The survey work was conducted between 19 and 27 May 2011 by means of RTK-GPS utilizing the elevation value of +1.18 NAVD. This elevation is referenced from the MHW value at the nearest ocean tidal station in Duck (NC). Figure 2.3 illustrates the various relationships among key reference datum for the tide station (ID 8651370) at the pier of the USACE FRF in Duck (NC), ~15 miles north of the project area. Survey results were prepared in an x,y,z ASCII point file and an MHW line plot. They were delivered to CSE on 7 June and were then forwarded to the Town and NC Division of Coastal Management (NCDCM).

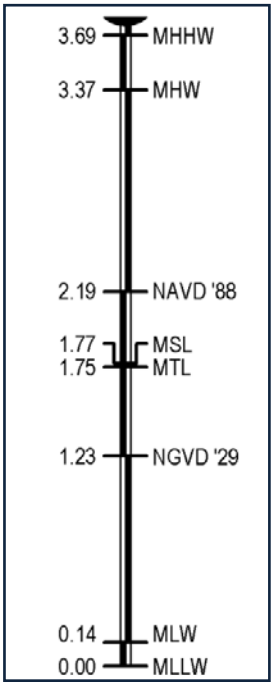

FIGURE 2.3. Relationship of various water levels and survey datum at Duck (NC). [Source: NGS–NOAA]

CSE prepared a map based on Quible's survey data for illustrative purposes. CSE took the MHW coordinates and inserted them onto an aerial orthophotograph, referencing Quible as the surveyor on the map. Quible's original MHW line plot and CSE's map are included in Appendix E.

2.6 CSE Construction Management

During construction, representatives from CSE visited the site several times per day with the exception of periods when dredging operations ceased because of weather issues or equipment maintenance. Additionally, whenever the dredge changed to a new borrow area, CSE representatives monitored the first few hours of discharge. Generally twice per day, the observer recorded wind and wave conditions, made a visual inspection of the most recent sediment placed, and noted the location of the beach-grading operation.

While on site, the observer also collected a composite, grab sand sample from the last station completed. A composite sample consisted of a series of grab samples at ~10-ft spacing along a transect from the landward limit of fill to the low-tide line mixed together to form one representative sample for the given station. Some additional single-point grab samples in the vicinity of the discharge point were also collected. Sand samples were analyzed after collection, and results will be discussed in Section 5.

Ground photos of pre-project and post-project conditions were taken during site visits. The photographs offered a simple visual assessment of dry beach width, dune condition, vegetative growth, escarpments, and general condition of the beach through time. Photos

were also taken of any areas or features of particular importance or interest observed during the construction phase. Site visits were recorded in CSE's daily observation reports which are provided in Appendix A1 along with other construction management documents.

During construction, a weekly project meeting was held every Thursday from 19 May to 3 November 2011 at the Nags Head Town Hall. Representatives from the Town, GLDD, NCDCM, Nags Head citizens, and CSE attended these meetings and reviewed work progress, upcoming areas of impact, and anticipated public events in the project area. CSE prepared a series of memos after each meeting (see Appendix A10).

In addition to daily observations on the dump site and the weekly project meeting, CSE periodically inspected the entire project site, including the active construction area as well as finished and unnourished sections. The purpose of these inspections was to evaluate the overall adjustment of the project and to identify any escarpments developed on the beach.

2.6.1 Escarpments on the Beach

According to the state major CAMA permit (Item #16f), *"any escarpments greater than 18 inches that were present between May 1st and August 30th shall be leveled."* Daily monitoring was conducted to determine if escarpments formed.

The first groups of significant escarpments during construction were observed around 7 July 2011 after some brisk winds from the south-southwest blew toward Nags Head for a few days. Wave action had cut back the nourishment berm and had left escarpments that were 2-3 ft high at the edge of the surf along thousands of feet of the beach. Beach goers, life guards, and the town staff noticed such escarpments.

Figure 2.5 is a photo taken on July 7 near the Hargrove Street beach access (station 820+00) looking north. CSE staff monitored the height and length of these escarpments. CSE's measurements showed that about 3,000 ft of escarpment occurred in the active work areas south of Jennette's Pier. CSE's measurements also showed that there were about 3,600 ft of escarpment occurring in completed sections outside the active project area north of Jennette's Pier. GLDD leveled these escarpments immediately and re-leveled them the next day when the escarpments re-occurred at some sections.

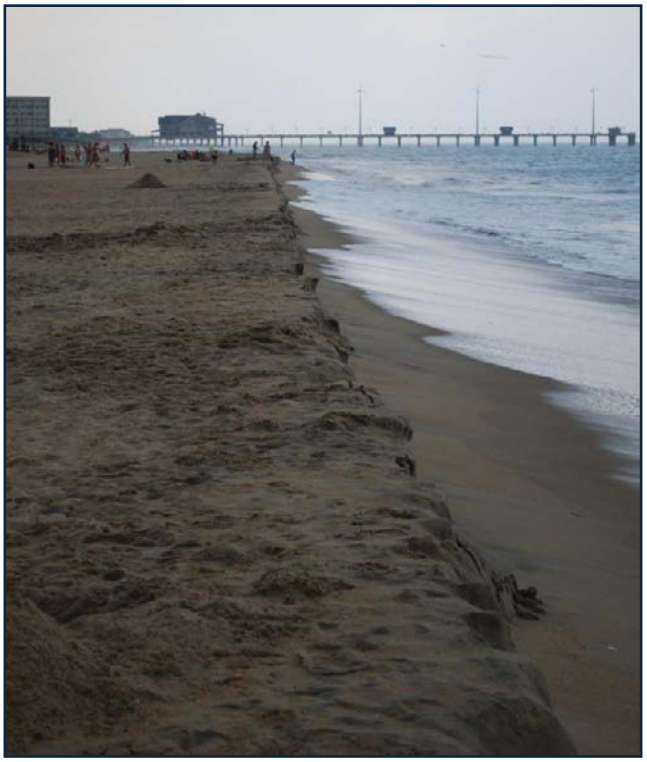

FIGURE 2.5. Near Hargrove Street beach access (station 820+00) looking north on 7 July 2011.

[Source: D Clark, Town of Nags Head public works director]

As to unnourished areas, neither GLDD nor the Town was responsible for leveling the escarpments under the permits.

During the final two months of construction (ie – September–October 2011), low escarpments formed at various times along short segments of the project (Fig 2.6). Almost without exception, berm escarpments healed naturally within several days of formation.

CSE staff monitored the entire beach regularly during the construction of the project and coordinated with the Town and GLDD to address escarpments in accordance with the state and federal permits.

FIGURE 2.6. Isolated low escarpment in the nourishment berm during fill adjustment on 26 October 2011.

2.6.2 Beach Tilling

It is specified by the USFWS that "*The filled beach is required to have compaction less than 500 pounds per square inch (psi) in the upper 18 inches. If a section is more compacted than this limit, the Contractor will be required to till the fill to a depth of 36 inches. Rakes must have tines at least 42 inches long and less than 36 inches apart. Tilling and grading of the entire placed beach above mean high water must be performed once by the Contractor unless a minimum of 90 percent of the compaction measurements show values less than 500 psi in the upper 18 inches. Re-tilling of sections in the final 15 days of the project will be required only if the escarpment and/or compaction limits listed above are exceeded.*"

CSE monitored the beach compaction from Kill Devil Hills (milepost 10) to Coquina Beach (milepost ~26) toward the end of construction on 14 September. The spot results of cone penetrometer measurements (Table 2.3) showed that the nourishment berm at the 18-inch depth had an average compaction of over 1,000 pounds per square inch (psi), while the corresponding compaction at the toe of dune averaged around 500 psi and ranged from 300 psi to 800 psi. The compaction along the native beach varied from north to south. The native beach at the 18-in depth at Coquina Beach had the same high compaction values as the nourished beach (over 1,000 psi), while the native beach at the 18-in depth at Kill Devil Hills was around 400 psi (ie – similar to the toe-of-dune compaction along nourished sections).

TABLE 2.3. Nags Head Beach compaction (psi) measured on 14 September 2011.

Location Information			Nags Head Beach Compaction (psi) Measured on 14 September 2011											
Street Name	Mile Post	Beach Condition	Toe of Dune						Berm					
			Point A			Point B			Point A			Point B		
			6 in	12 in	18 in	6 in	12 in	18 in	6 in	12 in	18 in	6 in	12 in	18 in
Coquina	~26	un-nourished	180	740	>1000	200	820	>1000	160	640	>1000	160	680	>1000
McCall St.	21		150	200	320	120	180	180	120	480	800	160	640	850
Oregon St.	20	nourished	180	320	820	100	480	720	480	>1000	>1000	380	>1000	>1000
Tides Dr.	18		100	100	480	120	120	480	160	760	>1000	180	780	>1000
Glidden St.	16		180	200	320	160	300	380	180	680	>1000	160	500	740
Loggerhead St.	14		160	180	350	180	280	350	220	750	>1000	100	520	800
Curlew St.	11.5		160	500	>1000	180	500	>1000	320	780	>1000	180	920	>1000
Albatross St.	10	un-nourished	120	680	920	120	450	930	80	100	320	50	80	420

CSE coordinated with representatives of NCWRC and the USACE to report the above-listed compaction conditions. GLDD had equipment on site and was ready to till the beach; however, there were several questions that had arisen about whether tilling should be performed as the project was nearing completion:

- It was the end of turtle-nesting season and, therefore, tilling would not benefit sea turtles.
- Tilling softens the beach to the point where it becomes difficult for people to walk across the wide nourished berm.
- The beach would compact again, before nesting resumes in the spring, through the action of normal wave processes and vehicle traffic. [USFWS and NCWRC guidelines and criteria require the Town to monitor the beach compaction in late winter (prior to nesting season) and to till the beach at that time if necessary.]

The final decision regarding tilling activity was made on 19 September after the regulators reviewed the compaction conditions and decided that no tilling was required at the time.

2.6.3 Construction Management Documentation

Overall, in addition to CSE's daily observation reports, construction management documents prepared and reviewed by CSE are listed in Table 2.4.

TABLE 2.4. Construction management documentation.

Prepared by	Period	Object	Name of Report
CSE	Daily	Overall	Observation Report
	Daily	Sand quality	Sediment Analysis
	Twice a week	Overall	Construction Progress Map
	Weekly	Overall	Memo of Weekly Project Meeting
	Periodically	Overall	Photographs (ground and aerial)
GLDD	Daily	Overall	Quality Control Report
	Daily	Hopper dredge	Hopper Dredges Operations Report (Form 27A)
	Daily	Hydraulic dredge	Hydraulic Daily Production Owner Report
	Daily	Trawlers	Trawler Logs
	Daily	Endangered species	Endangered Species Observer Program Daily Report
	Weekly	Endangered species	Endangered Species Observer Program Weekly Report
	Periodically	Overall	Survey Transmittals
	Periodically	Overall	Photographs (ground)
USACE	Weekly	Hopper dredge	Dredging Quality Monitoring (DQM) Report
Turtle Monitors	Daily	Sea turtle	Sea Turtle Daily Report
	Weekly	Sea turtle	Sea Turtle Weekly Report

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3.0 PROJECT SEQUENCE

Project planning assistance was initiated in 2005 when the Town of Nags Head retained CSE to prepare a preliminary coastal engineering analysis for large-scale beach restoration at Nags Head. CSE's involvement followed numerous meetings with Town officials; preparation of project summaries, fact sheets, and videos for community forums; development of project plans; preparation of project budget; application for state permit and federal permit; and responding to comments from federal and state resource agencies and regulators. Key technical reports prepared by CSE between 2005 and 2011 are listed as follows:

- Preliminary design and permit application for an "Interim" beach nourishment project.
- Draft Environmental Impact Statement (DEIS).
- Draft Essential Fish Habitat (EFH) assessment.
- Biological Assessment (BA).
- Final Environmental Impact Statement (FEIS).
- Coastal Engineering & Geotechnical Analyses (ie — Final Design Report).

The project permit from North Carolina Department of Coastal Management (NCDCM) was received on 29 April 2010 (NCDCM CAMA permit 45-10), and the federal permit from the USACE was received on 30 November 2011. Construction (pumping operations) of the beach nourishment project started on 24 May 2011 and was completed on 27 October 2011. Table 3.1 provides the sequence of events that made up the planning, project design, permitting, bidding, and construction of the 2011 Nags Head beach nourishment project.

The contractor (GLDD) opted to accomplish the work using a combination of ocean-certified hopper dredges and a traditional cutterhead-suction dredge, utilizing multiple “landing” areas for pumpout in either direction along the beach (Figure 3.1). Three hopper dredges (GLDD’s *Liberty Island, Padre Island,* and *Dodge Island*) and the cutterhead dredge (*Texas*) were mobilized to the project site at various times, completed all pumping and sand placement and were demobilized from the project site.

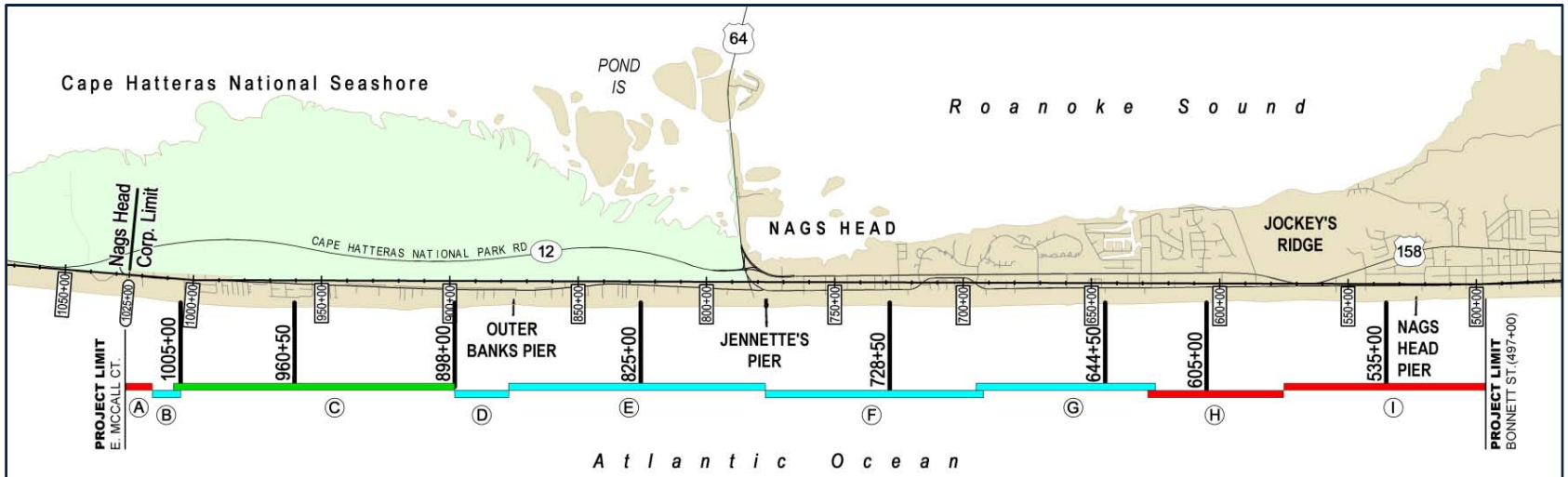
TABLE 3.1. Project time line for the beach nourishment project at Nags Head.

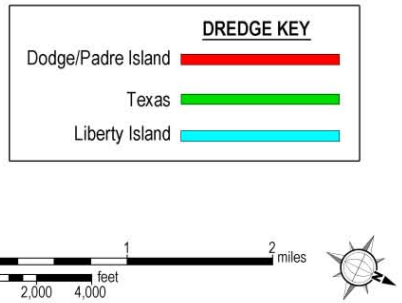
Aug 2005	CSE delivers technical report: Preliminary Coastal Engineering Analyses for Large-Scale Beach Restoration at Nags Head (CSE Job 2145-02).
Sep 2005	CSE retained by Town of Nags Head to develop a preliminary design and permit application.
Apr 2006	Draft Environmental Impact Statement (DEIS 2006) published for Town of Nags Head beach nourishment project under NCEPA requirements — prepared for Town by CSE.
11 Apr 2006	Draft Essential Fish Habitat (EFH) assessment published (becomes Appendix F of EIS 2006).
Jul 2006	Project plan and budget prepared — Scale: 9.94 miles, 4 million cubic yards ±15 percent, $31.5 million ±15 percent.
Jul 2006	Federal permit application and DEIS (2006) submitted to USACE — DEIS (2006) submitted to NCDCM and NCDENR for review.
Aug 2006	Public notice (federal) issued for project (Action ID SAW 2006-40282-128).
Sep 2006	Comments on DEIS (2006) received from federal and state resource agencies, USACE and NCDCM.
Oct 2006	Responses to comments submitted by CSE / Town.
Fall 2006	Town and CSE prepares project summaries, fact sheets, and video to explain the proposed project in community forums and responded to comments from resource agencies.
Winter 2007	Public information sessions: 18 January, 6 February, 22 February, 14 April.
23 Mar 2007	CSE issues Biological Assessment (103 pages plus appendices; updated January 2008) which addresses dredging schedule, borrow area use plan, threatened and endangered species, beach benthic communities, commitments to reduce impacts.
Mar 2007	Biological Assessment (BA) prepared and submitted by CSE per requirements of USFWS.
17 Apr 2007	Nags Head project funding referendum vote (fails).
Spring–Summer 2007	Extensive correspondence between resource agencies and CSE regarding additional issues to be addressed in the DEIS.
10 Aug 2007	Letter from D Huggett (NCDCM) to CSE indicating that the DEIS (2006) and associated comments and responses *"may now proceed to the State Clearinghouse for the next phase of the environmental review . . ."*
Fall 2007–Winter 2008	CSE prepares revised DEIS.
Mar 2008	Town and CSE meet with USACE and request the Corps force Section 7 consultation with USFWS because of plan for summer dredging.
31 Mar 2008	Updated plan and budget prepared and presented at community meeting — Scale: 9.94 miles, 4 million cubic yards ±15 percent, $35 million.
Jul 2008	NMFS informs Town and USACE that EFH assessment (under Magnuson-Stevens Act) is adequate.
Jul 2008	FEIS (state) submitted to State Clearinghouse for final review.
9 Jul 2008	Revised DEIS (2008) published under NCEPA requirements — Incorporates additions, comments, and responses to resource and regulatory agency concerns regarding dredging schedule and method, habitat alteration, turbidity, impacts to benthic communities, impacts to endangered and threatened species.

25 Jul 2008	Letter (3 pages) from P Wilbur (NMFS) to Col J Pulliam (USACE) regarding NMFS concerns with project, including schedule, impacts to fisheries – issues EFH Conservation Recommendation (decision document) against summer dredging – *"However (NMFS) will defer to the Wilmington District on the safety issues that might be involved in this project."*
18 Aug 2008	Biological Opinion (43 pages) by USFWS [transmittal letter from P Benjamin (USFWS) to K Jolly (USACE)] — The Biological Opinion concludes that the project as proposed (ie – hopper dredging in summer) *". . . is not likely to jeopardize the continued existence of the loggerhead, green, and leatherback sea turtles and is not likely to destroy or adversely modify designated critical habitat"* (pg 25) – USFWS reiterates its preference for winter dredging.
16 Feb 2009	Record of Decision from NCDENR [memo from D Huggett (NCDCM) to V McMillan (State Clearinghouse)] — The Record of Decision finds that the Town of Nags Head EIS *"does adequately address potential impacts associated with the project."* Further *". . . the EIS does serve as an appropriate decision-making tool to be utilized when making a final regulatory decision on whether or not to issue the required State permits for the proposed project."*
18 Aug 2009	Major CAMA permit application (revised) submitted by Town of Nags Head (c/o CSE) to NCDCM for processing.
Sep 2009	USACE issues draft EIS (DEIS 2009) for the Town of Nags Head beach nourishment project — Based on NCEPA DEIS – incorporates additions and revisions to the DEIS per comments from USACE, USFWS (BO), NCDENR, etc – includes additional cultural resource data, geophysical data, and operational data from similar projects in the area [eg – Sandbridge (VA) project].
5 Nov 2009	**Major CAMA permit application (revised) submitted to NCDCM.**
9 Nov 2009	NCDCM accepts major CAMA permit application.
19 Nov 2009	Public Notice – Federal Register — USACE release of the Draft Environmental Impact Statement (DEIS 2009) for the Town of Nags Head proposed beach nourishment project in Dare County (NC) — states that written comments will be received until 30 December 2009.
Dec 2009	NCDCM submits permit application to NCDENR agencies for circulation and public notice.
7 Jan 2010	Memorandum (2 pages) from S Winslow (NCDMF) to D Huggett (NCDCM) providing comments — The USACE 2000 EIS for Dare County is referenced, but it does not appear that the USACE 2009 DEIS covering the Town of Nags Head project is referenced — NCDMF expresses concerns regarding impacts fo finfish which utilize the surf zone and nearshore waters, turbidity levels, and benthic macrofauna — NCDMF reiterates (incorrectly) that the USACE 2000 Dare County project will adhere to the recommended dredging moratorium between 1 April and 15 November. [In fact, the proposed schedule for the Dare County project calls for initial nourishment to occur between 15 November and 1 June with a contingency period under the contract through the summer (USACE 2000 EIS Vol I).]
12 Jan 2010	USACE (c/o R Bland) receives request from NMFS to extend the comment period.
25 Jan 2010	Letter from M Croom (c/o P Wilbur, NMFS) to Col J Ryscavage (USACE) commenting on the DEIS and reiterating NMFS opposition to summer dredging.
29 Jan 2010	Letter from R Scheller (NCDWQ) to C Ogburn (Town of Nags Head) providing comments on the project — Letter expresses concern regarding summer dredging impact during "established moratorium dates: for sea turtles nesting (1 May to 15 November), piping plover nesting (1 April to 15 July), and manatee presence (June–October).
9 Feb 2010	Email from P Wilbur (NMFS) to R Bland (USACE) clarifying that NMFS position of 25 July 2008 remains the same Further – *"If the Wilmington District concludes that limiting dredging to this (Nov 15 to Apr 1) period would pose an unacceptable safety risk, we would accept the District's determination."*
29 Apr 2010	**NCDCM CAMA permit 45-10** issued to Town of Nags Head for project (expires 3 September 2014).

30 Apr 2010	Town officials establish an overall project budget of $35 million Project Scale: 10.0 miles, 4 million cubic yards ±15 percent.
May 2010	CSE prepares final EIS for the USACE (FEIS 2010).
Jun 2010	Biological monitoring initiated — quarterly data collection required for four seasons prior to commencement of dredging — pre-dredge sampling by CZR Incorporated in June, August, and November 2010, and April 2011.
2 Jul 2010	USACE Final Environmental Impact Statement (FEIS 2010) placed on Federal Register.
Fall 2010	CSE prepares final design analyses.
Nov 2010	CSE conducts comprehensive final design data collection for project plans and pre-construction condition.
30 Nov 2010	**Federal permit SAW-2006-40282** issued for up to 4.6 million cubic yards of nourishment using up to three offshore borrow areas — summer dredging allowed subject to strict environmental protection measures.
Dec 2010	Town officials finalize a funding plan for the project involving a combination of county beach nourishment trust funds (~50 percent), earmarks on future accommodations taxes (~25 percent), and a local tax assessment for oceanfront and non-oceanfront districts (~25 percent).
27 Dec 2010	**Town Council votes to proceed with the project** — Town establishes a construction budget NTE (~)$32 million.
6 Jan 2011	Local Government Commission (LGC) provides favorable review of funding plan subject to specified filings.
Jan 2011	CSE prepares plans, specifications, and bid documents for the project — bid documents are made available to qualified companies on 1 February.
10 Feb 2011	Pre-Bid meeting at Nags Head.
18 Feb 2011	CSE provides final estimate of probable construction cost based on construction cost NTE $32 million — under the budget cap, CSE estimates that ~3.8 million cubic yards can be accomplished (includes mobilization and pumping costs).
22 Feb 2011	**Bid opening** — three qualified companies provide valid bids — Great Lakes Dredge & Dock Company (GLDD) provides lowest apparent bid — after factoring in mobilization and unit pumping costs under two alternate schedules (~8-month window and ~16-month window), Town selects Alternate A (8-month window) for maximum permitted volume — construction contract finalized based on 10.0 miles, 4.6 million cubic yards at $30,184,000.
30 Mar 2011	Preconstruction meeting with contractor at Nags Head Town Hall.
Mar-Apr 2011	CSE revises final design based on contracted volume of 4.6 million cubic yards using November 2010 beach conditions.
10 May 2011	Regulatory preconstruction meeting at Nags Head Fire Station with federal and state officials — review environmental protection measures, activities disallowed around exposed sand bags, and endangered species monitoring plan.
May 2011	GLDD mobilizes equipment for initial dredging operations in the center of the project via hopper dredge.
19 May 2011	First weekly project meeting was held at the Town Hall. There are a total of 25 such meetings held during the 25 weeks of construction of the project. Representatives from the town, GLDD, NCDCM, Nags Head citizens and CSE attended these meetings, and CSE issued memos after the meetings.
24 May 2011	**First load of sand** is pumped at station 728+00 (E Forbes Street) via the GLDD Liberty Island at 8:20 p.m.
May-Jun 2011	CSE conducts comprehensive data collection for pre-construction condition.

21 Jun 2011	*Texas* starts pumping.
28 Jun 2011	CSE submits a letter to NCDCM reporting construction condition.
16 Aug 2011	*Texas* finishes work for this project — she has pumped from station 898+00 to 1007+00 (a total of 10,900 linear feet or 2.1 miles) with a reported volume of approximately 1.7 million cubic yards (~37 percent of the contract volume).
19 Aug 2011	*Dodge Island* starts pumping.
22 Aug 2011	*Padre Island* starts pumping.
24 Aug 2011	*Liberty Island* finishes work and leaves the job site — she completed 499 loads with a reported volume of 2.2 million cy (~48 percent of the contract volume).
25 Aug 2011	CSE assists the town to develop a beach monitoring and maintenance plan in accordance with relevant regulations issued by the Federal Emergency Management Agency (FEMA).
27 Aug 2011	Hurricane *Irene* (Category 1) impacts the project site. All four dredges leave the job site and sail to Norfolk (VA) to ride out the storm. Before *Irene*'s landfall, GLDD placed ~3.8 million cy of sand (~83 percent of the contract volume) onto ~40,300 ft (~7.6 miles) of the beach at Nags Head.
30 Aug 2011	CSE memo to the Town regarding Hurricane *Irene* impacts on the ongoing beach nourishment project based on the survey data collected before and after the storm.
8 Sep 2011	Hurricane *Katia* (Category 1) passage offshore.
12 Sep 2011	CSE submits a letter to NCDCM requesting a minor modification to major permit 45-10 to modify fill templates for the remaining sections.
15 Sep 2011	Hurricane *Maria* (Category 1) passage offshore.
19 Sep 2011	CSE receives instruction from the USACE project manager that no tilling is required at this time.
29 Sep 2011	CSE memo to the Town regarding updated post-Hurricane *Irene* erosion assessment based on the additional profile data collected — concludes an application for emergency renourishment under a FEMA "improved projects" grant is not warranted due to negligible losses within the project limits.
29 Sep 2011	CSE submits the pre-dredging biological monitoring report to the town and resource agencies.
27 Oct 2011	**Last load of sand** is pumped at station 585+00 (Sound Side Road) via the GLDD Padre Island at 8:20 a.m.
27 Oct 2011	CSE informs the USACE Regulatory Project Manager regarding the completion of the pumping operations.
5 Nov 2011	GLDD reports and submits final pay request for a total in-place nourishment quantity of 4,615,126 cy.
10 Nov 2011	**NCDCM CAMA Minor Modification of Permit 45-10** issued to Town of Nags Head for project (expires 3 September 2015).
Nov 2011	CSE obtains comprehensive condition data to determine the post-project conditions and verify placed quantities.
6 Dec 2011	CSE submits letter to the Town summarizing the condition of the beach along Nags Head after nourishment and verifying that 4.45-4.76 million cubic yards more sand is in place within the project limits measured to −12 ft, −19 ft, and −24 ft NAVD compared with the November 2010 (same season) pre-nourishment condition survey.
13 Dec 2011	CSE submits a detailed map of the final dimensions of the borrow areas and final Biological Monitoring Plan to the U.S. Environmental Protection Agency and the USACE





STA Range ID	Date	Dredge	Landing STA	Fill STA Range
A	10/8 - 10/10	Dodge/Padre Island	1005+00	1016+00 - 1025+00
B	8/22 - 8/24	Liberty Island	1005+00	1005+00 - 1016+00
C	6/21 - 8/16	Texas	960+50	898+00 - 1006+00
D	8/14 - 8/22	Liberty Island	898+00	878+00 - 898+00
E	6/18 - 8/3	Liberty Island	825+50	777+00 - 878+00
F	5/24 - 6/18	Liberty Island	728+50	692+00 - 777+00
G	8/3 - 8/14, 8/20 - 8/22	Liberty Island	644+50	625+00 - 695+00
H	10/13 - 10/27	Dodge/Padre Island	605+00	575+00 - 628+00
I	8/19 - 8/24, 9/2 - 9/7 9/11 - 9/16, 9/22 - 10/13	Dodge/Padre Island	535+00	497+00 - 575+00

FIGURE 3.1. Multiple landing areas, fill ranges and dates for the dredges GLDD utilized in the Nags Head beach nourishment project between 24 May and 27 October 2011.

4.0 PROJECT PERFORMANCE DURING HURRICANE SEASON

4.1 Hurricane Season Summary

The 2011 Atlantic hurricane season produced 20 tropical cyclones, 19 tropical storms, 7 hurricanes, and 3 major hurricanes. It featured an above-average number of tropical storms with a near-normal number of major hurricanes. The season officially began on 1 June and ended on 30 November, dates which conventionally delimit the period during which most tropical cyclones form in the Atlantic basin. The season tied 2010, 1995, and 1887 for the third highest number of tropical storms. The season's first hurricane, *Irene*, was a powerful Category 3 hurricane that made landfall in North Carolina as a Category 1, causing significant damage and record flooding to the northeastern United States. The other two hurricanes that affected the Nags Head project area were *Katia* and *Maria*. Although they did not directly strike the North Carolina coastline, the high wave conditions they generated caused several days of delay in the beach nourishment project.

4.1.1. Hurricane Irene

Forming on 20 August 2011, Hurricane *Irene* was the second earliest Atlantic tropical cyclone on record, along with an unnamed tropical storm from the 1936 season. It was the ninth named storm as well as the first hurricane and the most powerful and destructive hurricane of the 2011 hurricane season. *Irene* caused widespread destruction throughout its path (Fig 4.1), and at least 55 people were confirmed dead in the aftermath across the Caribbean, ten U.S. states, and Canada. Damage from Hurricane *Irene* reportedly totaled $10.1 billion (2011 USD). *Irene* resulted in "at least $53.9 million" in damages in Dare County (source: Greta Skeen, Dare County damage assessment officer), including those from sound-side flooding which was extensive given the storm's track up Pamlico Sound (see Fig 1.1).

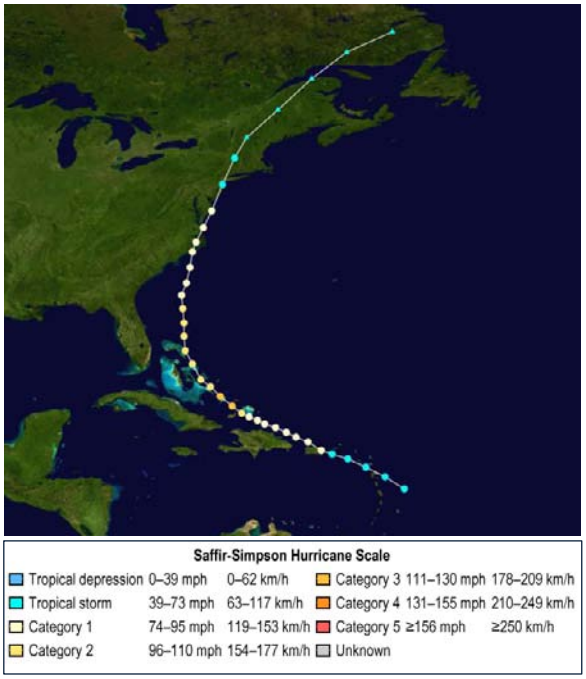


FIGURE 4.1. Storm path of Hurricane *Irene*. [Source: Wikipedia]

Hurricane *Irene* made its first landfall at Cape Lookout (NC), about 75 miles southwest of Nags Head, around 7:30 am on Saturday, 27 August. Maximum sustained wind speeds were 90 miles per hour (mph) (Category 1 hurricane), and the track was north-northeast at 14 mph. By early afternoon, the eastern edge of the eyewall was in the vicinity of Manteo (5 miles west of Nags Head). This path generated strong winds and high waves from the southeast at Nags Head with winds veering east to southwest as the storm passed west of town. According to NOAA wind and tide-gauge records and the USACE Field Research Facility wave gauge 430 (12 miles offshore) at Duck (NC), wind speeds reached 70 mph at the peak of the storm, tide levels were 3 ft, and significant wave heights were 23 ft with a period of 16 seconds (Fig 4.2a-c). GLDD's wave buoy (located between borrow subareas 2 and 3 about 2 miles offshore) recorded ***hourly*** maximum wave height which reached 29 ft at the peak of the storm at around 2 pm on 27 August (Fig 4.3).

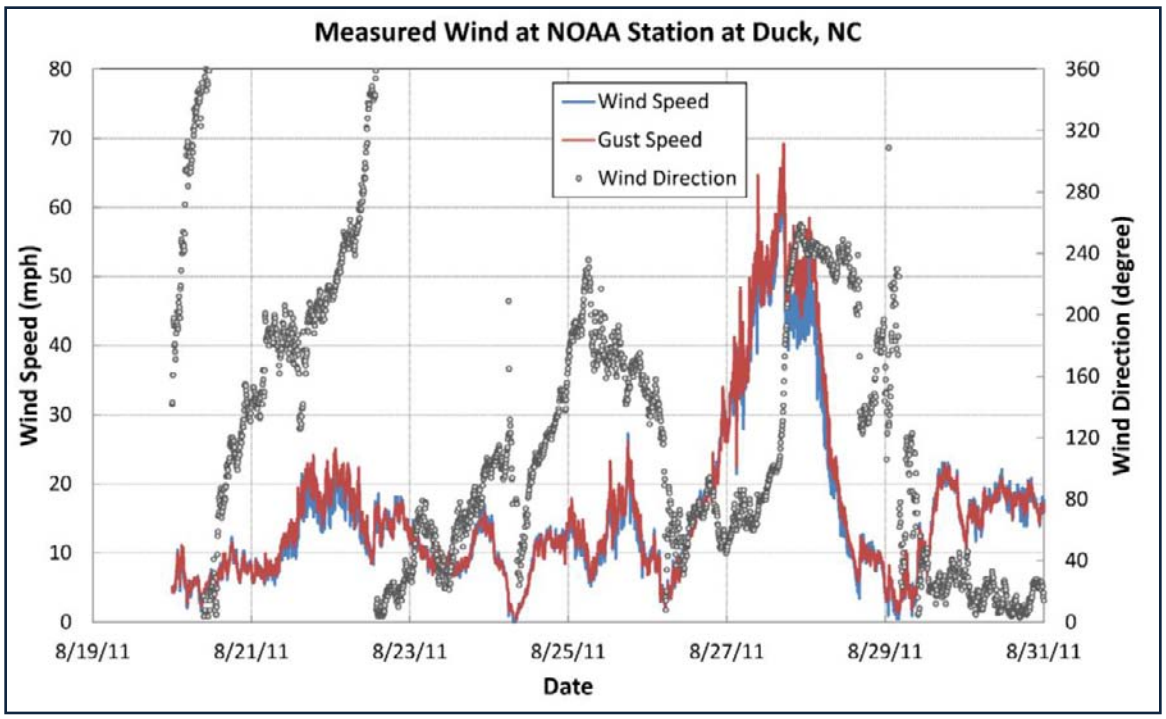


FIGURE 4.2a. Wind data for Hurricane *Irene*. [Source: NOAA-USACE]

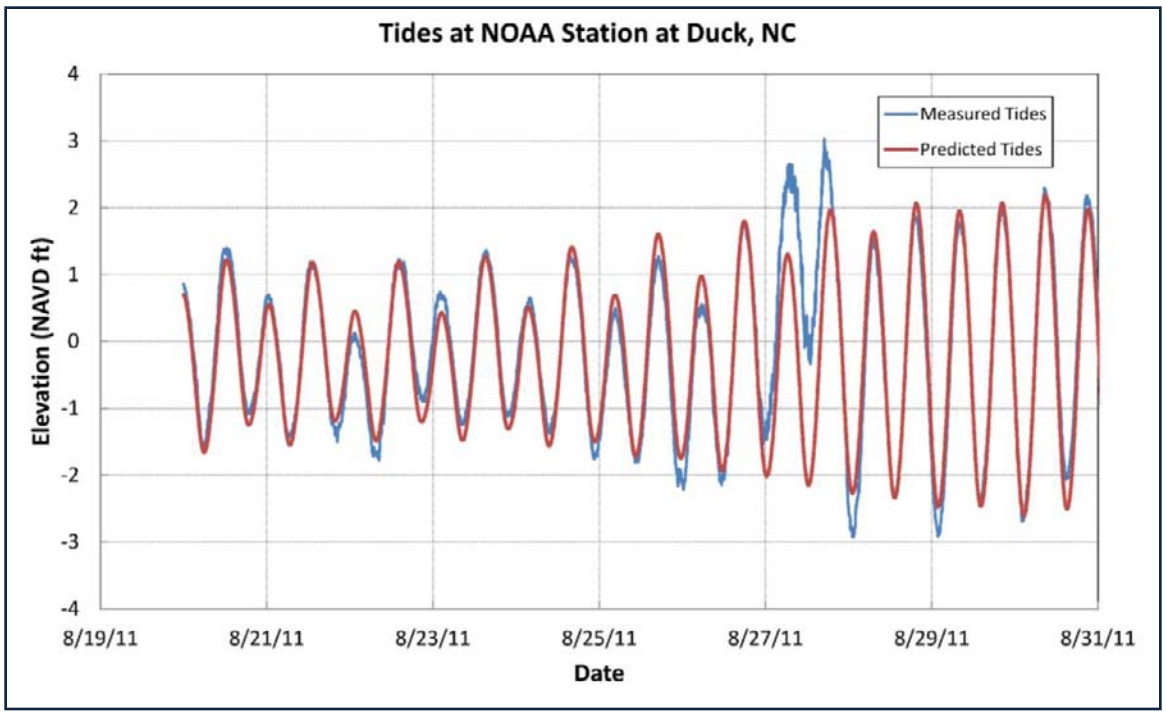


FIGURE 4.2b. Measured versus predicted tides at the Duck FRF showing a maximum surge of the order −2 ft around low tide during Hurricane *Irene*. [Source: NOAA]

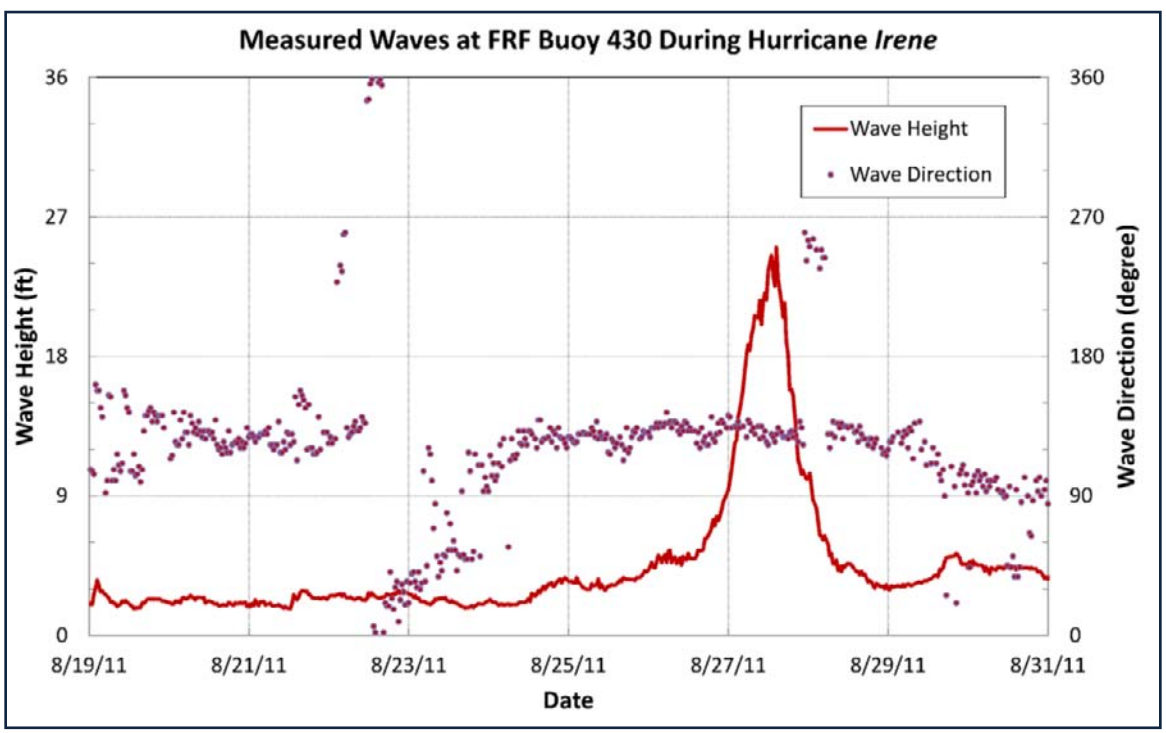


FIGURE 4.2c. Wave data for Hurricane *Irene*. [Source: USACE-FRF]

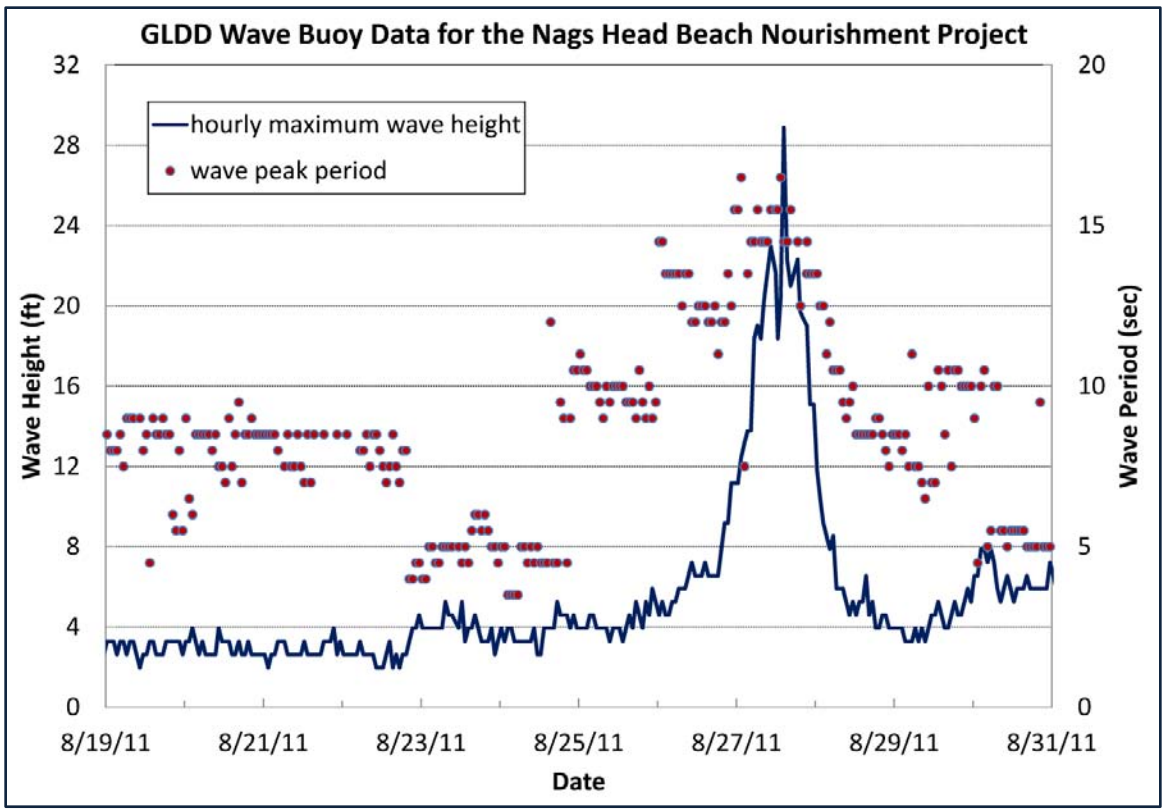


FIGURE 4.3 GLDD wave buoy data during Hurricane *Irene*. [Source: GLDD]

4.1.2. Hurricane Katia

Hurricane *Katia* was the eleventh named storm, second hurricane, and the second major hurricane of the 2011 Atlantic hurricane season. Formed on 27 August and strengthening to a Category 4 hurricane with winds of 135 mph, *Katia* weakened to a Category 1 by 8 September when it crossed the U.S. East Coast ~350 offshore of Nags Head. *Katia*'s storm path is shown in Figure 4.4, and tide, wind, and wave data are plotted in Figure 4.5(a-c). Wind gusts over 30 mph were measured at the FRF station at Duck (NC), and waves were as high as 10 ft at the peak of the storm. Unfortunately, GLDD's wave buoy was damaged at the end of August with the passage of Hurricane *Irene*; therefore, no site-specific wave data were recorded during the storms that followed.

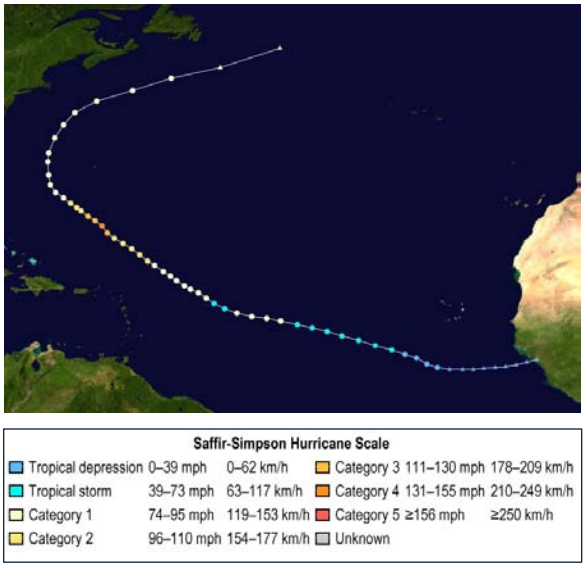


FIGURE 4.4. Storm path of Hurricane *Katia*. [Source: Wikipedia]

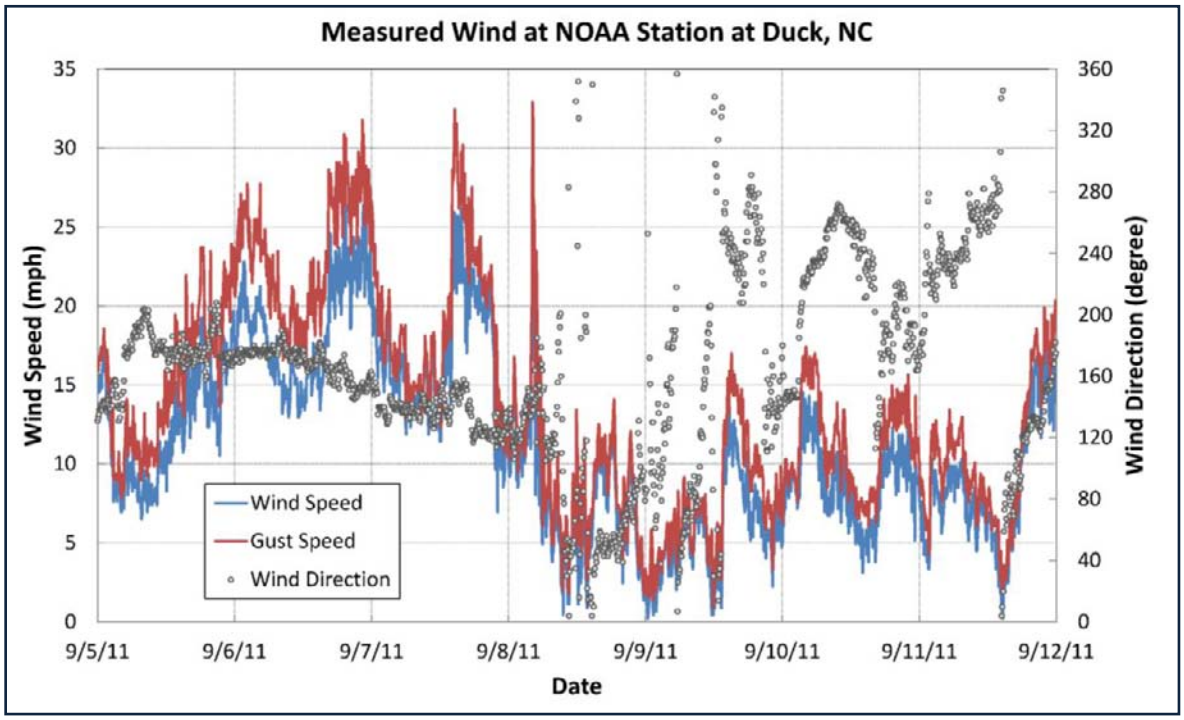


FIGURE 4.5a. Wind data for Hurricane *Katia*. [Source: NOAA]

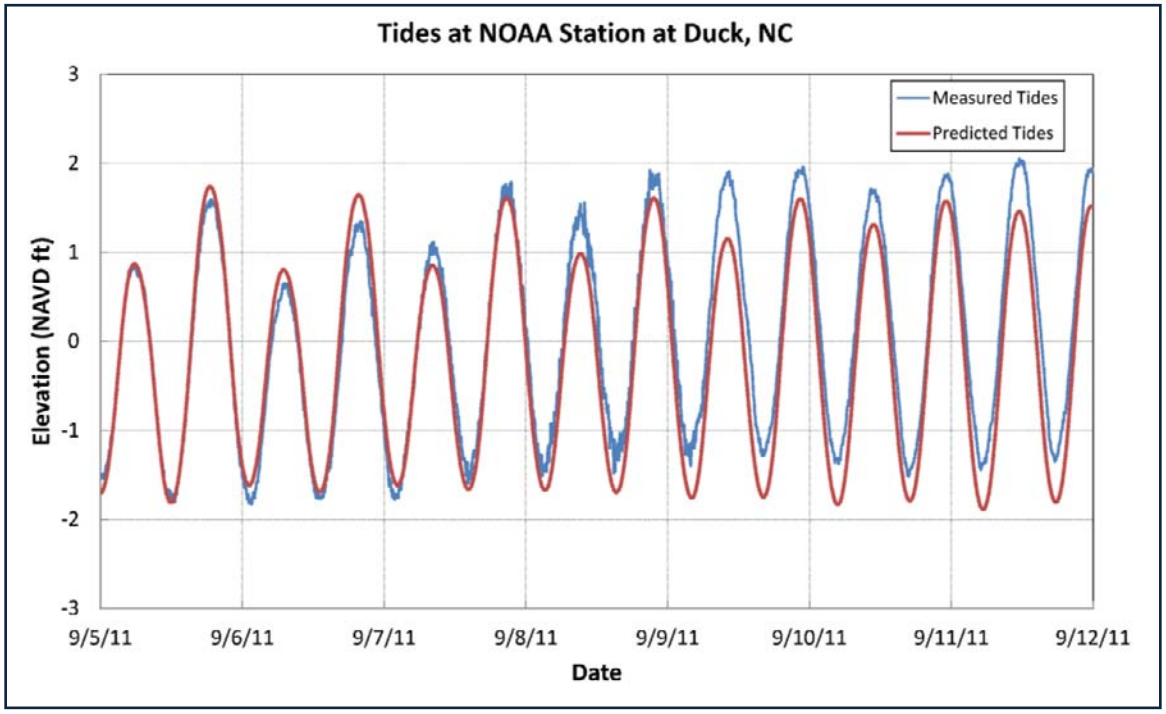


FIGURE 4.5b. Tide data for Hurricane *Katia*. [Source: NOAA]

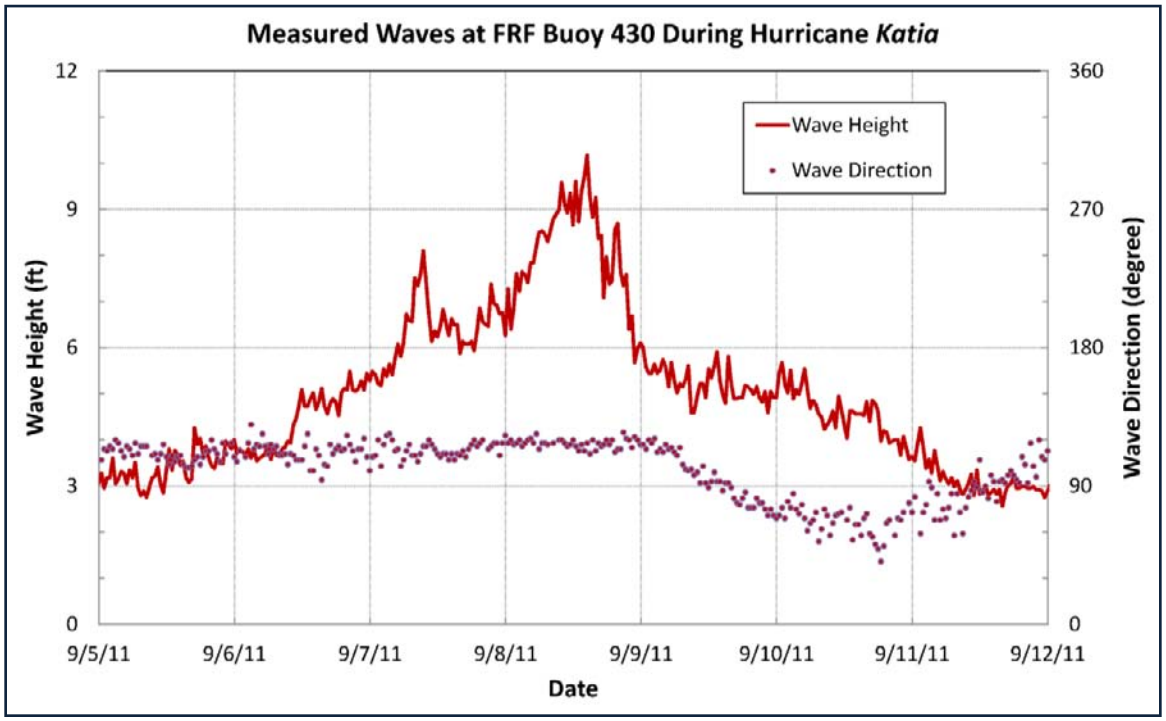


FIGURE 4.5c. Wave data for Hurricane *Katia*. [Source: USACE-FRF]

4.1.3. Hurricane Maria

Hurricane *Maria* was the thirteenth named storm and the third hurricane of the 2011 Atlantic hurricane season. Formed in early September, Hurricane *Maria* became a Category 1 hurricane during the afternoon hours of 15 September as it passed ~500 miles offshore of Nags Head and moved toward the northeast at a very fast pace (Fig 4.6). Almost 50 mph wind gusts were measured at the FRF station (Duck NC), and waves were over 10 ft (Fig 4.7a-c).

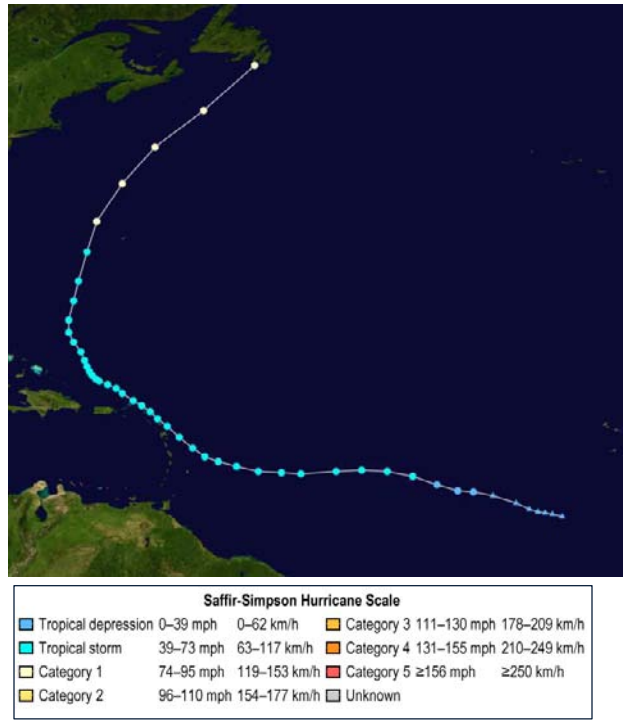


FIGURE 4.6. Storm path of Hurricane *Maria*. [Source: Wikipedia]

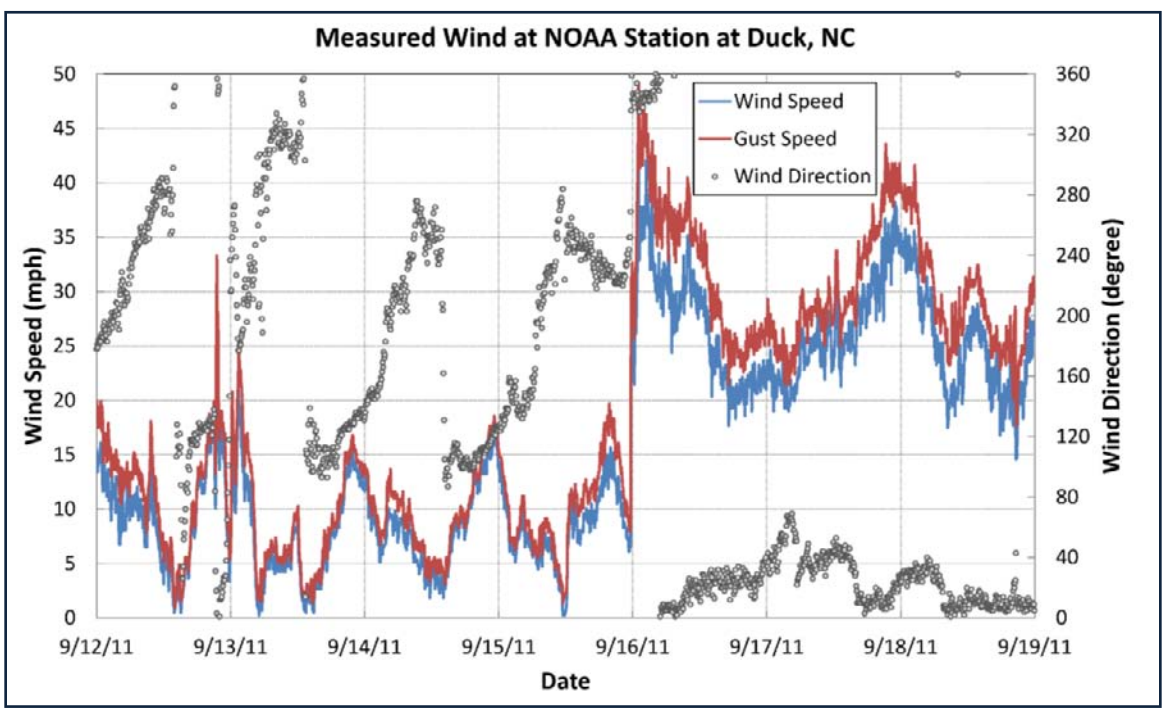


FIGURE 4.7a. Wind data for Hurricane *Maria*. [Source: NOAA]

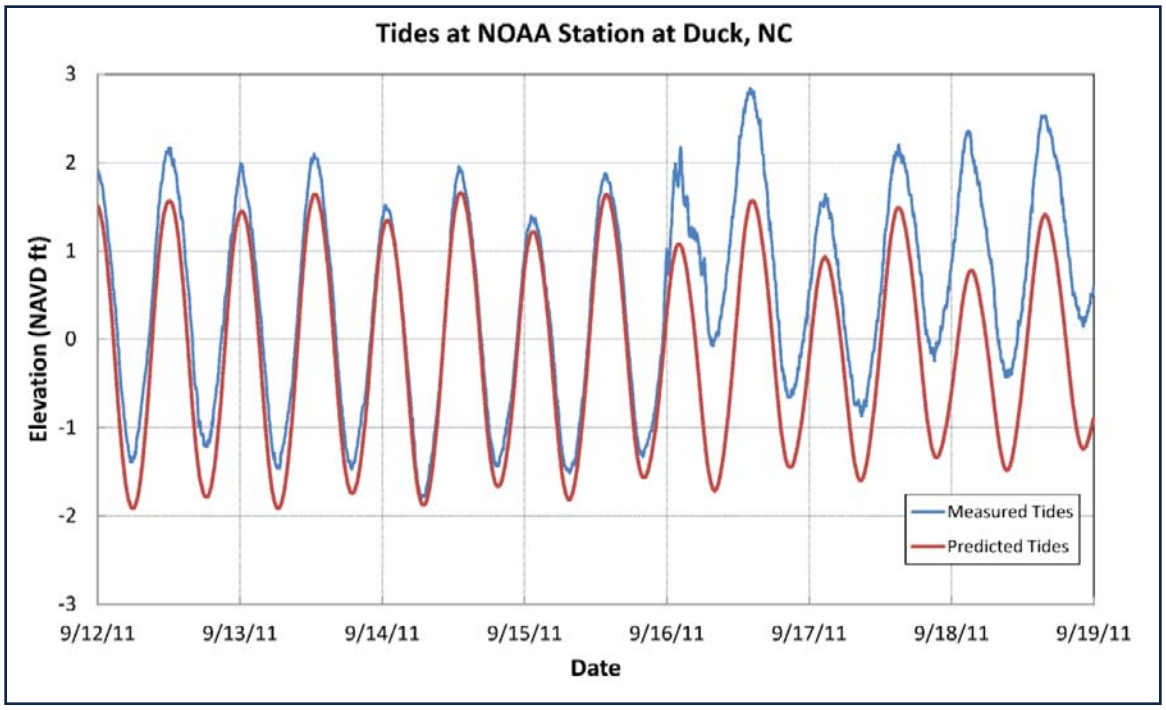


FIGURE 4.7b. Tide data for Hurricane *Maria*. [Source: NOAA]

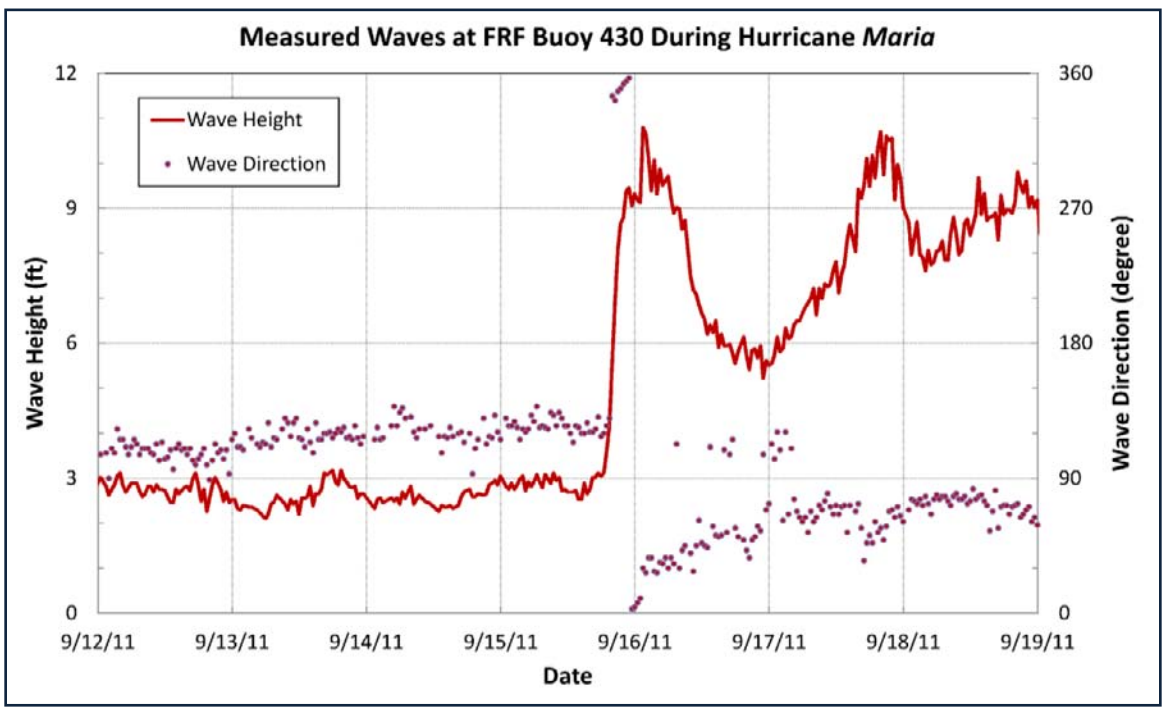


FIGURE 4.7c. Wave data for Hurricane *Maria*. [Source: USACE-FRF]

4.2 Hurricane *Irene* Impacts and Erosion Assessment

Hurricane *Irene* was the most powerful storm that impacted the Nags Head beach nourishment project during the construction. Its landfall coincided with high tide, so as the storm progressed up Pamlico Sound, the tide was falling at Nags Head. This had the favorable effect of reducing the peak water levels by as much as 4 ft. Even though estimated maximum wave runup along the foredune at Duck (NC) was ~13.5 ft NAVD (J McNinch, USACE-FRF, pers comm, September 2011)—at Nags Head, the maximum runup along the nourishment project was ~10 ft NAVD based on on-scene observations by CSE.

At the time of *Irene*'s landfall, ~3.8 million cubic yards had been placed in the project area, which is about 85 percent of the total contract volume. Figure 4.8 illustrates the project's progress as of 25 August after the four dredges evacuated to Norfolk (VA). A continuous section of beach was nourished by the dredges, *Liberty Island* and *Texas,* from station 627+00 (milepost ~13.6) to station 1016+00 (milepost ~21) for a total of 38,900 ft (~7.4 miles). Another section of beach was nourished by the *Dodge Island* and the *Padre Island* between station 522+00 (milepost ~11.5) and station 536+00 (milepost ~11.8) for a total of 1,400 ft. Thus, the total finished sections were about 40,300 ft (~7.6 miles) before the storm impacted the project area.

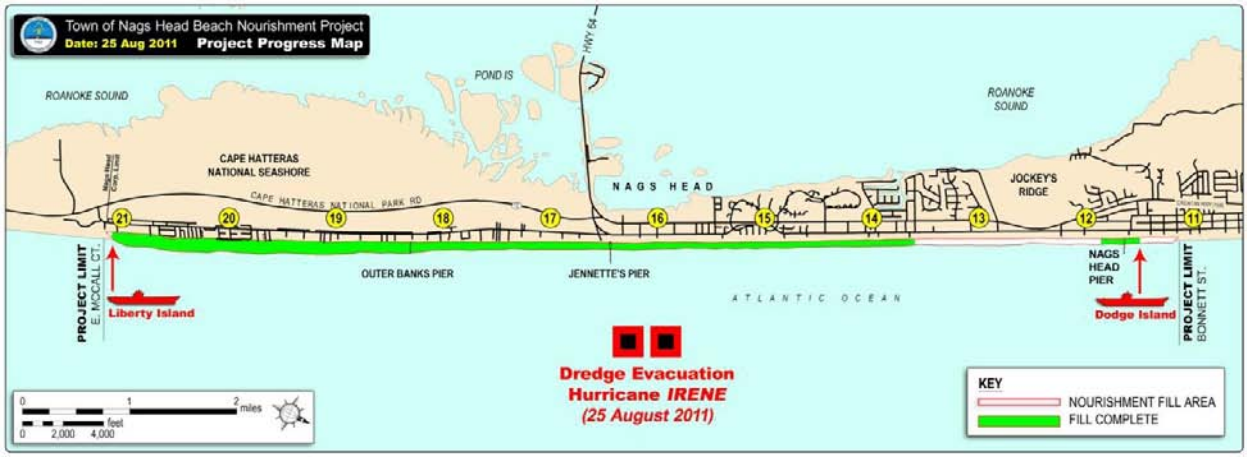


FIGURE 4.8. Progress map before Hurricane *Irene*'s landfall. [Source: CSE]

CSE's on-site staff conducted a pre-storm survey along the visible beach to low water depth in nourished and unnourished sections at 5,000-ft spacing on 23 August. On 28 August (the day after the storm), a post-storm survey was conducted on the visible beach at 5,000-ft spacing. CSE also collected ~13,000 data points on 29 August for comprehensive coverage of the

visible beach. Such continuous topography of the visible beach was used to prepare a digital terrain model (DTM) to compare with the pre-storm condition. Figure 4.9 presents an example of these DTM plots at the south end of the project area (between stations 965+00 and 1025+00) where nourished sections and unnourished sections meet at station 1016+00 (marked as "Nourishment End" in the graphic). Condemned houses at Seagull Drive are also shown. The plot includes contours at +5 ft NAVD with the pre-storm condition shown on the left and post-storm condition on the right at the same area. The entire set of DTM plots for the project is included in Appendix J6 Pre-storm data are based on GLDD's before-dredging or after-dredging survey data depending on whether or not the particular section was nourished.

Based on CSE's data collected before and after the storm and also based on on-scene observations, there was no scarping of the foredune or undermining of homes in the nourished sections while unnourished sections experienced an average dune recession of 15 ft measured at the +7 ft NAVD contour (toe of dune). There was considerable variability in the beach after the storm as a result of “profile adjustment.”

Beach nourishment is typically placed in a configuration that allows as much control of the sections as possible. This usually results in wider-than-expected dry-beach conditions and a steeper sloping section into the water. The “fill templates” for Nags Head were also modified after favorable bids so as to fit the full volume within the permitted seaward project limit. Thus, more sand was placed above mean low water (MLW) initially with the expectation that a significant portion would shift underwater. The construction berm, therefore, is almost always wider than the adjusted berm for nourishment projects.

Under normal construction practice, a portion of the nourishment sand on the construction berm is designed to shift underwater by wave action and eventually reach equilibrium. Northeasters or storms like *Irene* accelerate this process. Some sections had just received new sand days before the storm, and nearly all sections had not fully adjusted and that is why there was an extensive shift of sand from the visible beach into shallow water. The volume shifted beyond MLW reported from CSE's 28 August 2011 survey was ~930,000 cy. Fortunately, the storm’s intensity and surge were insufficient to penetrate across the nourishment berm and cut back the dunes. Even the condemned properties at Seagull Drive, which received nourishment about two weeks before the storm, made it through the storm without further damage.

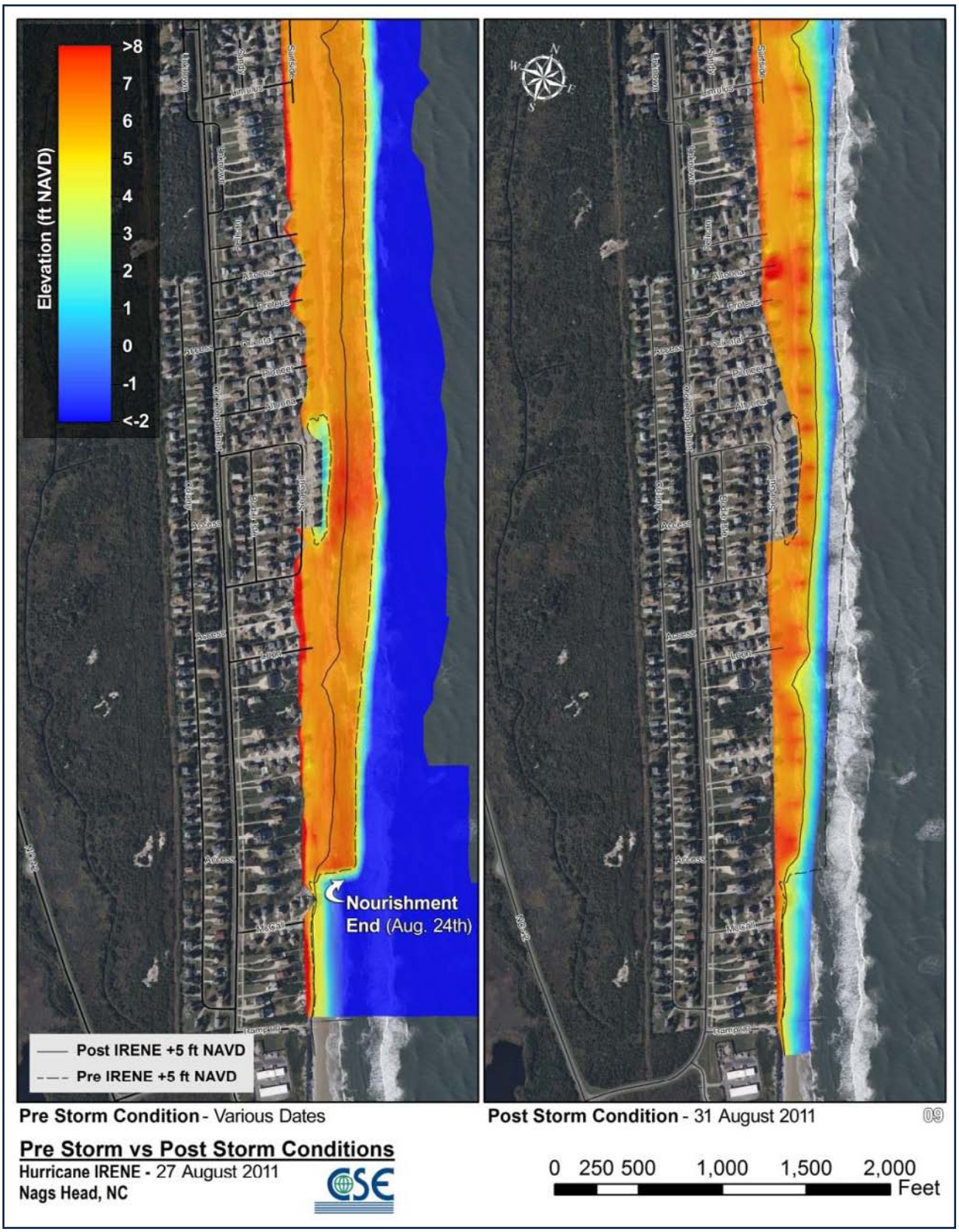


FIGURE 4.9. DTM plot for pre-storm versus post-storm conditions at the south end of Nags Head between station 965+00 and station 1025+00. The survey reflects changes along the visible beach and does not include the concomitant buildup of shallow-water bars.

Rough sea conditions under strong northeast winds (associated with passage of several extratropical storm systems in September 2011) prevented offshore data collection immediately after the storms. The Town and CSE obtained additional profile data and completed a comprehensive post-storm survey at ~2,500-ft spacing in late September. The net change to MLW as of 28 September was ~700,000 cy, already indicating some recovery of the low-tide beach compared to the ~930,000 cy volume loss to MLW reported from CSE's 28 August survey. A net loss of ~100,000 cy measured to the −12-ft NAVD contour was documented after CSE's 28 September survey. This is consistent with visual observations of bar development seaward of the low-tide mark. In other words, some nourishment sand shifted from the visible beach to the inshore breaker zone.

Figure 4.10 shows the total volumetric losses between the foredune and indicated reference contours within the project area (between stations 500+00 and 1025+00) due to *Irene* and September storms. Detailed analysis of volume changes due to Hurricane *Irene* and the storm impact on the beach nourishment project are discussed in the two memoranda (Appendixes J5 and J8) that were submitted to the Town by CSE.

The −12-ft NAVD contour is situated about 1,000 ft offshore. The results to −12-ft NAVD are considered fairly reliable because GLDD's survey data (collected by Coastal Reach Amphibious Buggy, CRAB) were used for comparison with CSE's data collection. However, the large spacing of the profiles introduces some error. The further offshore (ie – the deeper the water and the more sand volume between the fore dune and reference contours), the more error it may introduce in the calculation.

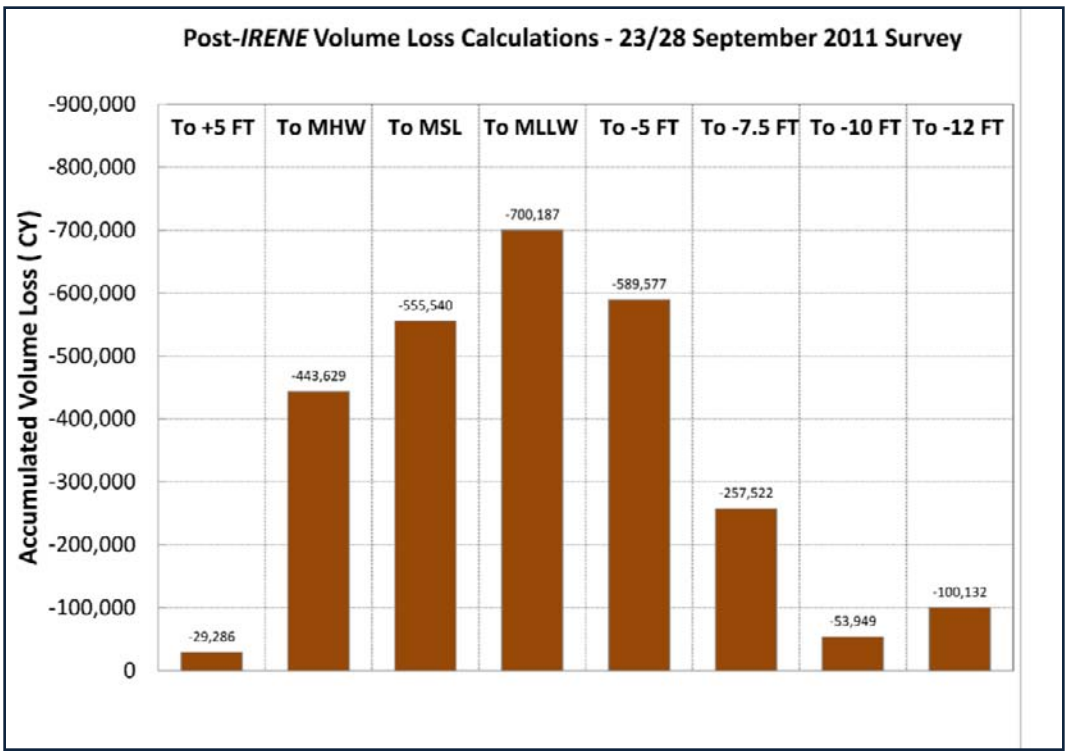


FIGURE 4.10. Total accumulated volumetric losses between stations 500+00 and 1025+00 to various reference contours based on limited measurements before *Irene* and measurements one month later. The results confirm a shift of sand from the visible beach above MLW to shallow water. Note small net volumetric losses when the calculation boundaries extend to −10 ft or −12 ft depth contours. [Note: Mean high water (MHW) is +1.18 ft NAVD. Mean sea level (MSL) is −0.42 ft NAVD. Mean lower low water (MLLW) is −2.19 ft NAVD.]

In conclusion, the newly placed sand served to absorb storm-wave energy and prevent adverse impact to the foredune, buildings, and roads. The Town public works staff indicated that there has almost always been ocean overwash somewhere along Nags Head during past hurricanes. In 2003, Hurricane *Isabel* severely damaged (beyond repair) 50 percent of the public beach accesses. By contrast, there was no ocean overwash and no beach access damage during Hurricane *Irene*. Based on the relatively low volume of sand that was "lost" to the −12-ft NAVD contour and the similarity in magnitude of the loss to the expected errors of such surveys, CSE did not recommend the Town apply for post-storm FEMA restoration funds following Hurricane *Irene*.

More comprehensive data were collected in November after the completion of the project, and the volume changes seaward of the −12-ft NAVD contour were evaluated then. The post-project survey results reinforced CSE's post-*Irene* recommendation and will be discussed in detail in Section 8.

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5.0 SUMMARY OF SEDIMENT ANALYSES

5.1 Sediment Analyses for the Recipient Beach and the Borrow Areas

Sediment samples of the native beach were collected by CSE in November 2008, and sediment characteristics were evaluated to confirm sediment quality of the nourished beach would closely match the pre-nourishment beach. The mean grain size of all native beach sand samples (composite) ranged from 0.136 millimeters (mm) to 1.641 mm, and averaged 0.306 mm. No samples possessed sediment in the gravel (4.76 mm or greater) size class. The granular fraction (2.0 to 4.76 mm) ranged from 0.0 to 60.6 percent, averaging 3.8 percent. Sand-sized sediment (0.0625 to 2.0 mm) averaged 96.1 percent for all samples with the majority being >98 percent. Fine-grained material (less than 0.0625 mm) ranged from 0.0 to 4.6 percent and averaged 0.1 percent. Shell (calcium carbonate) content ranged from 0.2 to 15.1 percent with an average of 1.8 percent.

Borrow Areas 2 and 3 were delineated within USACE (2000) borrow area “S1” (see Fig 2.1) based on collection of 100 borings by CSE between 2005 and 2008 (CSE 2005, 2008, 2011). USACE's (2000) previous studies had indicated S1 contained up to 100 million cubic yards of beach-quality sediment to be used as the borrow source for the federal beach nourishment project. Borings obtained by CSE in the borrow areas were designed to confirm sediment quality and limit the area of impact so that large areas would remain for future use. Cores were logged and analyzed for grain size, shell content, and mud content using sample splits at distinct changes in lithology. Core logs and photos can be found in the FEIS (USACE 2010) and in CSE's (2011) final design report.

Mean grain size for the offshore samples was generally uniform with sparse areas of fine and coarse sand occurring. Mean grain size ranged from 0.194 mm to 0.782 mm for individual samples with an average grain size of 0.410 mm. No gravel- (or greater) sized sediment was present in the offshore samples. Granular sediment ranged from 0.0 to 39.3 percent and averaged 4.0 percent. Sand-sized sediment ranged from 60.7 percent to 100 percent, averaging 96.0 percent. All samples in borrow areas 2 and 3 showed exceedingly low levels of fine material (under 1 percent) averaging 0.1 percent. Shell content was also relatively minor, generally <3 percent.

The similarity of the sand-size classes and shell content in sediment analyses for the recipient beach and the borrow areas suggested that the sand would look and perform well once placed on the beach. The designated borrow areas meet the updated North Carolina Coastal Resources Commission (NCCRC) sediment criteria and also meet CSE's sediment criteria*—aiming at producing a stable project which is as economically and environmentally compatible as possible.

*[*NCCRC sediment criteria for dredging and nourishment projects focuses on the "tails" of the grain-size distribution so as to minimize adverse environmental impacts associated with excessive fines (eg – mud), gravel, or shell. Beach nourishment stability criteria (CERC 1984), by comparison, seeks to match borrow sediment performance with native beach performance and therefore tends to require a close match of the mean grain size. CSE's criteria for Nags Head focused on borrow deposits matching the subaerial beach rather than the inshore zone which tends to consist of much finer sand.]*

5.2 Sediment Analysis During Construction Phase

As discussed in Section 2 (construction management), CSE representatives collected a composite-grab sand sample from the last station completed during their daily construction observations. A composite sample consisted of a series of grab samples at ~10-ft spacing along a transect from the landward limit of fill to the low-tide line mixed together to form one representative sample for the given station. Some additional single-point grab samples in the vicinity of the discharge point were also collected. Selected sand samples were analyzed to determine grain-size characteristics and shell content as a means of monitoring the quality of the material actually placed on the beach. These results are summarized in Table 5.1. Grain-size distribution for selected individual sand samples is given in detail in Appendix C.

Nourishment sand placed on the beach was found to be consistent with the borings obtained by CSE. It contained negligible mud, little shell material, and was compatible, clean, and free of debris and clay. The mean grain size of the samples collected during project construction was calculated to be 0.439 mm (ranging from 0.306 mm to 0.585 mm), which is classified as medium sand (0.25-0.5 mm diameter). The nourishment sand is similar in texture as the native beach (subaerial samples) and is expected to provide similar performance as the native beach with respect to annual erosion losses.

TABLE 5.1. Summary of grab sand samples during construction.

Date Taken	Station	Borrow Area	Mean Grain Size (mm)	Standard Deviation (mm)	Shell Fraction (%)
24-May-11	727+50	2	0.306	0.687	1.6
25-May-11	727+00	2	0.575	0.582	1.0
25-May-11	728+00	2	0.585	0.545	1.9
25-May-11	723+00	2	0.508	0.557	2.0
26-May-11	720+00	2	0.472	0.579	1.4
26-May-11	718+00	2	0.485	0.567	1.4
27-May-11	716+00	2	0.461	0.600	2.2
27-May-11	712+00	2	0.484	0.559	1.9
28-May-11	710+00	2	0.458	0.575	1.8
28-May-11	704+00	2	0.438	0.602	1.3
29-May-11	701+00	2	0.414	0.616	1.1
29-May-11	700+00	2	0.444	0.610	1.6
30-May-11	696+00	2	0.422	0.617	1.0
31-May-11	698+00	2	0.444	0.583	1.0
31-May-11	694+00	2	0.465	0.562	2.3
31-May-11	728+00	2	0.432	0.575	2.1
1-Jun-11	746+00	2	0.412	0.613	1.2
2-Jun-11	734+00	2	0.461	0.543	2.7
2-Jun-11	736+00	2	0.462	0.630	1.1
3-Jun-11	740+00	2	0.406	0.620	1.4
3-Jun-11	744+00	2	0.472	0.581	2.1
4-Jun-11	745+00	2	0.414	0.598	2.6
4-Jun-11	747+00	2	0.452	0.569	1.2
5-Jun-11	749+00	2	0.437	0.567	1.9
5-Jun-11	750+00	2	0.494	0.540	1.5
8-Jun-11	752+00	2	0.452	0.576	1.8
15-Jun-11	760+00	2	0.416	0.619	1.4
18-Jun-11	770+00	2	0.450	0.599	1.1
22-Jun-11	818+00	2	0.435	0.621	-
22-Jun-11	816+00	2	0.480	0.594	-
22-Jun-11	960+00	3	0.390	0.626	-
26-Jun-11	958+00	3	0.452	0.529	-
27-Jun-11	954+00	3	0.387	0.614	-
29-Jun-11	952+00	3	0.360	0.632	-
23-Jun-11	813+00	2	0.430	0.592	-
24-Jun-11	810+00	2	0.408	0.586	-
26-Jun-11	807+00	2	0.468	0.563	-
27-Jun-11	954+00	3	0.354	0.615	1.2
29-Jun-11	952+00	3	0.336	0.602	-
2-Jul-11	950+00	3	0.407	0.481	3.8
3-Jul-11	942+00	3	0.360	0.578	2.1
	Average	-	**0.439**	**0.588**	**1.7**

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6.0 SUMMARY OF ENDANGERED SPECIES PROTECTION MEASURES & RESULTS

6.1 Environmental Protection Measures on Hopper Dredges

One of the principal planning objectives for the Nags Head beach nourishment project was the preservation of the environmental resources in the project area, especially threatened or endangered species (including sea turtles, sturgeon and whales). Since construction activities were performed during the peak of the sea turtle nesting season, dredging and placement operations were subject to certain environmental protection measures as detailed in federal and state permits and discussed in Section 1.4 of this report. Protection measures included open-net trawling for turtles ahead of the dredges during designated periods, use of deflectors and specific equipment modification on board hopper dredges, specific operations requirements and use of silent inspectors on board dredges, and use of certified endangered species monitors on board dredges.

GLDD developed a Sea Turtle Protection Operational Plan of detailed measures and procedures to be taken in the execution of the project (Appendix A3–GLDD Serial Letter 02). Coastwise Consulting (Athens GA) was GLDD's subcontractor for endangered species monitoring as well as trawling. GLDD, along with its subcontractors, maintained a quality control system for environmental protection of all items set forth in the specifications, as discussed in the following sections.

6.1.1 Hopper Dredge Operations

Before dredging operations commenced, GLDD submitted detailed Turtle Exclusion Device (TED) drawings showing the proposed rigid sea turtle deflector device, the proposed drag-head grating systems and drag heads, and documentation that supports grate sizing such as dredge pump manufacturer's recommended maximum particle size dimensions, etc (Appendix A3–GLDD Serial Letter 01). All hopper dredges used in this project were equipped with a certified and functioning Dredge Quality Management (DQM) system. This arrangement was previously titled Silent Inspector (SI) and is a system that monitors and records a myriad of positioning, depth, and production data, and transmits the information to the DQM Support Center. These operational procedures were intended to stress the importance of balancing the suction pipe densities and velocities to prevent sea-turtle takes.