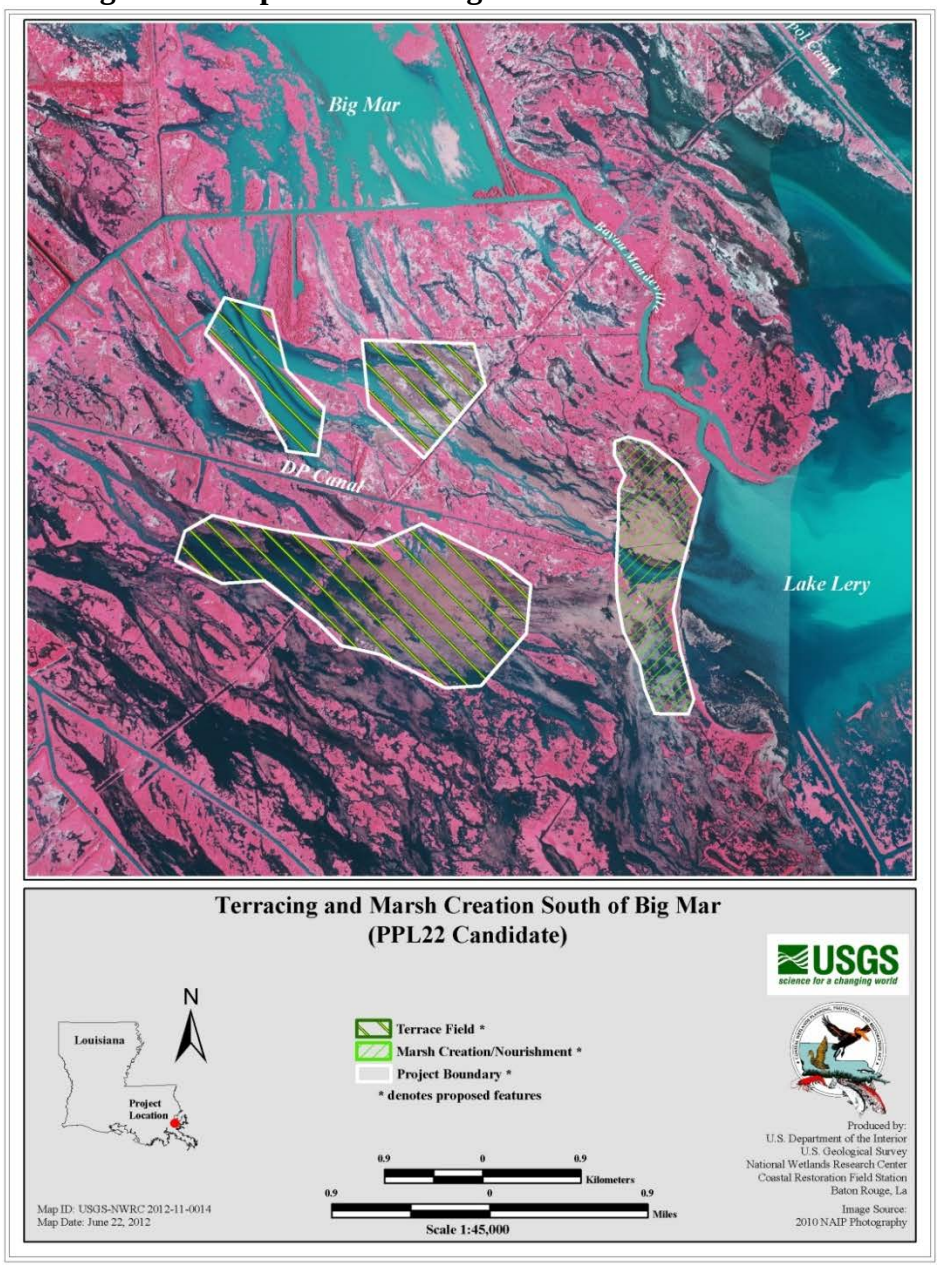
The primary goal is to create terraces in the shallow open water areas within the Caernarvon Diversion outfall area. Terraces will reduce wave fetch in the large open water areas and promote conditions conducive to growth of submerged aquatic vegetation. Additional benefits may be achieved through capturing suspended sediments. Marsh creation is also proposed to reestablish the western shoreline of Lake Lery in association with the Lake Lery Shoreline Restoration Project (BS-16).

Project Features

Approximately 65,000 linear feet of terraces will be constructed with in-situ material to reduce

fetch and turbidity and capture suspended sediment in approximately 900 acres of shallow open water, resulting in 37 acres of marsh creation, as determined by the Eng WG cost template. The terraces would have a 20-foot-wide top width and would be constructed to an elevation of 2.0 feet NAVD88, geoid 99, with 5 to 1 side slopes. Vegetative plantings are proposed including two rows along the crown and two rows along each slope of the terraces. Average water depths in the terrace fields are approximately 2.4 feet (using CRMS 0117 average water elevations).

Figure 1. Proposed Terracing and Marsh Creation Areas.



Sediments will be hydraulically dredged from Lake Lery and pumped via pipeline to create

approximately 287 acres and nourish 47 acres of marsh along the shoreline of Lake Lery and behind the BS-16 shoreline protection feature. Dredged material would be pumped into containment dikes to achieve a target marsh elevation of 1.8 ft NAVD 88, geoid 99 (6 inches above existing marsh elevation; CRMS 0117). The dikes would be gapped or degraded no later than 2 years post construction to allow for estuarine organism access. Water depths in the marsh creation cell are relatively shallow, averaging 2.3 feet.

Monitoring Information

Table 1 shows the results of former CWPPRA marsh creation project monitoring information. Numerous successful CWPPRA beneficial use and dedicated dredging marsh creation projects show that placement of dredged material in shallow open water areas can restore vegetated marsh within a few years post construction. Limited monitoring data indicates that natural revegetation and revegetation due to vegetative plantings may range from 0% to 40% cover after one growing season (Bayou Grand Liard WVA 2006).

Table 1. CWPPRA Marsh Creation Project Monitoring Results.

Project	**Vegetation Results**	**Comments**
Queen Bess Island MC (BA-05B)	28%/18 months	15.3 acres with 152,000 cuyds; average 9,335 cuyds/acre.
Barataria Bay WaterWay Wetland Creation (BA-19)	0%/2 yrs; due to low elevation of marsh creation area	9 acres
Lake Chapeau MC and HR (TE-26)	0%/1st year; 40%/1st year after planting; 80% cover in areas above mean water level.	168 acres
West Belle Pass Headland Restoration	20-30% cover/1st season	
Project	**Vegetation Results**	**Comments**
Bayou Labranche Wetland Restoration (PO-17)	70%/2 yrs post construction; 78%/3 yrs.	
Sabine Refuge Marsh Creation Cycle 1	52% vegetated 2 years post construction (compared to reference area which was 78% covered)	125 acres/800,000 cuyds; 6,400 cuyds/acre Slurry 5.0 ft high; 3.7 NAVD 88
Sabine Refuge Marsh Creation Cycle 3		230 acres/ 800,000 cuyds; 4,950 cuyds/acre

Terracing Projects

As described in the Fritchie Marsh and Terracing project (PPL 21) WVA, there are different terrace designs for different applications and project goals. Bay terraces and interior terraces are the two

general categories. These designs differ by cross section and alignment based on project objectives and site-specific conditions. Depending on the design, application, and location, terrace project benefits range from protecting marsh, trapping sediment, increasing SAV coverage, and reducing turbidity. Of these benefits, only some have been quantified due to limited monitoring and the short time terraces have been constructed. Generally, terraces in bays are intended to trap sediments in addition to creating marsh, reducing shoreline erosion, and promoting SAV growth. Terraces in interior marsh areas generally are not assumed to create marsh from accretion, although early projects anticipated that effect.

The Little Vermilion Bay Sediment Trapping project was the only CWPPRA project that had monitoring results relative to the sediment trapping abilities of terraces in bay areas. In 2002, 3 years after construction, approximately 200 acres of mudflat was created within the terrace field, 18% of the project area compared to 13% of the reference area accreting sediments. The monitoring report expresses confidence that these areas would transition into emergent marsh (Castellanos et al, 2004). Also, many of the borrow areas have filled in (Foret, personal communication via Fritchie Marsh Creation and Terracing project WVA, PPL21).

The Sabine (West Cove) Terracing Project, an interior marsh accretion project showed no long term accretion benefits; created marsh above the waterline with some lateral spread due to sedimentation and plant growth or sloughing; and two years after planting the terraces were completely covered by vegetation.

Sabine NWR terraces showed no growth in SAVs as a result of the project. However, Pecan Island CWPPRA project saw a 30% increase in SAV in the overall project area according to the 2004 Monitoring Report.

V1 - Emergent Vegetation

Historical and Present Vegetative Communities

The Caernarvon mapping unit marshes have been in a constant state of change. The floods of the 1920's caused natural crevasses to form and inundated the area with freshwater, sediments, and nutrients. By 1949, the fresh and intermediate marshes had transitioned to saline and brackish communities. Since 1991, the operation of the Caernarvon diversion structure has resulted in fresh marsh in the vicinity of Big Mar and around Lake Lery (LCWCRTF 1999). Hurricane Katrina in 2005 brought high salinities and caused scouring in the areas of fresh/intermediate marshes.

Using Helicopter Survey:

1949	Brackish
1968	Intermediate
1978	Brackish
1988	Brackish
1997	Intermediate
2001	Intermediate
2007	Fresh

Dominant vegetation reported at CRMS 0117 include dotted smartweed (*Polygonum punctatum Elliot*), American cupscale (*Sacciolepis striata*), coast cockspur grass (*Echinochloa walteri*), and bulltongue (*Sagittaria lancifolia*). CRMS survey data from CRMS station 0117 has classified the area as intermediate between 2007 and 2011 excepted for 2010 when the structure was operated at higher diversion rates during the BP oil spill. It is recommended that the intermediate model be used for this analysis.

Using CRMS Survey:

2007	Intermediate
2008	Intermediate
2009	Intermediate
2010	Fresh
2011	Intermediate

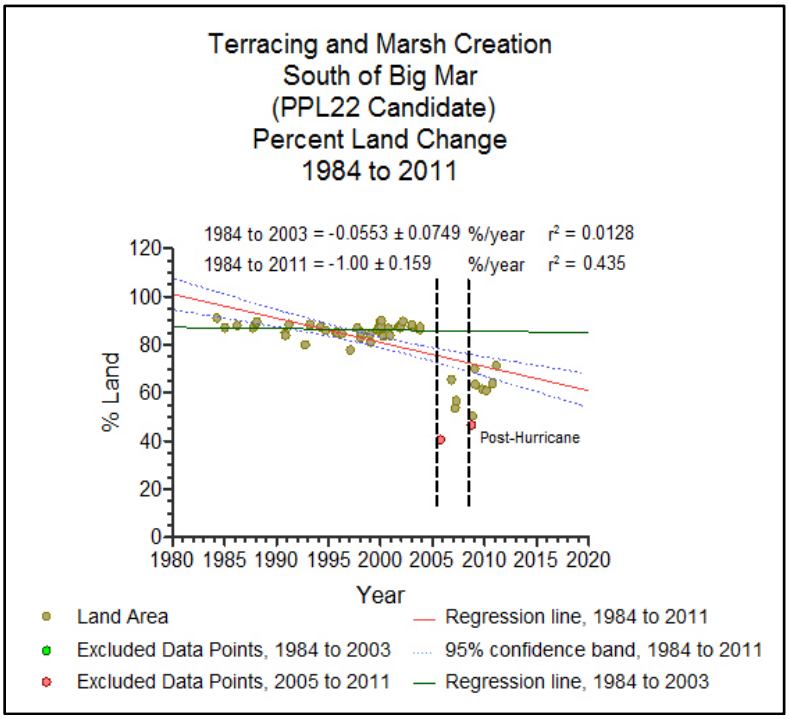
Soil Types

The Plaquemines Parish Soils Survey characterizes the soils in the project area as Clovelly and Lafitte series. Both series are organic soils typically found in brackish marsh that is poorly drained and ponded most of the time. The marsh creation area is dominated by the Clovelly muck and the terrace fields are composed primarily of Lafitte muck (Trahan 2000).

Land Loss Data

For interior marsh loss, USGS evaluated two periods (1984-2011 and 1984-2003) using a linear regression of percent land values demonstrated in the graph below. Because the BS-16 project is authorized for construction shoreline erosion rates are not a factor in future loss rates. Therefore, USGS omitted shoreline erosion rates by using the 2010 shoreline. Large, historically open water areas were delineated and omitted within the extended boundary. USGS excluded some data points from the regression analyses due to low and high water events. To incorporate losses associated with episodic tropical storm events, it is recommended that the rate of -1.00% per year be used for this assessment.

Figure 2. Percent Land Change for the Extended Project Boundary



V1 - Emergent Vegetation

<u>Project Area Acreage</u>
Two years of interior loss (1984-2011 marsh loss rate of 1.00 %/yr) was applied to the 2010 USGS TM data to arrive at TY0 project acreages.

<u>FWOP</u>

TY0	(10%)
Marsh:	140 ac
Water:	1,256 ac
Total:	1,396 ac
TY1	(10%)
Marsh:	139 ac
Water:	1,257 ac
Total:	1,396 ac
TY20	(8%)
Marsh:	115 ac
Water:	1,281 ac

Total: 1,396 ac

FWP

FWP acreage includes the marsh creation (287 ac) and nourishment areas (47 ac), the acreage created as a result of the terrace fields (37ac) and the existing acreage within the terrace fields (93 ac) that would not be impacted by the project. The loss rates for the marsh creation/nourishment areas and the terrace fields would be reduced by 50%, and the loss rate for the existing acreage within the terrace fields would be reduced by 33% assuming that the terrace fields would reduce wave fetch and shoreline erosion. This assumption is based on a broad inference from Morton et al. 2005, and was first applied to the Fritchie Terracing and Marsh Creation Project for PPL 21.

Per CWPPRA conventional methods, the following FWP functional marsh credit assumptions were applied:

Marsh Creation – no plantings = 10% @ TY1, 30% @ TY3, and 100% @ TY5
Marsh Nourishment = 50% @ TY1 and 100% @ TY5
Marsh Creation – Terracing (with plantings) = 25% @ TY1 and 100% @ TY3

TY1	(11 %)	
Marsh:	154 ac	(adjusted functional marsh acreage)
Water:	934 ac	
Total:	1,396 ac	
TY3	(19 %)	
Marsh:	259 ac	(adjusted functional marsh acreage)
Water:	939 ac	
Total:	1,396 ac	
TY5	(32 %)	
Marsh:	452 ac	
Water:	944 ac	
Total:	1,396 ac	
TY20	(30 %)	
Marsh:	417 ac	
Water:	979 ac	
Total:	1,396 ac	

V2 - Submerged Aquatic Vegetation (SAV)

Annual and seasonal changes (e.g., salinity, diversion operation, etc.) could affect aquatic vegetation in the area. Based on field observations the marsh creation cell and the southern terrace field (i.e., TF 3) have 100% SAV coverage. The northern terrace fields comparatively had less of an SAV presence. FWS estimates from the WVA field trip had 80% for terrace field

2 and 10% for terrace field 1. Despite the large open water areas being influenced by wind fetch and higher flows associated with diverted waters, SAVs seem to proliferate overall. The area is relatively shallow and the diversion is not operated during the summer months when the river is at low stages and SAV abundance is high. Also, nutrient rich waters supplied by the diversion likely contribute to this area being conducive for SAV production.

FWOP

Table 3. FWOP Percent Submerged Aquatic Vegetation

% SAV FWOP

	TF 1	TF 2	TF 3	MC	
% of ow area	14.8%	11.6%	50.8%	22.8%	
% SAV	10.0%	80.0%	100.0%	100.0%	**Total**
TY0	1.5%	9.3%	50.8%	22.8%	84%

With the influence of the diversion, existing conditions are expected to remain unchanged under the FWOP scenario. Subsidence was not considered to influence SAV reduction due to sediment input offsetting RSLR in the upper reaches of the basin (LDNR 2006).

TY0-20 = 84%

FWP

TY1 – Due to disturbances related to construction activities it is assumed that no SAVs would be present @ TY1. = 0%

TY3 –Assume SAV conditions would recover to half of FWOP conditions.
84%*0.5 = 42%

TY5 – FWOP coverage restored = 84%

TY20 – Based on Workgroup consensus, it was decided that TF1 would increase to 50% and TF2 would increase to 90%.

FWP TY20

	TF1	TF 2	TF 3	
% of area	19%	15%	66%	
% SAV	50%	90%	100%	
TY0	0.10	0.13	0.66	88.9%

V3 - Interspersion

FWOP

The 1,396 project area contains 140 acres of marsh at TY0 (10%) and losses 2% by TY20. Class 5 is characterized as a range between 0 and 10% marsh.

The interspersion tool classified the terrace fields as Class 5 and the marsh creation cell as Class 4.

TY0-20: 76 % Class 5, 24% Class 4

FWP

The marsh creation/nourishment area is 24% of the project area. At TY5 the marsh creation/nourishment area lost approximately 3% marsh, and at TY20 the marsh creation/nourishment area lost 9% of marsh (30 acres). CWPPRA conventional methods for interspersion were applied to the marsh creation area. Terrace spacing is currently designed at 300-400 ft apart; therefore, the terrace fields are classified as Class 4.

TY1 = 24% Class 5(marsh creation platform assumption); 76% Class 4
TY3 = 24% Class 3(carpet marsh assumption); 76% Class 4
TY5 = 24% Class 1; 76% Class 4
TY20 = 24% Class 1; 76% Class 4

V4 - Shallow Open Water Habitat (percent open water <1.5 ft)

FWOP

The following table provides a comparison between NAVD88 geoid 03 and geoid 99. Generally, geoid 03 is 0.5 feet lower than geoid 99.

		NAVD88 Geoid 03		NAVD88 Geoid 99	
	TME	1.3		1.8	*
BS-16	Existing BE	-1.7		-1.2	*
BS-16	AME	0.8		1.3	
BS-16	AW depth	2.3			
CRMS0117	AWE			1.5	
	AME			1.3	
CRMS4355	AWE			0.8	

Marsh Creation

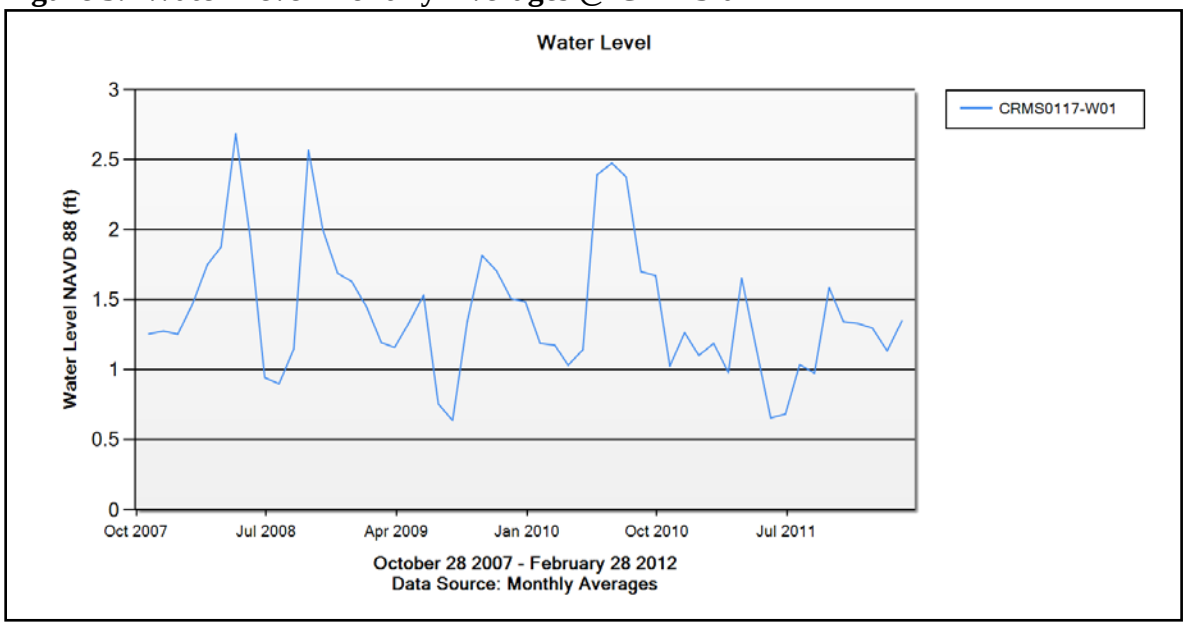
Bottom elevations were collected for the BS-16 project in NAVD 88 (geoid 03). Those elevations were subtracted from the BS08-09 (BS-08 monitoring gage) average water level of

+0.58 ft NAVD 88 (geoid 03). Of the 2,081 data points, 356 data points or 17% (49 acres) of the open water is less than/equal to 1.5 feet.

Terrace Fields

Water depths within the terraces fields were relatively uniform except for pipeline ROWs and areas around levee gaps. The terrace fields water depths taken during the WVA field trip were corrected using the average water elevation at the time of the survey subtracted from the mean water elevations for CRMS 0117. The average water elevation during the field trip, **0.8' NAVD 88, geoid 99**, was obtained from the DCP BS-09 gage near the boat launch and confirmed using CRMS 4355 (see Appendix). The mean water elevation for the area, **1.5' NAVD 88, geoid 99**, was determined using CRMS 0117 data from October 2007 to February 2012. Average water elevations determined by CRMS 0117 are 0.7' higher than CRMS 4355 because of the influence of the diversion (Figure 3).

Figure 3. Water Level Monthly Averages @ CRMS 0117



Of the 142 data points, 4 data points or 3% (29 acres) of the open water is less than/equal to 1.5 feet.

It is assumed that marsh loss within the FWOP life would convert to SOW. The marsh lost in 20 years (25 acres or 2% of the total project area) was added to the total SOW @ TY20.

Sediment deposition within the project area associated with the freshwater diversion is assumed to keep up with subsidence based on studies done throughout the diversion influence area. While subsidence has been documented at 0.56 feet over 20 years, deposition of mineral sediments is estimated at 0.42 feet over 20 years. Therefore, subsidence is not considered under future with and future without project.

TY0 SOW = 49+29/1256 = 6%

TY20 SOW = 49+29+25/1281 = 8%

FWP

For TY 1-20 the marsh creation/nourishment area is assumed to be 100% SOW. Through the construction of the terrace fields, the terrace field side slopes create SOW (22ac) and the borrow areas convert shallow open water areas to deeper areas (73 acres). Under FWP, 93 acres of marsh within the terrace fields are not directly influenced by the project features and historic marsh loss rates area applied to this marsh. Marsh loss associated with these acres is converted to SOW. After subtracting the SOW acres and borrow areas, the remaining acres are assumed to consist of the same FWOP percentage SOW (3% or 25 @ TY1-5 and 26 @ TY20).

Table 4: Shallow Open Water Assumptions

FWOP			FWP			
	TY0	TY20	TY1	TY3	TY5	TY20
Marsh Cell						
OW	287		2	5	8	32
SOW (%)	17%	17%	100%	100%	100%	100%
SOW (ac)	**49**	**49**	**1.7**	**5.0**	**8.3**	**31.9**
Terrace Fields						
Total OW	969		933	934	936	947
borrow areas (deep)			73	73	73	73
SOW						
side slopes (SOW) ac			22	22	22	22
3% SOW			25	25	25	26
FWOP existing marsh within terrace field			1	2	3	12
TF SUM SOW (ac)	**29**	**29**	**47.8**	**49.0**	**50.3**	**59.3**
SOW %	3%	3%				
Total PA FWOP Marsh Loss		**25**				
Weighted Total						
Total OW	1,256	1,281	934	939	944	979
Total SOW (ac)	78	103	49.4	54.0	58.6	91.1
Total SOW(%)	**6%**	**8%**	**5%**	**6%**	**6%**	**9%**

TY1 5%
TY3 6%
TY5 6%
TY20 9%

V5 – Salinity

Salinity is influenced greatly by the operation of the diversion. Yearly mean salinities for project and reference strata have averaged <1 ppt since data collection began from 2000 to 2005 for project specific data and from 2007 to 2010 for CRMS data (Moore 2011). 2011 Monitoring Report for BS-03a references a salinity spike in 2009 that cannot be attributed to any episodic event such as a storm of drought condition. However, to incorporate storm-related salinity spikes it is recommended that the average of 2009 through 2011 growing season averages be used for FWP and FWOP conditions.

Table 5: CRMS 0117 (2009-2011) (Growing Season Average)

2009	2010	2011	2009-11 Average
2.2	0.8	0.9	1.3

<u>FW & FWOP</u>
TY0-20 1.3 ppt

V6 – Estuarine Organism Access

The BS-16 project would construct a shoreline enhancement feature along the lake rim. While this feature would obstruct organism access on a normal to high tide, open access to the marsh creation site would be possible through the broken marsh to the south and the canal system and open water areas to the west.
FWOP
TY0- TY20 = 1.0

Containment dikes around the marsh creation area will result in a plug value during construction, while the terrace field would remain "open". TY1 is weighted to account for that.

FWP:
TY1 (0.0001*0.24)+(1*0.76) = 0.760024 (plug value based on containment dikes)
TY3 1.0 (containment dikes degraded @ TY 1)
TY5 1.0
TY20 1.0

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Appendix

Supporting Information

USGS Landloss Spreadsheet
Cost Estimate Supporting Calculations

APPENDIX H
CAERNARVON – LAKE LERY LAKE RIM RESTORATION PROJECT (BS-16) BORROW SITE IMPACT ANALYSIS

CAERNARVON – LAKE LERY
LAKE RIM RESTORATION PROJECT (BS-16)
BORROW SITE IMPACT ANALYSIS

FINAL
MAY 5, 2011

CAERNARVON – LAKE LERY
LAKE RIM RESTORATION PROJECT (BS-16)
BORROW SITE IMPACT ANALYSIS

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May 5, 2011

EXECUTIVE SUMMARY

STWAVE modeling was performed to evaluate the wave impacts of two proposed borrow areas in Lake Lery, Louisiana, as part of the Coastal Wetlands Planning Protection and Restoration Act Project BS-16: Caernarvon-Lake Lery Lake Rim Restoration Project. Lake Lery is an inland waterbody with the predominant influence on wave generation and propagation being surface winds. Proposed borrow area locations were provided by the Natural Resources Conservation Service (NRCS). Bathymetric data were obtained using field survey and geospatial gateway data. Seven modeling scenarios were identified based on statistical analysis of 40-year wind data. Wave modeling was carried out using the STWAVE nearshore wind-wave growth and propagation model.

There were no significant impacts to wave heights and wave direction changes along the shoreline for any of the seven modeled scenarios. Some impact was observed along the edge of the borrow areas but the impact was dissipated in the fetch between the borrow area and the shoreline. Since along-shore wave impacts correspond to longshore sediment transport pattern alterations, it can be concluded that there is no impact on the latter due to the proposed borrow area excavations.

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1.0 INTRODUCTION

STWAVE modeling was performed to evaluate the wave impacts of two proposed borrow areas in Lake Lery, Louisiana, as part of the Coastal Wetlands Planning Protection and Restoration Act Project BS-16: Caernarvon-Lake Lery Lake Rim Restoration Project (Louisiana Coastal Wetlands Conservation and Restoration Task Force 2009). Lake Lery is located in St. Bernard Parish and Plaquemines Parish, Louisiana. Figure 1.1 shows the project site and location of the two potential borrow sites. The approximate coordinates of the lake are Latitude 29.7991 and Longitude -89.8303. Marshes are located along the northern and southern shorelines of the lake. Oliver Canal, Creedmore Canal, Bayou Mandeville, Marine Canal, and Bayou Lery are the primary channels in the vicinity of Lake Lery (Figure 1.1). The lake experiences wind-induced waves that pose a risk of damage to shoreline and accelerated loss of adjacent, as well as interior, marshes. Two potential borrow areas are to be excavated within the lake with the excavated material being used for shoreline restoration. Locations of the proposed borrow areas were provided by the Natural Resources Conservation Service (NRCS). The depth of the proposed borrow areas was 10 ft below the existing bottom elevation. This report summarizes the wave modeling approach, procedures, results, and significant findings for the proposed borrow area excavations within Lake Lery.

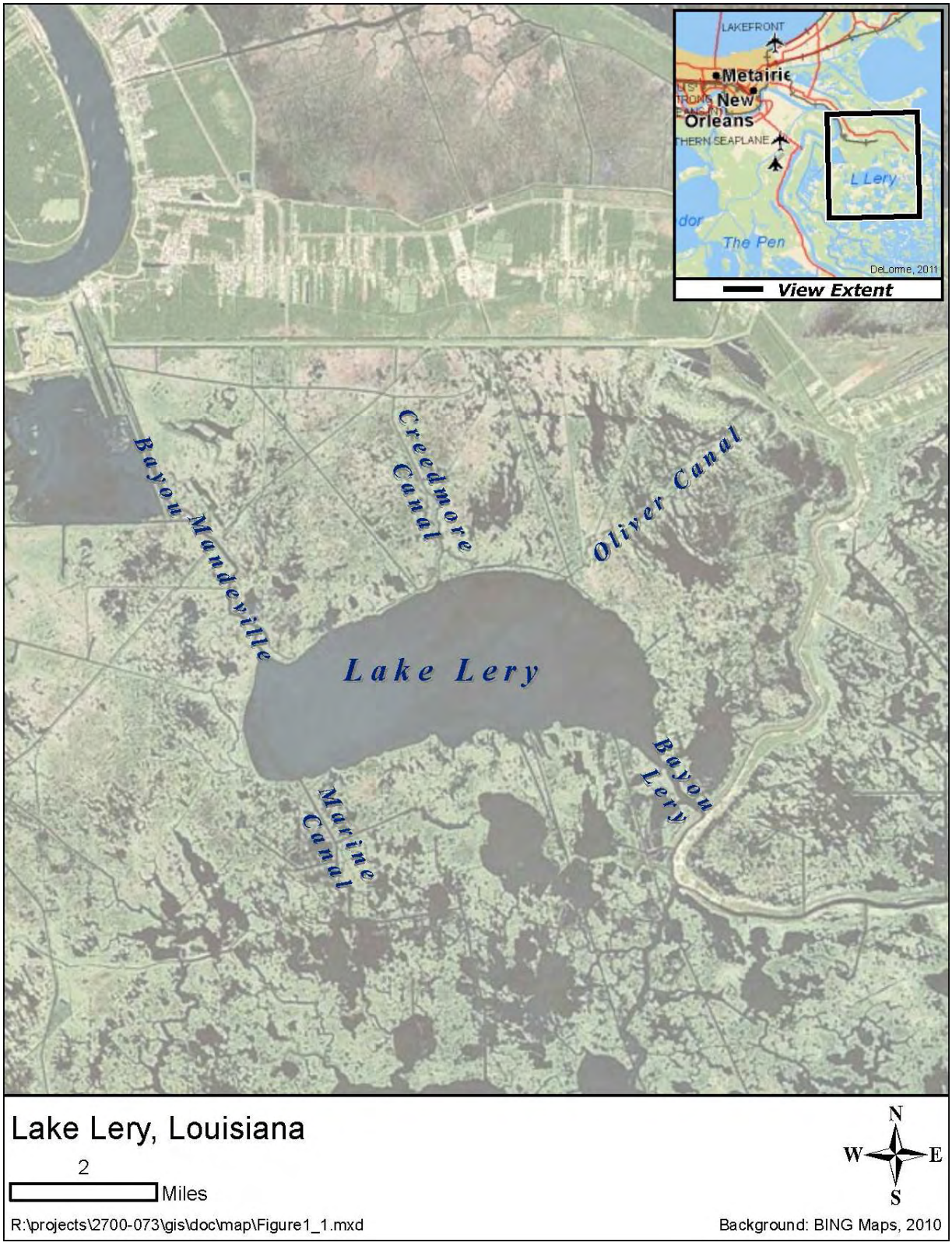

Figure 1.1. Project location map.

2.0 OBJECTIVES

The objective of this study was to evaluate impacts of potential borrow area excavations on wave heights, refraction (direction change), and sediment transport patterns. An appropriate wave model capable of simulating wave phenomena was to be selected and used to determine coastal changes over the length of the shoreline. If the model outputs indicated significant alterations in wave parameters and patterns, alternative runs were to be carried out to identify suitable borrow sites within the lake.

3.0 WAVE MODEL SELECTION

STWAVE (STeady-state spectral WAVE model) version 3.0 was chosen for this study since the model features directly corresponded to the requirements of the scope of work. Surface Modeling System (SMS) version 10.1 (Aquaveo Inc.), which allows for external execution of STWAVE 3.0 and provides pre- and post-processing tools, was used as the modeling interface.

STWAVE is a phase-averaged, steady-state, finite difference model (Resio 1987, 1988; Davis 1992; Smith et al. 1999, Smith et al. 2001). STWAVE incorporates near-shore wind-wave growth and propagation, radiation stress calculations, and identification of active wave-breaking regions. The main assumptions of the model are:

- Bottom slopes are mild;
- Wave reflection is negligible;
- Offshore wave conditions are spatially homogeneous;
- Waves, currents, and winds are steady;
- Refraction (i.e., wave direction change) and shoaling are linear;
- Currents are uniform vertically;
- Bottom friction is negligible; and
- Radiation stress (i.e., wave energy per unit area) is linear.

4.0 DATA COLLECTION AND ANALYSIS

4.1 Bathymetry

Existing topographic surface data were obtained from the NRCS Geospatial Data Gateway. T. Baker Smith, Inc. provided survey data for transects within the boundaries of the lake. The survey data were merged with the NRCS topographic map. A consolidated surface was developed from this merged surface for input bathymetry. Figures 4.1 and 4.2 show the bathymetry for the existing and proposed conditions, respectively. The proposed Borrow Area A is a pentagon with the following dimensions (clockwise starting from the pentagon base): 4,927 ft by 1,171 ft by 2,327 ft by 2,756 ft by 1,300 ft, located approximately 1,210 ft east of the western shoreline of Lake Lery. Borrow Area B abuts the southern shoreline, and is 5,274 ft long by 1,310 ft wide. The approximate areas of Borrow Areas A and B are 0.248 square mile each. The borrow material yield for an excavation depth of 10 ft and 1:1 side slopes will be approximately 2.65 million cubic yards from each borrow area.

The existing bathymetry in the vicinity of Borrow Area A is relatively uniform with depths increasing away from the shoreline, except at the southwestern end where the landmass protrusions and marsh-like extensions exist. The fetch (distance over which wind blows before the wind-induced wave reaches the shoreline) for Borrow Area A is 122 ft (400 m) and is, by and large, constant along the extents of Borrow Area A.

Borrow Area B is located offshore from an undulating coastline with multiple landmass projections and marsh-like extensions. The fetch of Borrow Area B varies between a few feet to up to 61 ft (200 m) towards the southwestern corner of Borrow Area B.

4.2 Wave and Current Data

Since Lake Lery is an inland lake with no hydraulically significant channel connections to the Gulf of Mexico, there are no tidal current influences on the lake. Wind-driven waves are the only significant inputs to the STWAVE model.

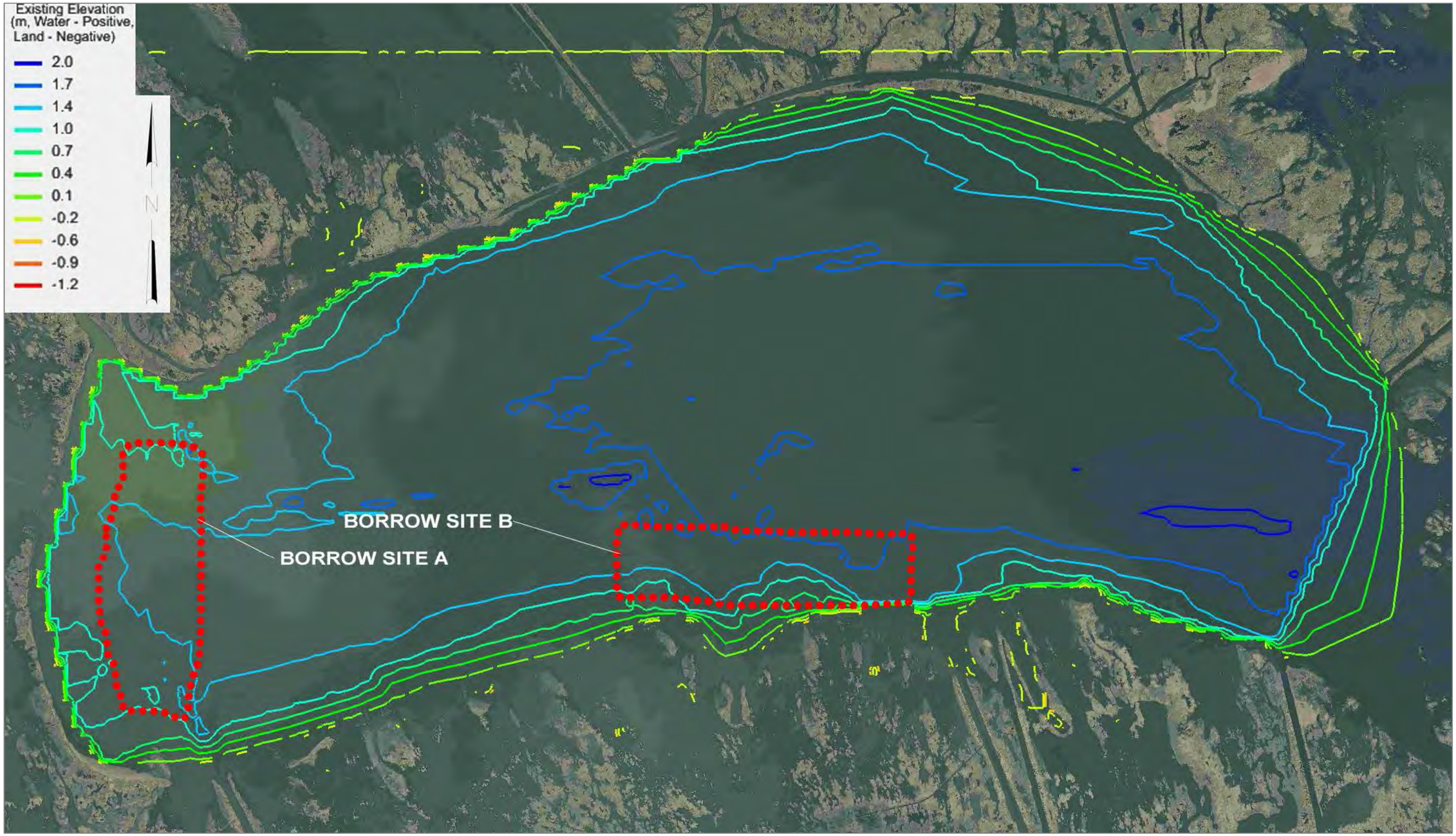

Figure 4.1. Existing bathymetry.

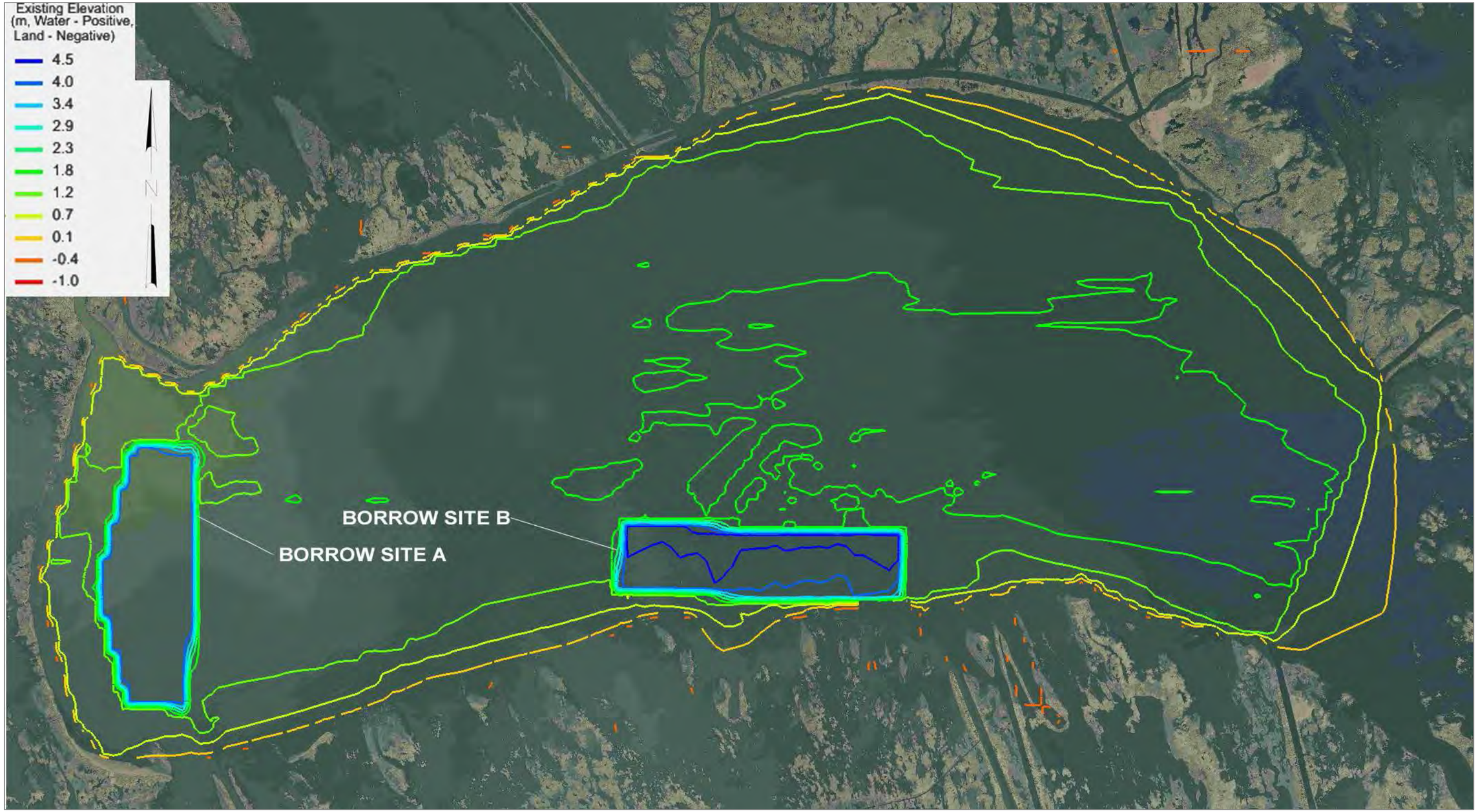

Figure 4.2. Proposed bathymetry.

4.3 Wind Data

Wind rose diagrams and wind data were obtained from the National Climatic Data Center (NCDC) National Environmental Satellite, Data, and Information Service (NESDIS) for the New Orleans Airport (Station 12916) and New Orleans Lakefront (Station 53917) locations. The stations are located approximately 30 and 20 miles northwest of Lake Lery, respectively. Statistical analysis of 40 years of wind data (1971 to 2011) excluding tropical storm and hurricane speed winds indicated the five dominant wind directions (DWD) listed in Table 4.1 based on wind rose diagrams.

The original scope of work required analyses of the 1-year and 20-year storm events. Use of wind speeds corresponding to rainfall for these events proved problematic because (1) there is no correlation between precipitation and wind speeds due to variations in relative humidity, and (2) if modeling had been done for these criteria, the impacts would be infinitesimal due to the very low wind speeds. Hence, the modeling scenarios were modified after discussion with NRCS to address statistically significant cases i.e., based on wind speeds corresponding to the 50% and 90% exceedance probabilities for the period of record. The 50% recurrence case was defined as winds blowing from the south-southeast (165º, clockwise due north – the meteorological convention), with a speed of 11.8 ft/s. The 90% recurrence case was defined as winds blowing from the south-southeast (170º) with a speed of 20.3 ft/s.

Table 4.1. Input parameters for STWAVE modeling scenarios.

Simulation Case*	Wind Direction		Wind Speed	
	Wind blowing from	Degrees	m/s	ft/s
DWD1	N	0	10.3	33.8
DWD2	NE	45	10.3	33.8
DWD3	E	90	10.3	33.8
DWD4	SSE	157.5	10.3	33.8
DWD5	S	180	10.3	33.8
50% Recurrence	SSE	165	3.60	11.8
90% Recurrence	SSE	170	6.19	20.3

* DWD cases are the dominant wind direction and speed derived from wind rose diagrams

5.0 STWAVE MODELING

5.1 Grid Definition

The model was set up and run using International System of Units (SI) units of measurement in accordance with SMS 10.1 requirements. Figures 5.1 and 5.2 show the computational grid superimposed on the bathymetry for existing and proposed conditions, respectively, in the SMS 10.1 interface.

A rectangular grid containing evenly spaced grid cells was designed with the origin at a Northing and Easting of 230233.89, 3297616.31. The horizontal reference coordinate system was Universal Transverse Mercator (UTM), North American Datum 1983 (NAD83), Zone 16 North, meters. The North American Vertical Datum of 1988 (NAVD88) was used as the vertical reference datum. The grid was made up of 171 columns (east-west) and 86 rows (north-south). Each grid cell was 164 ft (50 m) by 164 ft (50 m) and the entire computational grid was 14,104 ft (4,300 m) wide (north-south) by 28,044 ft (8,550 m) long (east-west). As per STWAVE 3.0 convention, positive elevation values indicate water, and negative values indicate land.

5.2 Project-Specific Model Assumptions

The following are the model assumptions for this project:

1. Both the northern and southern shoreline of Lake Lery were assumed to be affected by the borrow areas (requiring STWAVE be run in full-plane mode),
2. There was no tidal influence on waves – only source and propagation terms from wind were considered,
3. There is no bottom friction, and
4. Bottom slopes are mild.

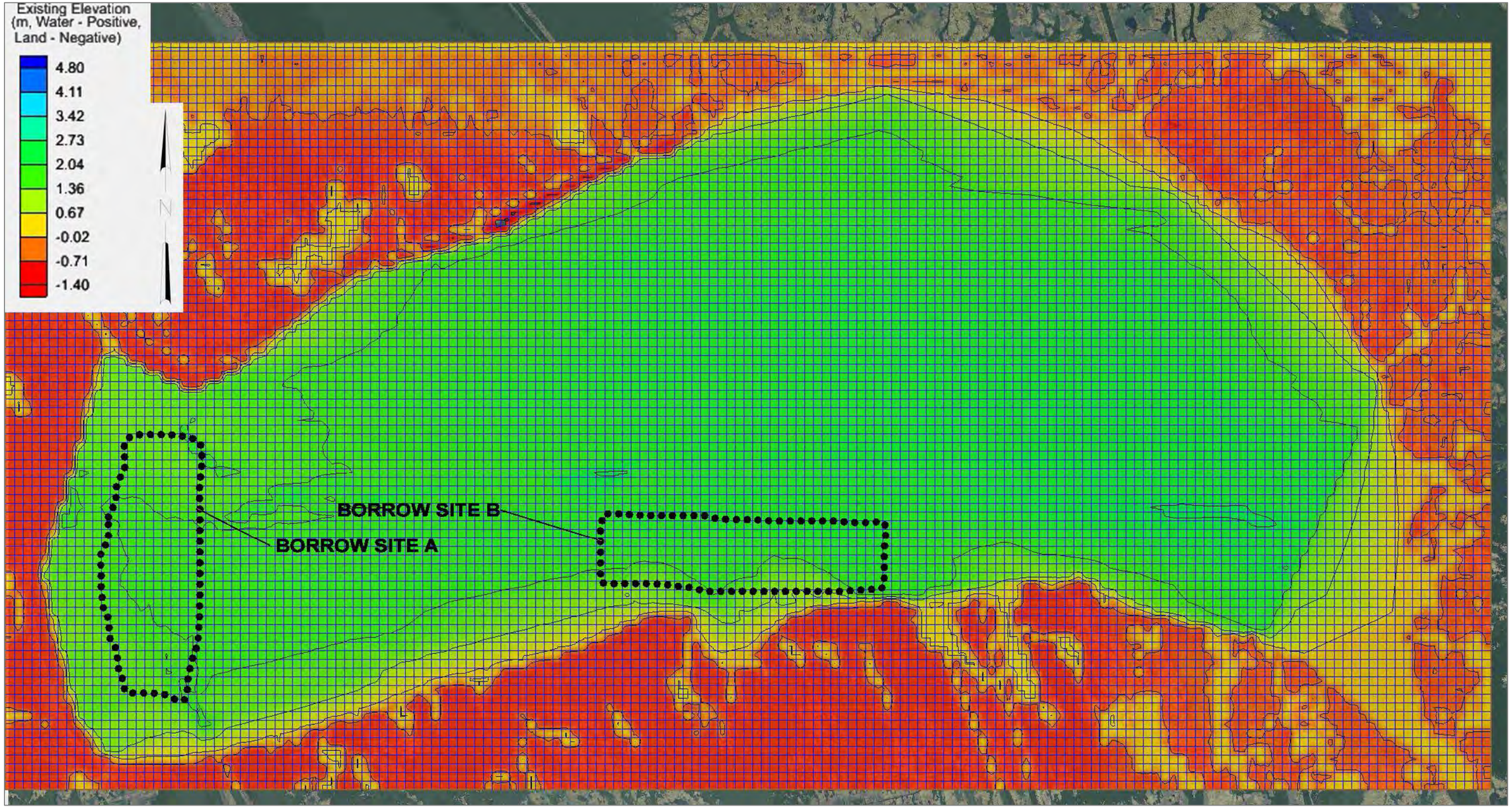

Figure 5.1 Computational grid for existing conditions.

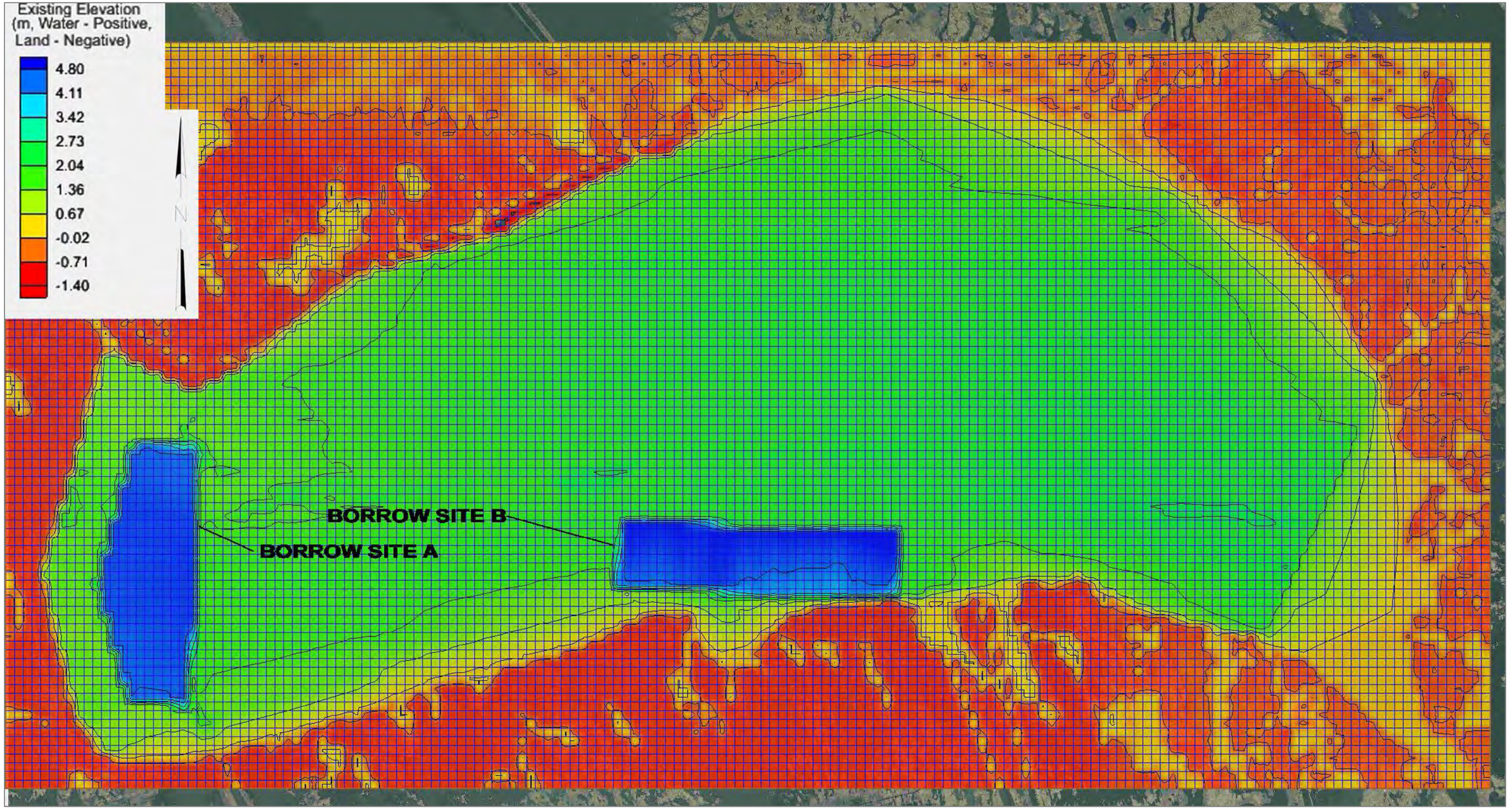

Figure 5.2. Computational grid for proposed conditions.

5.3 Results and Discussion

Simulations were run for all seven scenarios listed in Table 4.1 for both pre- and post-excavation grids. Wave height and direction differences were obtained by subtracting the wave height results for existing bathymetry from the proposed bathymetry for each case. Shoreline wave energy flux ratios were used to determine the alterations in longshore sediment transport patterns. The following is a discussion of STWAVE model results for the seven modeled scenarios. Figures showing the wave height and direction differences are presented in Appendix A.

5.3.1 Wave Height and Direction

Tables 5.1 and 5.2 summarize the differences in wave heights and directions (post-excavation minus pre-excavation) near the shoreline, within the borrow areas, and across the entire area of Lake Lery. Since it is a completely inland lake, STWAVE was run in full plane mode to evaluate the impacts along the entire lake shoreline.

Wave refraction occurs when wind-induced waves change direction as the depth decreases towards the shoreline. This is primarily due to velocity change with depth. As waves approach the shoreline at an angle, the wave base on one end drags the bottom before the other end, resulting in wave bending. Wind-induced waves bend to become more parallel with the shoreline. For shallow water depths, the wave heights are not more than 0.55 times the depth (Massel 1998).

Table 5.1. Summary of borrow area impacts on wave heights.

Case #	BORROW AREA A Maximum Wave Height Increase/Decrease		BORROW AREA B Maximum Wave Height Increase/Decrease		ENTIRE LAKE	
	Within Borrow Area (m)	Near Shoreline (m)	Within Borrow Area (m)	Near Shoreline (m)	Maximum Wave Height Increase (m)	Maximum Wave Height Decrease (m)
1	+0.024 / -0.032	-0.00 / +0.00	+0.038 / -0.018	-0.00 / +0.00	0.066	-0.06
2	+0.044 / -0.082	-0.00 / +0.00	+0.026 / -0.01	-0.00 / +0.00	0.062	-0.1
3	+0.052 / -0.028	-0.00 / +0.00	+0.02 / - 0.044	-0.00 / +0.00	0.084	-0.06
4	+0.015 / -0.045	-0.00 / +0.00	+0.015 / -0.12	-0.00 / +0.00	0.015	-0.12
5	+0.016 / 0.00	-0.00 / +0.00	+0.006 / -0.07	-0.00 / +0.00	0.016	-0.07
6	+0.006 / -0.018	-0.00 / +0.00	+0.018 / -0.078	-0.00 / +0.00	0.018	-0.09
7	0.00 / -0.06	-0.00 / +0.00	+0.015 / -0.105	-0.00 / +0.00	0.015	-0.12

Table 5.2. Summary of borrow area impacts on wave direction.

Case #	BORROW AREA A Maximum Wave Direction Change		BORROW AREA B Maximum Wave Direction Change		ENTIRE LAKE	
	Within Borrow Area (Degrees)	Near Shoreline (Degrees)	Within Borrow Area (Degrees)	Near Shoreline (Degrees)	Maximum Direction Increase (Degrees)	Maximum Direction Decrease (Degrees)
1	23	0.6	23	0.0	29	-25
2	24	0.5	16	0.0	32	-40
3	-20	0.4	20	0.0	160	-20
4	-34.7	0.4	10.3	0.0	46.3	-34.7
5	-30	0.6	10	0.0	50	-40
6	-28	0.5	16	0.0	49	-50
7	-31.5	0.5	20	0.0	36.6	-40

Wind-induced waves result in surface whirls, which cause pressure differences that break the flat surface. The waves start as small wrinkles and continue to grow. Small waves are steep in the beginning, but in the course of developing, they grow faster in length than in height. The most important factors controlling the growth of wind-driven waves are wind speed, wind duration, and fetch. When wind duration is not limiting its growth, wind speed and fetch determine the wave height. Bathymetry, especially the presence of sudden obstructions and transient structures, and marsh features (however small they are) strongly influence wave height, direction change, and breaking. For stronger winds, the wave propagation speed is comparable to the wind speed but for calmer winds, the former is always greater than the latter because the wind cannot feed energy to the waves.

Borrow Area A is located at almost a constant offset (400 m off the shoreline), except at the southwestern end where there are some land mass projections and marsh-like extensions. Depending on the wind direction, these can cause wave height and direction changes. On the other hand, Borrow Area B is located against an undulating shoreline with multiple such projections and extensions. The offset of Borrow Area B from these features ranges from few meters to up to 200 m towards the southwestern edge. As a consequence there will be varying changes (increases as well as decreases) in wind speeds and directions depending on the wind directions. For winds blowing perpendicular to the shoreline, this directly translates to varying fetch, the effects of which are discussed above. For winds blowing at an angle, waves will tend to align themselves parallel to the shoreline, and therefore have to refract by a larger angle. Therefore, more wave parameter variation is expected due to Borrow Area B than to Borrow Area A; based on wind direction and speeds, some of these impacts, though minor, could reach as far as the northern shoreline of Lake Lery.

5.3.2 Wave Energy

Waves in Lake Lery are wind-driven, long waves (wave length much greater than wave height), and therefore, linear wave theory is applicable. Since there are no tidal and current influences, the model was run with a zero spectra (no specific wave heights, frequency). Moreover, since there are no significant channel (current) inflows/outflows, wind-driven waves

are the only sources of wave energy for the project area. As mentioned earlier, the changes in wave heights were not significant for all modeled scenarios for both Borrow Areas A and B (i.e, had maximum increases of 2.5 inches). Therefore, though there were significant wave direction changes in certain areas for some scenarios, the resulting wave energy changes were not significant. Moreover, the available fetch was adequate to dissipate the wave energy, without causing adverse impacts to the shoreline as compared to existing conditions.

5.3.3 Sediment Transport Pattern

To determine the impacts of changes in wave height and direction caused by proposed borrow site excavations on the longshore sediment transport, analyses of wave energy flux ratios along the shoreline were performed. Alongshore energy flux influences the longshore sediment transport patterns (Dean and Dalrymple 2002). The flux per unit length of shoreline is given by the following equation:

$$F = \frac{1}{16}\rho g H^2 \sqrt{gh} \sin 2\theta$$

Where ρ = density of water,
g = acceleration due to gravity,
H = wave height,
h = water depth, and
θ = angle between wave ray and onshore direction (perpendicular to shore = 0).

Wave energy flux ratios (non-dimensional) were developed for each of the seven modeling scenarios based on the near-shore parameters. Since wave heights and water depth did not vary significantly between existing and proposed conditions, the flux ratios reduced to the ratio of the sine of twice the wave ray direction angles. From Table 5.2, the near shore deflection angles were zero for Borrow Area B, and 0.4º to 0.6º for Borrow Area A, and hence the wave energy flux ratios were 1 for all seven modeling scenarios for both sites. Therefore, it can be concluded that there will be no significant impact on the longshore sediment transport potential due to the proposed borrow area excavations.

6.0 CONCLUSIONS

Based on the STWAVE modeling performed for the seven dominant (statistically significant) scenarios, there will be no significant impacts to wave heights, direction, and longshore sediment transport patterns due to the excavation of the proposed borrow areas. There may be some localized increases and decreases in wave heights and directions due to the undulating southern shoreline and depth decrease along the western shoreline. However, these changes (increases and decreases) are not significant enough to be sustained over the available fetch and cause an impact along any of the shoreline. Pipelines present in the area will also be unaffected due to their layout and the very slight increase in wave heights.

7.0 REFERENCES

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APPENDIX A

STWAVE Model Outputs

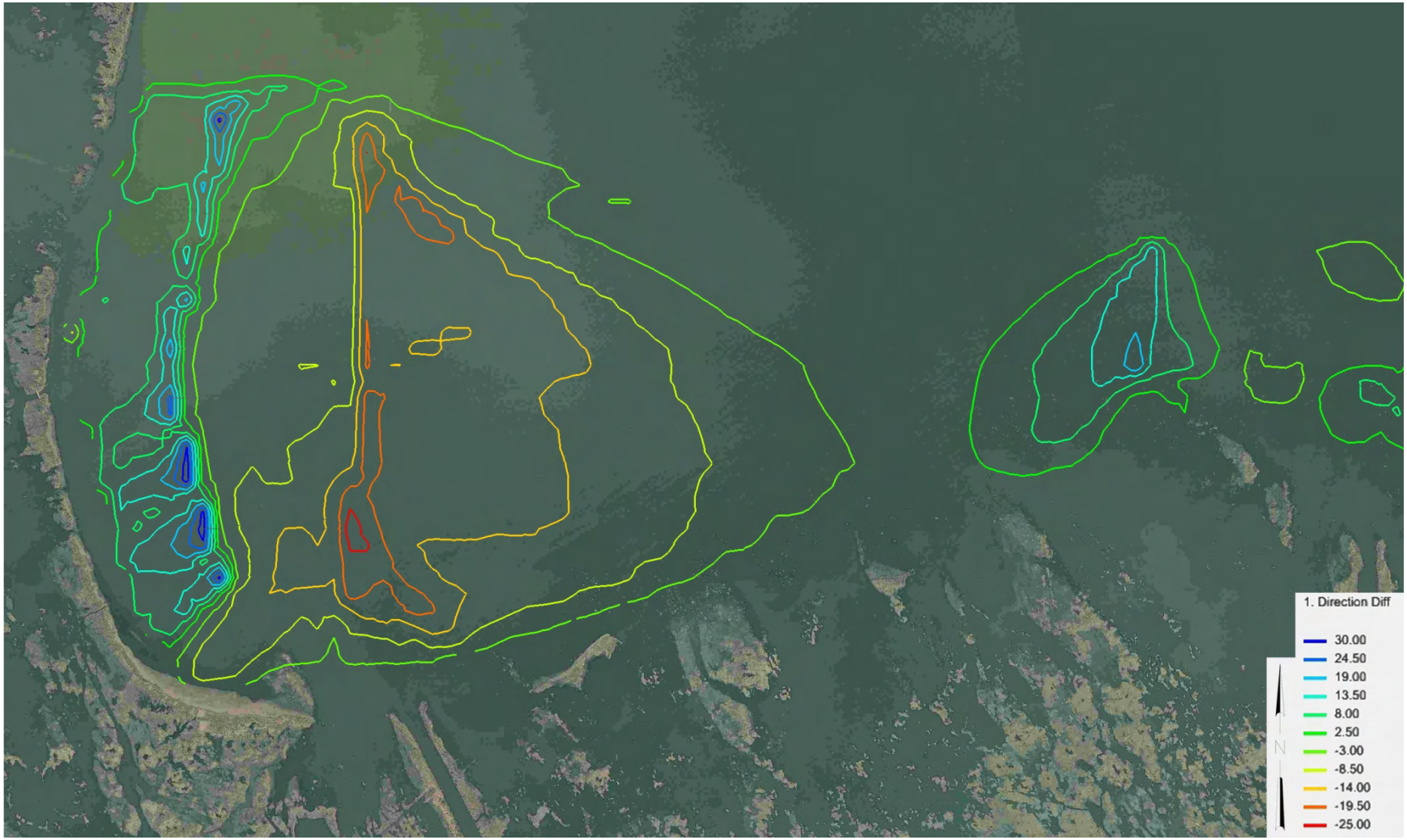

Figure A1. Borrow Area A Wave Direction Difference – Case 1 (units = meters).

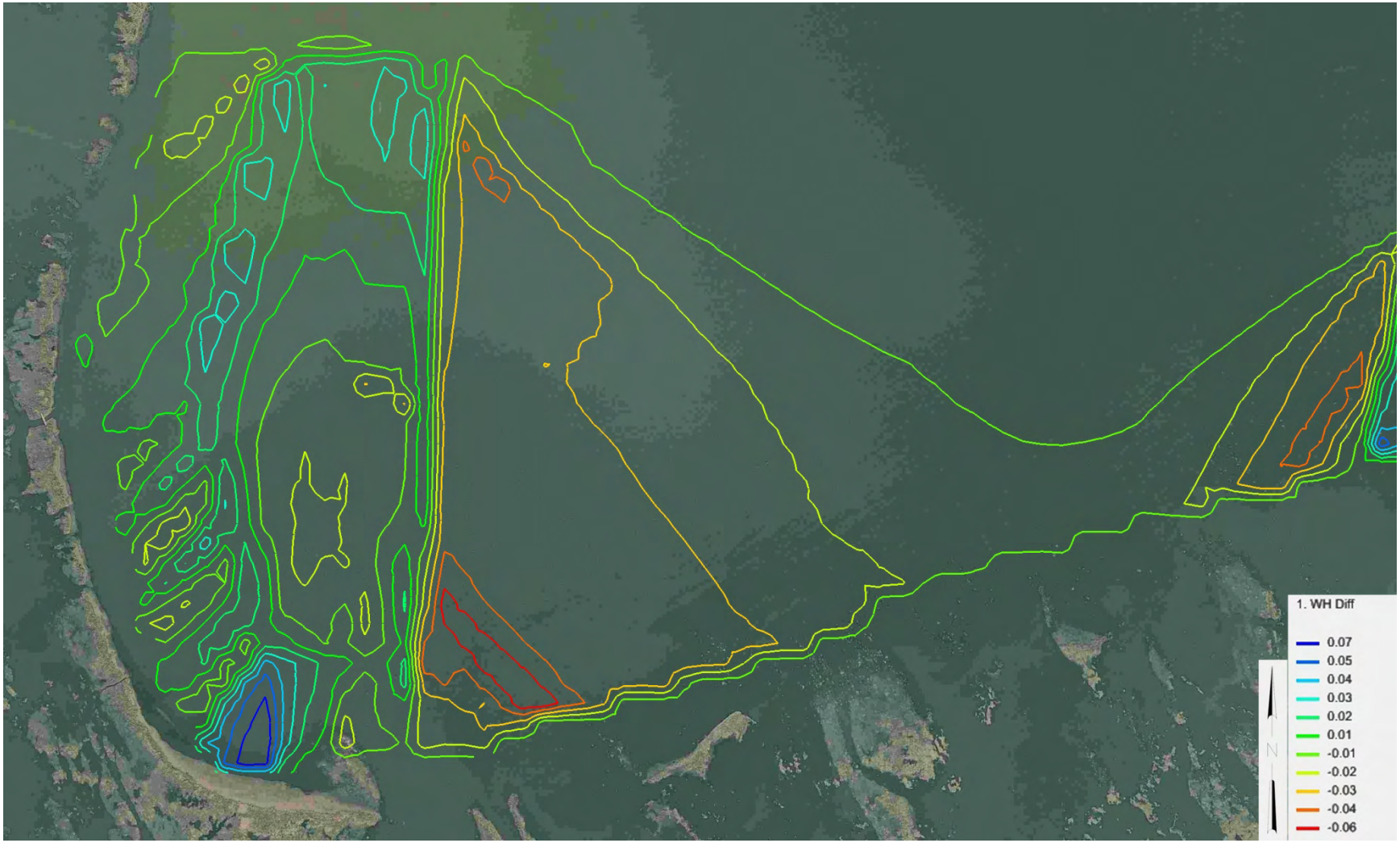

Figure A2. Borrow Area A Wave Height Difference – Case 1 (units = meters).

Figure A3. Borrow Area B Wave Direction Difference – Case 1 (units = meters).

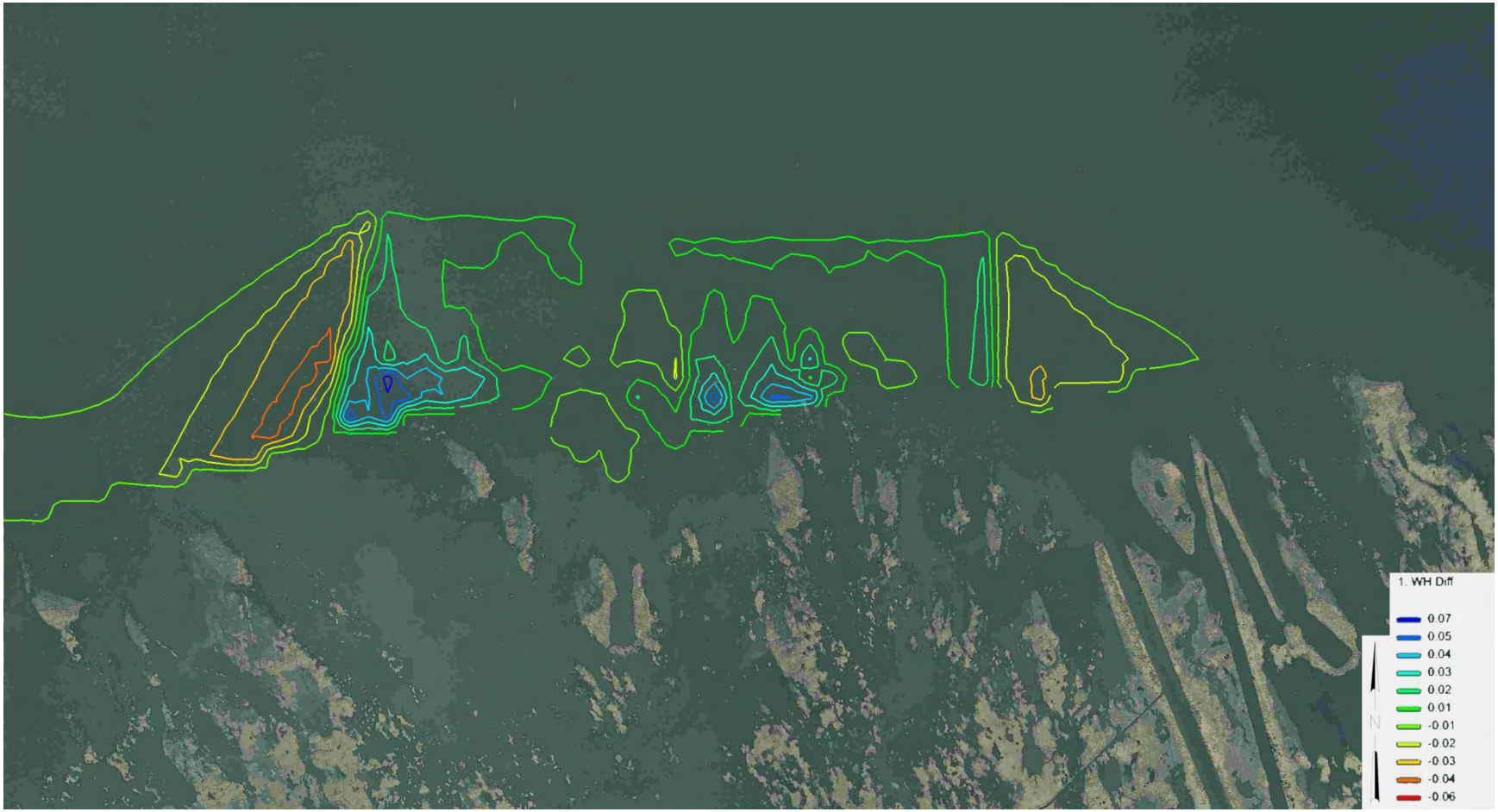

Figure A4. Borrow Area B Wave Height Difference – Case 1 (units = meters).

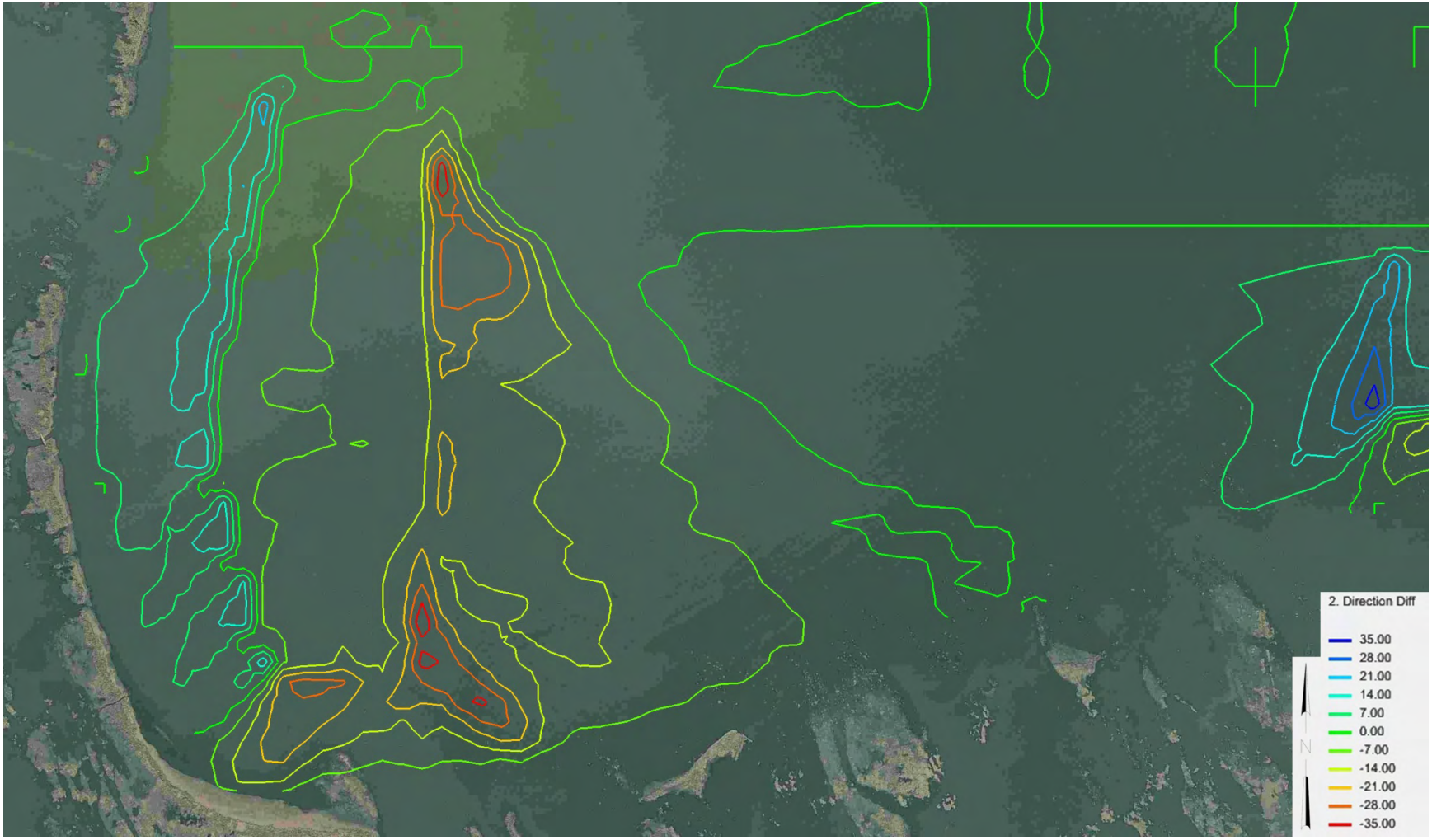

Figure A5. Borrow Area A Wave Direction Difference – Case 2 (units = meters).

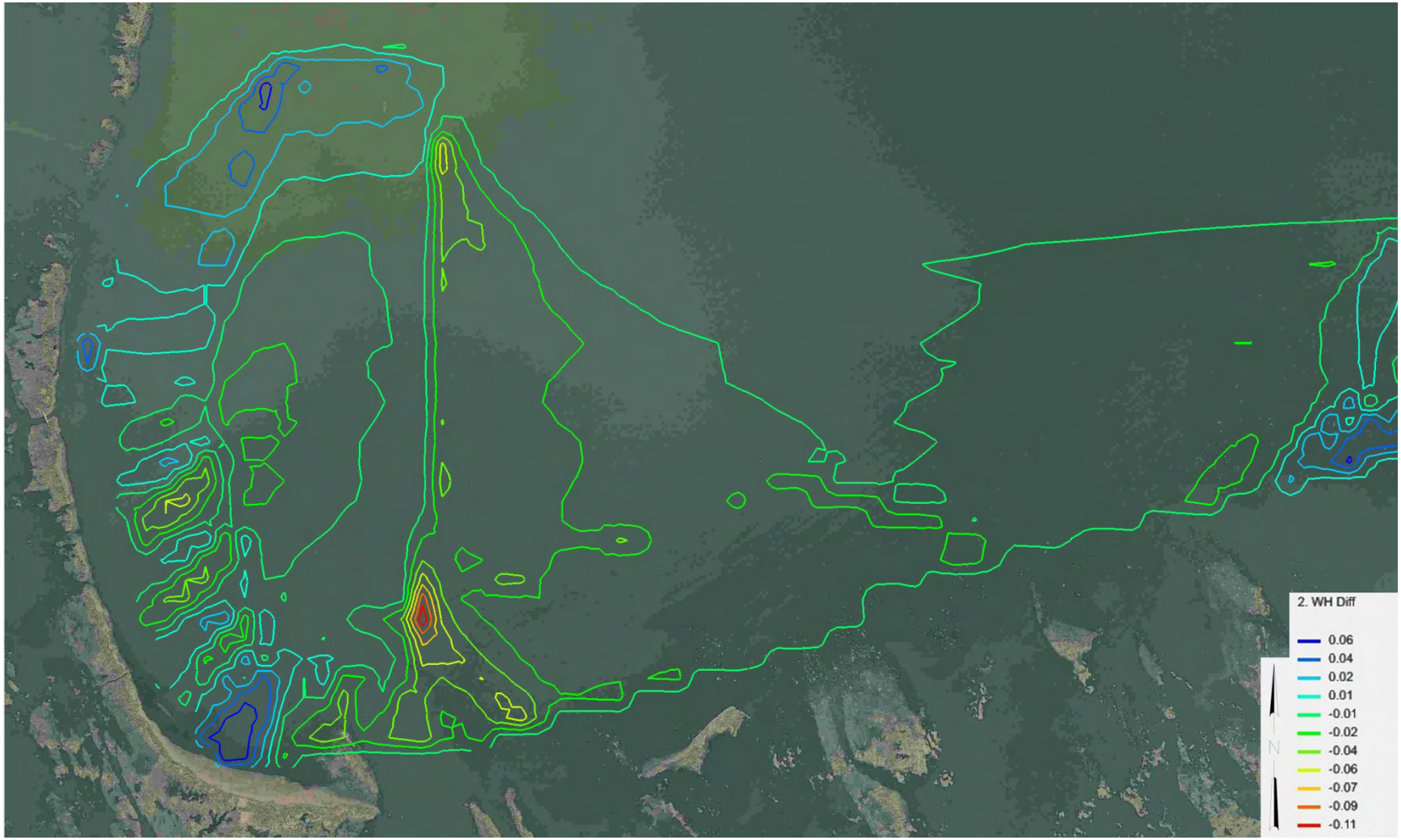

Figure A6. Borrow Area A Wave Height Difference – Case 2 (units = meters).

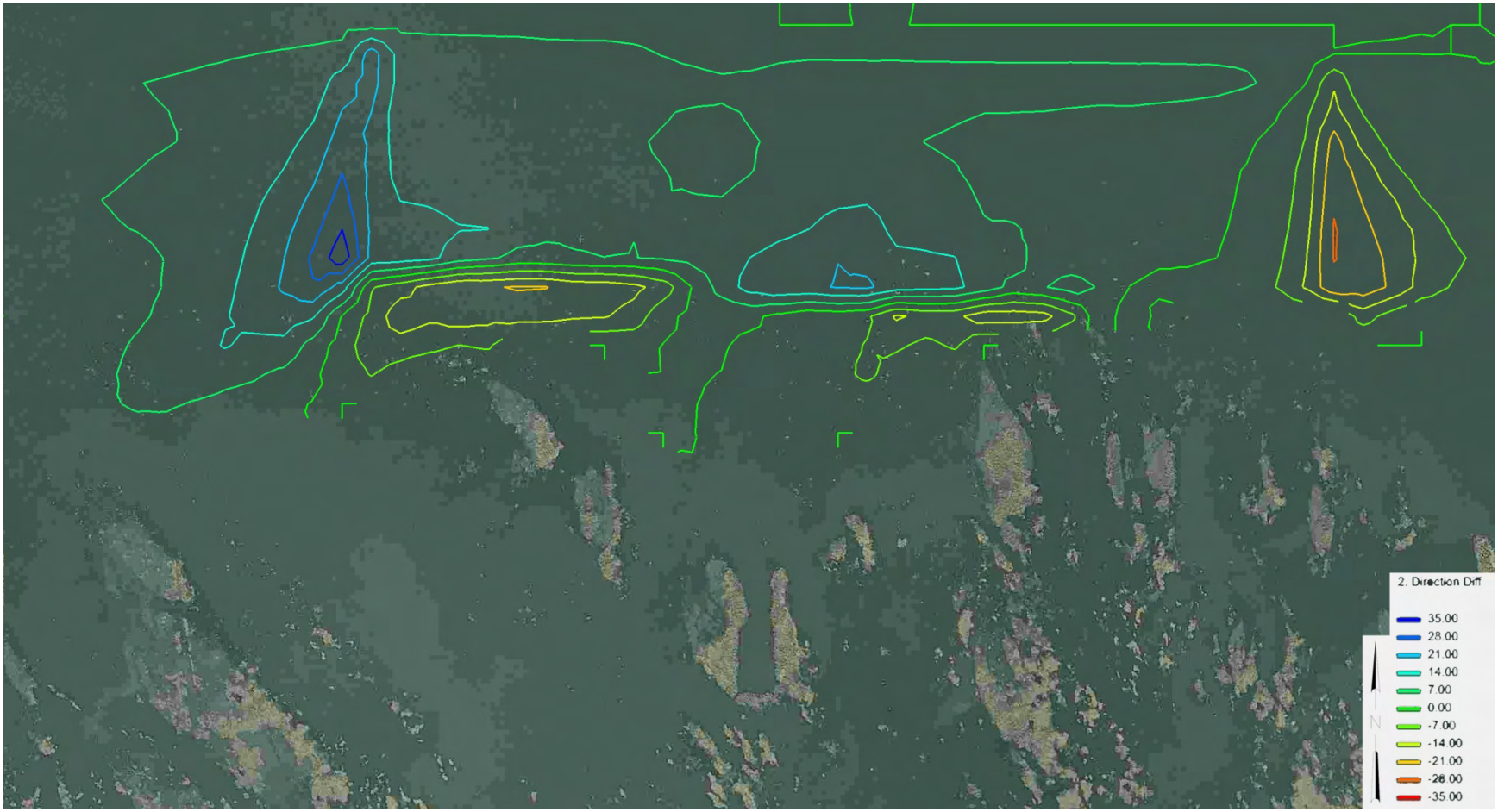

Figure A7. Borrow Area B Wave Direction Difference – Case 2 (units = meters).

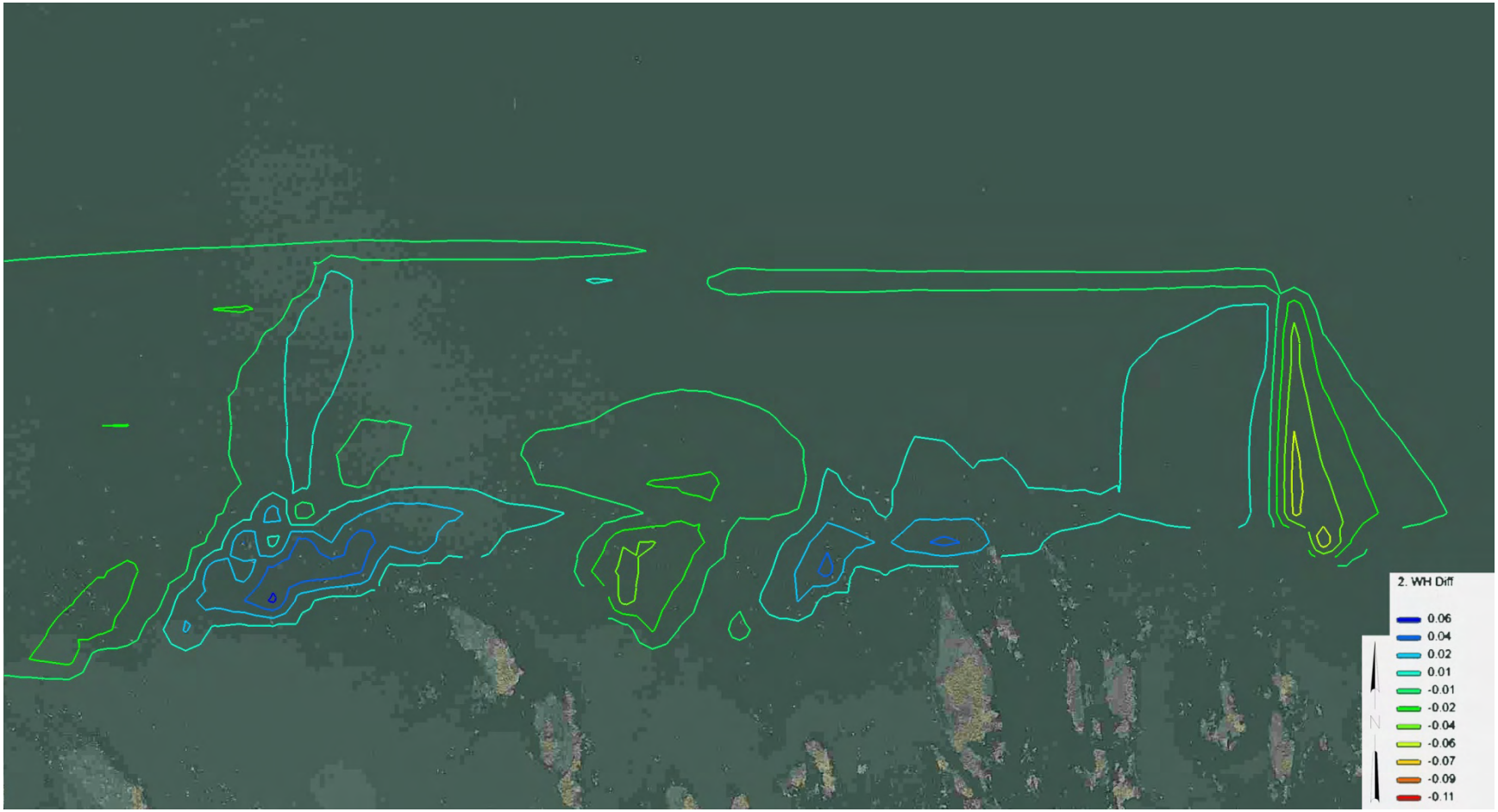

Figure A8. Borrow Area B Wave Height Difference – Case 2 (units = meters).

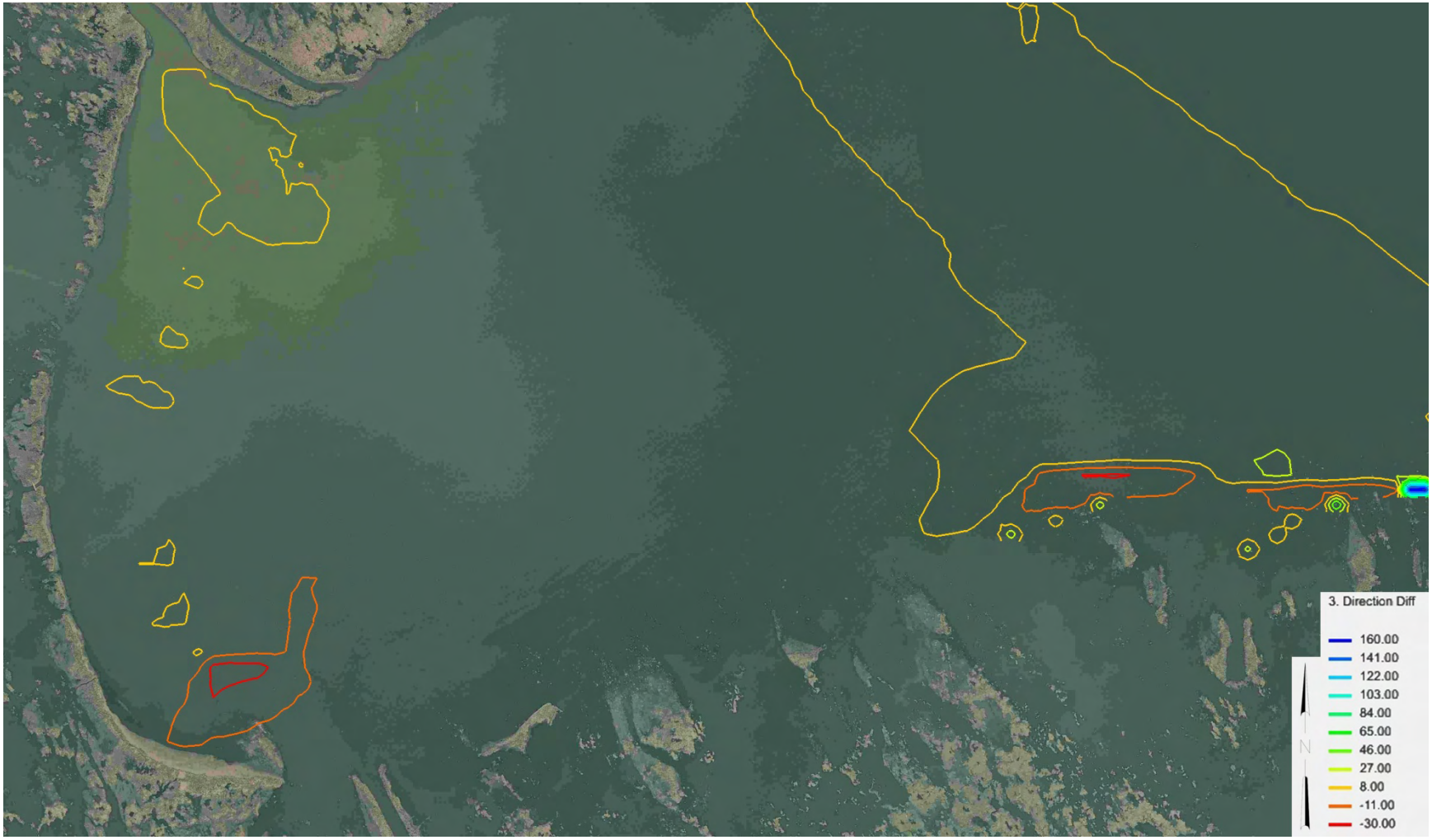

Figure A9. Borrow Area A Wave Direction Difference – Case 3 (units = meters).

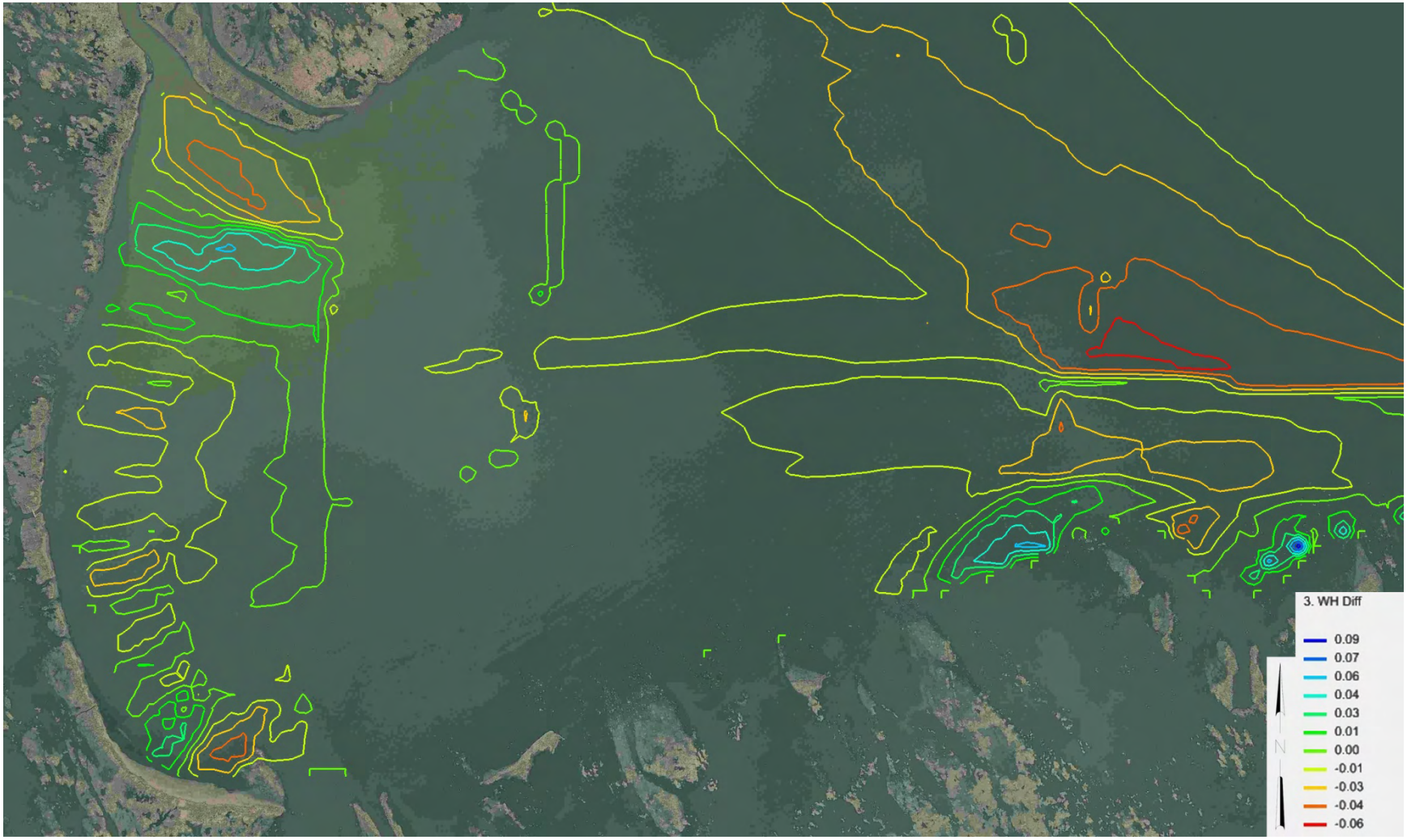

Figure A10. Borrow Area A Wave Height Difference – Case 3 (units = meters).

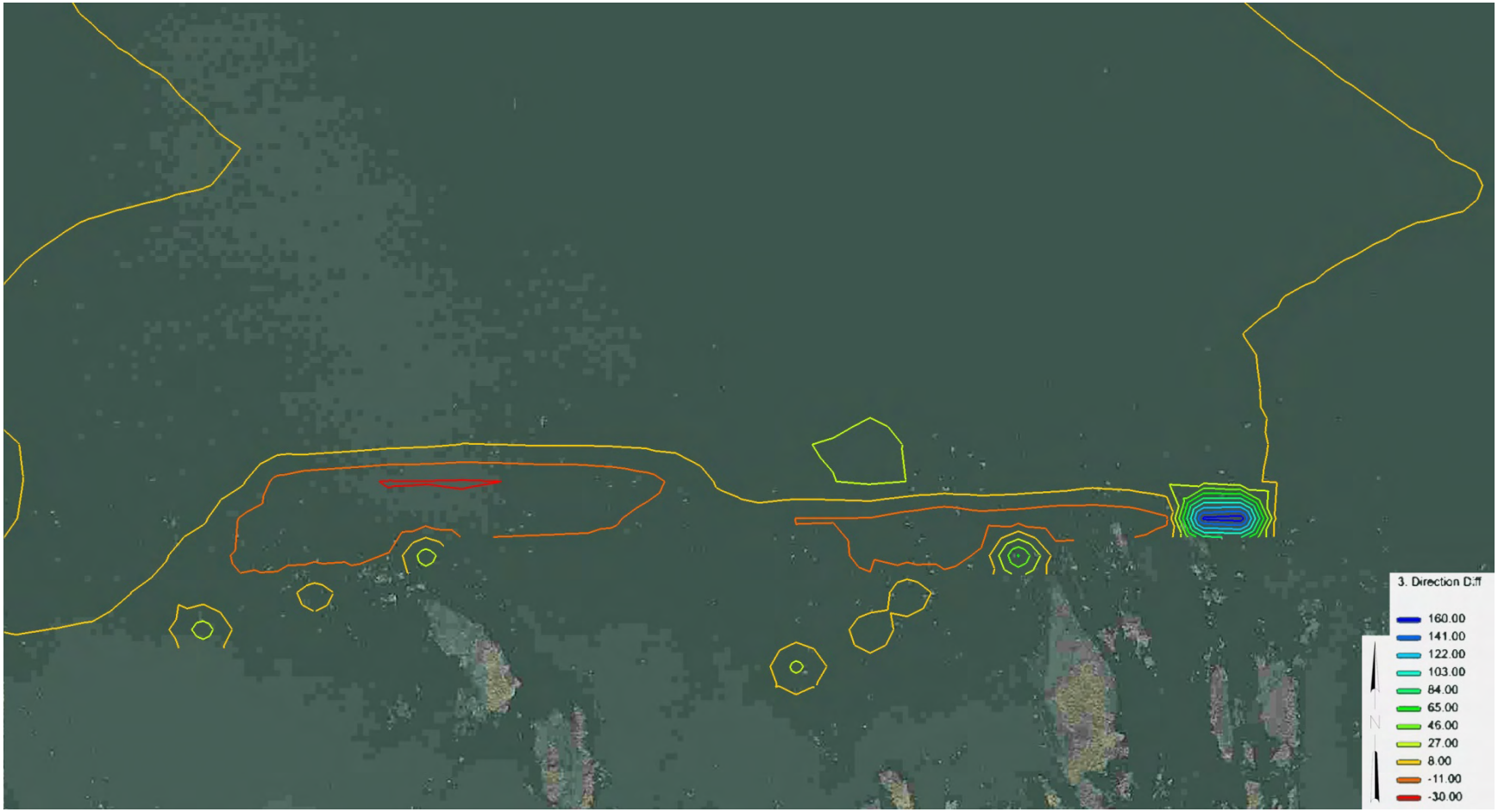

Figure A.11. Borrow Area B Wave Direction Difference – Case 3 (units = meters).

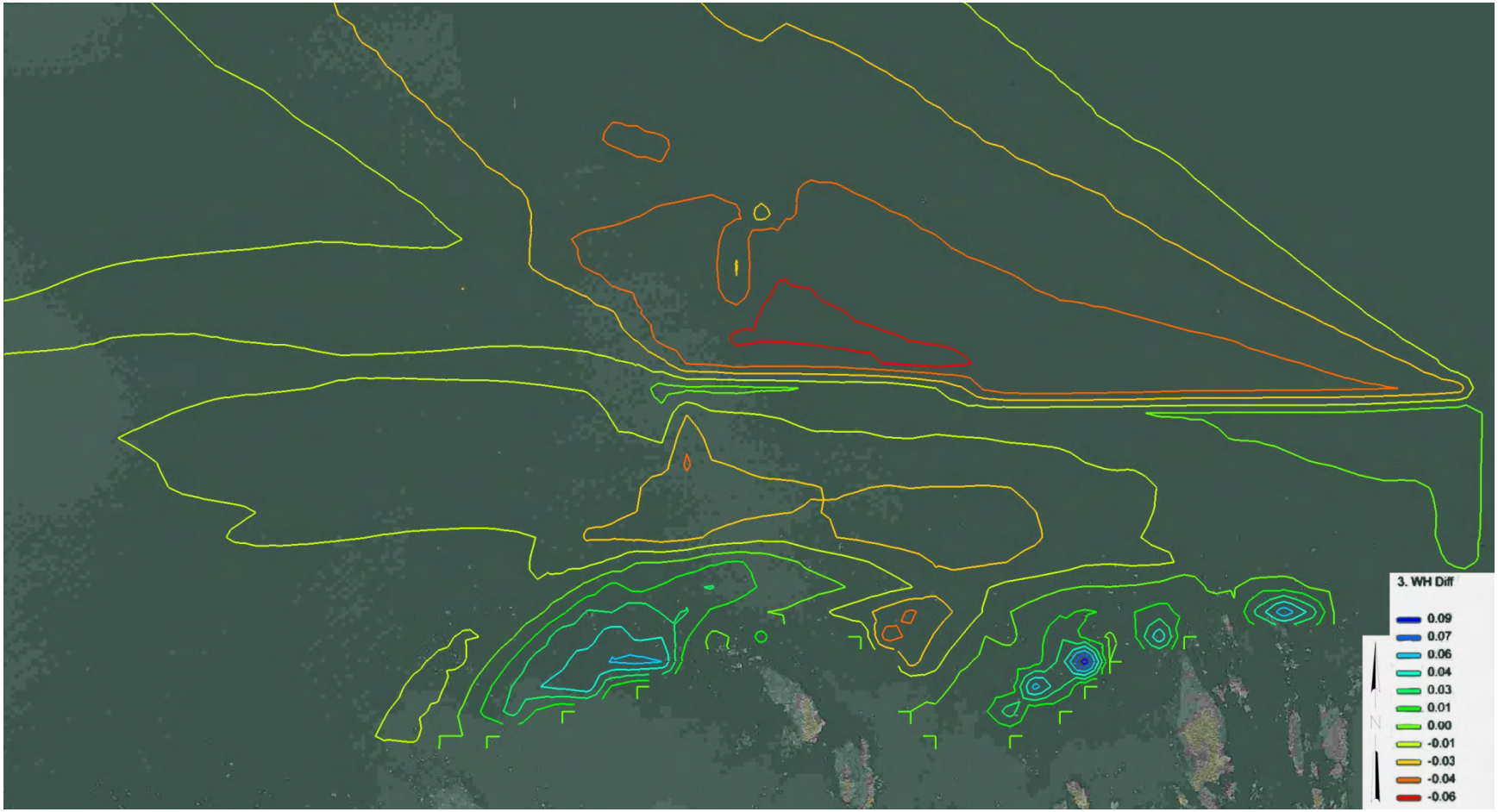

Figure A.12. Borrow Area B Wave Height Difference – Case 3 (units = meters).

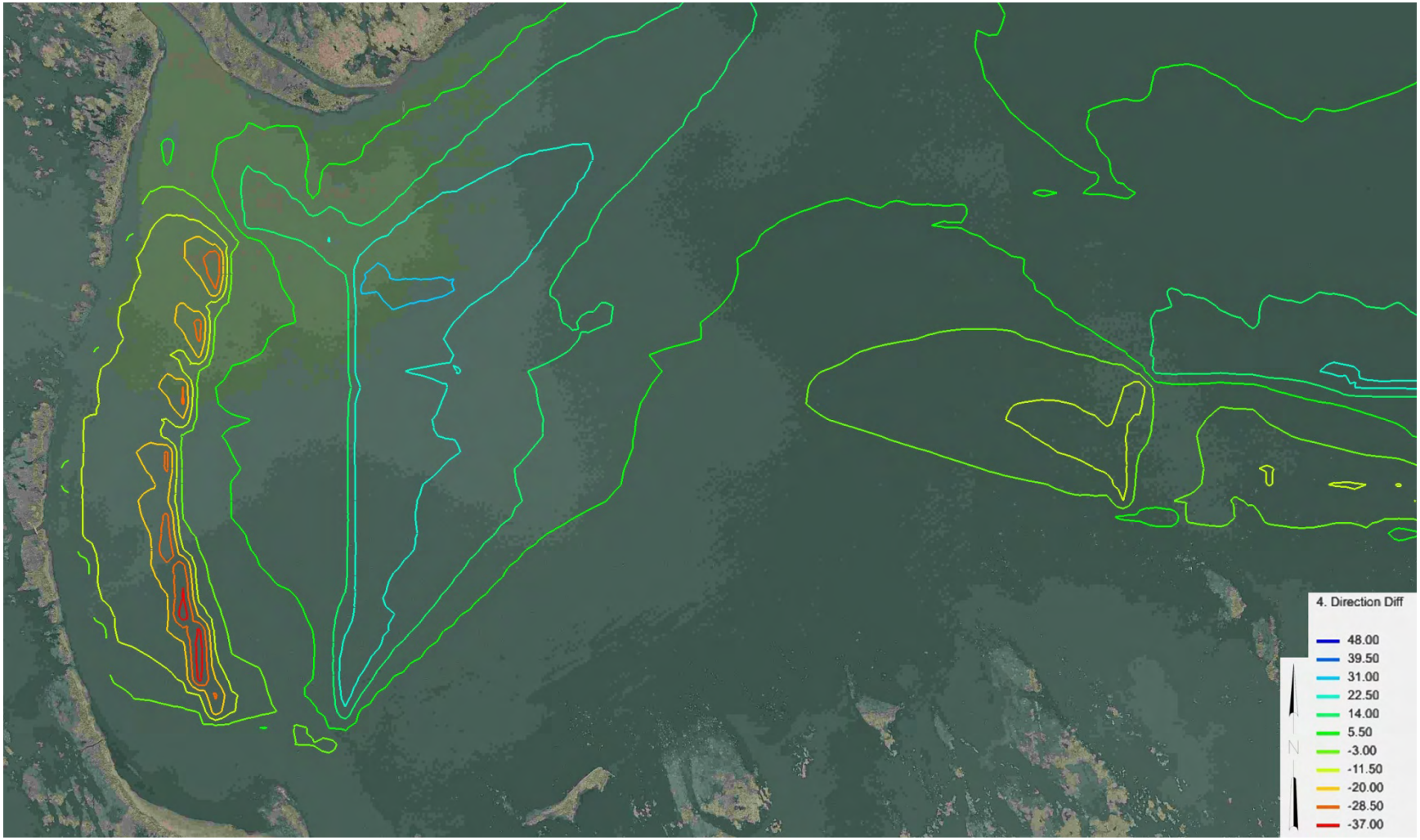

Figure A.13. Borrow Area A Wave Direction Difference – Case 4 (units = meters).

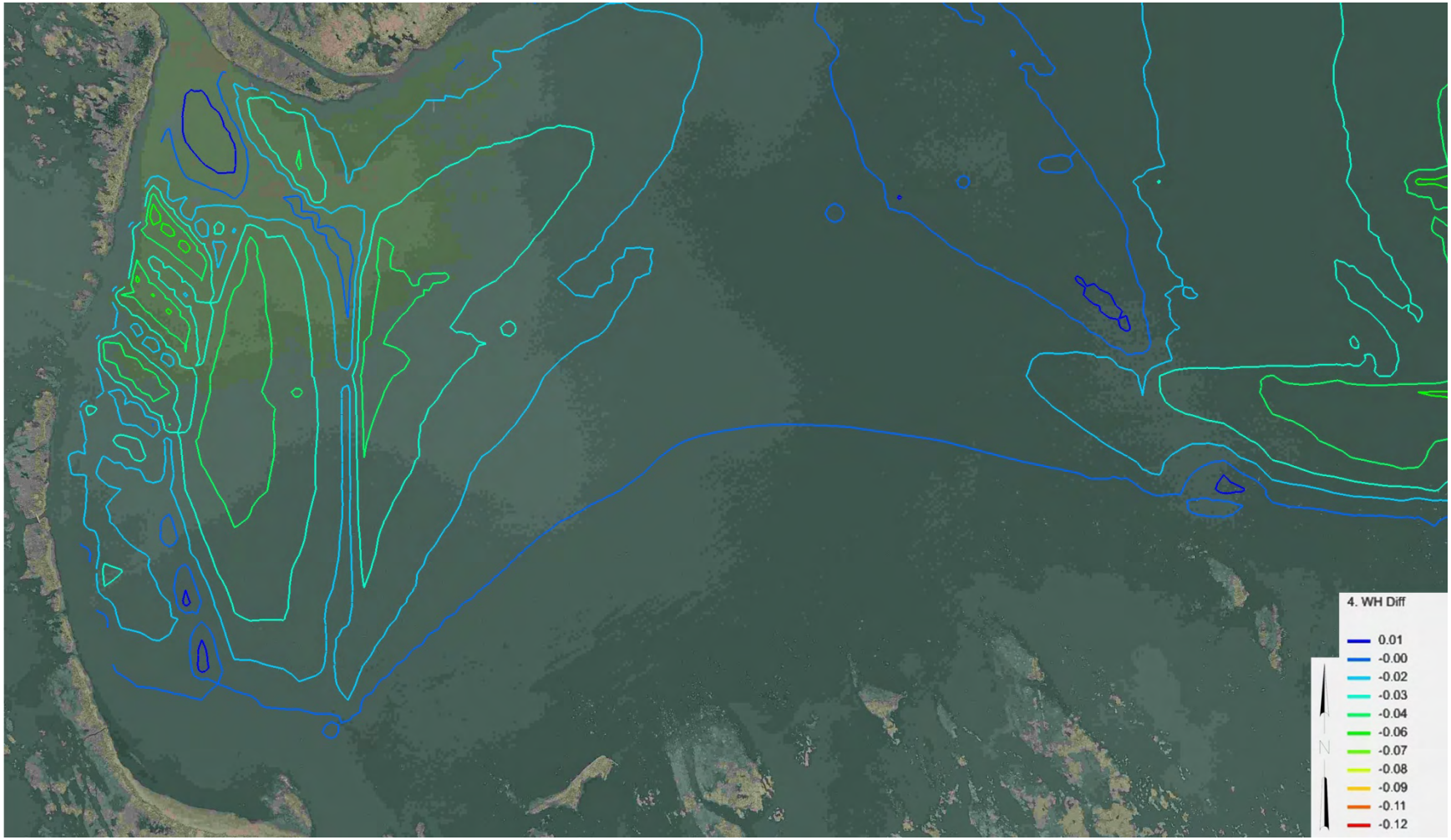

Figure A.14. Borrow Area A Wave Height Difference – Case 4 (units = meters).

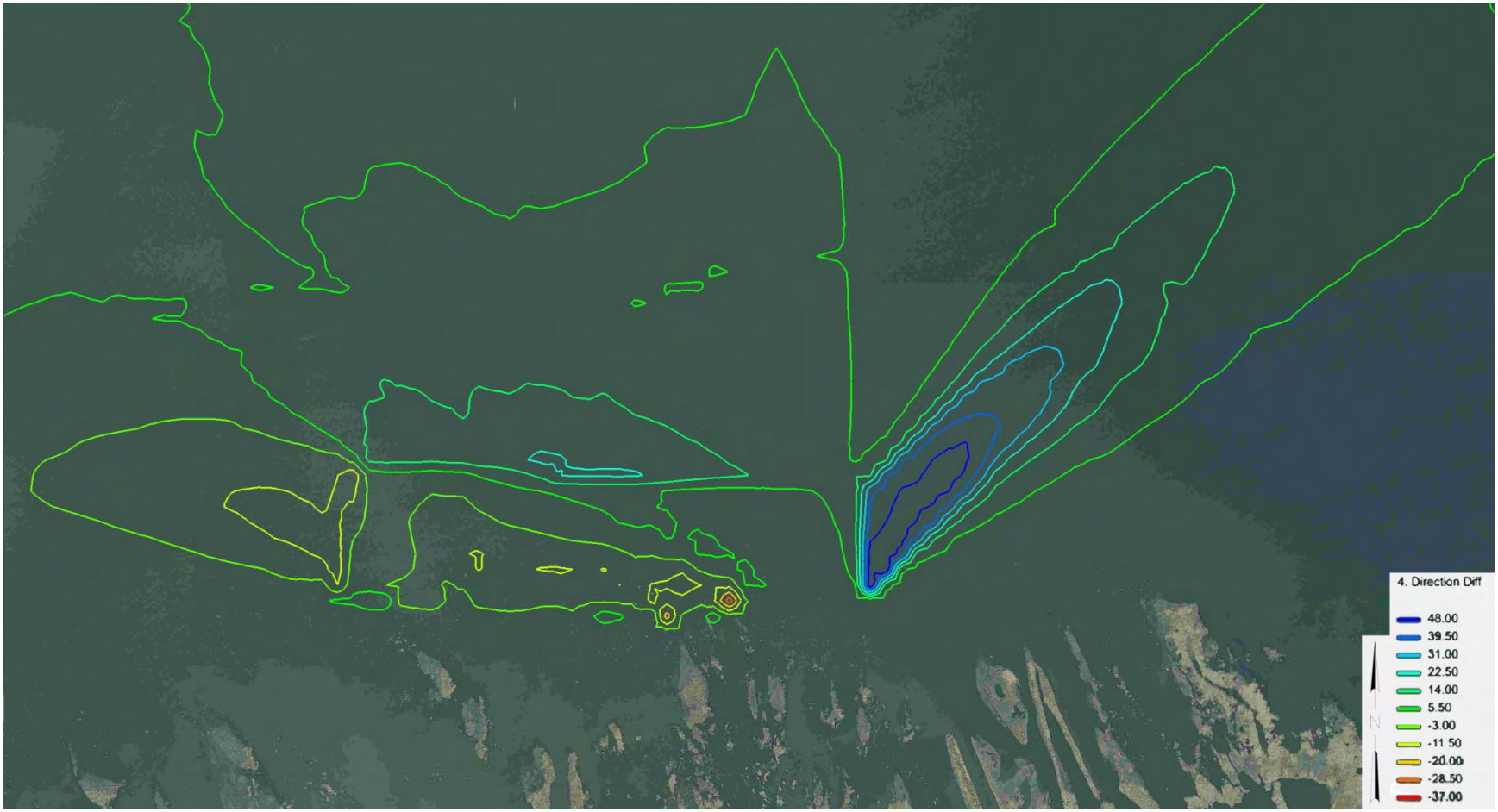

Figure A.15. Borrow Area B Wave Direction Difference – Case 4 (units = meters).

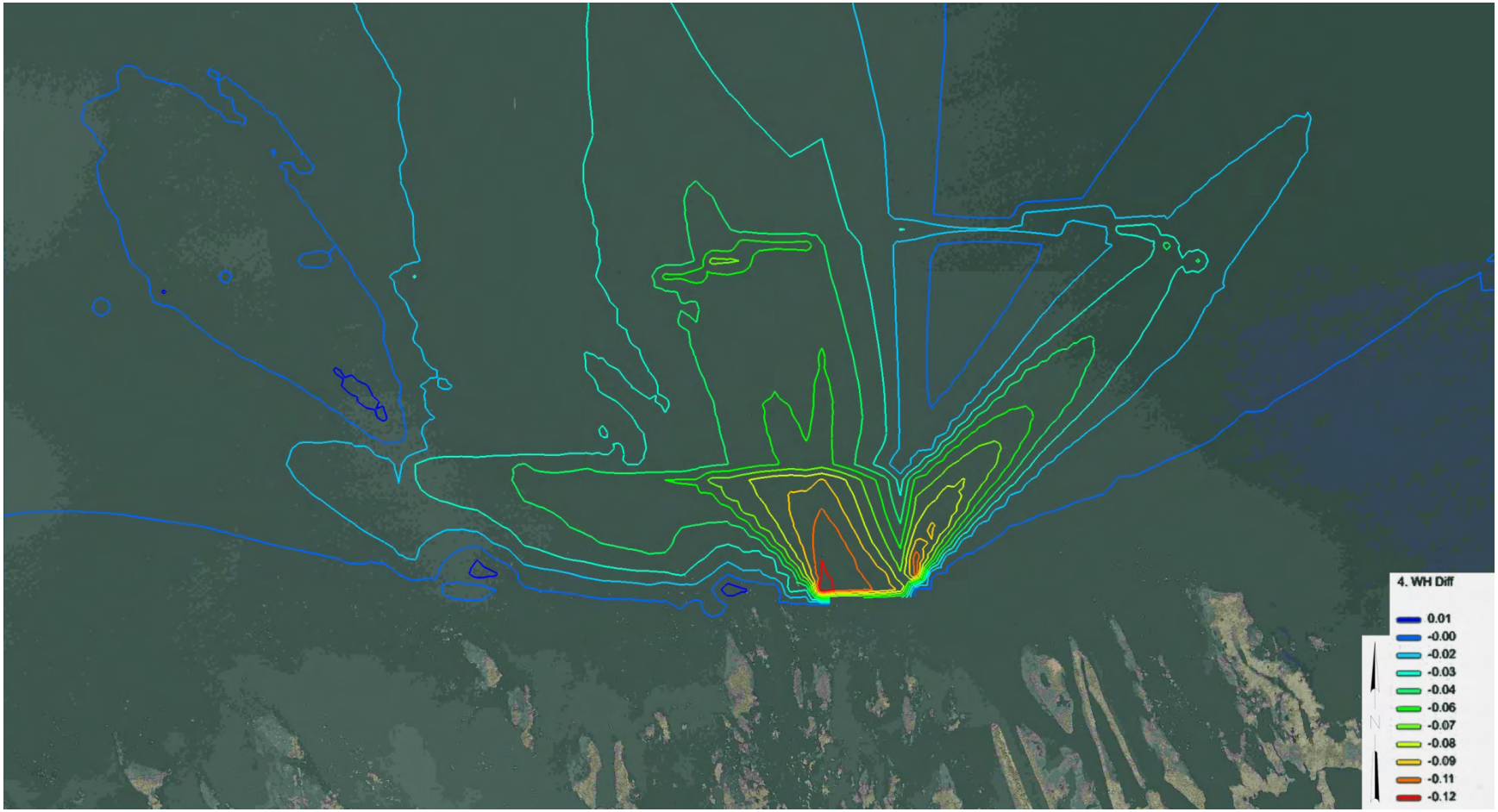

Figure A.16. Borrow Area B Wave Height Difference – Case 4 (units = meters).

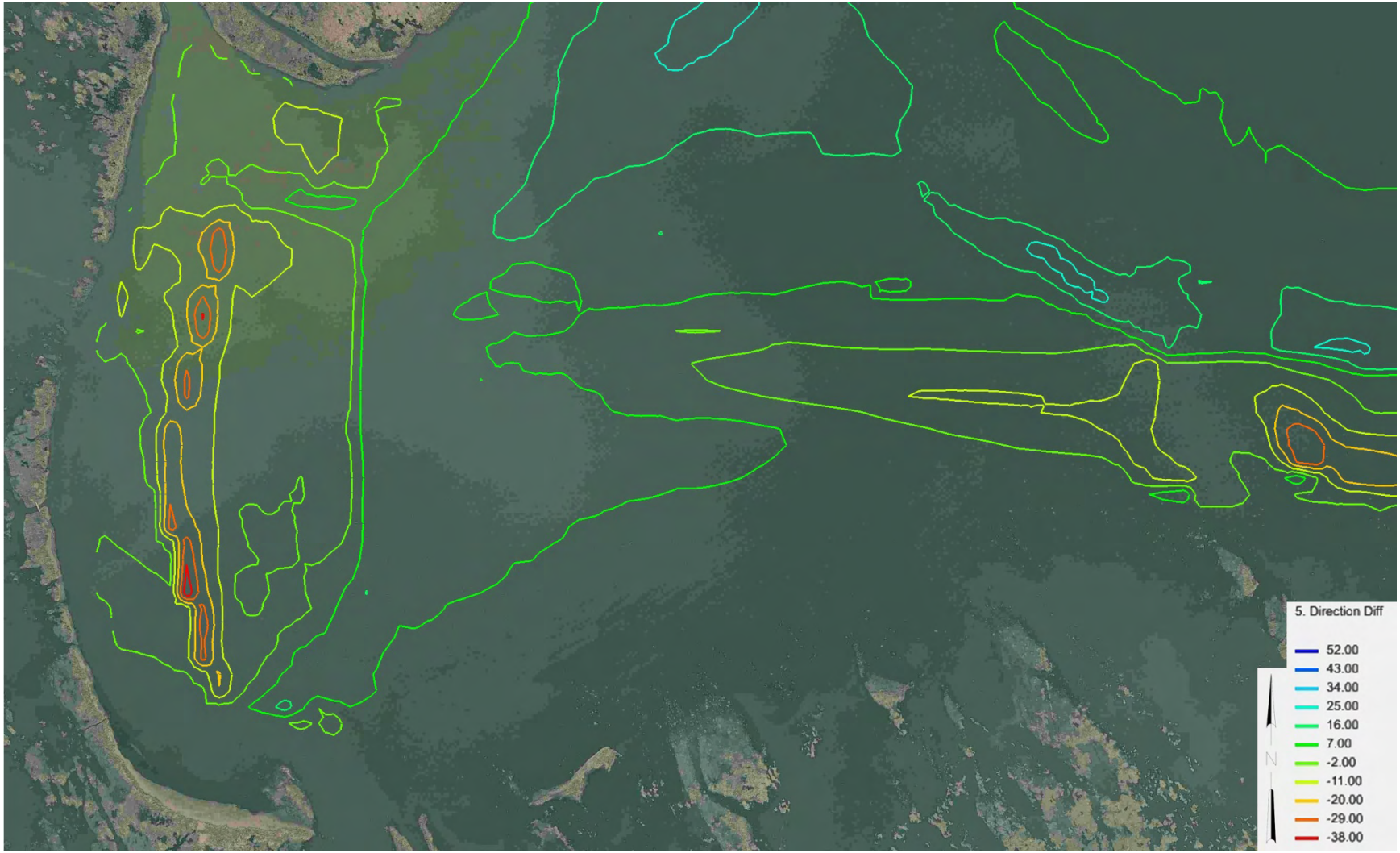

Figure A.17. Borrow Area A Wave Direction Difference – Case 4 (units = meters).

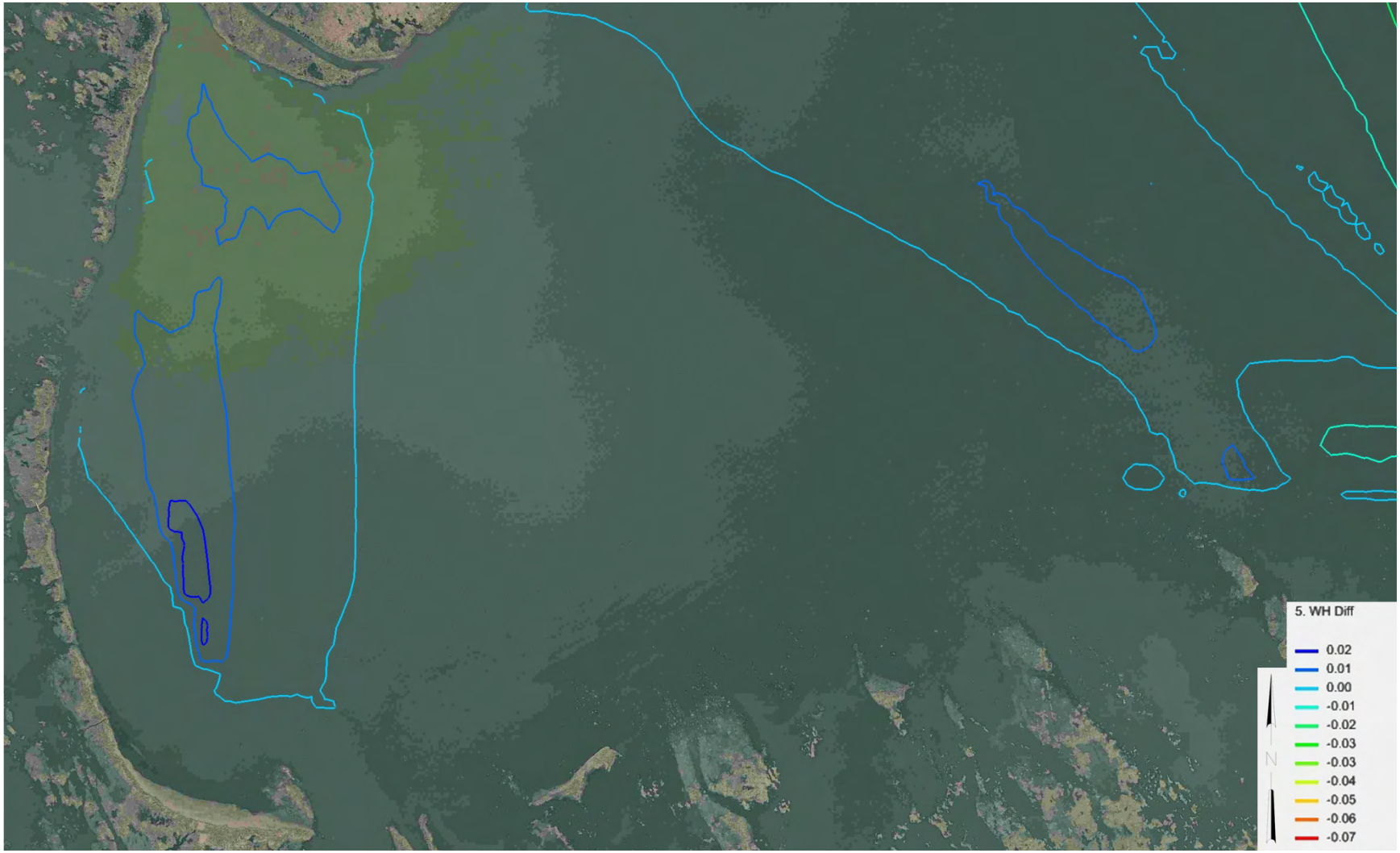

Figure A.18. Borrow Area A Wave Height Difference – Case 5 (units = meters).

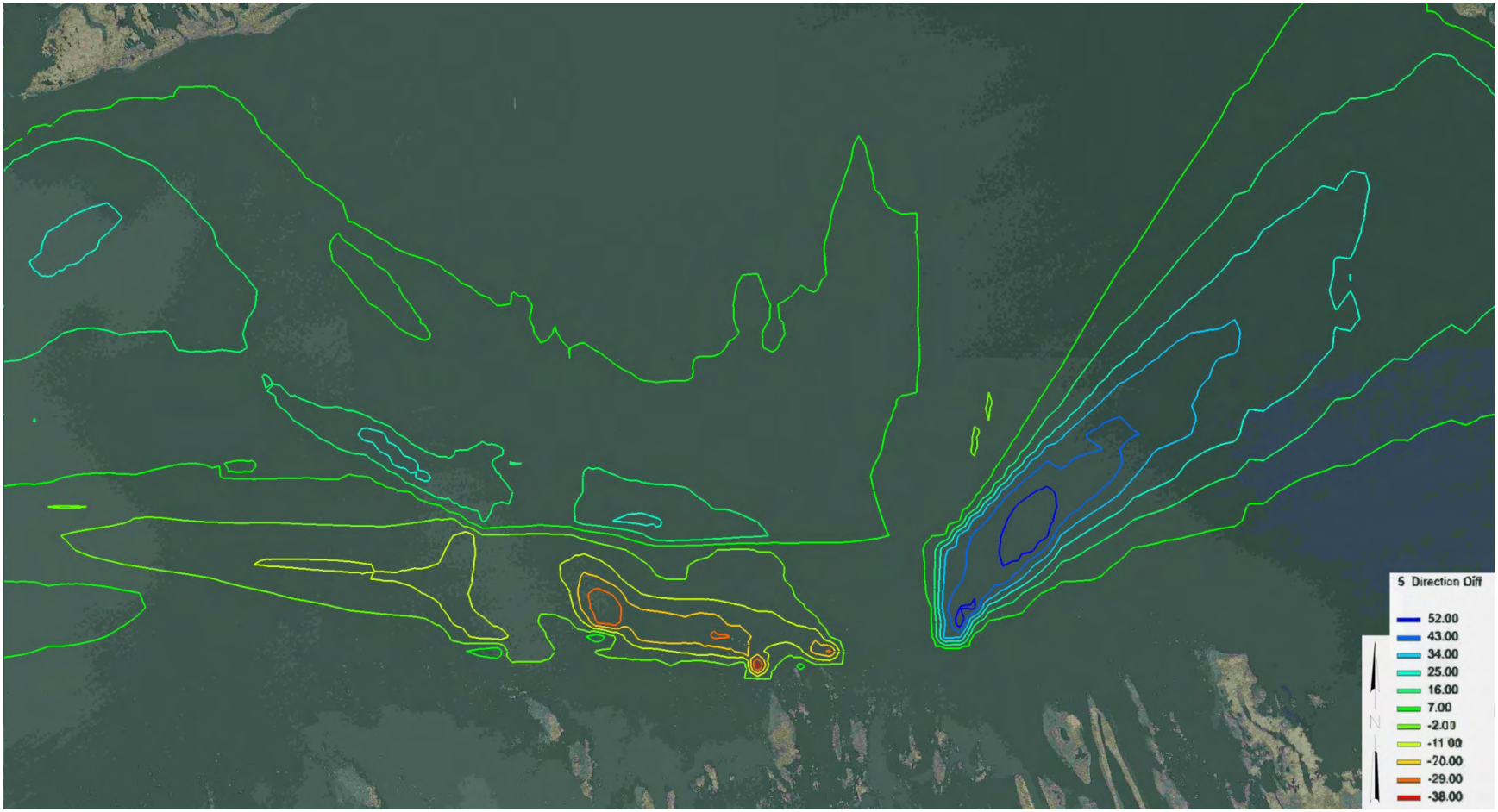

Figure A.19. Borrow Area B Wave Direction Difference – Case 5 (units = meters).

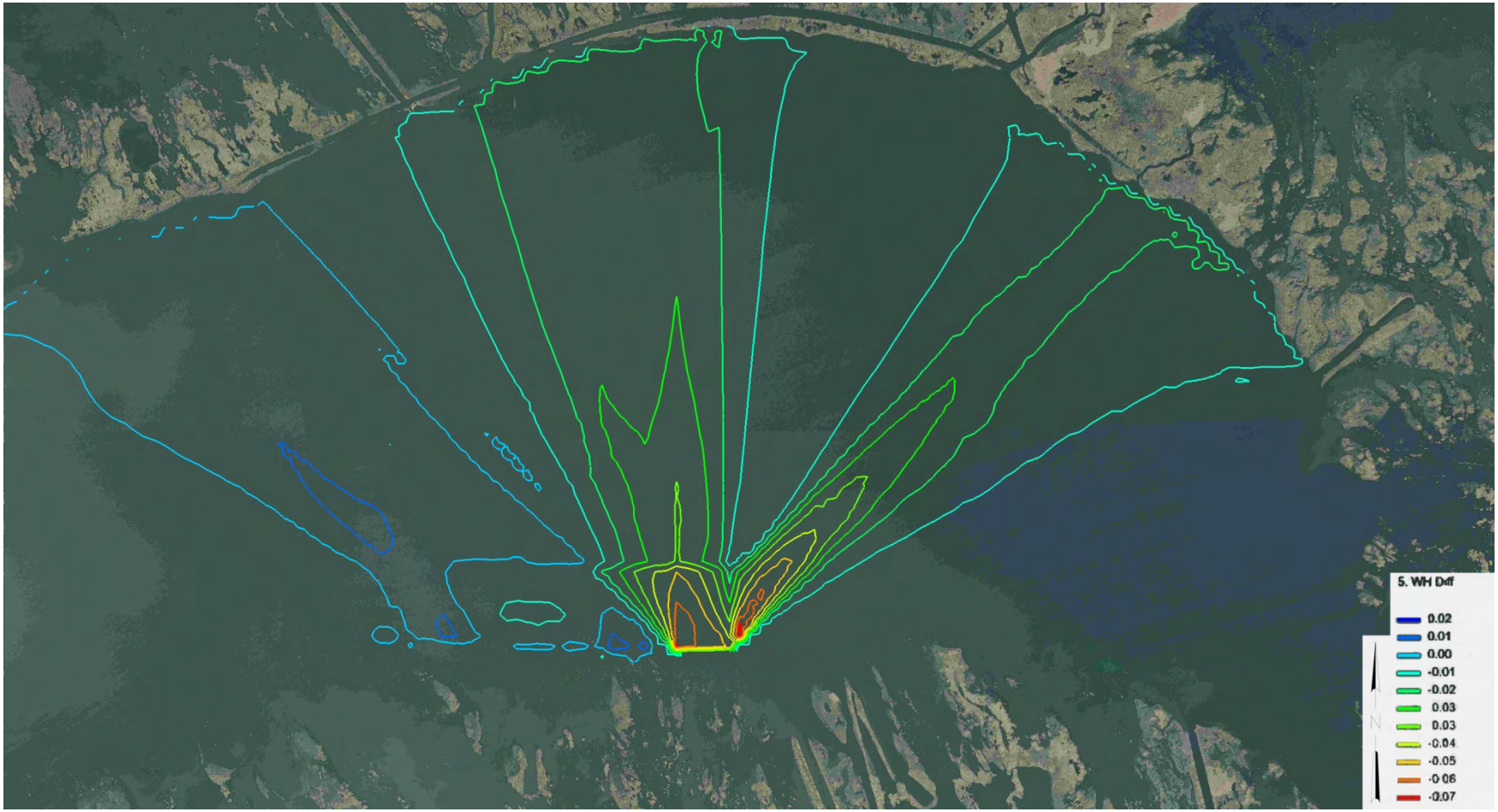

Figure A.20. Borrow Area B Wave Height Difference – Case 5 (units = meters).

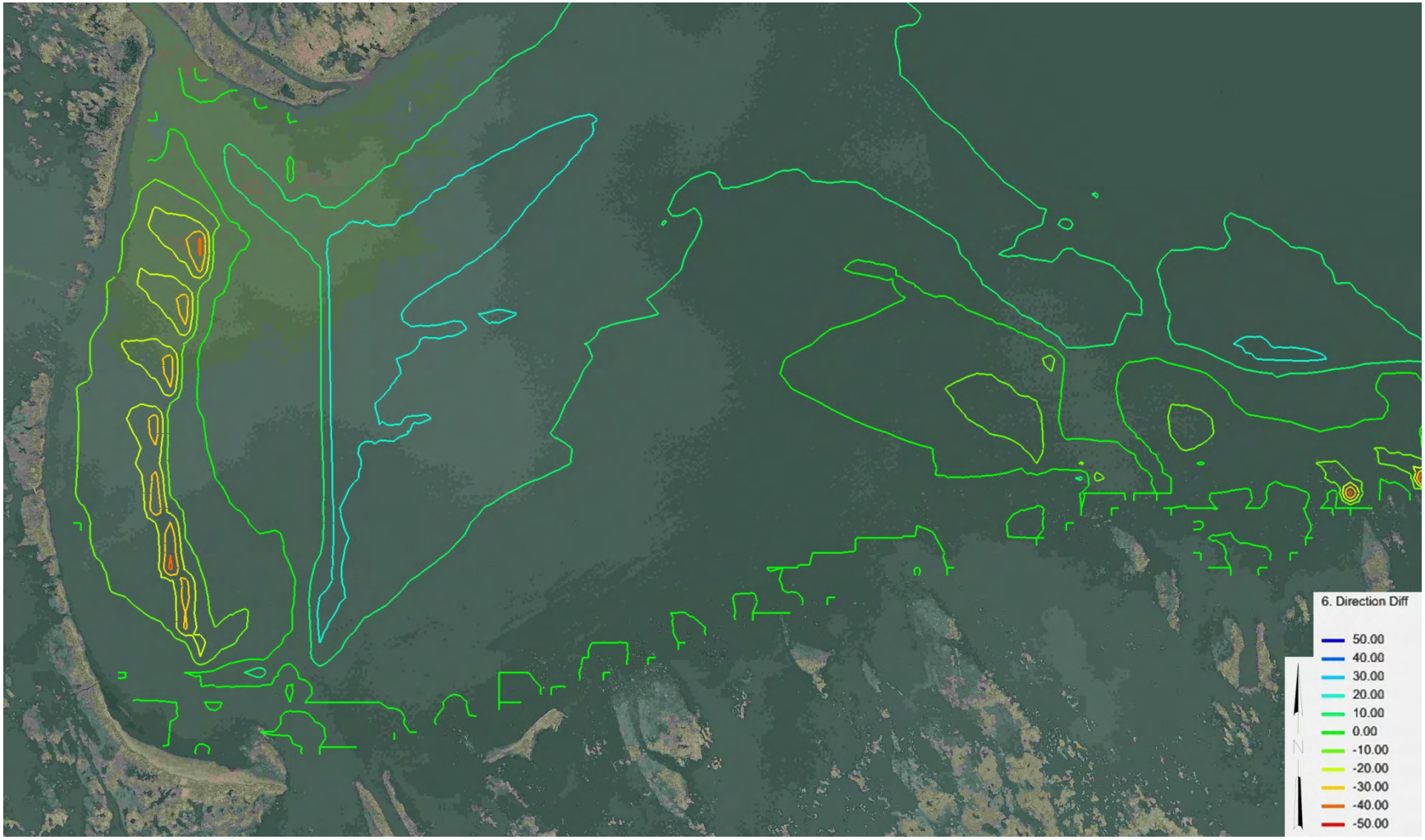

Figure A.21. Borrow Area A Wave Direction Difference – Case 6 (units = meters).

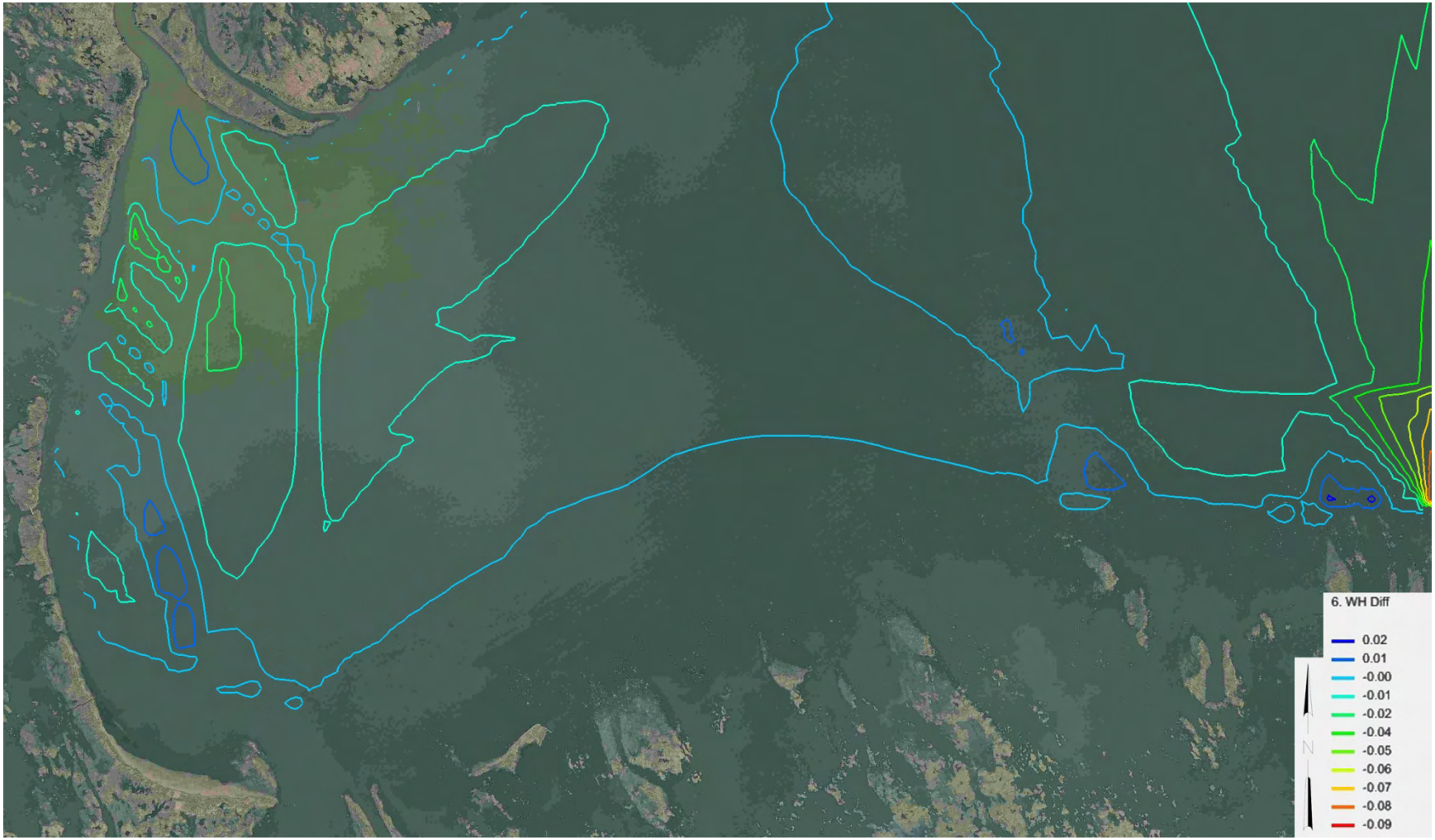

Figure A.22. Borrow Area A Wave Height Difference – Case 6 (units = meters).

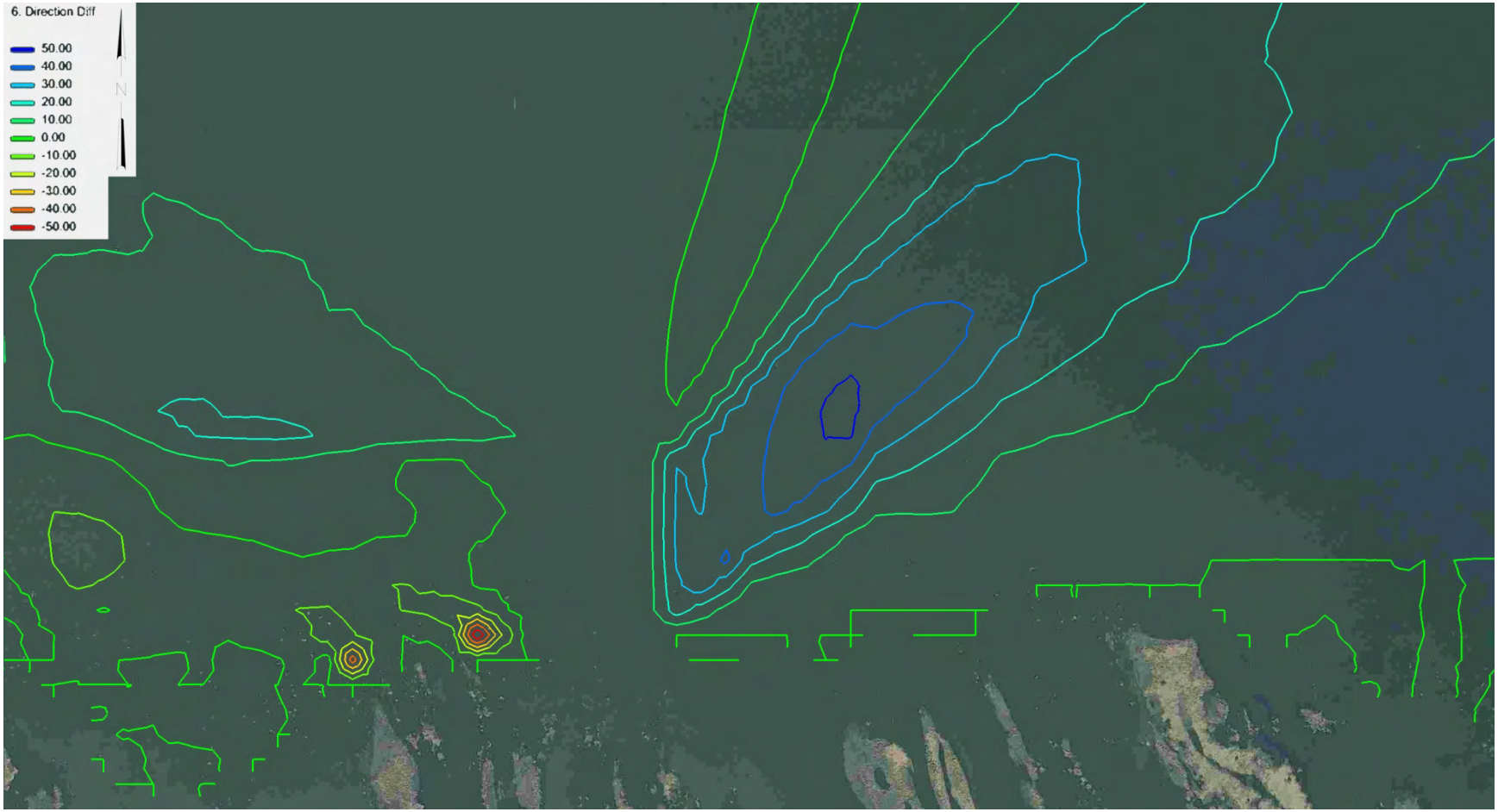

Figure A.23. Borrow Area B Wave Direction Difference – Case 6 (units = meters).

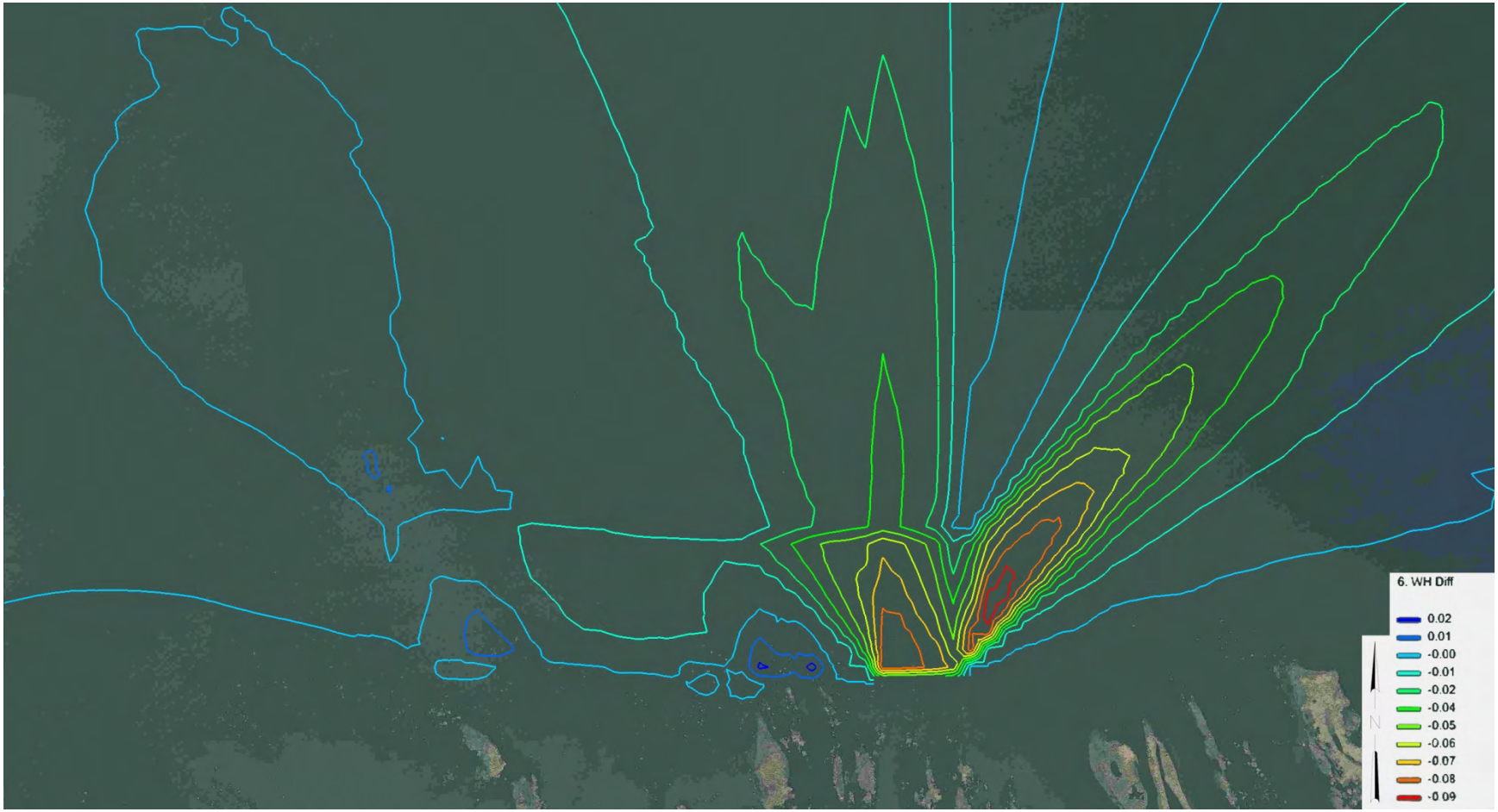

Figure A.24. Borrow Area B Wave Height Difference – Case 6 (units = meters).

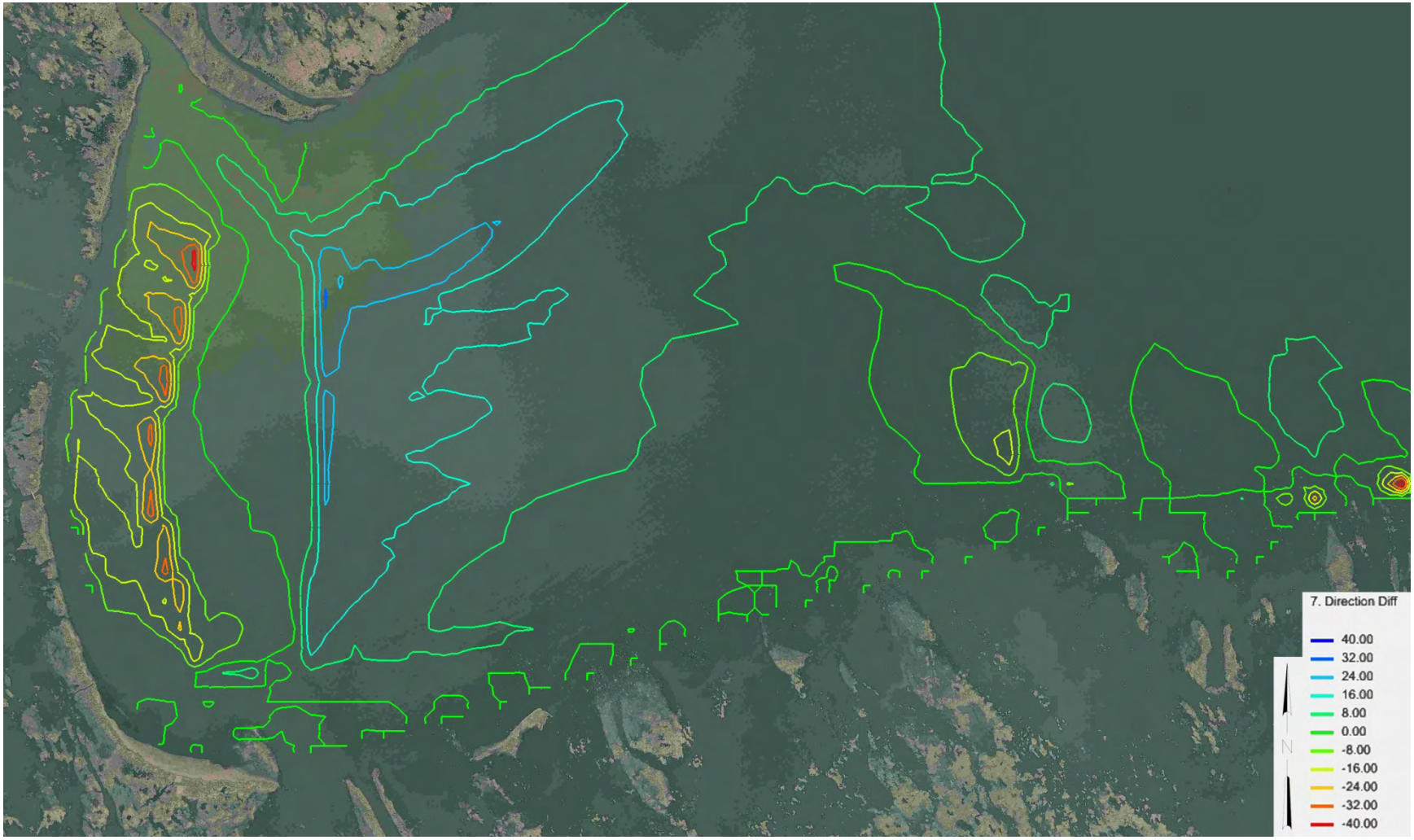

Figure A.25. Borrow Area A Wave Direction Difference – Case 7 (units = meters).

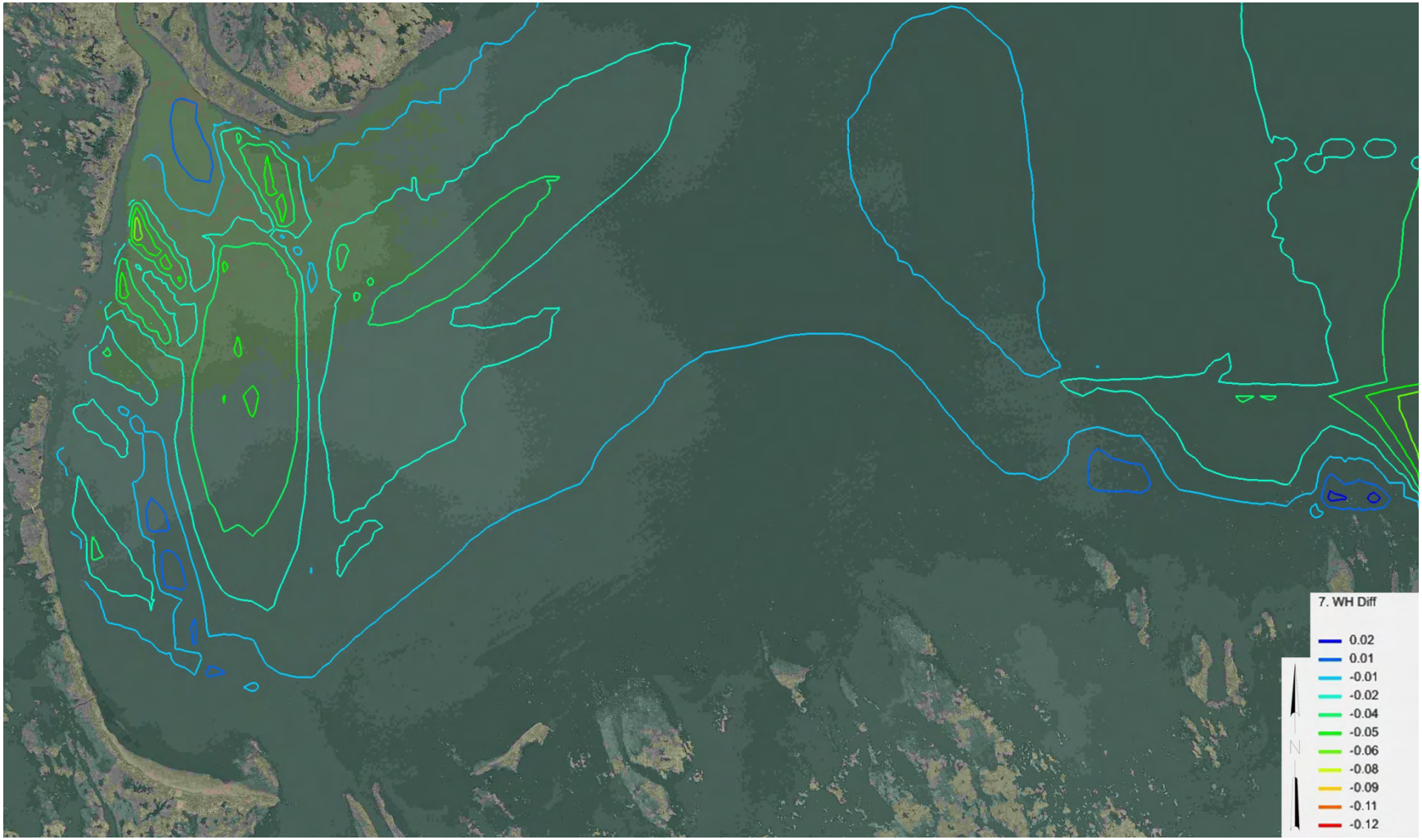

Figure A.26. Borrow Area A Wave Height Difference – Case 7 (units = meters).

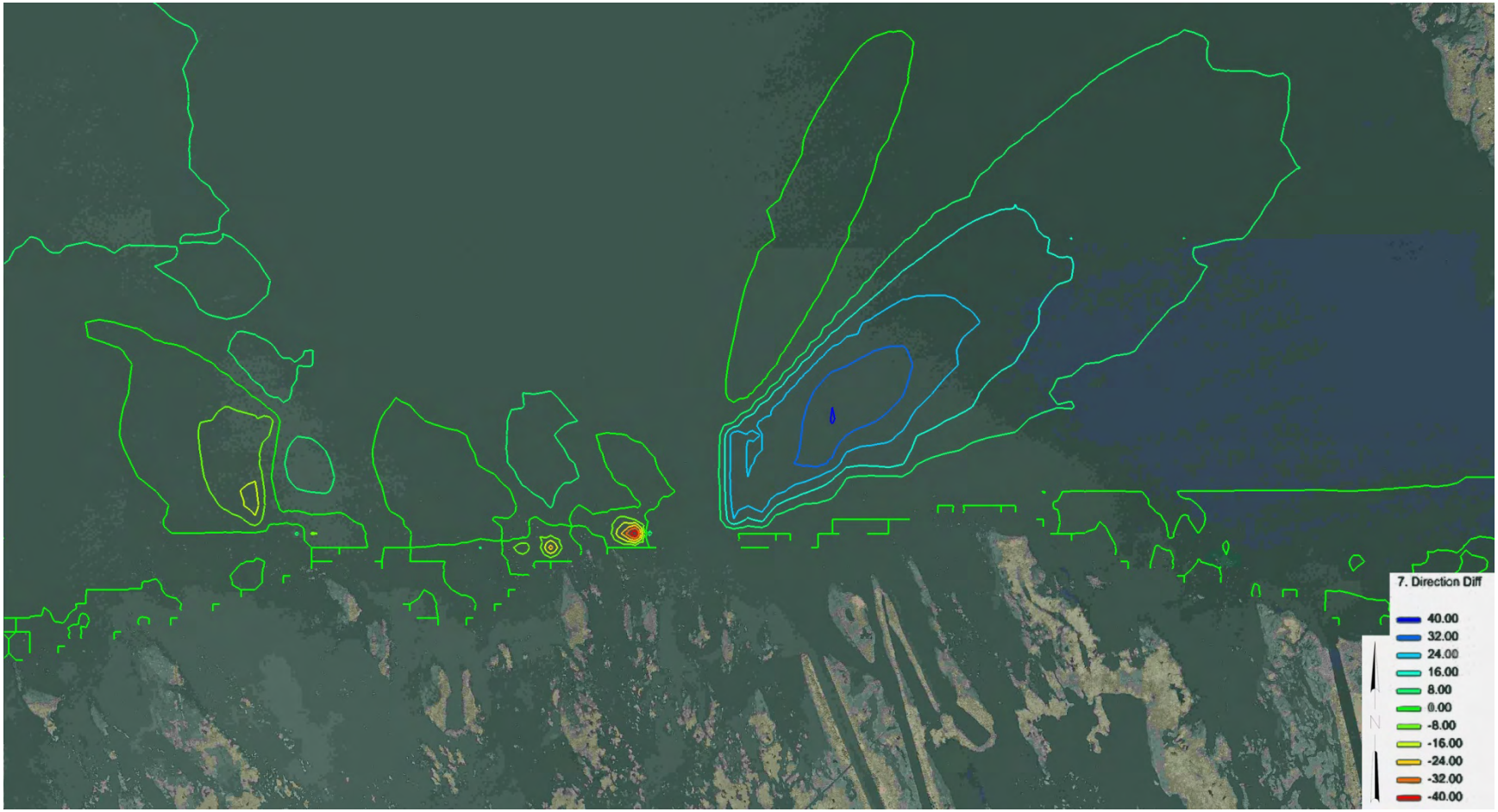

Figure A.27. Borrow Area B Wave Direction Difference – Case 7 (units = meters).

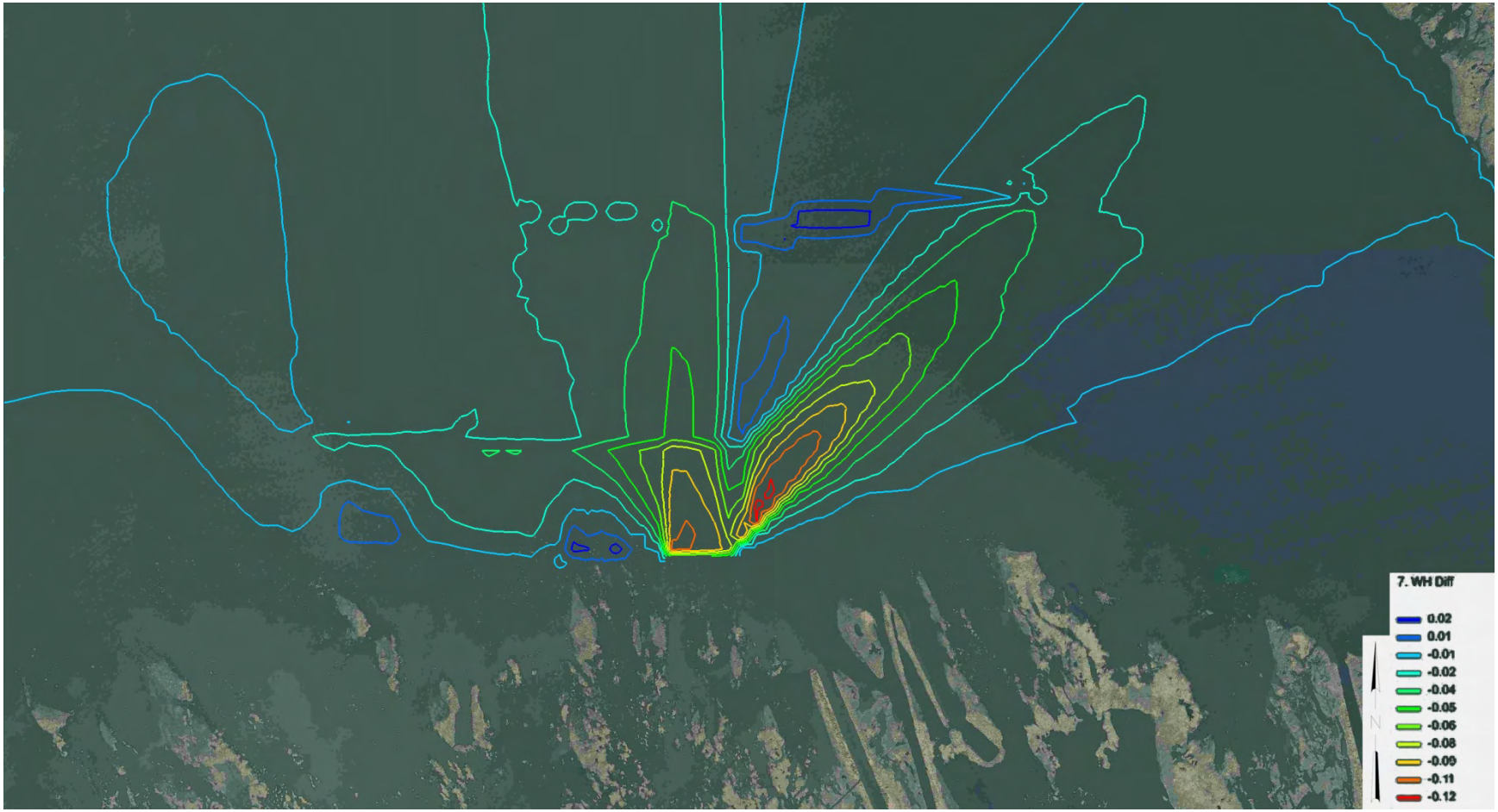

Figure A.28. Borrow Area B Wave Height Difference – Case 7 (units = meters).