Appendix A- Scoping

Ocean Isle Beach Shoreline Protection Project
Public Scoping Meeting
3 October 2012

GROUP 1

- Address private and public economic impacts, positive and negative.
- Address Senate Bill 110, each point in the bill
- How will the terminal groin affect the west end of the island
- Adequately address the downdrift affect well beyond the proposed terminal groin, including Sunset Beach
- Cost of continuing maintenance of terminal groin
- Address the length of the EIS study
- Negative impacts on town, state, and tourism economy if no terminal groin is installed, or if no other project is approved
- Visual aesthetics of completed terminal groin
- If only beach nourishment were to continue without the terminal groin, how does it affect the east end of OIB
- 30 year model, include category 1 and over hurricanes, with and without the terminal groin
- All comments should include with and without terminal groin
- Disclose the funds paying for the terminal groin
- Address property values if nothing is done, or if terminal groin is installed
- Assess the opening up of the inlet as it affects navigation and recreational opportunities
- Assess the impacts of sea level rise from a long-term perspective
- How will the terminal groin affect the flow of the inlet, and how often will the inlet have to be maintained
- Address private and public property east of the terminal groin
- Addressing adequate funding for monitoring environmental effects of groin, funding for mitigation for negative effects west of the groin on OIB and adjacent islands. Requirements for removal of groin, if needed
- Address effects from removal of groin, if needed
- Address/assess movement of sand with and without the terminal groin, along the eastern end of OIB
- Additional effects of critical bird habitat on the west end of OIB
- Impacts on sea turtle population if the terminal groin is put in.

GROUP 2

- Identify solution for existing problem
- Money spent to save infrastructure and relocating utilities
- Address impacts to Sunset Beach and Bird Island, down-drift
- Long-term options beyond ACOE renourishment efforts
- Immediate solutions available
- Long-term solutions
- Does current ACOE renourishment project affect erosion rates now

- Imminent threat for loss of existing structures
- Hardened structures existing in other states (NJ), and their affects
- Impacts to west end, will it affect wave refraction, sand accretion, and erosion
- Aesthetic affects to beach-goers
- Long-range costs, operations and maintenance-proliferation
- Will this groin set a precedence for future groins at all inlets in NC
- OIB central reach is stable, will the groin affect this
- Changes in sand transport into Shallotte Inlet
- Will groin only slow erosion, or stop it
- Is this a permanent solution
- Unintended consequences
- Will ACOE expand existing nourishment efforts to include east end
- Are jetties a viable alternative
- Will groin cause loss to adjacent islands
- Nesting shorebirds and sea turtles
- Will groin create additional habitat for fish and bring back turtles
- Impacts to Holden Beach and Shallotte Inlet AIWW Shallotte River
- Does terminal groin affect the federal project
- Will groin allow expansion of federal project into inlet hazard area-policy change
- Will it cost more and/or save money to construct groin. Less cost to renourish beach
- Effect to Shallotte Inlet, will it increase navigation and stabilize inlet
- Expert input-studies and observations by academic community showing effects of groins
- Will sea level rise impact project viability

GROUP 3

- Terminal groin siting
- Effect of construction timing based on protected species
- Channel re-alignment alternative
- Will there be access to the east end by ATV or foot
- Downdrift effects of groin
- Is there west end erosion
- What are the effects of the groin on the east end and west end of Holden Beach (i.e. Turtles)
- Are there other options out there
- How visible will the structure be
- What material will the groin consist of
- Cumulative effects of other terminal groins in the area
- Effects of structure on bed flow sediment
- Impact to Sunset Beach (turtle issues, Bird Island, and erosion toward Bird Island)
- Economical feasibility of groin
- Depth of previous studies
- Fisheries and other environmental issues
- Effect of groin on east end of Sunset Beach
- Accuracy of previous models
- Comment made supporting the use of the structure

- Assessment of no build alternative, 20-25 year
- Effect of stop dredging the inlet

GROUP 4

- Consider effects that timber structure (temporary reinforcement) had on the system
- Provide schedule/timeline of event for completeness of project
- Concern for time
- Negative consequences downstream
- Added expense for litigation if something were to go wrong
- "Coastal Research" document is not a peer-reviewed study, it is an opinion
- Sunset Beach has benefitted from their jetty
- What will accretion mean for reclaiming private property (moving of setback lines)
- What erosional affects this will have on Sunset Beach
- Who will pay for consequences of the project to neighboring beaches (monitoring and mitigation)
- Effects on Saucepan Creek (positive/negative effects of shoaling in the inlet)
- Engineered distinction of this being a terminal groin, not a jetty or a groin (compare to other studies, i.e. Fort Macon, Pea Island –NCSU study)
- Concern about cost of studies on tax payers, how much information is enough
- Cost reduction of federal project (long-term)
- Time it will take to get the project in the ground, propose sooner rather than later)
- Impact on tourism, loss of money due to unsightly sandbags and loss of infrastructure
- Clear statement in EIS on how OIB will address future effects of the project
- Positive/negative impact on shoaling on inlet and navigability of the ICW
- Desire for a more expeditious process with less time and frustration

<u>Terminal Groin Comments Received in Response to September 21, 2012 Public Notice:</u>

1) Economics/Financial

- How to pay for future costs should be disclosed by the Town Council (if by increasing taxes notice should be given now).
- Non-resident property owners should have a say re: approving/disapproving bonds.
- Concern that tax increase will lower property values.
- Est. of losses to landowners should only consider lots with structures and buildable lots that would be lost to shoreline erosion within the proposed project period (not lots already submerged/unbuildable). Areas not eminently threatened should not be considered. Undeveloped interior lots should be discussed for relocation of structures.
- Applicant needs to provide detailed info to "demonstrate that structures or infrastructures are imminently threatened by erosion." The actual number and location of structures that qualified as "imminently threatened" by the CRC need to be identified.
- DEIS must demonstrate that the construction and maintenance of the TG must not result in sig. adverse impacts to private property or public beach. Need to ID what constitutes a sig. "negative" impact that must be mitigated for and ID boundaries when considering lack of sig. adverse impacts. Boundaries should be ID in the DEIS before project costs are est. or prior to any permit

decisions.

- In evaluating costs and benefit of alternatives, applicant should represent scenarios that include the effects of storms on the project area and compare with a TG, with non-structural alts, and with no action.
- Exact costs of financial assurances need to be determined so they can be factored into the cost/benefit analysis.
- Additional project costs include increased commitment to beach renourishment near the inlet and inlet management costs, and how the proposed TG will affect the inlet as well as the inner beaches and estuarine ecosystems.
- DEIS should detail costs of preparing the EIS, obtaining permits, and expected legal proceedings.
- Major beneficiary of the project is the Williamson family (a.k.a. LW Legacy Assets and Ocean Isle Developing Co.) who own 61% of total properties within the project area, to include 65% of $100-value (underwater) properties. If renourished with public funds, these properties become public property. The DEIS should clarify who owns these lots before it can evaluate the impact of any alt, including no action.
- Need to est. who will be financially liable for loss or protection of privately owned property downdrift of the TG (i.e. will the Town/citizens be liable for loss of $100-properties?)
- Relocation of threatened structures is a viable alt that needs to be carefully examined.
- Need to provide a timeline model of how predicted erosion could threaten structures on the east end not currently considered imminently threatened.
- Provide for modification or removal of the TG if adverse impacts cannot be mitigated and the costs for these mods and removal.
- ID funding sources necessary to fund the TG and beach fill given that no state funds are available and local funds need voter approval.
- Applicant must provide cost estimates for the required financial assurances for the TG project to cover costs of removal, restoration of beach, long-term maintenance and probably litigation.
- Economic costs and benefits of each project alt should include the positive econ. Values associated with natural inlet processes (fishing, tourism, habitat creation, larvae transport and fish migration).
- Need to factor in long-term management costs associated with maintain sediment balance in the Shallotte Inlet.
- DEIS must proposed adequate funding for monitoring, along with monitoring and mitigation on adj. islands and estuaries.
- If the TG fails/causes damage, the DEIS must proposed appropriate funding for repairs, mitigation and/or removal. All funding should be placed in escrow and monitored by the Corps in accordance with its standard practices.
- How to pay for the future cost of a TG should be determined and disclosed by the Town Council. Richard Bernhardt (resident?)

2) Engineering/design/construction

- $300,510 allotted for Engineering Support, to include use of computer models which are not appropriate/unreliable for this type of analysis; they are very poor predictors of future geological changes on barrier islands, especially around tidal inlets.

- Plan for construction and maintenance of TG and beach fill (prepared by licensed NC engineer) must be provided as part of the TG option.

- Potential effects of "leaky" structure design; how injury or death to sea turtles and other marine mammals who could get trapped within the TG.
- Detailed description/calculation of "leakage" rate and how it will affect the required beach renourishment and use of public beach, erosion or accretion of inlet habitats, tidal sands and inner inlet areas.
- Consideration of gradual blockage of "leaky" groin due to growth of marine life, debris and other impediments.

3) Biological/Natural Resources

- Risk that beaches located down drift will be deprived of sand.
- Project area not designated PNA or closed to taking of shellfish.
- Substrate is primarily sand.
- Listed species known to occur in the area are the West Indian manatee, piping plover, seabeach amaranth, Kemp's Ridley, hawksbill, leatherback, loggerhead and green sea turtles.
- Whales, shortnose and Atlantic sturgeon and sea turtles are under NOAA Fisheries' Protected Species Division.
- Most important aspects are the construction schedule and the compatibility of material imported for beach fill.
- Concern with potential long-term impacts of sea-level rise; how may result in increased erosion and influence need for more frequent renourishments.
- Need to address potential impacts to Holden Beach shoreline and piping plover critical habitat for entire length of shoreline.
- All existing data re: species of concern should be provided.
- State rule does not include criteria for mineral content, organic content and color. DEIS should include discussion of mineral/organic content and color of nourishment material and native material. The approach for ID native material should be explained.
- 404 wetlands throughout the project area should be ID and mapped. Compliance with avoidance, minimization and mitigation requirements should be explained for each alt.
- "Critical habitat" as defined by USFWS needs to be mapped on both sides of the inlet and the effects of all project alts need to be evaluated on this habitat.
- Concerns about impacts of the TG on critical bird habitat on west end of Holden Beach and Shallotte Inlet must be fully explored.
- Need to investigate effect of TG on inlet narrowing and loss of natural inlet shoals and sand flats as well as possible increase in tidal flow.
- Thorough evaluation of effects on ebb shoal deflation along with both economic and resource related costs.
- Effects of the TG on the navigation channel and effects of continued required maintenance of the channel on the integrity of the TG itself.
- Effects of the TG on piping plover and sea turtle habitat on each side of the inlet; need to address how the project will comply with the ESA.

- Potential effects on the Atlantic and Short-Nosed Sturgeon, West Indian Manatee and other listed species.
- How will adult and hatchling sea turtles survive storm and wave action in and around the TG.
- DEIS must adequately address the down-drift, ocean side environmental impact well beyond the TG.
- Concerns that the TG will alter larval transport and impact important fish habitats through altered beach and nearshore sediment and profile.
- Concern about altered longshore sediment transport; TGs may modify sediment grain size, increase turbidity in the surf zone, narrow and steepen beaches and result in reduced intertidal habitat and diversity and abundance of macroinvertebrates.
- DMF requests a field investigation of the current distribution of larval and juvenile fishes in the Shallotte Inlet as well as another similar inlet as a control. Need to ID most highly utilized habitat areas and serve as baseline data to compare to data collected after the TG.
- Request for detailed discussions of: all EFH and state protected habitats that occur in the area; all fish habitats outlined in the most recent NC CHPP that occur in the area; characterization of fish and invertebrate composition and abundance in the inlet and adj. surf zone.
- Compilation of relevant research re: larval transport through inlets, esp. inlets with hardened structures.
- Potential impacts to benthos of surf/swash zone and nearshore areas and a detailed plan to monitor for impacts within project area.
- Potential impacts to wetlands due to anticipated erosion on the east end of the island.
- Potential impacts to commercial and recreational fishing (including indirect economic impacts).
- Potential direct impacts from dredging, beach placement, and nearshore placement and how those impacts will be minimized.
- Potential impacts on regional sand budgets.
- All oceanfront activity should be conducted outside of sea turtle nesting season (May 1 – Nov. 15) or until the last known nest has hatched.
- Avoid all work during shorebird nesting period (April 1 – Aug. 31).
- Preconstruction monitoring should be incorporated in to the DEIS for overwintering birds to better establish use of the inlet area by these species. Concerns for impacts to piping plover (must also be addressed in the DEIS).
- Red knot is being considered for listing on the endangered species list; it utilizes inlet complexes in this area and could potentially be impacted and must be addressed.
- Concern for impacts to benthic invertebrates found in intertidal habitats. NCWRC requests that benthic sampling be conducted pre and post-construction of the TG and beach renourishment events.
- Address the influence that the groin may have on localized erosion rates and how to determine the appropriate nourishment needs for the groin to function properly and maintain desired beach profile.
- Need to discuss the life of the project as well as all direct, indirect, secondary and cumulative impacts that will occur during the life of the project.
- Need to provide a discussion on the potential mitigation options that may be available to offset any unintended direct and indirect impacts from the proposed TG.
- All owners of property in OIB should be informed now of the risk that beaches located down drift of a TG will be deprived of sand. – Richmond Bernhardt (resident?)

4) Modeling

- Detailed modeling should be required to review possible effects of the TG on Shallotte Inlet and navigable access to the Waterway and Ocean.
- Detailed evaluation and reasoning on the selection of the modeling process to reveal any possible effect of TGs at both OIB and Holden Beach and any cumulative impacts associated with the two in relatively close proximity to each other. How will the responsible party be identified for impacts and mitigation.
- Proof and analysis that the TG will reduce the frequency of required beach renourishment and how the "leaky" structure will affect that frequency.
- DMF requests a detailed scientific field investigation, analysis and modeling of larval transport dynamic that exist in and near Shallotte Inlet. This info should be used to model estimated impacts of any TG alternatives to larval ingress and egress through the inlet.

5) Monitoring

- DEIS should discuss proposed daily monitoring programs for sediment compatibility, compaction and escarpments, and the potential presence of listed species in the project area during construction.
- Proposed methods to monitor beach biota and species of concern should be fully addressed (to include location of pipeline, species surveys before and after work, recovery of beach biota, impacts to down-drift beaches and areas east and west of the project, and monitoring of the piping plover critical habitat).
- Post-project monitoring and necessary mitigation must comply with the definition of thresholds; will serve as a baseline for determining mitigation of any future impacts and serve as a baseline for future monitoring; need to identify correct baselines.
- Thresholds should be determined based on predictions of future shoreline and inlet configurations associated with each individual project alt. To demonstrate that non-structural alts are impractical, the DEIS must clearly prove that the TG will result in more beneficial shoreline and inlet configuration and cost-effectively accomplish the project purposes.
- Describe post-construction activities the applicant will undertake to monitor impacts on coastal resources.
- ID mitigation measures to be implemented if adverse impacts reach defined thresholds and state the costs of these mitigation measures.
- DMF requests benthic macroinvertebrate monitoring within the impact areas of the TGs.

6) General

- Purpose of project is somewhat vague, and it is unclear what is meant by "environmentally-justified"; project alts should meet the P&N in order to receive full consideration of the EIS; purpose of the project should be general enough to allow consideration of a full suite of alts.
- Alts should include "abandon and/or relocate" as well as other protection measures without use of a TG.

- DEIS should recognize and discuss the requirement that "nonstructural approaches to erosion control are impracticable" and clearly indicate the practicality of each of the alts.
- DEIS should ID an expected project life (with consideration to sea level rise).
- The Cum Impacts Anal for all alts should include an analysis of potential sea-level rise scenarios (similar to EC 1165-2-211) and influence it will have on the nourishment schedule and overall life of the project.
- DEIS should provide info concerning previous shoreline mgmt. projects for the entire length of OIB (federally funded and private), along with an aerial showing extent of those projects.
- DEIS should provide substantial data on tidal currents and sediment transport around the inlet and erosion rates along the entire length of the shoreline.
- Project description is troublesome in that it clearly states the preferred alt before thoroughly investigating/discussing any alternatives. CEQ warns against consideration of choice outside of public view; preferred alts should be identified later in the process.
- Town's 3rd party consultant and engineer, CPE-NC, stated their preferred alt was the proposed TG and offered very little info about alts required in the NEPA process for DEIS purposes. This consequently biased the 3rd party requirement to research and review all reasonable alts.
- To comply with State policy, investigating non-structural alts should be the main objective of the analysis.
- Incorporation of the State Beach and Inlet Management Plan into the EIS process and consideration of recommendations for avoidance of hardened structures.
- Consideration of possible effects of the TG reducing the long shore transport of sediment to Shallotte Inlet.
- Consideration of effects of Shallotte Inlet morphology and inlet channel migration upon the TG structure itself.
- Consideration of possible effects of the TG upon the west end of Holden Beach, historic shipwreck sites in the inlet and public and private property.
- Ensure protection of properties down-drift of the TG and consider impacts on Town of Sunset Beach.
- What impacts will placing groins on OIB have on Sunset Beach? Groins will block the movement of sand to the beaches that are downstream and trigger erosion on those beaches. TGs are only temporary fixes. Richard Hilderman, Sunset Beach resident.

Ocean Isle Beach Shoreline Management Project
March 5, 2013 PRT Meeting Minutes
Ocean Isle Beach, NC Town Hall

The meeting was called to order at 1pm by **Emily Hughes** of the US Army Corps of Engineers (USACE). Introductions were made. Emily discussed the agenda for the meeting in which it would focus on the purpose and needs of the project, the proposed project alternatives, and a preliminary inventory of baseline biological data compiled for the Draft Environmental Impact Statement. Open dialog from the attendees was encouraged. (*A list of attendees is provided at the end of the minutes*.)

Emily reviewed the agenda and provided a brief overview of the role of the USACE and North Carolina Division of Coastal Management (DCM) in the permitting process. She discussed how the National Environmental Policy Act (NEPA) comes into play with projects such as this. Emily then reviewed the role of the Project Review Team (PRT) suggesting that the group has been assembled as a forum for participants to provide input and suggestions as the project progresses. The PRT is not, however, a group that develops the EIS or an advisory team. She then explained that Coastal Planning & Engineering of North Carolina (CPENC) has been selected as the 3rd Party Contractor and will be developing the EIS in tandem and under the review and guidance of the USACE.

Steve Candler of the Brunswick County Association of Realtors posed two questions to Emily. First, he asked how the UACE determines if significant impacts are expected and if an EIS is needed for this project. **Emily** responded by stating that an Environmental Assessment (EA) may be developed to determine if impacts are expected. If so, an EIS is developed. In this case, however, SB110 required that an EIS would be required. **Doug Huggett** from DCM explained this rationale in greater detail. Steve also asked if any other terminal groins had been built on the east coast and if any EIS documents have been developed. **Doug** answered that there is a Draft EIS for Figure Eight Island and drafts in development for Bald Head Island and Holden Beach. Two terminal groins had been built in North Carolina at Pea Island and Fort Macon; however, those were constructed prior to the SB110 legislation. **Brad Rosov** from CPENC added that EISs have been developed for other terminal groins within recent years in other states including South Carolina (Hilton Head) and Florida (Amelia Island). These documents could be available from the Jacksonville District and the Savannah District.

Doug then discussed the recent terminal groin legislation known as SB110 and reviewed the various components of the legislation. Several aspects of the legislation will require a careful interpretation as the project moves forward including the development of a monitoring plan and proof of financial assurances. He also added that the alternatives analysis would need to be included as a supplement to the CAMA Major Permit application packet as the NEPA process does not require this level of analysis within the EIS. Rather, this analysis is conducted during the Record of Decision (ROD) process which occurs after the submittal of the EIS. **Mike Giles** with the North Carolina Coastal Federation asked for clarification. Brad explained that the timing of the EIS and the ROD are not compatible with the state legislation which is why the supplemental information will be provided to CAMA within the application packet.

Emily then introduced the purpose and needs of the project and why they are important. **Brad** reviewed the draft purpose and needs and explained that these were developed by the Town as they identified their problem and CPENC would then work to develop project alternatives that would serve to solve those problems. The draft purpose and needs are as follows:

- Reduce or mitigate erosion along _____ miles of Ocean Isle Beach oceanfront shoreline west of Shallotte Inlet;
- Maintain the Town's tax base by reducing storm damage to development and infrastructure on the ocean front shoreline of Ocean Isle Beach between Shallotte Inlet and the western terminus of the Federal Project;
- Maintain existing recreational resources; and
- Balance the needs of the human environment with the protection of existing natural resources.

Following a review of the purpose and needs, **Brad** showed the team a figure illustrating the proposed project location which includes Shallotte Inlet, a portion of the oceanfront shoreline of Ocean Isle Beach and Holden Beach as well as areas within the Atlantic Intracoastal Waterway and the Shallotte River. **Brad** emphasized that this project location is only a draft and will be adjusted once the modeling results provides an indication of the extent of any impacts to the area in terms of changes in hydrology, sedimentation, or erosion. The domain within the project/permit area will then be utilized as the basis for the delineation of the acreages of the various biotic communities found within. Any changes in the acreages of biotic communities following the construction of the project will be monitored via the interpretation of high resolution aerial photography. Doug asked how much of the oceansfront shoreline along Ocean Isle Beach is included in the project location. It was confirmed that it was approximately 1 mile and would overlap the Federal Project. **John Ellis** from USFWS asked where the borrow area was located for the Federal Project. **Tom Jarrett** from CPENC stated that the borrow area was located within Shallotte Inlet as the Federal Project was designed as an inlet relocation project. **Tom** then described that the area east of the Federal Project has experienced high rates of erosion and therefore this project would serve to address this need.

Robert Neal with CPENC then provided an overview of the proposed project alternatives. These include:

- Abandon/Retreat
- No New Action
- Beach Nourishment
- Terminal Groin with Associated Beach Nourishment

Robert explained that the abandon/retreat alternative would be evaluated in terms of practicality and cost to remove or relocate structures and infrastructure. The No New Action alternative would entail evaluating the efficacy of the existing shoreline management activities in place along the Town's oceanfront shoreline in terms of meeting the Town's purpose and needs. The existing management activities include sandbag protection, a local beach fill project, the Federal Project, etc. The beach nourishment alternative would only include adding beach fill to the ocean front shoreline while the terminal groin alternative would include the construction of a terminal groin of a to-be-determined length and location along with beach fill which would form a "fillet".

Doug recommended including an inlet relocation alternative as well despite the fact that the Federal Project was designed as one, yet it has not performed as intended. **Robert** agreed and stated that it would indeed be included as a listed alternative with the understanding that this alternative would most likely not suit the Town's purpose and needs considering it has been attempted and failed. **Tom** reiterated the history of the relocated inlet and the rationale of why it failed and how high rates of erosion have continued along the eastern portion of the island. **Kathryn Mathews** from USFWS asked where the material that gets placed during the Federal project goes as it erodes- to the east or to the west. **Tom** interjected that some of the material moves towards the inlet and actually helped develop the spit that exists there today. **John Ellis** asked **Tom** why the Federal project did not include the eastern most portion of the island in its project. **Tom** responded by stating that the economic benefit was not justified. For this project, however, the economic benefit is determined by the applicant. **Robert** went on to show the PRT several conceptual designs of the terminal groin at a location east of Shallotte Blvd. He emphasized that the precise location and length of the structure will be determined following Delft3D modeling which has the ability to measure the hydrology, waves, and morphology. The Delft3D model will be used to analyze the efficacy of the beach fill alternatives including the alternative incorporating the terminal groin. CPENC has deployed a series of tide gauges and ADCPs used to collect data that would be fed into Delft3D and used for calibration of the model. CPENC is currently working to calibrate the model such that they can evaluate the proposed project alternatives. **Tom** made a point in emphasizing that the model is not to be used as a prediction of future conditions; rather, it is used to indicate differences between existing conditions and the proposed project alternatives following the input of a set of conditions (waves, hydrology, and morphology) into the model. **Maria Dunn** from North Carolina Wildlife Resources Commission asked if there was a certain percentage threshold for which the model would be deemed to be calibrated. **Tom** responded that there is no set percentage of agreement; however, the modelers would accept the model as they feel comfortable with its output.

Kathryn inquired about the history of some old groins that were installed along the inlet in the past. **Tom** mentioned that the series of groins were installed by Odell Williamson several decades ago. The structures were built by driving wooden telephone poles into the sand but they contained large gaps and therefore did not retain any sand. Therefore, they did not function as intended and were eventually removed. **Debbie Smith**, mayor of Ocean Isle Beach, emphasized that the Town did not install them and that, rather, they were installed by a private citizen.

Mike asked how the model will address sea level rise. **Robert** mentioned that the project would have a 30 year permit lifespan, so sea level rise would not play a large role in the modeling effort. **John** asked if the USACE is looking into how sea level rise should be integrated into project formulation. **Emily** responded that there is a committee looking into this now, however, she does not expect any action in the near future. **Tom** added that even in the worst case predictions in sea level rise over the next 30 years or 100 years would not influence the project. **Ana Zivanovic-Nenadovic** with the Coastal Federation inquired how much weight the USACE would put on the modeling results when it comes to evaluating project alternatives. **Tom** answered that modeling is the best tool that we have to understand the anticipated response to the various project alternatives. **Doug** added to this and stated that the terminal groin legislation recognizes the dependence on models and, in response, incorporated the requirement of stringent post-construction monitoring efforts.

Brad then provided an overview of the biological data that has been collected to date for the EIS. This includes information regarding various habitat types as well as data on individual species, primarily threatened and endangered species, located within the proposed project area. After sharing the inventory of data collected thus far, **Brad** asked the PRT for any input on any additional biological data known to exist that would help bolster the EIS. **Anne Deaton** from DMF mentioned that the UASCE may have conducted some sidescan sonar surveys for hardbottom off the Brunswick County Beaches. **John** mentioned that CPENC should be cognizant of the various environmental windows regarding construction timing as the plan formulation progresses. **Doug** interjected that along with biological resources, it would be important to attempt to quantify recreational resources and usage in the permit area. **Brad** responded that CPENC plans to provide a qualitative method using aerial photos to count boats in the inlet area. **Anne** added that information pertaining to larval and juvenile fish distribution within the area should be included in the EIS such the post-construction monitoring could be applied if needed. In addition, **Anne** suggested that the Delft3D modeling could include a simulation of larval distribution and movement in relation with the groin. **Tom** mentioned that the model could indeed be used, however, the model would not account for any behavior or movement by the larval in relation to salinity or where they reside in the water column. **Anne** suggested that CPENC contact Dr. Lankford at UNCW for larval transport studies. **Fritz Rohde** from NMFS indicated that there was a series of studies conducted in Georgetown, SC and perhaps this data could be used as well. He also mentioned that an Essential Fish Habitat (EFH) document would be required for the project.

Emily wrapped the meeting up and mentioned that the presentations from this meeting and meeting notes would be available on the website. **Mike Giles** asked if the CPENC work plan was available on the USACE website and **Emily** confirmed that it should be. The next PRT meeting would focus on the results from the Delft3D modeling and the resultant environmental consequences.

The meeting adjourned at 3:30.

Meeting Attendees

Name	Agency	Phone	E-mail
Kathy Matthews	USFWS	919 856-4520 x27	cameron.weaver@ncdenr.gov
Doug Huggett	DCM	252 808-2808	doug.huggett@ncdenr.gov
Amanda Wiggins	Town of Sunset Beach	910 842-6488	amanda@hbtownhall.com
Jonathan Howell	DCM	252 808-2808	jonathan.howell@ncdenr.gov
John Ellis	USFWS	919 856-4520 x26	john_ellis@fws.gov
Holley Snider	DCM	910 796-7270	holley.snider@ncdenr.gov
Debbie Wilson	DCM	910 796-726	debra.wilson@ncdenr.gov
Anne Deaton	DMF	910 796-7315	anne.deaton@ncdenr.gov
Wilson Sherrill	Town of Sunset Beach	910 540-9984	wilsonsherrill@hotmail.com
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Robert Neal	CPENC	910 791-9494	robert.neal@cbi.com
Mike Giles	NC Coastal Federation	910 509-2838	mikeg@nccoast.org
Ana Zivanovic-Nenadovic	NC Coastal Federation	252 393-8185	anaz@nccoast.org

David Hewett	Town of Holden Beach	910 842-6488	dhewett@hbtownhall.com

Appendix B- Engineering Report

ENGINEERING REPORT
OCEAN ISLE BEACH SHORELINE MANAGEMENT PROJECT

Prepared For:

Town of Ocean Isle Beach
Three West Third Street
Ocean Isle Beach, NC 28469

Prepared By:

Coastal Planning & Engineering of North Carolina, Inc.

January 2015

ENGINEERING REPORT
OCEAN ISLE BEACH SHORELINE MANAGEMENT PROJECT
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ENGINEERING REPORT
OCEAN ISLE BEACH EROSION MITIGATION PLAN

1.0 INTRODUCTION

Ocean Isle Beach is approximately 29,200 ft. long (5.5 miles) and is located along the coastline of Brunswick County, North Carolina (Figure 1-1). The island is separated from Holden Beach on the northeast tip by Shallotte Inlet and from Sunset Beach on the southwest terminus by Tubbs Inlet. The island is comprised of approximately 3.4 square miles of land and 0.9 square miles of marsh or water (US Census, 2011, Wikipedia). The only vehicular access to the island is along state road 904 (Causeway Drive), which connects at approximately mid-island. The Town was incorporated in 1950 and has approximately 500 permanent residents and nearly 25,000 daily seasonal habitants (Insiderinfo, 2013).

Prior to the construction of the Atlantic Intracoastal Waterway (AIWW) in the 1930's, Ocean Isle Beach was separated from the mainland by tidal marshes interlaced with numerous tidal creeks. Material excavated during construction of the AIWW was placed in a series of upland disposal areas on the south side of the waterway; however, many of the pre-AIWW tidal creeks are still evident today.

In 2001, the US Army Corps of Engineers (USACE) constructed a Federal storm damage reduction project that begins near Shallotte Boulevard and extends 17,100 feet west (Figure 3.1). The main fill of the project consists of three segments:

> Segment 1: A dune and berm section extending from baseline station 51+50 to baseline station 103+00. The dune has a crest elevation of +8.5 feet NAVD which is fronted by a 50-foot wide berm at elevation +6.0 feet NAVD.
>
> Segment 2: A 50-foot wide berm at elevation +6.0 feet NAVD extending from stations 103+00 to 129+00.
>
> Segment 3: A 25-foot wide berm at elevation +6.0 feet NAVD extending from stations 129+00 to 153+00.
>
> A 4,200 foot transition section is provided on the east and a 2,900 foot transition on the west.

The Town of Ocean Isle Beach is developing a plan to address erosion impacts along the eastern most 2,500 feet of shoreline on the island. Approximately 2,000 feet of this shoreline is developed with single and multi-family homes. The remaining 500 feet lies east of the development on the east end of the island. About 1,000 feet of the focus area, situated between baseline station 10+00 (Shallotte Boulevard) and baseline station 20+00, lies within the limits of the Federal storm damage reduction project. The Town is considering several different management alternatives to minimize potential damages that may occur as a result of future erosion. The alternatives will be reviewed by the Town and state and Federal agencies to assess potential adverse impacts that each alternative may create. An engineering analysis evaluating each alternative is presented to support the findings of the environmental study and aid in the permitting process.

The management alternatives are evaluated based on how each one is estimated to perform towards the Town's intended goals. These goals are (1) to reduce or mitigate erosion impacts along approximately 2,500 feet of the Ocean Isle Beach oceanfront shoreline beginning at a point approximately 1,500 feet east of Shallotte Boulevard and extending 1,000 feet west of Shallotte Boulevard, (2) to reduce periodic nourishment requirements of the Federal storm damage reduction project, (3) to maintain the Town's tax base by reducing erosion damages to development and infrastructure located immediately behind the 2,500-foot ocean front shoreline, (4) to maintain existing recreational resources, and (5) to balance the needs of the human environment with the protection of existing natural resources. Five management solutions for the east end of Ocean Isle Beach are presented in the analysis and include reactive and proactive responses. The five alternatives are as follows:

- Alternative 1 – No Action (Continue Current Management Practices)
- Alternative 2 – Abandon / Retreat
- Alternative 3 – Beach Fill Only (Including Federal Project)
- Alternative 4 – Shallotte Inlet Bar Channel Realignment with Beach Fill (Including the Federal Project)
- Alternative 5 - Terminal Groin with Beach Fill (Including Federal Project)/ Applicant's Preferred Alternative

The 2013 shoreline location was used as the initial condition for the evaluation of how future erosion trends will respond to the management alternatives. While shoreline erosion on the east end of Ocean Isle Beach continues to reshape the island and impact some of the structures and infrastructure, the use of the 2013 shoreline condition provides a uniform base to measure the relative difference in potential impacts of various shoreline management approaches.

2.0 PHYSICAL CHARACTERISTICS OF THE PROJECT AREA

Physical aspects as well as the natural characteristics typical to the site are essential for understanding the coastal processes relevant to the study area. These items include the study location and limits, sediment characteristics of the beach, the profile depth of closure, typical wave patterns, and tidal current velocities impacting the site.

2.1 Location and Layout

The study area is approximately 2,500 feet in length located on the eastern tip of Ocean Isle Beach and is generally situated between USACE baseline stations having Profile ID's of OI -5 to OI 20. Table 2.1 provides the control information for the USACE baseline within the study area and Figure 2.1 shows a plan view of the profile positions and alignments. Also shown on this figure are measured positions of the scarp line which will be discussed later.

Table 2.1. Baseline Control Data for the Study Area and Shallotte Inlet

Profile ID	Station (ft.)	Easting (ft.)	Northing (ft.)	Monitoring Azimuth (◦)
OI -5	-4+99	2,185,376.78	54,438.74	172.47
OI 0	0+00	2,184,881.09	54,373.23	172.4
OI 5	5+00	2,185,376.78	54,307.82	172.4
OI 10	10+77	2,183,814.03	54,231.29	172.4
OI 15	15+00	2,183,394.94	54,175.62	172.4
OI 20	19+02	2,182,898.55	54,109.52	172.4

(1) Coordinates reference North Carolina State Plane (Zone 3200) NAD83

(2) Azimuths are measured clockwise from true north.

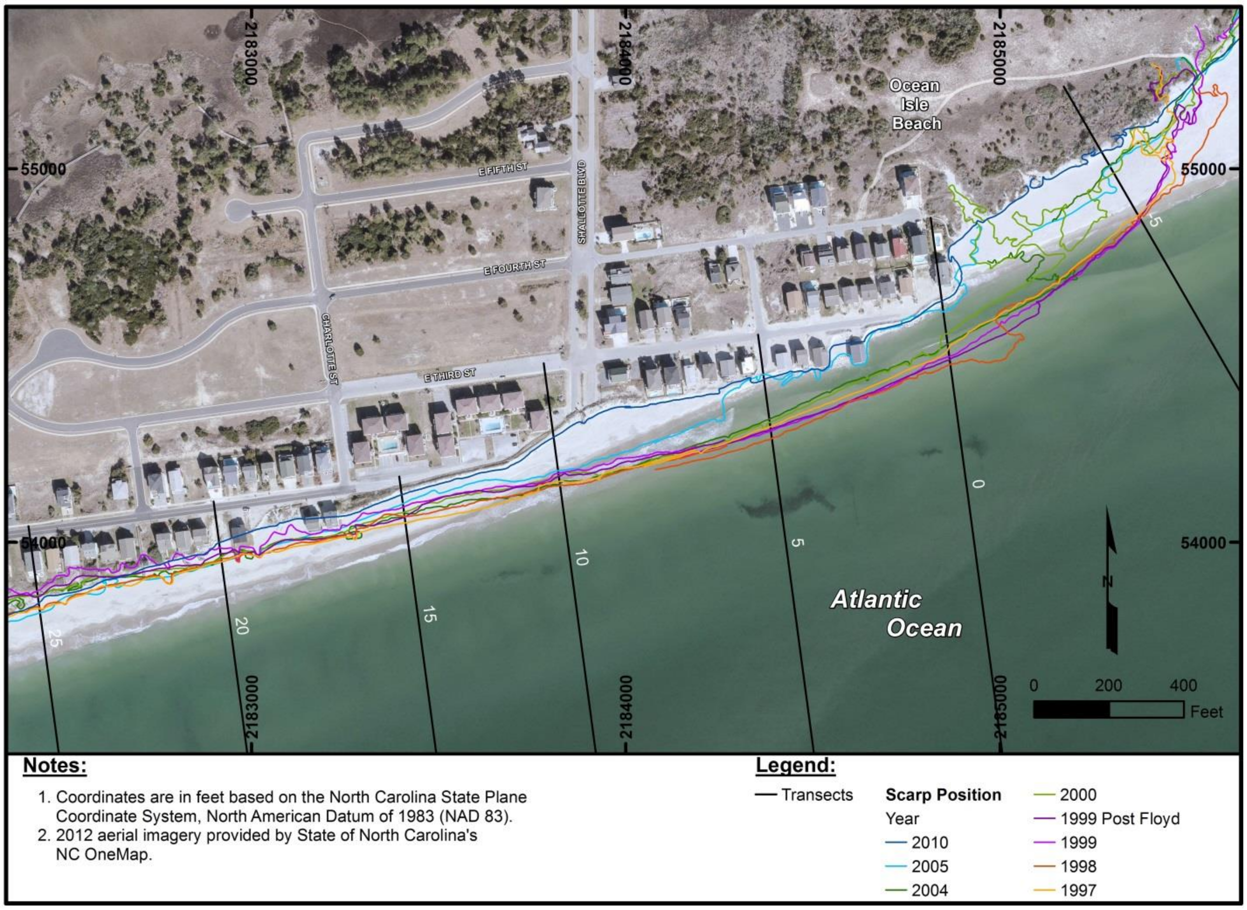

Figure 2.1. Profile locations on east end Ocean Isle Beach used to measure changes in the position of the erosion scarp.

Single and multi-family residential homes are located along the shorefront of the study area. Roadways and utilities are also present. Figure 2.1 shows the current development within the study area. Shallotte Boulevard is a landmark roadway positioned at approximately station 10+00 on the USACE baseline. The roadway extends across the width of the island and is approximately 2,000 feet in length. East 2nd Street is the seaward-most road running in a west to east direction. Five (5) additional streets running parallel to East 2nd Street are positioned landward of East 2nd Street. The upland development is generally concentrated on East 2nd, 3rd, and 4th Streets. East 4th Street connects with Shallotte Boulevard approximately 500 feet from the beach face.

Shallotte Inlet borders the study area on the east, separating Ocean Isle Beach from Holden Beach. The inlet connects the Atlantic Ocean with the AIWW. The inlet serves as a navigational entrance into the AIWW and the nearby estuarine systems; however, there is no Federally authorized navigation channel through the ocean bar of the inlet. Saucepan Creek and Shallotte River also connect to the AIWW in the vicinity of Shallotte Inlet. These two (2) water bodies receive tidal flows from Shallotte Inlet and storm runoff from upland sources.

2.2 Tides

Ocean tides for Ocean Isle Beach are semi-diurnal, with a spring-neap variation of 28 days. Oceanfront tidal datums are based on the NOAA tide gage and benchmark at Yaupon Pier on Oak Island. This benchmark is the closest oceanfront tidal benchmark established by NOAA and is located approximately 18 miles from Ocean Isle Beach. Tidal datums at Yaupon Pier appear in Table 2.2 below. The mean tidal range at Yaupon Pier is approximately 4.7 feet (NOAA, 2013).

Table 2.2. Oceanfront Tidal Datums; Yaupon Pier, NC

TIDAL DATUM	ELEVATION (feet MLLW)	ELEVATION (feet NGVD)	ELEVATION (feet NAVD)
MEAN HIGHER HIGH WATER (MHHW)	5.26	3.27	2.16
MEAN HIGH WATER (MHW)	4.89	2.90	1.79
NORTH AMERICAN VERTICAL DATUM-1988 (NAVD)(1)	3.10	1.11	0.00
MEAN TIDE LEVEL (MTL)	2.53	0.54	-0.57
MEAN SEA LEVEL (MSL)	2.54	0.55	-0.56
NATIONAL GEODETIC VERTICAL DATUM-1929 (NGVD)	1.99	0.00	-1.11
MEAN LOW WATER (MLW)	0.16	-1.83	-2.94
MEAN LOWER LOW WATER (MLLW)	0.00	-1.99	-3.10

(1)Elevations in this document are referenced to NAVD.

Additional water level measurements were collected May 25-July, 2005 by CPE-NC within Shallotte Inlet and the Atlantic Intracoastal Waterway (AIWW). The locations of the two (2) tide gages appear in Figure 2.2. Tidal ranges inside the AIWW range from 3.2 to 3.6 feet. The tidal range in the throat of the inlet is approximately 3.7 feet. Tides in the AIWW lag the Yaupon Pier tides by approximately 1 hour. Tides in the throat of Shallotte Inlet lag the Oak Island tides by approximately 30 minutes.

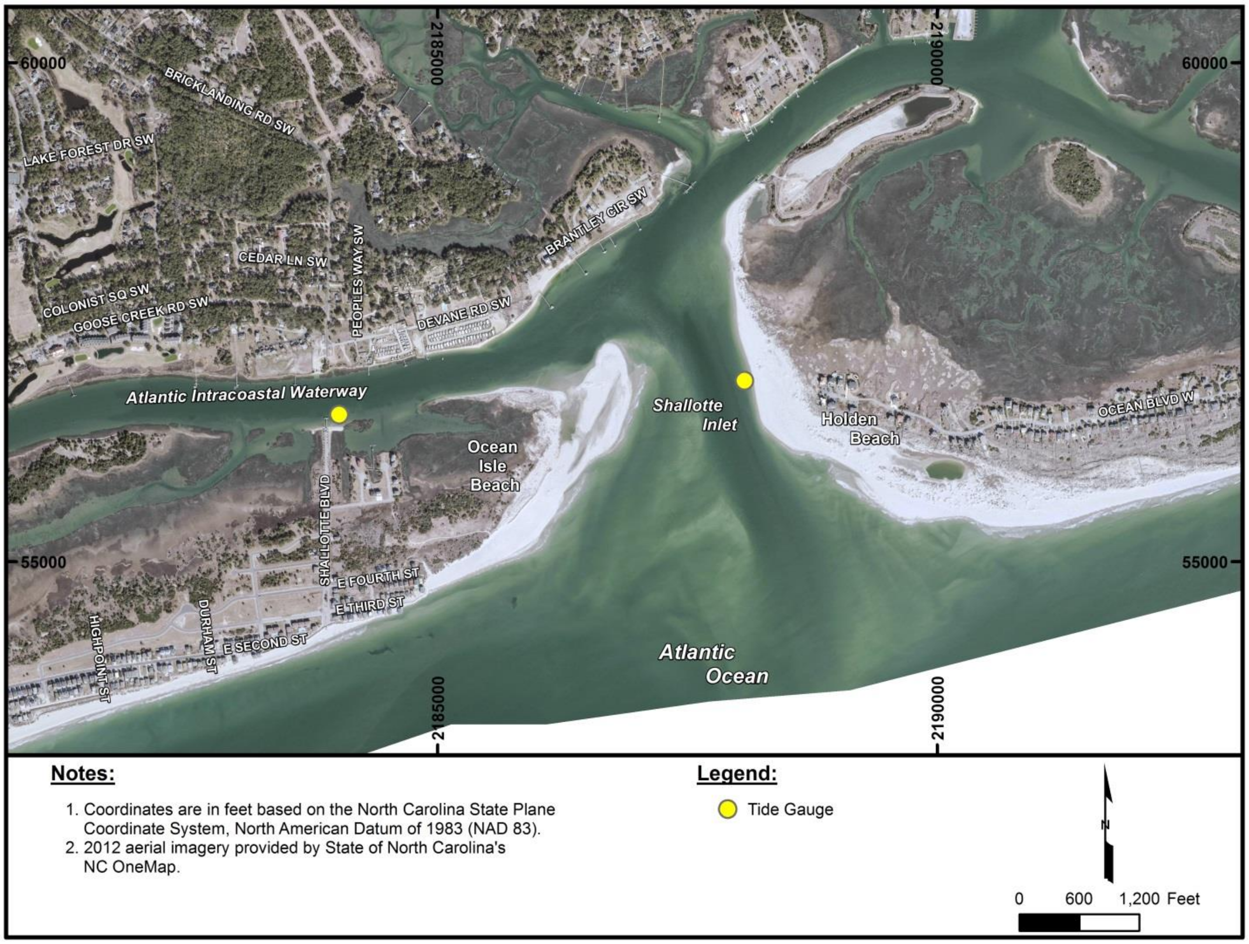

Figure 2.2. Tide gage locations.

2.3 Sea Level Rise

Historical changes in relative mean sea level are available for various stations along the East Coast at the NOAA website, www.tidesandcurrents.noaa.com. Reporting stations close to the Ocean Isle Beach study area that have been collecting data for at least 80 years include Wilmington, NC (collecting data since 1935) and Charleston, SC (collecting data since 1923). The trends in sea level rise for these two stations are 0.68 feet/century for Wilmington and 1.03 feet/century for Charleston.

While there is considerable debate regarding the future trends in sea level, the general consensus is sea level will continue to rise and possibly accelerate over the next century. However, regardless of the total rise in sea level over the next 100 years, most projections indicate a gradual acceleration in the rate of rise which does not have a significant impact until 25 to 30 years in the future. With the planning period for the Ocean Isle project being 30 years, very little if any significant impact of changes in sea level are anticipated for any of the shoreline management alternatives evaluated.

Regardless of the future changes in sea level, the impacts of historic rates of rise in sea level are implicitly included in the historic shoreline change and volume change data used for developing management alternatives for Ocean Isle Beach. By extrapolating data from long term sea level monitoring sites located in Wilmington, NC and Charleston, SC, the rate of rise in sea level applicable to the project area appears to be slightly less than one foot/century. Even if the rate of sea level rise doubled over the next 30 years, the impact on future shoreline changes and/or volumetric change rates along Ocean Isle Beach would not double since only a portion of the historic changes are associated with sea level rise, i.e., doubling the rate of sea level rise would only double the sea level rise component inherent in the historic data.

2.4 Waves, Currents, and Wind

Appendix C, appended to the end of this Engineering Report, provides details of the waves, currents, and winds used in the Delft3D numerical model simulations for the various shoreline and inlet management alternatives discussed below.

2.5 Storm Water Levels

Storm water elevations from June 1994 for the Town of Ocean Isle Beach were made available by the Federal Emergency Management Agency (FEMA). The frequency of the various storm water levels is expressed as a return interval in years. For a 10 year return interval, which actually means the storm water level has a 10% chance of occurrence in any given year, the storm water level is +6.4 feet NAVD88. Likewise, the 100-year storm, which has an elevation of +11.7 feet NAVD88 has a 1% change of occurrence in any year.

While storms play a significant role in shoreline behavior, the focus of the Ocean Isle Beach project is the prevention damages associated with shoreline erosion not storm induced damages that could be caused by inundation or wave impacts. The alternatives under consideration that would increase the size of the beach fronting development on the east end of the island would provide some reduction in storm damages, however, the potential reduction in storm damages was not included in the formulation of the erosion response measures.

2.6 Depth of Closure

The depth of closure is defined as the “depth beyond which repetitive profile or topographic surveys (collected over several years) do not detect significant vertical sea bed changes. This is generally considered the seaward limit of littoral transport” (Morang and Szuwalski, 2003). The depth of closure is typically estimated by comparing historic profiles and observing where a “pinch point” occurs, that is the point beyond which significant profile variations appear approach zero.

Profiles of Ocean Isle Beach collected at baseline stations 20+00, 40+00, 70+00, and 100+00 between March 2006 and August 2013 are shown in Figures 2.3, 2.4, 2.5, and 2.6, respectively. This comparison of the repetitive profile surveys covers a time period beginning about 5 years after initial construction of the Federal project to allow for post-construction adjustments. The point where the repetitive surveys appear to shown a decrease in vertical variability ("pinch point") is identified by the circle in the figures and appears to be approximately -18 feet NAVD. While vertical changes continue to be observed seaward of -18 feet NAVD, those changes are not significant in terms of total volumetric changes.

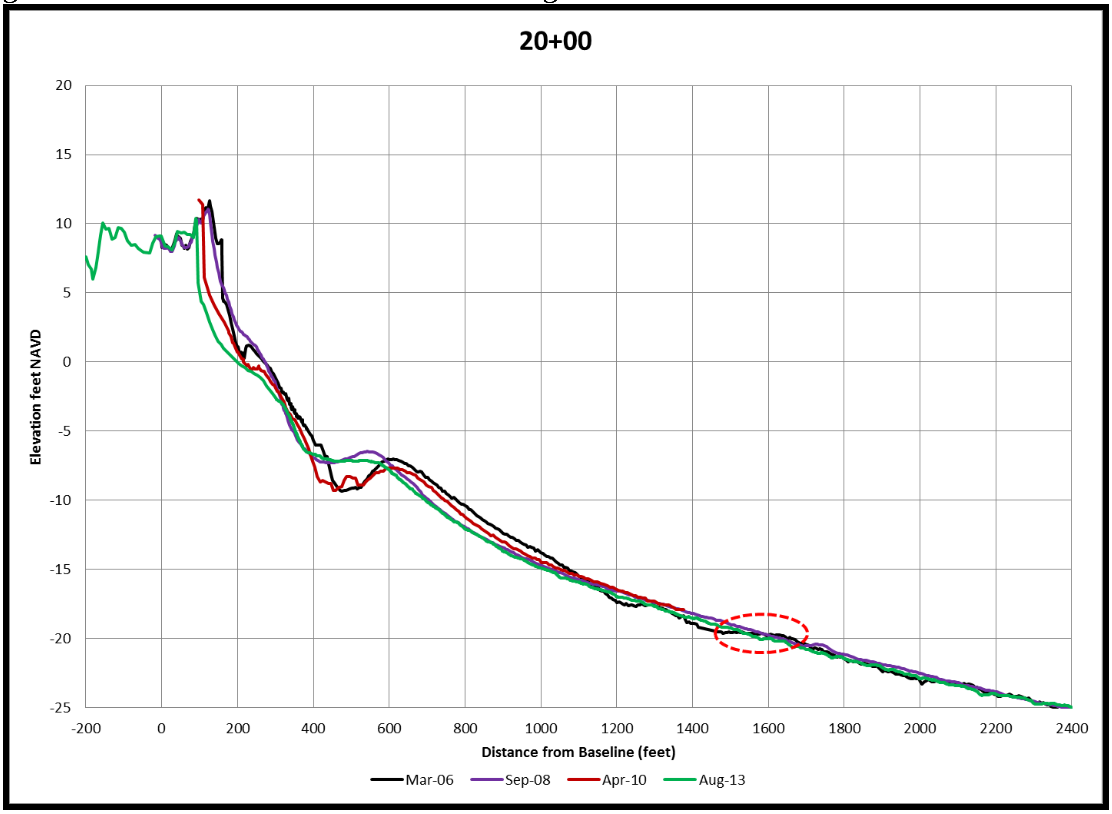

Figure 2.3. Comparison of profiles taken at station 20+00 between March 2006 and August 2013.

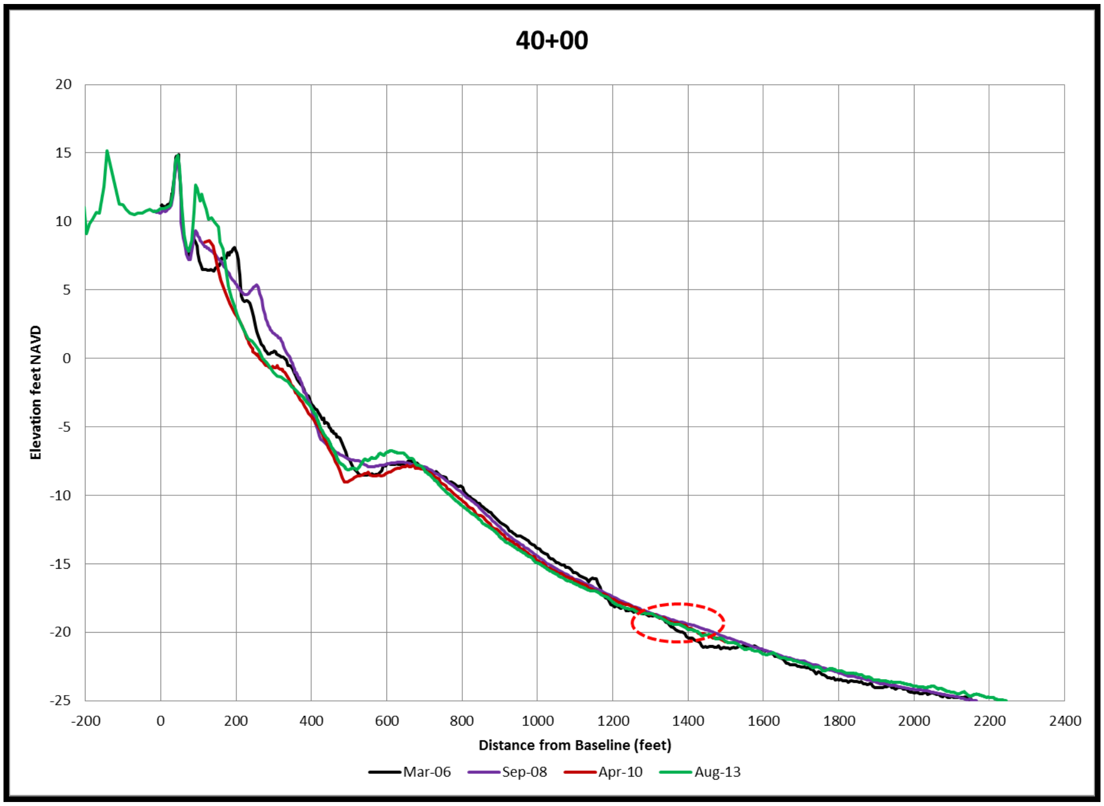

Figure 2.4. Comparison of profiles taken at station 40+00 between March 2006 and August 2013.

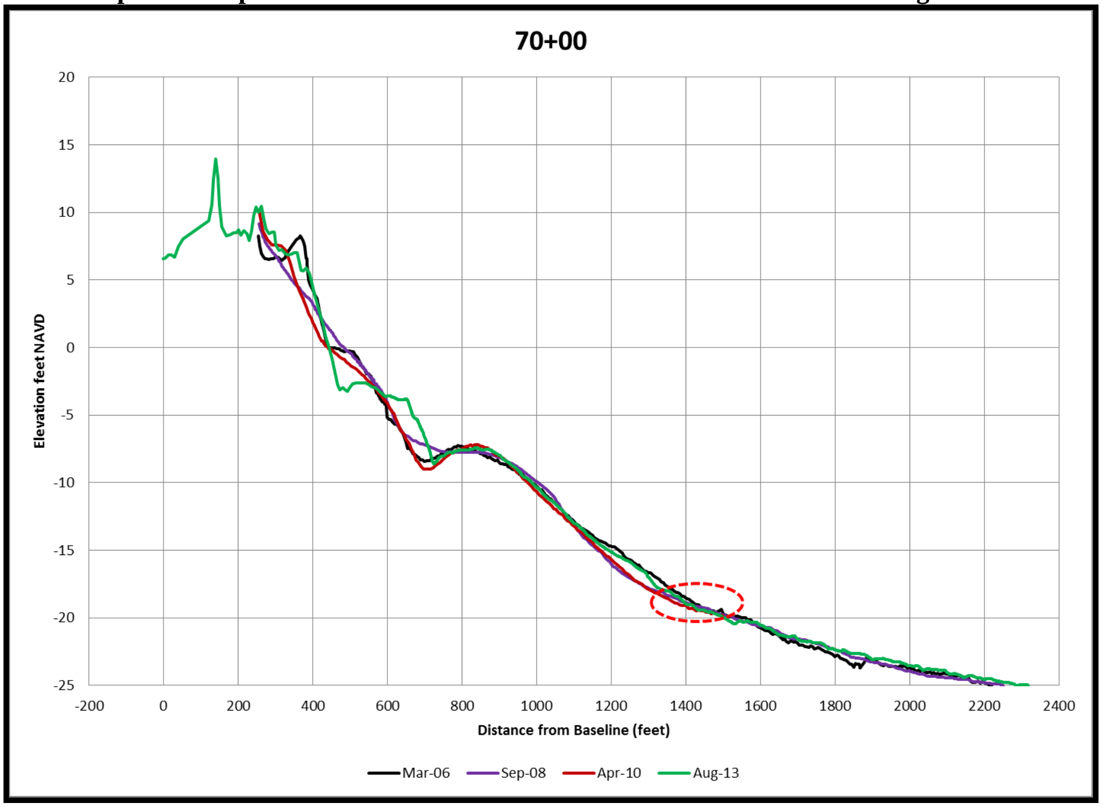

Figure 2.5. Comparison of profiles taken at station 70+00 between March 2006 and August 2013.

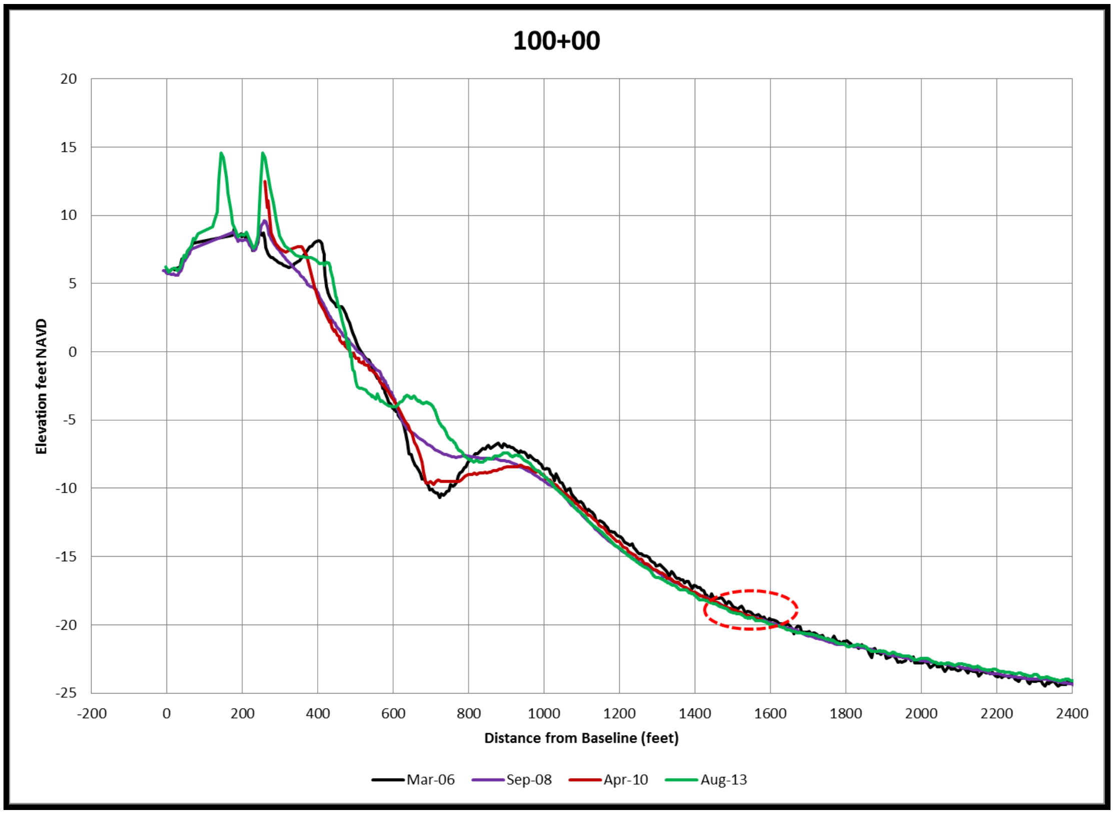

Figure 2.6. Comparison of profiles taken at station 100+00 between March 2006 and August 2013.

2.7 Native Grain Size

During preparation of the General Reevaluation Report for the Ocean Isle Beach project, completed in 1994, the USACE collected beach samples along three profiles within the Federal project area. Samples were collected from the dune out to a depth of -30 ft NGVD29. The state sediment standards dictate a specific number of samples along at least five profiles within the project area (15A NCAC 07H.0312)(1)(c and d). However, 15A NCAC 07H.0312 (1)(i) provides language that would allow special consideration of projects which were constructed prior to the adoption of the rules.

In order to meet state requirements, CPE-NC obtained samples along four (4) additional profiles on the east end of Ocean Isle Beach. On April 5, 2013, April 17, 2013 and January 23, 2014 CPE-NC collected beach samples and nearshore sediment samples along four (4) profiles (0+00 (OIB000), 10+00 (OIB010), 25+00 (OIB025), and 60+00 (OIB060)) (Figure 4). Along these profiles, samples were collected from the Dune, Toe of Dune, Midberm, Berm Crest, Mean High Water (MHW), Mean Tide Level (MTL), Mean Low Water (MLW), Trough, Bar Crest, and four (4) additional depths evenly spaced between the Bar Crest and -20 ft. NAVD. Sediment characteristic data obtained by the USACE along baseline station 40+00 were also used to determine composite beach characteristics.

Analyses of the samples collected from the existing beach by CPE-NC and the USACE indicate that sediment along the eastern end of Ocean Isle Beach has a mean grain size of 0.23mm. The percent by weight of fines (less than 0.0625 millimeters) for the sampled area is 1.34%. The percent by weight of granular (greater than or equal to 2 millimeters and <less than 4.76 millimeters) and gravel (greater than or equal to 4.76 millimeters) for the sampled area is 0.43% and 0.40%, respectively. The wet Munsell Color value ranges from 4 to 7, with a typical value of 5. The dry Munsell Color value ranges from 6 to 8, with a typical value of 7. These characteristics represent the existing beach, which is a composite of the characteristics of material that has been placed on the beach during past nourishment projects and native beach sediment.

2.8 Borrow Area Grain Size

Given the proposed borrow area is completely confined to the authorized dredge depth of a maintained sediment deposition basin within the inlet shoal system, compatibility as defined by the rule (15A NCAC 07H.0312), is primarily defined in Section (2) (e) and (3) (a). Section (2) (e) allows an applicant to use previously collected data to establish sediment characteristics where both a pre-dredge and a post-dredge data set exist. Section (3) (a) states that compatibility for sediment completely confined to the permitted dredge depth of a sediment deposition basins within the inlet shoal system is defined as having an average percentage by weight of fine-grained (less than 0.0625 millimeters) sediment less than 10%. As stated above, the composite fine-grained sediment within the footprint of the area dredged in 2001 based on the data from six (6) vibracores collected in 1998 (Appendix 9) is 1.3%. The composite fine-grained sediment within the same footprint of the area dredged in 2001 based on data collected after the dredging event (Appendix 11) is 1.95%. The composite percent fine grained material for the existing beach sampled along the east end of Ocean Isle Beach is 1.34%. Therefore, sediment confined to the footprint of the area dredged in 2001 in Shallotte Inlet is compatible in accordance with rule 15A NCAC 07H.0312.

Sediments recovered within the vertical boundaries of the proposed borrow area were described by the USACE as having a tan and or gray color (USACE, 1997c; Catlin, 2009). The wet Munsell Color values for sediment samples collected by CPE-NC in 2013 and 2014, range from 5 (gray to olive gray) to 7 (light gray), with a typical value of 7 (light gray). The samples collected by CPE-NC in 2013 and 2014 represent the existing beach, which is a composite of the characteristics of material that has been placed on the beach during past nourishment projects and native beach sediment.

Vibracore data obtained from the 2005 and 2009 vibracores recovered from within the proposed borrow area indicate a percent carbonate by weight of 15.5%. The carbonate content of the existing beach ranges from 5% to 7% with a composite value of 6%.

3.0 PROBLEM IDENTIFICATION

Shoreline impacts have been a prominent issue along the coastline of Ocean Isle Beach for multiple decades. The Town of Ocean Isle Beach has actively pursued a management alternative since at least 1989. During this timeframe, the Town provided the necessary local support for a Federal study to implement an erosion control-hurricane wave protection project (presently referred to as a storm damage reduction project). Impacts from Hurricane Hugo (September 1989) were the primary reasons the Town initiated its request for the study (USACE, 1997). The Town and USACE worked together to design an alternative to address most of the shoreline impacts on Ocean Isle Beach. The resulting storm damage reduction project was constructed along 17,100 feet (3.25 miles) of the island in 2001. Approximately 1,000 feet of the shoreline in the current study area lies within the limits of the Federal project. This 1,000-foot segment is a portion of the taper section that merges the main fill of the Federal project with the existing shoreline. The easternmost 1,500 feet of the current study area was not included in the Federal project as this section did not meet Federal cost/benefit requirements primarily due to the predicted excessive cost of beach nourishment needed to maintain a fill in this area. The limits of the Federal storm damage reduction project extend from USACE station 10+00 west to station 181+00 (USACE, 2002), or from Shallotte Boulevard to approximately Dunside Dr., respectively (Figure 3.1).

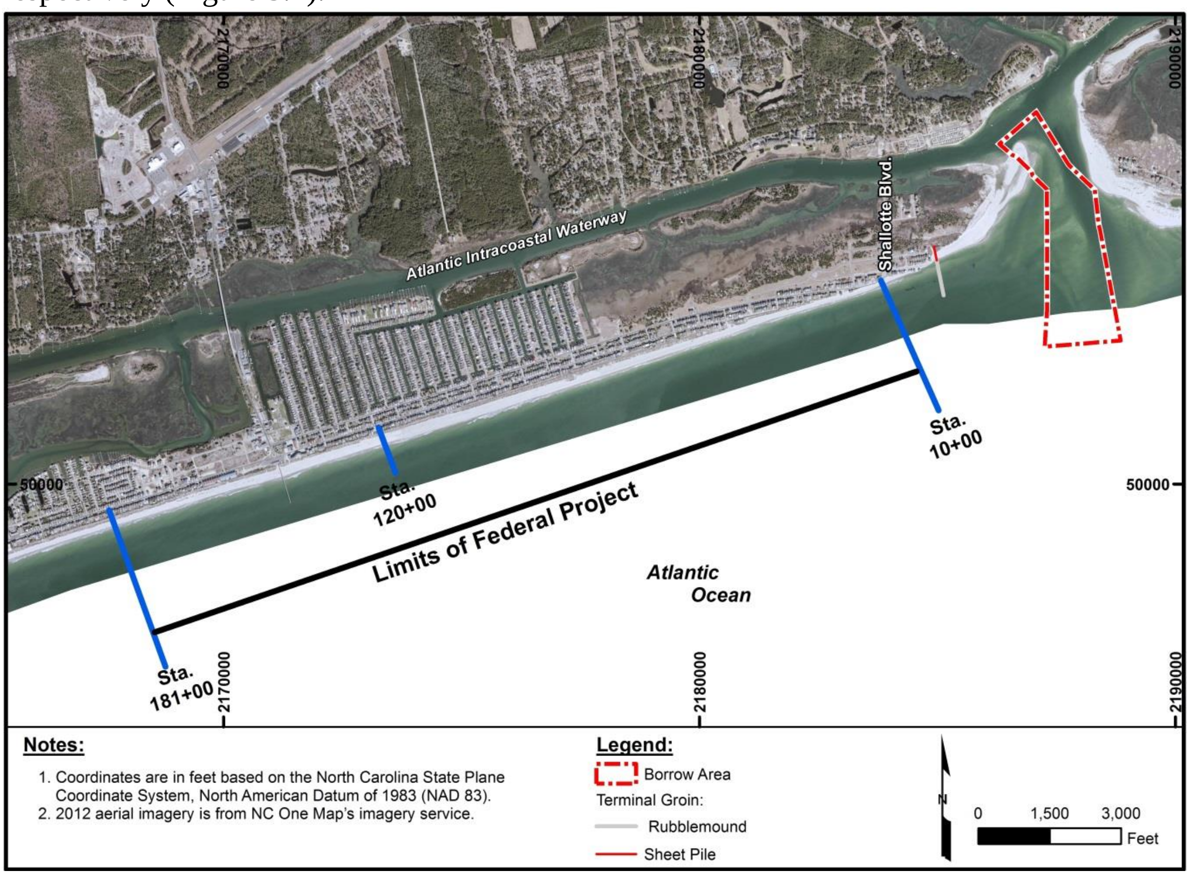

Figure 3.1. Federal Project Limits

Approximately 1,866,000 cubic yards of material were dredged from Shallotte Inlet and placed along Ocean Isle Beach for the initial restoration (USACE, 2002). Periodic nourishment events were completed in January 2007 and May 2010. Approximately 449,400 cubic yards were placed during the 2007 nourishment event between baseline stations 10+00 and 72+00 (CPENC, 2012). The 2007 nourishment operation also included a non-Federal component, funded entirely by the Town of Ocean Isle Beach, which placed 155,000 cubic yards between baseline stations -3+00 and 17+00. Roughly 30,000 cubic yards of 155,000 cubic yards was placed within the limits of the Federal project between stations 10+00 and 17+00. The 2010 nourishment operation placed 550,000 cubic yards between baseline stations 10+00 and 120+00 (USACE, 2013).

Periodic nourishment of the Ocean Isle Beach storm damage reduction project is scheduled for the early part of 2014. The USACE awarded a contract to place 640,000 cubic yards within the limits of the Federal project for a contract cost of around $7.1 million. Including the upcoming 2014 nourishment operation, the average amount of fill placed on Ocean Isle Beach to maintain the Federal project has been around 408,000 cubic yards every three years.

The locally funded beach fill component included in the 2007 nourishment event experienced extremely high rates of loss. Based on this poor performance, the Town of Ocean Isle Beach opted not to include a non-Federal fill component on the extreme east end during the 2010 nourishment event (Town source) nor is one included in the scheduled 2014 nourishment event.

Additional measures implemented by the Town to manage the erosion includes placement of sandbags along 1,400 feet of shoreline beginning at the eastern limits of the upland development (CPE-NC, 2012). The sandbags have been repaired and replaced since the original installation and now extends approximately 1,800 feet to Charlotte Street. NC DOT has also installed sand bags in an attempt to manage the erosion impacts. Sand bags were installed along 1st and 2nd Streets in 2009 when erosion undermined the roadways (CPE-NC, 2012). The USACE has also placed additional material from navigation dredging of the AIWW along the study area. An estimated 350,000 cubic yards have been placed along the developed shoreline outside the limits of the Federal project between 2001 and 2012 (CPE-NC, 2012).

3.1 Shoreline Change Analysis

Shoreline changes along the east end of Ocean Isle Beach were evaluated using LiDAR (Light Detection and Ranging) data. LiDAR is an optical remote sensing technology that can measure the distance to a target by the use of light. Eight (8) sets of LiDAR data were obtained from the USGS for Ocean Isle Beach. Five (5) sets of the data obtained were collected between 1997 and 2000, prior to the initial construction of the Federal project. The remaining three (3) sets were collected in 2004, 2005, and 2010 after the Federal project commenced.

Traditional shoreline change analyses are aimed at tracking the movement of the mean high water (MHW) line. However, for the east end of Ocean Isle Beach, changes in the position of the MHW line do not adequately define the erosion problem. This is due to the Federal erosion control project and additional navigation maintenance events that placed material within the current study area. The installation of temporary sandbag revetments also contributes to issues with measuring changes in the MHW location. These activities distort the natural movement of the MHW line and prevent an accurate measurement of the migration rates.

An alternate indicator of the erosion threat along the study area is the position and movement of the erosion scarp (Figure 3.2). The movement of the erosion scarp is impacted to a lesser degree by sand placement and to some extent by the installation of sandbag revetments. The position of the scarp line also provides a more reasonable indicator as to when a structure is likely to experience erosion damage. In this regard, once the erosion scarp moves past the front of a building, that building would be situated on the active beach foreshore and would be subject to continuous wave and tide action. During storm events, when the water level is elevated and wave action is more severe, these exposed structures become increasingly more vulnerable and are likely to fail.

Figure 3.3 shows the position of the erosion scarp from the analysis of the LiDAR data. Table 3.1 provides the cumulative movement of the scarp line between September 1997 and May 2010 in the current study area. A plot of the cumulative movement of the scarp line at each profile is shown in Figure 3.4. Note that due to the Federal storm damage reduction project there was no landward scarp movement west of station 20+00.

The 2004 scarp line essentially follows the alignment of the sandbag revetment existing at that time (Figure 3.3). This revetment held the erosion scarp line in place for several years until it failed sometime prior to October 2005. Once the sandbags failed, the scarp line migrated rapidly landward, essentially occupying the position it would have assumed had the sandbags not been present. The relative rapid movement of the scarp line following the failure of the sandbag revetment is apparent in the cumulative plot shown on Figure 3.4. Such shoreline/scarp behavior is typical of sandbag failures.

The scarp line at station -5+00 also made a dramatic landward shift between October 1999 and August 2000. Since August 2000, the landward movement of the scarp line has moderated primarily due to the development of the sand spit off the east end of Ocean Isle Beach following the initial construction of the Federal storm damage reduction project in 2001. As discussed later, the excavation of material from the Shallotte Inlet borrow area during initial construction of the Federal project altered flow patterns in the inlet, briefly focusing more of the flow through the center of the inlet. The change in the flow pattern contributed to the elongation of the sand spit into Shallotte Inlet.

Figure 3.2. Example of erosion scarp on east end of Ocean Isle Beach.

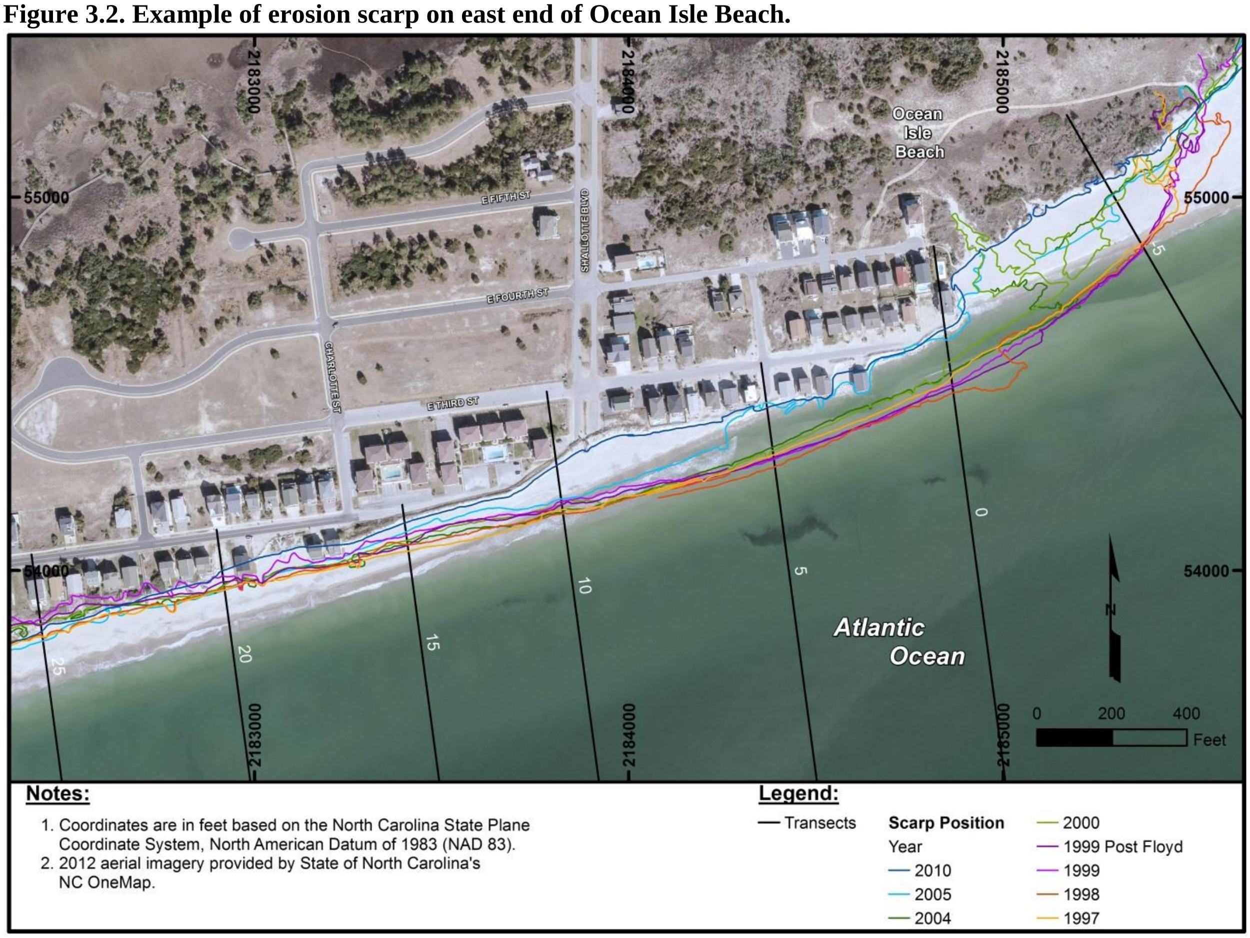

Figure 3.3. Scarp Line Position (1997 – 2010)

Table 3.1. Cumulative movement of the Scarp Line since September 1997

Profile ID	Sep 97	Sep 98	Sep 99	Oct 99	Aug 00	Jul 04	Oct 05	May 10
-5	0	12.6	6.0	7.1	-130.4	-152.2	-149.6	-196.8
0	0	41.6	22.4	31.0	-39.1	-12.2	-100.1	-129.7
5	0	33.6	9.9	6.6	-13.2	-19.2	-143.0	-128.1
10	0	12.8	-21.6	-13.6	-14.1	7.4	-26.7	-118.9
15	0	-17.3	-41.0	-15.6	-28.4	-17.7	-51.6	-75.5
20	0	-5.6	-40.2	-23.2	-13.1	-15.1	-0.2	-51.9

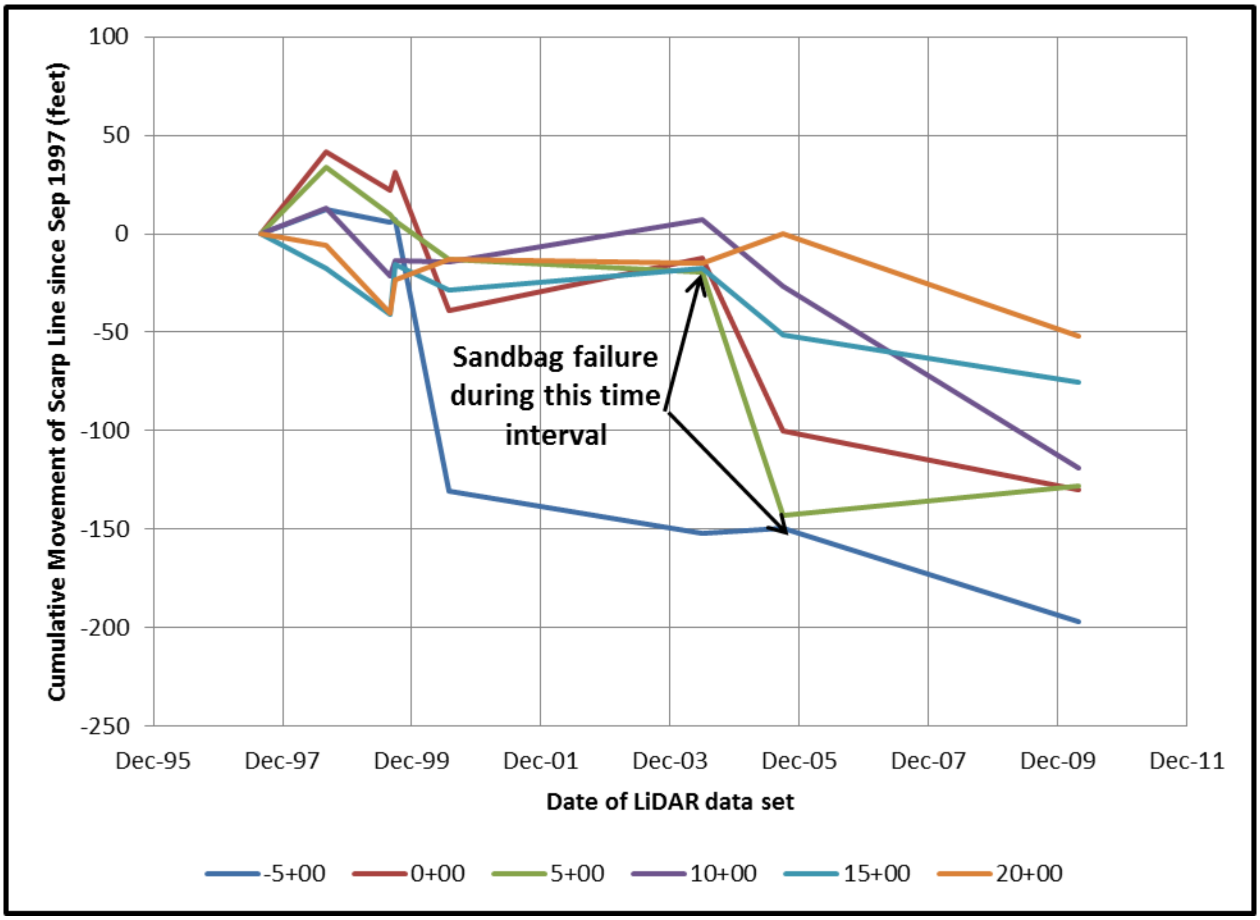

Figure 3.4. Cumulative movement of scarp line since Sept 1997 (negative movement is landward).

The decreasing trend in the recession of the scarp line moving west away from Shallotte Inlet provides additional evidence of the negative shoreline impacts Shallotte Inlet is having on the east end of Ocean Isle Beach. Some of the decrease in scarp recession west of profile 10 can be attributed to nourishment of the Federal storm damage reduction project. However, with very little material placed directly on the shoreline near profile 10, the impact of the Federal project is more indirect in this area and is associated with horizontal spreading of the fill material toward the east.

3.2 Volumetric Change Analysis

A volumetric change analysis is presented to provide additional details regarding the magnitude of erosion occurring within the current study area. As part of the monitoring protocol for the Federal beach fill project, the USACE has obtained 15 sets of beach profile data since 2001. The coverage varies from those areas where fill was placed during initial construction or subsequent nourishment events to nearly the entire length of Ocean Isle Beach. The profile survey data collected by the USACE was used to compute volume changes along the eastern half of Ocean Isle Beach out to a depth of -18 feet NAVD. The computations were conducted for three post-nourishment periods, namely; December 2001 to March 2006, April 2007 to April 2010, and May 2010 to August 2013. The April 2010 survey ended at station 120+00, therefore, volume change computations for all three periods end at station 120+00. Also, the April 2010 survey did not include the area east of profile 10. However, an April 2009 survey did include this area and volume changes, in terms of cubic yards/linear foot, measured between April 2007 and April 2009 were assumed to be applicable to the April 2007 to April 2010 time period.

A graph of the computed volume change for the December 2001 to March 2006 time period, expressed in cubic yards/lineal foot of beach/year (cy/lf/yr), is shown in Figure 3.5. Similar graphs for the April 2007 to April 2010 time period and May 2010 to August 2013 time period are provided in Figures 3.6 and 3.7, respectively. The average annual rate of volume change within the approximate 1,000 foot shoreline segments for all three time periods is provided in Table 3.2. Also shown in Table 3.2 is the average rate of volume change that occurred following the three nourishment events.

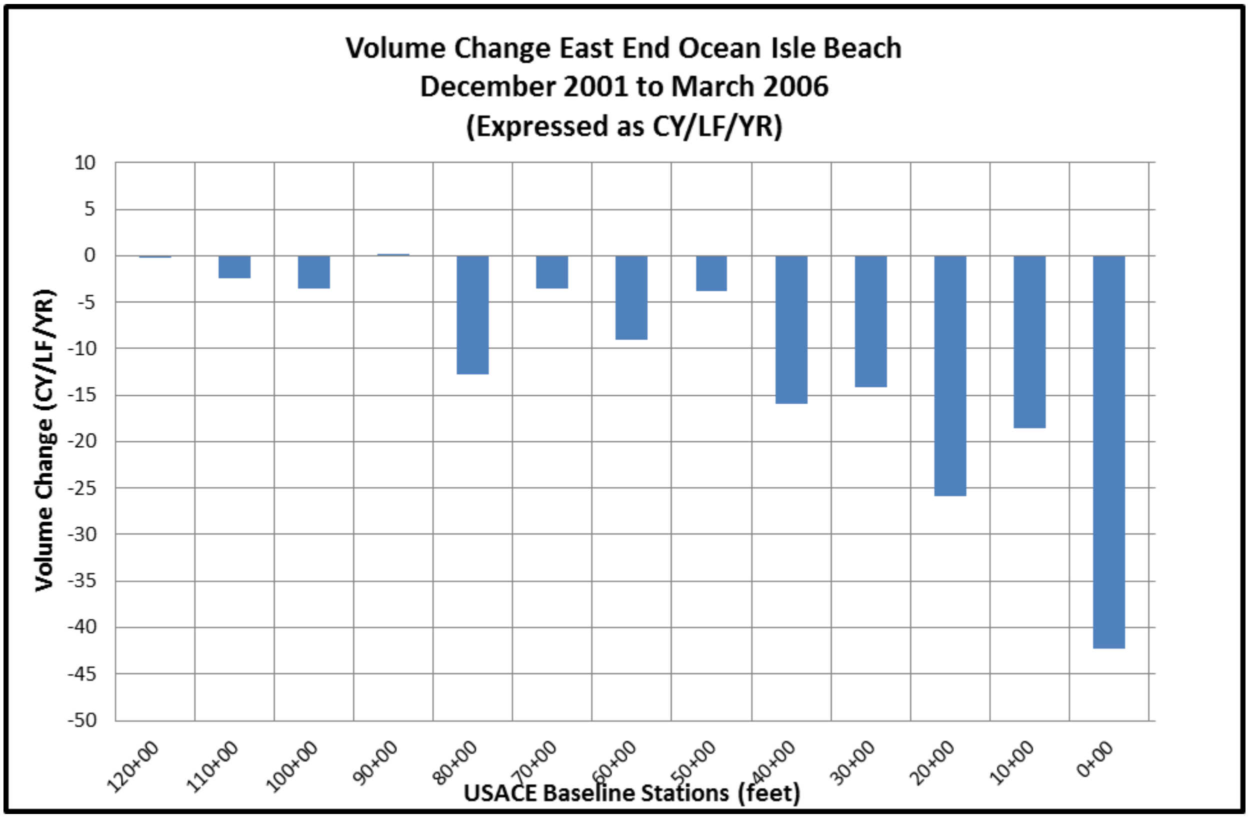

Figure 3.5. Volume Change East End Ocean Isle Beach - Dec 2001 to Mar 2006

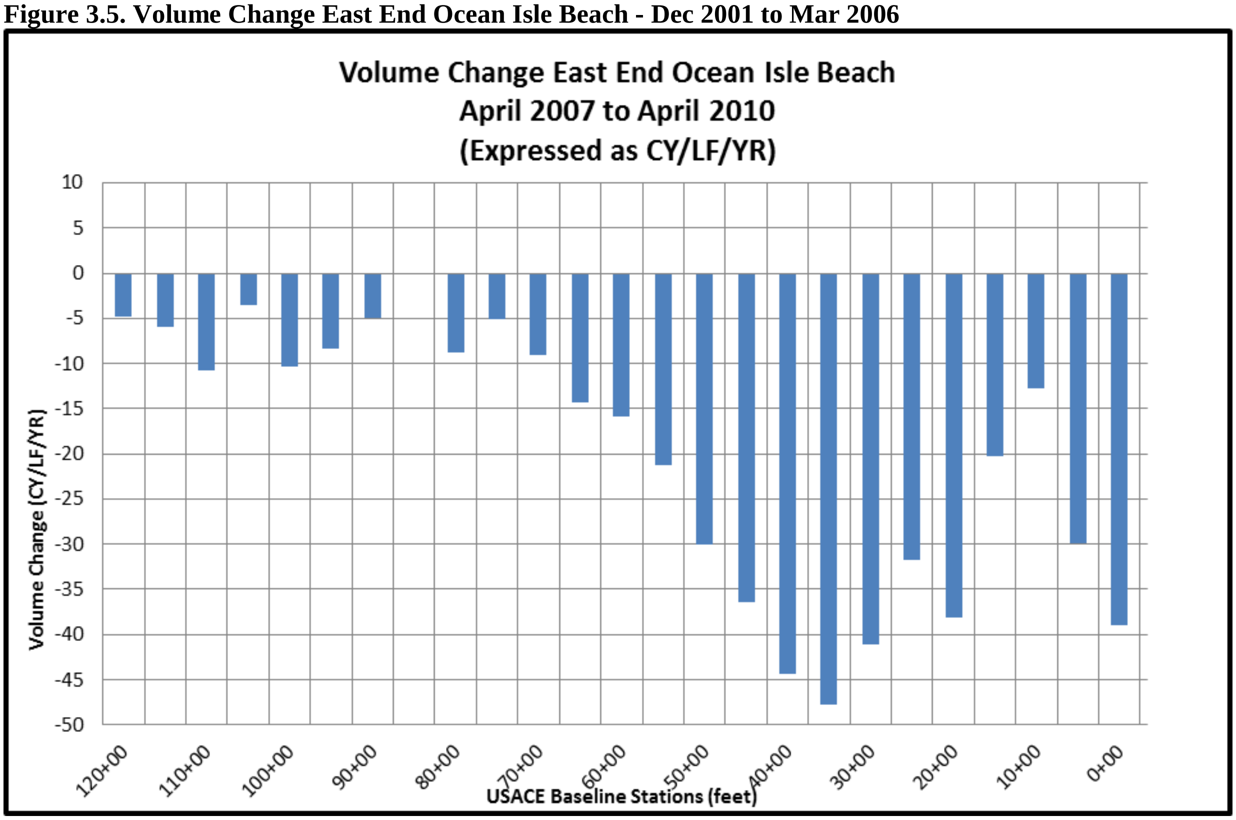

Figure 3.6. Volume Change East End Ocean Isle Beach - Apr 2007 to Apr 2010

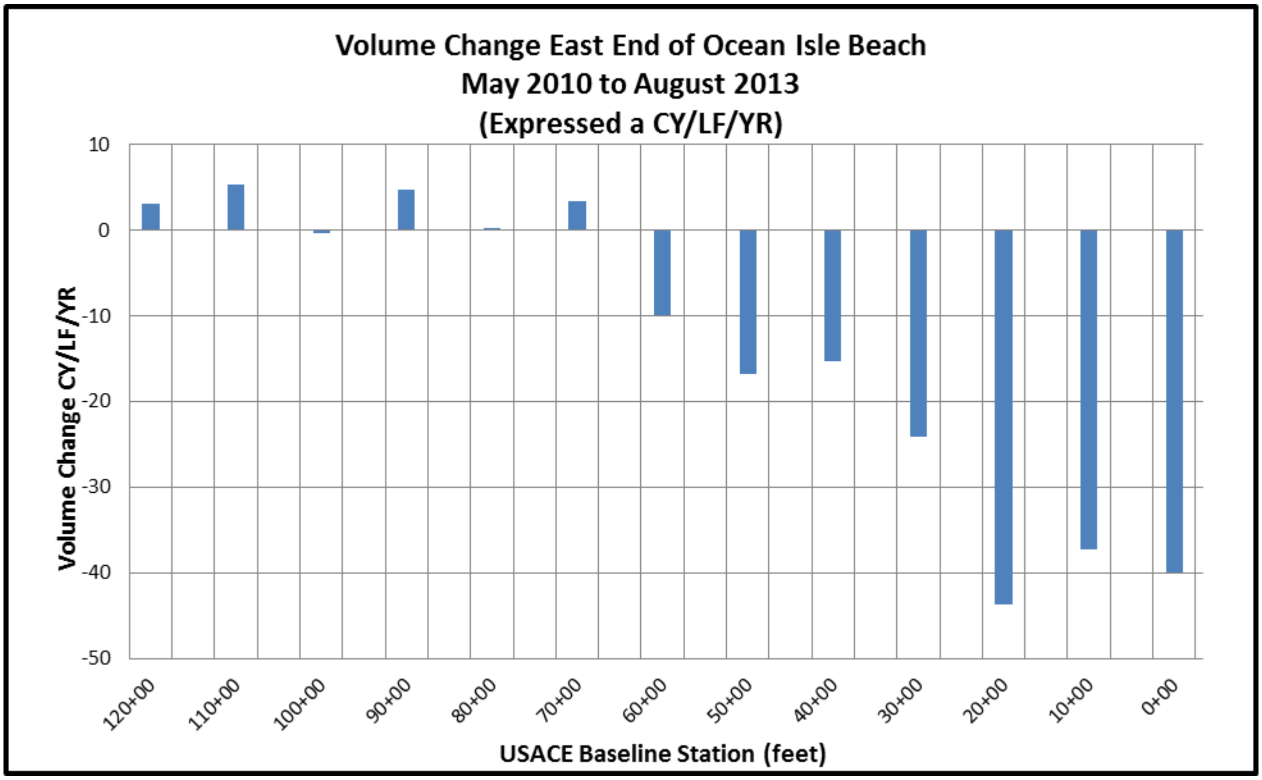

Figure 3.7. Volume change East End Ocean Isle Beach – May 2010 to Aug 2013

Table 3.2. Volume change rates on Ocean Isle Beach for three post-nourishment periods

From Profile to Profile	Volume Change Rate (cy/yr)			
	Dec 2001 to Mar 2006	Apr 2007 to Apr 2010	May 2010 to Aug 2013	Average for all three episodes
0 to 10[(1)]	-30,000	-29,000	-42,000	-34,000
10 to 20	-22,000	-19,000	-34,000	-25,000
20 to 30	-20,000	-40,000	-38,000	-33,000
30 to 40	-15,000	-42,000	-19,000	-25,000
40 to 50	-10,000	-38,000	-16,000	-21,000
50 to 60	-6,000	-21,000	-13,000	-13,000
60 to 70	-6,000	-15,000	-4,000	-8,000
70 to 80	-8,000	-7,000	2,000	-4,000
80 to 90	-6,000	-3,000	2,000	-2,000
90 to 100	-2,000	-8,000	2,000	-3,000
100 to 110	-3,000	-7,000	3,000	-2,000
110 to 120	-1,000	-3,000	4,000	0
Total 0 to 120	-129,000	-236,000	-153,000	-170,000

(1) The shoreline from profile 0 to profile 10 lies outside the limits of the authorized Federal project.

The volume changes calculated indicate high rates of loss from the eastern limits of the study area to around profile 50, which is located near Raleigh Street. Volume losses gradually decrease west of profile 50. The increase in volume loss from the island in a west to east direction is a clear indication of the influence Shallotte Inlet has on the stability of the beach.

Between stations 10+00 and 120+00, which are within the limits of the Federal storm damage reduction project, the volumetric loss following each periodic nourishment operation has averaged 136,000 cubic yards/year. This would indicate the three year nourishment requirement for the Federal project between stations 10+00 and 120+00 would be about 408,000 cubic yards. As discussed above, the 2007 nourishment operation placed 449,700 cubic yards within the limits of the Federal project and the locally funded fill placed 30,000 cubic yards for a total of 479,700 cubic yards. The 2010 operation placed a total of 550,000 cubic yards. The most recent nourishment operation, completed in April 2014, placed 640,000 cubic yards. The average nourishment volume for these three events would be around 560,000 cubic yards per operation. However, due to funding and contractual issues, periodic nourishment has actually occurred about once every 4 years inferring a nourishment volume of 130,000 cubic yards/year. The measured volume change rates notwithstanding, an average of 408,000 cubic yards every three years was adopted as the required nourishment volume needed to maintain the Federal project under existing conditions. Note the nourishment volume does not extend to the west limits of the Federal project which lies at station 181+00. Based on the USACE beach profile monitoring program, the Federal project has performed exceptionally well west of station 120+00 and should not require periodic nourishment at any time in the near future.

3.3 Littoral Sediment Budget

A sediment budget was developed for existing conditions in the project area using measured volume changes in Shallotte Inlet and along the adjacent beaches for the time period between April 2007 and April 2010. The purpose of the sediment budget was to identify existing rates of sediment transport along the west end of Holden Beach and along the Ocean Isle Beach shoreline west to station 120+00 and to demonstrate the interrelationship between various sections of the project area. Details of how the sediment budget was developed follow.

Sediment Budget Methodology. The annual rates of volume change within the Shallotte Inlet complex were determined from hydrographic surveys taken by the USACE in 2007 and 2009. Annual rates of volume change along the adjacent shorelines of Ocean Isle Beach and Holden Beach were computed using April 2007 and April 2010 beach profile surveys. Boxes used to compute volume changes in various sections of the Shallotte Inlet complex are shown in Figure 3.8.

The West Delta box on Ocean Isle Beach extends from baseline station 0+00 to the west boundary of the Shallotte Inlet borrow area while the East Delta box on Holden Beach extends from the east boundary of the borrow area to Holden Beach baseline station 385+00 (HB 385). Computed annual rates of volume change in each of the boxes for the 2007 to 2009 time period are given in Table 3.3.

Table 3.3. Annual rates of volume change in the Shallotte Inlet complex measured between 2007 and 2009.

Volume Change Box	Volume Change (cy/yr)
West Delta	44,000
East Delta	-33,000
Borrow Area	251,000
West Channel	2,000
East Channel	5,000
Total	**269,000**

The Ocean Isle Beach shoreline from baseline stations 0+00 to 120+00 was divided into four cells, namely; 0+00 to 30+00, 30+00 to 60+00, 60+00 to 90+00, and 90+00 to 120+00. The shoreline on Holden Beach consists of only one cell extending from baseline stations 385+00 east to 344+00. The area included in the sediment budget is shown on Figure 3.9.

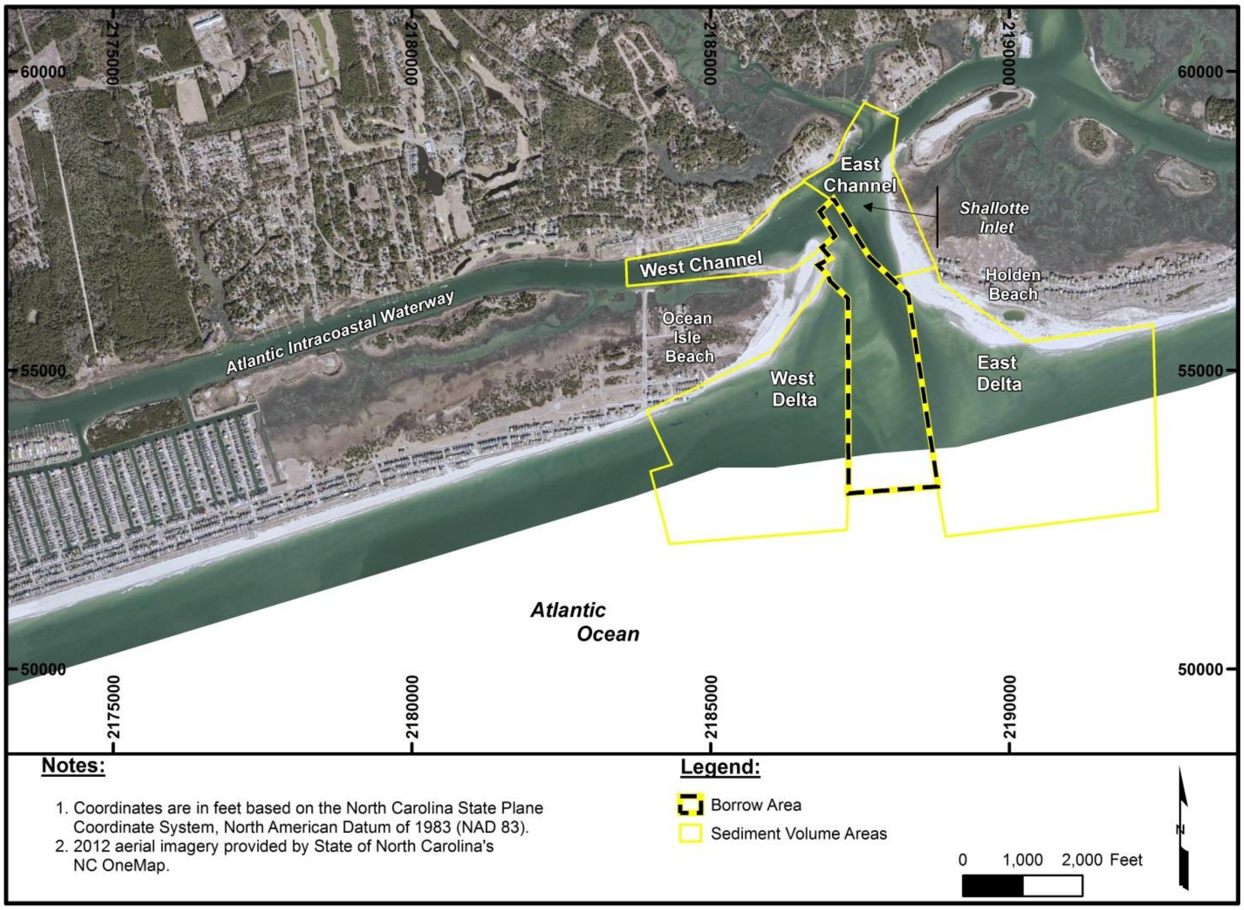

Figure 3.8. Boxes used to compute sediment volumes in the Shallotte Inlet complex.

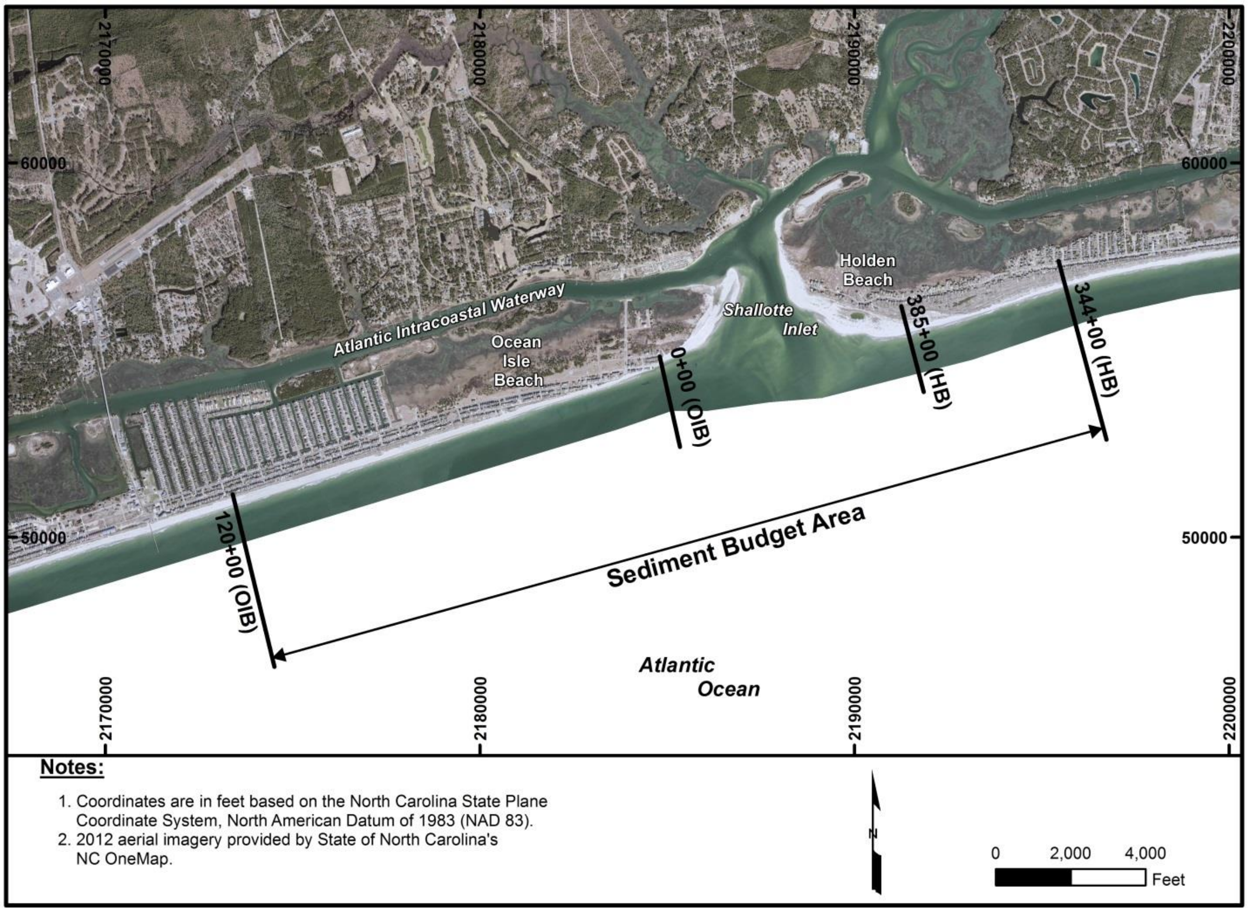

Figure 3.9. Sediment Budget Area.

The volume changes within each cell for the 2007-2010 time period on Ocean Isle Beach were computed using USACE profile survey out to the -18-foot NAVD contour. The measured volume changes, expressed as average annual rates of change (cy/yr), are provided in Table 3.4.

Table 3.4. Measured volume changes along Ocean Isle Beach and Holden Beach between 2007 and 2010.

Shoreline Cell	Annual Rate of Volume Change (cy/yr)
120+00 to 90+00 – Ocean Isle	-18,000
90+00 to 60+00 – Ocean Isle	-25,000
60+00 to 30+00 – Ocean Isle	-101,000
30+00 to 0+00 – Ocean Isle	-88,000
385+00 to 344+00 – Holden Beach	-44,000

Longshore sediment transport rates (LST) to the east and west at the boundaries of each cell on Ocean Isle Beach and Holden Beach were interpolated from the results of the Delft3D model run for Alternative 1 which represents the existing conditions in the project area. The results of the Delft3D model simulations for all the alternatives are discussed later. The model transport rates at each cell boundary are given in Table 3.5.

Table 3.5. Model generated longshore transport rates for Alternative 1.

Cell Boundary (BL station)	Delft3D model LST rates (cy/yr) for Run 43A	
	LST to West	LST to East
344+00 (Holden Beach)	73,000	90,000
385+00 (Holden Beach)	47,000	68,000
0+00 (Ocean Isle Beach)	67,000	134,000
30+00 (Ocean Isle Beach)	46,000	118,000
60+00 (Ocean Isle Beach)	45,000	96,000
90+00 (Ocean Isle Beach)	69,000	103,000
120+00 (Ocean Isle Beach)	83,000	105,000

The model LST rates were interpreted as representing relative orders of magnitude of the transport rates rather than absolute rates. The relative LST rate from one cell to the other was computed by dividing the model transport rates by the LST to the east at station 0+00. This resulted in the relative transport rates at each cell given in Table 3.6 with the LST to the east at 0+00 equal to $1.0Q_E$.

Table 3.6. Relative LST rates at cell boundaries with the LST rate to the east at 0+00 designated as $1.0Q_E$.

Cell Boundary (BL station)	Delft3D model LST rates (cy/yr) for Run 43A	
	LST to West	LST to East
344+00 (Holden Beach)	$0.5Q_E$	$0.7Q_E$
385+00 (Holden Beach)	$0.4Q_E$	BPE
0+00 (Ocean Isle Beach)	BPW	$1.0Q_E$
30+00 (Ocean Isle Beach)	$0.3Q_E$	$0.9Q_E$
60+00 (Ocean Isle Beach)	$0.3Q_E$	$0.7Q_E$
90+00 (Ocean Isle Beach)	$0.5Q_E$	$0.8Q_E$
120+00 (Ocean Isle Beach)	$0.6Q_E$	$0.8Q_E$

Note that the sediment transport past Shallotte Inlet to the east and west are not represented by relative transport rates. Rather, these sediment bypassing rates are assumed to be unknown and are determined by solving a set of three equations and three unknowns based on sediment budget equations for the cells on the west end of Holden Beach, the Shallotte Inlet cells, and the cell between stations 0+00 and 30+00 on Ocean Isle Beach. The three unknowns in the equations are Q_E, BPE, and BPW. A schematic of the sediment budget for 2007 to 2010 showing the relative LST rates and the measured annual rate of volume change within each cell is shown in Figure 3.10.

Sediment Budget Results. Three equations involving the three unknowns (Q_E, BPE, & BPW) were developed using the Shallotte Inlet cell, the cell on the east end of Ocean Isle Beach (0+00 to 30+00), and the cell on the west end of Holden Beach. The three equations follow:

Sediment Budget Equations

Shallotte Inlet

$Q_E - BPW - BPE + .04Q_E = 269$

Rearranging results in:

$1.4Q_E - BPW - BPE = 269$

East End Ocean Isle Beach (0+00 to 30+00)

$0.9Q_E - Q_E + BPW -.03Q_E = -88$

Rearranging results in:

$BPW = 0.4Q_E - 88$

West End Holden Beach

$0.5Q_E - 0.7Q_E + BPE - 0.4Q_E = -44$

Rearranging results in:

$BPE = 0.6Q_E - 44$

(Note: Volumes are in 1,000's cy/yr.)

The equations for BPW and BPE as functions of Q_E were inserted into the equation for Shallotte Inlet resulting in one equation with one unknown (Q_E) as shown below:

$$1.4Q_E - (0.4Q_E - 88) - (0.6Q_E - 44) = 269$$

Combining and solving for Q_E results in the following value for Q_E:

$Q_E = 343$ (343,000 cy/yr.)

Given Q_E equal to 343, the values for BPE and BPW were computed with the following results:

BPE = 162 (162,000 cy/yr.)

BPW = 49 (49,000 cy/yr)

The final sediment budget for 2007 to 2010 is shown on Figure 3.11.

Based on the final sediment budget for 2007 to 2010, the gross rate of sediment transport moving toward Shallotte Inlet (west transport off the west end of Holden Beach plus the east transport off the east end of Ocean Isle Beach) is equal to 480,000 cubic yards/year.

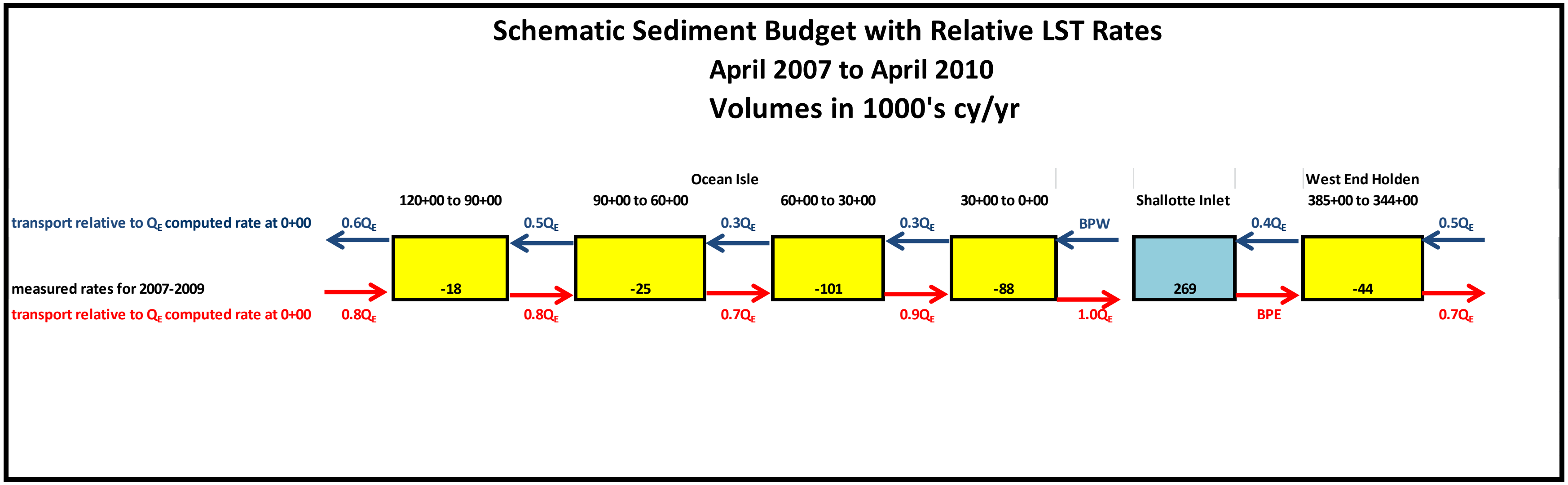

Figure 3.10. Sediment budget schematic for 2007 to 2010 with relative LST rates.

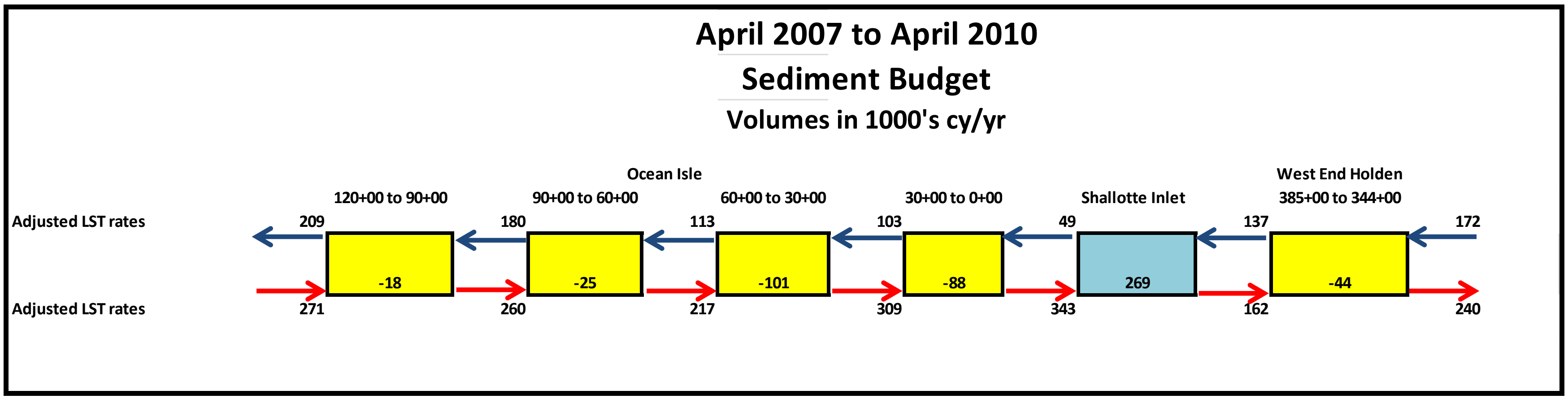

Figure 3.11. Final Sediment Budget for 2007-2010.

4.0 MANAGEMENT ALTERNATIVES

Five (5) erosion response alternatives were evaluated as means to address the erosion impacts currently taking place on the eastern end of Ocean Isle Beach. Each erosion response alternative was evaluated in terms of the economic resources required to uphold the management option and the anticipated damages expected. The design lifespan of each erosion response alternative was assumed to be 30 years to provide the Town a reasonable and consistent outlook on anticipated costs and construction schedules. The five (5) erosion response alternatives evaluated are as follows:

- Alternative 1 – No Action (Continue Current Management Practices)
- Alternative 2 – Abandon / Retreat
- Alternative 3 – Beach Fill Only (Including Federal Project)
- Alternative 4 – Shallotte Inlet Bar Channel Realignment with Beach Fill
- Alternative 5 - Terminal Groin with Beach Fill (Including Federal Project)/ Applicant's Preferred Alternative

The potential impacts of the various alternatives on Shallotte Inlet (and its environs), Holden Beach, and Ocean Isle Beach were evaluated with the Delft3D numerical model. A detailed discussion of the modeling effort is provided at the end of this engineering report as Sub Appendix A.

4.1 Alternative 1 – No Action (Continue Current Management Practices)

Introduction. Under Alternative 1, the Town of Ocean Isle Beach and individual property owners on the extreme east end of Ocean Isle Beach would continue to respond to erosion threats in the same manner as in the past. These measures include possible intermittent beach nourishment, the deployment of sandbags, and possibly occasional beach scraping. The NCDOT has also installed sandbags and conducted road repairs to maintain infrastructure within the project area. The Town of Ocean Isle Beach would also continue to participate in the Federal storm damage reduction project, however, the Federal project has very little impact on reducing erosion rates on the extreme east end of the island.

The evaluation of potential impacts for Alternative 1 was based on the continued movement of the erosion scarp line over the next 30 years at rates measured at each profile station during the period from September 1999 to May 2010. The average rates of movement of the scarp line during this period, which are presented in Table 4.1, appeared to provide a reasonable representation of recent changes on the east end of Ocean Isle Beach.

Table 4.1. Scarp Line Annual Migration Rates - Sept 1999 to May 2010

USACE Baseline Station ID	Migration Azimuth (◦)	Annual Change in Scarp Line (ft./yr)
-5	150.0	-19.1
0	172.4	-14.3
5	172.4	-13.0
10	172.4	-9.2
15	172.4	-3.2
20	172.4	-1.1
Average		**-10.0**

Potential impacts to development and infrastructure on the east end of Ocean Isle Beach under Alternative 1 were based on the shoreline change scenario described below.

Shoreline Change Scenario – Alternative 1

Initial Year 2015 – The 1,800-foot sandbag revetment extending from just west of Shallotte Boulevard to the last house on the east was assumed fail with the shoreline eventually assuming a position it would have occupied in 2015 had there not been a revetment. A new 1,800 foot long sandbag revetment would be installed along the 2015 escarpment line.

Homes and parcels overtaken by the 2015 scarp line would either be demolished or moved to a new location on Ocean Isle Beach. In this regard, since 2001, a total of four (4) homes have been demolished and two (2) have been relocated. Therefore, damage estimates are based on the assumption that two-thirds ($^{2}/_{3}$) of the impacted structures will be demolished and one-third ($^{1}/_{3}$) will be relocated.

Year 2020 – The 1,800-foot sandbag revetment installed in 2015 is assumed to fail allowing the scarp to move landward at each profile station to a position it would have occupied in the absence of the sandbag revetment. A new sandbag revetment would be constructed along the 2020 scarp line to protect the upland development.

Homes and parcels overtaken by the 2020 scarp line would either be demolished or moved to a new location on Ocean Isle Beach in the same 2/3 to 1/3 ratio as described above.

Year 2025 – The sandbag revetment installed in 2020 would fail and the shoreline would jump to the 2025 position it would have occupied in the absence of the sandbag. The 2025 scarp position was determined by multiplying the scarp movement rates for each profile given in Table 4.1 by 5 years. Demolition or relocation of affected homes would occur in the same ratio, i.e., 2/3 would be demolished and 1/3 relocated.

Years 2030 to 2045 – The same sequence of events as described above for the Year 2025 would continue in 5-year increments to the end of the 30-year analysis period (Year 2045). That is, new sandbag revetments would be installed along the shoreline every 5 years. After each sandbag revetment fails, the shoreline would move to the next 5-year shoreline position.

The projected future positions of the scarp line under Alternative 1, which were used as a basis for estimating potential future damages, are shown in Figure 4.1. Homes were assumed to be impacted once the erosion scarp reaches the front of the structure. Homes assumed to be relocated to another lot on Ocean Isle Beach would retain their assessed value. Parcels impacted were assumed to maintain their value until one-half of the parcels is lost at which time its value was assumed to decrease to zero.

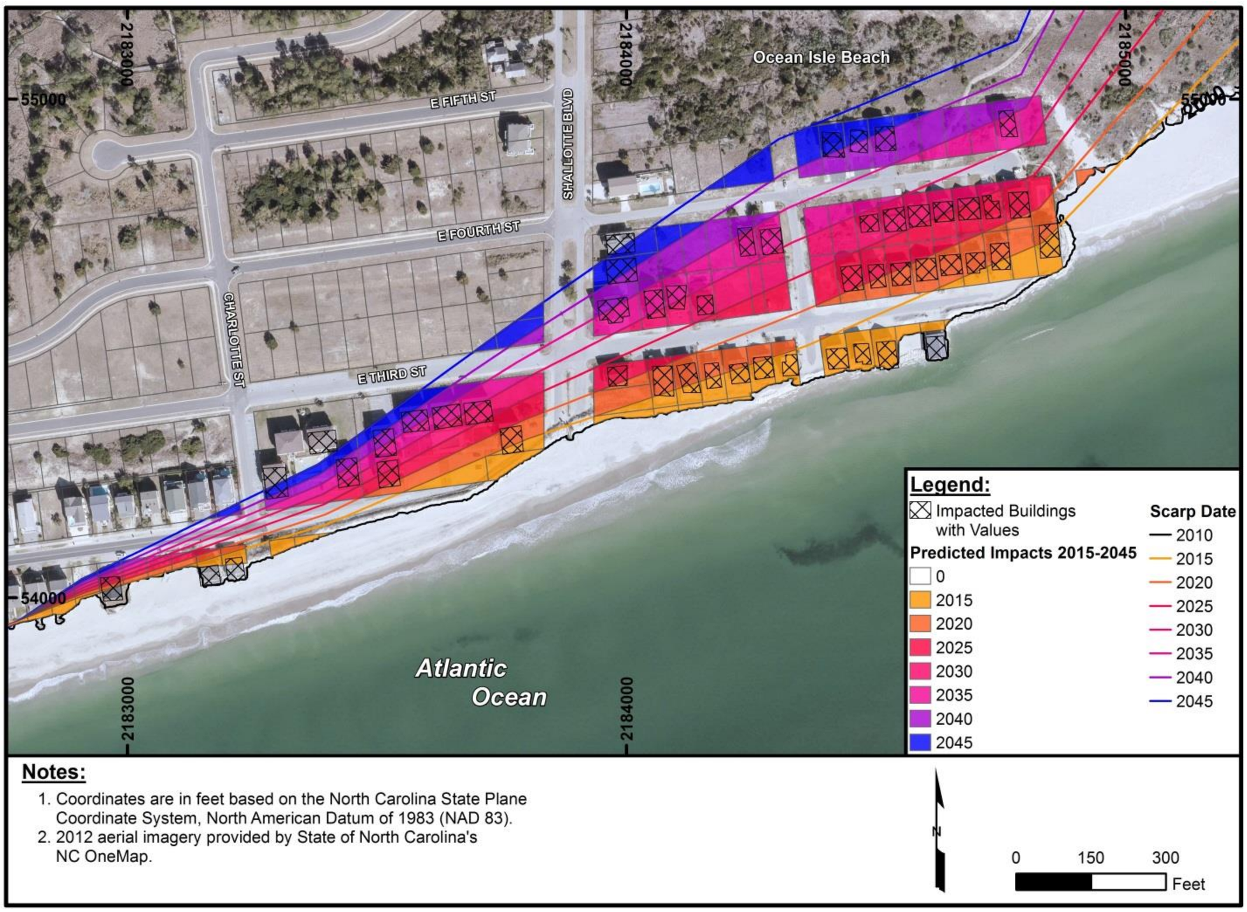

Figure 4.1. Future Scarp Line Positions under Alternative 1 - Current Management Practices

A summary of potential future damages for Alternative 1 on the east end of Ocean Isle Beach is provided in Table 4.2.

Table 4.2. Economic Impact – Alternative 1 – Continue Current Management Practices

Item	Time Periods						Cumulative 2015 to 2045
	2015 to 2020	2020 to 2025	2025 to 2030	2030 to 2035	2035 to 2040	2040 to 2045	
# Parcels affected	77	37	35	31	31	27	238
Acres lost	2.77	1.40	1.34	1.31	1.28	0.95	9.05
Value lost parcels	$2,529,000	$2,099,000	$1,998,000	$4,044,000	$5,642,000	$5,081,000	$21,393,000
Structures impacted(1)	23	8	5	4	1	4	45
Demolition costs	$409,900	$127,100	$81,500	$96,400	$41,900	$66,400	$823,200
Relocation costs	$954,200	$438,300	$324,400	$178,200	$0	$460,500	$2,355,600
Value lost structures	$1,785,600	$467,600	$321,400	$115,000	$91,600	$104,800	$2,886,000
Length roads lost (ft.)	380	200	360	470	540	437	2,387
Value lost roads	$217,000	$114,000	$205,000	$268,000	$308,000	$249,000	$1,361,000
Utilities lost							
Sewer	$57,000	$30,000	$54,000	$71,000	$81,000	$66,000	$359,000
Water	$21,000	$11,000	$20,000	$26,000	$30,000	$24,000	$132,000
Pump Station	$0	$0	$200,000	$0	$0	$0	$200,000
Electric & Telephone	$38,000	$20,000	$36,000	$47,000	$54,000	$44,000	$239,000
Temporary sandbags	$900,000	$900,000	$900,000	$900,000	$900,000	$900,000	$5,400,000
Total Damages	$6,911,700	$4,207,000	$3,940,300	$5,745,600	$7,148,500	$6,535,200	$35,148,800

(1) Building assumed impacted once scarp line intercepts the structure's footprint.
(2) Building values were distributed evenly for parcels with multiple buildings.
(3) Parcel value is lost when scarp reaches mid-way point of parcel.

Equivalent Annual Cost of Damages and Erosion Response Measures – Alternative 1. In order to put the cost and damages associated with all of the alternatives on an equal economic basis, all future damages and response costs for the alternatives were converted to average annual equivalent costs using compound interest methods with a discount rate of 4.125% amortized over the 30-year analysis period. The equivalent average annual costs of the economic impacts of Alternative 1 given in Table 4.2 are provided as average annual equivalents in Table 4.3.

Table 4.3. Average annual equivalent damages and erosion response cost – Alternative 1

Damage/Response Category	Equivalent Annual Cost
Value of lost parcels	$583,000
Demolition Cost	$32,000
Relocation Cost	$86,000
Value of lost structure	$121,000
Damage to utilities & roads	$61,000
Sandbag revetments	$166,000
Total Annual Damages/Response Cost	**$1,048,000**

30-Year Cost – Alternative 1. Under Alternative 1, a total of 45 houses would be impacted by erosion trends within the next 30 years. The economic impact of the damage was calculated at approximately $3.18 million for the cost of relocating or demolishing threatened structures, $2.89 million for the value of structures that would be demolished, and $21.39 million for the loss of approximately 238 parcels. In addition, damages to roads and utilities would total $2.09 million with the cost of installing temporary sandbag revetments equal to $5.40 million. The damages and erosion response costs over the next 30 years total approximately $35.15 million.

Approximately 32% of the total damages would occur within the first ten years of the 30-year planning period.

The Town of Ocean Isle Beach will continue to participate in the Federal storm damage reduction project under Alternative 1. Assuming each three-year periodic nourishment operation will provide 408,000 cubic yards of material, the cost for future periodic nourishment would be around $6,644,000. Based on the existing Project Cooperation Agreement with the Federal Government, the Federal share of the cost for each periodic nourishment operation would be 65% or $4,320,000 with the non-Federal share equal to $2,324,000 or 35%. Over the 30-year planning period, the total cost for periodic nourishment of the Federal project would be $66.44 million with the Federal government share equal to $43.19 million and the non-Federal share equal to $23.25 million.

Thus, the total economic cost for Alternative 1 over the 30-year planning period, including the cost for periodic nourishment of the Federal storm damage reduction project, is $101.49 million.

Note the cost for maintaining the Federal storm damage reduction project is included in the total economic impact of Alternative 1 since some of the other management alternatives have an impact on the amount of nourishment needed for both the east end of the island and the Federal project.

Delft3D Model Results – Alternative 1. Simulated changes in Shallotte Inlet and the adjacent shorelines obtained from the Delft3D model over a three-year simulation period for Alternative 1 are provided in Figures 4.2a to 4.2d.

Under Alternative 1, the seaward portions of the Shallotte Inlet ocean bar channel evolved toward a southwesterly orientation which resulted in the accumulation of sediment in the offshore areas off the east end of Ocean Isle Beach. The southwesterly channel orientation appeared to be due to the simulated removal of material from the Shallotte Inlet borrow area as depicted in Figure 4.2a. In general, the areas seaward of the -6-foot NAVD contour accreted while the area landward of this contour eroded. The model also indicated the extreme eastern tip of the Ocean Isle sand spit would experience some erosion.

Erosion and deposition patterns indicated by the Delft3D model at the end of the three-year simulation are shown in Figure 4.3. Red areas indicate erosion and green accretion. The build-up of material off the east end of Ocean Isle Beach is clearly evident as is some minor erosion of the ebb tide delta situated off the west end of Holden Beach.

The model also indicated the extreme eastern tip of the Ocean Isle Beach sand spit could experience some erosion while the western tip of Holden Beach would continue to gain material. The interior of the inlet, in particular the portion of the AIWW leading to the mouth of the Shallotte River eroded in the middle of the channel while the north and south sides of the channel accumulated sediment. The model did not indicate any significant changes west of the intersection of the inlet with the AIWW.

Over the three year simulation for Alternative 1, the Delft3D model indicated an average sedimentation rate of 210,000 cubic yards/year in the Shallotte Inlet sediment trap represented by the box shown in Figure 3.8, while the measured rate between April 2007 and April 2009 was 251,000 cubic yards/year. Therefore, the model sediment retention in the sediment trap was about 80% of the measured rate of retention. The model also replicated sediment losses from the east delta lying off the west end of Holden Beach with the model rate equal to -30,000 cubic yards/year and the measured rate equal to -33,000 cubic yards/year. However, with the bar channel maintaining a southwesterly orientation during the entire 3-year simulation, the model volume changes off the east end of Ocean Isle Beach were considerably higher than the rate measured between April 2007 and April 2009. For the interior portions of the model represented by the Eastern and Western Channels in Figure 3.8, both the measured and modeled volume changes indicated relatively small amounts of accretion.

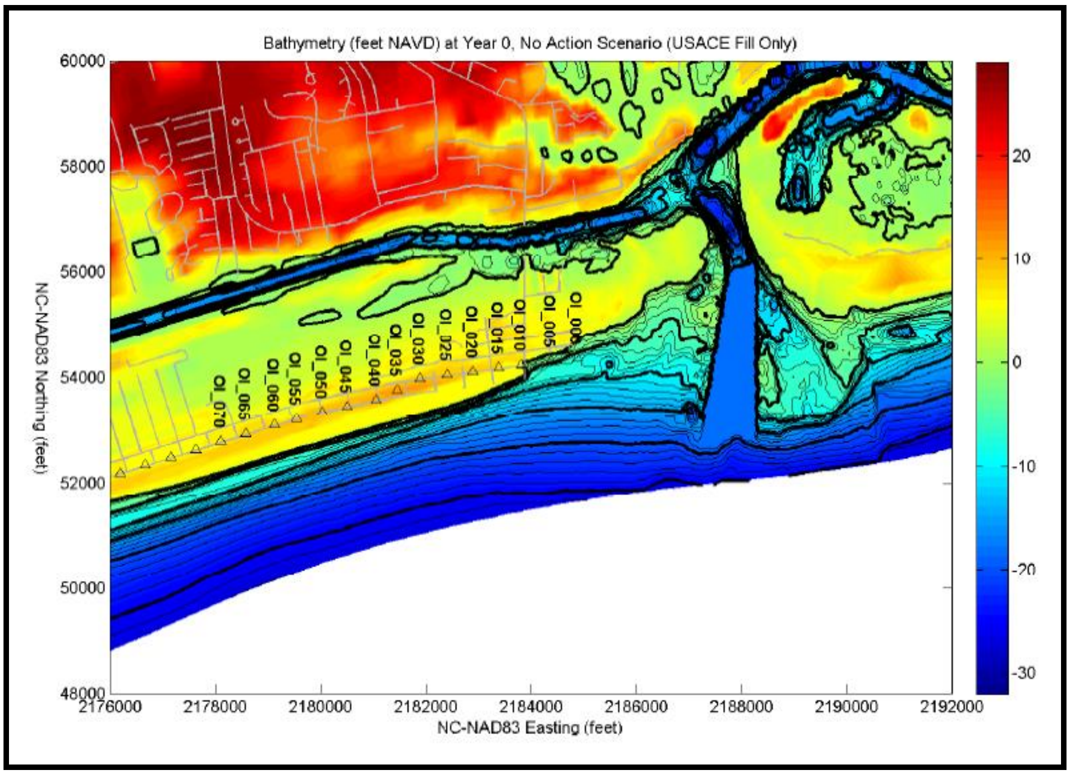

Figure 4.2a. Alternative 1 – Year 0.

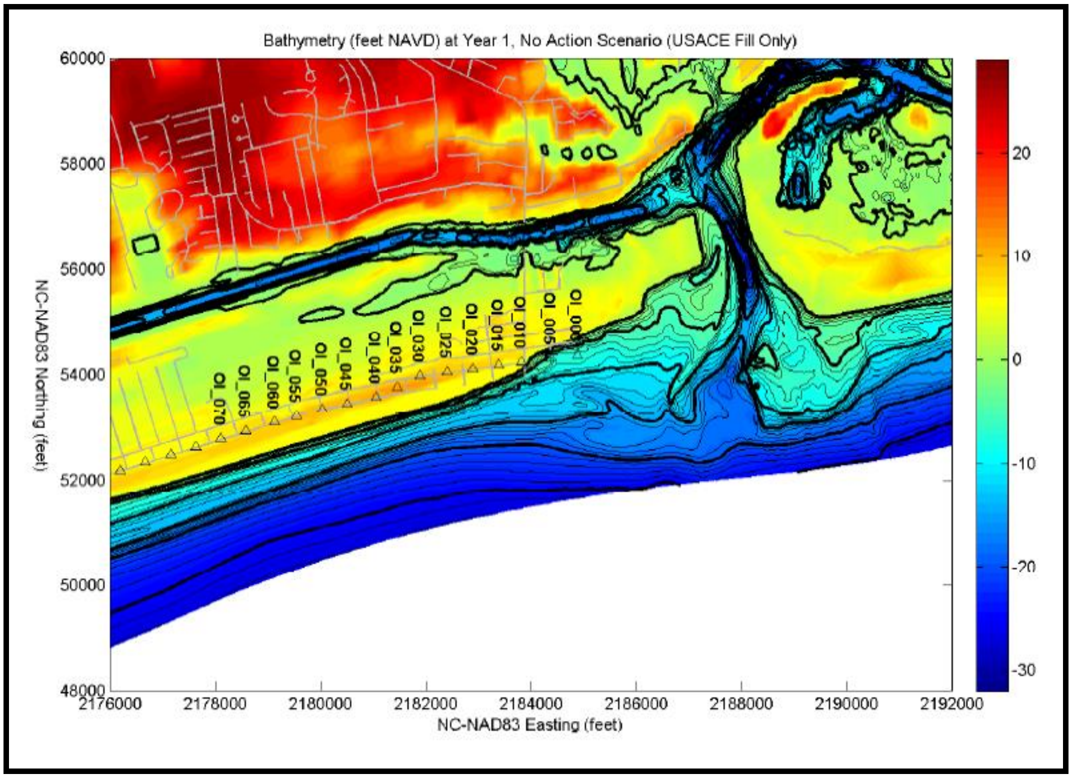

Figure 4.2b. Alternative 1 – Year 1.

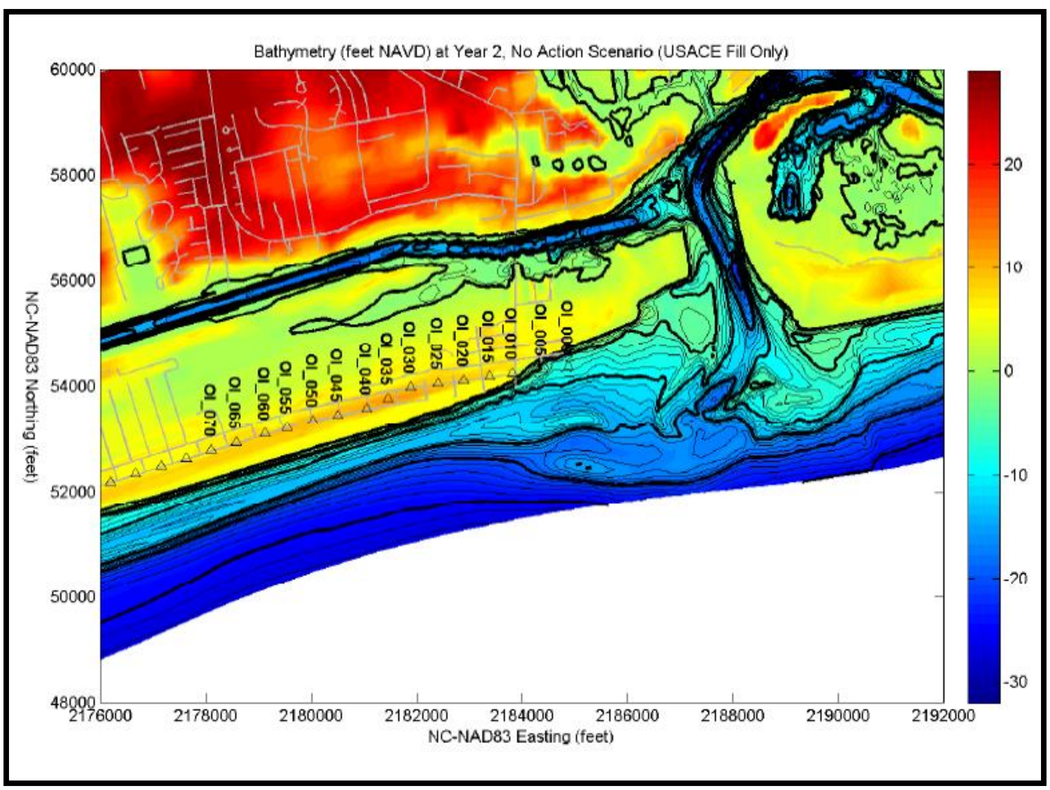

Figure 4.2c. Alternative 1 – Year 2.

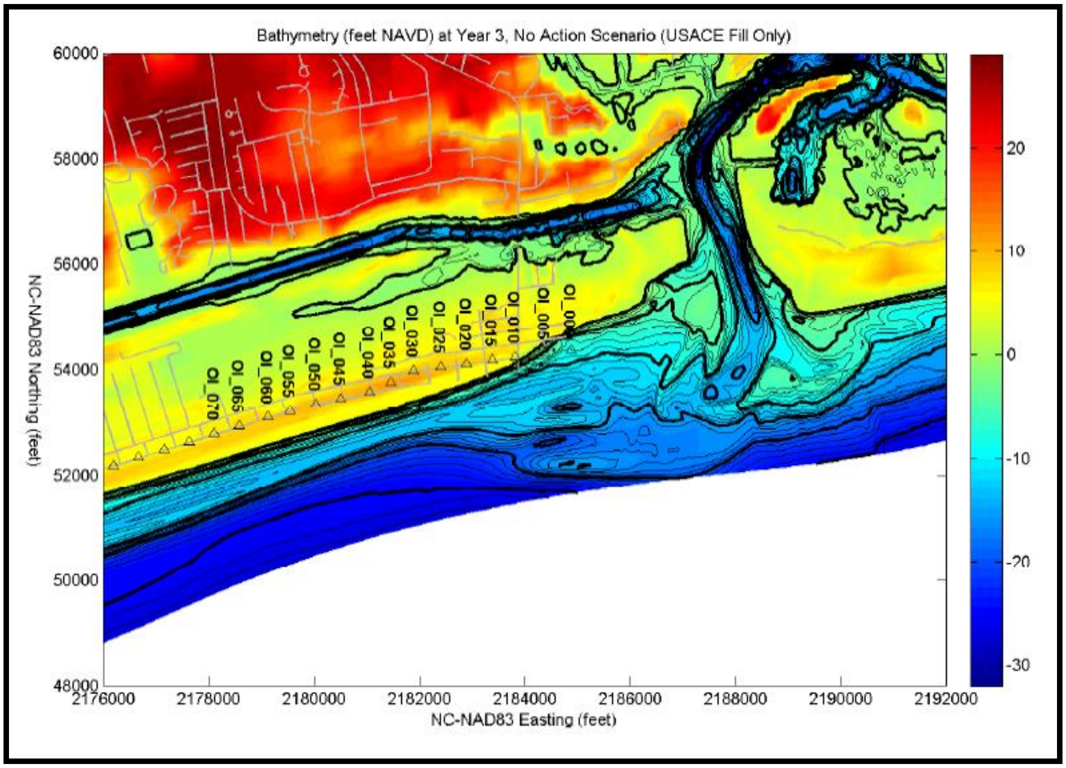

Figure 4.2d. Alternative 1 – Year 3.

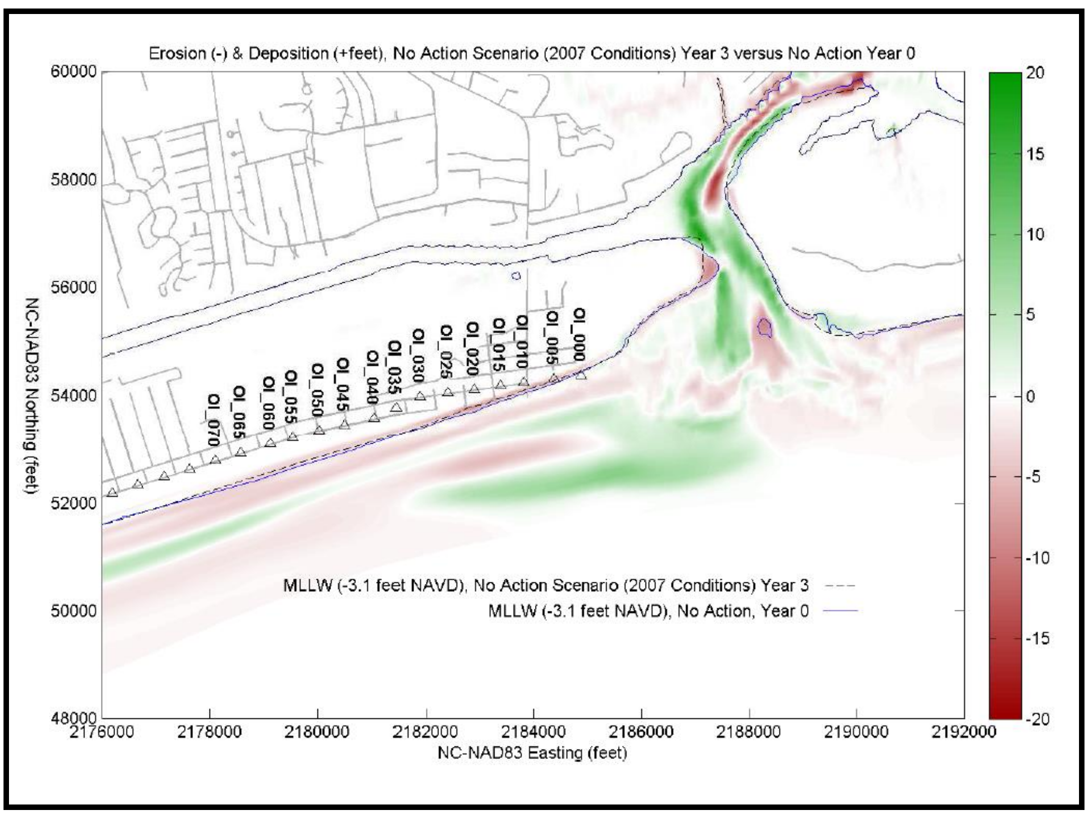

Figure 4.3. Alternative 1 – Three-year erosion and deposition patterns.

4.2 Alternative 2 – Abandon / Retreat

Introduction. For Alternative 2, no new actions would be taken by the Town or property owners to slow the rate of shoreline retreat on the east end of Ocean Isle once the existing 1,800-foot sandbag revetment fails. The Town would continue to participate in the Federal storm damage reduction project which, as stated previously, has very little impact on reducing erosion rates on the east end of the island. Under this scenario, potential damages would begin in the Year 2015 and would continue uniformly until the Year 2045. Future damages are based on the scarp migration rates provided in Table 4.1 with damages to homes and parcels determined on a yearly basis rather than every 5 years as was the case for Alternative 1. Homes would be impacted once the scarp line reaches the front of the structure and parcel values would decrease to zero in the year in which one-half of the parcel is lost.

Based on this scenario, the future positions of the scarp line under Alternative 2 would be the same as shown for Alternative 1 (Figure 4.1). However, rather than all homes and parcels being impacted in 5-year increments, not using sandbag revetments to temporarily stop the landward progression of the scarp line every 5 years would result in the loss of structures and infrastructure in each year of the analysis period. As a result, the number of parcels impacted and the number of homes relocated or demolished would be the same over the 30-year planning period as under Alternative 1. The difference would be the timing of when individual homes as well as the upland infrastructure are impacted. Also, there would not be any cost for installing sandbags.

The equivalent average annual costs of future damages and erosion response measures under Alternative 2 over the 30-year planning period are given in Table 4.4.

Table 4.4. Average annual equivalent damages and erosion response cost – Alternative 2

Damage/Response Category	Equivalent Annual Cost
Value of lost parcels	$633,000
Demolition Cost	$35,000
Relocation Cost	$93,000
Value of lost structure	$132,000
Damage to utilities & roads	$66,000
Total Annual Damages/Response Cost	**$958,000**

30-Year Project Cost – Alternative 2. Under Alternative 2, the Town of Ocean Isle Beach would continue to participate in periodic nourishment of the Federal storm damage reduction project. As given above under Alternative 1, the total 30-year cost for continued nourishment of the Federal project would be $66.44 million. The existing cost-sharing agreement for the Federal project would continue under Alternative 2. In addition to the cost for beach nourishment, the economic impact of Alternative 2 would include the loss of 238 parcels, the costs of relocating or demolishing 45 threatened homes, the value of demolished homes, and damages to roads and utilities. Over the 30-year planning period these potential damages total $29.55 million. Note the 30-year cost for Alternative 2 is less than Alternative 1 due to eliminating the use of sandbags. The addition of damages and erosion response cost to the cost of continued nourishment of the Federal storm damage reduction project results in a total economic impact under Alternative 2 of $95.99 million. As with Alternative 1, the cost for periodic nourishment of the Federal project is included in the 30-year cost for Alternative 2 due to the impact of some of the other alternatives on future nourishment cost.

Delft3D Model Results for Alternative 2. The Delft3D model simulation for Alternative 1 is also applicable to Alternative 2 in terms of potential changes in Shallotte Inlet and the adjacent shorelines. Again, the only difference between Alternative 1 and Alternative 2 would be the exclusion of sandbags on the extreme east end of the island. Under Alternative 2, the USACE would continue to nourish the Federal storm damage reduction project every three years using material from the Shallotte Inlet borrow area. Since this is the exact same set-up that was used for Alternative 1, there would be no difference in the model results for the two alternatives.

4.3 Alternative 3 – Beach Fill Only

Introduction. The beach fill only alternative would address the east end erosion issue through the initial construction and subsequent periodic nourishment of a beach fill on the extreme east end of Ocean Isle Beach. The formulation of this alternative is described below.

Initial Design. A preliminary design of the beach fill for Alternative 3 was developed in order to evaluate the potential performance of a beach fill on the east end of the island in the Delft3D model. Once the initial assessment of beach fill performance was completed, the beach fill design was modified to include material to initially construct beach fill design template and provide advanced nourishment to account for volumetric losses associated with long-term erosion trends and diffusion losses (horizontal spreading) of the fill material out of the initial placement area that would occur between periodic nourishment operations.

The preliminary design of the main fill used in the assessment covered 3,500 feet of shoreline along the eastern end of Ocean Isle Beach from baseline station -5+00 (500 feet east of the end of development) and station 30+00 (located just west of Lumberton Street). The fill included 500-foot transition or taper section on each end of the fill to merge the fill with the existing Federal storm damage reduction project making the entire fill length 4,500 feet (Figure 4.4). Based on this preliminary design, the main fill of the Beach Fill Only alternative would overlap 2,000 feet of the Federal project between stations 10+00 and 30+00. While the preliminary design of the beach fill only alternative would cover more than the 2,500-foot length of shoreline in the project area, the added length is needed to provide a gradual merger of the beach fill with the Federal storm damage reduction project.

The Town of Ocean Isle Beach attempted to address the erosion problem on the east end of town in 2007 with the placement of 155,000 cubic yards of material along 2,000 feet of shoreline between baseline stations 17+00 and -3+00. This operation was accomplished as an add-on to the USACE contract to nourish the Federal storm damage reduction project. As a result, the Town realized considerable cost savings through elimination of mobilization and demobilization cost. This combined with the relative short pumping distance from the Shallotte Inlet borrow area to the east end fill area allowed the Town to accomplish the beach fill for $721,000 which is equivalent to a gross unit cost (pumping cost + mobilization & demobilization cost divided by the yardage) of $4.66/cubic yard.

Monitoring surveys along the east end of Ocean Isle Beach following the placement of the fill on the east end of the island found that most of the 155,000 cubic yards had been lost in a period of about 9 months. Previous beach fills have been placed in the area east of Shallotte Boulevard by the USACE during routine maintenance of the AIWW. Generally, the volume of fill provided by these disposal operations has ranged from 30,000 cubic yards to around 60,000 cubic yards. While profile monitoring surveys are not available for these fill/disposal episodes, antidotal information indicates positive impacts of these fills were also short lived.

The performance of the 2006-07 beach fill on the east end of Ocean Isle Beach as well as the lack of substantial erosion mitigation provided by the USACE disposal operations indicates a beach fill only alternative on the east end of the island must account for volume losses from a beach fill that would be greater than normal volume losses from the area.

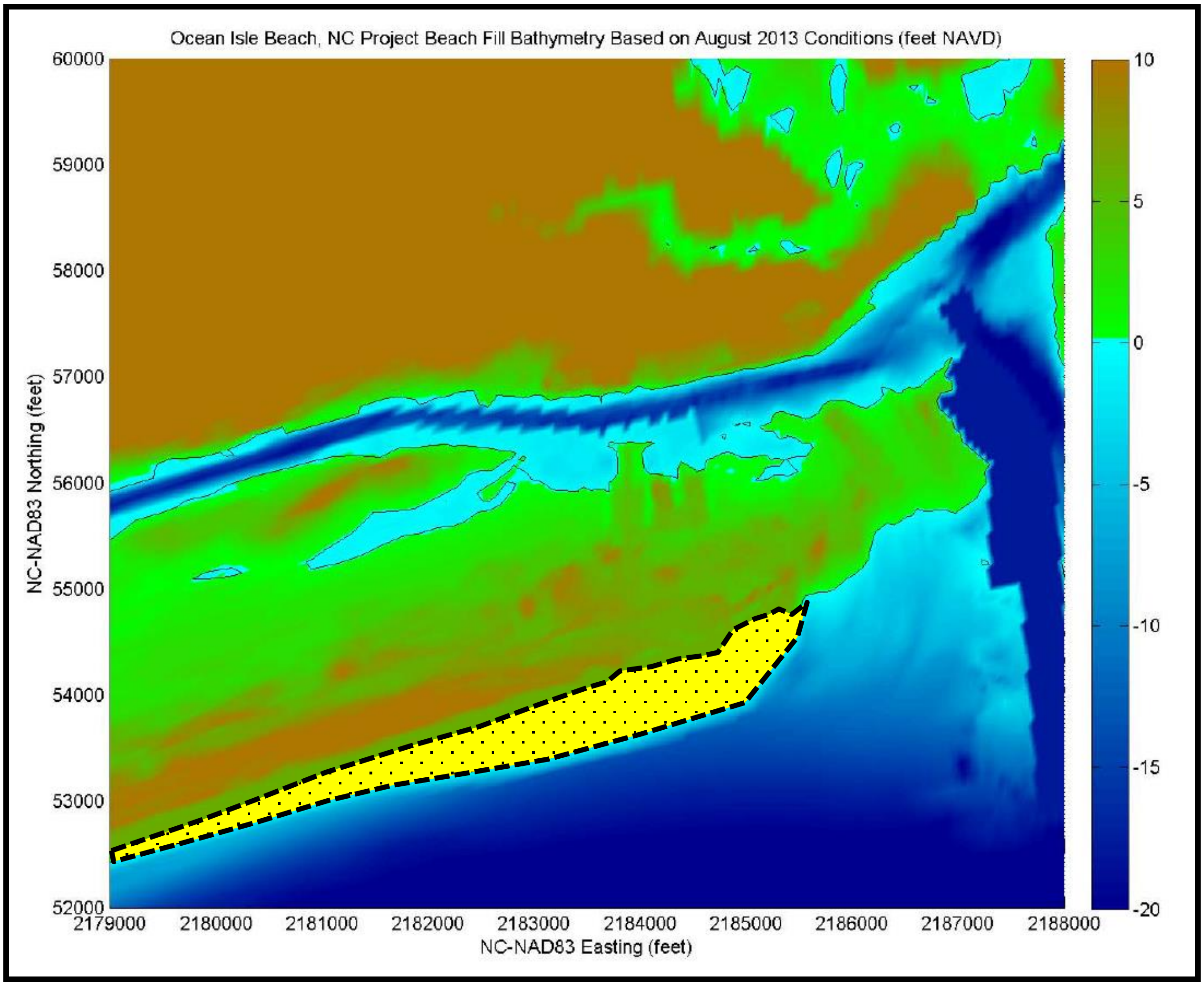

Figure 4.4. Beach Fill Only – Alternative 3.

The USACE has been monitoring the Town's shoreline since construction of the Federal project in 2001. Also, the Town of Ocean Isle Beach has initiated a supplemental survey program to cover areas on the extreme east end of the island that are not included in the USACE surveys. This survey information was used to determine volumetric erosion rates on the east end of Ocean Isle Beach following each of the three previous nourishment operations. The results of this analysis are summarized in Table 4.5 for the area between baseline station 0+00 and station 30+00.

Table 4.5. Volume change rates for post-nourishment periods on east end of Ocean Isle Beach (baseline stations 0+00 to 30+00)

Post-nourishment time period	Time Interval Years	Measured rate of volume change cubic yards/year
Dec 2001 to Mar 2006	4.2	-72,000
Apr 2007 to May 2010	3.1	-88,000
May 2010 to Aug 2013	3.2	-114,000
Average 2001 to 2013	**10.5**	**-91,000**

The average annual retreat of the scarp line between stations 0+00 and 20+00, measured between September 1999 and May 2010, was approximately 10 feet/year (Table 4.1). For the preliminary beach fill design, periodic nourishment of the beach fill on the east end of Ocean Isle Beach was assumed to be nourished every three years in conjunction with the periodic nourishment of the Federal project. Therefore, the preliminary design for the beach fill used an average fill width of 30 feet resulting in an initial construction volume of 107,000 cubic yards.

Based on the measured loss rate of 91,000 cubic yards/year between stations 0+00 and 30+00 as shown in Table 4.5, the volume of advanced nourishment needed to address the measured rate of volume loss of the east end of the island over a three year period would be 273,000 cubic yards. However, given the performance of the 155,000 cubic yard beach fill placed on the east end of the island in 2006-07, the volume of advanced nourishment was increased about 25% from 273,000 cubic yards to 343,000 cubic yards. As a result, the total initial fill volume for the preliminary beach fill was 450,000 cubic yards.

Simulation of the 450,000 cubic yard beach fill in the Delft3D model indicated the rate of volume losses from a beach fill placed between station 30+00 and Shallotte Inlet would be 54% higher than under existing conditions. With the existing rate of loss east of station 30+00 equal to 91,000 cubic yards/year, the expected loss rate from a beach fill placed east of station 30+00 would be equal to 140,000 cubic yards/year. Figures 4.5 to 4.8 show the simulated performance of the east end beach fill over a three-year period. The red areas in the figures represent volume loss (erosion) while the green areas show volume gain (accretion).

Figure 4.5. Alternative 3 – initial post-fill condition.

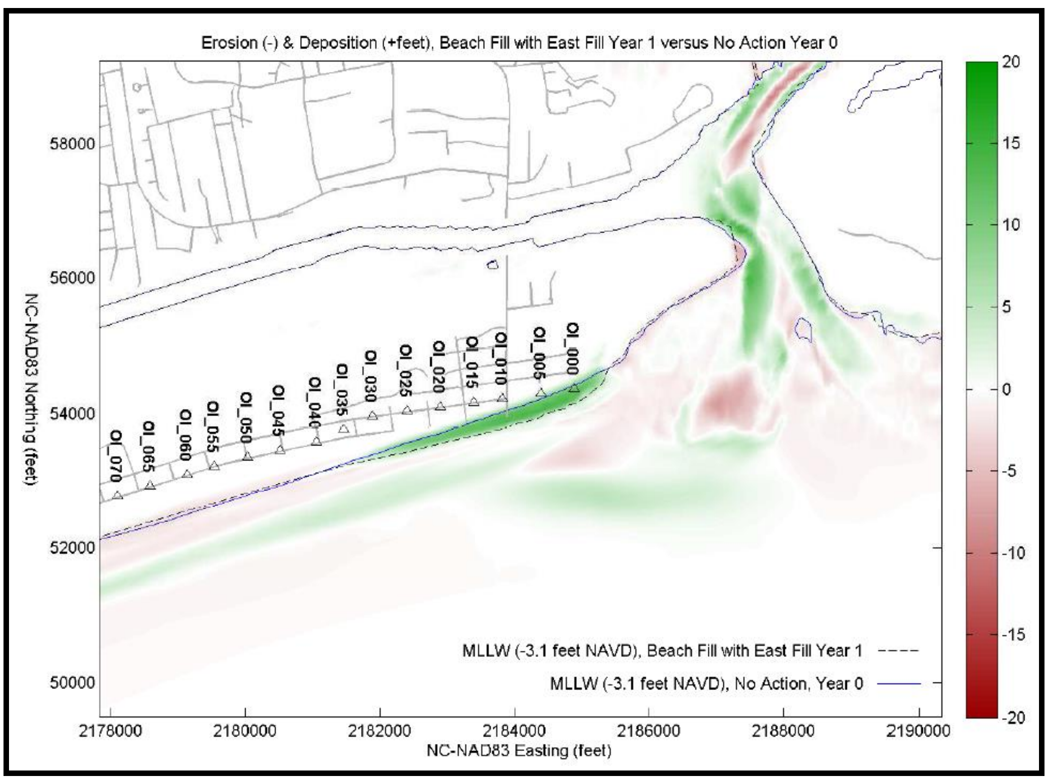

Figure 4.6. Alternative 3 – scour and deposition one year after construction.

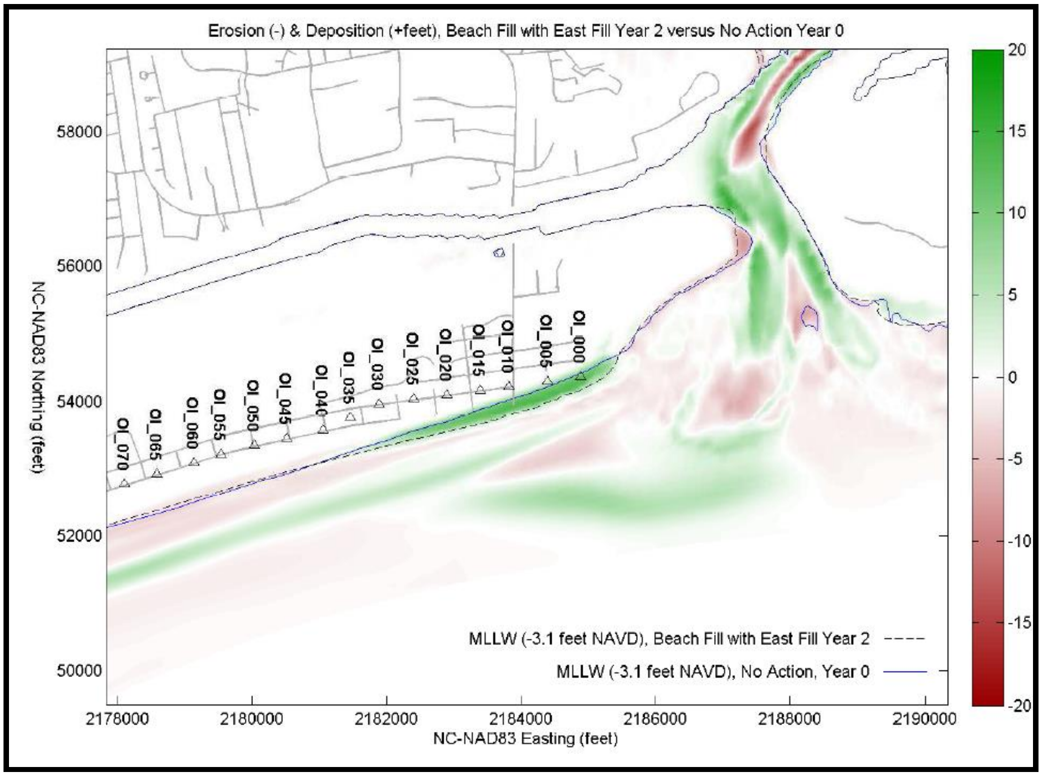

Figure 4.7. Alternative 3 – scour and deposition two years after construction.

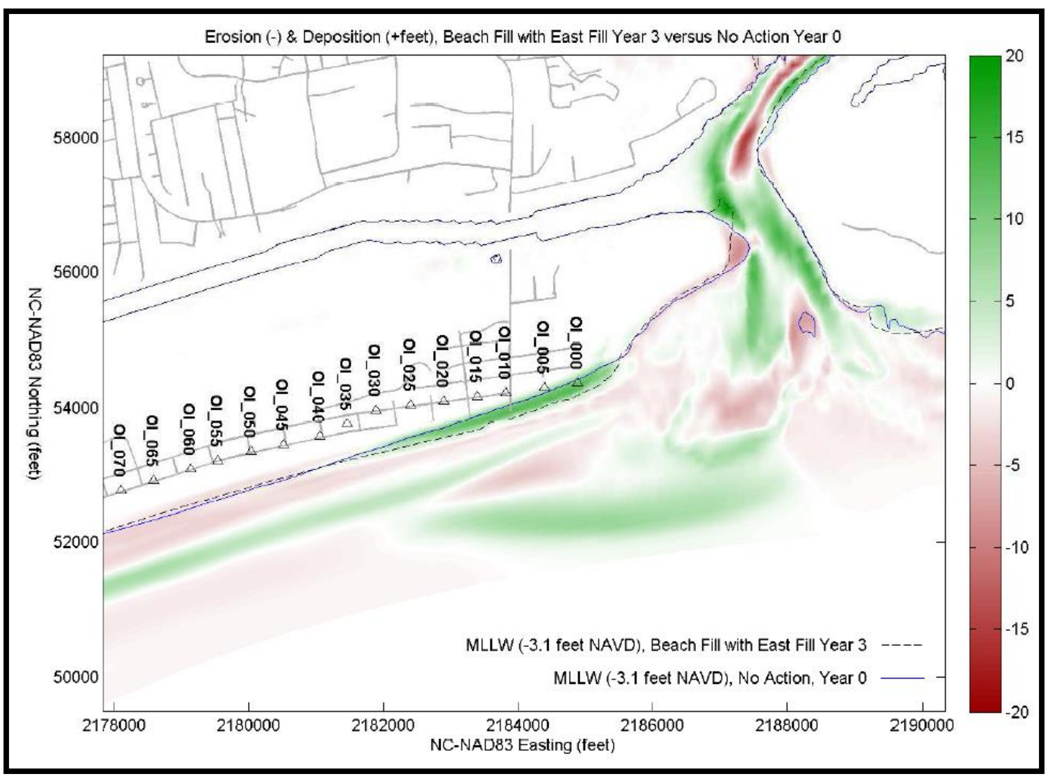

Figure 4.8. Alternative 3 – scour and deposition three years after construction.

Volumetric losses from the east end of the Federal project under existing conditions (i.e., between stations 10+00 and 30+00) have averaged 58,000 cubic yards/year (Table 3.2) while the total loss from the area between stations 0+00 and 30+00 has averaged 91,000 cubic yards/year (Table 4.5). Based on the Delft3D simulated performance of a beach fill on the east end of the island, implementation of the Alternative 3 fill would increase the volume loss rate to 140,000 cubic yards/year from this area. The loss of the additional 82,000 cubic yards/year (=140,000 cy/yr -58,000 cy/yr) would be attributable to changes associated with the Alternative 3 fill. That is, the increased cost for placing an additional 82,000 cubic yards/year on the east end of Ocean Isle Beach to maintain the east end beach fill would not be eligible for Federal cost sharing.

For the area west of station 30+00 to station 120+00, the Delft3D model simulation for Alternative 3 did not indicate any differences in the erosion rates compared to losses being experienced under existing conditions (i.e., Alternative 1). For the area west of station 30+00 to station 120+00, erosion losses have averaged 78,000 cubic yards/year. Thus under Alternative 3, the expected volume loss between station -5+00 and station 120+00 totals 218,000 cubic yards/year. The estimated volumetric loss rates between various stations on Ocean Isle Beach under Alternative 3 are summarized in Table 4.6.

Table 4.6. Annual rates of volume change along Ocean Isle Beach under Alternative 3.

-5+00 to 30+00	30+00 to 60+00	60+00 to 90+00	90+00 to 120+00	Total
-140,000	-59,000	-14,000	-5,000	-218,000

As discussed above for Alternative 1, periodic nourishment of the Federal storm damage reduction project has averaged 408,000 cubic yards every three years. This average periodic nourishment volume was arbitrarily set as a maximum nourishment volume per operation in the evaluation of all of the alternatives that include beach fill. In the case of Alternative 3, adhering to this limit would mean periodic nourishment would be needed once every 1.9 years in order to provide an average of 218,000 cubic yards/year between stations -5+00 and 120+00. Since this is not practicable, the 408,000 cubic yard maximum per operation was relaxed slightly for Alternative 3 to allow 436,000 cubic yards to be deposited along Ocean Isle Beach every two years. Note that the initial assumption with regard to the periodic nourishment interval for Alternative 3 was three years resulting in a design width of 30 feet. However, changing the nourishment interval to 2 years under Alternative 3 did not warrant a change in the designed width of the beach fill.

While Alternative 3 is formulated with a 2 year nourishment interval in order to evaluate it on the same basis as Alternatives 4 and 5 in terms of the volume of material placed during each nourishment interval, this may not be practical since it would require the USACE to alter the periodic nourishment schedule for the Federal project from 3 year to 2 years. This would mean the cost of the Federal project would be higher due to additional mobilization and de-mobilization costs associated with a more frequent nourishment interval. In all likelihood, an economic reevaluation of the Federal project indicating the project is still economically viable with a two-year nourishment interval would be required before Alternative 3 could be implemented.

With the adoption of a two year nourishment interval for Alternative 3, the advanced fill volume needed for the initial construction of the Alternative 3 beach fill to account for anticipated volume losses over two years would be 280,000 cubic yards. Based on this revised design formulation, the initial fill volume for Alternative 3 would be 107,000 cubic yards for the 30-foot design width plus 280,000 cubic yards for advanced nourishment resulting in a total initial fill volume of 387,000 cubic yards for Alternative 3. This initial fill volume would be in addition to the volume of material that would be normally placed east of station 30+00 to maintain the Federal storm damage reduction project and would therefore be the responsibility of non-Federal interests.

The material to construct the Alternative 3 beach fill would be derived from the USACE borrow area in Shallotte Inlet.

The width of the design beach fill and the density of fill placement between each baseline station on the east end of Ocean Isle Beach for Alternative 3 are listed in Table 4.7.

Table 4.7. Design beach fill widths and fill densities for Alternative 3 – Beach Fill Only.

Baseline Stations	Type of Fill	Design Fill Width (ft)	Fill Density (cy/lf)
-10+00 to -5+00	Transition	0 to 76	0 to 85
-5+00 to 0+00	Main Fill	76 to 151	85 to 170
0+00 to 5+00	Main Fill	151 to 133	170 to 150
5+00 to 10+00	Main Fill	133 to 107	150 to 120
10+00 to 15+00	Main Fill	107 to 89	120 to 100
15+00 to 20+00	Main Fill	89 to 66	100 to 75
20+00 to 25+00	Main Fill	66 to 44	75 to 50
25+00 to 30+00	Main Fill	44 to 21	50 to 24
30+00 to 35+00	Transition	21 to 0	24 to 0

Periodic Nourishment-Alternative 3. As discussed above, periodic nourishment under Alternative 3 would be accomplished every two years with the placement of an average of 436,000 cubic yards during each operation. The material would be deposited from baseline stations -10+00 to 120+00 which includes both the Federal project and the non-Federal fill on the east end.

Material for periodic nourishment would also be obtained from the existing borrow area in Shallotte Inlet. In this regard, the USACE monitoring of the borrow area following the 2006-07 and 2010 nourishment operations indicated the borrow area collects an average of 16,500 cubic yards/month or a little less than 200,000 cubic yards/year (Dennis, 2012 personal communication). While this measured rate of entrapment in the borrow area is slightly less than the annual volume needed to nourish the beach under Alternative 3, past nourishment operations have not utilized the full extent of the borrow area. Expansion of the area dredged to nourish the Ocean Isle Beach shoreline should enable the borrow area to accumulate the volume needed to satisfy nourishment requirements for Alternative 3.

30-Year Project Cost – Alternative 3. The erosion damages that could occur to existing development on the east end of Ocean Isle Beach were assumed to be prevented under Alternative 3. The initial placement of 387,000 cubic yards east of baseline station 30+00 to construct the beach for Alternative 3 was assumed to take place during a normal periodic nourishment cycle for the Federal project. Based on this assumption, the cost for the 387,000 cubic yards of material was based only on the dredging cost, i.e., there would not be any additional mobilization and demobilization costs for the added fill.

The economic costs for Alternative 3 would be associated with providing the necessary volume of material to offset these future erosion threats. The total 30-year cost for Alternative 3, which includes continued nourishment of the Federal storm damage reduction project, is estimated to be $115.50 million.

The Federal government would presumably continue to provide its share of the cost for periodic nourishment of the Federal project but would not participate in the added nourishment costs associated with Alternative 3. Therefore, the Federal share of the 30-year project costs under Alternative 3 would be equal to that of Alternatives 1 and 2 or $43.19 million with the balance of $72.31 million the responsibility of non-Federal interests. Based on this cost-sharing arrangement, the Federal share of future periodic nourishment costs along Ocean Isle Beach under Alternative 3 would be about 37.4% (=$43.19/$115.50) with the non-Federal share equal to 62.6%.

Detailed cost estimates for Alternative 3 are presented in Section 5 at the end of this Appendix.

4.4 Alternative 4 - Shallotte Inlet Bar Channel Realignment with Beach Fill

Introduction. An alternative method to managing the erosion stress associated with Shallotte Inlet on Ocean Isle Beach could be to reposition the ocean bar channel closer to Ocean Isle Beach along an alignment essentially perpendicular to the adjacent shorelines. Realigning the bar channel closer to the east end of Ocean Isle Beach should result in the reconfiguration of the ebb tide delta of Shallotte Inlet over time. The reconfiguration of the ebb tide delta would include onshore movement of sediment from the delta located off the west end of Holden Beach and rebuilding the delta off the east end of Ocean Isle. A larger delta on the west side of Shallotte Inlet would provide some wave sheltering for the east end of the island and could eliminate formation of flood channels that run parallel and close to the shoreline on the east end of Ocean Isle Beach. Realignment of the ocean bar channel would be accompanied by a beach fill that would front the existing development east of Shallotte Boulevard.

The USACE assessed the possibility of realigning the channel to stabilize both Ocean Isle Beach and Holden Beach. The USACE found that the east end of Ocean Isle Beach and the western portion of Holden Beach could benefit from positioning the ocean bar channel in the middle of the inlet. The analysis was conducted in the 1997 General Revaluation Report compiled for the 2001Federal erosion control project (USACE, 1997). Based on the USACE analysis, when the Shallotte Inlet bar channel was in a more central position and aligned generally perpendicular to the adjacent shorelines, as was the case between 1954 and 1965, the east end of Ocean Isle Beach was relatively stable and actually experienced some accretion.

Given this finding, the Federal storm damage reduction project incorporated channel realignment in its design and designated the realigned channel as the source of beach fill material for initial construction and periodic nourishment of the Federal project. Figure 4.9 shows a March 2001 post-construction survey of the borrow area superimposed on a February 2001aerial photograph.

Following initial construction, the ebb tide delta of Shallotte Inlet began to adjust to the new channel with significant onshore sediment transport of the delta material on both the east side and west side of the inlet. The material that migrated onshore on the east side of the inlet eventually welded to the west end of Holden Beach, significantly increasing the width of the beach. Once onshore, much of the material was transported into Shallotte Inlet in the form of a sand spit. A similar response was observed on the east end of Ocean Isle Beach. Evidence of these spit formations is shown in an October 2005 Google Earth aerial photograph provided on Figure 4.10. Unfortunately, the ebb tide delta material that migrated onto the east end of Ocean Isle Beach welded too close to the inlet to provide any significant protection to development on the east end of the island with the end result being the formation of a sand spit east of the developed portion of Ocean Isle Beach.

The relatively wide expanse of the Shallotte Inlet borrow area was not effective in concentrating flow in one particular area and as a result, the borrow area accumulated sediment primarily on the west side. This post-construction shoaling pattern resulted in the movement of the bar channel back toward the west end of Holden Beach as indicated by the dashed line on Figure 4.10.

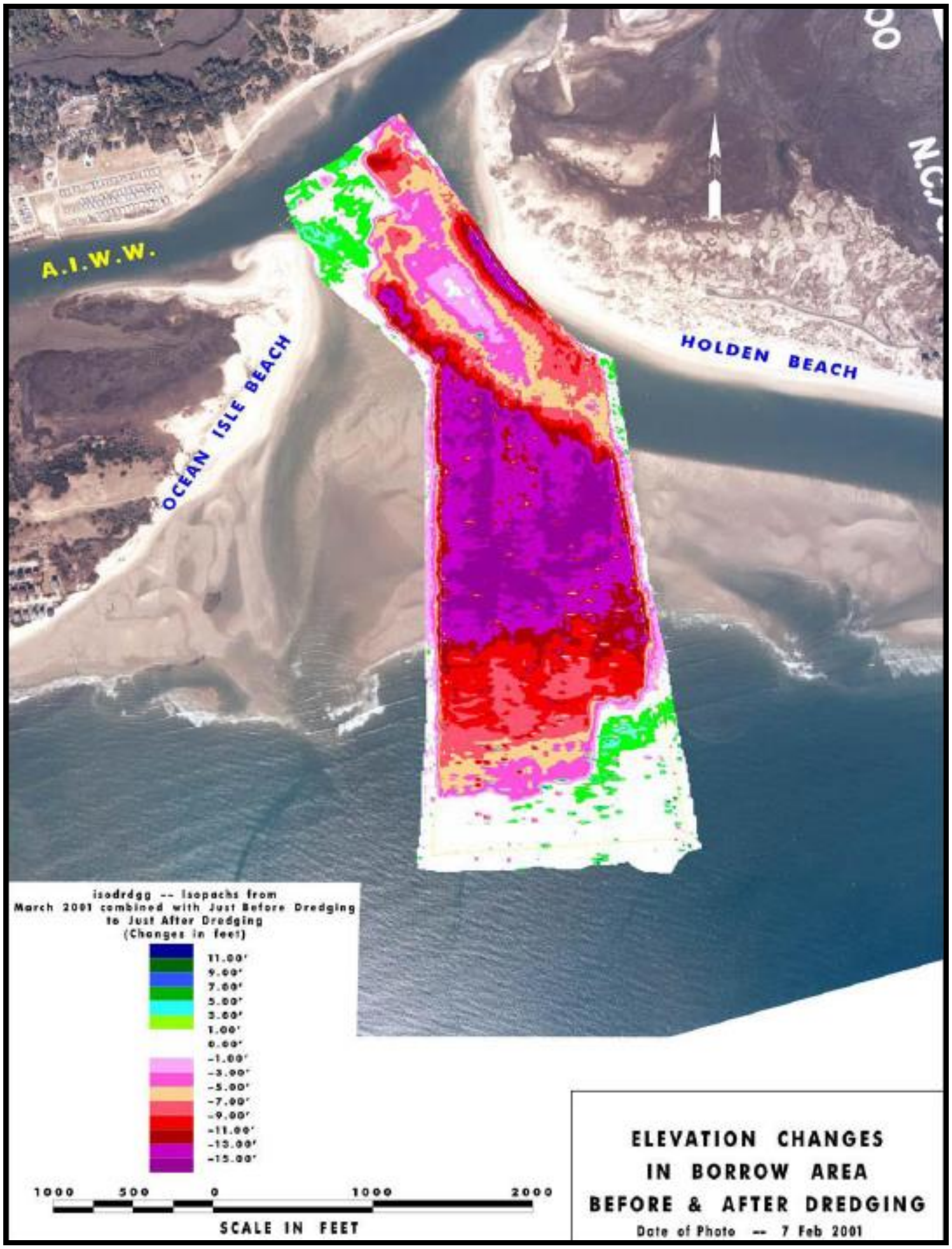

Figure 4.9. March 2001 post-construction survey of Shallotte Inlet borrow area superimposed on a February 2001 aerial photograph.

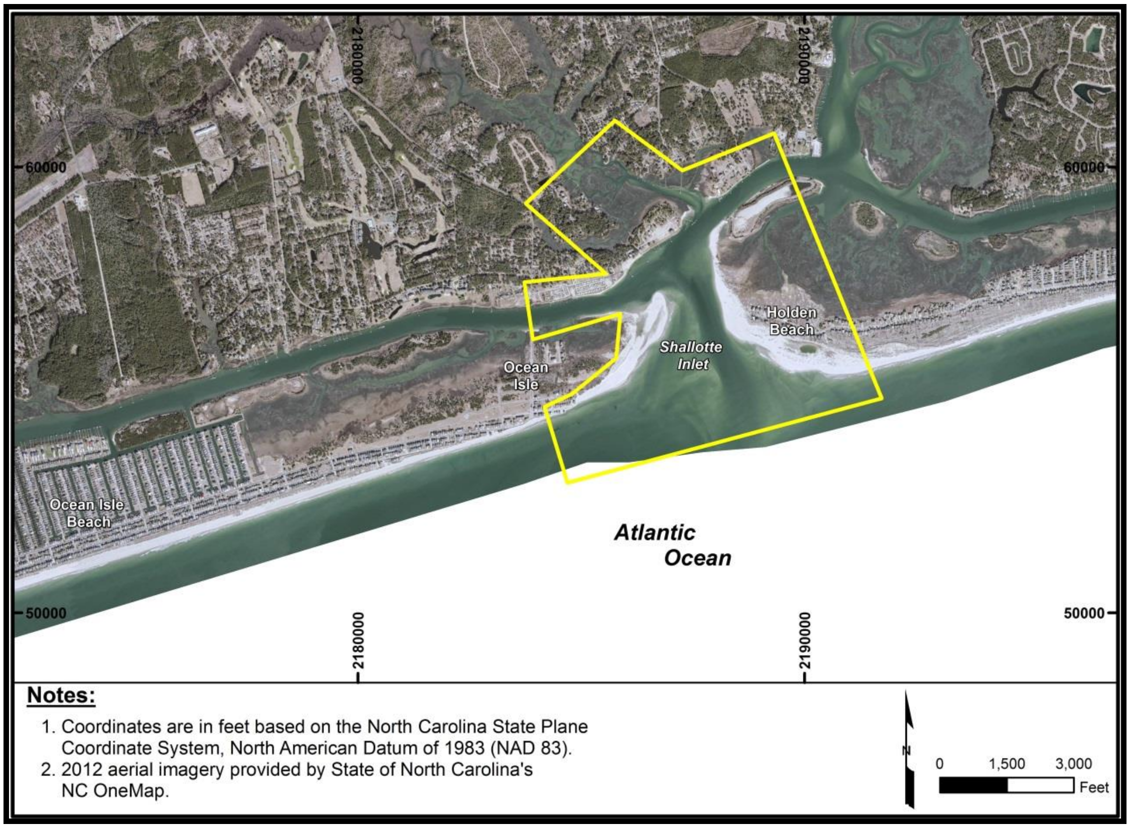

Figure 4.10. October 2005 Google Earth aerial photograph of Shallotte Inlet.

If an inlet channel is relocated for the purpose of effecting shoreline changes on either side of the inlet, the channel must be maintained in the preferred position and alignment. However, subsequent periodic nourishment operations for the Ocean Isle Beach Federal storm damage reduction project did not reestablish a preferred channel location, rather, the inlet borrow area was selectively dredged to obtain the volume of material needed to maintain the Federal storm damage reduction project not to reestablish the preferred channel position. Outlines of the areas dredged for the 2007 and 2010 periodic nourishment operations are shown on Figure 4.11 superimposed on an August 2013 survey of the borrow area.

As shown on Figure 4.11, the areas dredged in the borrow area for the 2007 and 2010 periodic nourishment operations did not follow the same alignment. While the 2007 cut was located close to the west boundary of the borrow area, the 2010 cut was concentrated more to the east side of the borrow area and was bordered on the east by the existing bar channel.

A sequence of surveys of Shallotte Inlet beginning with the 2007 post-dredging condition and ending with the 2013 condition are provided on Figures 4.12a to 4.12d. Figure 4.12a shows that following the dredging operation the inlet actually had two bar channels, the natural channel next to Holden Beach and the dredge channel located closer to the east end of Ocean Isle Beach.

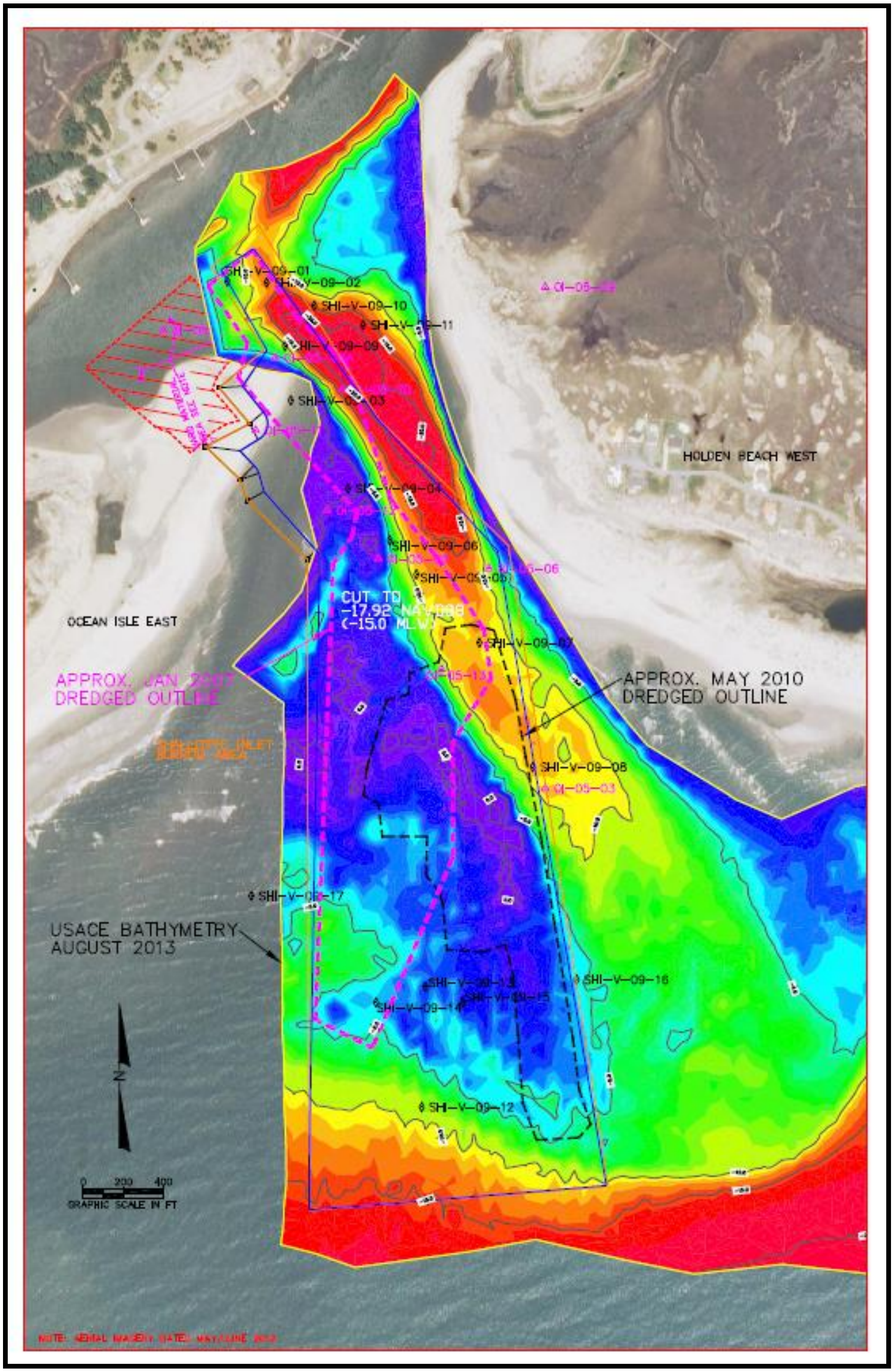

Figure 4.11. Outline of 2007 and 2010 dredged areas in the Shallotte Inlet borrow area superimposed on August 2013 bathymetry.

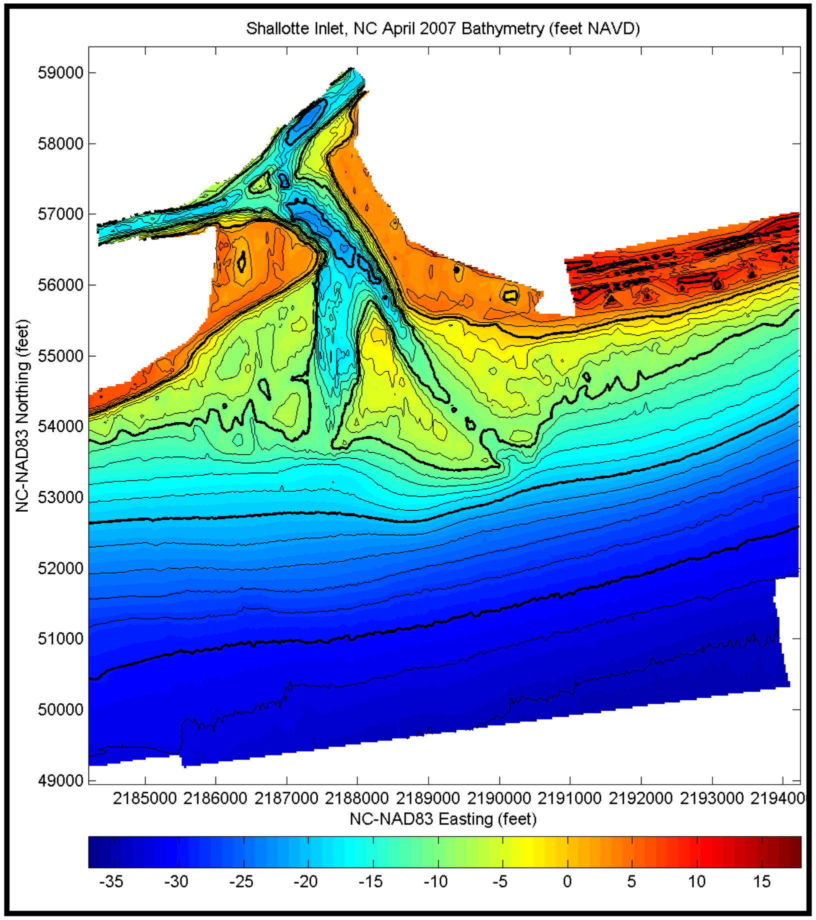

Figure 4.12a. April 2007 post-dredging survey of Shallotte Inlet.

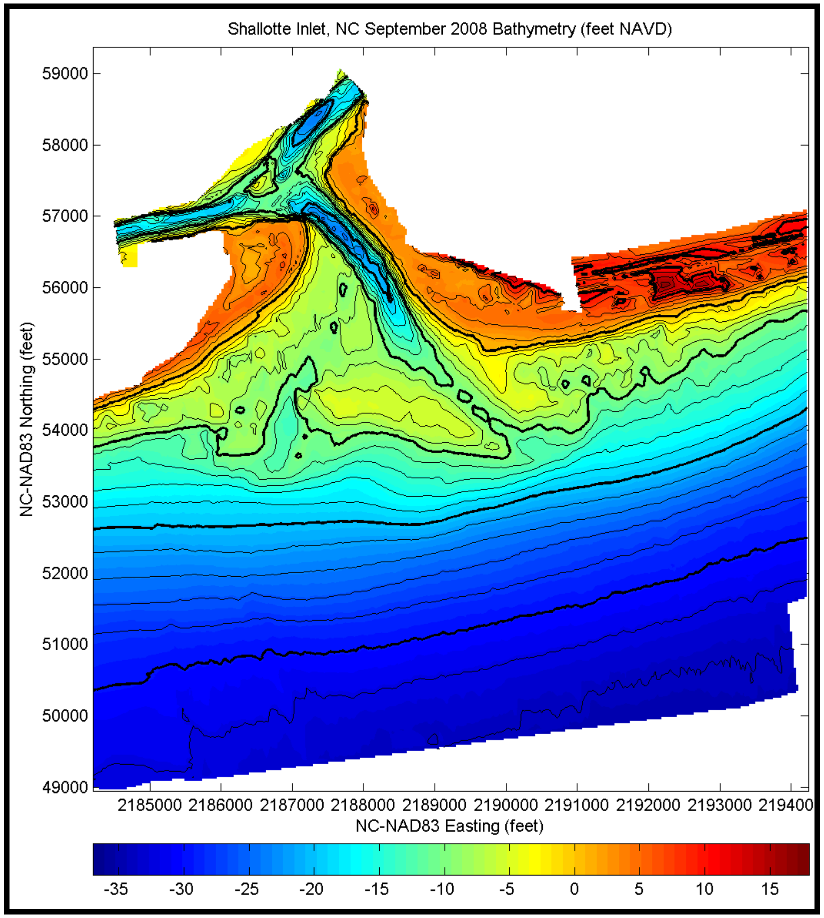

Figure 4.12b. Sept. 2008 condition survey of Shallotte Inlet.

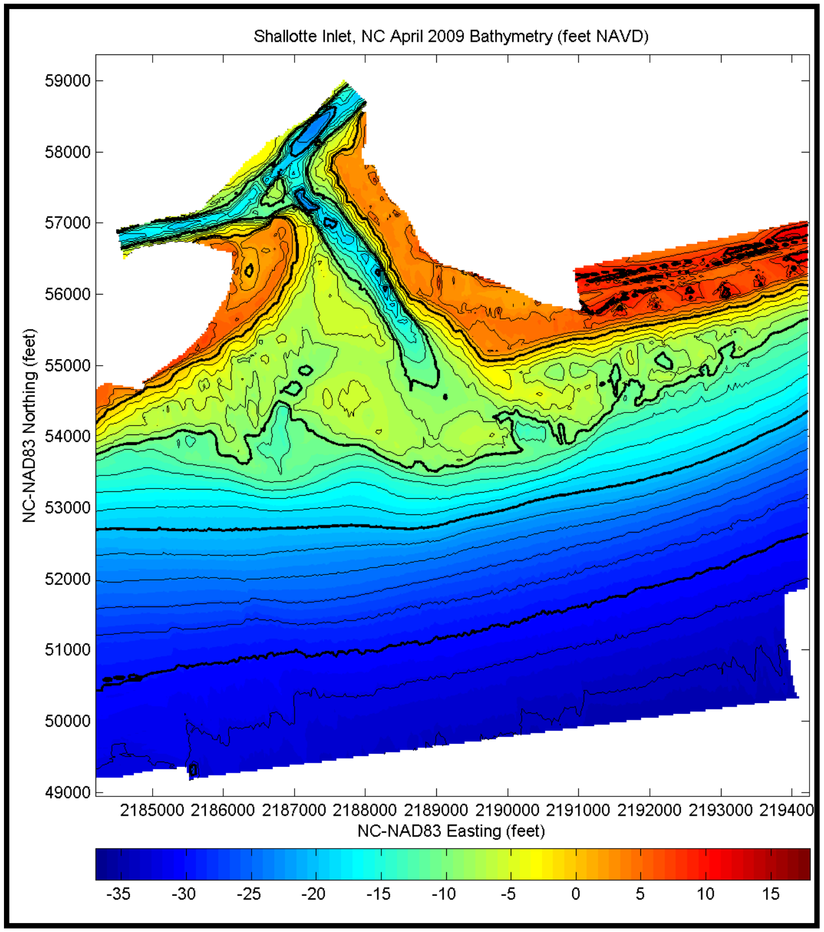

Figure 4.12d. Jul-Aug 2013 Condition Survey of Shallotte Inlet

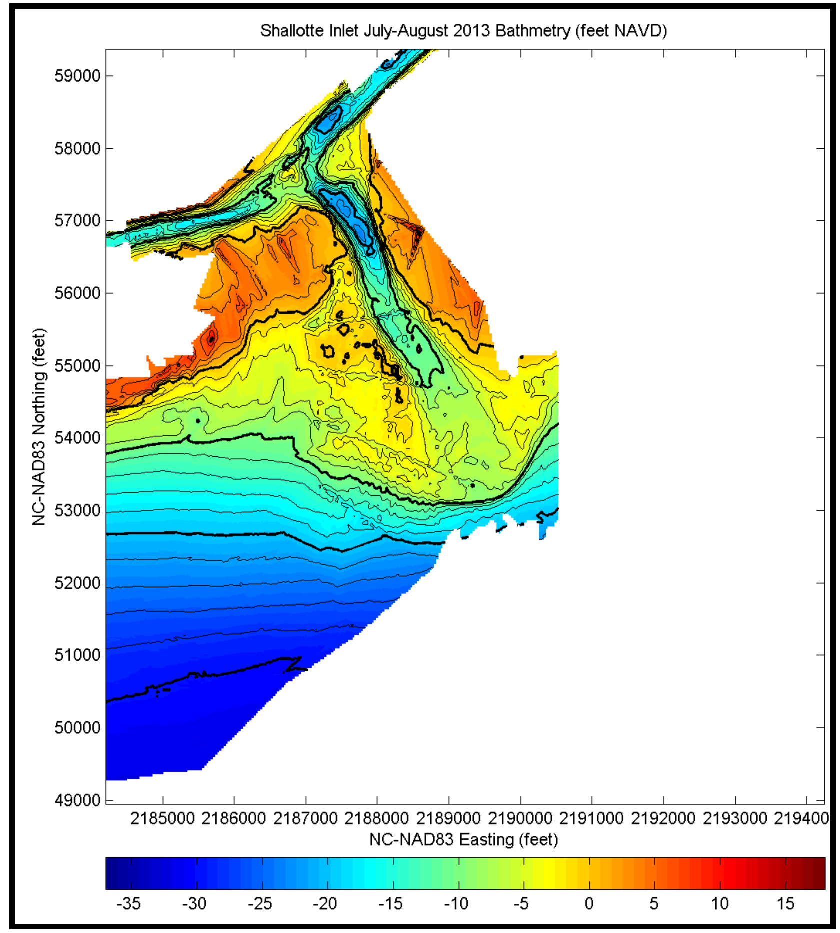

Figure 4.12c. April 2009 Condition Survey of Shallotte Inlet.

By September 2008 (Figure 4.12b) the dredged channel was almost completely closed resulting in flow concentrating through the channel closer to the west end of Holden Beach. By April 2009, only a small portion of the outer end of the dredged channel was evident. The 2010 periodic nourishment operation (Figure 4.11) removed material from an area just west of the natural bar channel which allowed flow to continue to be concentrated in the natural bar channel. The 2010 cut also shoaled rapidly and by September 2013 (Figure 4.12d), the dredged area was completely shoaled and flowed again concentrated in the natural channel off the west end of Holden Beach.

Alternative 4 Borrow Area Modifications. In order to make the borrow area in Shallotte Inlet function as a true channel relocation, material removed during periodic nourishment operations should be derived from an area close to and generally parallel to the west boundary of the USACE borrow area. The dredge cut should also extend across the ocean bar and merge with the existing -17.9 foot NAVD depth contour in the ocean in order to encourage flow to move through the dredged cut rather than through the natural bar channel. By continuing to use the same cut area for each nourishment operation the borrow area should eventually become the dominant flow path for waters exiting through the inlet. Over time, the inlet should respond to the new "permanent" channel position and alignment with a wholesale shift in the ebb tide delta to the west resulting in the accumulation of sediment on the west side of the ebb tide delta. As a result of the reconfiguration of the ebb tide delta, the shoreline on the east end of Ocean Isle Beach should respond in much the same manner as was observed between 1954 and 1965.

Beach Fill Design and Periodic Nourishment Requirements for Alternative 4. The initial beach fill for Alternative 4 would be the same as that described for Alternative 3 which would involve the placement of 387,000 cubic yards between baseline stations -5+00 and 30+00. Note this is the additional volume needed over and above the normal three-year periodic nourishment requirement for the Federal project. Periodic nourishment would also be the same as Alternative 3 until such time the repeated removal of material from the west side of the borrow area captures the majority of flow through the inlet and the inlet ebb tide delta assumes a configuration comparable to that which existed between 1954 and 1965.

The exact amount of time that would be required for the ebb tide delta of Shallotte Inlet to respond to the modified dredging scheme to the point where it begins to modify shoreline erosion rates on the east end of Ocean Isle Beach cannot be defined with any degree of certainty. The bar channel of Bogue Inlet was moved to the west away from the west end of Emerald Isle in March 2005 in an attempt to rebuild the sand spit off the west end of Emerald Isle. The predicted recovery of the sand spit was not complete until about 2011 or about 6 years after the relocation. A similar channel relocation project was completed in New River Inlet in February 2013 for the Town of North Topsail Beach for the purpose of restoring the shoreline on the extreme north end of the island. Significant recovery of the north end of North Topsail Beach was predicted to take at least 5 years with essentially full restoration taking as long as 15 years. With only slightly more than one year having elapsed since the channel was moved, the success of the North Topsail Beach project is still being evaluated although early signs seem to indicate the inlet and shoreline are responding in the expected manner.

The aerial photographic history of the Shallotte Inlet indicates the bar channel migrated toward Holden Beach sometime between 1965 and 1972. Since 1972, the channel has persistently been aligned toward the west end of Holden Beach. Thus the current erosive condition on the east end of Ocean Isle Beach associated with the inlet bar channel has persisted for about 45 to 50 years. While reconfiguration of the inlet and ebb tide delta may not take a comparable amount of time, a conservative estimate of the timeframe for the full recovery of the east end of Ocean Isle Beach in response to the new channel would be about 20 years. During this recovery period, volume losses from the fill placed on the extreme east end of Ocean Isle Beach (stations 0+00 to 30+00) would be comparable to the volume losses estimated for Alternative 3 for at least two periodic nourishment cycles or about 4 years. From year 4 to year 20 following implementation of the new borrow area dredging scheme, the reconfiguration of the ebb tide delta of Shallotte Inlet should begin to have a positive impact on the east end of the island. This would result in a gradual reduction in the periodic nourishment requirements along the east end of the island (stations 0+00 to 30+00) with the nourishment requirement for the area being eliminated by the end of year 20.

Table 4.8 provides the estimated periodic nourishment requirements for both the east end of the fill between baseline station -5+00 and station 30+00 as well as the two year nourishment requirement from stations 30+00 to 120+00. Based on the assumed decrease in nourishment requirements along the east end of Ocean Isle Beach under Alternative 4 (columns 2 and 3 in Table 4.8) and the assumed 408,000 cubic yard maximum for individual nourishment operations, periodic nourishment would take place during the year indicated in column 4 in Table 4.8 with the volume of material to be placed during that operation provided in column 5. Given the assumed reduction in periodic nourishment requirements, the periodic nourishment interval could be increased to 4 years after year 14 and every 5 years after year 18. Note maximum nourishment volume of 408,000 cubic yards was relaxed slightly for year 18.

Table 4.8. Periodic nourishment volumes under Alternative 4.

Project Year	Nourishment Volumes (CY) For:		Nourishment Operations[1]	
	OIB Fed Proj. OI 30 to OI 120	East End OIB – OI -5 to OI 30	Periodic Nourishment Year	Total
2	156,000	280,000	2	436,000
4	156,000	280,000	4	436,000
6	156,000	245,000	6	401,000
8	156,000	210,000	8	366,000
10	156,000	175,000	10	331,000
12	156,000	140,000	12	296,000
14	156,000	105,000	14	261,000
16	156,000	70,000		
18	312,000	35,000	18	417,000
20	156,000	0		
22	156,000	0	23	390,000
24	156,000	0		
26	156,000	0		
28	156,000	0	28	390,000

[1]Nourishment operations generally limited to maximum fill volume of 408,000 cubic yards except for years 2, 4, and 18.

30-Year Project Cost – Alternative 4. Over the 30-year planning period, periodic nourishment of Ocean Isle Beach under Alternative 4 would cost a total of $62.13 million. The Federal government should continue to participate in periodic nourishment of the Federal storm damage reduction project, contributing 65% of the cost for providing beach fill within the authorized Federal limits. Under existing conditions, periodic nourishment of the Federal project is performed every three years with an average of 175,000 cubic yards of material deposited east of station 30+00. For a two-year nourishment cycle, the nourishment volume east of station 30+00 would be 116,000 cubic yards. As shown in Table 4.8, the two-year periodic nourishment requirement east of station 30+00 is assumed to decrease from an initial amount of 280,000 cubic yards down to zero by year 20. During nourishment cycles in which the nourishment requirement east of station 30+00 exceeds 116,000 cubic yards, the Federal government was assumed to pay 65% of the cost for the 116,000 cubic yards and non-Federal interests responsible for 100% of the cost of the nourishment volume in excess of 116,000 cubic yards. Once the nourishment requirement east of 30+00 equals or falls below 116,000 cubic yards every two years, cost sharing for the entire nourishment operation would be 65% Federal – 35% non-Federal. Based on the projected decrease in periodic nourishment over the 30-year planning as presented in Table 4.8, the Federal share over the 30-year planning period would be $30.98 million (49.9%) leaving a balance of $31.14 million for non-Federal interests.

Detailed cost estimates for Alternative 4 are presented in Section 5 of this Appendix.

4.5 Alternative 5 - Terminal Groin w/ Beach Fill

Introduction. During the 2011 legislation session, the North Carolina Legislature passed Session Law 2011-387, Senate Bill 110 which allows consideration of terminal groins adjacent to tidal inlets. The legislation limited the number of terminal groins to four (4) statewide and included a number of provisions and conditions that must be met in order for the groins to be approved and permitted. In 2013, the State Legislature passed the Coastal Policy Reform Act of 2013 (SL2013-384) that modified some of the requirements included in the 2011 legislation. The major changes include:

(a) Elimination of the requirement to show an imminent erosion threat to structures and infrastructure. Now the applicant only needs to demonstrate structures and infrastructure are threatened.
(b) Eliminated the need to demonstrate that nonstructural measures, including relocation of threatened structures, are impractical.
(c) The required inlet management plan "must be reasonable and not impose requirements whose costs outweigh the benefits."
(d) Eliminated the requirement of the applicant to fund restoration of public, private, or public trust property if the groin has an adverse impact on the environment or property.

(e) Provided more flexibility in providing financial assurances for maintenance and/or removal of the terminal groin.

The State legislation notwithstanding, compliance with NEPA still mandates the development of all practical alternatives. Hence, as discussed above, this document includes the impacts of continuing the present shoreline management practices (Alternative 1), the impacts of abandoning structures or retreating to new locations (Alternative 2), protection of the east end development with beach nourishment only (Alternative 3), and relocation of the main bar channel of Shallotte Inlet (Alternative 4).

The purpose of a terminal groin on the east end of Ocean Isle Beach would be to create a permanent accretion fillet west of the structure. This would be accomplished by controlling tide induced or influenced sediment transport off the extreme east end of the island. The resulting position and alignment of the shoreline within the accretion fillet would mimic that of the shoreline immediately to the west. The elimination or reduction in tide induced sediment transport off the extreme east end of the island should improve the performance and longevity of beach fills placed east of Shallotte Boulevard as well as the performance of a portion of the Federal storm damage reduction project that extends west of Shallotte Boulevard. Since wave induced sediment transport (i.e., littoral sand transport) would still be in play, erosion will continue to be a management issue for the shorelines lying outside the direct influence of the terminal groin.

The design objective for the terminal groin alternative was to minimize the combined cost associated with construction and maintenance of the terminal groin and nourishment of the Ocean Isle Beach west to USACE baseline station 120+00. This optimization process involved the evaluation of three terminal groins that would project 250 feet, 500 feet, and 750 feet seaward of the 2007 mean high water shoreline. Schematic representations of the three terminal groin options are shown on Figures 4.14a to 4.14c. All of the terminal groins are positioned approximately 148 feet east of station 0+00.

With regard to describing the terminal groins in terms of their length seaward of the 2007 mean high water shoreline, the Delft3D model, which is discussed in Appendix C, was used to evaluate the relative impacts of the three structures. The Delft3D model was calibrated and verified using conditions that existed in 2007 and these same initial conditions were used for the terminal groin options in order to obtain a direct correlation of the potential difference in the model's response since the only change in the model set-up for the terminal groin options being the terminal groins and associated beach fills. The subsequent discussion of the model results will reference the terminal groin options as the 250-foot, 500-foot, and 750-foot; however, if constructed, the terminal groin option would include a shore anchorage section that would extend approximately 300 feet landward of the 2007 mean high water shoreline. This would place the landward end of the shore anchorage section well landward of historic shoreline positions on the east end of Ocean Isle Beach (Figure 4.13).

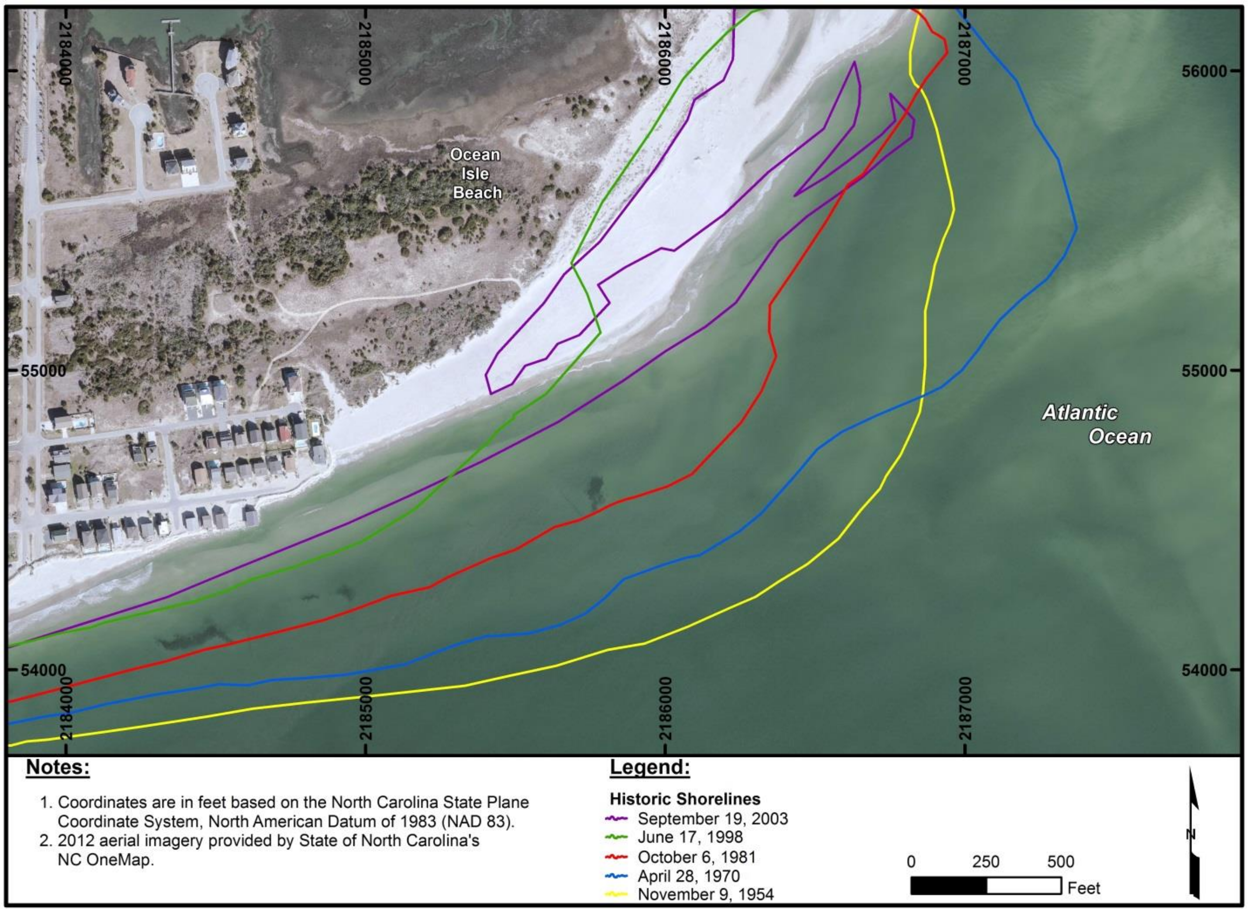

Figure 4.13. Historic shoreline positions on the east end of Ocean Isle Beach.

Each of the terminal groin options includes beach fill to pre-fill the area west of the terminal groins. The length of the beach fill and the volume required for each terminal groin option are given in Table 4.9. The fill volumes in Table 4.9 are just for pre-filling the fillet area.

Construction of the terminal groin and pre-filling the accretion fillet were assumed to be timed to coincide with the normal three-year periodic nourishment cycle of the Federal storm damage reduction project. Based on the arrangements the Town of Ocean Isle Beach was able to negotiate with the dredging contractor back in 2006-2007, the Town should be able to obtain the fillet fill material for just the added dredging costs. That is, there should not be any additional mobilization and demobilization costs for the added volume.

Table 4.9. Fillet beach fills for the three terminal groin options

Terminal Groin Option	Fill Length (ft.)[1]	Fill Volume (cy)[2]
250-ft	1,693	87,000
500-ft	2,194	185,000
750-ft	3,214	264,000

[1]Measured west of terminal groin
[2]Volume needed to pre-fill the accretion fillet

Delft3D Model Evaluation. The three-year erosion and deposition patterns for the three terminal groin options produced by the Delft3D model are provided in Figures 4.15b to 4.15d. For easy reference, Figure 4.15a repeats the erosion deposition patterns for Alternative 1 which was previously shown in Figure 4.3.

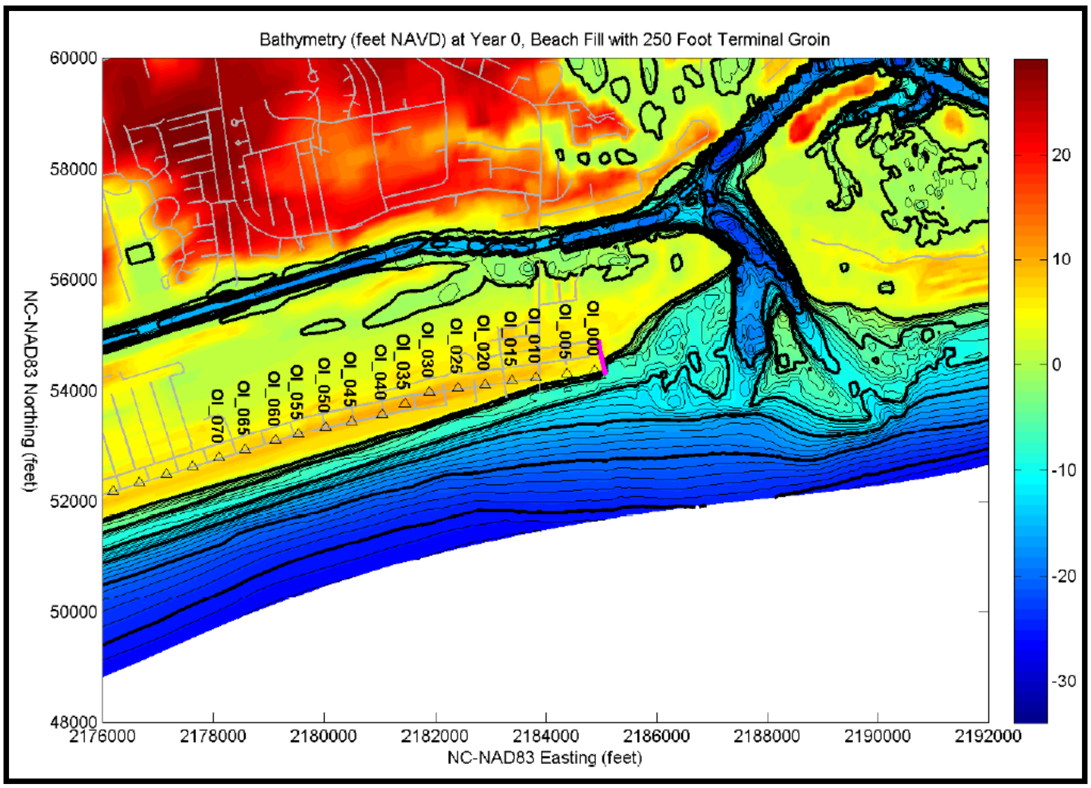

Figure 4.14a. Schematic 250-foot terminal groin.

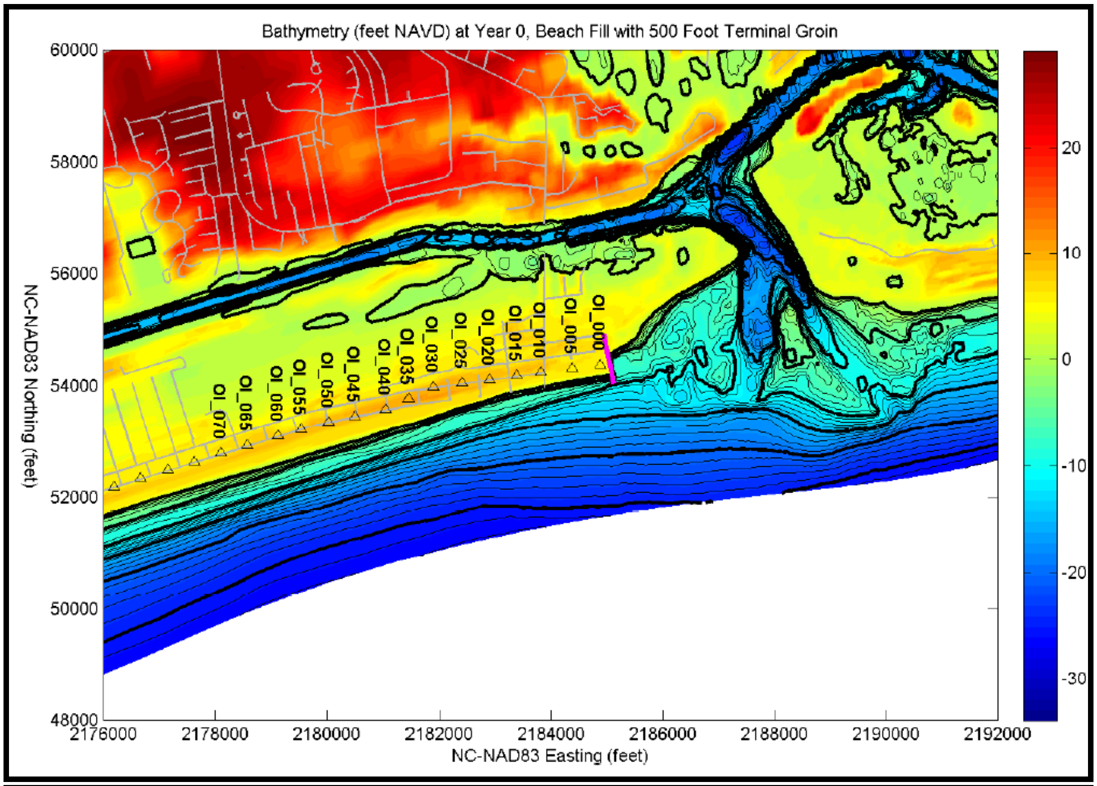

Figure 4.14b. Schematic 500-foot terminal groin.

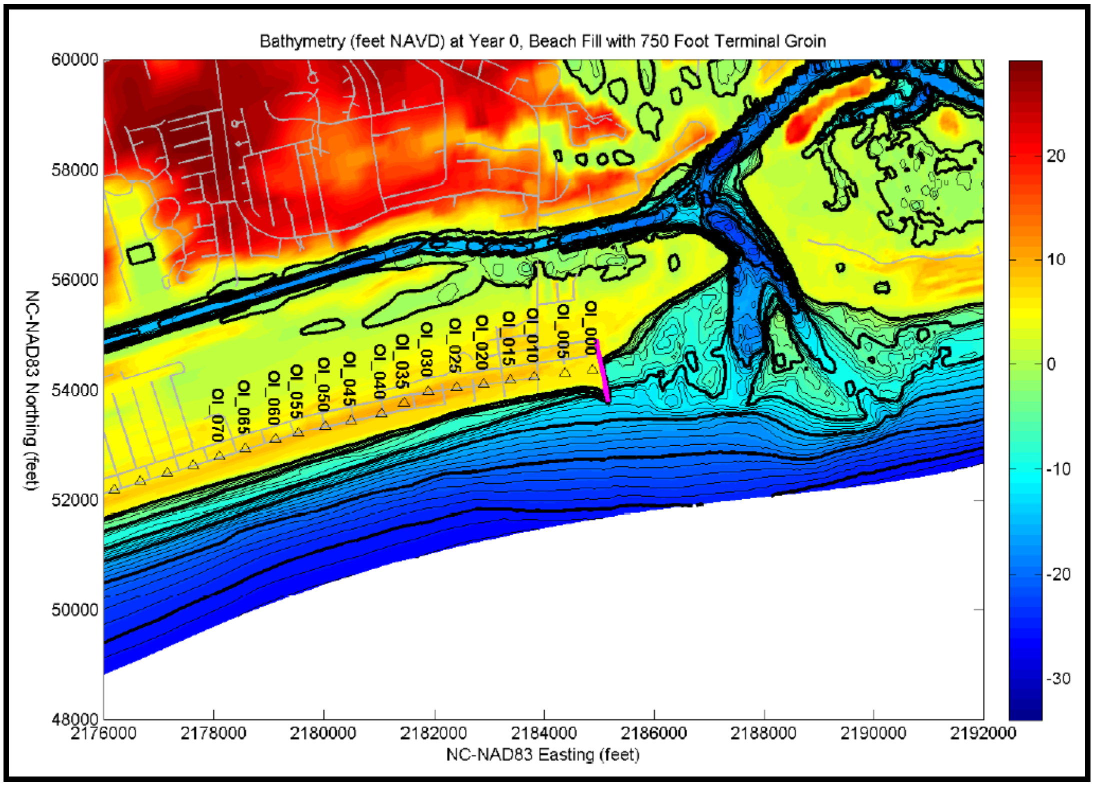

Figure 4.14c. Schematic 750-foot terminal groin.

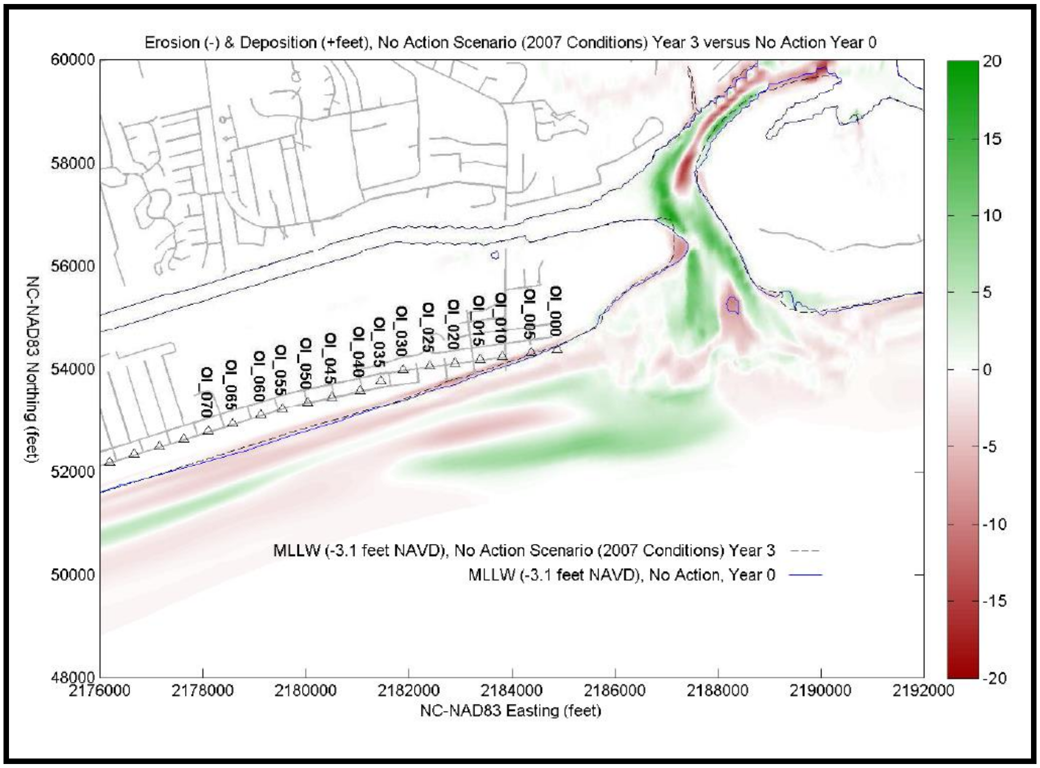

Figure 4.15a. Alternative 1 – Three-year erosion deposition patterns indicated by the Delft3D model.

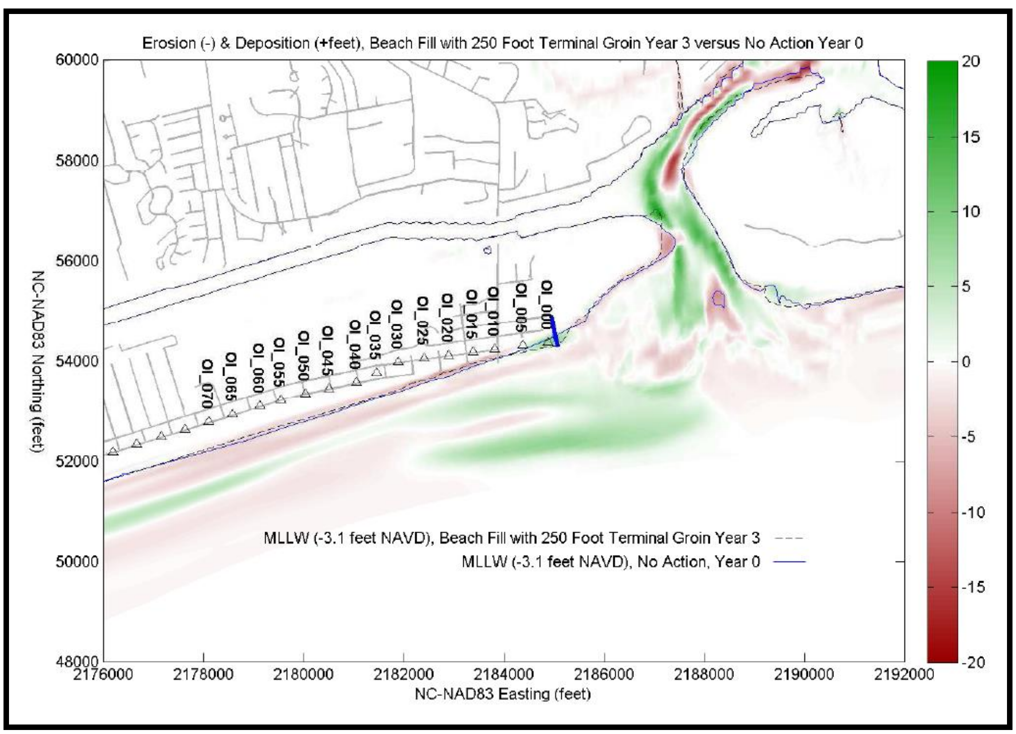

Figure 4.15b. Three-year erosion deposition patterns indicated by the Delft3D model for 250-foot terminal groin.

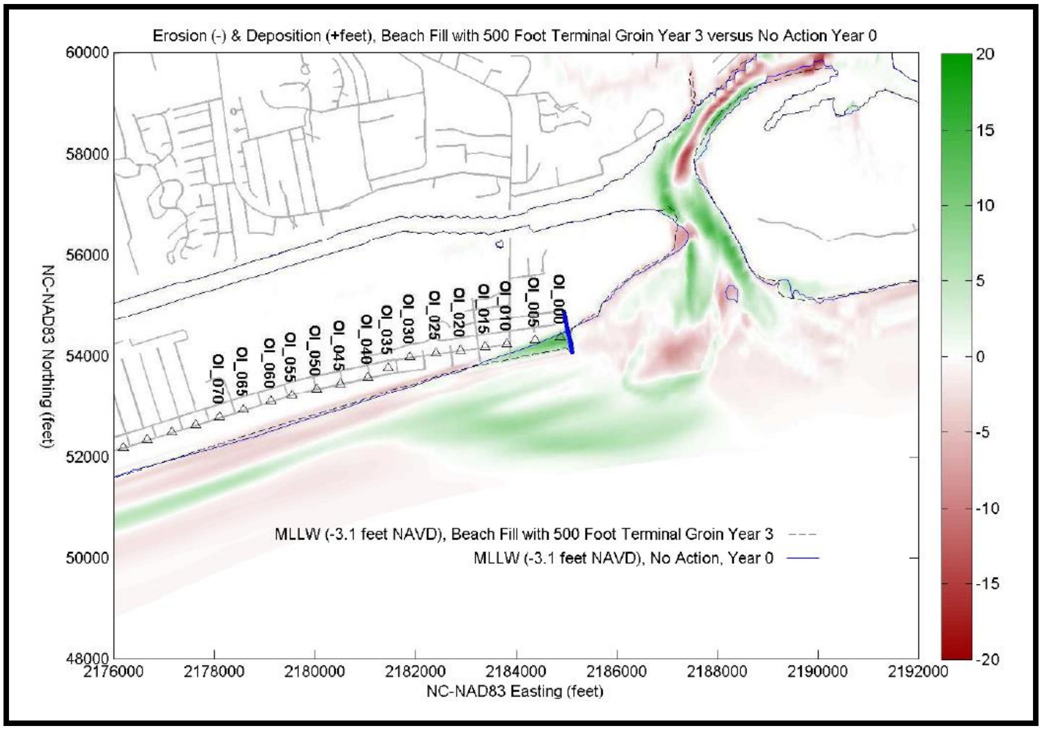

Figure 4.15c. Three-year erosion deposition patterns indicated by the Delft3D model for 500-foot terminal groin.

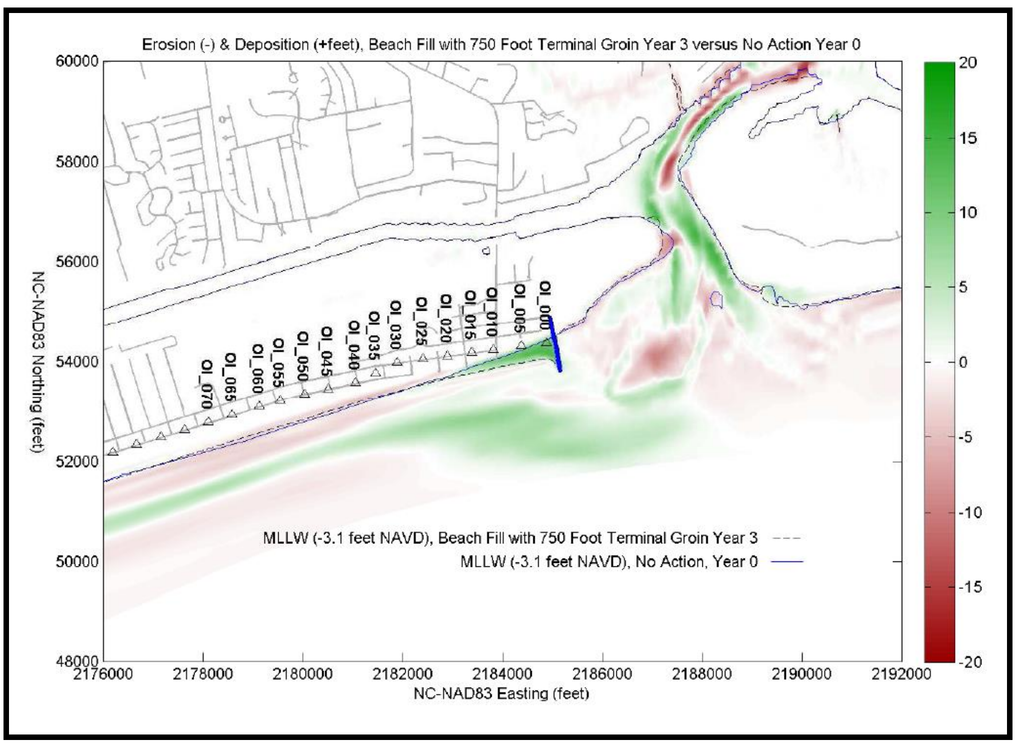

Figure 4.15d. Three-year erosion/deposition patterns indicated by the Delft3D model for 750-foot terminal groin.

The simulation of the three terminal groin options produced similar results in the area off the east end of Ocean Isle Beach as observed under the No Action Alternative (Alternative 1), i.e., all of the model simulations indicated accretion in the offshore area. This accretion appeared to be related to the orientation of the bar channel of Shallotte Inlet rather than impacts associated with the terminal groins. For example, model generated annual volume change rates along Ocean Isle Beach and the west end of Holden Beach for the areas landward of the -18-foot NAVD are provided in Table 4.10. Above the -18-foot depth contour, the model indicated accretion in the beach segment between the terminal groin west to station 30+00 for all three terminal groin options and some reduction in the volume loss rate compared to Alternative 1 between baseline stations 30+00 and 60+00. West of station 60+00, the relatively small difference in the volume changes between Alternative 1 and the three terminal groin options was within the accuracy of the Delft3D model and were deemed not to be significant.

Given the similar offshore response indicated by the model for Alternative 1 and the three terminal groin options, the evaluation of the model indicated volume changes along the east end of Ocean Isle Beach focused on changes that occurred in the nearshore area landward of the -6-foot NAVD contour. As shown in Table 4.10, the terminal groins did have some impact on volume losses above the -6-foot depth contour compared to Alternative 1 west to about station 30+00. However, west of station 30+00, there was virtually no impact of the terminal groins on volume changes.

On the west end of Holden Beach, the apparent impacts of the three terminal groin options indicated relatively minor increases in annual rate of volume change above the -18-foot NAVD depth contour and essentially no measurable difference in the impacts above the -6-foot NAVD depth contour.

Table 4.10. Model volume change rates above the -18-foot NAVD and -6-foot NAVD contours.

Volume Changes above -18-ft NAVD							
Alternative	Ocean Isle Beach						Holden Beach
	Model Rates (cy/yr)						
	Groin to OI 30	OI 30 to OI 60	OI 60 to OI 90	OI 90 to OI 120	Total Groin to IO 120		HB 385 to HB 345
Alternative 1 - No New Action	-53,000	-51,000	-27,000	0	-131,000		-46,000
Alternative 5 - Terminal Groin Options:							
250-ft terminal groin	39,000	-44,000	-25,000	0	-30,000		-51,000
500-ft terminal groin	90,000	-23,000	-21,000	1,000	47,000		-58,000
750-ft terminal groin	133,000	-7,000	-18,000	3,000	111,000		-62,000

Model Volume Changes above -6-ft NAVD							
Alternative	Ocean Isle Beach						Holden Beach
	Model Rates (cy/yr)						
	Groin to OI 30	OI 30 to OI 60	OI 60 to OI 90	OI 90 to OI 120	Total Groin to IO 120		HB 385 to HB 345
Alternative 1 - No New Action	-24,000	-18,000	-14,000	-7,000	-63,000		-11,000
Alternative 5 - Terminal Groin Options:							
250-ft terminal groin	-17,000	-18,000	-14,000	-7,000	-56,000		-11,000
500-ft terminal groin	-6,000	-19,000	-14,000	-7,000	-46,000		-10,000
750-ft terminal groin	-1,000	-19,000	-14,000	-7,000	-41,000		-12,000

Periodic Nourishment Requirements for Terminal Groin Options. A more detailed analysis of the impact of the terminal groins on volume changes above the -6-foot NAVD depth contour is provided in Table 4.11 which shows model generated volume changes between beach profile stations beginning at the terminal groin and extending west to station 30+00 (OI 30) and between profile stations east of the terminal groin (stations -5 to -30). The locations of stations -5 to -30 are shown on Figure 5.1 in Chapter 5. Model volume changes are provided for the No Action Alternative (Alternative 1) and the three terminal groin options. Models indicated volume changes for along the west end of Holden Beach between HB 385+00 and HB 345+00 are also provided in the Table 4.11.

For the 250-foot terminal groin, stabilizing impacts were only evident west to station OI 5 which is 693 feet west of the terminal groin. There was also some reduction in volume loss compared to Alternative 1 west to about station OI 15 but essentially no impact west of that point. For the 500-foot terminal groin, the model indicated a stable beach west to station OI 15 with some significant reduction in volume losses from OI 15 to OI 30 relative to Alternative 1. Similarly, the 750-foot terminal groin would essentially stabilize the shoreline west to station OI 20 and significantly reduce volume losses west to station IO 30. Again, the model indicated volume changes west of station 30+00 for the terminal groin options compared to Alternative 1 were not considered to be significant given the inherent accuracy of the model.

East of the proposed locations of the terminal groin, the model results for all three terminal groin options indicated there could be an increase in the volume loss immediately east of the structure, i.e., between stations -5 and -20, relative to the Alternative 1. However, in all three cases, the model indicated volume loss at the end of the three year simulation was essentially equal to the volume loss observed after year 1 of the simulation. That is, following an initial year of adjustment, the shoreline response east of the proposed structure stabilized. For example, for the 750-foot terminal groin option, the model indicated volume loss after year 1 of the simulation was -53,000 cubic yards but over the next two years of the simulation this segment of the shoreline actually gained 3,100 cubic yards indicating the shoreline response to the groin had equilibrated.

For the area closest to the inlet (stations -20 to -30), the model indicated this section of the shoreline would gain material which is an indication material was moving to the east past the structure in the model simulations.

Along the west end of Holden Beach, the model indicated volume changes above the -6-foot NAVD depth contour were essentially the same as the model indicated volume change for Alternative 1 for all three terminal groin options.

Table 4.11. Delft3D model volume changes landward of the -6-foot NAVD contour on the east end of Ocean Isle Beach and the west end of Holden Beach for Alternative 1 and the three terminal groin options.

Baseline Station ID	Length (ft)	Volume Change for Alternative:			
		1: No Action	250-ft TG	500-ft TG	750-TG
Ocean Isle Beach					
-20 to -30	992	-1,500	31,300	24,700	7,400
-5 to -20	2,384	-11,000	-31,300	-53,300	-49,900
Groin to OI 0	148	-1,600	10,900	21,300	33,300
OI 0 to OI 5	545	-8,500	22,000	56,300	75,900
OI 5 to OI 10	577	-13,000	-1,300	31,600	48,200
OI 10 to OI 15	423	-9,300	-8,200	10,300	22,700
OI 15 to OI 20	501	-13,500	-13,500	-1,300	13,100
OI 20 to OI 25	499	-16,500	-14,700	-8,700	-400
OI 25 to OI 30	521	-10,900	-12,300	-7,700	-3,000
Total (Groin to OI 30)	**3,214**	**-73,300**	**-17,100**	**101,800**	**189,800**
Annual Rate (Groin to OI 30)		**-24,000**	**-6,000**	**+34,000**	**+63,000**
Holden Beach					
HB 385 to HB 345	**4,740**	**-34,000**	**-34,200**	**-31,000**	**-34,500**

Based on the model results for volume losses above the -6-foot NAVD depth contour, the impacts of the terminal groin options on periodic nourishment rates along Ocean Isle Beach would be limited to the area east of station 30+00, i.e., periodic nourishment requirements between stations 30+00 and 120+00 would be the same as under existing conditions. Also, periodic nourishment would not be needed east of the terminal groin.

An average three-year nourishment volume for the Ocean Isle Beach Federal storm damage reduction project, which is based on the average volume for the last three periodic nourishment operations, totals 408,000 cubic yards. The distribution of this three-year periodic nourishment volume between profile stations is given in Table 4.12.

Table 4.12. Average three-year nourishment volume for the Ocean Isle Beach Federal storm damage reduction project – existing conditions.

Beach Segment (baseline stations)	Three-year Nourishment Volume (CY)
10+00 to 30+00	174,000
30+00 to 60+00	177,000
60+00 to 90+00	42,000
90+00 to 120+00	15,000
Total	**408,000**

The model results of volume changes above the -6-foot NAVD depth contour measured between the terminal groins and station 30+00 given in Table 4.10 indicate the volumetric erosion rates and hence the periodic nourishment requirements in this area would be reduced by 29.2% for the 250-foot terminal groin (= (24,000-17,000)/24,000)). Similarly, the nourishment requirements between the terminal groin and station 30+00 would be reduced by 75.0% and 95.8% for the 500-foot and 750-foot terminal groins, respectively. Applying these reduced nourishment requirements for the beach segment between the terminal groin and station 30+00 results in the total three-year nourishment requirement for each terminal groin option given in Table 4.13.

Table 4.13. Estimated three-year nourishment requirement for terminal groin options

Terminal Groin Option	Three-year nourishment requirement between stations:				Total 3-yr nourishment
	Groin to 30+00	30+00 to 60+00	60+00 to 90+00	90+00 to 120+00	
250-foot	123,000	177,000	42,000	15,000	**357,000**
500-foot	45,000	177,000	42,000	15,000	**279,000**
750-foot	6,000	177,000	42,000	15,000	**240,000**

The reduction in periodic nourishment requirements, particularly for the 500-foot and 750-foot terminal groin options, provides an opportunity to increase the time interval between nourishment operations. Since the past nourishment operations have placed an average of 408,000 cubic yards on Ocean Isle Beach, the target volume for nourishment operation for the three terminal groin options was set to be equal to or less than 408,000 cubic yards. For the 250-foot terminal groin, increasing the nourishment interval to 4 years would require a volume of 476,000 cubic yards. Since this exceeds the target volume, the nourishment interval for the 250-foot terminal groin would remain at 3 years. For the 500-foot terminal groin, the nourishment interval could be increased to 4 years which would require 372,000 cubic yards of nourishment per operation, which is less than the target volume of 408,000 cubic yards. Similarly, the nourishment interval for the 750-foot terminal groin could be increased to 5 years which would require 400,000 cubic yards per operation.

The selected nourishment interval and nourishment volume for each terminal groin option is summarized below in Table 4.14:

Table 4.14. Periodic nourishment intervals and volume requirements for the terminal groin options.

Terminal Groin Option	Nourishment Interval (years)	Nourishment Volume per Operation (cubic yards)	Equivalent Annual Nourishment Volume (cubic yards/year)
250-foot	3	357,000	119,000
500-foot	4	372,000	96,000
750-foot	5	400,000	80,000

In the past, the USACE has combined periodic nourishment of the Ocean Isle Beach project into contracts involving Wrightsville Beach, Masonboro Inlet, Carolina Beach and Kure Beach. In this regard, dredging contracts for Wrightsville Beach and Masonboro Inlet are on a four-year dredging cycle while Carolina Beach and Kure Beach are on three-year cycles. The use of the selected periodic nourishment intervals for the 500-foot and 750-foot terminal groin options given above could have some impact on the ability to combine contracts for these projects;

however, the potential cost savings for extending the nourishment interval would offset most if not all of the cost impacts.

The Delft3D model simulations of the three terminal groin options indicated some possible reduction in sediment retention in the Shallotte Inlet borrow area for each of the terminal groin options. In the case of the 250-foot structure, the modeled retention rate in the borrow area was 184,000 cubic yards/year. However, compared to measured sediment retention rates in the borrow area, the model results for Alternative 1 underestimated sediment retention in the borrow area by about 80%. Assuming the model also underestimated sediment retention in the borrow area for the 250-foot terminal groin by a similar amount, the model rate was adjusted by a factor of 1.2 resulting in an estimated retention rate in the borrow area of 219,000 cubic yards/year for the 250-foot structure. Similar adjustments were made to the model retention rates for the 500-foot and 750-foot structures resulting in estimated borrow area retention rates of 160,000 cubic yards/year for the 500-foot structure and 128,000 cubic yards/year for the 750-foot structure.

The periodic nourishment requirements for Ocean Isle Beach for the three terminal groin options, given in Table 4.14, also include an equivalent average annual rate. Based on the adjusted model retention rates in the Shallotte Inlet borrow area, the borrow area would be able to meet the nourishment requirements for all three terminal groin options.

Model Volume Changes in Shallotte Inlet for Terminal Groin Options. Modeled volume changes for the three terminal groin options computed within each of the Shallotte Inlet complex sediment boxes shown in Figure 3.8 are provided in Table 4.15. Model volume changes for Alternative 1 are also shown in Table 4.15 for comparison purposes. The model volume changes given in Table 4.15 were not adjusted in order to provide a direct one-to-one comparison of model indicated changes between the alternatives.

Table 4.15. Delft3D model volume changes in the Shallotte Inlet complex sediment boxes for Alternative 1 and the three terminal groin options.

Shallotte Inlet Sediment Box (see Figure 3.8)	Model Volume Change (cubic yards/year) for:			
	Alternative 1	250-foot terminal groin	500-foot terminal groin	750-foot terminal groin
West Delta	178,000	168,000	130,000	124,000
East Delta	-30,000	-34,000	-41,000	-41,000
Borrow Area	210,000	184,000	134,000	107,000
West Channel	15,000	13,000	10,000	9,000
East Channel	18,000	19,000	20,000	22,000
Total	**391,000**	**350,000**	**253,000**	**221,000**

In addition to the modeled differences in the borrow area sediment retention rates between the three terminal groin options, the model indicated a reduction in sediment retention on the West Delta for each terminal groin option, however there was no significant difference in the volume changes computed for the East Delta. The model also did not indicate any significant differences in volume changes in the East and West Channels inside the inlet.

Structural Design of Terminal Groins. All three of the terminal groin options would include a 300-foot shore anchorage section extending landward from the 2007 mean high water shoreline and a rubblemound section extending seaward of the 2007 mean high water shoreline. The shore anchorage section would be constructed with sheet pile, either steel or concrete. The sheet piles would have a top elevation of +4.9 feet NAVD for a distance of about 130 feet between the landward end of the rubblemound section and the existing dune. The top elevation of the shore anchorage section would be reduced to +4.5 feet NAVD for the remaining 170 feet. The top of the landward most portion of the shore anchorage section would be below the existing ground level.

The rubblemound portion of the terminal groins would be constructed with loosely placed armor stone on top of a foundation mat or mattress and would have a crest elevation of +4.9 feet NAVD. The lose nature of the armor stone was designed to facilitate the movement of littoral material through the structure while the relative low crest elevation of +4.9 feet NAVD would allow some sediment to pass over the structure during periods of high tide. Profiles of the three terminal groins are shown in Figures 4.16 to 4.18. Note the terminal groin profiles are shown relative to the June 2013 beach profile survey at station 0+00; however, the April 2007, the mean high water shoreline (+1.8 feet NAVD), which is used as a point of reference for defining the length of the terminal groins, was located approximately 100 feet seaward of the June 2013 mean high water contour. The head or seaward end of the terminal groins would slope 1H:3V from the structure crest down to the existing ocean floor. A typical cross-section of the rubblemound portion is shown in Figure 4.19.

The 250-foot terminal groin would require a total of 4,500 tons of stone, including both the bedding and armor stone while the 500-foot and 750-foot terminal groins would require 8,500 tons and 14,300 tons, respectively.

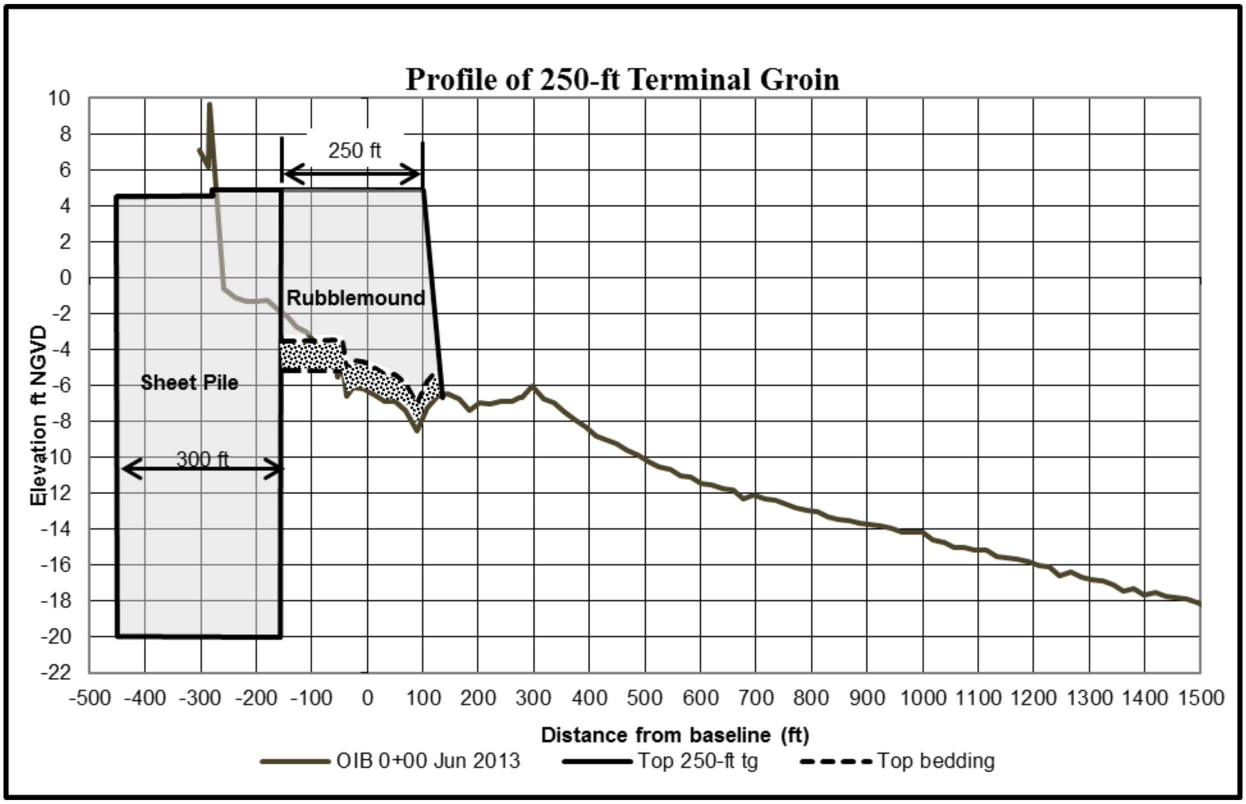

Figure 4.16. Profile of 250-foot terminal groin.

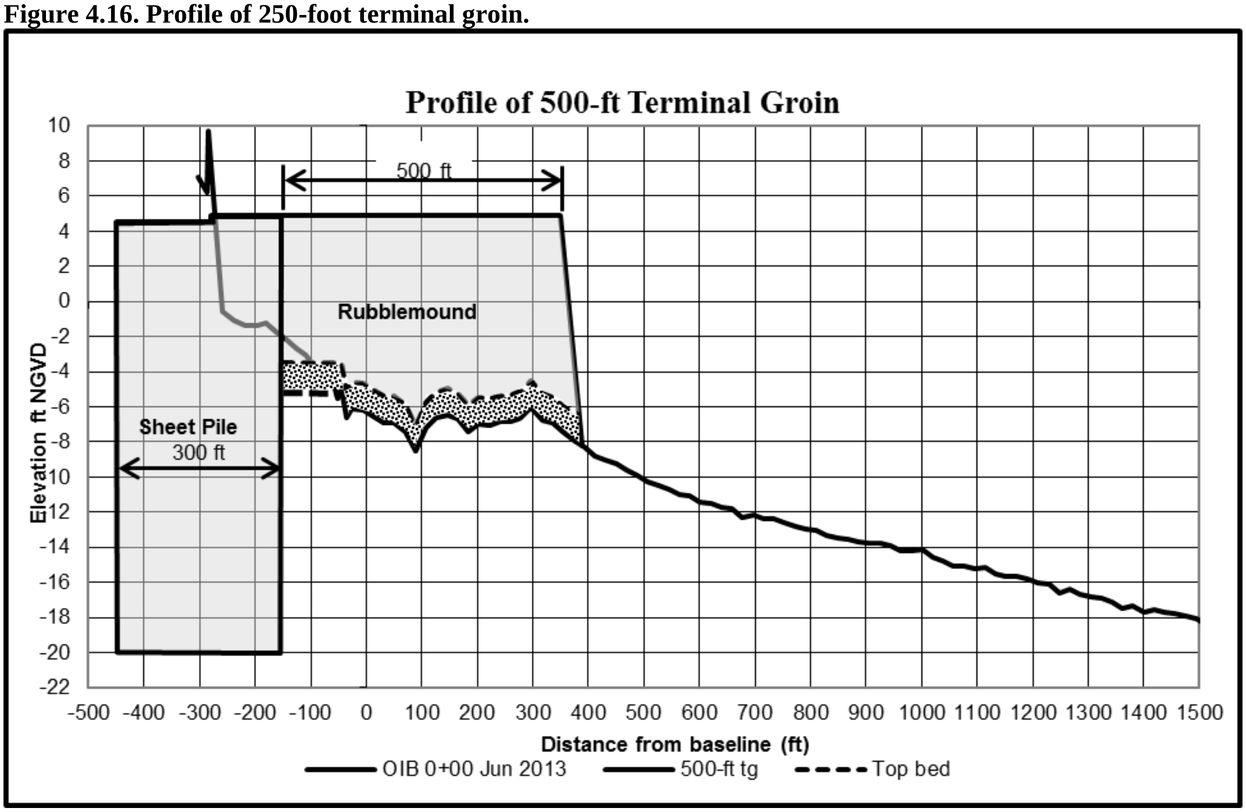

Figure 4.17. Profile of 500-foot terminal groin.

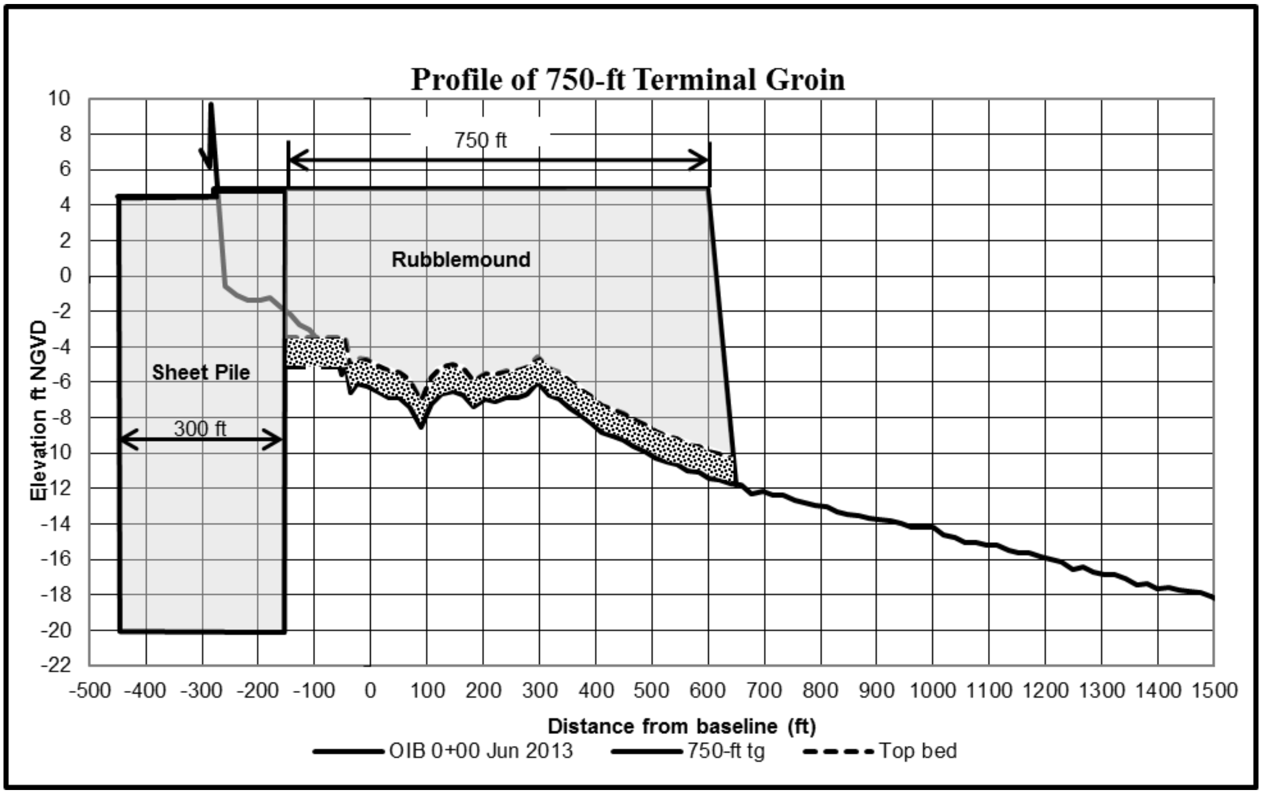

Figure 4.18. Profile of 750-foot terminal groin.

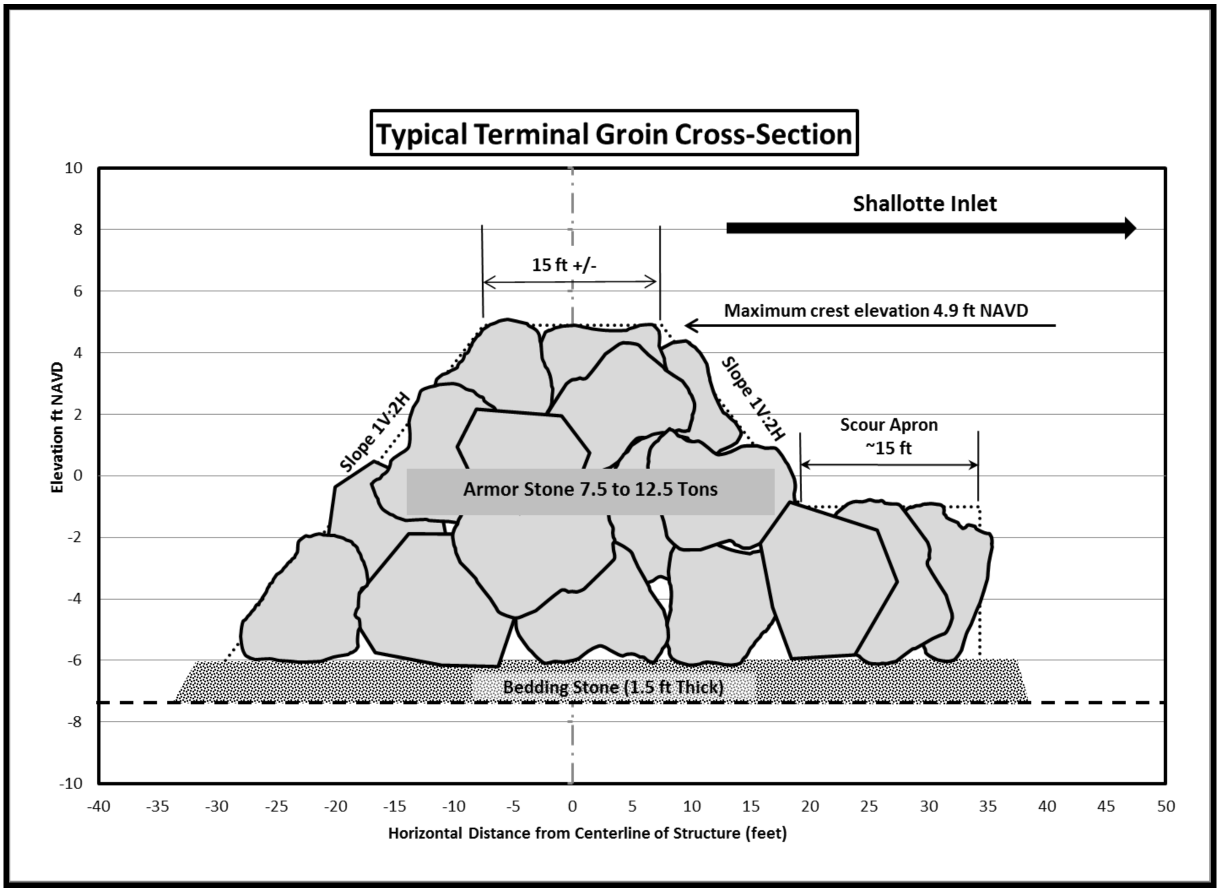

Figure 4.19. Typical rubblemound cross-section for terminal groin.

Cost Estimates for Terminal Groin Alternatives. Preliminary cost estimates for the terminal groin options are provided in Table 4.16. The initial construction cost of the terminal groins included $345,000 for the shore anchorage section for all three terminal groin options and a stone cost of $173/ton. The stone costs were based on updated costs experienced for the repair of the Masonboro Inlet south jetty accomplished by the USACE in 2012. The volume of sand needed to initially fill the accretion fillet area west of each terminal groin option was provided in Table 4.9. Periodic nourishment requirements for the options were given in Table 4.14. Initial construction of the terminal groins and associated beach fills were assumed to occur in conjunction with periodic nourishment of the Federal storm damage reduction project. As a result, the cost to initially fill the accretion fillet area was based on just the dredging cost, that is, no additional mobilization and demobilization would be necessary. Also as noted above, installation of the terminal groins would change the periodic nourishment interval for the Federal project from 3 years under existing conditions to 4 years with the 500-foot structure and 5 years with the 750-foot structure. The nourishment interval for the 250-foot structure would continue to be every three years. The borrow source for both the initial beach fill and periodic nourishment would continue to be the existing borrow area in Shallotte Inlet. The periodic nourishment costs provided in Table 4.16 include mobilization and demobilization cost.

Table 4.16. Cost estimates for terminal groin option

Terminal Groin Option	Feature	Units	Quantity	Costs Including 15% Contingency
250-foot	**Initial Construction**			
	Fillet Beach Fill	CY	87,000	$751,000
	Terminal Groin	linear feet	585	$1,143,000
	Engr & Design	job	Lump Sum	$200,000
	Construction Oversight	job	Lump Sum	$234,000
	Total Initial Construction			$2,328,000
	Periodic Nourishment Every Three Years			
	Nourishment	CY	357,000	$6,205,000
	Terminal Groin Maintenance (Average Annual)			
	Maintenance Cost	NA	NA	$7,000
500-foot	**Initial Construction**			
	Fillet Beach Fill	CY	185,000	$1,596,000
	Terminal Groin	linear feet	839	$1,834,000
	Engr & Design	job	Lump Sum	$200,000
	Construction Oversight	job	Lump Sum	$336,000
	Total Initial Construction			$3,966,000
	Periodic Nourishment Every Four Years			
	Nourishment	CY	372,000	$6,334,000
	Terminal Groin Maintenance (Average Annual)			
	Maintenance Cost	NA	NA	$13,000
750-foot	**Initial Construction**			
	Fillet Beach Fill	CY	264,000	$2,277,000
	Terminal Groin	linear feet	1100	$2,783,000
	Engr & Design	job	Lump Sum	$200,000
	Construction Oversight	job	Lump Sum	$440,000
	Total Initial Construction			$5,700,000
	Periodic Nourishment Every Five Years			
	Nourishment	CY	400,000	$6,575,000
	Terminal Groin Maintenance (Average Annual)			
	Maintenance Cost	NA	NA	$21,000

Thirty-Year Project Cost. The total cost (in present-day dollars) for periodic nourishment under Alternatives 1 and 2 and the total 30-year cost associated with the three terminal groin options are provided in Table 4.17. Note that the cost for nourishing the Federal storm damage reduction project in year 0 of the analysis is not included in any of the 30-year cost projects since all alternatives would include nourishment of the Federal project in year 0. The purpose of the 30-year cost projections is to show the difference in 30-year periodic nourishment cost between Alternatives 1 and 2 and the three terminal groin options.

Table 4.17. Thirty-year beach nourishment cost for Alternatives 1 and 2 and total cost for the three terminal groin options.

Alternative	Total 30-Year Cost
Alternatives 1 and 2	$66,440,000
250-foot terminal groin	$68,465,000
500-foot terminal groin	$51,062,000
750-foot terminal groin	$46,655,000

Equivalent Annual Cost. The equivalent annual cost for the terminal groin options were computed using compound interest methods with an interest rate of 4.125% and a 30-year amortization period. While maintenance of the terminal groin would not be required every year, given the uncertainty as to when repairs may be needed, terminal groin repairs were assumed to occur every year. The equivalent annual costs of the three terminal groin options are given in Table 4.18.

For comparative purposes, the equivalent annual cost for periodic nourishment of the Federal storm damage reduction project, which would continue under Alternatives 1 and 2, is also included in Table 4.18. The equivalent annual cost for the nourishment of the Federal project was based on providing 408,000 cubic yards to Ocean Isle Beach every three years.

Table 4.18. Equivalent annual cost of terminal groin options and beach nourishment under Alternatives 1 and 2.

Alternative	Equivalent Annual Cost
Alternatives 1 and 2	$2,126,000
250-foot terminal groin	$2,129,000
500-foot terminal groin	$1,682,000
750-foot terminal groin	$1,567000

Cost Sharing. All initial costs to pre-fill the accretion fillet and construct the terminal groin as well as any future maintenance of the terminal groin would be a non-Federal responsibility. Following construction of the terminal groin, all future beach nourishment would occur within the limits of the Federal storm damage reduction project and would be eligible for cost-sharing with the Federal government in the same 65%/35% Federal/non-Federal ratio as under the existing Project Cost Sharing Agreement. The resulting Federal and non-Federal cost responsibilities for the total 30-year project costs for the terminal groin options and Alternatives 1 and 2 are given in Table 4.19.

Table 4.19. Cost-Sharing responsibilities for 30-year project cost of the terminal groin options and the existing Federal storm damage reduction project.

30-Year Cost			
Alternative	Total 30-Year Cost	Federal Share	Non-Federal Share
Alternative 1 and 2	$66,440,000	$43,190,000	$23,250,000
250-foot terminal groin	$68,465,000	$41,484,000	$26,981,000
500-foot terminal groin	$51,062,000	$28,354,000	$22,708,000
750-foot terminal groin	$46,655,000	$23,432,000	$23,223,000

Selection of Terminal Groin Option. The 250-foot terminal groin would only have a minor impact on volume losses off the east end of Ocean Isle Beach and would only stabilize the shoreline for about 700 feet west of the structure and slightly reduce volume losses over another 1,000 feet. Also, the total 30-year cost for the 250-foot option would be slightly more than Alternative 1 and the non-Federal 30-year cost would be significantly greater than that for Alternative 1 (Table 4.19). This is due to the inability of the 250-foot structure to reduce periodic nourishment requirements that would offset the cost for constructing and maintaining the structure. Therefore, the 250-foot terminal groin in not considered to be a viable option.

With regard to the 500-foot structure, it would provide positive shoreline impacts in terms of shoreline stability and reduced nourishment requirements west to about station 20+00. The 750-foot structures positive shoreline impacts would extend west to station 30+00 and would almost eliminate all nourishment requirements east of station 30+00.

Construction of the 750-foot terminal groin and its associated beach fill needed to pre-fill the accretion fillet west of the terminal groin would cost about $1.7 million more than the 500-foot terminal groin option (Table 4.16), however, over the 30-year analysis period, the total cost for the 750-foot option would be about $4.4 million less than the 500-foot structure. While non-Federal cost over the 30-year analysis period would be slightly less for the 500-foot structure, the added shoreline stability provided by the 750-foot structure combined with the possibility of future reductions in Federal funding for the Ocean Isle Beach storm damage reduction project prompted the Town of Ocean Isle Beach to select the 750-foot terminal groin as its preferred option.

5.0 COST ESTIMATES

The costs for the five (5) alternatives evaluated for addressing the erosion problem on the east end of Ocean Isle Beach are provided below. The primary purpose of the cost estimates was to determine the incremental cost difference between continued periodic nourishment of the Federal project under existing conditions versus what these costs would be under the various management alternatives.

A summary of the average annual equivalent cost for all the alternatives is provided in Table 5.4. The average annual equivalent costs were computed using a discount rate of 4.125% and an amortization period of 30 years. Table 5.5 summarizes the total 30-year project costs for each alternative along with an estimate of the Federal and non-Federal share of the 30-year project costs. The economic costs for Alternatives 1 and 2 given in Table 5.4 include the cost of erosion response measures such as demolition and/or relocation of threatened homes, damage to infrastructure, and the value of land that would be lost over the 30-year planning period.

Alternatives 1 and 2. The cost of the operation for providing periodic nourishment of the Federal storm damage reduction project every 3 years under Alternatives 1 and 2 is provided in Table 5.1. While there are differences in erosion response measures on the east end of the island for Alternatives 1 and 2, none of the response measures would have an impact on periodic nourishment of the Federal project.

Table 5.1. Three-year periodic nourishment costs under Alternatives 1 and 2.

Item	Units	Quantity	Unit Cost	Cost
Mobilization & Demobilization	Job	1	Lump Sum	$2,500,000
Dredging	CY	408,000	$7.50	$3,060,000
Sub Total				$5,560,000
Contingencies (15%)				$834,000
Total Construction				$6,394,000
E & D				$100,000
S & I				$150,000
Total Nourishment Cost				$6,644,000

Alternative 3. Alternative 3 would include the initial construction of a beach fill on the extreme east end of Ocean Isle Beach followed by periodic beach nourishment to maintain the fill. The initial fill volume included in the cost estimate is only that volume needed for the east end fill and does not include the fill that would be placed at the same time to nourish the Federal storm damage reduction project. Both fills are assumed to occur under the same contract which would not require an incremental increase in the cost for mobilization and demobilization. During periodic nourishment, material would be placed on both Ocean Isle Beach and on the west end of Holden Beach. Placement of material on Holden Beach, which would be needed to mitigate for project induced impacts, would entail an additional $500,000 in mobilization and demobilization costs to run a discharge pipeline to the west end of Holden Beach.

Due to the large volume of material that would be needed to maintain the beach fill on Ocean Isle Beach and mitigate for project related impacts on the west end of Holden Beach, an alternative source of beach nourishment material would have to be located to supplement the limited supply of sand that could be obtained from the Shallotte Inlet borrow area. The probable location of the alternative source has not been identified, however, a cost of $500,000 is included to cover geotechnical investigations and permitting that would likely be needed to identify a supplemental source.

The estimated initial cost and the cost of periodic nourishment, which would be needed every three years, are given in Table 5.2.

Table 5.2. Initial construction and periodic nourishment cost for Alternative 3 – Beach Fill Only

Item	Units	Quantity	Unit Cost	Cost
Initial Construction of Fill on East End Ocean Isle Beach				
Mobilization & Demobilization	Job	1	Lump Sum	$0
Dredging	CY	387,000	$7.50	$2,903,000
Sub Total				$2,903,000
Contingencies (15%)				$435,000
Total Construction				$3,338,000
E & D				$100,000
S & I				$150,000
Total Initial Cost Beach Fill				$3,588,000
Cost of Periodic Nourishment every Two Years				
Mobilization & Demobilization[1]	Job	1	Lump Sum	$3,000,000
Dredging		436,000	$7.50	$3,270,000
Sub Total				$6,270,000
Contingencies (15%)				$2,165,000
Total Construction				$941,000
E & D				$100,000
S & I				$150,000
Total Periodic Nourishment (every 2-yrs)				$7,461,000

[1]Mobilization and demobilization cost for Ocean Isle Beach.

Alternative 4. The cost associated with Alternative 4, the channel relocation alternative, was computed in a manner similar to that for Alternative 3. Since the nourishment requirements vary over the 30 year planning period due to assumed reductions in periodic nourishment requirements associated with anticipated changes in the configuration of the ebb tide delta of Shallotte Inlet, only the total costs for each periodic nourishment operation is provided in Table 5.3. In all instances, the unit dredging cost was $7.50/cubic yard and contingencies were maintained at 15%.

Table 5.3. Periodic nourishment cost for Alternative 4 – Channel Relocation.

Project Year	Total Nourishment Volume (cy)	Nourishment Cost
2	436,000	$7,461,000
4	436,000	$7,461,000
6	401,000	$6,584,000
8	366,000	$6,282,000
10	331,000	$5,980,000
12	296,000	$5,678,000
14	261,000	$5,377,000
18	417,000	$6,722,000
23	390,000	$6,489,000
28	390,000	$6,489,000

Alternative 5 – 750-foot Terminal Groin with Beach Fill. The estimated construction cost and periodic nourishment cost for the 750-foot terminal groin option was presented in Table 4.16. The total initial cost of this option would be about $5.7 million. Periodic nourishment of Ocean Isle, including the Federal storm damage reduction project, would only be required every 5 years with an estimated 400,000 cubic yards being distributed from baseline station 30+00 (OI 30) west to baseline station 120+00 (OI 120). Periodic nourishment needs west of station 120+00 would be determine based on beach profile monitoring surveys, but based on past performance of the Federal project west of 120+00, periodic nourishment should be an infrequent occurrence.

Each 5-year periodic nourishment operation would cost approximately $6,575,000 while maintenance of the terminal groin would average $21,000 per year. Note that maintenance of the terminal groin would not be needed every year but since the specific time when maintenance would be needed cannot be determined in advance, the cost of terminal groin maintenance is presented as an annual cost.

Cost Summary. The equivalent average annual cost for all of the alternatives, computed using a discount rate of 4.125% and an amortization period of 30 years is provided in Table 5.4. The costs of each alternative over the 30-year planning period are given in Table 5.5.

Table 5.4 Summary of average annual economic impact of alternatives.

Alternative	Long-Term Erosion Damages & Response Cost	Construction & Periodic Nourishment Cost	Total Economic Cost
1- No New Action	$1,048,000	$2,126,000	$3,174,000
2 – Abandon/Retreat	$958,000	$2,126,000	$3,084,000
3 – Beach Nourishment	$0	$3,866,000	$3,866,000
4 – Channel Relocation	$0	$2,500,000	$2,500,000
5 – 750-ft terminal groin	$0	$1,567,000	$1,567,000

Table 5.5 Summary of 30-year implementation costs of alternatives

Alternative	Total 30-Year Beach Nourishment/Implementation Cost	Federal Share	Non-Federal Share
1- No New Action		$43,190,000	$23,250,000
2 – Abandon/Retreat	$66,440,000(1)	$43,190,000	$23,250,000
3 – Beach Nourishment	$115,503,000	$43,190,000	$72,313,000
4 – Channel Relocation	$62,126,000	$30,982,000	$31,144,000
5 – 750-ft terminal groin	$46,655,000	$23,432,000	$23,223,000

(1)Nourishment of Federal storm damage reduction project only, does not include demolition, relocation, or sandbags.

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Appendix C- Delft3D Numerical Modeling Study

TOWN OF OCEAN ISLE BEACH

DELFT3D NUMERICAL MODELING STUDY

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TOWN OF OCEAN ISLE BEACH

DELFT3D NUMERICAL MODELING STUDY

1.0 INTRODUCTION

The Town of Ocean Isle Beach (TOWN) is evaluating the feasibility of constructing a terminal groin on the east end of the town's shoreline near Shallotte Inlet to mitigate the chronic erosion problem caused by Shallotte Inlet's influence on the movement of littoral sediment in the area (see Figure 1). Part of the town's shoreline is a Federal beach nourishment project, which received fill in 2001, 2006, and 2010. As detailed in the *Assessment of Terminal Groin Feasibility* study (CPE, 2012), much of the Town's beach erosion occurs between Concord Street (Station 120+00) and Shallotte Inlet.

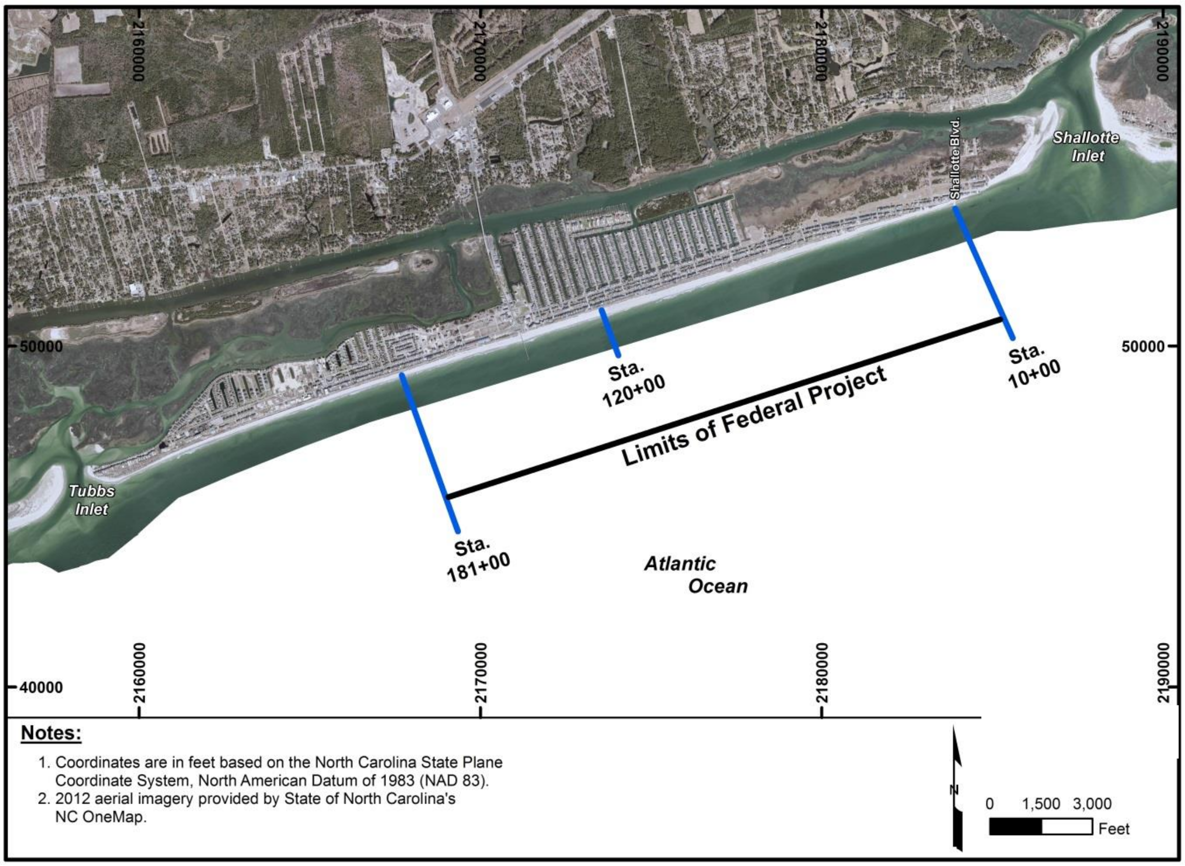

Figure 1: Map of Ocean Isle Beach Showing the Limits of the Federal Project.

In addition to the federal shore protection project, the USACE has periodically deposited material on the east end of Ocean Isle Beach from maintenance of the Atlantic Intracoastal Waterway (AIWW) at the intersection of the AIWW with Shallotte Inlet. Although no definitive total volume has been provided by the USACE at the time of publishing, an estimated 300,000 to 400,000 cubic yards of navigation maintenance material has been placed on the extreme east end of Ocean Isle Beach since 2001. All of this material has been deposited generally within the area fronting the development east of Shallotte Boulevard (i.e., outside the limits of the federal project). The material removed from the AIWW erodes quickly and has been generally ineffective in slowing the rate of erosion in the area east of Shallotte Boulevard (Station 10+00). Even with the rather substantial beach nourishment effort by the USACE and the TOWN, erosion along the east end of Ocean Isle Beach has continued to affect existing structures and infrastructure.

To reduce the erosion along the eastern end of Ocean Isle Beach, the *Assessment of Terminal Groin Feasibility* study (CPE, 2012) proposed two terminal groin options. The objective of the Engineering Report (Appendix B) and this numerical study is to refine the terminal groin's design and develop a recommended plan which includes groin construction and strategic placement of beach fill.

2.0 METHODOLOGY

The primary modeling tool in this investigation is the Delft3D morphological modeling package (Deltares, 2011). This packages consists of two models, which are coupled together to determine changes in a topographic and bathymetric surface based on the effects of waves, water levels, winds, and currents. Wave propagation from the offshore to the nearshore area is estimated using the Simulating Waves Nearshore Model (SWAN 40.72ABCDE, Delft University of Technology, 2008). Delft3D-FLOW utilizes the output waves from SWAN, along with the varying water levels offshore and the bathymetry, to determine the resulting currents, water levels, sediment transport, erosion, and deposition. Based on the estimated erosion and deposition at each time step, the Delft3D-FLOW model calculates the subsequent elevations of the topographic and bathymetric surface and sends the updated bathymetry back to the SWAN model. Typical time steps in Delft3D-FLOW range from 1 second to 60 seconds, while wave propagation estimates in the SWAN model are performed every 1 to 3 hours. Given the interaction between the tidal currents and waves near Ocean Isle Beach and Shallotte Inlet, Delft3D is the best means of evaluating the performance and impact of terminal groin and beach fill alternatives along the town's beach.

3.0 GRIDS

3.1 Modeling Grids

To evaluate wave propagation, flow, sediment transport, erosion, and deposition along the study area, 4 grids were created (see Figure 2, Figure 3, and Table 1). The Regional Wave Grid was used to examine wave propagation between the offshore areas and the intermediate depth zones (-65 feet NAVD) between Cape Fear and the North Carolina / South Carolina state line (see Figure 2). The offshore boundary of the Regional Wave Grid roughly follows the depth contours near wave gages 41013 (-91 feet NAVD) and FPSN7 (-45 feet NAVD). The Intermediate Wave Grid was used to examine wave propagation between the intermediate depth zones and the depth of closure (-27 feet NAVD, USACE, 1997) (see Figure 2). The Local Wave Grid was used to examine wave propagation in Shallotte Inlet and the nearshore zones along Ocean Isle Beach and Holden Beach (see Figure 2 and Figure 3).

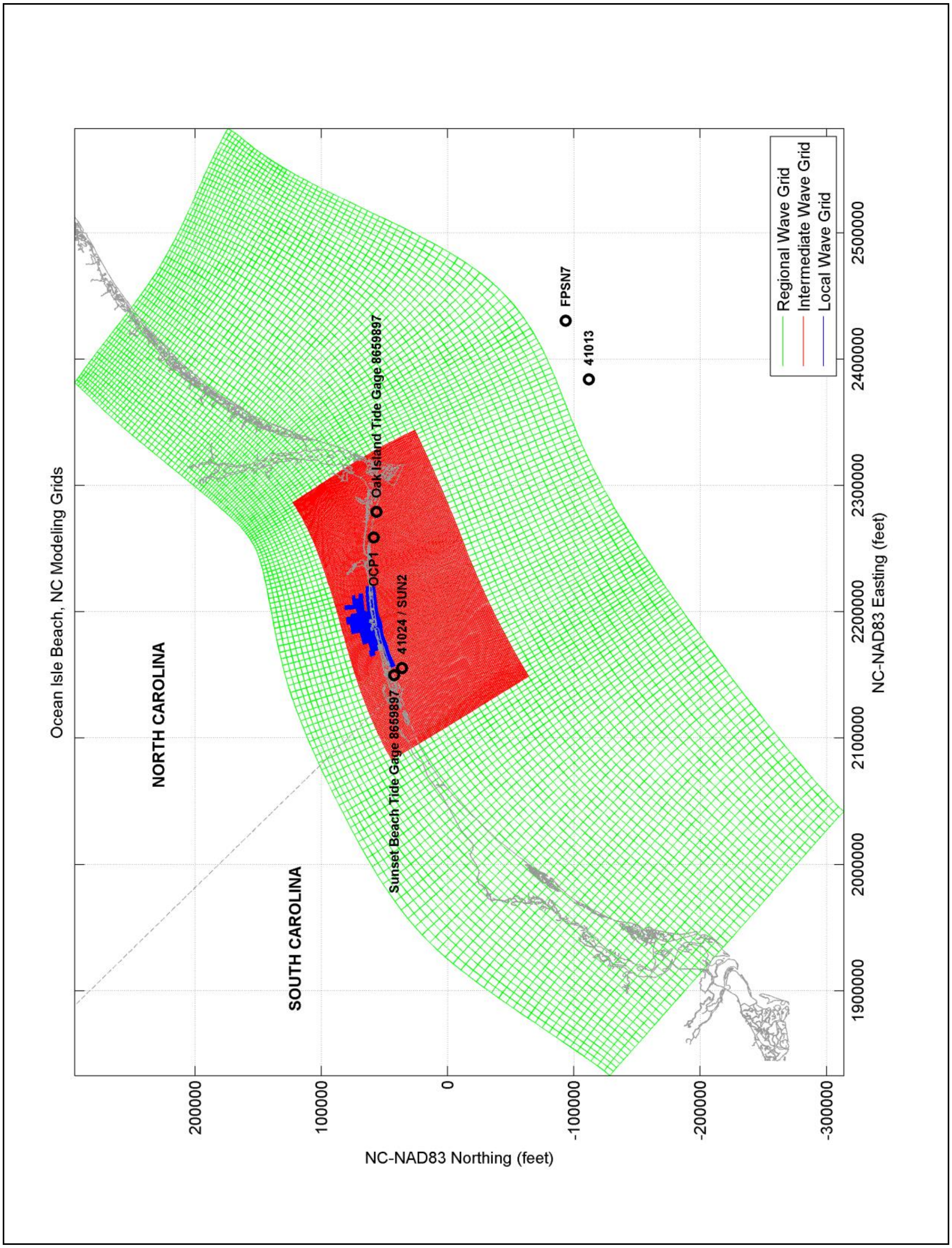

Figure 2: Ocean Isle Beach Wave Modeling Grids.

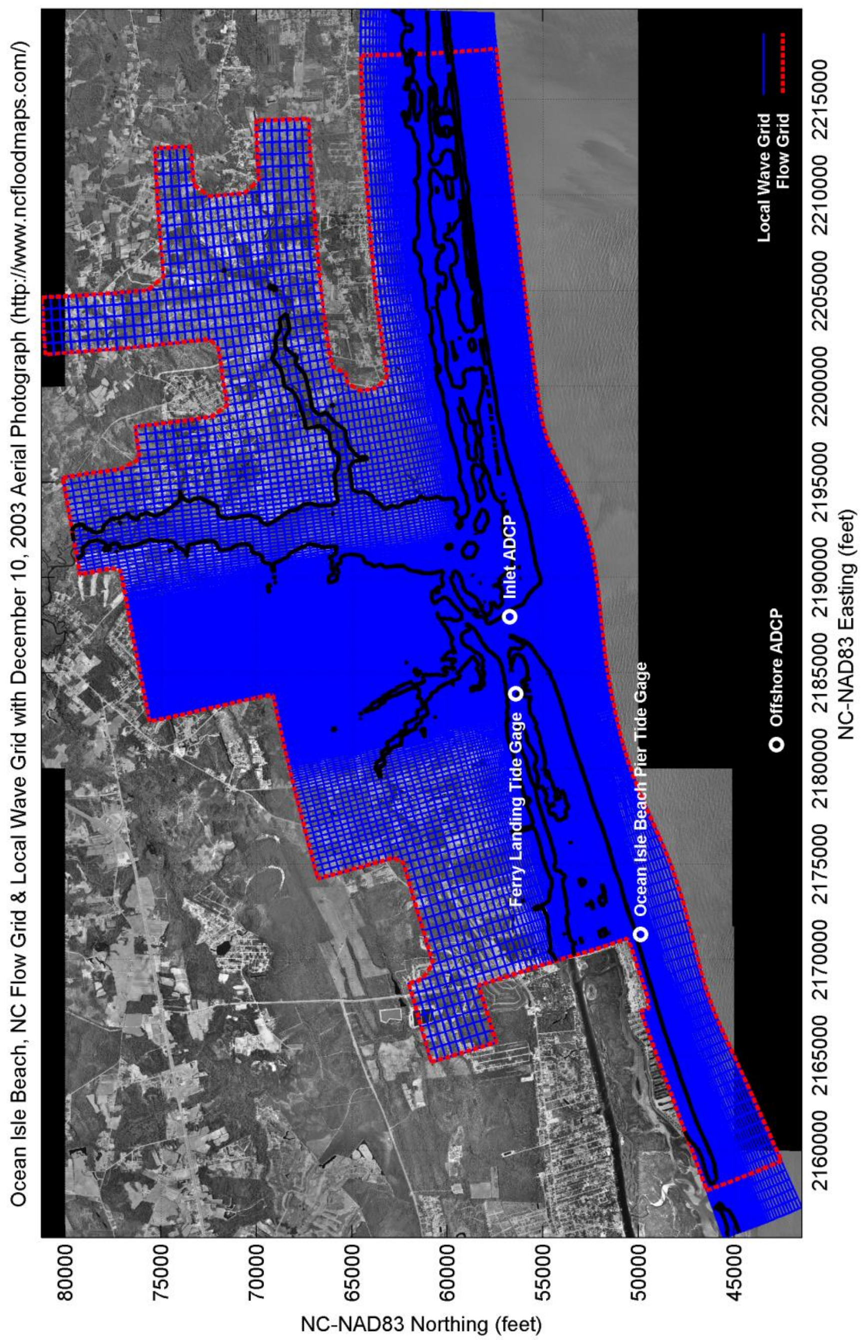

Figure 3: Ocean Isle Beach Flow Grid & Local Wave Grid.

The Flow Grid was used to examine currents, sediment transport, erosion, and deposition over the same areas (see Figure 3). Except for the removal of grid lines along the eastern and western ends of the grid to provide for stable coupling between SWAN and Delft3D-FLOW, the Flow Grid was identical to the Local Wave Grid. Grid characteristics are summarized in Table 1.

Table 1: Ocean Isle Beach Model Grids

	Long-shore Grid Cells	Cross-Shore Grid Cells	Grid Spacing (feet)		Orthogonality (º)		Grid Smoothness	
			Min.	Max	Min.	Max	Min.	Max
Regional Wave Grid	163	55	1,761	8,643	85.4	90.0	1.00	1.21
Intermediate Wave Grid	205	93	623	1,508	89.6	90.0	1.00	1.04
Local Wave Grid	309	151	37	691	87.9	90.0	1.00	1.20
Flow Grid	299	151	37	691	89.4	90.0	1.00	1.20

The modeling grids generally follow the guidelines established by Deltares (2011) for smoothing and orthogonality. The smoothing values represent the change in cell size between two rows of grid cells. Smoothing values of 1.1 and 1.2 indicate that the cell sizes between two rows of grid cells increase by 10% and 20%, respectively. The maximum smoothing value recommended by the model's developer is 1.2. The orthogonality is equivalent to the angle between the longshore and cross-shore grid lines, which should be at least 87.7 degrees within the area of interest. Except for the edges of the Regional Wave Grid, all grids follow the guidelines for smoothing and orthogonality established by Deltares (2011).

3.2 Bathymetry

Bathymetry over the modeling grids was based on the sources listed in Table 2. The initial conditions to be depicted in each model simulation governed the data sources that were used. Further details regarding the bathymetry are discussed later in this appendix.

4.0 HYDRODYNAMIC & METEOROLOGICAL DATA

4.1 Waves

Wave data sources appear in Table 3, Figure 2, and Figure 3. NOAA Buoy 41013, which began operation in November 2003, was the primary source of directional wave data. Offshore waves prior to November 2003 were taken from the non-directional observations at NOAA Buoy FPSN7. Gaps in the wave records were filled using the National Oceanographic and Atmospheric Administration's (NOAA) Wavewatch hindcast for the Western North Atlantic (NOAA, 2013e). This source also provided the wave directions at NOAA Buoy FPSN7.

Table 2: Bathymetric & Topographic Data Sources

Survey Date	Area	Type	Source
SURVEYS:			
November 2012	Intracoastal Waterway	Channel Surveys	USACE (2013)
May 2012	East & West Ends of Ocean Isle Beach	Beach Profiles	McKim & Creed (2012)
Jan.- July 2012	Intracoastal Waterway	Channel Surveys	USACE (2013)
December 2011	Shallotte River	Hydrographic Survey	USACE (2013)
May 2010	Shallotte Inlet	Post-Construction Borrow Area Survey	Dennis (2012a)
May 2010	Ocean Isle Beach Eastern Half	Post-Construction Pay Profiles	Dennis (2012a)
April 2010	Shallotte Inlet	Pre-Construction Borrow Area Survey	Dennis (2012a)
April 2010	Ocean Isle Beach Eastern Half	Pre-Construction Pay Profiles	Dennis (2012a)
April 2009	Shallotte Inlet, Ocean Isle Beach, & West End of Holden Beach	Inlet Survey & Beach Profiles	Dennis (2012a)
April 2006	West End of Holden Beach	Beach Profiles	Dennis (2012a)
March 2006	Ocean Isle Beach	Beach Profiles	Dennis (2012a)
February 2003	Bald Head Island	Beach Profiles	Dennis (2012b)
Nov. - Dec. 2002	Oak Island	Beach Profiles	Dennis (2012b)
May 2002	Shallotte Inlet	Inlet Survey	Dennis (2012a)
December 2001	Ocean Isle Beach & West End of Holden Beach	Beach Profiles	Dennis (2012a)
October 2001	Oak Island	Beach Profiles	Dennis (2012b)
January 2000	Oak Island	Beach Profiles	Dennis (2012b)
January 2000	Holden Beach	Beach Profiles	Dennis (2012b)
1934	Shallotte River	Hydrographic Survey	NOAA (2012)
DIGITAL ELEVATION MODELS (DEMs):			
Aug. - Oct. 2001	Brunswick County	LIDAR-Based Digital Elevation Model	NC Floodplain Mapping Program (2010)
c. 1924-1970	North & South Carolina	US Coastal Relief Model	NOAA (2013d)

Table 3: Hydrodynamic & Meteorological Data Sources

	NC-NAD83		NAD83	
	Easting (feet)	Northing (feet)	Lat. (°N)	Long. (°N)
WAVES:				
41013	2,383,626	-111,867	33.43600000	77.74300000
FPSN7	2,430,064	-93,405	33.48500000	77.59000000
OCP1	2,258,553	58,617	33.90800000	78.14800000
41024 / SUN2	2,155,185	36,069	33.84800000	78.48900000
Offshore ADCP	2,181,227	42,786	33.86605469	78.40311374
Inlet ADCP	2,187,919	56,734	33.90426283	78.38078795
WATER LEVELS:				
Sunset Beach Tide Gage 8659897	2,149,688	42,229	33.86500000	78.50700000
Oak Island Tide Gage 8659897	2,278,703	56,491	33.90166667	78.08166667
Ferry Landing Tide Gage	2,183,895	56,433	33.90350556	78.39405278
Ocean Isle Beach Pier Tide Gage	2,171,303	49,890	33.88573333	78.43566667

Observed waves at gages OCP1, SUN2, the Offshore ADCP, and the Inlet ADCP were used in the model calibration process. Directional measurements at gages OCP1 and SUN2 were provided by the Coastal Ocean Research and Monitoring Program (http://www.cormp.org/).

The Offshore ADCP was a Nortek AWAC Acoustic Doppler Current Profiler (ADCP) (see Figure 4), which was deployed from October 18 through November 29, 2012. Measurements at the Offshore ADCP were used in the calibration of the SWAN wave transformation model. Configuration of the instrument is summarized in Table 4.

The Inlet ADCP was initially deployed over the same dates. However, during the recovery operation, extensive disturbance of the instrument was found. The Inlet ADCP's pitch and roll records suggested that disturbance of the instrument occurred on October 18, 2012. Data recorded after this date could not be used. Accordingly, the Inlet ADCP was deployed a second time from November 30 to December 20, 2012. The data that was collected during the second deployment was reviewed, deemed acceptable, and subsequently used in the calibration of the Delft3D-FLOW model and the verification of the SWAN model. The configuration of the Inlet ADCP is summarized in Table 4.

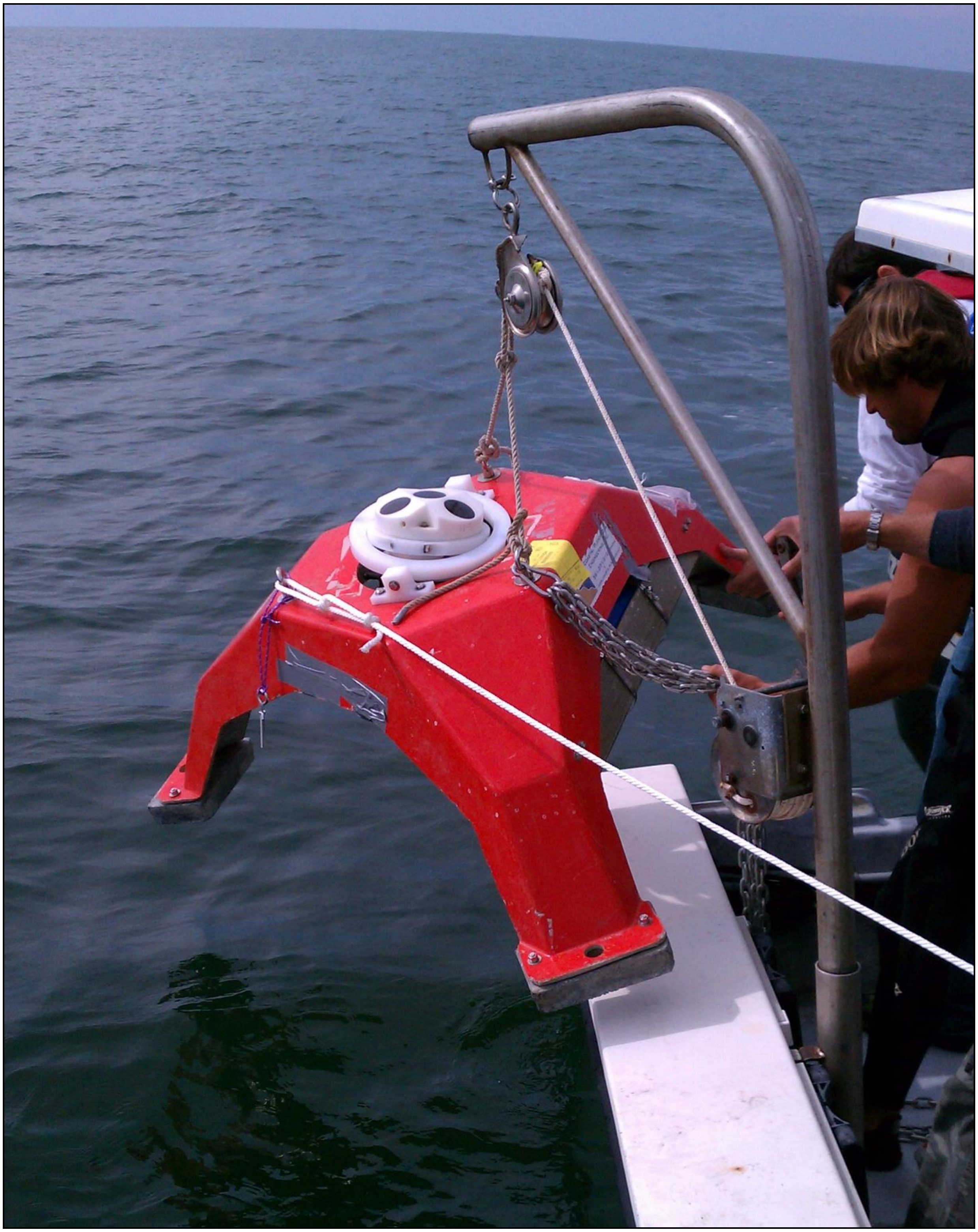

Figure 4: Photograph of Offshore ADCP during the October 17-18, 2012 Placement Operation.

Table 4: Ocean Isle Beach ADCP Configuration

	Offshore ADCP (Nortek AWAC)	Inlet ADCP (Nortek Aquadopp)
Current Profiles:		
Profile Interval (seconds)	600	600
Number of Vertical Profiling Layers	13	20
Cell Size (meters)	1	0.5
(feet)	3.3	1.6
Average Interval (seconds)	60	60
Blanking Distance (meters)*	1	0.5
(feet)	3.3	1.6
Compass Update Rate (seconds)	600	600
Wave Measurements:		
Number of Samples	2048	2048
Sampling Rate (Hz)	2	2
Interval (seconds)	3600	3600
Miscellaneous:		
Duration (days)	60	60
Depth (meters)	14	10.5
(feet)	45.9	34.4
Battery Utilization (Watt-hours)	448.2	122.0
Memory (MB)	69.5	69.3
Vertical Velocity Precision (cm/second)	0.7	0.7
(feet/second)	0.023	0.023
Horizontal Velocity Precision (cm/second)	2.2	2.2
(feet/second)	0.072	0.072

*NOTE: Equal to the vertical distance between the seafloor and the lowest profiling layer.

4.2 Water Levels

Tidal datums along the study area were based on published values at the Oak Island Tide Gage (see **Table 5**). Additional characterization of the open-ocean tides was based on the observed record at the Sunset Beach Tide Gage between November 14, 2003 and March 16, 2008 (NOAA, 2013a). The additional analysis is discussed later in this appendix. To provide site-specific measurements for the Delft3D-FLOW calibration, two more tide gages were deployed at the Ocean Isle Beach Pier and the Ferry Landing pier at the north end of Shallotte Blvd (see Table 3 and Figure 3) between October 16, 2012 and January 2, 2013. At both gages, the majority the data was found to be acceptable for use in the calibration of the Delft3D-FLOW model.

Table 5: Tidal Datums at the Oak Island Tide Gage (NOAA Station 8659182)

TIDAL DATUM	ABBREV.	ELEV. (feet MLLW)	ELEV. (feet MSL)	ELEV. (feet NAVD)
MEAN HIGHER HIGH WATER	MHHW	5.26	2.72	2.16
MEAN HIGH WATER	MHW	4.89	2.35	1.79
NAVD	NAVD	3.10	0.56	0.00
MEAN SEA LEVEL	MSL	2.54	0.00	-0.56
MEAN TIDE LEVEL	MTL	2.53	-0.01	-0.57
NGVD	NGVD	1.99	-0.55	-1.11
MEAN LOW WATER	MLW	0.16	-2.38	-2.94
MEAN LOWER LOW WATER	MLLW	0.00	-2.54	-3.10

4.3 Winds

Long-term wind statistics, discussed later in this appendix, were based on wind velocity measurements at NOAA Buoys 41013 and FPSN7. The time- and space-dependent winds used in the SWAN calibration and flow calibrations were taken from the NOAA Wavewatch hindcast for the Western North Atlantic (NOAA, 2013e).

5.0 CALIBRATION

5.1 SWAN Model Calibration

Calibration of the SWAN wave transformation model was performed using wave and water level measurements collected between October 22 and November 14, 2012. Hurricane Sandy passed the study area offshore between these dates.

Bathymetry

Bathymetry during the calibration period was based on the following data sources (see also Table 2):

1. The May 2012 beach and inlet survey.
2. The 2012 Atlantic Intracoastal Waterway (AIWW) surveys.
3. The 2011 Shallotte River survey.
4. May 2010 surveys.
5. April 2010 surveys.
6. April 2009 surveys.
7. The 2002 Oak Island survey.
8. The 2001 Oak Island survey.

9. The January 2000 Holden Beach and Oak Island surveys.
10. The 1934 Shallotte River survey.
11. North Carolina Floodplain Mapping program DEM.
12. The U.S. Coastal Relief Model.

The May 2012 survey was the primary data set. Grid points outside the area surveyed in May 2012 were covered by the other sources in the order listed above, with the U.S. Coastal Relief Model as the data set of last resort. The resulting bathymetry appears in Figure 5 through Figure 8.

In general, the regional bathymetry follows a series of arcs whose endpoints are defined by Cape Fear (E = 2,300,000’ in Figure 5) and the entrance to Winyah Bay near Georgetown, SC (E = 1,950,000’ in Figure 5). The most prominent bathymetry features offshore are the Frying Pan Shoals, which extend from the tip of Cape Fear at depths ranging from -10 to -20 feet NAVD (see Figure 5).

The local bathymetry is characterized by Shallotte Inlet and the Shallotte River (see Figure 7 and Figure 8). The southernmost extent of the Shallotte River forms a 3½ long basin, with depths on the order of -8 feet NAVD (see Figure 7). This area connects with the Atlantic Ocean via the AIWW and Shallotte Inlet, whose deepest depths are on the order of -20 feet NAVD (see Figure 8).

Waves

Input waves on the offshore boundary of the Regional Flow Grid were based on spectral wave measurements at NOAA Buoy 41013 (see Table 3 and Figure 2). The input waves were given on an hourly basis in terms of power spectral density (in m^2/Hz) and direction as a function of frequency (see Figure 9). A summary of the input wave conditions over the calibration period as a whole appears in Figure 10.

Winds

Input winds were given as time- and space-dependent wind fields, which were taken from the NOAA Wavewatch hindcast for the Western North Atlantic (NOAA, 2013e). A typical wind field appears in Figure 11. In general, the wind fields were consistent with measurements at the various buoys in Table 3 and Figure 2. Local wind velocities at NOAA Buoy 41013 appear in Figure 10.

Water Levels

Water level measurements at the Ocean Isle Beach Pier Tide Gage were only available during isolated portions of the calibration period – October 23 to 27 and October 31 to November 14. Accordingly, input water levels were based on continuous depth measurements at wave gage OCP1 (see Table 3, Figure 2, and Figure 12). As a first approximation, water levels were assumed to be uniform over the model domain.

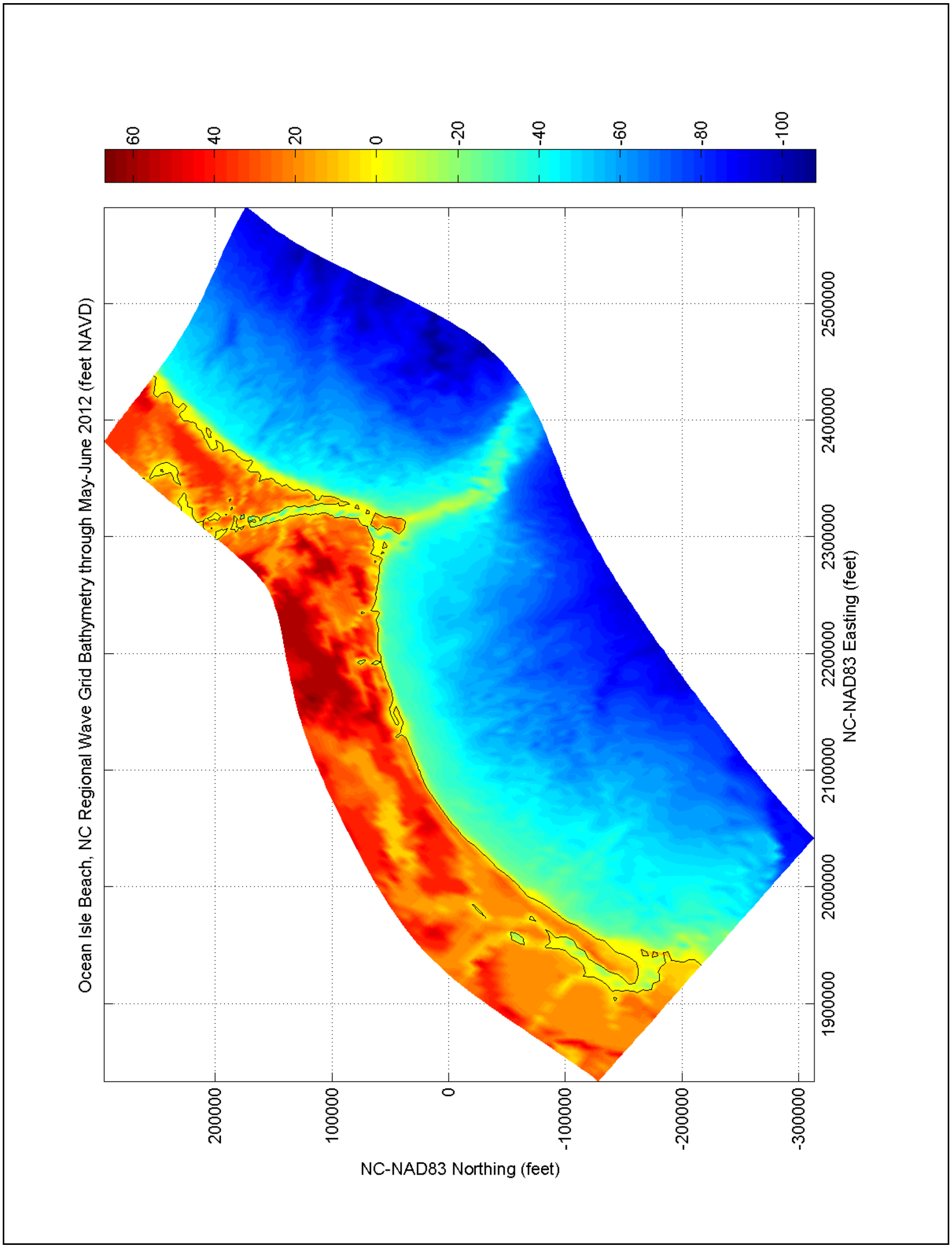

Figure 5: Regional Bathymetry through May 2012.

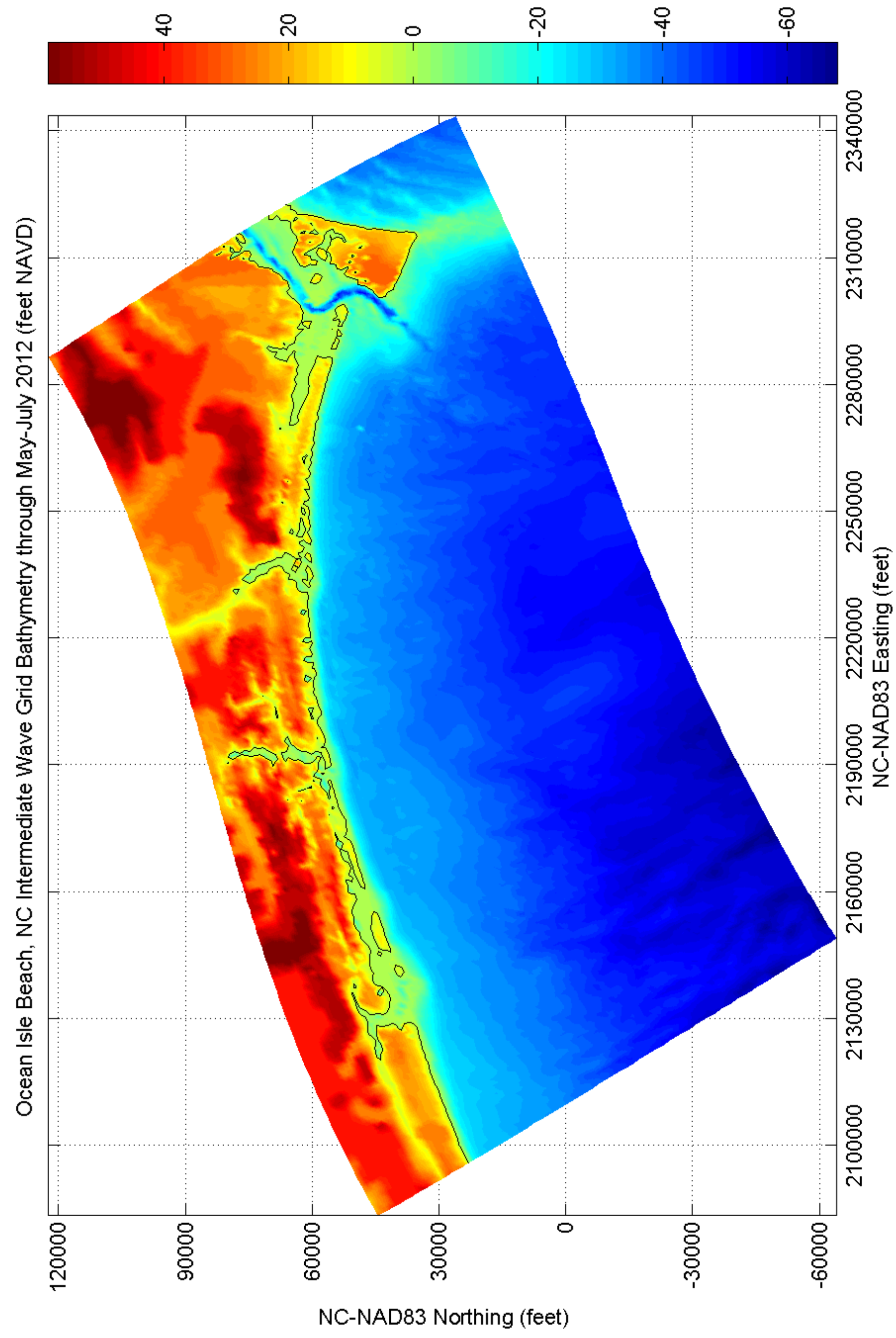

Figure 6: Intermediate Wave Grid Bathymetry through May 2012.

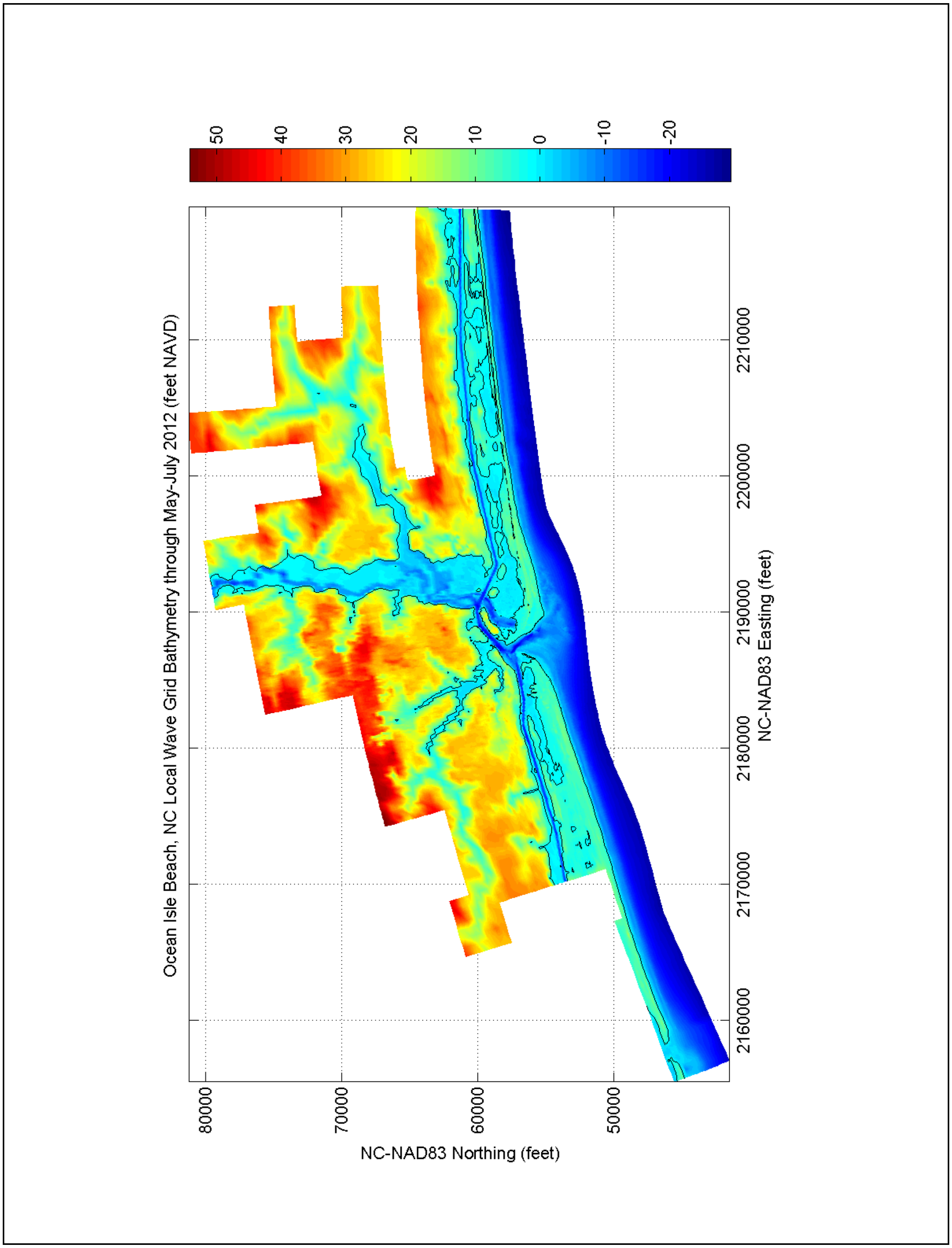

Figure 7: Local Wave and Flow Grid Bathymetry through May 2012.

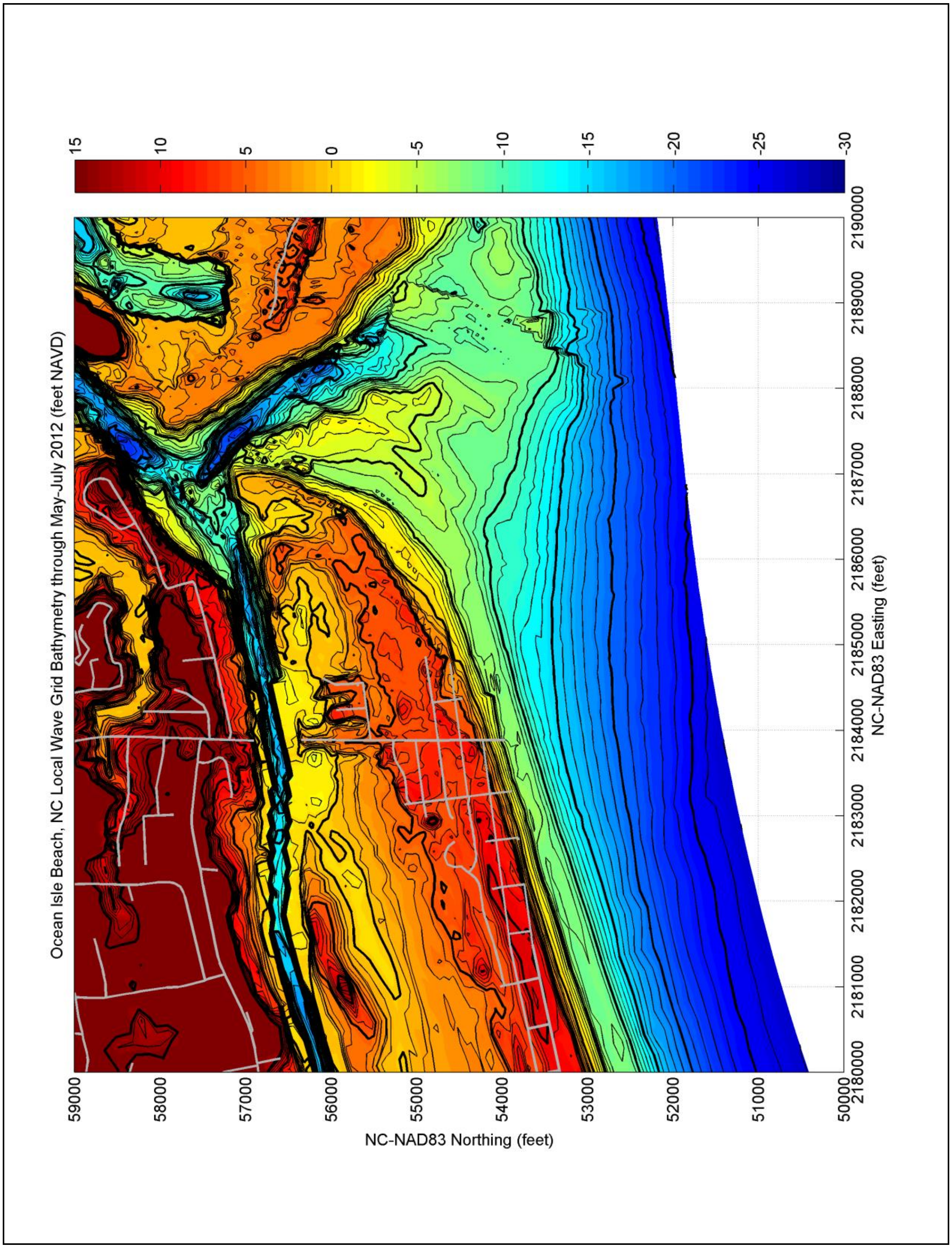

Figure 8: Shallotte Inlet Estimated May 2012 Bathymetry.

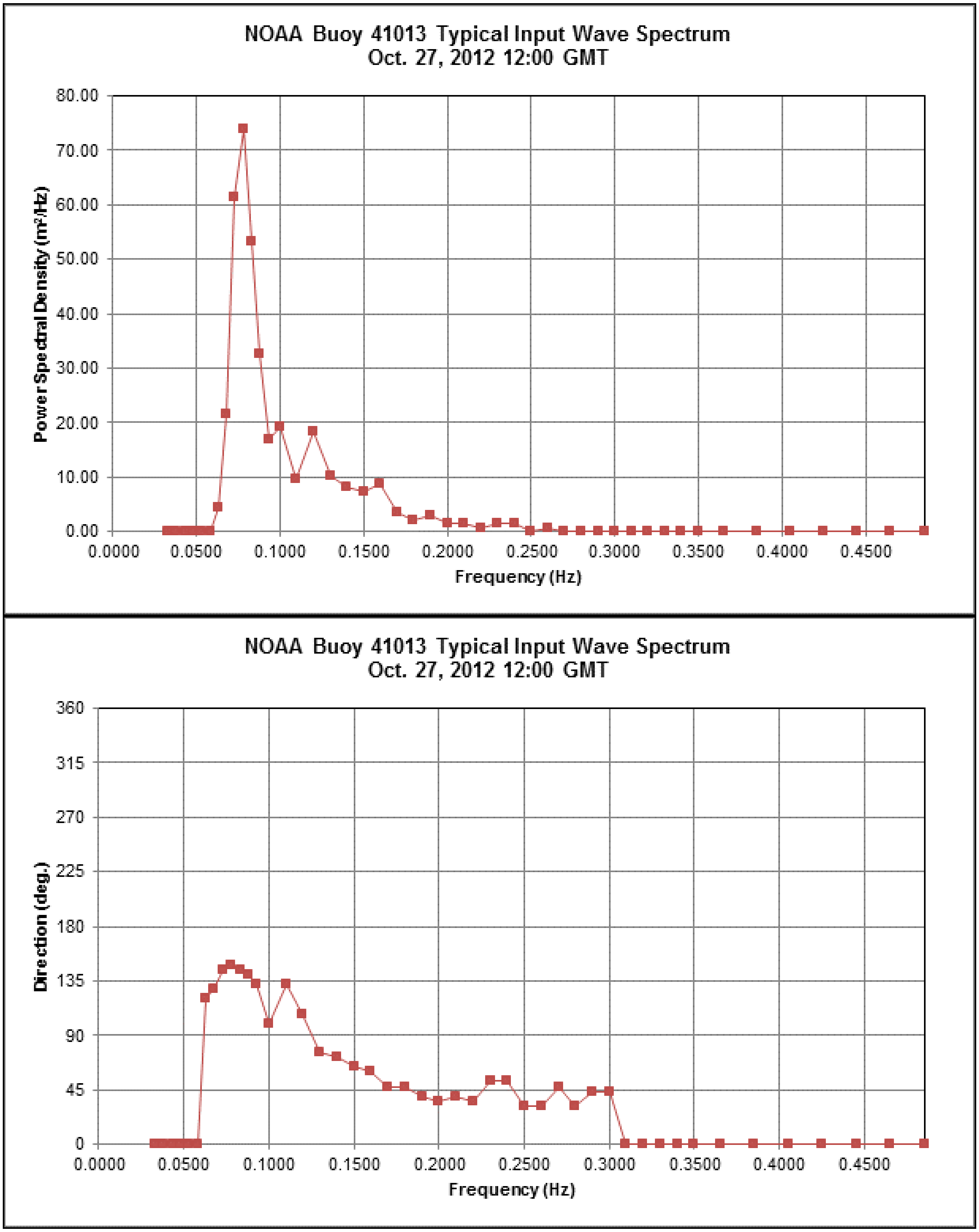

Figure 9: Typical Input Wave Spectrum.

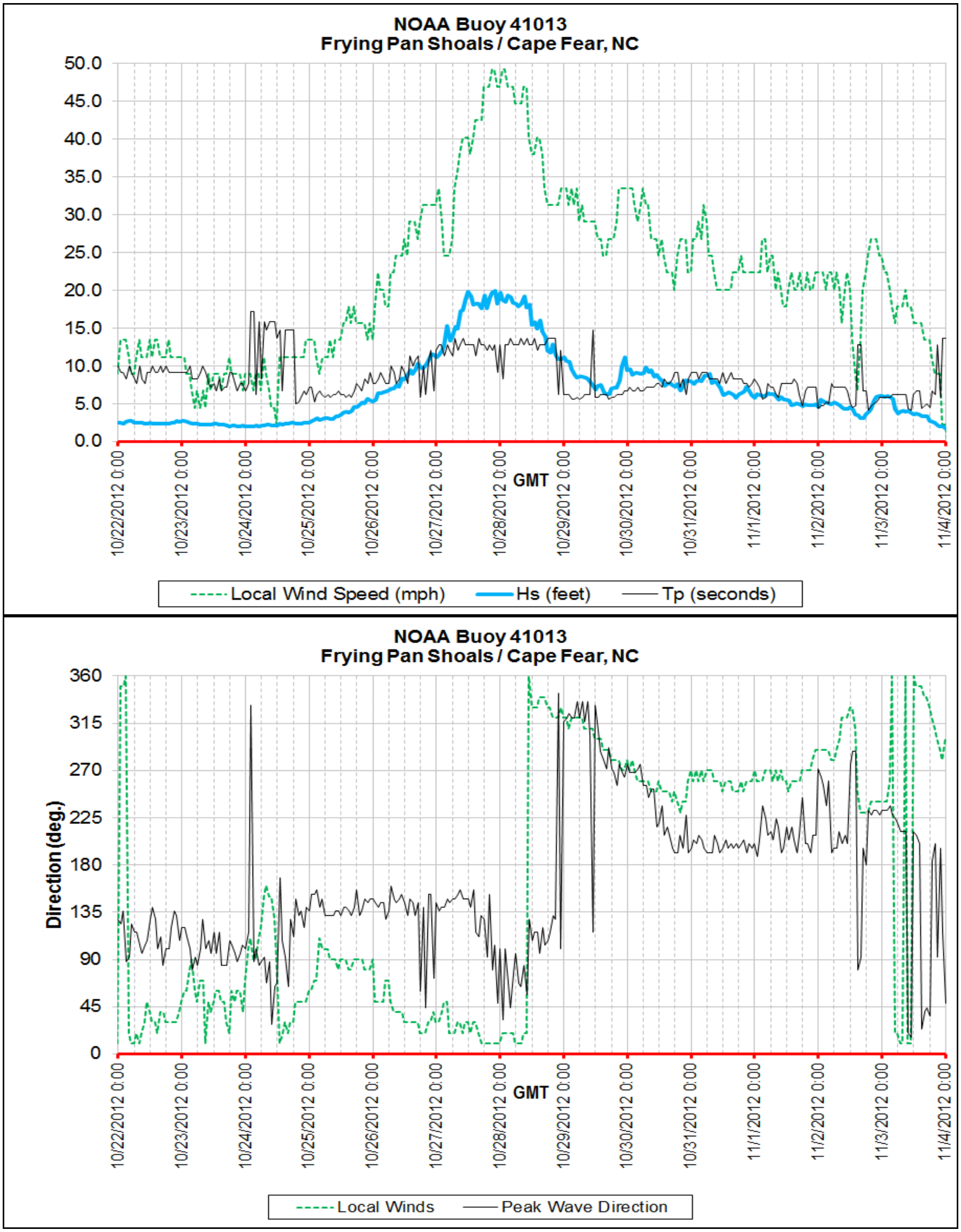

Figure 10: Summary of Input Wave Conditions during the SWAN Calibration Period.

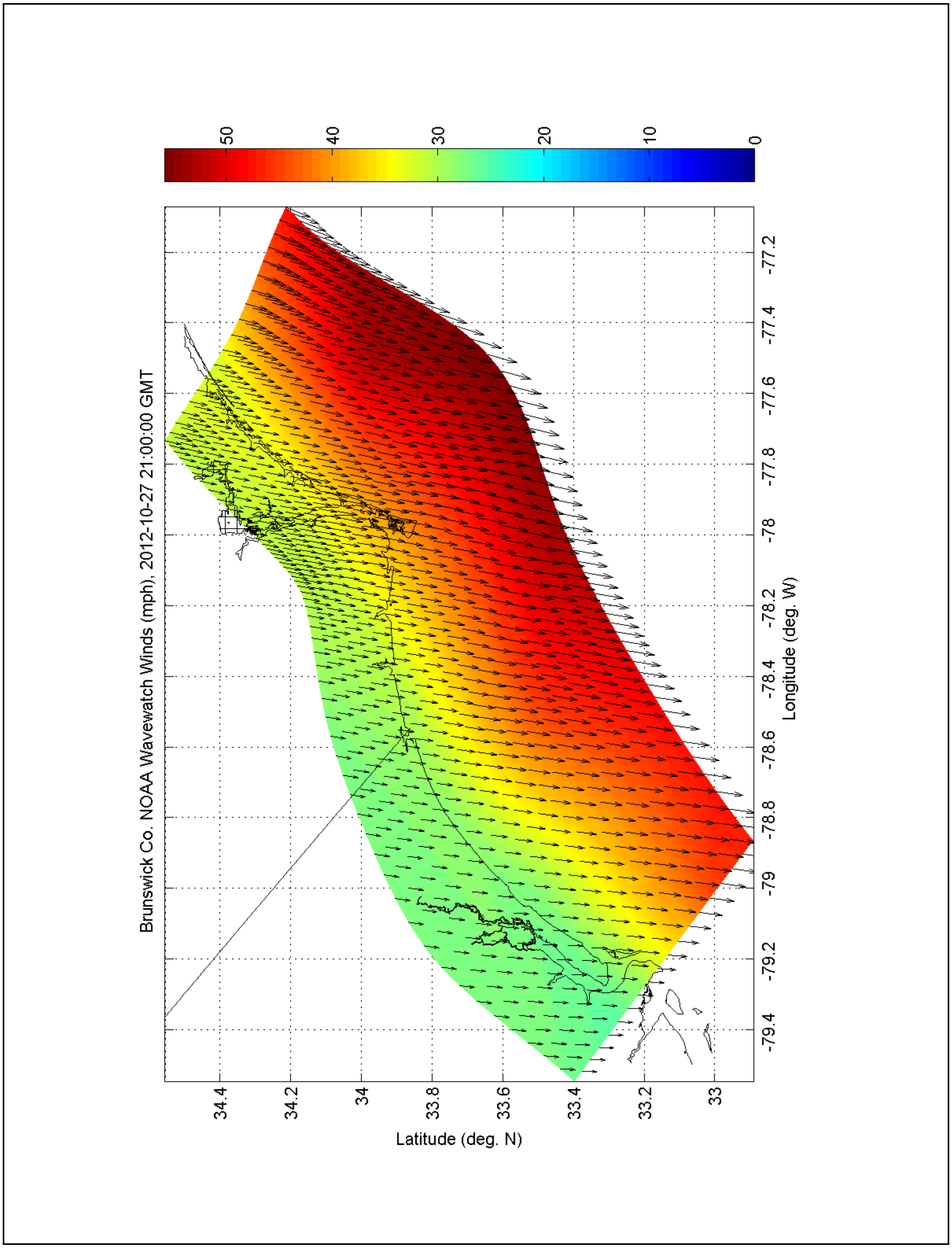

Figure 11: Typical Input Wind Field during the SWAN Calibration.

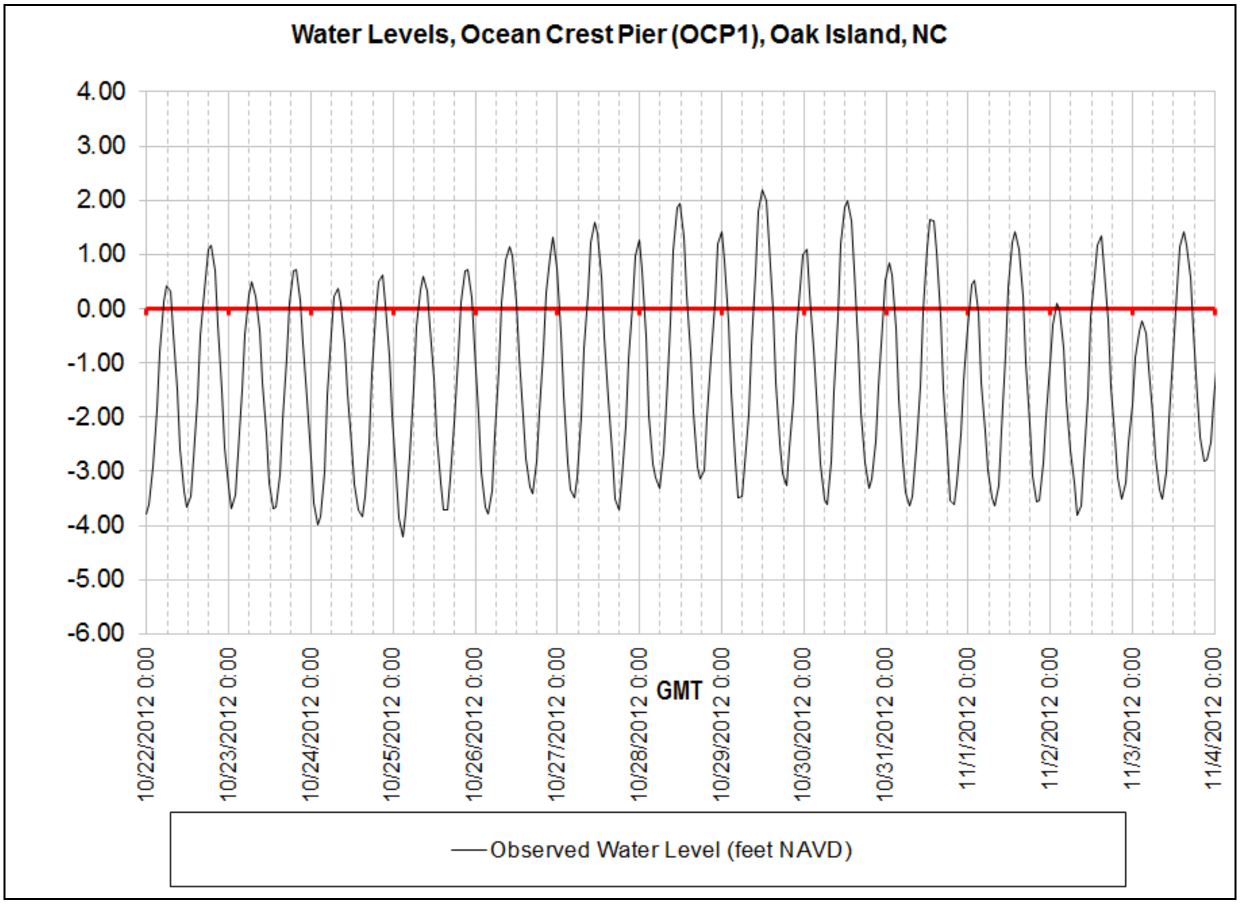

Figure 12: Input Water Levels during the SWAN Calibration.

Model Results

Calibration of the SWAN model was performed by varying the values of the JONSWAP bottom friction coefficient. All other model parameters were set to their default values. The model results were then compared to the observed wave heights at the Offshore ADCP and OCP1 (see Figure 2, Table 3, and Table 6). Due to the disturbance of the instrument, measurements at the Inlet ADCP could not be used to evaluate the model results. The best model results at the Offshore ADCP and OCP1 were achieved by setting the JONSWAP bottom friction coefficient to 0.064 (see Table 6, Figure 13, and Figure 14).

Typical model results over the various grids appear in Figure 15 through Figure 17. On either side of Cape Fear, wave heights underwent reductions due to bottom friction, shoaling, and refraction. However, due to the presence of the Frying Pan Shoals, wave heights on the western side of Cape Fear tended to be lower than those on the eastern side (see Figure 15 and Figure 16). Near Shallotte Inlet, waves along the fringe of the ebb shoal during the passage of Hurricane Sandy were roughly 2/3 of their offshore value (see Figure 13, Figure 15, and Figure 17). Near Shallotte Blvd., wave breaking occurred relatively close to the shoreline (see Figure 17). East of this location, wave breaking occurred somewhat further offshore due to the presence of the Shallotte Inlet ebb shoal (see Figure 17).

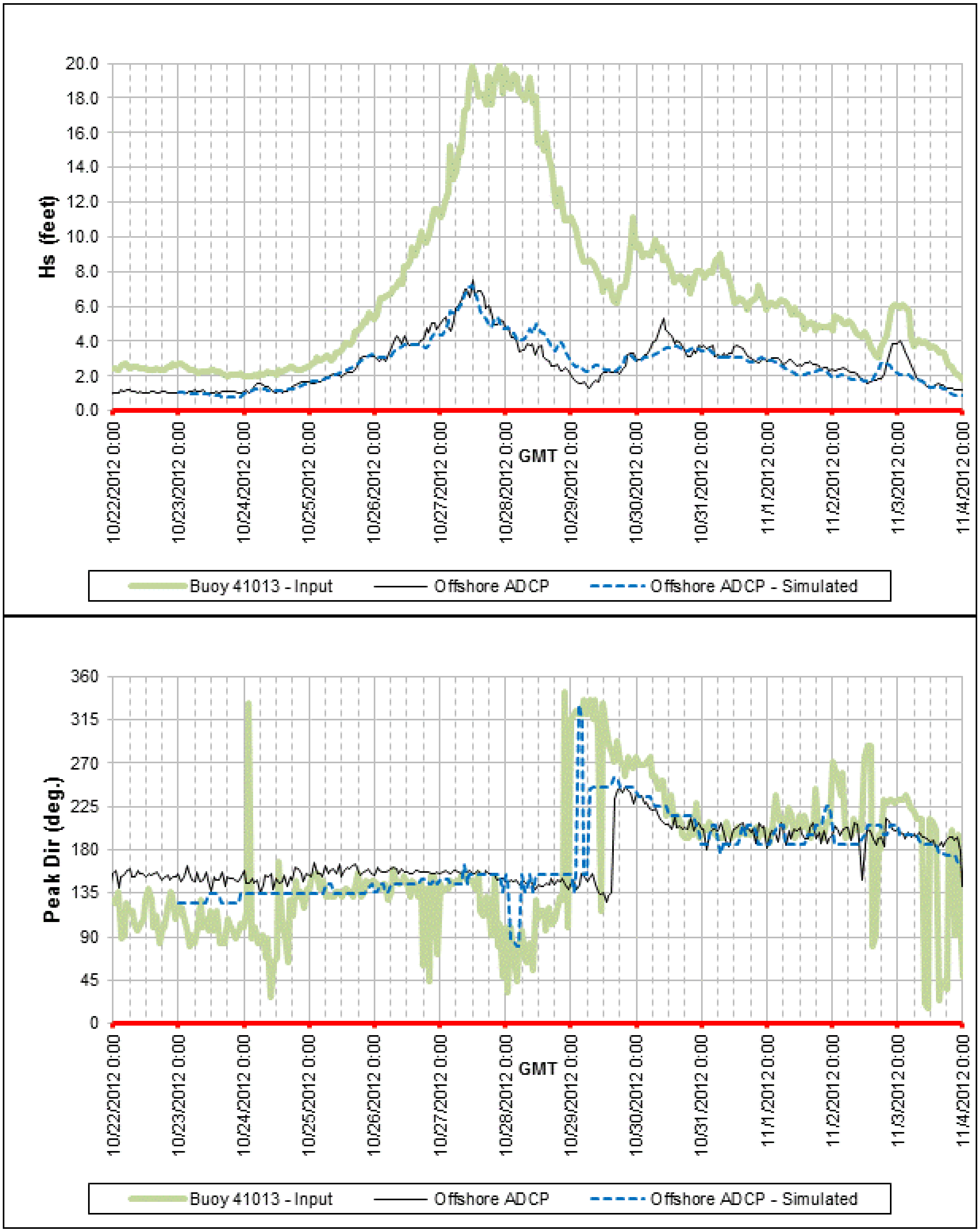

Figure 13: SWAN Calibration Results at the Offshore ADCP, JONSWAP Bottom Friction Coefficient = 0.064.

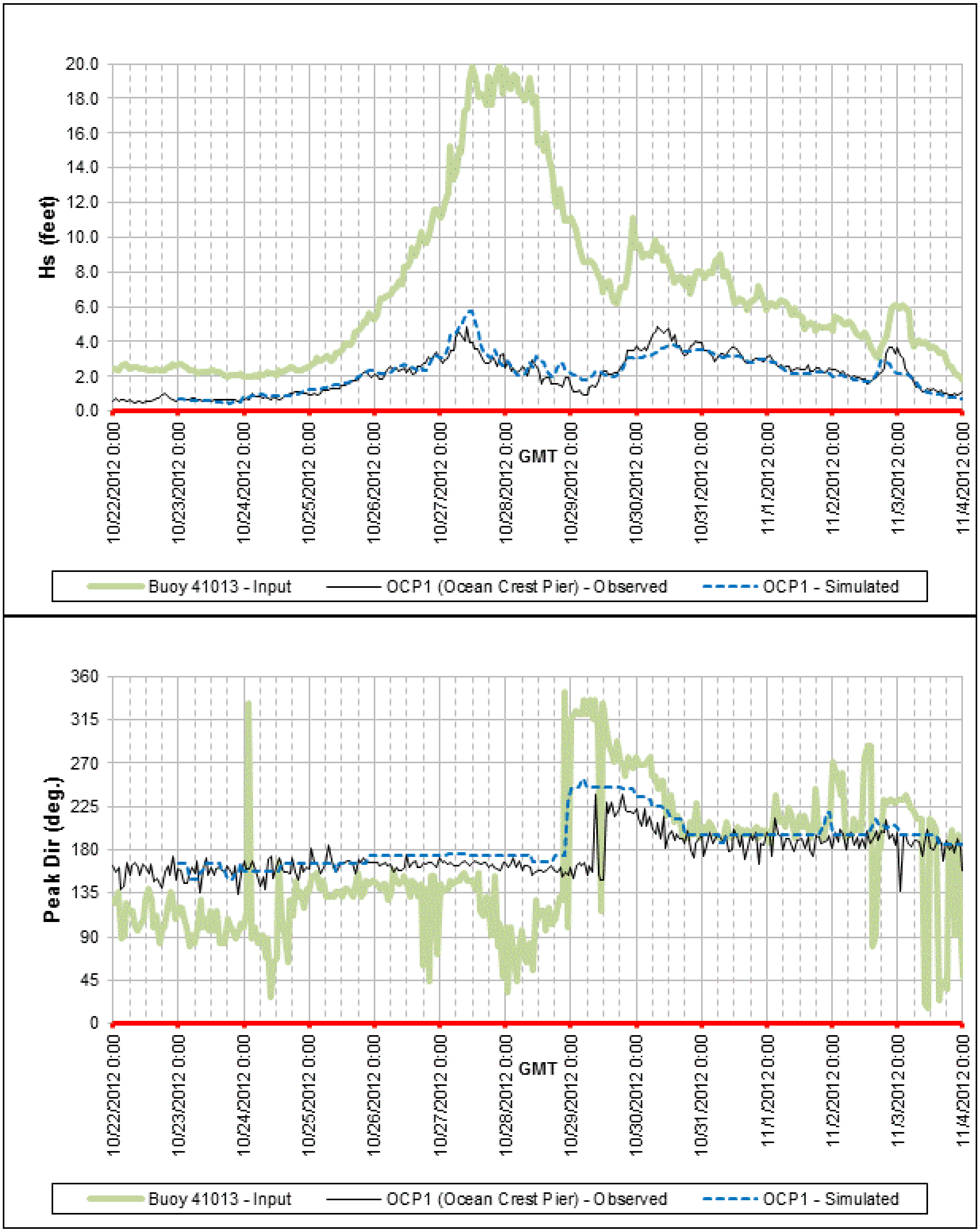

Figure 14: SWAN Calibration Results at OCP1, JONSWAP Bottom Friction Coefficient = 0.064.

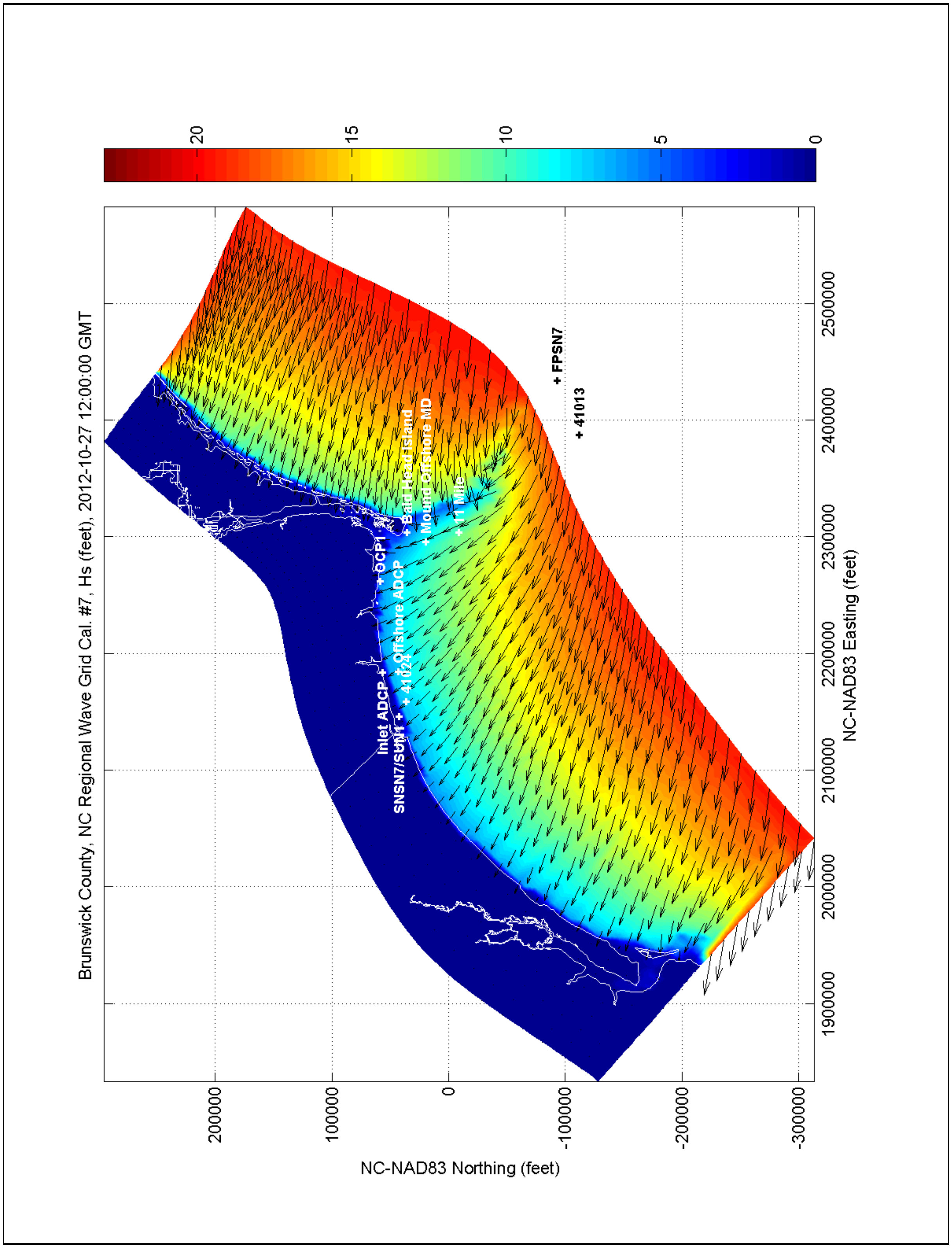

Figure 15: Typical SWAN Calibration Results over the Regional Wave Grid.

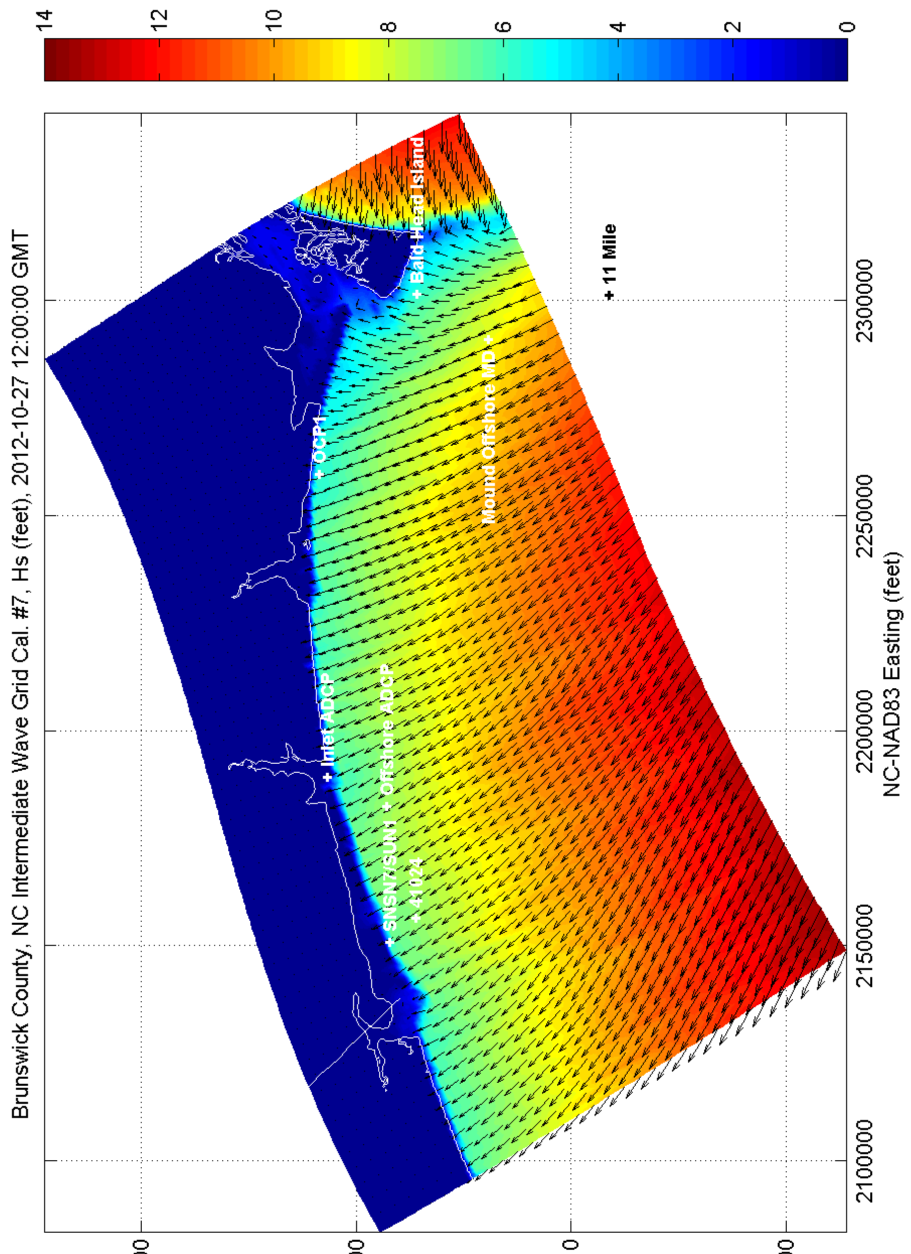

Figure 16: Typical SWAN Calibration Results over the Intermediate Wave Grid.

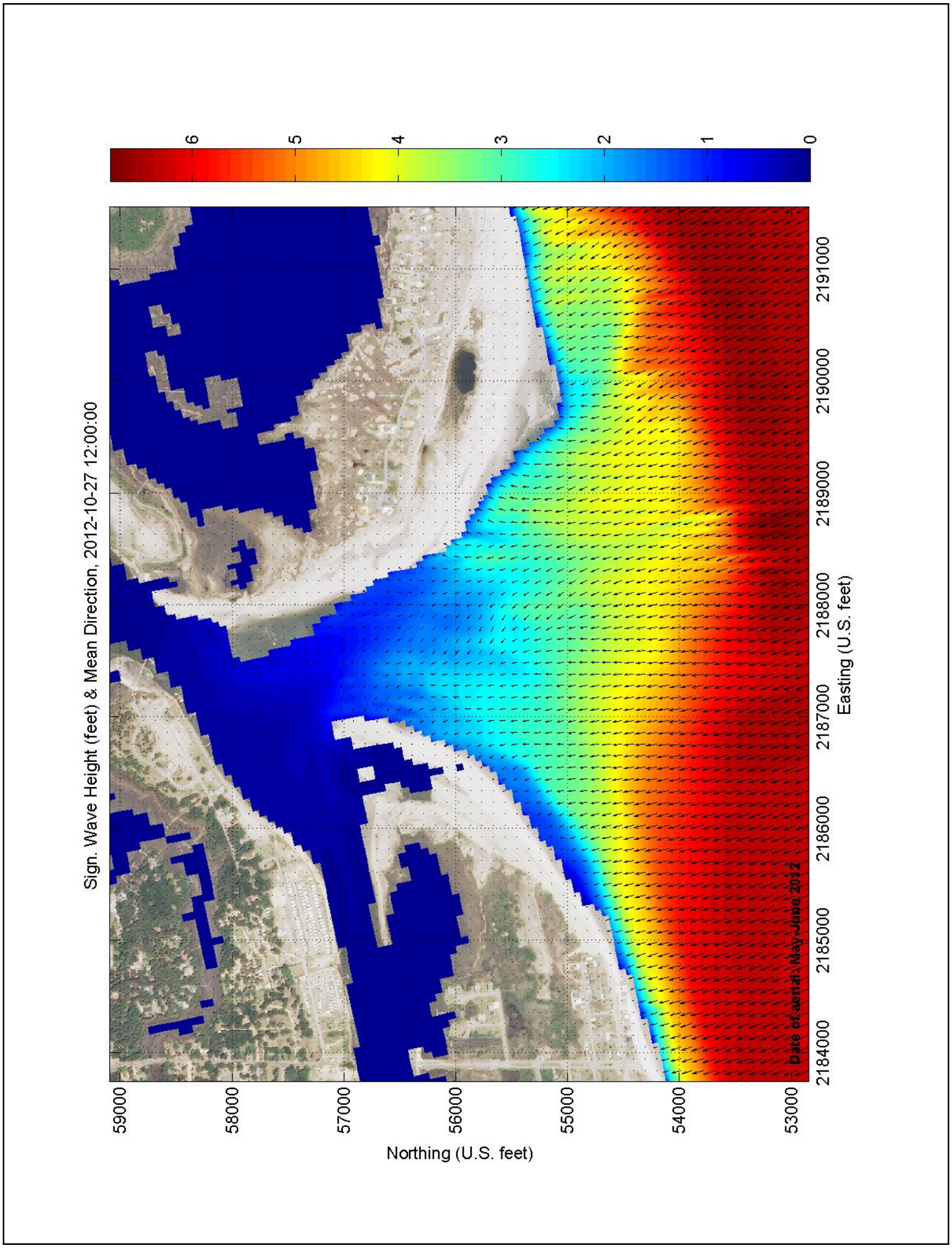

Figure 17: Typical SWAN Calibration Results near Shallotte Inlet.

Table 6: Summary of SWAN Calibration Results

JONSWAP Bottom Friction Coef.	Simulated Hs – Observed Hs (feet) OCP1		Simulated Hs – Observed Hs (feet) Offshore ADCP		Simulated Hs – Observed Hs (feet) Avg. of Both Locations	
	Mean	RMS	Mean	RMS	Mean	RMS
0.056	0.14	0.54	0.04	0.57	0.09	0.56
0.060	0.07	0.50	-0.02	0.55	0.03	0.53
0.064 (selected)	**0.02**	**0.47**	**-0.08**	**0.55**	**-0.03**	**0.51**
0.067 (default)	-0.03	0.48	-0.12	0.55	-0.08	0.52
0.084	-0.23	0.47	-0.34	0.64	-0.29	0.56
0.100	-0.38	0.58	-0.51	0.76	-0.45	0.68

5.2 Flow Calibration

Calibration of the hydrodynamics within the Delft3D-FLOW model was performed using current, wave, and water level measurements between November 30 and December 20, 2012. This time period corresponds to the second deployment of the Inlet ADCP, during which value data was collected.

To account for the effects of waves, the Delft3D-FLOW model was coupled with SWAN during each calibration run. Thus, the flow calibration results could also be used to verify the SWAN model calibration detailed above.

Bathymetry

Bathymetry during the calibration period was identical to the bathymetry used in the calibration of the SWAN model (see Figure 5 through Figure 8).

Water Levels

Water levels on the offshore boundary of the flow grid were equal to those measured at the Ocean Isle Beach Pier (see Figure 18). Observed water levels at the Ferry Landing tide gage and the Inlet ADCP were used to evaluate the results of the model.

Waves

Input waves on the offshore boundary of the Regional Flow Grid were based on hourly, observed wave spectra at NOAA Buoy 41013 (see Table 3 and Figure 2). A summary of the input wave conditions over the flow calibration period appears in Figure 19.

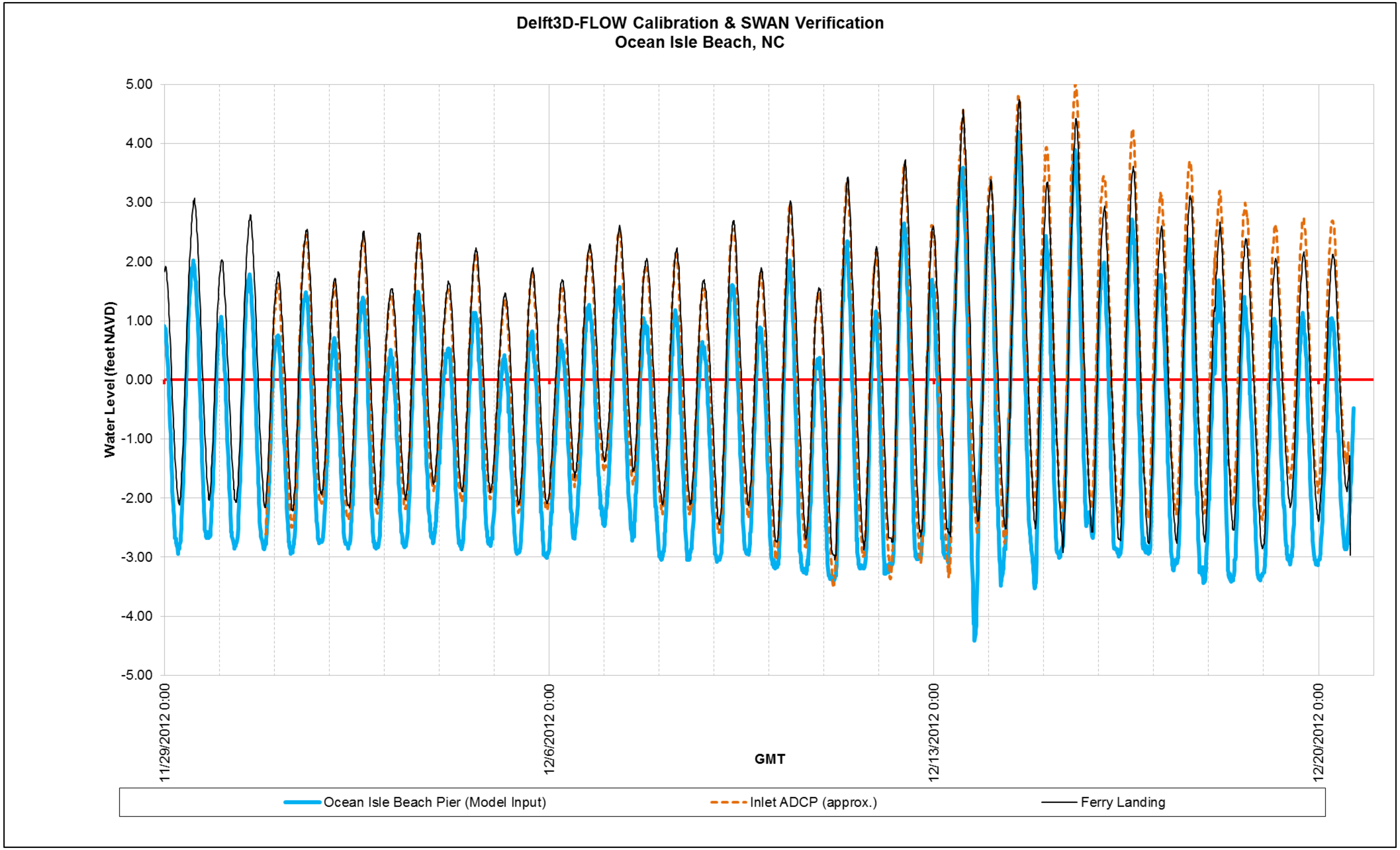

Figure 18: Observed Water Levels during the Flow Calibration.

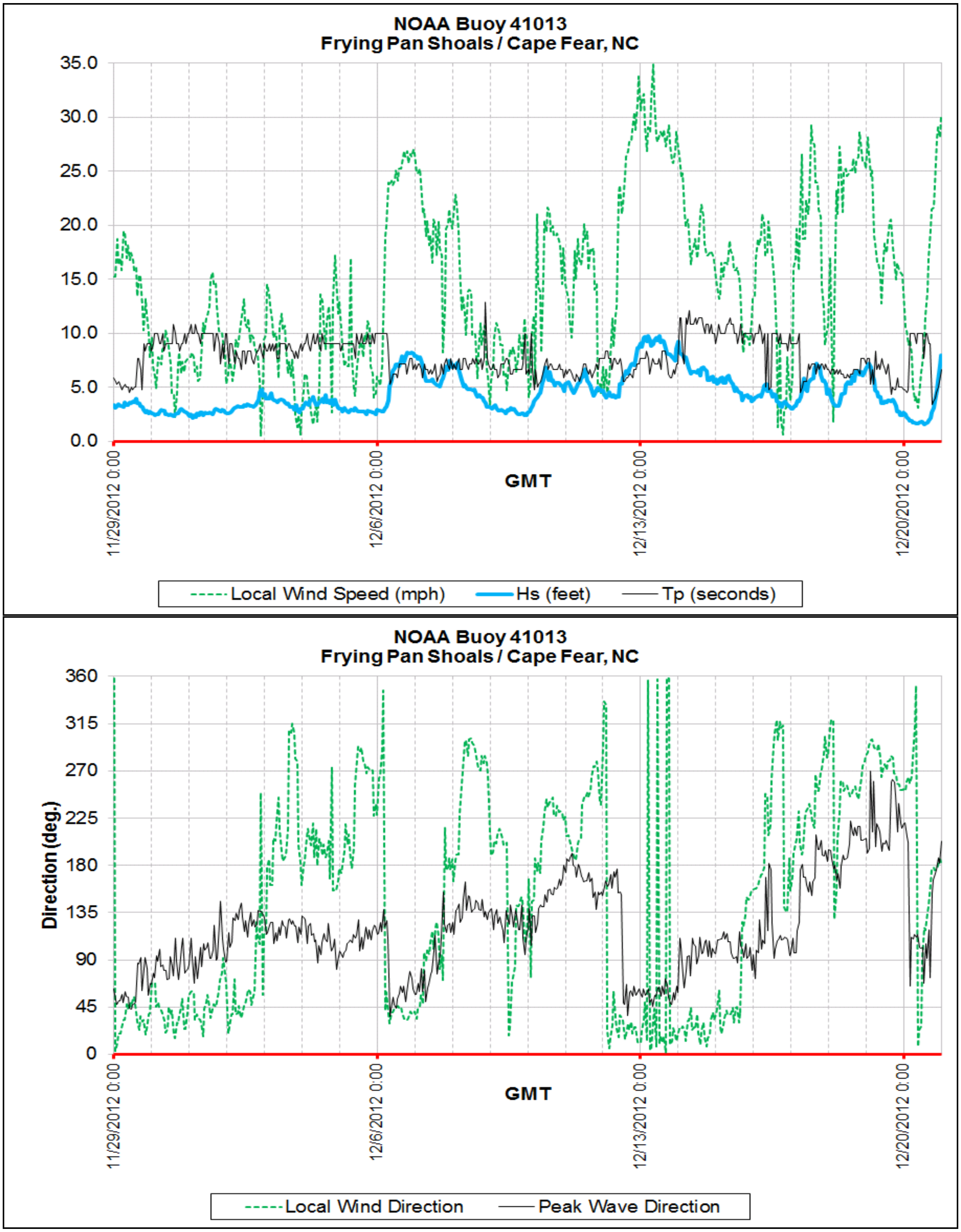

Figure 19: Summary of Input Wave Conditions during the Flow Calibration Period.

Winds

Similar to the SWAN calibration, input winds were given as time- and space-dependent wind fields, which were taken from the NOAA Wavewatch hindcast for the Western North Atlantic (NOAA, 2013e). A typical wind field appears in Figure 20. Local wind velocities at NOAA Buoy 41013 appear in Figure 19.

Model Results

Calibration of the hydrodynamics within Delft3D-FLOW was performed by varying the values of the Chezy bottom friction coefficient for flow. Higher values of the Chezy bottom friction coefficient lead to higher currents and less friction; lower values lead to lower currents and more bottom friction. All other hydrodynamic model parameters were set to their default values, except for the bottom friction coefficient used in the SWAN model (see Table 6). Model results were evaluated near the Inlet ADCP to determine the most suitable value of the bottom friction coefficient. The best fit between the simulated and observed currents was achieved by setting the Chezy bottom friction coefficient to 65, which was the default value (see Table 7).

Table 7: Summary of Flow Calibration Results

Chezy Bottom Friction Coefficient	Simulated – Observed Current (feet/s) OCP1	
	Mean	RMS
30	-0.16	1.23
40	-0.23	1.01
65 (selected)	**-0.31**	**0.86**
102	-0.33	0.89
129	-0.38	0.94

Typical model results appear in Figure 21 through Figure 27. In general, agreement between the simulated and observed currents was satisfactory, and agreement between the observed and simulated water levels was good. In addition, simulated wave heights at the Inlet ADCP and OCP1 (Table 3, Figure 2, and Figure 27) were consistent with their observed values.

In general, both the model results and the observations suggest that the currents near the Inlet ADCP are ebb dominated (see Figure 21). Currents are on the order of 2 to 4 feet/second during peak flood and 2 to 5 feet/second during peak ebb. The model results also suggest that strong currents in both the throat of the inlet and the AIWW just east of the inlet (see Figure 24 and Figure 25). This appears to be due to the constriction of flow between the south end of the Shallotte River basin and the north end of Shallotte Inlet.

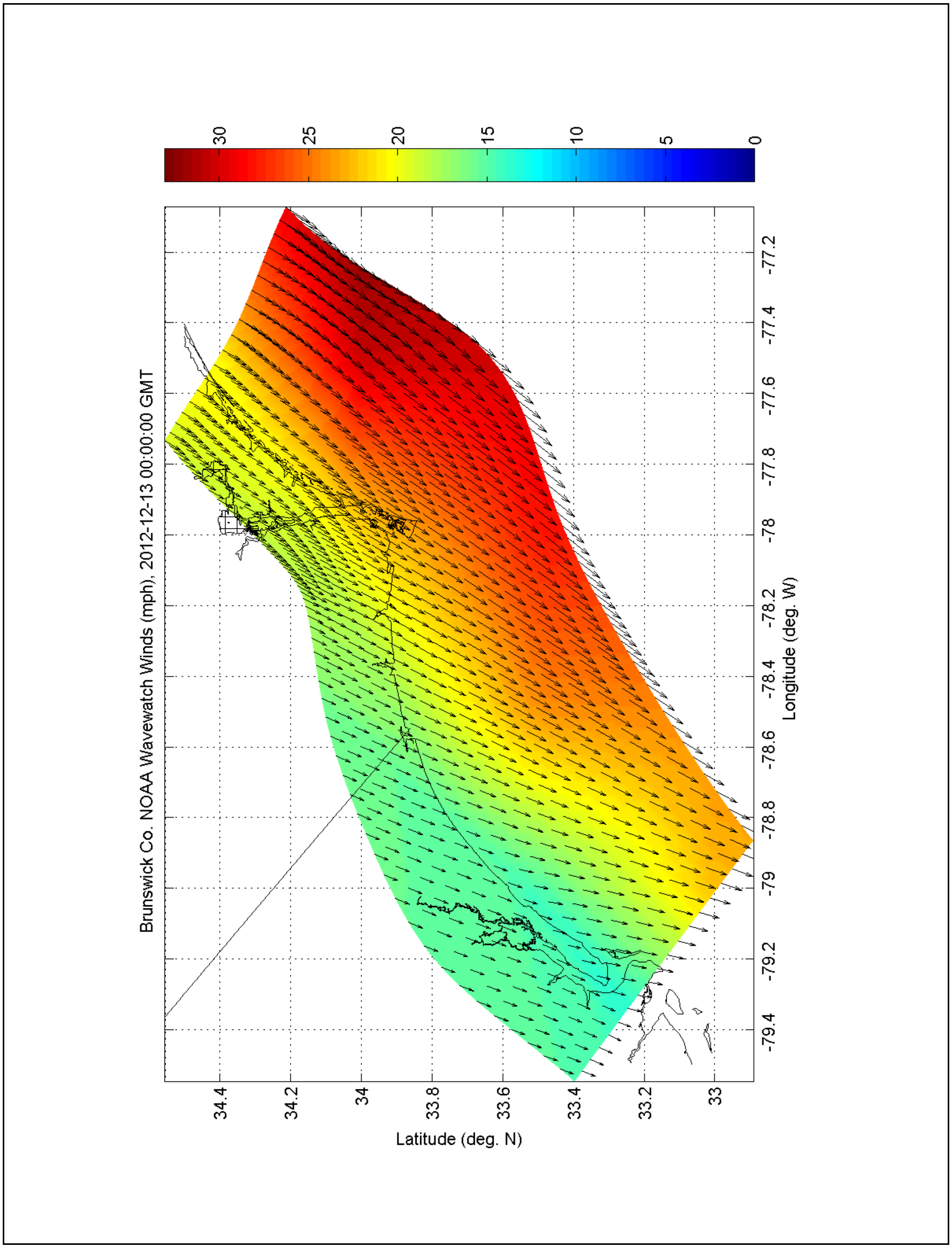

Figure 20: Typical Input Wind Field during the Flow Calibration.

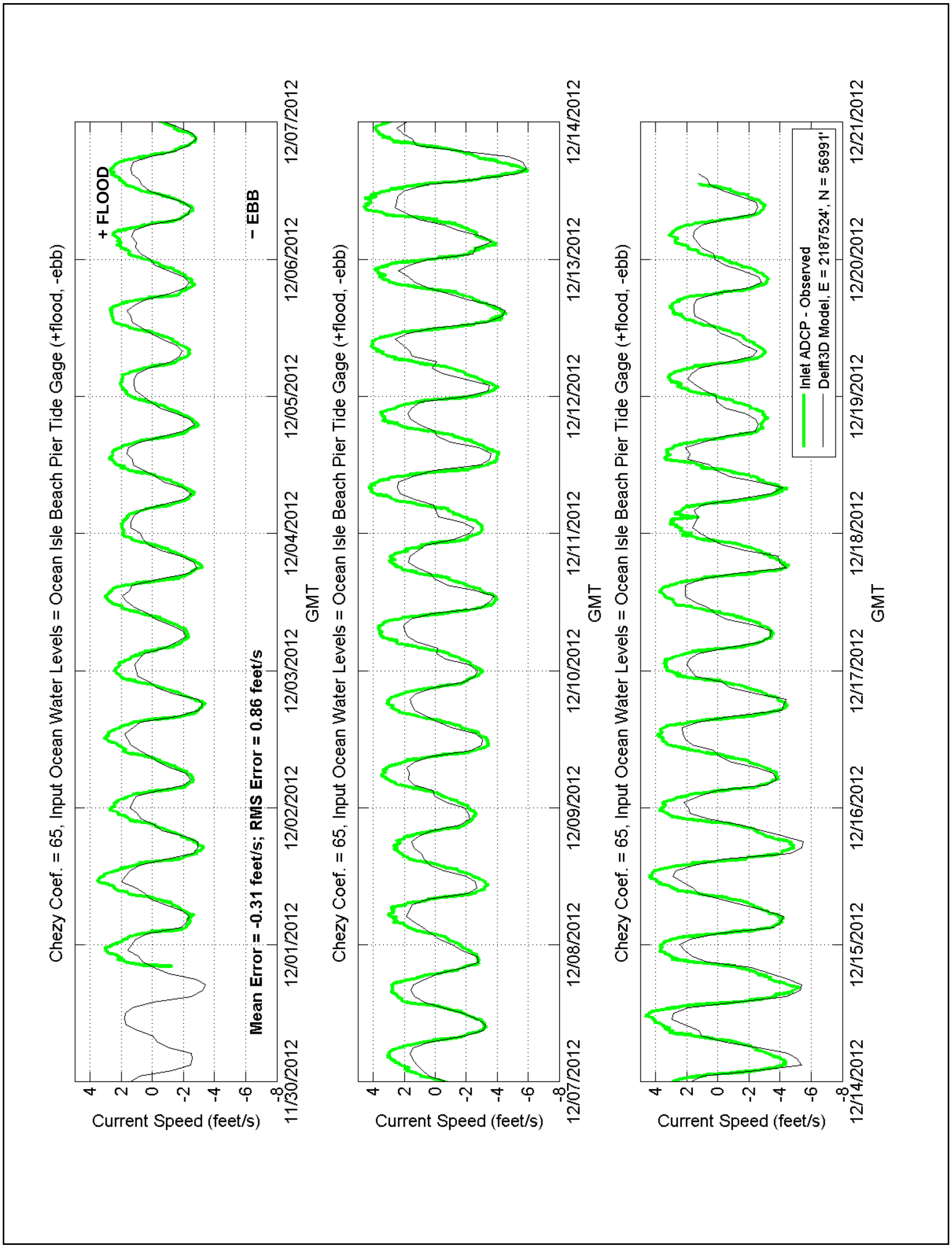

Figure 21: Simulated and Observed Currents near the Inlet ADCP during the Flow Calibration.

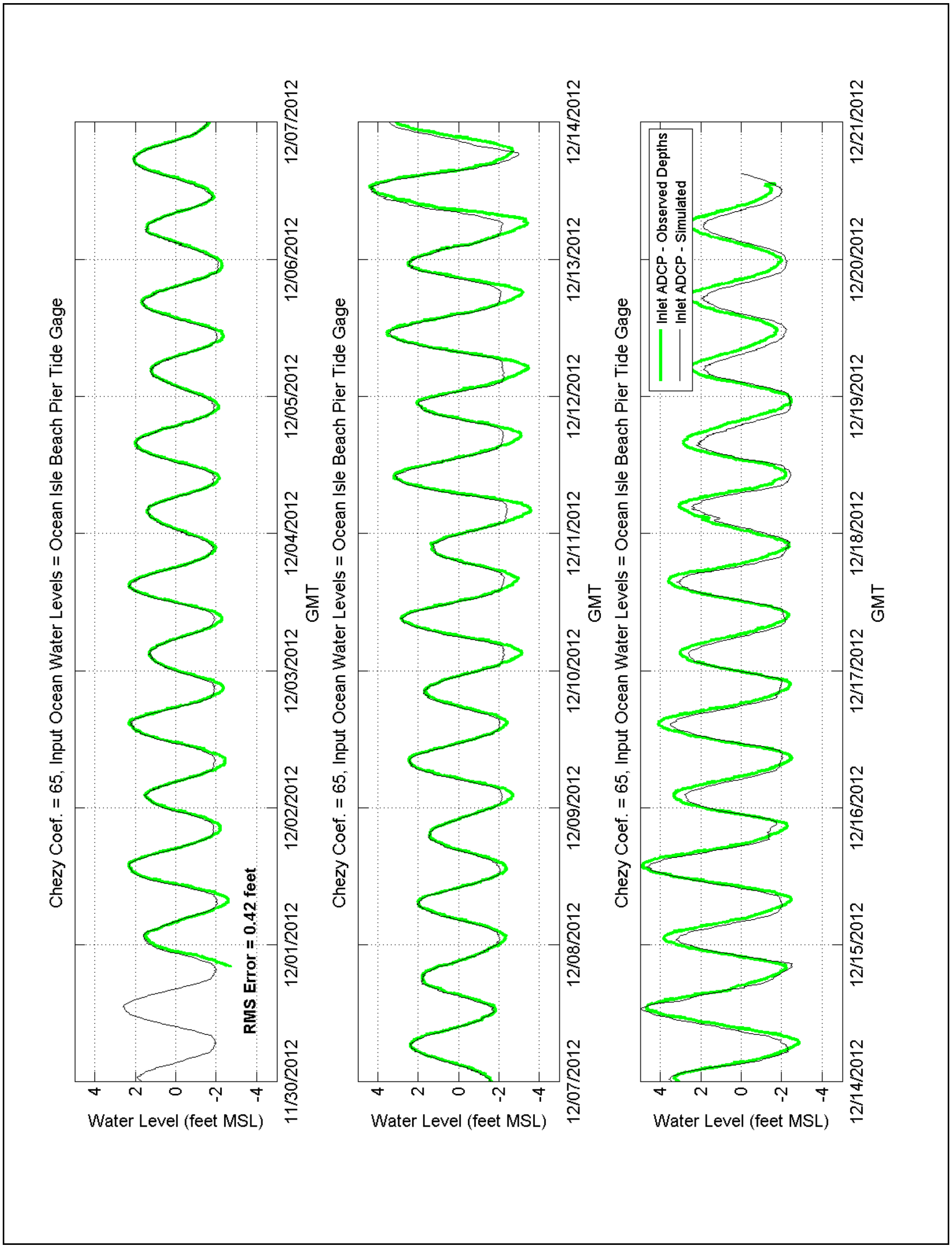

Figure 22: Simulated and Observed Water Levels at the Inlet ADCP.
(Note – Due to datum referencing issues at the tide gages (see Figure 18), values in this figure are shown in feet MSL, not feet NAVD)

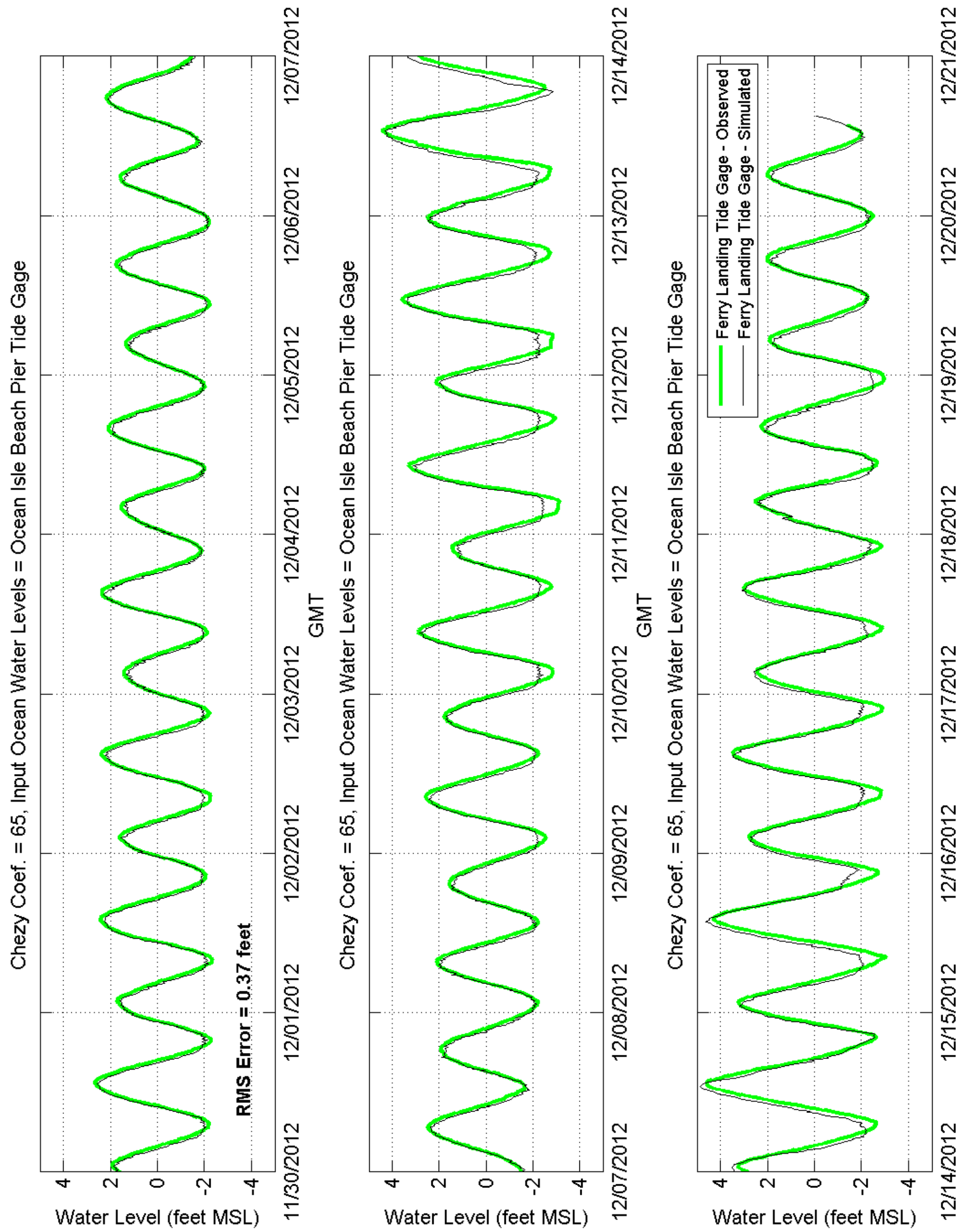

Figure 23: Simulated and Observed Water Levels at the Ferry Landing Tide Gage. (Note – Due to datum referencing issues at the tide gages (see Figure 18), values in this figure are shown in feet MSL, not feet NAVD)

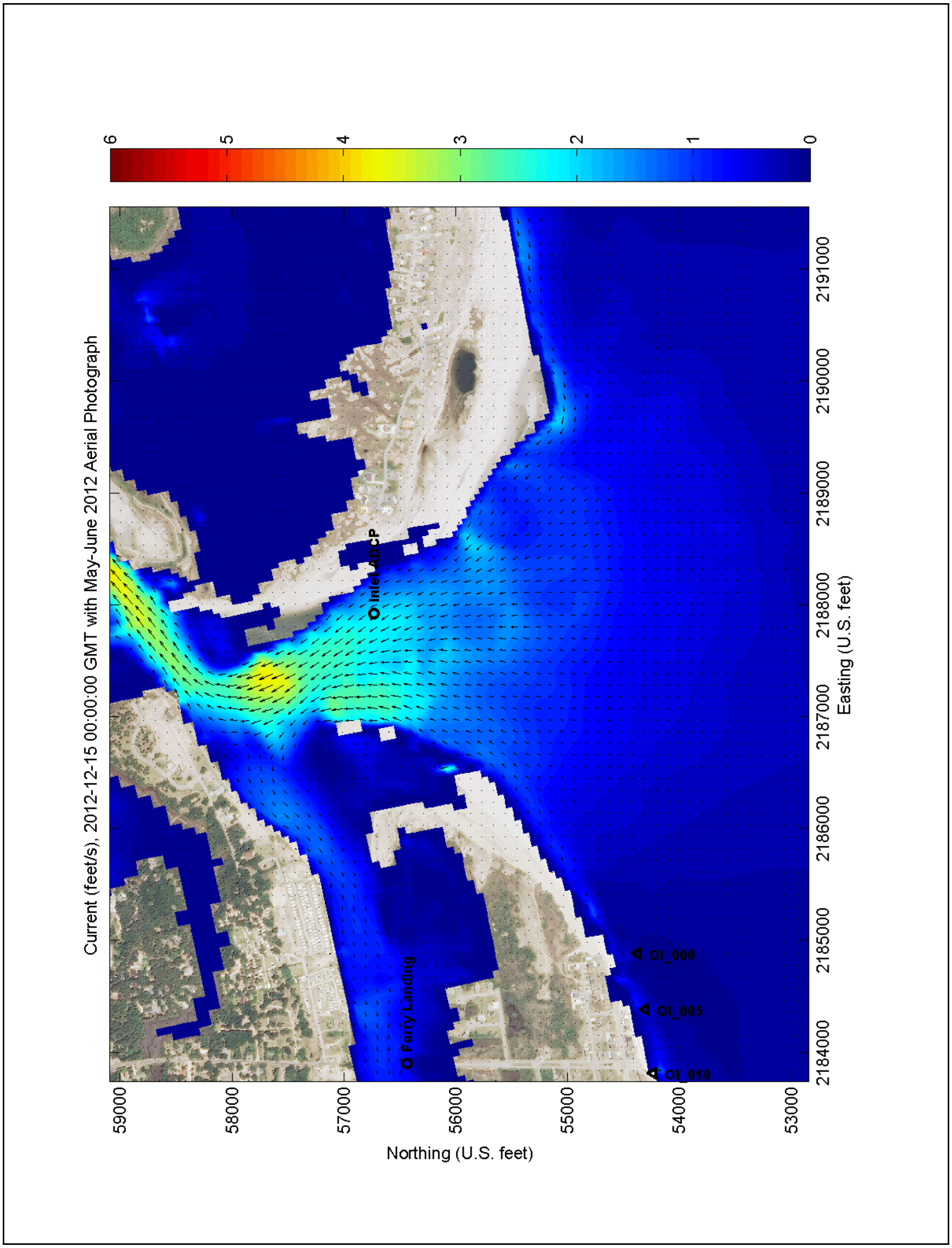

Figure 24: Typical Simulated Currents during Peak Flood.

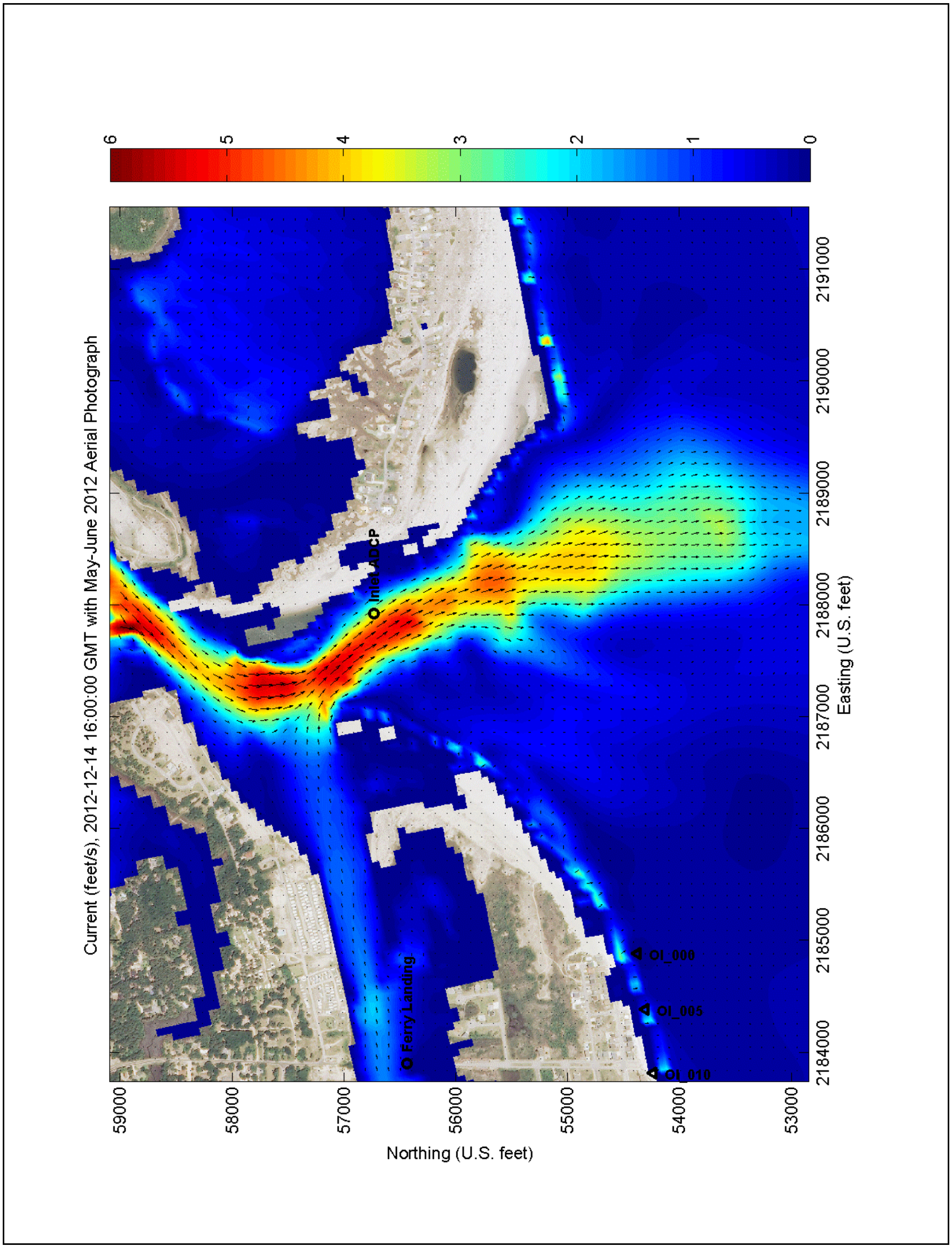

Figure 25: Typical Simulated Currents during Peak Ebb.

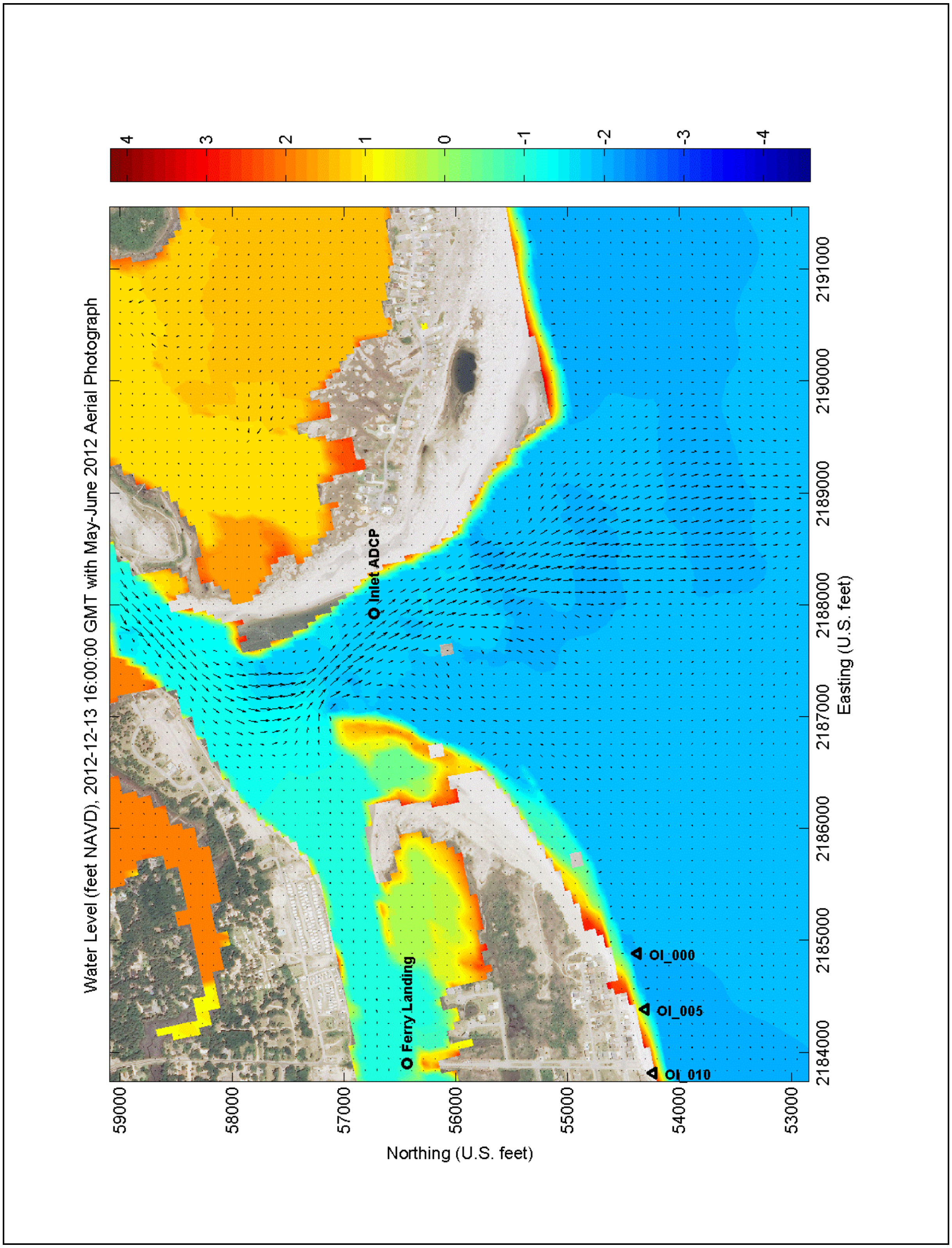

Figure 26: Typical Simulated Water Levels.

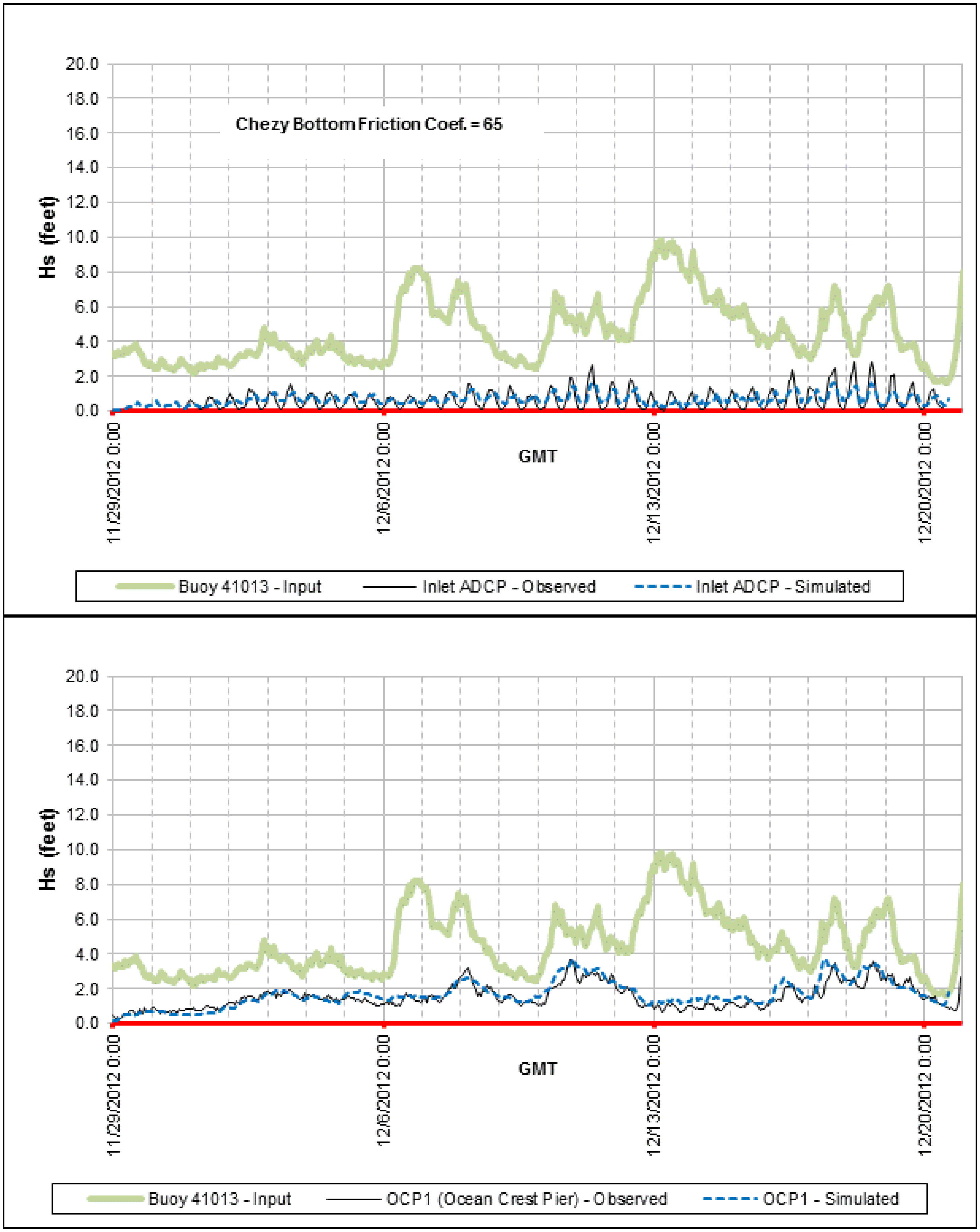

Figure 27: Typical Simulated and Observed Waves during the Flow Calibration.

5.3 Calibration of Sediment Transport, Erosion, & Deposition

Calibration of sediment transport, erosion, & deposition within the Delft3D-FLOW model was performed based on the volume changes between April 26, 2007 and April 26, 2010. This period of time began shortly after the 2006-2007 beach renourishment project, and ended immediately prior to the 2010 beach renourishment project.

Initial Bathymetry

The initial bathymetry was based on the April 2007 survey of Ocean Isle Beach, Shallotte Inlet, and Holden Beach. Areas outside the 2007 survey limits were filled using the July 2012 surveys of the AIWW, the 2011 and 1934 surveys of the Shallotte River, the January 2000 survey of Holden Beach, DEMs

The initial bathymetry was based on the following data sources (see also Table 2):

1. The April 2007 survey of Ocean Isle Beach, Shallotte Inlet, and Holden Beach.
2. The 2012 Atlantic Intracoastal Waterway (AIWW) surveys.
3. The 2011 Shallotte River survey.
4. The 2002 Oak Island survey.
5. The 2001 Oak Island survey.
6. The January 2000 Holden Beach and Oak Island surveys.
7. The 1934 Shallotte River survey.
8. North Carolina Floodplain Mapping program DEM.
9. The U.S. Coastal Relief Model.

The April 2007 survey was the primary data set. Grid points outside the area surveyed in April 2007 were covered by the other sources in the order listed above, with the U.S. Coastal Relief Model as the data set of last resort. The resulting bathymetry appears in Figure 28 and Figure 29. The primary features of the bathymetry near the project area are the Shallotte Inlet channel and the 2006-2007 borrow area, which was not completely dredged (see Figure 29).

Water Levels

Water levels on the offshore boundary of the flow grid were schematized in terms of a simple, sine-wave tide with a period of 12.4 hours, a mean tide level value of -0.6 feet NAVD, and an amplitude of 2.4 feet based the mean high water and mean low water elevations in **Table 5**.

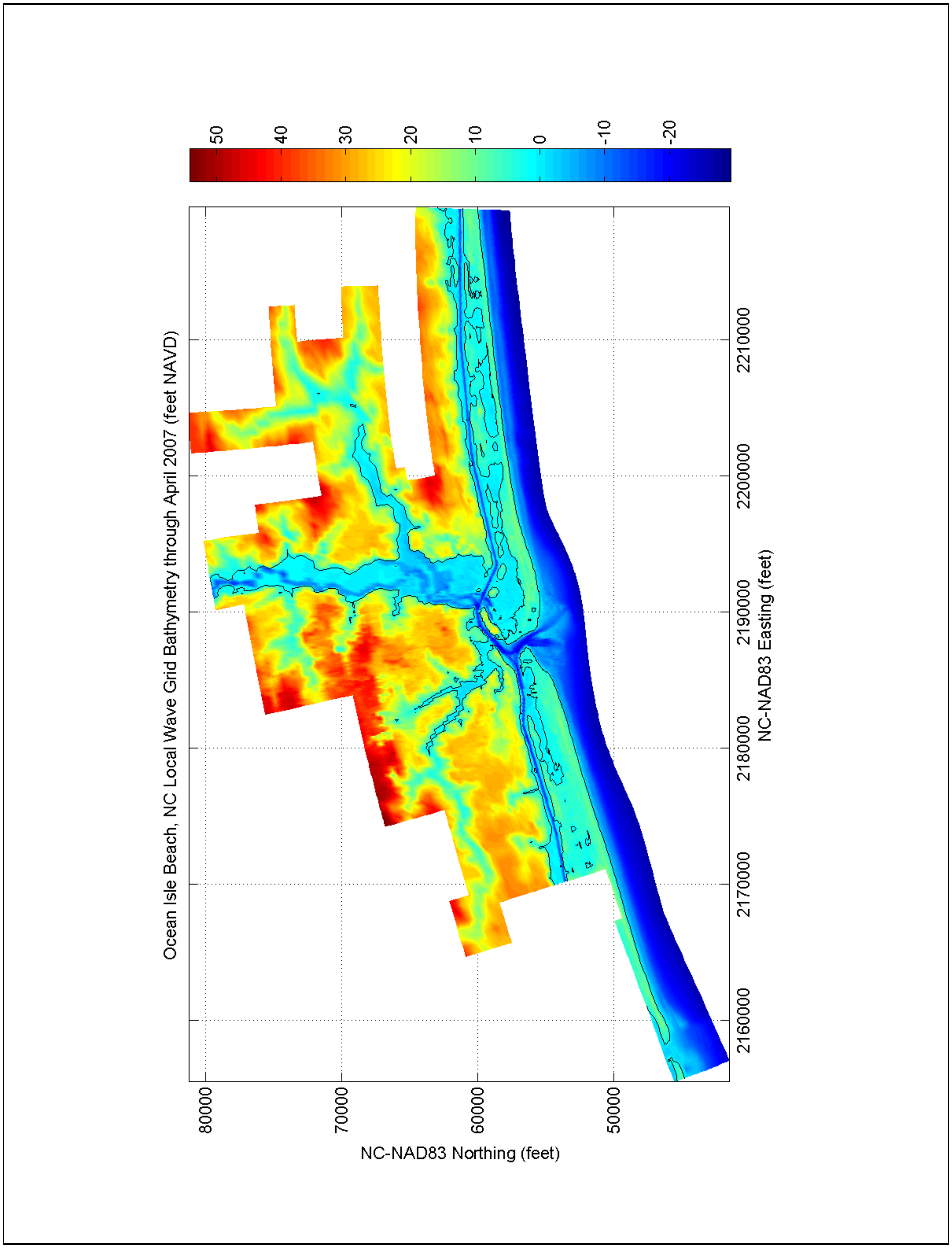

Figure 28: Initial Conditions Based on the April 2007 Survey.

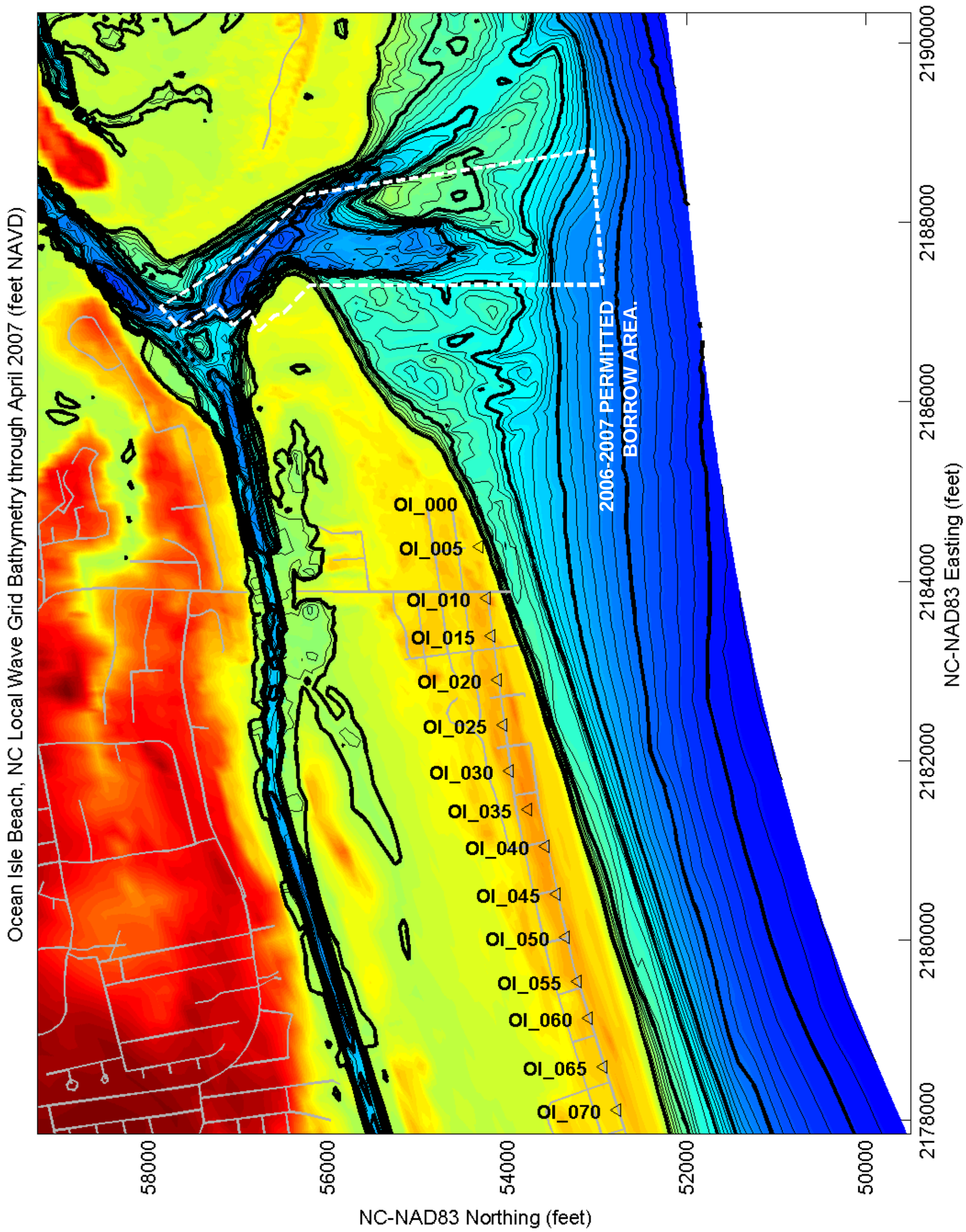

Figure 29: Initial Conditions Based on the April 2007 Survey (closeup).

Hypercube Method for Estimating Nearshore Waves

To develop wave cases using the wave record at NOAA Buoy 41013, a concurrent record of nearshore waves was developed at the Offshore ADCP location (see Table 3 and Figure 2). Due to the multi-year record length at NOAA Buoy 41013, modeling each hourly wave record using the SWAN model was not possible. As an alternative, the Hypercube technique has been developed by the Environmental Hydraulic Institute of the University of Cantabria, Spain (Instituto de Hidraulica Ambiental de la Universidad de Cantabria - IH Cantabria). It consists of simulating a large number of deep water wave cases in SWAN using different combinations of wave height, period, and direction that cover the entire ranges of these parameters (see Table 8). Using three-dimensional ("cube"), linear interpolation, a multi-year time series of the waves closer to the shoreline can be constructed based on the concurrent wave record further offshore and the SWAN results for each wave case (see Figure 30). This procedure is similar to the lookup method used to couple GENESIS to an external wave transformation model (Hanson & Kraus, 1989, p. 74). However, the number of wave cases is much larger; the total number of wave cases summarized in Table 8 is 901.

Table 8: Summary of Hypercube Wave Cases at NOAA Buoy 41013

Sign. Wave Height (m)	Sign. Wave Height (feet)	Peak Wave Period (sec.)	Wave Direction (deg.)
0.0	0.0	2	0.0
1.0	3.3	3	22.5
2.0	6.6	4	45.0
3.0	9.8	5	67.5
4.0	13.1	6	90.0
5.0	16.4	7	112.5
6.0	19.7	8	135.0
7.0	23.0	9	157.5
8.0	26.2	10	180.0
9.0	29.5	11	202.5
		12	225.0
		13	247.5
		14	270.0
		15	292.5
		16	315.0
		17	337.5
		18	360.0
		19	
		20	
		21	
		22	

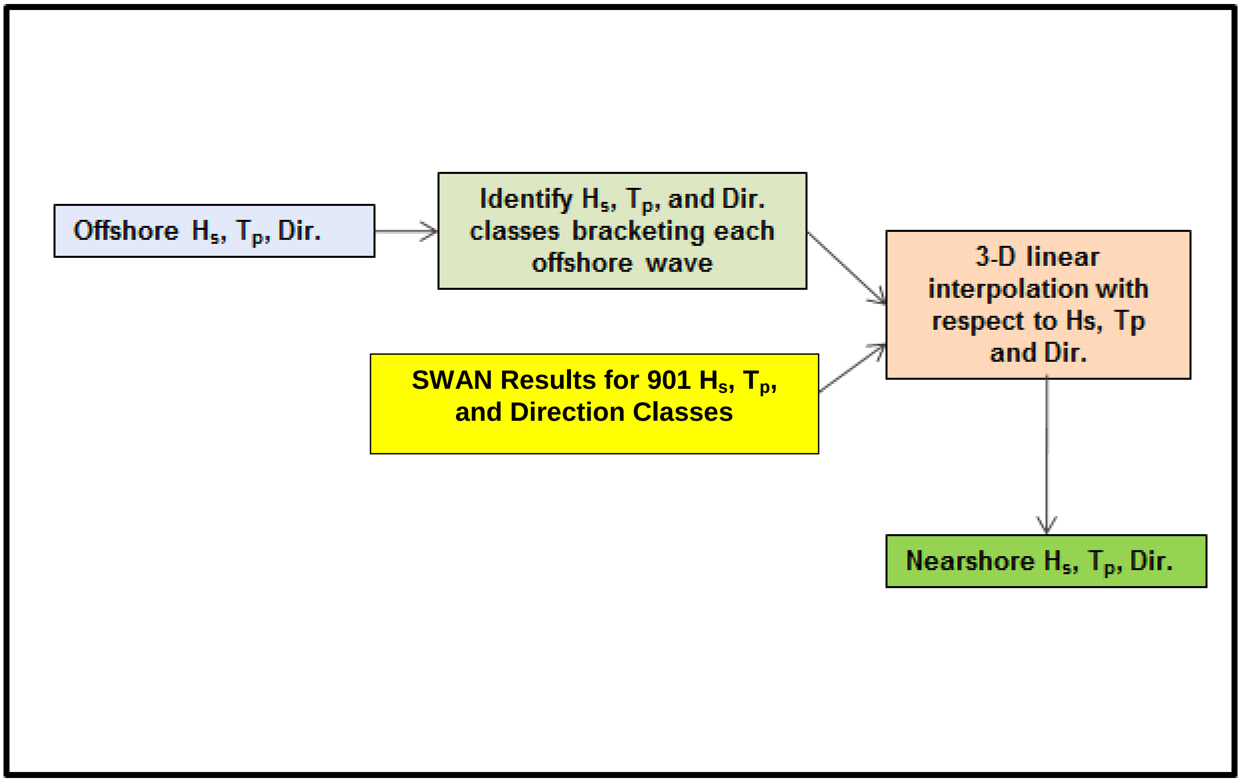

Figure 30: Schematic representation of the Hypercube methodology.

To approximate the multi-year wave record at the Offshore ADCP, the observed wave record at NOAA Buoy 41013 was reviewed to delineate the wave cases summarized in Table 8. An average wind velocity was added to each of the 901 wave cases used in the Hypercube analysis based on the winds that occurred during each wave case. As a first approximation, water levels were assumed to be equal to the mean tide level (-0.57 feet NAVD) for all cases.

Each of the 901 wave cases at NOAA Buoy 41013 was then run through the SWAN model to determine the corresponding wave height and direction at the Offshore ADCP. The SWAN model was run in stationary mode, which assumed that changes to the waves with respect to time were slow in comparison to the time required for a wave to travel the lengths of each grid. The multi-year wave record at NOAA Buoy 41013 and the SWAN model results were then fed into the lookup and interpolation algorithm in Figure 30 to estimate the concurrent wave heights and directions at the Offshore ADCP.

Typical results based on the Hypercube method appear in Figure 31. Due to the approximations that are required by the Hypercube method, the nearshore wave estimates do not follow the observed waves as closely as the calibration results appearing in Figure 13. However, for the purposes of selecting wave cases, the estimated waves using the lookup method are sufficient. Wave cases based on the 2007-2010 wave record at NOAA Buoy 41013 and the estimated wave record at the Offshore ADCP over the same period of time are discussed below.

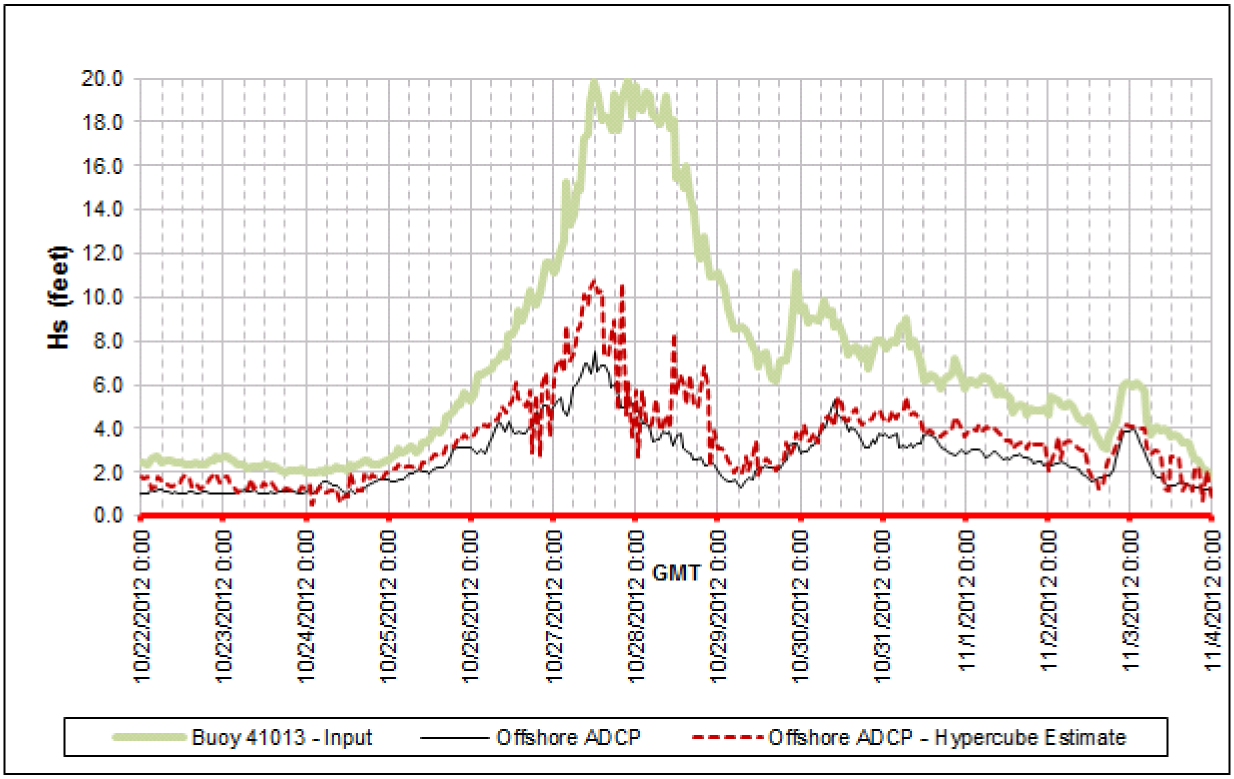

Figure 31: Typical Hypercube Results at the Offshore ADCP.

Wave and Wind Cases

To simulate 3 years of morphological change, a wave climate was developed using the offshore wave and wind record at NOAA Buoy 41013 (Figure 2). For each hourly wave record offshore:

1. A concurrent wave record at the Offshore ADCP location (Figure 2) was estimated using the Hypercube method detailed above.

2. The nearshore wave energy flux (P_n) at the Offshore ADCP was estimated based on the following:

   $P_n = E_n C_{gn}$ = nearshore wave energy in watts per m

   where:

   $E_n = \rho g H_{sn}^2$ = nearshore wave energy in Joules per m^2
   (3,600,000 Joules = 1 KW-hour)

   $C_{gn} = (1/2)(L_n/T_p)\{1 + [(4\pi d_n/L_n)/\sinh(4\pi d_n/L_n)]\}$
   = nearshore group wave velocity in m/s

$L_n = [gT_p^2/(2\pi)] \tanh(2\pi d_n/L_n)$ = wavelength in m at the Offshore ADCP

and:

ρ = seawater density = 1,025 kg/m^3 (63.99 lbm/$foot^3$)
g = gravity = 9.81 m/s^2 (32.2 feet/s^2)
H_{sn} = estimated significant wave height in m at the Offshore ADCP
T_p = peak wave period in seconds
d_n = depth in m at the Offshore ADCP

3. The amount of nearshore wave energy over each one hour (Δt = 3,600 seconds) sampling interval in KW-hour/m was estimated based on $P_n\Delta t$.

Based on the estimates above, the offshore direction bands generating 95% of the nearshore wave energy were identified, as shown in Figure 32. Waves originating from the north (7°) to the south-southeast (235°) at NOAA Buoy 41013 accounted for approximately 95% of the wave energy reaching the offshore ADCP between 2007 and 2010.

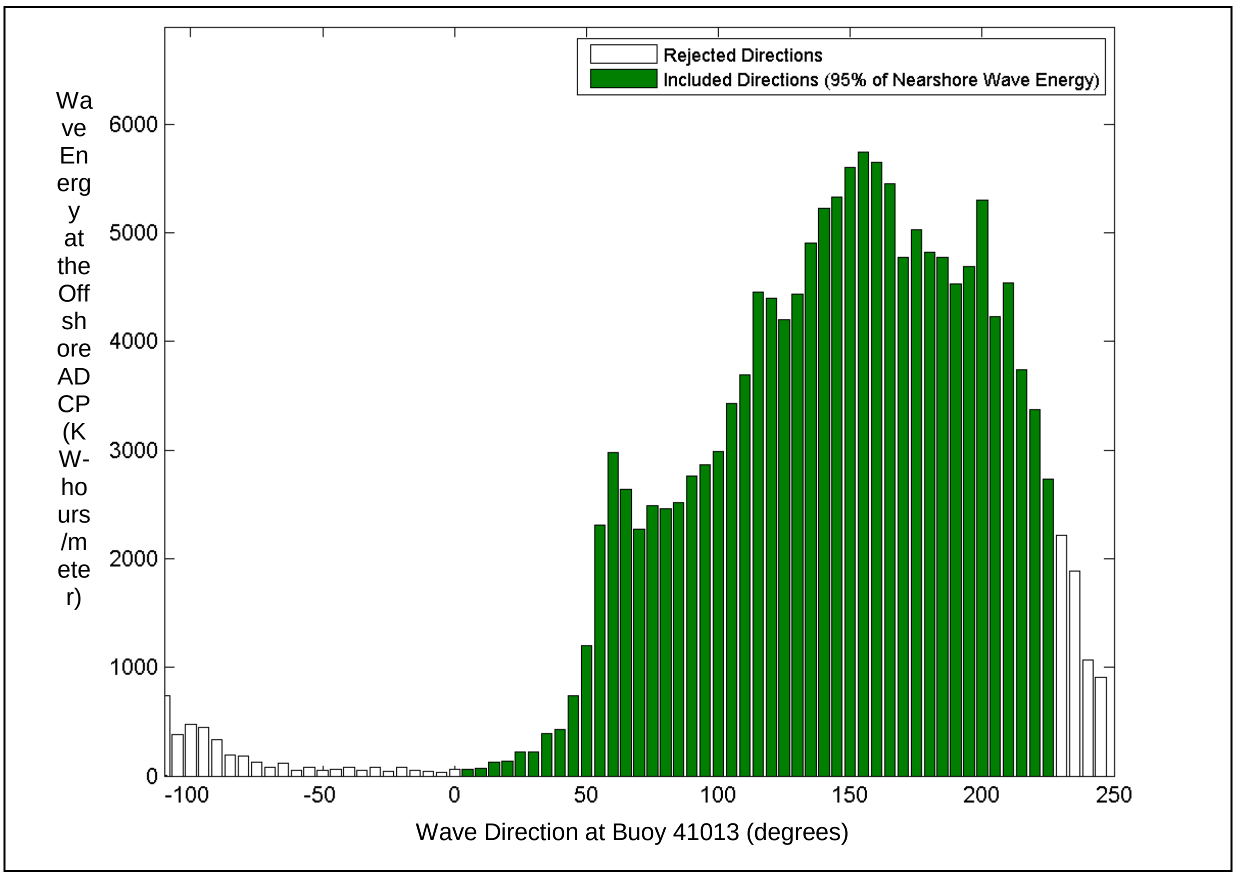

Figure 32: Portion of April 2007 to April 2010 Wave Record at Buoy 41013 Generating 95% of the Wave Energy at the Offshore ADCP.

The dark-colored wave records in Figure 32 were subsequently divided into 4 direction bands with 3 wave height classes each (see Figure 33 and Table 9). Based on the remaining wave records, a "Miscellaneous" wave case was then added to represent calm conditions and times during which the predominant wave directions offshore were from land to sea. Except for the "Miscellaneous" wave case, each wave case at NOAA Buoy 44013 represented a nearly equal amount of wave energy at the Offshore ADCP. However, since higher, more energetic waves occurred less often than lower waves, the various wave cases did not represent an equal portion of the wave record with respect to time (% occurrence).

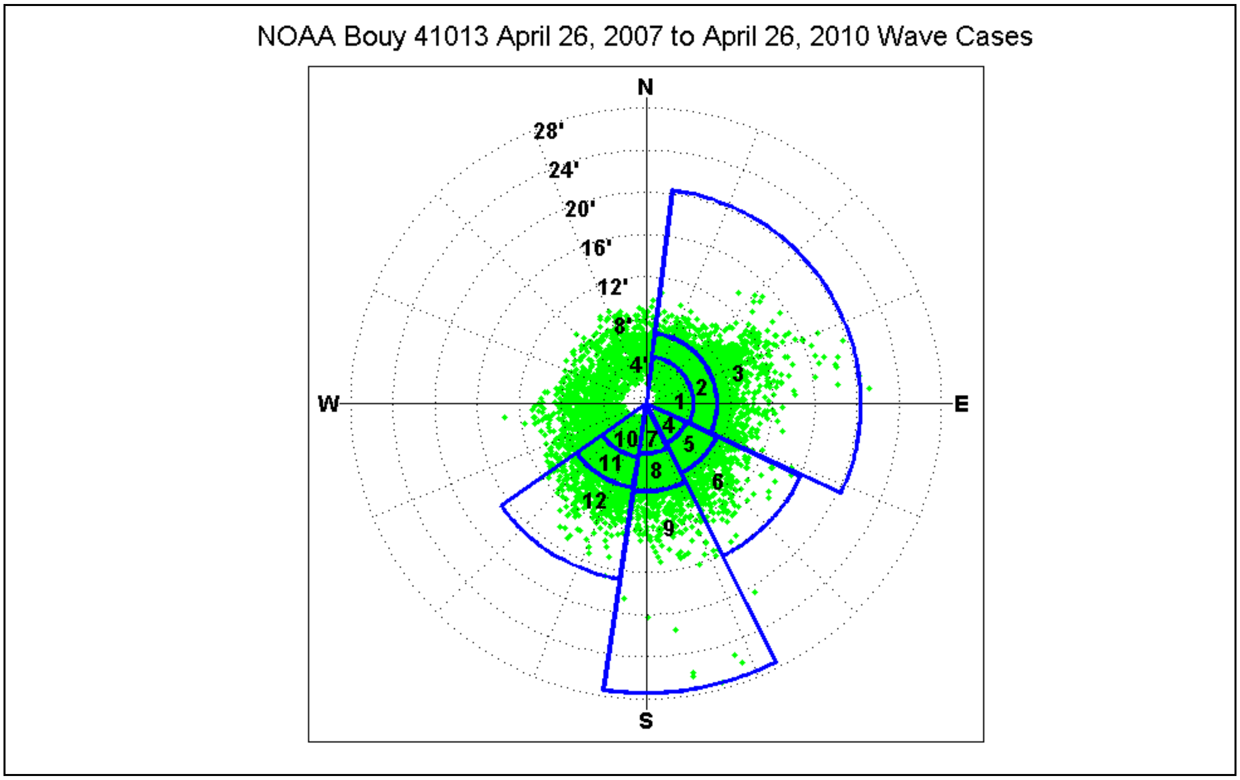

Figure 33: Wave Rose Showing Offshore Wave Cases Used in the Morphological Model Calibration.

Wind velocities during each wave case were averaged based on the concurrent wind records at NOAA Buoy 44013, and were assumed to be uniform over the model grids in Figure 2 and Figure 3. The default directional spreading value equivalent to 25 degrees was assumed for each wave case.

The sequencing of the wave cases was based on the time of the year that each case would be most likely to occur (see Table 9). Given the beginning of the calibration period (April 26, 2007), the June wave case #10 was the first wave case, followed by wave cases 7, 4, 2, 1, 3, 5, 6, 12, the "Miscellaneous" wave case, 11, 9, and 8. This sequence of wave cases was repeated 3 times, with each repetition representing one year.

Table 9: April 2007 to April 2010 Wave Cases

Case #	RMS Sign. Wave Height (feet)	Average Peak Wave Period (sec.)	Average Wave Direction (deg.)	Average Wind Speed (mph)	Average Wind Dir. (deg.)	Sign. Wave Height Range (feet)		Wave Direction Range (deg.)		Most Freq. Month	Percent Occur.	Days of Occur.	Days in Model	Morphological Acceleration Factor	
						Min.	Max.	Min.	Max.					Preliminary	Adjusted
1	3.3	8.8	85	11.4	52	0.0	4.5	7	115	Oct.	22.72	249	3.10	80.31	90.01
2	5.5	8.1	74	18.4	47	4.5	6.7	7	115	Sep.	11.18	123	1.55	79.06	88.61
3	9.2	8.5	72	27.5	47	6.7	20.4	7	115	Oct.	4.97	54	1.55	35.13	39.38
4	3.0	8.5	132	9.4	191	0.0	4.2	115	153	Aug.	15.82	173	3.10	55.91	62.67
5	5.7	8.6	133	14.8	153	4.2	7.4	115	153	Dec.	4.84	53	1.55	34.25	38.38
6	10.2	8.9	137	25.3	144	7.4	16.2	115	153	Dec.	1.47	16	1.55	10.40	11.66
7	3.4	7.5	169	12.4	226	0.0	4.7	153	189	July	12.26	134	1.55	86.71	65.11
8	6.4	8.0	171	17.5	225	4.7	8.3	153	189	April	3.55	39	1.55	25.08	18.83
9	12.0	9.4	169	26.8	209	8.3	27.5	153	189	March	1.22	13	1.55	8.62	6.47
10	3.9	6.0	209	16.1	249	0.0	5.1	189	235	June	10.32	113	1.55	72.98	54.81
11	6.5	7.2	210	21.9	256	5.1	8.1	189	235	Jan.	3.71	41	1.55	26.21	19.68
12	10.4	9.0	208	28.7	259	8.1	16.8	189	235	Dec.	1.60	18	1.55	11.32	8.50
Misc.	5.8	5.8	318	22.1	318	All		> 235 & < 7		Jan.	6.35	70	1.55	44.89	50.31

Morphological Acceleration Factors

To decrease the time needed for the morphological computation, morphological acceleration factors were used, as described in Lesser et al (2004) and Benedet and List (2008). The preliminary morphological acceleration factor M (Table 9, second-to-last column) was estimated according to the following:

$M = T_{study\ period} / T_{model\ period}$

where

$T_{study\ period}$ = (length of the study period) x (percent occurrence for each wave case)

$T_{model\ period}$ = duration of the wave case in the model simulation

For example, a wave case that occurs 14 days a year can be simulated over 24 hours with an M value of 14. With the Delft3D modeling community, it is common practice to use lower M values for high wave cases, when the most significant morphological changes occur, and higher M values for smaller wave cases, where little change takes place.

To better simulate the sediment transport rates occurring along the study area, the morphological acceleration factors were adjusted. Further details regarding that adjustment appear later in this section.

Bottom Sediments

The grain sizes of the bottom sediments govern both the type of sediment transport that occurs and the magnitude of the sediment transport. Fine-grained (d < 0.10 mm) sediments are commonly schematized as cohesive. Grain size information was gathered from the following sources (see **Table 10**):

Table 10: Sources of Bottom Grain Size Information

Samples	Location	Source
2013 Ocean Isle Beach Samples	OI_000 to OI_060	Present Study
2009 Core Samples	Shallotte Inlet	Freedom of Information Act Request (Fauser, 2013)
2005 Core Samples	Shallotte Inlet	Freedom of Information Act Request (Fauser, 2013)
1994 Core Samples	Shallotte Inlet & Tubbs Inlet	Freedom of Information Act Request (Fauser, 2013)
1998 Holden Beach Samples	Holden Beach	Freedom of Information Act Request (Fauser, 2013)
1994 Ocean Isle Beach Samples	OI_040 to OI_130	Freedom of Information Act Request (Fauser, 2013)
USGS Coastal and Marine Geology Program Internet Map Server	Offshore Areas	USGS (2013)

In most of the data sets in **Table 10**, the percentages of fine-grained materials were small. Accordingly, the bottom sediments were schematized as non-cohesive materials. Using the grain size information from the sources above, several mappings of the mean grain size variation were developed as a function of location, initially by triangulating the mean grain sizes of the samples in phi units. To allow for a variable grain size in the model, the grain size variation was summarized as two sediment fractions whose grain sizes were equal to the minimum and maximum values of the mean grain size in phi units:

$$\phi_{mean} = (\phi_{coarsest} P_{coarsest} + \phi_{finest} P_{finest}) / 100\%$$

$$P_{coarsest} + P_{finest} = 100\%$$

where

ϕ_{mean} = Mean grain size in phi units as a function of location
$\phi_{coarsest}$ = Coarsest value of ϕ_{mean} (minimum phi size) over the model grid
ϕ_{finest} = Finest value of ϕ_{mean} (maximum phi size) over the model grid
$P_{coarsest}$ = Percentage of material equal to the coarsest grain size a function of location
P_{finest} = Percentage of material equal to the finest grain size a function of location

Given a known value of the mean grain size ϕ_{mean}, along with the known values of $\phi_{coarsest}$ and ϕ_{finest}, there were two unknown values to determine at any given location – $P_{coarsest}$ and P_{finest}. Using the two equations above, the two unknown values could readily be determined at any location within the model grid. Over successive calibration runs, the variation of the mean grain size was adjusted to better fit the simulated bathymetric and volume changes to the observed bathymetric and volume changes. The final variation of the mean grain size appears in Figure 34 and Figure 35, with the corresponding values of $P_{coarsest}$ and P_{finest} in Figure 36 and Figure 37.

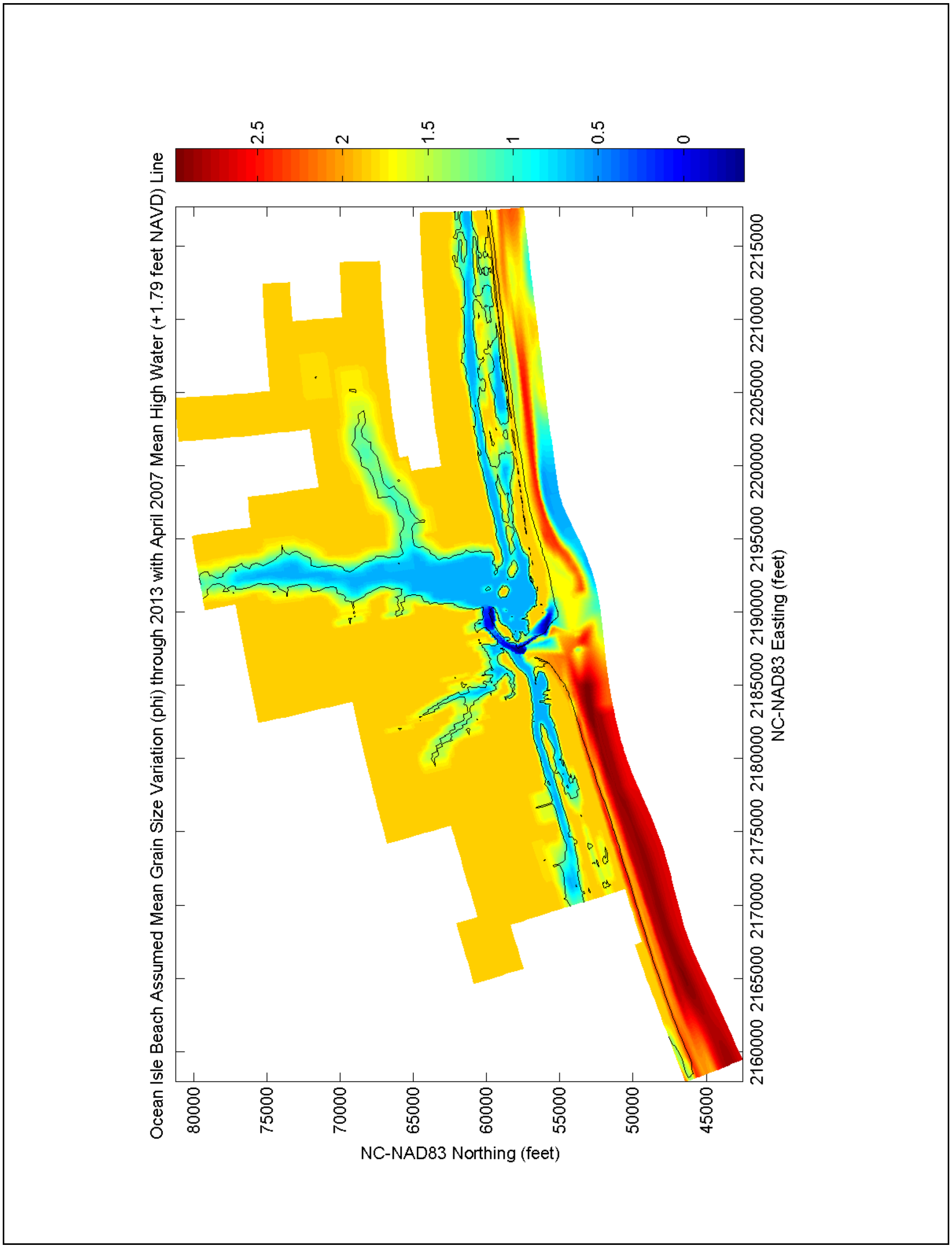

Figure 34: Final Variation of the Mean Grain Size in Phi Units with Respect to Location.

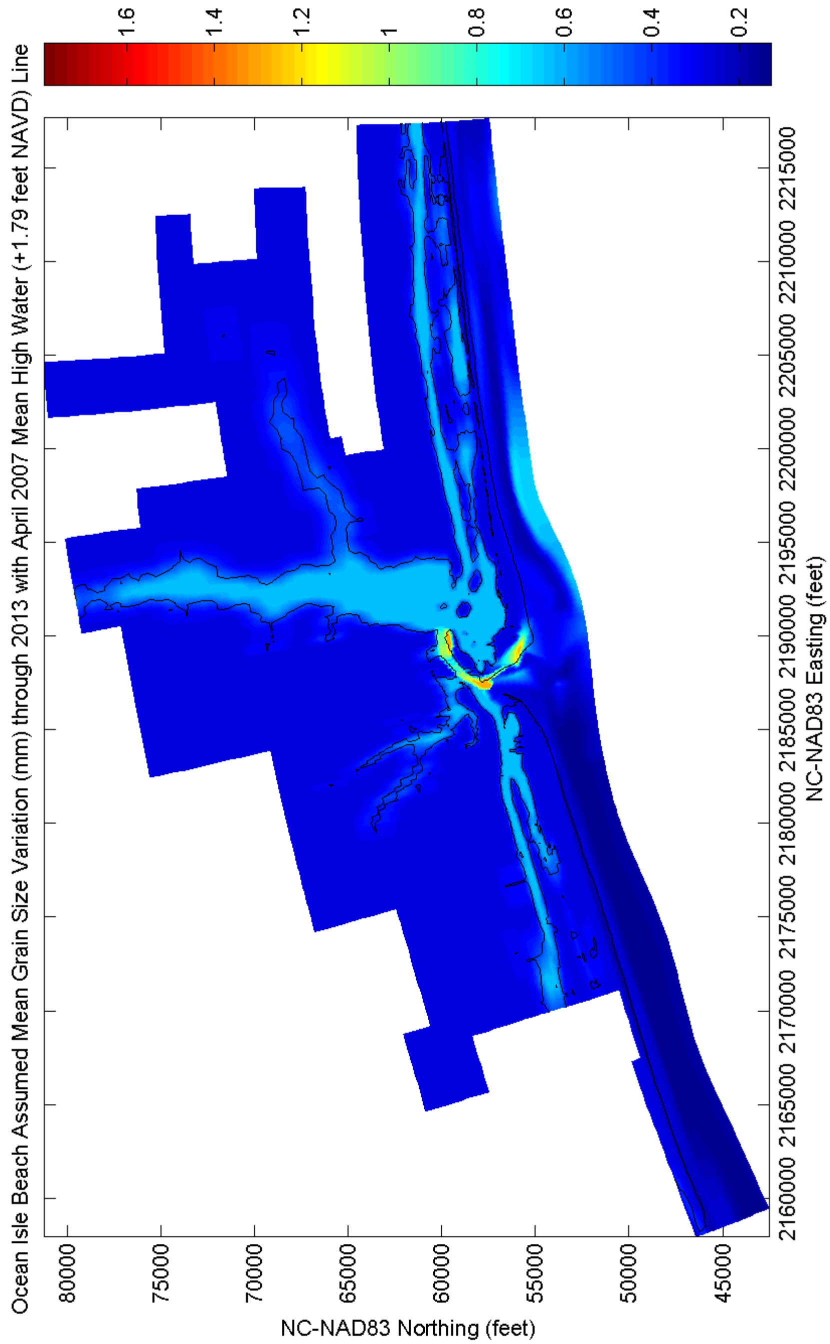

Figure 35: Final Variation of the Mean Grain Size in mm with Respect to Location.

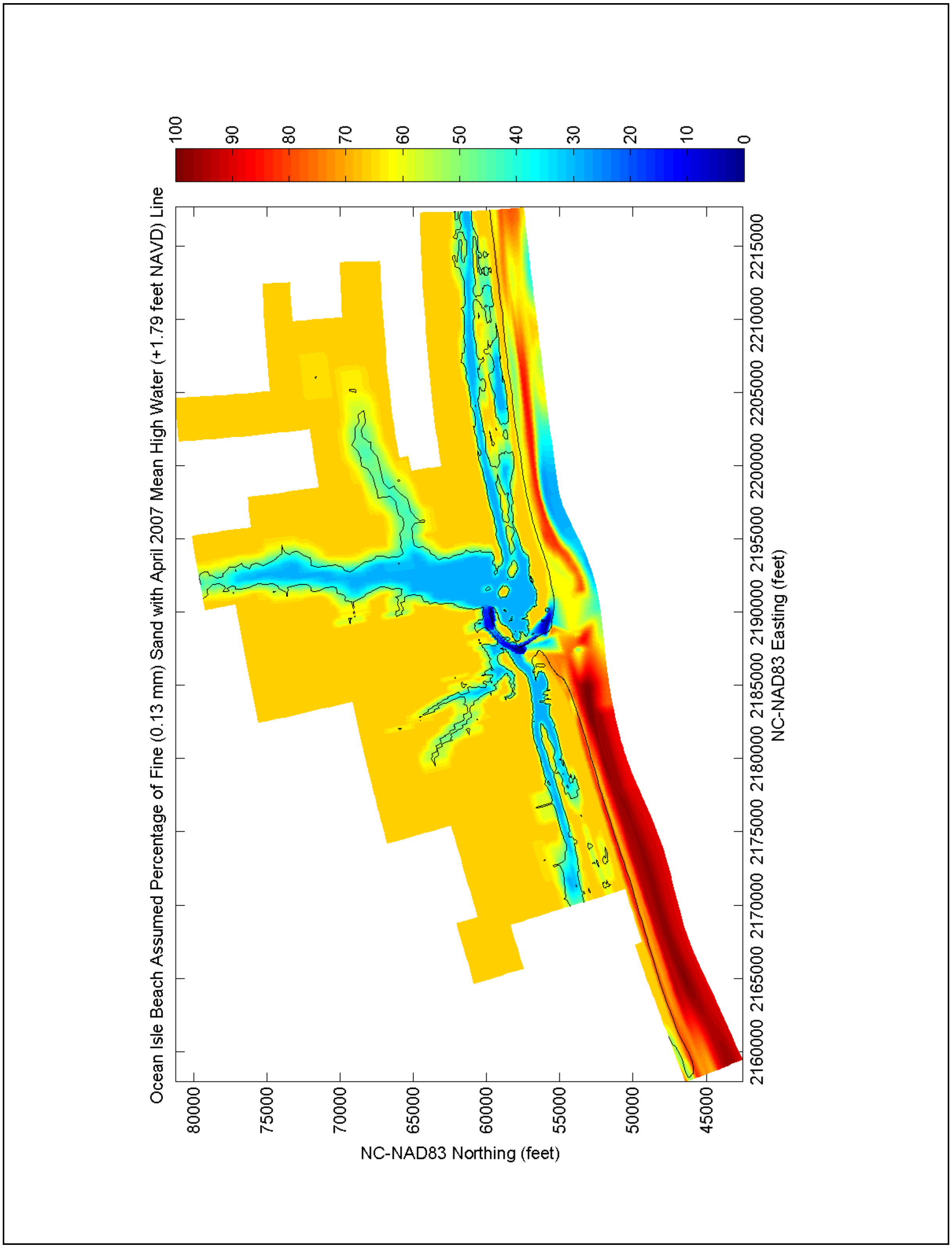

Figure 36: Final Variation of the Fine Sand Fraction with Respect to Location.

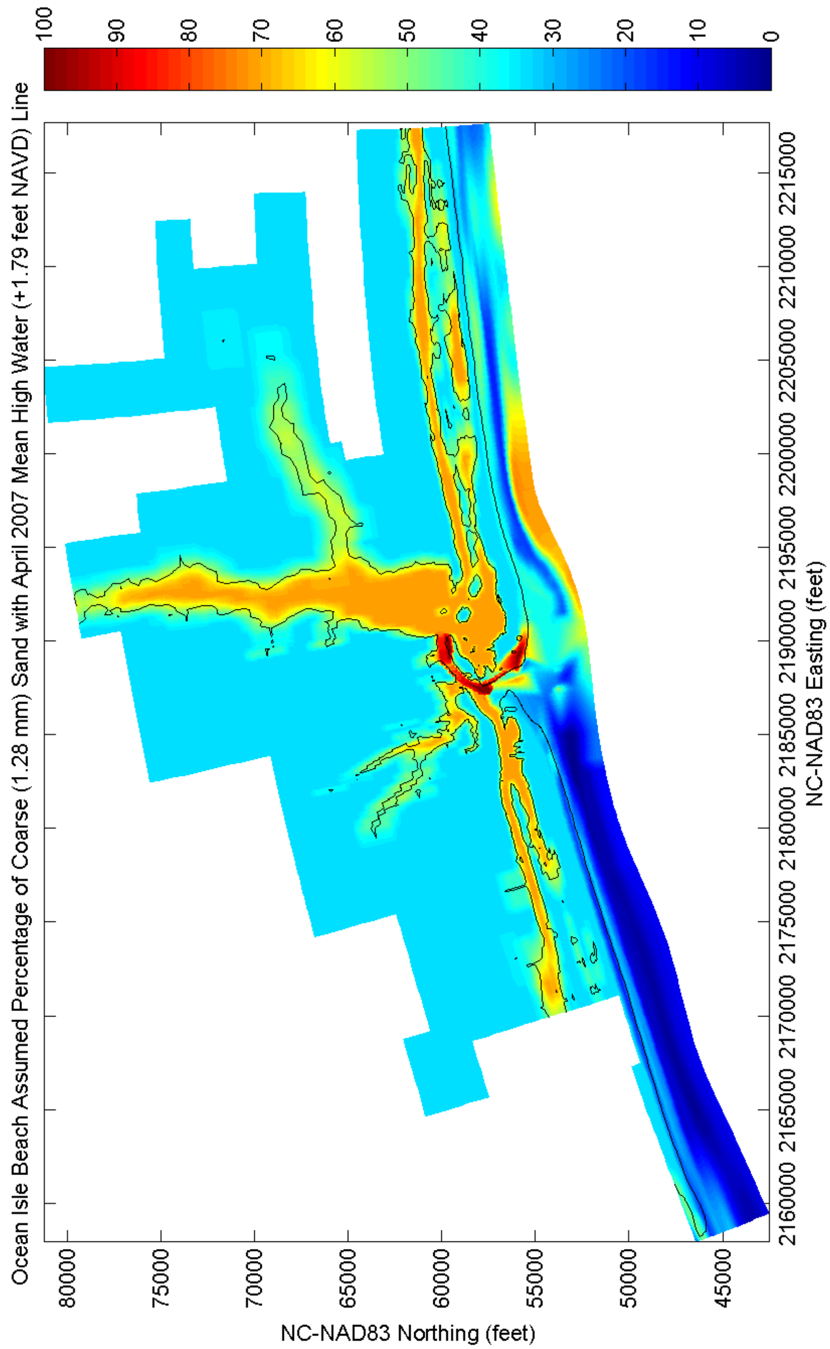

Figure 37: Final Variation of the Coarse Sand Fraction with Respect to Location.

Model Calibration and Results

Calibration of sediment transport, erosion, & deposition within the Delft3D-FLOW model was performed in terms of the volume changes above -18 feet NAVD between the April 2007 and April 2010 beach surveys (see Figure 38 through Figure 40). As an additional check, the bathymetry and bathymetric changes were evaluated in Shallotte Inlet. Since the April 2010 surveys only covered a small portion of the inlet, bathymetry and bathymetric changes in Shallotte Inlet were evaluated based on the April 2009 survey using the model results of the 2/3 of the way through completion (see Figure 41 and Figure 42). To improve the fit between the model results and the observed changes, the following model inputs were examined:

- <u>The variation of the mean grain size</u>. Four different variations of the mean grain size versus location were used. The final variation of the mean grain sizes appears in Figure 34 through Figure 37.

- <u>The selection of the wave cases</u>. Some researchers (Walstra, 2011) have suggested using the "CERC Equation" (USACE, 1990) or other longshore transport formulae to assist in the selection of wave cases (Walstra, 2011). Selecting wave cases based on "CERC Equation" (USACE, 1990) did not appear to improve the results. Accordingly, the method outlined earlier was utilized. The resulting wave cases used in the final calibration appear in Table 9.

- The values of the following model parameters:

    - <u>BED & SUS</u>: These two values govern sediment transport due to currents, including wave-driven currents. Of the various constants in the Delft3D-FLOW model, these value have the largest influence on the sediment transport, erosion, and accretion rates, and typically range from 0.5 to 2.0. The final values adopted for the study area were BED = SUS = 1.00

    - <u>BEDW & SUSW</u>: These two values govern the sediment transport associated with the orbital motions that waves generate over the water depth at a given location. Higher values of BEDW and SUSW tend to increase onshore-directed sand transport and nearshore bar formation. Typical value of BEDW & SUSW range from 0 to 0.3, but tend to be smaller in most studies. The final values adopted for the study area were BEDW = SUSW = 0.0125.

    - <u>Horizontal Eddy Viscosity and Eddy Diffusivity</u>: These two values govern the horizontal, diffusive spreading of momentum and materials, respectively. Higher values of either parameter increase the degree of diffusive spreading. In the case of eddy diffusivity, increased spreading of material results in smoother bathymetric contours. The default values of the horizontal eddy viscosity and eddy diffusivity are 1 and 10 m^2/s, respectively. The final values adopted for this study were an eddy viscosity of 4 m^2/s, and an eddy viscosity of 1 m^2/s.

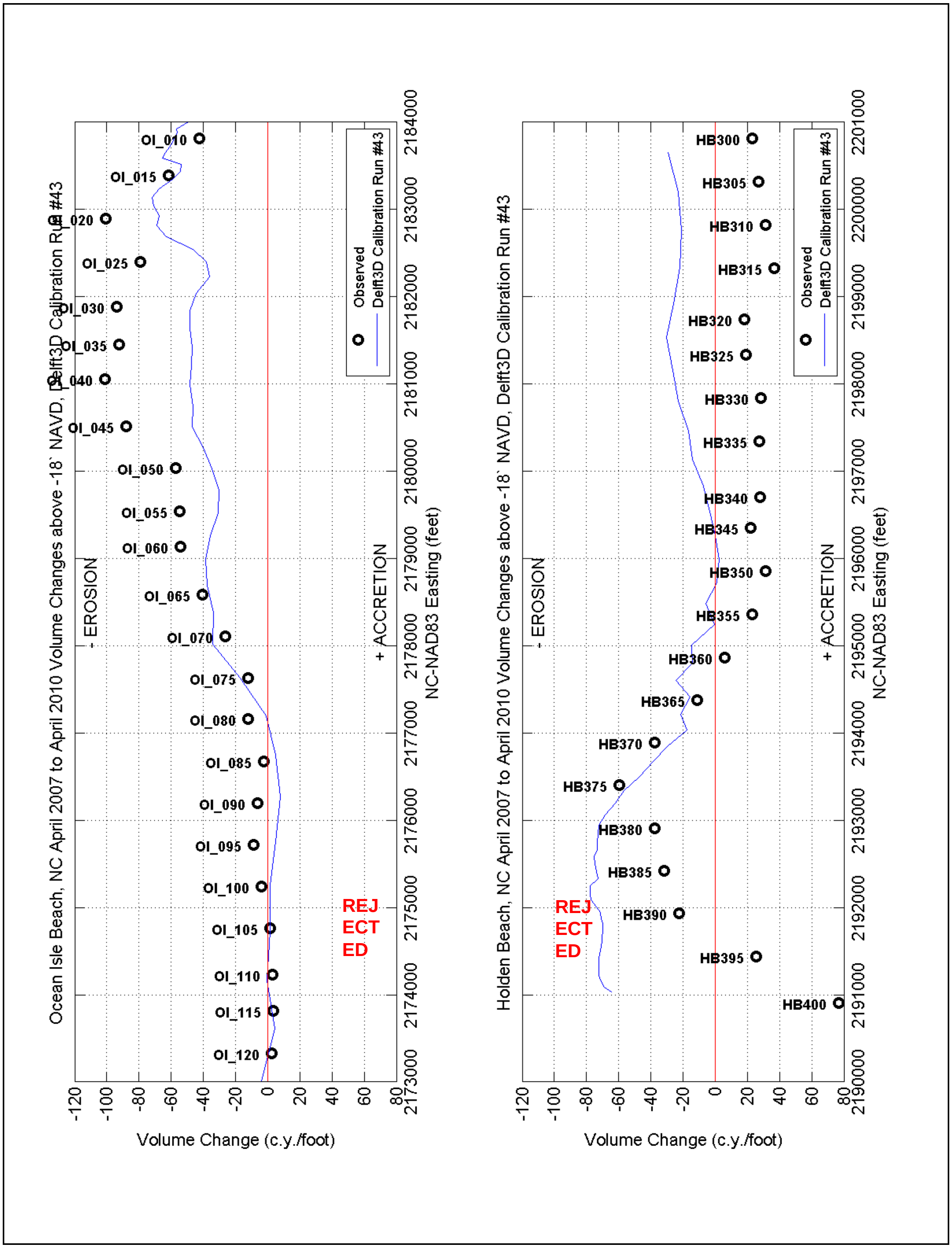

Figure 38: Simulated and Observed Volume Changes above -18 feet NAVD between April 2007 and April 2010 Given Calibration Run 43 (Rejected).

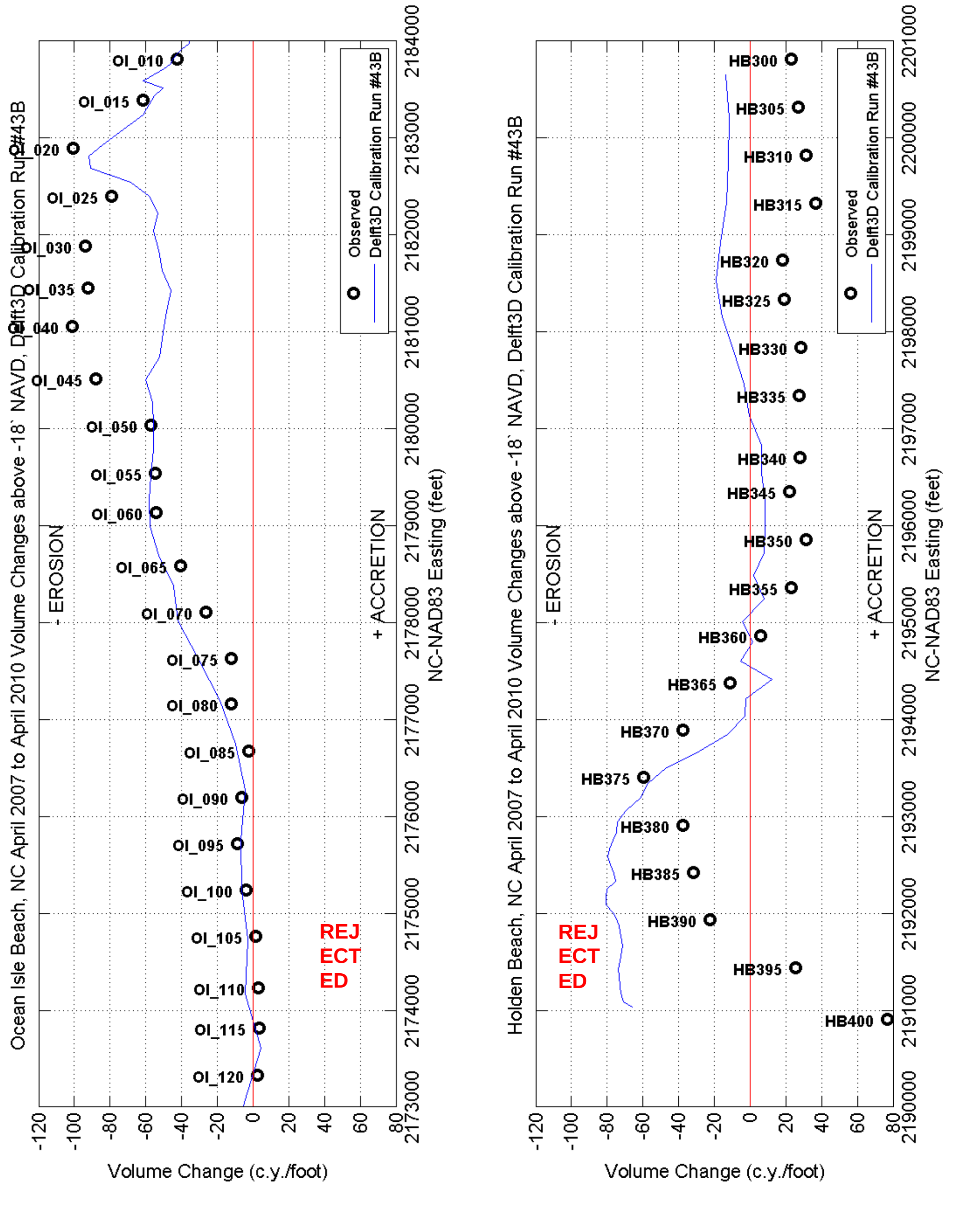

Figure 39: Simulated and Observed Volume Changes above -18 feet NAVD between April 2007 and April 2010 Given Calibration Run 43B (Rejected)

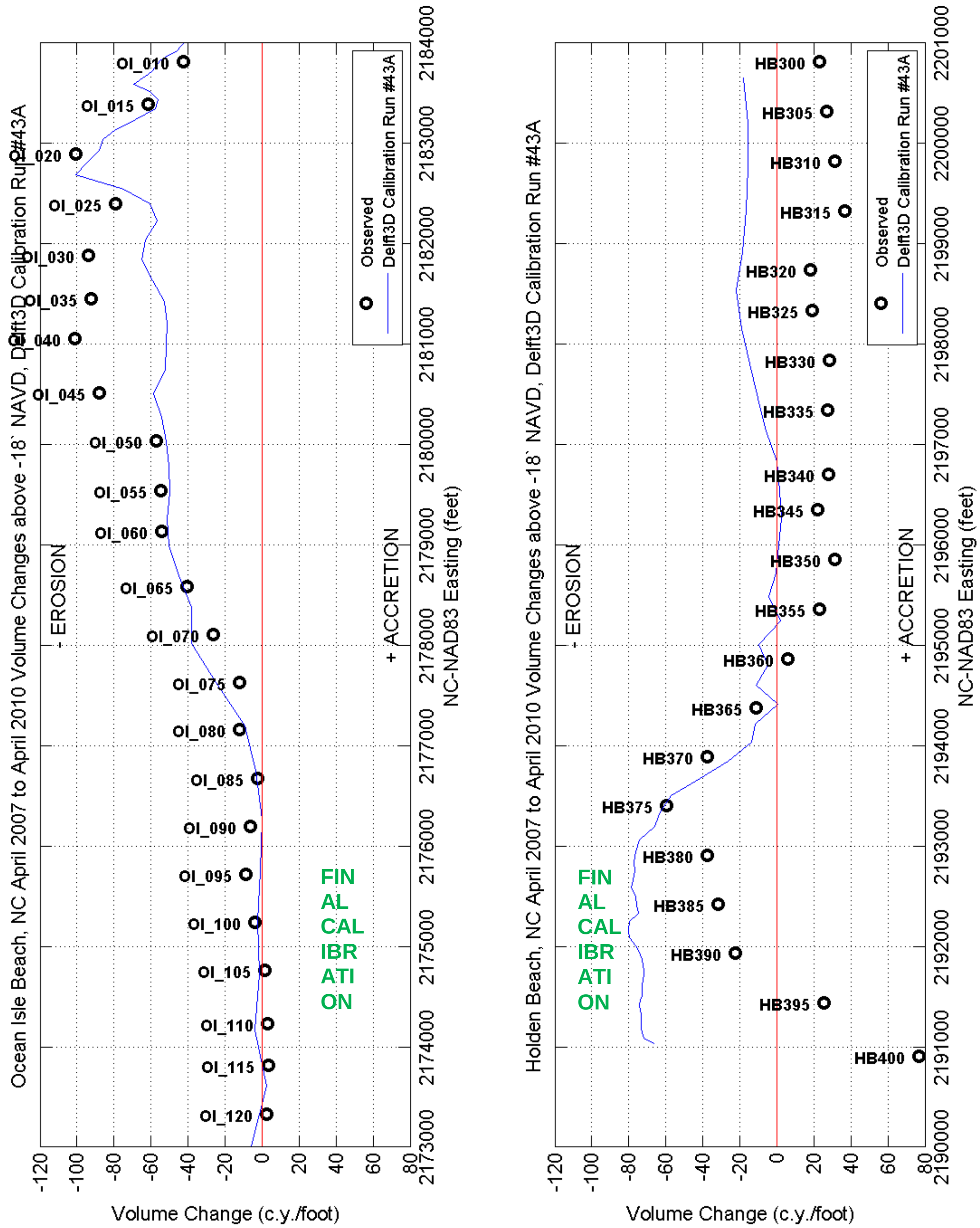

Figure 40: Simulated and Observed Volume Changes above -18 feet NAVD between April 2007 and April 2010 Given Calibration Run 43A (Final Calibration).

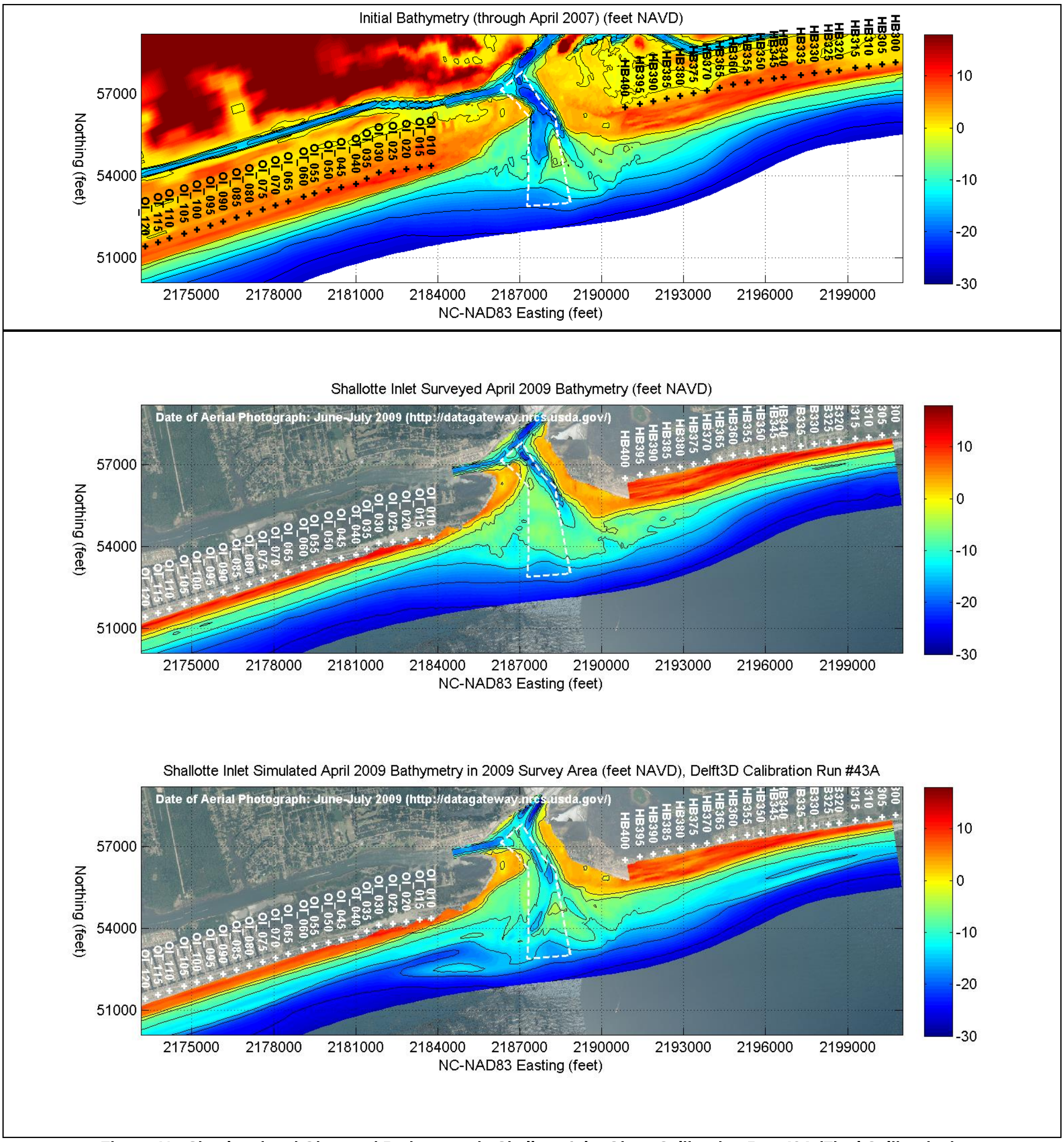

Figure 41: Simulated and Observed Bathymetry in Shallotte Inlet Given Calibration Run 43A (Final Calibration).

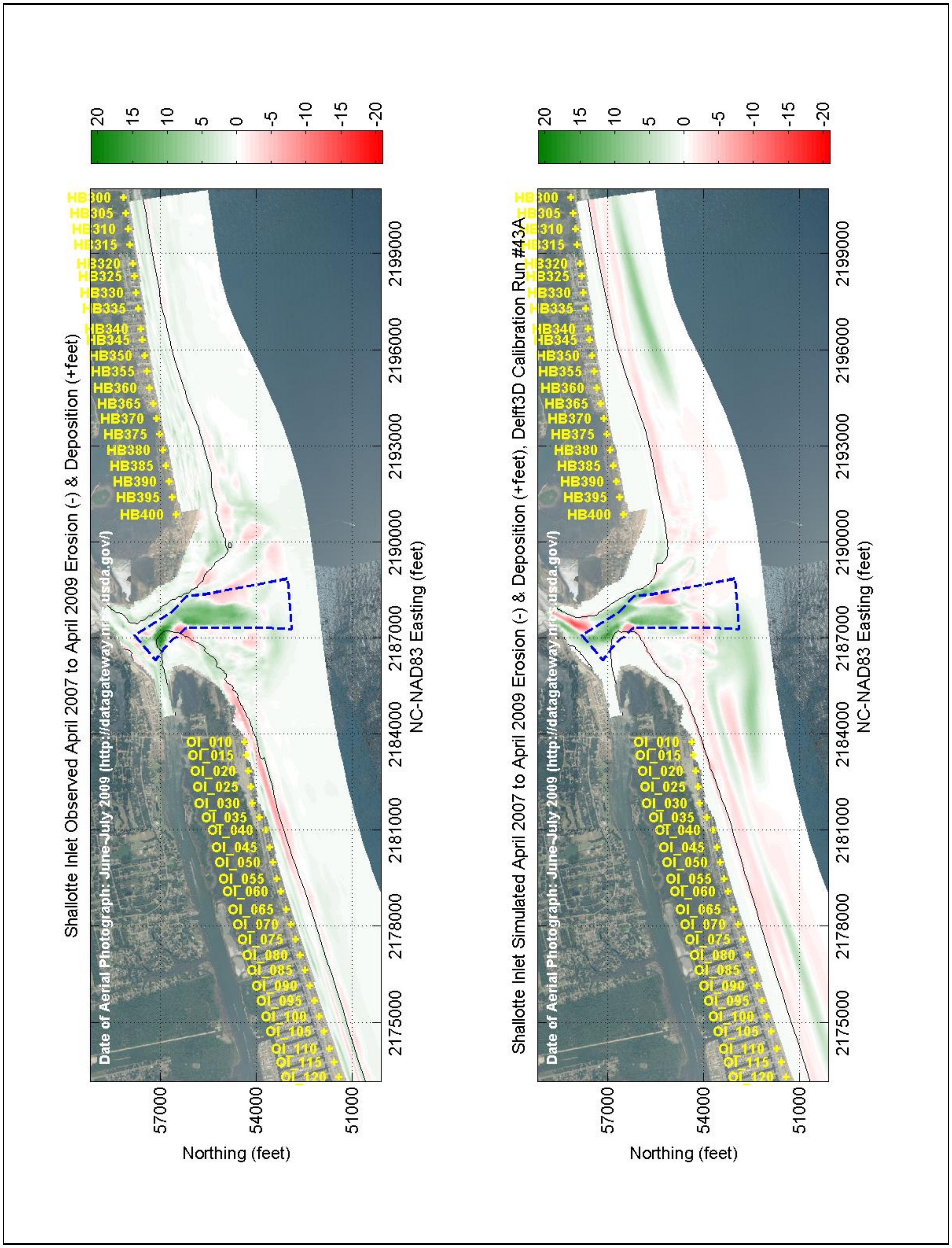

Figure 42: Simulated and Observed Bathymetric Changes in Shallotte Inlet Given Calibration Run 43A (Final Calibration)

- The values of the morphological acceleration factors. In some cases, the morphological acceleration factors can be adjusted to provide for more realistic sediment transport rates. In general, sediment transport along Ocean Isle Beach occurs in both directions – from east to west and from west to east. However, most sources have estimated the net sediment transport direction to be from east to west along the majority of Ocean Isle Beach (CPE, 2012; Thompson, Lin, and Jones, 1999; Offshore and Coastal Technologies).

  Many of the model simulations were able to estimate some of the general erosion patterns (see Figure 38). However, the net longshore transport based on the model results was from west to east, even along the midpoint of Ocean Isle Beach (see Figure 43, dotted line). To increase the amount of sediment transport from east to west, the morphological acceleration factors were adjusted by:

    - Increasing the values for wave cases 1-6 and the "Miscellaneous" case by 12%. Wave cases 1-6 were generally associated with sediment transport from east to west.

    - Decreasing the values for wave cases 7-12 by 25%. Wave cases 7-12 were generally associated with from west to east.

  The resulting values of the morphological acceleration factor appear in the last column of Table 9. Adjusting the morphological acceleration factors enabled the model to estimate net littoral drift from east to west along the midpoint of Ocean Isle Beach (see Figure 43, thin, solid line). Although the nodal point estimated by the model was located further west than the sediment budget would suggest (see Figure 43, thin and fat solid lines), the adjustment improved the model results as a whole (compare Figure 38 versus Figure 40).

  Larger adjustments morphological acceleration factors were also considered. While these adjustments moved the nodal point closer to Profile OI_090 (see Figure 43, fat, solid line and dashed line), they did not improve the fit between the observed and simulated volume changes along Ocean Isle Beach (compare Figure 39 versus Figure 40). Based on this finding, the morphological acceleration factors in the last column of Table 9 were adopted as the final values.

Model results given the final calibration run 43A appear in Figure 40 through Figure 43. Overall, the model is able to reproduce the general erosion patterns along Ocean Isle Beach – high erosion rates from Shallotte Inlet to Profile OI_065 (Chadbourn Street) with stable beaches further to the west (see Figure 40). On Holden Beach, the model is able to estimate high erosion rates along the west end of the island (HB365 to HB390), although it does not follow the observed erosion pattern exactly (see Figure 40). Further to the east (HB300 to HB360), the model suggests a stable beach, while the 2007 and 2010 surveys indicate mild accretion.

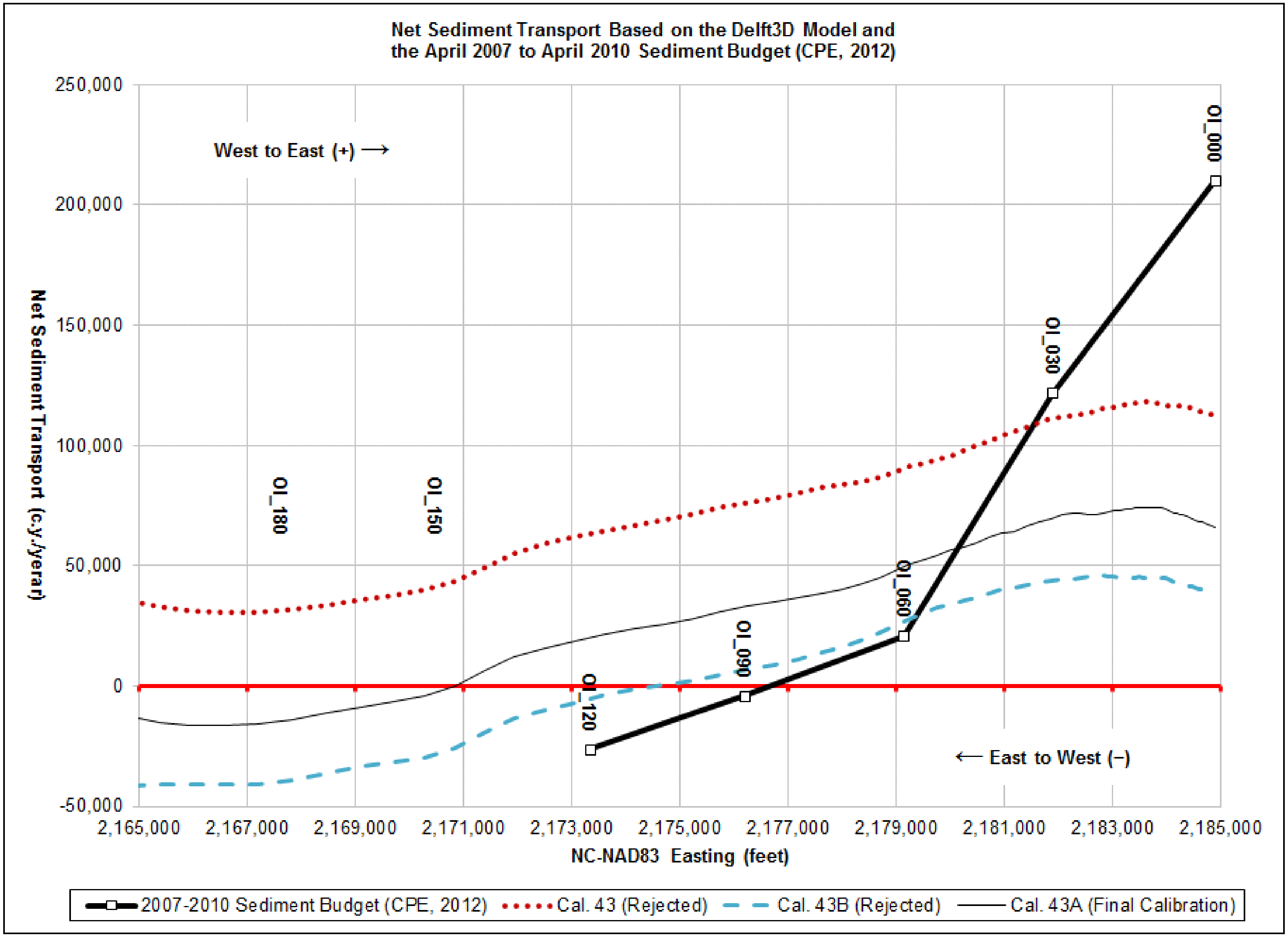

Figure 43: Net Sediment Transport Based on the Delft3D Model and the April 2007 to April 2010 Sediment Budget (CPE, 2012).

Within Shallotte Inlet the erosion and deposition in roughly the same locations as the 2007 and 2009 surveys show (see Figure 42). The differences in the appearance of the bathymetry are largely due to the infilling rates in the 2006-2007 borrow area and the main channel of the inlet just to the east (at X = 2,189,000 feet, Y = 54,000 feet in Figure 41, top graph). The 2007 and 2009 surveys indicate nearly complete refilling of the 2006-2007 borrow area and substantial infilling of the main channel (see Figure 41, top and middle graphs). By comparison, the model estimated partial refilling of the borrow area and less infilling of the main channel (see Figure 41, top and bottom graphs, and Figure 42).

Overall, the Delft3D-FLOW model as calibrated is best suited to estimating general trends, rather than providing exact estimates of erosion rates into the future. Given this finding, the most appropriate application of the model is evaluating the impacts and benefits of the various groin and/or beach fill alternatives relative to a no-action scenario. The evaluation of the alternatives in the next section will focus on the advantage of each alternative relative to each other and the no-action scenario, rather than exact projections of beach fill or structural performance that would occur in future years.

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Appendix D- Summary of Impacts Table

Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
SALT MARSH				
No direct, indirect, or cumulative impacts are anticipated.	Same as Alternative 1.	Same as Alternative 1.	Same as Alternative 1.	Same as Alternative 1
SHELLFISH				
No direct, indirect, or cumulative impacts are expected due to the remote location of the shellfish resources from Shallotte Inlet.	Same as Alternative 1	Same as Alternative 1	Same as Alternative 1.	Same as Alternative 1
UPLAND HAMMOCK				
No direct or indirect impacts expected to upland hammock resources in the Permit Area, due to their distance from active construction area Cumulative impacts include potential salt water intrusion attributed to sea level rise.	Same as Alternative 1	Same as Alternative 1	Same as Alternative 1.	Same as Alternative 1
INLET DUNES AND DRY BEACHES				
No direct impacts are anticipated. Natural erosion is expected to result in negative indirect impacts to 1-2 acres of inlet dune and 5-10 acres of inlet dry beach communities along Ocean Isle and Holden Beach. Natural erosion along the extreme east end of the Ocean Isle Beach oceanfront shoreline, particularly near sandbag revetments would cause negative indirect impacts to suitable dry beach habitat for seabeach amaranth, shorebirds; possible increase in inundation of sea turtle nests. Reduction in recreational beach available. Erosion along western end of Holden Beach would indirectly and negatively impact critical habitat for the piping plover (unit NC-17) and the loggerhead sea turtle (LOGG-T-NC-08).	Same as Alternative 1	Negative direct impacts of 0.6 acre of inlet dry beach habitat on Ocean Isle Beach are expected due to disturbance from construction activities and direct burial of invertebrate and infaunal species. No direct impacts are anticipated to the inlet dry beach habitat on Holden Beach. An estimated 5-10 acres of inlet dry beach and 1-2 acres of inlet dune habitat would be indirectly impacted due to erosion of the sand spit on Ocean Isle Beach and the west end of Holden Beach. Loss of this habitat would bring about negative indirect impacts to seabeach amaranth, shorebirds, nesting sea turtles, and recreational beach for humans. Additionally, should the erosion continue along the inlet beaches on Ocean Isle Beach and Holden Beach, piping plover overwintering Critical Habitat and nesting habitat could be impacted	Direct and direct impacts would be the same as discussed for Alternative 3. The two year nourishment interval may not allow for full recovery of benthos populations within the intertidal flats and shoals in Shallotte Inlet, causing cumulative impacts to these habitats and associated communities. This could indirectly impact foraging piping plovers which utilize the intertidal flats and shoals within Shallotte Inlet as part of their critical habitat Unit NC-17	Direct impacts are the same as Alternative 1. Indirect impacts are the same as Alternative 3.
INTERTIDAL FLATS AND SHOALS				
Direct impacts expected to 11.2 acres of intertidal shoals within Shallotte Inlet due to periodic excavation of the authorized Federal borrow area. Approximately 10-15 acres of ephemeral inlet shoals could be removed and directly impacted in subsequent inlet dredging. Excavation of intertidal flats and shoals may indirectly impact bird and fish species that use them for foraging, refuge, spawning and nursery habitat. An estimated 1-2 acres of intertidal flats will be indirectly impacted due to changes in sediment transport within the inlet. No cumulative impacts are anticipated due to the dynamic and resilient nature of these environments.	Same as Alternative 1	Direct and indirect impacts are the same as Alternative 1. The two-year nourishment interval may prevent shoal reformation after dredging of the borrow area, retard or prevent infaunal recovery. Cumulative impacts of this disturbance every two years could substantially alter the benthic environment within the borrow area such that negative indirect impacts are incurred by piping plovers and piping plover critical habitat.	Direct and indirect impacts would be the same as Alternative 1. The two-year nourishment interval may prevent these habitats within the borrow area from recovering completely, resulting in detrimental cumulative impacts to these habitats and the associated biological communities, including benthic infauna and the shorebirds, fishes and crustaceans that depend on them.	Direct impacts would be the same as Alternative 1. Indirect impacts are expected for an estimated 1-2 acres of intertidal habitat, most likely attributable to changes in sediment transport within the Shallotte Inlet system. Due to the 5-year nourishment interval, recovery and reformation of the flats and shoals is expected to occur, minimizing cumulative impacts.
OCEANFRONT DUNE COMMUNITIES				
No direct impacts are anticipated on Ocean Isle Beach or Holden Beach. Indirect positive impacts incurred from increased stability provided by a wider, more stable beach; may promote additional dune growth and establishment of vegetation. Indirect positive impacts to biological resources utilizing oceanfront dunes as habitat. Positive cumulative impacts may result from periodic nourishment due to maintenance of dunes;	Same as Alternative 1	Same as Alternative 1.	Same as Alternative 1	Same as Alternative 1.

negative cumulative impacts may be incurred form sea level rise.				
OCEANFRONT DRY BEACH COMMUNITIES				
Periodic nourishment of the Federal project will result in direct impacts to approximately 15.1 acres of dry beach on Ocean Isle Beach, including disturbance from construction activity and burial of infaunal communities. No direct impacts are anticipated for Holden Beach. Indirect impacts to 0-5 acres is expected due to continued high rates of erosion along the east end of Ocean Isle Beach and the west end of Holden Beach. Burial of infaunal prey during Federal nourishment will indirectly impact piping plovers and red knots. Temporary indirect benefits to nesting sea turtles via increased nesting habitat. Dry beach would continue to erode over time, reducing sea turtle nesting habitat and recreational beach	Direct impacts would be the same as discussed under Alternative 1. Indirect impacts would be similar to Alternative 1, however, because the sandbag revetment is predicted to fail, the shoreline would be expected to retreat to a position it would have occupied in 2015 had sandbags not been present. This would cause the loss of dry beach that serves as important nesting and foraging habitat for sea turtles and shorebirds.	During initial construction, approximately 16.5 acres of dry beach habitat will be impacted via sand placement, namely by disturbance from construction activity and burial of the infaunal community. Positive direct impacts include increased dry beach habitat for birds, sea turtles, and recreating humans. Due to continued erosion, a total of 0-5 acres of oceanfront dry beach would be anticipated to be lost to indirect impacts. Temporary removal of the infaunal prey base will indirectly impact nesting and roosting habitats for shorebirds. The two-year nourishment interval may lead to limited recovery of infaunal resources, thereby reducing the habitat quality for shorebirds.	Direct and indirect impacts would be the same as discussed under Alternative 3. The two-year nourishment interval may limit the recovery of infaunal resources between fill events on Ocean Isle Beach and cumulatively reduce the quality of shorebird foraging habitat. This may also cumulatively impact seabeach amaranth through repeated burial of seeds. Nourishment intervals would likely increase to 4 years after 14 years of nourishment, and then to 5 years after 18 years of nourishment; thereby reducing cumulative impacts.	Sand placement between the terminal groin and station 90+00 is estimated to directly impact 16 acres of dry beach habitat. These direct impacts include mortality due to burial of invertebrates, reduction of foraging and nesting habitat for sea turtles and piping plovers. Sand placement will provide habitat for sea turtle nesting and roosting and foraging by sea birds and shore birds. Indirect impacts include the stabilization of 0-5 acres of oceanfront dry beach The cumulative effect of a 5 year nourishment interval is expected to maintain important habitat for sea turtles and colonial waterbirds, and shorebirds.
WET BEACH COMMUNITIES				
Direct impacts are expected for approximately 14.4 acres of wet beach on Ocean Isle Beach due to sand placement during the Federal nourishment. Direct burial of infaunal prey community will indirectly impact piping plovers and red knots. Continued high erosion rates will impact approximately 25-30 acres of wet beach within the Permit area, indirectly impacting shorebird, crustacean and fish foraging anticipated due to continued high erosion rates. Sandbags may also reduce wet beach habitat. Infaunal communities will be directly impacted due to burial, however due to the resilient nature of these organisms, the impacts will be temporary.	Same as Alternative 1	Approximately 16.0 acres of the marine intertidal community along Ocean Isle Beach will be directly impacted during and following beach nourishment events. Infaunal communities will be directly impacted due to burial, however due to the resilient nature of these organisms, the impacts will be temporary. Indirect impacts to 25-30 acres will affect shorebird, crustacean and fish foraging. The two-year nourishment interval may cumulatively impact benthic infaunal communities by preventing full recovery between disturbances.	Direct and indirect impacts would be the same as those described under Alternative 3.	Approximately 15.6 acres of the marine intertidal will be directly impacted by burial during sand placement and terminal groin construction. Infaunal communities will be directly impacted due to burial, however due to the resilient nature of these organisms, the impacts will be temporary. Indirect impacts are expected for approximately 25-30 acres of intertidal habitat, which may affect shorebird, crustacean and fish foraging.
SOFTBOTTOM COMMUNITIES				
Direct impacts include increased turbidity levels, direct removal, and burial of infaunal biota during dredging operations within Shallotte Inlet and following the disposal of the material during maintenance events. These direct impacts are anticipated for 161.1 acres of soft bottom habitat within the toe-of-fill and Shallotte Inlet borrow area. Negative indirect impacts include the temporary loss of prey for foraging fish and invertebrates from the dredged softbottom habitat. No cumulative impacts are anticipated. No impacts to soft bottom habitats within Holden Beach are anticipated	Generally the same as Alt. 1; however, should the Town forego nourishment of the extreme east end of the island , the borrow area within Shallotte Inlet may not be utilized to the same extent as presented in Alt. 1	Sand placement on Ocean Isle beach and excavation of the Shallotte Inlet borrow area would result in direct impacts to approximately 197.2 acres of soft bottom habitat. Indirect impacts would be similar to those discussed under Alternative 1, however, because the beach fill associated with Alternative 3 extends further east to station -5+00, these indirect effects would be slightly greater. In total, 0-1 acres of softbottom would be indirectly impacted. Due to the extensive soft bottom resources outside of the permit area, no cumulative impacts are anticipated.	Direct and indirect impacts would be the same as described under Alternative 3. Cumulative impacts within the borrow area could be incurred due to the two-year nourishment interval, as the frequent disturbance may deter full recovery of the soft bottom resources. However, the increase in nourishment interval from two to four (after 14 years), and then five years (after 18 years) may minimize these cumulative impacts.	Direct impacts are expected for approximately 180.7 acres of soft bottom habitat. These direct impacts include removal and mortality of organisms within the borrow area, and burial of infuana within the toe-of-fill. Indirect impacts include temporary removal of prey for foraging fishes; hindrance of fish movements by the terminal groin. After the initial construction of the terminal groin, cumulative impacts are expected to be the same as Alternatives 1 and 3.
WATER QUALITY (TURBIDITY, TSS, AND NUTRIENTS)				
Direct impacts include temporary increases in suspended sediment and turbidity in the immediate area of dredge and fill operations within the nearshore environment. Elevated turbidity levels can subsequently clog fish gills, reduce invertebrate recruitment, cause low oxygen events, and mortality of organisms in the soft bottom community. No cumulative impacts to	Same as Alternative 1	Direct and indirect impacts would be similar to those discussed under Alternative 1, however, the larger fill template under Alternative 3 would increase the duration of increased turbidity during each dredge and fill event. Cumulative impacts would be similar to those discussed under Alternative 1, although the relatively high renourishment rate would result in periods of elevated turbidity within the Permit Area on a more frequent basis	Direct and indirect impacts to turbidity and TSS would be the same as discussed under Alternative 3. Cumulative impacts would be the same as described under Alternative 1, albeit on a more frequent basis due to the 2 year nourishment interval. The frequency of impacts will be reduced when the nourishment interval increases to 4 years, and then 5 years. No direct, indirect, or cumulative impacts to nutrients are anticipated.	Similar as Alternative 1; however, excavation require for construction of terminal groin may cause additional temporary elevated turbidity levels. Cumulative impacts would be similar to Alternative 1, albeit less frequent due to the 5-year nourishment interval. No direct, indirect, or cumulative impacts to nutrients are anticipated.

water quality are expected. No direct, indirect or cumulative impacts to nutrients are anticipated.				
WATER COLUMN (HYDRODYNAMICS, SALINITY, LARVAL TRANSPORT				
Due to the large volume of water moving through the Shallotte Inlet system, no direct, indirect, or cumulative impacts to hydrodynamics and salinity are anticipated. Likewise, no impacts are expected for larval transport. Of important note, some winter and spring-spawning fishes are expected within the project area and may therefore be impacted.	Same as Alternative 1; however, should the Town decide to forgo its attempts to nourish the extreme east end of the island, the frequency and/or duration of dredging within Shallotte Inlet may be reduced, thereby further limiting impacts to larval transport through the inlet	Same as Alternative 1.	Same as Alternative 1.	Impacts to hydrodynamics and salinity would be the same as Alternative 1. Due to the comparatively short nature of the terminal groin, the project is not expected dot impact larval transport within the inlet system. While some larva may be entrained by the dredge, it is scheduled to occur outside the times of peak juvenile fish settlement. Of important note, some winter and spring-spawning fishes are expected within the project area and may therefore be impacted.
PUBLIC SAFETY				
Positive direct and indirect impacts include storm damage reduction to homes and infrastructure in Federal nourishment area. Public safety will be temporarily impacted due to the usage of heavy machinery within Shallotte Inlet and along the oceanfront shoreline Ocean Isle Beach Continued erosion leaves at least 45 homes and other infrastructure vulnerable to erosion and presents a significant public safety hazard due to unstable roadways, debris from demolished homes, and unstable water and sewer pipes. These impacts may include the release of sewage and other hazardous materials onto the beach and into the coastal waters resulting in closed areas of the beach impeding recreation. Continued erosion, exacerbated by sea level rise, could result in cumulative impacts including continued demolition activities, road undermining, and exposure of utilities.	Same as Alternative 1, however, with no action being taken to protect threatened homes and infrastructure via the utilization of sandbags, damages would occur continuously throughout the 30-year analysis period rather than in 5-year increments as in Alternative 1	Although the presence of heavy machinery within Shallotte Inlet and along the oceanfront shoreline of Ocean Isle Beach would directly impact public safety, construction will be temporary and take place outside of peak public use of these areas. Management of erosion along extreme eastern end of Ocean Isle Beach would provide protection to homes and infrastructure in the area. The removal or burial of sandbags would improve public safety. These impacts will be incurred every 2-years during maintenance nourishment.	Direct and indirect impacts are the same as discussed under Alternative 3. These impacts will occur every two years for the first 14 years after initial construction. Thereafter, impacts would be reduced to a 4 year interval (after year 14), and then 5 year interval (after year 18).	Direct and indirect impacts would be the same as discussed under Alternative 3. These impacts will be incurred every 5-years during maintenance nourishment.
AESTHETIC RESOURCES				
Direct impacts could include the presence of construction equipment for maintenance nourishment of the Federal project, which would temporarily detract from the aesthetics of the waterways and beach of Ocean Isle Beach. Indirect and cumulative impacts could include a significant loss of land, personal property, and roads, which would negatively affect the aesthetic quality of Ocean Isle Beach.	Same as Alternative 1. Also, deterioration of sandbags, if abandoned, would further reduce aesthetic quality of the beach.	The presence of construction equipment would temporarily detract from the aesthetics of the waterways and beach of Ocean Isle Beach. This would occur every two years.	Direct and indirect impacts would be the same as described under Alternative 3. These impacts will occur every two years for the first 14 years after initial construction. Thereafter, impacts would be reduced to a 4 year interval (after year 14), and then 5 year interval (after year 18).	Temporary direct negative impacts to aesthetic resources will occur due to the presence of construction equipment used for dredging, sand placement and terminal groin construction. These impacts will be incurred every 5 years, therefore cumulative impacts will be minimal.
RECREATIONAL RESOURCES				
Negative direct impacts will include the reduction of recreational opportunities during nourishment events. As the erosion continues along the effected stretch of shoreline on Ocean Isle Beach, recreational opportunities such and beachcombing, sunbathing, surf fishing, and walking along the beach may be negatively impacted.	Same as Alternative 1	Direct impacts would be similar to those described for Alternative 1. Recreational resources (surf fishing, bird watching, etc.) will indirectly benefit from increased size and extent of the nourished beach. However, recreational activities will be interrupted every two years.	Same as Alternative 1	Direct impacts would be similar to those described for Alternative 1. Indirect impacts include increased area for recreational activities due to increased beach size. Recreational activities will be temporarily interrupted within the Permit area every 5 years.

NAVIGATION				
Dredging in Shallotte Inlet at three year intervals will benefit navigation due to a maintained depth. During the dredging, however, navigation will be temporarily directly impacted due to the presence of pipelines within the waterway. At no time during dredge operations will complete restriction of navigation occur in Shallotte Inlet.	Same as Alternative 1	Navigation will be directly negatively impacted due to the presence of the dredge and pipeline during the implementation of Alternative 3. No indirect or cumulative impacts are anticipated.	Direct and indirect impacts would be the same as described under Alternative 3. These impacts will occur every two years for the first 14 years after initial construction. Thereafter, impacts would be reduced to a 4 year interval (after year 14), and then 5 year interval (after year 18).	Dredging in Shallotte Inlet will benefit navigation due to a maintained depth. During the dredging, navigation will be temporarily directly impacted due to the presence of pipelines within the waterway. At no time will complete restriction of navigation occur in Shallotte Inlet during dredge operations. The terminal groin will be clearly marked; therefore it should not pose a threat to boats.
INFRASTRUCTURE				
Positive direct and indirect impacts incurred for existing infrastructure located west of 15+00 due to the short-term protection provided by beach nourishment and sandbags. East of 15+00 may experience negative direct impacts due to predicted erosion. Negative cumulative impacts are anticipated as the threatened homes and infrastructure will not be protected in the long term.	Similar as those described for Alternative 1, however, with no action being taken to protect threatened homes and infrastructure via the utilization of sandbags, damages would occur continuously throughout the 30-year analysis period rather than in 5-year increments as in Alternative 1.	Impacts to navigation will be the same as those described for Alternative 1. However, the frequency of renourishment activities will be every 2 years, resulting in increased temporary impacts to navigation as a result of the presence of dredge equipment in Shallotte Inlet.	Positive direct, indirect and cumulative impacts to infrastructure due to long-term protection from erosion between stations -5+00 and 90+00 along the Ocean Isle Beach shoreline.	Positive direct, indirect and cumulative impacts to infrastructure due to long-term protection from erosion between 148 ft. west of station 0+00 and 90+00 along the Ocean Isle Beach shoreline.
SOLID WASTE				
Should the sandbagged homes along the extreme eastern end of Ocean Isle Beach succumb to erosion and become demolished, increased levels of solid waste would be expected. Further to the west, no direct impacts will be anticipated due to the short term protection provided by beach nourishment, beach scraping, and installation of sandbags. The debris generated from the demolition of homes and infrastructure could indirectly and cumulatively impact the amount of solid waste deposited in local sanitary landfills. Deterioration of sandbags could result in debris that becomes a threat to marine animals.	As homes along the extreme eastern end of Ocean Isle Beach succumb to erosion and become abandoned or demolished, increased levels of solid waste would be expected. Further to the west, no direct impacts will be anticipated due to the short term protection provided by the Federal beach nourishment project. Indirect and cumulative impacts incurred as the continued chronic erosion of the oceanfront shoreline along the east end of Ocean Isle Beach could result in debris generated from demolition of compromised sandbags, residential homes and infrastructure.	Both short and long-term benefits are expected from the reduction of solid waste. This alternative will provide protection along portions of Ocean Isle beach thereby decreasing the risk of damage to residential buildings and infrastructure. This would alleviate the potential of increased amount of solid waste through demolition.	Increased protection along portions of Ocean Isle Beach will decrease the risk of damage to homes and infrastructure, thereby reducing the potential for creation of solid waste created by demolition of compromised structures.	Same as Alternative 4.
ECONOMICS				
Over the 30-year analysis period, the total cost associated with Alternative 1 would be about $101.49 million.	Over the 30-year analysis period, the total cost associated with Alternative 2 would be about $95.99 million. Note this is less than Alternative 1 due to exclusion of sandbags.	Over the 30-year planning period, the total implementation cost for Alternative 3 would be about $115.50 million.	Over the 30-year planning period, the total cost estimated for Alternative 4 is $62.13 million.	The initial construction cost of Alternative 5 is $5,700,000, including construction of the structure as well as the fillet. The periodic nourishment cost every 5 years, including fill within the fillet and advanced fill for the Federal project, is estimated at $6,575,000
NOISE POLLUTION				
Dredging and fill operations would temporarily raise noise level in the area; however no indirect or cumulative impacts pertaining to noise pollution are anticipated.	Same as Alternative 1.	Same as Alternative 1.	Direct impacts are the same as described for Alternative 1. No cumulative impacts are anticipated.	The dredging of Shallotte Inlet, the placement of beach compatible material on the oceanfront and estuarine shoreline, use of a pile driver and heavy machinery to construct the terminal groin, would all temporarily raise the noise level in the areas. No indirect or cumulative impacts pertaining to noise pollution are anticipated.