Beneficial Use of Dredged Material to Enhance Salt Marsh Habitat in New Jersey

Project Summary and Lessons Learned

August 2021

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Glossary

The following terms have been defined according to how they have been specifically used in this document and in the context of the marsh enhancement projects discussed herein. These definitions may differ from those used by others for the same/similar terms.

Adaptive management—The process of continually, iteratively reviewing data and information to develop, design, construct, monitor, and manage a project, in order to meet the project objectives.

Beneficial use of dredged material—The placement of dredged material to enhance, create, or restore a variety of habitats, as opposed to the usual practice of disposing of it in a confined disposal facility.

Biological benchmarks—The optimum tidal elevation range of the plant species of interest. These benchmarks are used (at least, in part) to design a habitat (e.g., marsh) enhancement and to establish target ecological elevations for enhancement projects.

Coastal resiliency—The ability of coastal communities and natural habitats to withstand and recover from the impacts of storms, flooding, accelerating sea-level rise, and other natural hazards.

Dredging team—Personnel whose primary responsibility is to ensure the dredging success of the projects.

Ecological resiliency—The ability of an ecosystem (e.g., a salt marsh) to resist, respond to, and recover from a disturbance (e.g., an increase in the rate of sea-level rise).

Elevated Nesting Habitat (ENH)—Colonial shorebird nesting habitat created by placing sandy dredged material in a mound on the marsh platform to increase the elevation of the land and create sparsely vegetated sandy habitat. The ENH is high enough to protect the nests from flooding during high tides and storms.

Enhancement—The improvement of a wetland's ability to support natural aquatic life, through substantial alterations to the soils, vegetation, and/or hydrology, as defined by New Jersey Regulations. Also called "restoration" in other parts of the country.

Marsh team—Personnel whose primary responsibility is to ensure the ecological success of the projects.

Mean High Water (MHW)—The average of all the daily tidal high water heights observed over a period of several years.

Mean Higher High Water (MHHW)—The average height of the highest tide recorded at a tide station each day during the recording period.

New Jersey Intracoastal Waterway (NJIWW)—A system of navigation channels maintained by the U.S. Army Corps of Engineers that extends along the New Jersey Coast from the Atlantic Ocean at Manasquan Inlet to Delaware Bay, about 3 miles north of Cape May Point.

Placement areas—Specific areas on the marsh selected for enhancement that received sediment dredged from a nearby navigation channel or marina. Also called "marsh enhancement areas" or "dredged material placement areas."

Stressed marsh—Marshes in need of enhancement (not a regulatory term). Characteristics of stressed marshes include eroded edges, expanded and degraded pools with undercut banks, sparse (low percent cover) and stunted vegetation, mosquito ditches, fragmented high marsh vegetation, elevation deficits, and minimal faunal usage of pools.

Target dredged material placement elevation—The initial elevation up to which dredged material is placed on the habitat enhancement site (e.g., marsh plain). After placement, the material undergoes predicted dewatering and consolidation of the dredged material, sinking from the target dredged material placement elevation to achieve the target ecological elevation.

Target ecological elevation—The elevation necessary to meet the specific habitat (e.g., marsh) enhancement ecological objectives for a project. The target ecological elevation is lower than the target dredged material placement elevation and is based on biological benchmarks**,** desired hydrology, and other conditions at the project site.

Thin-layer placement (TLP)—A wetland enhancement method in which dredged material (i.e., sediment) is intentionally placed on a wetland to increase its elevation, enhancing its resiliency while maintaining the hydroperiod necessary for native wetland vegetation. The thickness of the material is limited to enable the vegetation to grow back through the placed dredged material. Wetland ecosystems are expected to recover more quickly after TLP than after thicker applications of dredged material.[1]

[1] The U.S. Army Corps of Engineers defines TLP as "Purposeful placement of thin layers of sediment (e.g., dredged material) in an environmentally acceptable manner to achieve a target elevation or thickness. Thin layer placement projects may include efforts to support infrastructure and/or create maintain, enhance, or restore ecological function." (Berkowitz et al. 2019)

This drone photo shows the salt marsh enhancement project in Fortescue, NJ, after sediment was added (outlined in black). Photo credit: TNC 2016

Summary

Tidal marshes are an integral part of New Jersey's estuaries. They form a charismatic green band that cleans water; provides critical habitat and food sources for fish, shellfish, and birds; and buffers coastal communities from storms, erosion, and flooding (Mitsch and Gosselink 2007, NJDEP 2007, Narayan et al. 2017). However, the continued existence of many tidal wetlands is threatened by sea-level rise. To maintain healthy salt marsh vegetation, marshes must accrete sediment and plant matter to gain elevation at a rate that keeps pace with sea-level rise and subsidence (Nyman et al. 2006, Mitsch and Gosselink 2007, Cahoon et al. 2009, Kirwan and Megonigal 2013). Some salt marshes are stressed and literally "drowning" because they cannot gain surface elevation at a rate that keeps pace with accelerating sea-level rise (Hartig et al. 2002, Ganju et al. 2017, Watson et al. 2017a).

A variety of factors decrease tidal wetland resilience to sea-level rise, including historic alterations, like ditching and diking, and ongoing stressors, such as severe storms, dredging, decreased sediment content of tidal waters, and edge erosion (Bertness et al. 2002, Hartig et al. 2002, Church and White 2011, Partnership for the Delaware Estuary 2012, Weston 2014, Watson et al. 2017b).

One possible solution to the problem is increasing the elevation of a salt marsh by placing sediment on it (e.g., dredged material; Daiber 1986, Ray 2007). An increase in marsh elevation reduces inundation by the tides, promoting the growth of vegetation. The vegetation in turn stabilizes the marsh soil and promotes further accretion and increased elevation via sediment trapping and root production. It forms a positive feedback loop that increases marsh resiliency (Wolanski et al. 2009).

New Jersey's navigation channels and marinas must be dredged regularly to maintain safe passage for recreational and commercial vessels, which creates a ready supply of dredged material. There is great interest in leveraging existing dredging projects to restore and enhance salt marshes. This practice, the **beneficial use of dredged material**, combines the routine maintenance and post-storm dredging required to keep waterways navigable with projects to enhance, restore, and create salt marshes and other estuarine habitats.

One of the many impacts of Superstorm Sandy in 2012 was major shoal creation in the navigation channels along New Jersey's coast. Traditionally, in coastal areas of the state, dredged material was placed in confined disposal facilities, effectively removing it from the coastal system. New Jersey lacks confined disposal facilities with the capacity to accept additional dredged material, and this has become a major problem for coastal communities, as well as for state and federal agencies that need to maintain navigable waterways. Following Hurricane Irene (2011) and Superstorm Sandy, the U.S. Army Corps of Engineers, Philadelphia District (USACE-OP), obtained emergency supplemental funding to clear critical shoals from the **New Jersey Intracoastal Waterway (NJIWW)**, and the New Jersey Department of Transportation's Office of Maritime Resources (NJDOT-OMR) planned to restore navigability by removing sediment from channels in Cumberland County.

In 2013, the New Jersey Department of Environmental Protection, Division of Fish and Wildlife (NJDEP-DFW), partnered with the USACE-OP, the USACE Engineer Research and Development Center (USACE-ERDC), NJDOT-OMR, The Nature Conservancy (TNC), and the Green Trust Alliance (GTA) to initiate three pilot projects. These projects intended to advance the concept that beneficial use of dredged material on stressed salt marshes to increase their elevation would increase the abundance of native salt marsh vegetation and would result in ecological uplift over their baseline condition, ultimately increasing their resiliency to sea-level rise. All parties acknowledged that this was an opportunity to explore a paradigm shift from thinking of dredged material as waste to thinking of it as a resource. The total cost of the pilot projects was $8 million. Approximately half of the funds were provided to NJDEP-DFW from the Hurricane Sandy Coastal Resiliency Competitive Grant Program (Grant #43095, administered by the National Fish and Wildlife Foundation; NFWF). The grant period was August 2014 through October 2017. The other half of the funds were provided by the USACE-OP and NJDOT-OMR.

Project Goals and Objectives

One of the main components of the project was the development, implementation, and monitoring of the three pilot projects to enhance approximately 90 acres of salt marsh, with associated restoration of beach and dune and creation of avian nesting habitat. The goals of these pilot projects were to (1) improve existing management of dredged material, (2) increase the technical and practical knowledge and science behind these innovative beneficial use projects, (3) change standard dredged material management practices in the state of New Jersey, and (4) in the aftermath of Superstorm Sandy, advance these practices to enhance **coastal resiliency**.

Project locations were selected on the basis of three factors: (1) USACE-OP and NJDOT-OMR needs for dredging and management of the dredged material, (2) the needs of state-owned salt marshes for **enhancement**, and (3) the potential for the marsh to provide wave attenuation and storm surge buffering services for a coastal community. The three pilot projects differed in the composition of dredged material used (sand, silt, or clay), the dredged material placement methods (spraying or direct pumping), the depth of placed dredged material, and the existing condition of the marshes. The pilot projects were monitored comprehensively for three primary purposes: (1) to evaluate how the salt marsh ecosystem responded to dredged material placement in the short term, (2) to identify factors that negatively impact marsh recovery, and (3) to determine whether the condition of the marsh was improved (i.e., whether it experienced ecological uplift).

The objectives for the three marsh pilot projects were (1) to increase and maintain the optimal tidal elevation (hydroperiod) for native salt marsh species, (2) to increase the cover and health of native salt marsh vegetation, and (3) to return all other metrics to baseline (i.e., pre-implementation) conditions (unless they were expected to change due to habitat conversion).

Purpose of This Document

This document (*Project Summary and Lessons Learned*) discusses the planning and implementation of the three pilot projects. This report is being released before the project objectives have been fully achieved. This is because many similar potential projects in New Jersey need information about how these pilot projects were implemented. It can take considerable time to recover the biogeochemical functions and structure of a natural marsh after restoration (Zedler 2000; Moreno-Mateos et al. 2012). We will continue monitoring the projects to learn how they change over time. We are also preparing another report, the *Monitoring and Data Evaluation Report*, that will present, analyze, and evaluate the project monitoring data through 2019.

Project Development

The project team[2] consisted of USACE-OP and NJDOT-OMR navigation managers, the landowner (NJDEP-DFW), conservation practitioners, scientists, state regulators, and engineers. Beginning in 2014, this team identified salt marsh sites that were within hydraulic pumping distance of planned dredging projects and that could benefit from the placement of dredged material. All state-owned marshes within one mile of the planned dredging projects were preliminarily assessed via desktop analyses using a combination of LiDAR mapping, current and historic aerial photos, and TNC's NJ Living Shoreline and Marsh Explorer Apps[3] (internet-based decision support tools).

The project team visited the sites several times to select specific areas for additional evaluation and to discuss potential techniques to enhance the marsh and other habitats. The marshes selected for enhancement were dominated by short form, stunted *Spartina alterniflora*. During the selection of preliminary **placement areas**, the team documented qualitative observations of vegetative health, pool and panne conditions, platform stability, edge erosion, flooding, and faunal use. Sites adjacent to coastal towns and infrastructure were prioritized for their potential storm buffering capacity. Project feasibility analyses and quantitative data further refined the selection of placement areas and the appropriate enhancement technique(s) for each area, considering the grain size and chemistry of the source sediment, schedule of the dredging projects, and elevation of the site.

Monitoring

To track progress toward achieving project objectives and to better understand the effects of placing dredged material on the marshes, the team developed a comprehensive monitoring program that included multiple ecological parameters and generally followed a Before-After-Control-Impact (BACI)

[2] See page 2 for full list of project team members.

[3] The Nature Conservancy's Marsh Explorer App on its Coastal Resilience decision support tool. The Marsh Explorer App is focused on salt marshes along New Jersey's Atlantic coast and identifies the need for tidal marsh restoration based on the amount and size of linear ditches, marsh edge erosion, unvegetated marsh, and unused dredge lagoons. https://maps.coastalresilience.org/newjersey/

design. The parameters that were monitored included elevation, depth and extent of the placed dredged material, sediment characteristics, surface water elevation, vegetation, invertebrates, fish, birds, and habitat changes. In addition, the team made qualitative observations during monthly site visits that informed post-construction **adaptive management** of the projects.

Summary of Projects

Between August 2014 and April 2017, pilot projects were constructed at three locations: Ring Island and Avalon in the Cape May Wetlands Wildlife Management Area, and the Fortescue Wildlife Management Area in Fortescue, Cumberland County (Fig. 1). The marsh enhancement techniques included **thin-layer placement** (**TLP**) of dredged material on the platform of a vegetated, **stressed marsh** (all three sites) and the filling of degraded and expanding pool–panne complexes with TLP on the surrounding stressed marsh platform (Avalon). In addition, **Elevated Nesting Habitat (ENH)** for birds was added at Ring Island, and

Figure 1. *Pilot projects for the beneficial use of dredged material were implemented at three locations in New Jersey.*

dune restoration and beach restoration projects were conducted at Fortescue. Table 1 shows a summary of the projects.

Table 1. Summary of the pilot projects at Ring Island, Avalon, and Fortescue

Project	Ring Island		Avalon		Fortescue		
	Marsh	**ENH***	**Phase 1**	**Phase 2**	**Marsh**	**Beach**	**Dune**
Constructed	Aug 2014	Aug 2014	Dec 2014 to Jan 2015	Nov 2015 to Feb 2016	Mar 2016	Mar to Apr 2016	Feb to Apr 2017
Habitat Size (Acres)	0.89	1	6.9	45	6.6	1.3	2.25
Sediment Volume (CY)**	1,000	6,000	~6,000	~49,300	6,490	7,245	18,335
Sediment Type	96% fine sand	96% fine sand	65% silt/clay	72% silt/clay	30% silt/clay	>75% sand	>90% sand
Placement Technique	Spray	Direct pumping	Spray	Spray, direct pumping	Direct pumping	Direct pumping	Direct pumping

* ENH = Elevated Nesting Habitat
** CY = cubic yards

Ring Island

The dredged material for the Ring Island project was 96% fine sand and came from a shoaled area in the NJIWW located next to the island. The sand was used to construct two TLP areas (~0.5 acres each) and an ENH (~1 acre).

Elevated Nesting Habitat

The purpose of the ENH at Ring Island was to create suitable habitat for the black skimmer (*Rynchops niger*), which is endangered in New Jersey, and other bird species of concern (Fig. 2). It was designed as a 1-acre mound with a platform elevation of six feet above the **Mean Higher High Water (MHHW)** and 1:12 (vertical to horizontal) side slopes.

In August 2014, the 1-acre ENH was created from approximately 6,000 cubic yards (CY) of the dredged sand. To keep the dredged material within the boundary of the ENH, the area was mostly enclosed during placement (except for a small outlet area for water to exit) using straw bales, a sand berm, and a silt fence. A skid loader was used to grade the placed dredged material and form the ENH mound. The top of the ENH was above the spring high-tide line—an important nest survival threshold for coastal birds—but below the target elevation in the design and the permit. Post-construction adaptive management included planting vegetation on the slopes of the site, removing invasive *Phragmites australis*, removing plants from the top of the platform, and, in early 2018, placing additional dredged material to restore elevation above the spring high tide.

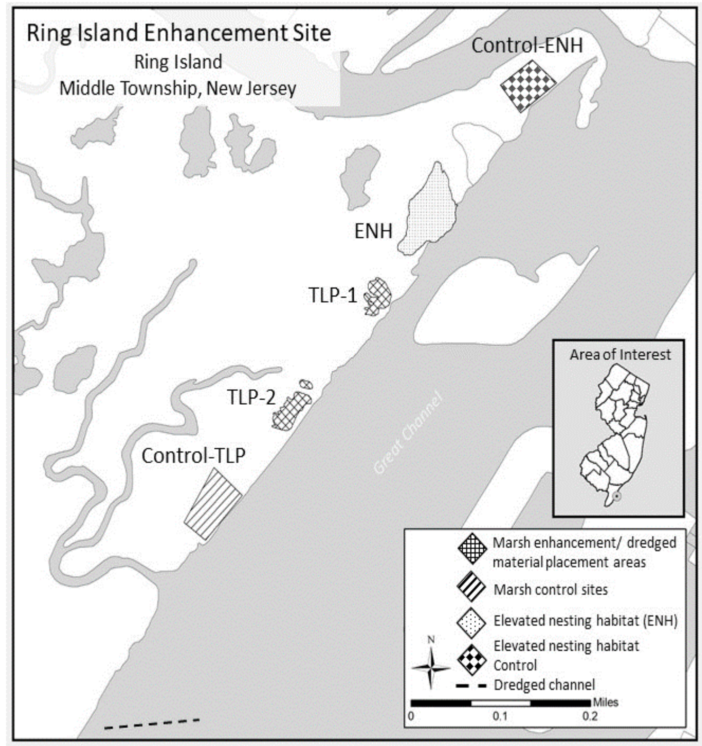

Figure 2. *This map of the Ring Island site shows the elevated nesting habitat (ENH), the marsh enhancement thin-layer placement areas (TLP-1 and TLP-2), and the control areas (Control-ENH and Control-TLP).*

Marsh Enhancement

The goal of marsh enhancement at this site was to increase the abundance and rigor of native marsh vegetation by increasing the elevation of “low-lying”[4] marsh. We accomplished this by spraying thin (three- or six-inch thick) layers of sandy dredged material. These placement depths were chosen to allow existing vegetation to survive and quickly recover, growing through the placed dredged material (Ray 2007). No perimeter containment was used because the surrounding areas of the marsh platform were at higher elevations than the placement areas and the sand did not disperse far during placement.

During two days in August 2014, approximately 1,000 CY of fine-grained sand was sprayed on two 0.5-acre sections of marsh platform using a hydraulic dredge and a spray nozzle system. The discharge end of the dredge pipe was placed on a pontoon at the edge of the marsh, with the spray landing approximately 150–200 feet from the pipe. Spraying the sand to achieve an even thickness of placement was difficult, as it accumulated wherever it landed, with little natural spreading. Dredging was stopped intermittently and water was sprayed through the nozzle system in an unsuccessful effort to disperse the placed sand across the marsh platform.

Topographic surveys and depth measurements in the weeks immediately after construction indicated that, although the average placement depth (6 inches) was within the 3- and 6-inch targets, placement was uneven, ranging from 0.5 to 9 inches. In March 2017, native salt marsh species were planted on half of the bare areas within each of the TLP areas.

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[4] The location of the possible TLP sites on Ring Island changed several times in the weeks preceding placement, due to the presence of nesting birds and a change in the dredging schedule. As a result, the baseline topographic data could not be used to quantitatively assess the elevation of the selected TLP areas. However, observations during site visits suggested that the selected TLP areas were lower than the surrounding, more densely and diversely vegetated marsh. The project team decided it was worth moving forward with the project as an experiment and learning experience. Assessments after construction showed that the baseline elevation of the TLP areas was closer to the Mean High Water level than the Mean Higher High Water level and was 0.75 feet below the lower end of the range in elevation at which *Spartina patens* was found at the site.

Avalon

At the Avalon site, there were two phases of dredged material placement. The dredged material for these projects came from the NJIWW near the project site; following Superstorm Sandy, this stretch of the NJIWW was one of the critical channel shoals that the USACE-OP needed to dredge. The sediment in the channel was predominantly silt and clay.

Building on the Ring Island project, the goal of the Avalon marsh enhancement project was to increase the area of vegetated marsh by filling expanding and degraded pools and pannes to the elevation of the surrounding marsh. The newly created topography was expected to improve drainage off the marsh and reduce excessive ponding of water, which is a primary stressor to plants. To accomplish this, the dredged material was either sprayed or directly pumped into the pools, with the overflow resulting in a thin layer of dredged material on the adjacent marsh platform. To keep the fine-grained dredged material within the placement area boundaries, perimeter containment (coconut-fiber logs) was installed prior to construction. Containment was added as needed during construction.

Avalon Phase 1

In early January 2015, approximately 5,000 CY of predominantly fine-grained sediment was placed on 7 acres of marsh (Fig. 3, Areas A and C). The goal was to fill pools and add 3 to 6-inches of sediment to the surrounding marsh platform. In addition, sediment was sprayed directly onto the marsh platform to learn how TLP of fine-grained material differed from that of sandy material.

Avalon Phase 2

Additional data collection and detailed engineering work were completed to design the Avalon Phase 2 project. Topographic surveys, high marsh **biological benchmarks**, and tidal data were used to establish **target dredged material placement elevations** and **target ecological elevations**, rather than simply establishing target dredged material placement thicknesses. Between November 2015 and March 2016, about 50,000 CY of fine-grained dredged material from the nearby NJIWW navigation channel were placed on approximately 45 acres of the Avalon marsh (Fig. 3, Areas A, C, D, E, and F).

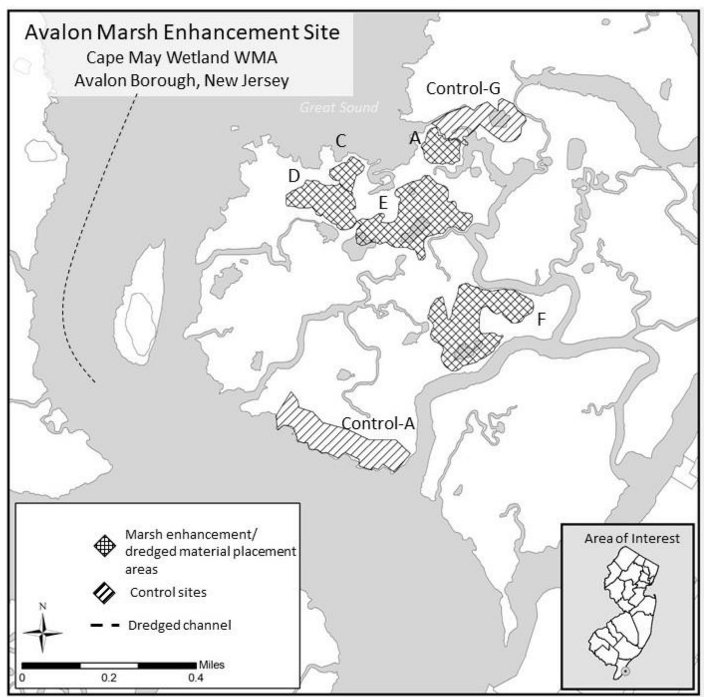

Figure 3. *This map of the Avalon site shows the locations of the marsh enhancement areas (A through F) and marsh control areas (Control-A and Control-G).*

Topographic surveys in the weeks following sediment placement showed the mean elevation of each placement area was within 4 inches of the target dredged material placement elevations. However, it is clear that some sections of each placement area did not achieve the target dredged material placement elevations, while in other areas, the targets were exceeded by more than 1 foot. The depth of sediment placed on the marsh platform ranged from 1 to 9 inches, while the depth in some pools was even greater. Two years after placement, the areas had lost some of their initial elevation and the mean elevation was within 1 inch of the target ecological elevations at four of the five placement areas. However, some pools had re-formed by 2017, indicating differential settling, consolidation, and compaction of the placed dredged material and underlying marsh.

After construction of the Avalon Phase 2 project, an adaptive management program was implemented. For example, based on observations that the dredged material was still dewatering and elevations were changing, combined with concerns regarding the potential to disrupt nesting birds, planting was delayed for a year. The original planting plan was also adaptively implemented in the field in response to the changed conditions. In addition, during the first summer after construction, vegetation die-off was observed in some areas outside and directly adjacent to the perimeter containment. Supplemental monitoring was conducted to investigate the cause(s) of the die-off and to suggest potential adaptive management actions to mitigate it. Initial results from this monitoring suggested that the containment was blocking tidal flow and that this, in combination with acid produced by the oxidation of the placed dredged material, may have created extreme water chemistry fluctuations and less than optimal flooding patterns. In response, we removed most of the containment at both Avalon and Fortescue rather than continuing with the original plan for it to biodegrade in place.

Fortescue

The marsh enhancement component of the Fortescue pilot project was designed to improve growing conditions for native salt marsh plants and create positive drainage off the marsh platform by increasing the elevation of a low-lying ditched marsh. In addition, to protect the marsh and nearby marina from erosion, a dune restoration project was designed and a nearby eroding beach was restored (Fig. 4). These projects used mostly sandy sediment that was dredged from the nearby Fortescue Creek navigation channel.

Marsh Enhancement

The Fortescue project was designed to increase the elevation of the marsh by approximately 9 inches. The target dredged material placement elevation of 3.3 feet and the target ecological elevation of 2.8 to 3.0 feet NAVD88 were based on biological benchmarks and local site hydrology, with the objective of producing high marsh habitat. The project team applied the lessons learned from the construction of the Avalon Phase 2 project to the design and construction of the Fortescue project. The marsh enhancement design included a branching system of pipes with valves that could be opened and closed and included some flexible pipes that could be moved more easily by hand. This design would, in theory, avoid the costly downtime that was experienced during the Avalon Phase 2 project when the team had to stop the discharge of dredged material to prevent overflow of the containment and had to reposition the dredge pipe. A double containment row of plastic mesh tubes filled with wood chips (Filtrexx SiltSoxx™) was installed around each dredged material placement area.

In March 2016, 6,490 CY of a heterogeneous mix of sandy and fine-grained dredged material from the Fortescue Creek navigation channel was placed on two areas, totaling 6.4 acres of the marsh, which was less than 30% of the originally planned marsh enhancement area. The efficacy of the highly engineered dredge pipe network could not be evaluated because it was not used to its full advantage, and the team used large machinery to reposition the pipe outlet rather than employing the smaller flexible pipes. Several challenges were encountered during the marsh enhancement. For example, the dredged material was sandier than expected, the winter weather was especially harsh, and there were contracting issues. As a result, the team was unable to complete construction the first year and decided not to finish the project in the second year.

In permanent monitoring plots, the average depth of placement was 6 inches and the material depth ranged from minimal to 18 inches.[5]

After construction, portions of the bare sections of the marsh enhancement areas were planted with native salt marsh species. As part of the project adaptive management plan, the plastic netting around the Filtrexx SiltSoxx™ was removed and the wood chip filling was dispersed across the marsh.

Dune Restoration

The Fortescue dune restoration was designed to protect the adjacent marsh and the marinas on Fortescue Creek from erosion caused by tidal flow and storm waves. Originally, this project component was designed to be constructed mainly in the footprint of an existing dune adjacent to the marsh platform, but after a winter storm eroded portions of the shoreline, the dune footprint was redesigned to be farther inside the marsh.

In early 2017, approximately 18,000 CY of sandy dredged material was used to construct the dune. Filtrexx SiltSoxx™ and sand berms were used to retain the dredged sand. Outlets through the containment on the marsh side of the dune were constructed to allow fine-grained sediment to flow into the marsh, creating an area of TLP.

As-built surveys showed that the final constructed dune was 900 feet long, 40 feet wide at the top, and 80 feet wide at the bottom, with an elevation of 10.0 feet NAVD88 (5 to 6 feet above the marsh surface). After construction, the dune was planted with native shrubs and grasses.

[5] Results from annual real-time kinematics (RTK) transect surveys of the elevation at Fortescue showed improbable gains in elevation for the control areas. Therefore, elevation data are not summarized here.

Beach Nourishment

The Fortescue beach was eroded by winds and waves. The project's beach nourishment component was designed to restore a natural beach near Fortescue Creek. Approximately 7,000 CY of sediment (at least 80% sand) dredged from the Fortescue Creek navigation channel was spread over 1.3 acres (700 linear feet) of beach at a 15:1 (horizontal to vertical) slope. The team expected that a plateau would form naturally as the placed dredged material was "worked" by the tides and wind.

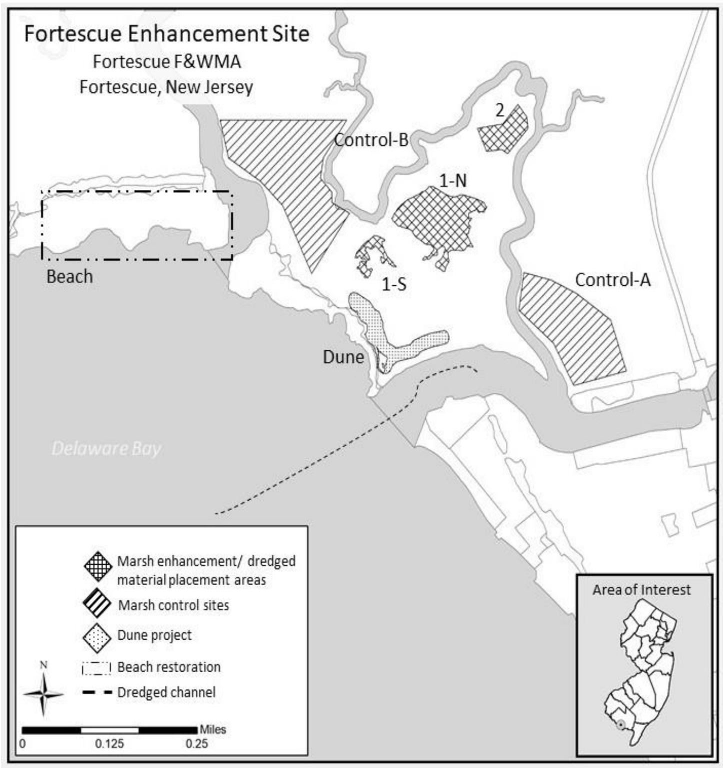

Figure 4. *This map of the Fortescue site shows the locations of the marsh enhancement (1-S, 1-N, and 2), dune restoration (Dune) and beach nourishment (Beach) dredged material placement areas and the marsh control sites (Control-A and Control-B).*

Cost Analysis

After construction of all three pilot projects, the project team estimated the total cost of each project and the costs of selected project components. While these estimates do not represent the full life-cycle costs of the projects, and while the Fortescue project was led by the NJDOT-OMR and not USACE-OP (leading to different contracting processes and associated costs), the cost per CY of placed dredged material and acre of enhanced habitat were highest at Fortescue ($150 per CY and $470,000 per acre) and lowest at Avalon ($45 per CY and $55,000 per acre). The per-acre costs are comparable to the reported median and average costs of salt marsh restoration in developed countries, which are $61,160 per acre and $421,730 per acre, respectively (in 2010 U.S. dollars; Bayraktarov et al. 2016), as well as other similar projects that used dredged material in Rhode Island. The pilot project costs can also be compared with the cost of placing dredged material in confined disposal facilities (CDFs), which has historically been the "business as usual" method of managing dredged material in New Jersey's estuaries. The expense of placing sediment in a CDF is highly variable but is typically $15 to $75 per CY.

The dredging and the placement of the dredged material on the marshes were the most expensive components of each marsh enhancement project, ranging between 50% and 60% of the total project budget. The second largest expense for the pilot projects was monitoring, ranging from 10% of the budget at Fortescue to 31% at Ring Island.

Chapter 1: Lessons Learned

The three pilot projects evaluated the potential of using dredged material for marsh enhancement and tested potential placement methods for dredged material. From the outset, the project team was focused on implementing these projects to inform the development of best management practices for similar marsh enhancement projects across New Jersey. The team developed a series of lessons learned and associated recommendations and applied them from earlier projects to the design and construction of the subsequent projects.

As any marsh enhancement project is unique in its design and objectives, the lessons learned presented in this report should be used as general guidance and not as firm standards to inform future projects. Future experiences will vary as these techniques become more commonplace in New Jersey and as new lessons are learned. However, we recommend that practitioners focus on the following key lessons learned as they investigate and develop similar marsh enhancement projects:

Key Lesson 1. Coordinate at multiple levels and throughout all phases of project development, implementation, and monitoring. This includes coordination within an interdisciplinary team of ecologists, engineers, and dredge contractors, as well as coordination between the team and federal and state regulatory agencies, resource managers, landowners, and other stakeholders. Such coordination helps to ensure smoother project implementation and more timely and effective adaptive management.

Key Lesson 2. Use an adaptive management approach throughout the lifecycle of the project. Adaptive management will likely start in the site selection phase of the project, when the needs of the marsh enhancement project, including sediment volume and characteristics, must be matched to those of a nearby dredging project. Adaptive management is critical during construction of the project and throughout the post-construction monitoring and maintenance period if the trajectory of marsh response differs from what was anticipated. Adaptive management impacts both the project timeline and the budget, so plan accordingly and set aside funds.

Key Lesson 3. Use data from initial assessment and from ongoing monitoring as the foundation for the design and implementation of marsh enhancement projects. Projects that beneficially use dredged material are not typical dredging projects. Their primary goal is the ecological uplift of natural habitats, not simply the disposal of dredged material. Substantial data are needed to identify a potential marsh enhancement site and pair it with a suitable dredging project. Additional data are needed to design the marsh enhancement project, and multiple years of post-construction monitoring are needed to assess the trajectory of marsh response and determine the need for adaptive management and maintenance (especially now, as these types of projects are relatively new in New Jersey). The data needed will vary with the scope of the project and may decrease over time as more experience is gained with these projects.

While the beneficial use of dredged material to restore and enhance salt marshes has great potential to support the resilience of both coastal habitats and coastal communities in New Jersey, these projects must be planned and implemented in a technologically and ecologically sound manner. The project team hopes this report and the lessons learned can guide similar projects as they are proposed, discussed, planned, and implemented throughout New Jersey.

The project team gained considerable insights into the technical and ecological aspects of these types of projects over the first four years. These lessons learned and the team's recommendations for similar projects are presented in this chapter. However, due to the unique nature of individual marsh enhancement projects, these lessons learned and recommendations should be considered guidelines, not hard and fast prescriptions.

The lessons learned are grouped into the project phase with which they are most closely associated:

- Phase 1: Marsh Assessment and Placement Area Selection
- Phase 2: Project Design
- Phase 3: Permitting
- Phase 4: Bidding and Contracting
- Phase 5: Construction
- Phase 6: Post-Construction Adaptive Management
- Phase 7: Project Assessment

The phases are discussed in greater detail in Chapter 2 of this document. In addition, many of the most important lessons learned were derived from the iterative nature of project development and the adaptive management approach used throughout the projects. These cross-phase lessons learned are presented here.

Cross-Phase Lessons Learned

Cross-Phase Lesson 1. Tailor development and assessment plans to specific projects. Each project is unique and should be developed accordingly. Existing marsh conditions were very different at each of our pilot sites, as were the characteristics of the dredged material. As a result, the objectives and strategies of the marsh enhancement projects at each of these sites differed. We also expect that the trajectory of marsh response—and the habitat or habitats that ultimately develop—will differ among sites.

Cross-Phase Lesson 2. Establish SMART objectives and results chains at the beginning of the project to ensure that all members of the team understand and address these same objectives. SMART objectives are Specific, Measurable, Achievable, Relevant, and Time-bound. Marsh enhancement projects are complex, and combining them with dredging projects makes them more complex. Having a working results chain can help the various team members understand the objectives for each step in the project, how they relate to one another, and how they build toward the SMART objectives. The combination of the SMART objectives and results chains that clearly explain assumptions can help the team make decisions as they adaptively manage the project. When issues arise, the team will have a better idea of how management options will affect the overall project objectives. See Figure 5 for an example of a results chain and its assumptions.

Cross-Phase Lesson 3. Use an iterative project development process. The development of a marsh enhancement/dredged material beneficial use project is inherently an iterative process, from its conceptualization through site identification, placement area selection, design, and permitting and contracting (i.e., Phases 1–4). These projects include many components that must be developed in a coordinated manner by all the project partners to help ensure project success. Project development and design should also be coordinated with the dredging project manager, landowner, dredging contractor, and the state (NJDEP) and federal (USACE) regulatory agencies. Recommendations and issues raised by any of these parties could result in the need to acquire and evaluate additional data and require revisions to the scope of the project (including design/engineering, dredging, and monitoring plans).

Development of the marsh enhancement/dredged material placement component of the project must be closely coordinated with the design of the associated dredging component. As data are collected for both components, revisions to the scope of one may require revisions to the other. In particular, the characteristics of the sediment to be dredged must be determined to evaluate its suitability for marsh enhancement. Not all the available dredged material may be suitable for use on a marsh, which can limit the volume that can be dredged if there is no suitable option to dispose of the excess dredged material. This was the situation at Fortescue, and it required us to develop multiple projects (marsh enhancement, beach nourishment, and dune restoration) to make the dredging project economically viable. The multiple projects allowed us to test the enhancement of multiple habitats using dredged material.

Cross-Phase Lesson 4. Be aware when scheduling a project that the process, from site selection through post-construction monitoring and evaluation, may require a minimum of eight years. The objectives of both construction and marsh enhancement must be realistically achievable and measurable within the project timeframe. Table 2 presents the minimum estimated timeline to complete a marsh enhancement/dredged material beneficial use project, including post-construction monitoring.

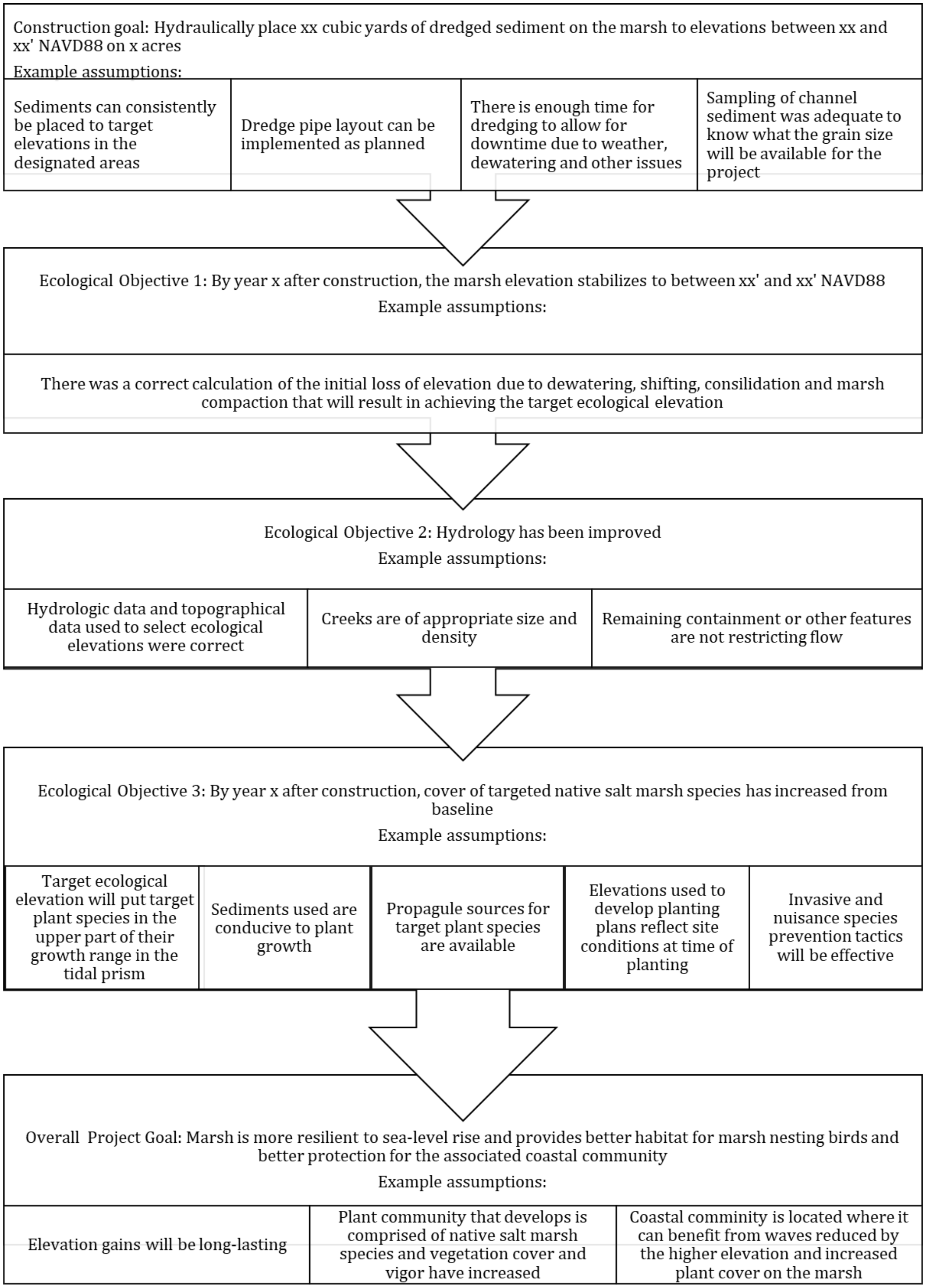

Figure 5. *This figure shows a results chain, including the assumptions associated with various ecological objectives, for a hypothetical marsh restoration project.*

The marsh enhancement objectives should include not only achieving the **target ecological elevations**, but also recovering marsh structure (e.g., achieving ecological uplift of vegetation) and function (e.g., providing wave attenuation) to approach the conditions of a reference marsh. In general, the scientific literature recommends that marsh enhancement projects be monitored either until their objectives have been met or for at least five years after construction. A minimum monitoring period of ten years is frequently recommended (Neckles and Dionne 1999, Niedowski 2000, Zedler 2001).

It is apparent that the initial two-year timeframe of the National Fish and Wildlife Federation grant to design, construct, and monitor these projects was unrealistic. This timeframe, which was later extended, limited pre-construction site assessment at each site. Although a one-year grant extension allowed time for construction, the post-construction monitoring was limited to only two years at Avalon and Fortescue, and three years at Ring Island. At the end of the grant period, the sites were still changing, and vegetation, soils, and faunal use did not yet match baseline conditions. This is a common issue for grant-funded voluntary restoration projects.

As shown in Table 2, it takes a minimum of three years to complete Phases 1–5 (i.e., site assessment through construction) of a marsh enhancement project. This assumes that marsh assessment is completed in one year (Phase 1) and that dredging and dredged material placement are also completed in a single year, immediately followed by planting. Larger and more complex marsh sites (particularly those with limited available data) may require more than one year to properly evaluate marsh enhancement areas and design and permit projects. In addition, the construction phase of larger dredging and marsh enhancement projects may take longer, and the placed dredged material may need to settle, consolidate, and stabilize chemically for a year or more before it is suitable for planting. See Phase 6: Post-Construction Adaptive Management, Phase-Specific Lesson 10, and Phase-Specific Lesson 12.

Cross-Phase Lesson 5. Be aware that the costs of a marsh enhancement project can vary widely, as can the cost of individual project components. The largest component cost for the pilot projects was for dredging and dredged material placement (50–60% of total project costs). The total cost of each project ranged from $45 per CY dredged and $55,000 per acre enhanced at Avalon to $140 per CY and $405,000 per acre at Fortescue. A driving factor in this difference was the marsh enhancement components (for example, containment and planting) rather than the volume of dredged material that was placed. This may be different for projects that use larger volumes of dredged material. Monitoring can also be a significant portion (10–30%) of total project costs, while sediment sampling (1–3%) and planting (3–11%) can be a much smaller portion. See the Cost Analysis section.

Cross-Phase Lesson 6. Use adaptive management throughout the course of project development, construction, and post-construction monitoring. This approach is critical to ensure compliance with all regulatory requirements and to achieve the project objectives. No matter how well a project is planned, questions and issues are likely to arise during implementation, and they will need to be addressed and evaluated to ensure the success of the project. Therefore, project managers should set aside time and money for adaptive management.

An adaptive management plan outlines potential issues that could arise during and after construction. The plan should be closely coordinated with the monitoring program. It should include a list of "if-then" statements that can be revised as the project is implemented and the marsh responds to the enhancement, such as "if X is observed, then Y monitoring will be implemented" and "if A results are observed during monitoring, B actions will be implemented." In addition, the project budget should include contingency funds to address issues as they arise. See Cross-Phase Lesson 2, Phase-Specific Lesson 2, and Phase 6.

Cross-Phase Lesson 7. Determine the scope of containment required to control the placement of dredged material. This is a critical design decision that can affect the success of the project and minimize adverse impacts to the surrounding marsh. Containment is difficult and expensive to install, and if equipment is used to install and remove material, it can damage the marsh. To minimize potential impacts to the marsh, the amount of containment should be the minimum required to meet the objectives of the project. For example, containment could be limited to the amount needed to (a) minimize the dispersal of the placed dredged material out of the designated placement area, (b) protect waters, and (c) consistently achieve the target dredged material placement elevations. In addition, it is important to consider whether to remove containment during or after construction if it is blocking tidal flow or otherwise impeding the potential for marsh recovery.

Dispersal of the placed dredged material across the marsh will vary with the grain size composition and the marsh topography, which will change during construction as the dredged material is placed, settles, and dewaters. Because silt and clay remain in suspension longer, containment may be needed to efficiently achieve the target dredged material placement elevation and to keep it within the placement area. This is less of a concern when placing sandy dredged material, and containment may not be needed in that case.[6]

Here are some other considerations when planning containment:

- During construction of the Avalon Phase 2 project, dredging was stopped for significant periods of time to allow dredged material that had reached the top of containment to undergo dewatering.
- Containment may block tidal flow to and within the marsh, leading to ponding adjacent to the containment. As pooled water on the marsh evaporates and the pool is not regularly flushed by the tides, the soil and water can develop unusual and challenging chemical conditions (e.g., hypersalinity, sulfide concentration, production of acid sulfate soils). Such conditions can impede marsh recovery and adversely impact the marsh directly outside the material placement areas.
- The various containment options have advantages and disadvantages. For example, Filtrexx SiltSoxx™ and coconut-fiber logs retained sediment equally well, but Filtrexx SiltSoxx™ were more difficult to install, and the coconut-fiber logs were more difficult to remove.

[6] This lesson learned reflects the project team's experience with hydraulically placed dredged material and may not be applicable to mechanically placed dredged material.

Table 2. Estimated Timeline to Implement a Marsh Enhancement/Dredged Material Beneficial Use Project		
Project Phase and Step	**Time to Complete***	**Notes**
Phase 1. Marsh Assessment and Placement Area Selection	**1.5+ years**	
Step 1. Project Conception	3 months to several years	Varies with available site information at project initiation.
Step 2. Dredging Project Data Collection	6 months	Includes sediment sampling.
Step 3. Marsh Enhancement/ Placement Area Selection	1+ years	Requires assessment during the growing season. May take more than one year. May be combined with baseline monitoring (Phase 7).
Phase 2. Project Design	**6+ months**	
Step 1. Placement Area Design	6 months	
Step 2. Dredging Design	6 months	
Phase 3. Permitting	**6 months**	
Phase 4. Bidding and Contracting	**3–6 months**	
Phase 5. Construction	**3+ months**	Consider environmental timing restrictions for dredging and work on marsh.
Step 1. Pre-placement	1 month	Varies with project size; includes site preparation.
Step 2. Placement	1 week to several months	Varies with project size.
Step 3. Post-placement	1–2 months	Includes site inspection, clean-up and as-built topographic survey.
Phase 6. Post-Construction Adaptive Management	5–10 years**	Includes planting and containment management.
Phase 7. Project Assessment	**6 years**	Minimum
Monitoring/Data Evaluation	**1+ to 5–10 years**	Baseline monitoring (1+ years) and post-construction (5-10 years).
Total Estimated Time to Phase 5	**3+ years**	Larger projects could take longer.
Total Estimated Time to Phase 7	**5+ years**	Post-construction.
Total Estimated Time to Complete	**8+ years**	Larger projects could take longer.
* This table assumes that each step within a phase may be implemented concurrently and in coordination with the other steps to varying degrees and in an iterative manner. The time to complete each phase will be longer if the steps are implemented sequentially.		
** Contemporaneous with placement and post-placement (phase 5 steps 2 and 3) and post-construction monitoring/data evaluation (phase 7). Planting the marsh enhancement site may be delayed up to one year until the dredged material consolidates and chemically stabilizes after construction.		

Cross-Phase Lesson 8. Coordinate the design and construction of the marsh enhancement closely with the dredging. This is critical to the success of the project. The objectives of the dredging project will probably differ from the ecological objectives for a marsh enhancement project, and the project team and the state and federal regulatory agencies must agree to both sets of objectives. Establishing the project team at the conceptual stage of project development helps to ensure that enhancing the marsh is a primary objective, while meeting the needs of the dredging community and remaining feasible from a technical and budgetary perspective. Ideally, all members of the project team have experience with marsh enhancement projects. The project team should include state (NJDEP) and federal (USACE) dredging project and wetland regulators, the landowner, dredging project managers (USACE-Operations, NJDOT-OMR, municipal and private contractors), the dredging contractor (if known), a wetland ecologist, a restoration ecologist, an environmental engineer, a wetland hydrologist, and a soil scientist.

The managers of the dredging project and marsh enhancement project should communicate early and often during the development of both projects. In addition, the dredging project manager and its construction contractor must be fully aware of the marsh enhancement objectives of the project: it is not just another dredging and dredged material disposal project. Coordination is important during the design phase to ensure that the project is feasible, including identifying the available dredging equipment and its capabilities. (This was a problem during construction at both the Avalon Phase 2 and Fortescue projects.) Adaptive management and shared decision-making between the **marsh team** and the **dredging team** during project construction are also crucial to the success of the marsh enhancement project. See Cross-Phase Lesson 2.

The ability to construct a successful marsh enhancement project using dredged material depends on the volume and characteristics of the sediment to be dredged. The project needs to be large enough to accommodate the volume of dredged material generated by the dredging project, or else alternatives to handle the dredged material need to be identified. The selection and design of marsh enhancement areas can vary with the ability to route the dredge pipeline onto the marsh and move it, as needed, to achieve the target dredged material placement elevations. Dredged material placement must also be adaptively managed to achieve both the target placement elevation and marsh enhancement target ecological elevation. Coordination is needed to ensure that adaptive management actions implemented by one set of project partners do not prevent other partners from reaching their goals.

Cross-Phase Lesson 9. Take the characteristics of the dredged material to be used for the marsh enhancement project into consideration when planning. The dredged material must be physically and chemically suitable for the specific use, and its characteristics (grain size distribution and chemical composition) significantly affect the design, construction, and adaptive management of the project. The volume of dredged material needed to achieve target elevations depends, in part, on the grain size composition of the sediment, which affects the sediment bulking factor, the extent of dredged material dispersal across the marsh (see Cross-Phase Lesson 7), the rates of dewatering, and the degree of short- and long-term consolidation of the placed dredged material. At best, the dredging project manager can only develop an estimate of the volume and types (coarse/fine-grained) of sediment to be dredged. The ability to meet the project objectives will depend, in part, on the accuracy of this estimate.

For marsh enhancement purposes, very fine dredged material (i.e., predominantly silt and clay), which remains in suspension longer, requires less frequent repositioning of the dredge pipe outlet than does sand. This results in greater dispersal of dredged material and more even coverage of the enhancement site, which makes it easier to reach the target dredged material placement elevations. However, sorting by grain size will naturally occur during placement of any hydraulically dredged material that is a mixture of sand, silt, and clay. Because sand falls out of suspension first, it tends to build up within a short distance of the dredge pipe outlet. The pipe must be moved more often to consistently place hydraulically dredged material that has a high sand content across a large area without grading; this increases the time to complete the project and its cost.

Hydraulically spreading sand for TLP across a marsh plain is challenging. At Ring Island, Avalon, and Fortescue, sand content above 30–35% resulted in dispersal problems. If dredged material exceeds that threshold, stationary hydraulic placement (i.e., cribbing the pipe and pumping from a set location for a long period) may be unacceptable, as the dredged material likely will not disperse throughout the placement area. Future projects should further explore and evaluate this issue. Better equipment and placement methodology are needed, in order to (1) reduce the amount of downtime to move the dredge pipe or reposition the spray direction and (2) improve the accuracy and precision in attaining the target elevations.

With a good estimate of the initial, short-term rate of dewatering for dredged material, it may be possible to use adaptive management to improve placement during construction, thereby more efficiently and accurately achieving the target dredged material placement elevations. Dewatering rates depend on a variety of factors, including grain size, type and permeability of containment, containment configuration (e.g., a small gap every 10 feet vs. every 100 feet) and amount of water incorporated during hydraulic dredging.

Cross-Phase Lesson 10. Be aware that it is challenging to estimate the volume of dredged material needed to meet the target ecological elevations. The volume of material needed depends, in part, on the grain size composition of the sediment, the potential compaction of the marsh, and the sediment dispersal (see Cross-Phase Lesson 7 and Cross-Phase Lesson 9). More accurate estimates of the bulking factor for the dredged material would make it possible to more accurately determine the target dredged material placement elevations and estimate the volume of dredged material that could be placed into each enhancement area. In addition, better estimates of post-placement dewatering and consolidation factors and the amount (if any) that the marsh surface subsides due to the weight of sediment and water placement would also improve the ability to achieve the target ecological elevations.

Cross-Phase Lesson 11. Choose an accessible project site if possible. It is difficult to execute a project at a site that can only be accessed by boat, as was the case for all three of our pilot project sites. Our access was further limited each day by four-hour periods during low tide when boats could neither reach nor leave the sites. In addition, containment could only be transported to and from the sites via barges during high tide. Safely traversing the Avalon and Fortescue sites was also a problem, as creeks and ponds could not be crossed or accurately surveyed on foot. After placement, large areas of the Avalon site were hazardous to traverse because people could quickly sink up to the waist when they stepped on areas that were formerly pools.

Phase-Specific Lessons Learned

Phase 1: Marsh Assessment and Placement Area Selection

Phase-Specific Lesson 1. Allow sufficient time (at least 12 months, including one full growing season) to collect data that identify and characterize marsh sites, determine the cause(s) of stress, and determine whether the beneficial use of dredged material can address those causes. The identification of marsh enhancement sites should be conducted in an iterative manner as data are collected, decisions are made, the project scope is refined, and additional data needs are identified. In some cases, the need to complete a dredging project may be the primary driving force for a proposed project, but the primary consideration must be the identification of a marsh that could benefit from dredged material placement.

Biological benchmarks and hydrology and topography data are useful in determining whether a marsh might benefit from sediment addition. Such data are also needed for monitoring, using a Before-After-Control-Impact (BACI) design.

Phase-Specific Lesson 2. Identify more and larger potential enhancement areas at each marsh site than are needed for the volume of dredged material. The marsh enhancement areas initially selected by the project team may ultimately be reduced in number and size, so it is helpful to have enough sites as options. Site assessments may conclude that some of the initially identified marsh enhancement areas would not benefit from dredged material placement (which occurred at both the Avalon Phase 2 and Fortescue projects). Also, the volume of dredged material that has suitable physical and chemical characteristics may be limited (which was an issue for the Fortescue project). Other limiting factors, such as site accessibility and timing restrictions based on the presence of endangered or threatened species, can also affect the final areas selected for the placement of dredged material.

Phase-Specific Lesson 3. Multiple beneficial uses for the sediment may be required to meet the minimum needs of the dredging project. Since a minimum volume of sediment must be dredged to meet the navigational needs of a dredging project and make it cost-effective, this situation may arise frequently. For example, the initial scope of the marsh enhancement project at Fortescue was reduced to account for a smaller volume of fine-grained dredged material available than was originally estimated, and beneficial uses had to be found for the sandy sediment. This resulted in the creation of multiple projects at Fortescue: marsh enhancement, dune restoration, and beach nourishment. At Ring Island, the TLP project was purposely kept small (1 acre total) to test the spraying of sand. In order to make the dredging project viable and to create desired habitat for threatened and endangered species, the shorebird ENH project was created and implemented there.

Phase-Specific Lesson 4. Keep local stakeholders informed about the proposed marsh enhancement project, beginning in the initial phases of the site identification process. The objectives of such communication are to obtain local input, resolve potential issues, and garner local support for the project prior to submitting permit applications. Stakeholders might include local officials, environmental groups, fishers and birdwatchers, and residents who can see the project from their properties. Ideally, this stakeholder engagement would continue throughout the life of the project. In the course of adaptive management, stakeholders could participate in monitoring as citizen scientists, which would encourage them to feel ownership of the project and increase the chances of success as the project evolves.

Phase 2: Project Design

Phase-Specific Lesson 5. When designing the marsh enhancement project, address factors that could potentially constrain the constructability of the project. These factors include the abilities and limitations of the available technology for transporting and placing dredged material and the abilities and limitations of the dredging contractor. For examples, see the Phase 5 Lessons Learned. The project's design should consider the numerous factors that could affect the contractor's ability to dredge and construct the project. To ensure that the project can be constructed as designed, ideally involve the dredging contractor in the project before finalizing the design.

Phase-Specific Lesson 6. In addition to basic elevation data, understand the topography and integrity of the marsh, including locations of pools and tidal creeks. In each dredged material placement area, assess the stability of the existing marsh surface and whether the weight of placed dredged material would compact the existing marsh surface. Compaction could affect whether the target ecological elevations can be achieved and whether the marsh can recover from the placement. For example, at Avalon, former pools in placement areas lost more elevation over time than did the marsh plain. In some places, this resulted in shallow pools re-forming in pre-existing pool areas. These factors should also be considered when estimating the volume of dredged material needed to achieve the target ecological elevations. Understanding the marsh topography can result in better dredge pipeline routes, staging, and outlet and discharge locations, resulting in more efficient and accurate dredged material placement.

Phase-Specific Lesson 7. Be flexible about the design of marsh enhancement projects. While careful planning of these projects is key, so is adaptive management. This requires flexibility to be built into the design, with continual oversight from a team of technical experts. Flexibility and the ability to adaptively modify the design during and after dredged material placement improve the chance of implementing both the dredging and marsh enhancement projects in a cost-effective manner.

Phase 3: Permitting

Phase-Specific Lesson 8. Coordinate between the project team and the regulatory agencies to ensure that permits are issued in a timely manner. These coordination activities should be initiated early in project development (Phase 1) so that all issues can be addressed before the permit applications are submitted to the regulatory agencies. This coordination should include at least one Joint Permit Processing meeting, if possible, with the NJDEP, USACE, and other federal regulatory and resources agencies.

Phase-Specific Lesson 9. Allow adequate time for permitting and contractor mobilization. Permit application packages should be submitted to the regulatory agencies (NJDEP, USACE, and any others) a minimum of six months prior to the intended start of project construction. Both the NJDEP and USACE regulatory reviews can take this long to resolve outstanding issues and issue the required permits, assuming no major concerns are raised and significant project revisions are not needed to minimize potential adverse environmental impacts. In addition, requirements for public notice and, potentially, a public hearing may increase the time to review permit applications. Close coordination between the permit applicants and the regulatory agencies could reduce this timeframe (see Phase-Specific Lesson 8). Once the permits are issued, the contractor also needs time to mobilize and begin construction.

Phase 4: Bidding and Contracting

Phase-Specific Lesson 10. Be aware that the type of dredging contract may impact the ability to innovate and adaptively manage the construction phase of the project. The marsh team had very different experiences working with two dredging contractors due to the type of contract. One contractor had a lease-of-plant maintenance contract with USACE-OP, and the other contractor had a pay-per-cubic-yard dredging contract (which is more typical of the industry) with NJDOT-OMR. In the lease-of-plant contract, the dredge contractor was paid for each day that the dredge was available for work, regardless of whether it was actively dredging, which increased the options for adaptive management and added flexibility during project construction (for example, dredging could be ceased temporarily to allow for dewatering of the dredged material).

Because the three projects were pilot projects, operational flexibility during construction was important. The lease-of-plant contract took the financial risk off the dredge contractor because costs were borne by the USACE-OP. In addition, the lease-of-plant contractor fully understood and supported the objectives of the marsh enhancement projects, and there was close coordination and a good working relationship between the marsh team and the dredging team. In contrast, at the Fortescue site, the dredging contractor was operating under the typical pay-per-cubic-yard dredging contract. The project lacked flexibility and ease of coordination. See Phase-Specific Lessons 4, 5, and 13.

Phase 5: Construction

Phase-Specific Lesson 11. Realize that the maximum pumping distance without using booster pumps will vary with the size of the dredge and the characteristics of the dredged material. In addition, marsh topography (e.g., tidal creeks, pools, unstable substrate) and the need to minimize equipment use on the marsh can limit pumping distance. In the three pilot projects, pumping distance was only a limitation at the Avalon Phase 2 project, where marsh topography dictated where the dredge discharge pipe could be located on the marsh. The location of the discharge pipe outlet, in combination with marsh topography, affected the ability to achieve target dredged material placement elevations in the areas that were farthest from the outlets. There were tradeoffs between construction efficiency and environmental impacts, that affected equipment selection and use, the volume of sediment that could be placed, and the amount of construction-related marsh damage. The use of machinery, such as a Marsh Master, increases the distance that a dredge pipe can be pushed and pulled into the marsh, but even low-pressure equipment like this can leave scars on the marsh.

Phase-Specific Lesson 12. The time available to dredge and place dredged material may limit how much marsh can be enhanced, which may limit the achievement of project objectives. To avoid additional costs associated with mobilization and demobilization, dredging and dredged material placement should be completed in a single, uninterrupted construction operation. This construction timeframe is typically limited by applicable "dredging windows," or restrictions on the time(s) of year when dredging and dredged material placement can occur due to the presence of threatened and endangered species, anadromous fish, colonial nesting shorebirds, and other protected natural resources. Construction can also be interrupted by inclement weather and equipment breakdowns. For example, winter storms limited site preparation and construction at both Avalon and Fortescue. In addition, depending on the design of the project, it may not be possible to dredge 24 hours per day due to restrictions on when dredged material can be placed (e.g., avoiding high tide to minimize sediment loss out of the project site). These factors will increase the construction time and project costs.

The dredging contractor and design team must consider these factors when they schedule and plan dredging and placement of dredged material. In addition, it can require considerably more time to use dredged material for marsh enhancement than to dispose of it in a traditional way, such as at a CDF.

Phase-Specific Lesson 13. As these construction techniques are in an early stage of development, the success of marsh enhancement projects depends heavily on adaptive management. For all three pilot projects, tentative dredged material placement strategies were developed, but activities were adaptively managed in real time during placement. The key to successfully constructing the projects and achieving the target dredged material placement elevations was to have the marsh team constantly on site and observing the dredged material placement. Frequent communication between the marsh team and the dredging team ensured that any problems or modifications were promptly addressed during construction. In addition to this active communication during construction, weekly project status meetings were useful for construction planning and adaptive management.

Phase-Specific Lesson 14. The maximum distance that hydraulically dredged sediment can be sprayed onto a marsh will vary with the equipment used and is likely limited to 150–200 feet. At Ring Island, hydraulically dredged sand was sprayed a maximum distance of about 170 feet onto the marsh. The USACE-OP expects dredge contractors to be capable of spraying dredged material 100 feet using a 12- to 14-inch dredge and 75 feet using a smaller dredge. In contrast, high-pressure spray equipment has been reported to reach nearly 300 feet into the marsh (Ray 2007). These limitations should be considered when designing a project. Once the dredged material is placed on the marsh, the distance it spreads will vary with its grain size and marsh topography. Sandy dredged material falls out of suspension relatively quickly and is minimally dispersed when it is hydraulically sprayed on to a marsh plain; for example, at Ring Island, the dredged material was 96% fine sand and settled in areas that were approximately 50 feet from the pipe outlet. Dredged material that is predominantly silt or clay will disperse across a much larger area, but dispersal distance depends on marsh topography and the presence of containment or vegetation.

Phase-Specific Lesson 15. Both heavy equipment and extensive equipment use on the marsh can damage it and slow marsh recovery after dredged material is placed. Even low-ground-pressure equipment damaged the marshes at both Fortescue and Avalon. In 2019, tracks from the low-pressure machinery remained at both sites, two to three years after work had been completed. If straw bales and coconut-fiber logs are used to contain placed dredged material, the use of equipment on the marsh to install and remove these items should be minimized, and such equipment use should be clearly described in contracts for site work.

Phase 6: Post-Construction Adaptive Management

Phase-Specific Lesson 16. Monthly qualitative monitoring, through visual inspections and photographs, is very useful after construction to adaptively manage the marsh enhancement project. This type of monitoring can be very effective in identifying problems in the marsh that should be addressed immediately. While there is no substitute for comprehensive quantitative monitoring of marsh response, there is typically a time delay between collecting the quantitative data and reporting the monitoring results. In contrast, qualitative monitoring can be the basis for rapidly implementing additional monitoring and adaptive management. For example, observations of vegetation die-off at the Avalon Phase 2 project resulted in the implementation of both new types of monitoring and the experimental removal of some containment.

Phase-Specific Lesson 17. Adaptive management may be needed if unexpected wildlife use the site. The presence of such wildlife may be either desirable or undesirable. For example, at Ring Island, erosion of the sand placed for the ENH created a beach that was used by horseshoe crabs (*Limulus polyphemus*) and diamondback terrapins (*Malaclemys terrapin*), which was an unintended positive outcome. In contrast, portions of the ENH were colonized by common reed (*P. australis*; an invasive plant) and other plant species, to which the team responded with adaptive monitoring and control (i.e., vegetation removal). In addition, the marsh enhancement areas at Avalon, which were not designed as shorebird habitat, attracted American oystercatchers (*Haematopus palliates*) due to the creation of large elevated and unvegetated areas. Planting of the site had to be pushed back a year out of concern for this species.

Phase-Specific Lesson 18. For ecological, practical, and safety reasons, finalizing and implementing the planting plan cannot occur until the placed dredged material has dewatered, consolidated, and chemically stabilized. The time needed for the dredged material to stabilize enough for planting can be highly variable. A topographic survey must be conducted to verify that the dredged material elevations are consistent with those in the planting plan. The planting plan may also need to be revised based on vegetation recovery and soil composition in the marsh enhancement site. In addition, areas that do not drain during the tidal cycle (i.e., where pools form and re-form) may not be suitable for planting. Planting should occur in early spring, before birds nest and before summer’s higher temperatures and low rainfall could adversely impact the newly planted vegetation. Waiting to plant may be advisable if preliminary soil survey data indicate that the placed dredged material has extreme physical or chemical characteristics. These characteristics may normalize over time[7].

The following is a possible schedule for post-construction planting:

- Growing Season #1
    - No planting
    - Monitor natural recovery of the marsh enhancement/dredged material placement areas
    - Monitor topography and dredged material properties
    - Develop a pilot planting plan and order plants
- Growing Season #2
    - Implement and evaluate the pilot planting plan
    - Continue monitoring
    - Develop a final planting plan and order plants
- Growing Season #3
    - Implement the final planting plan and continue monitoring

Phase-Specific Lesson 19. Reserve contingency funds for adaptive management and monitoring. Adaptive management of a marsh enhancement project will be needed during construction and post-construction monitoring phases. Expect that unplanned situations will require additional monitoring or management, and set aside funds to address conditions that may develop on the marsh and hinder its recovery.

Phase 7: Project Assessment

Phase-Specific Lesson 20. The project team should be dedicated to consistently implementing a comprehensive monitoring program and should have the resources to do so from the start of project development. The monitoring goals, metrics, and methods should be developed early in the process. The monitoring program should be designed to provide the data needed to (1) determine whether the specific marsh enhancement project goals and objectives have been met, (2) evaluate whether the project was built as designed (as-built survey), (3) evaluate the effects of the project on populations of interest (*Spartina* spp., birds, crabs, etc.) and (4) inform potential adaptive management. In addition, all data should be collected from the same monitoring locations in a consistent manner, using standardized protocols and formats. If a database will be used to house the data, it is helpful to collect the data in a format that can be input easily. Both baseline (pre-construction) and post-construction data should be collected at the spatial and temporal scales needed to evaluate the project and the trajectory of marsh response.

The marsh team initially found that most ecological parameters responded negatively to the placement of dredged material and recommend not drawing conclusions about project success or failure too soon after placement. They recommend that the monitoring program include baseline monitoring for at least

[7] See USDA NRCS Soil Survey Technical Note 430-SS-11 Acid Sulfate Soils in the Coastal and Subaqueous Environment: https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/ref/?cid=nrcseprd1461815

one year and post-construction monitoring for at least five, but preferably ten, years. The project team should secure funding for a long-term, comprehensive monitoring program. See Cross-Phase Lesson 2.

Phase-Specific Lesson 21. Map habitats at the project site (e.g., vegetated and unvegetated areas of the marsh plain and marsh pools) before and after construction. The post-construction monitoring program should take these different habitat types into consideration. The baseline marsh habitat can have a significant influence on how the placed dredged material dewaters and consolidates, ultimately determining whether the target ecological elevations are achieved. In addition, vegetation recovery and colonization can be impacted by the pre-existing habitats and their connectivity. Without this spatial information on pre-existing habitat types, which should also be used as covariates in many analyses, it will be difficult to interpret post-construction monitoring data.

Phase-Specific Lesson 22. Review the monitoring plan after construction to ensure that it adequately characterizes and represents post-construction conditions. The horizontal extent of dredged material placement and the elevations achieved after the dredged material has consolidated and stabilized may vary from those on which the sampling strategy was developed. This may require relocation of the sampling point (e.g., some planned locations may not have received dredged material) and parameters.

Chapter 2: Project Details

Tidal marshes are an integral part of New Jersey's Atlantic Ocean and Delaware Bay coasts. They form a charismatic green band that cleans water; provides critical habitat for fish, shellfish, and birds; and buffers coastal communities from storms, erosion, and flooding (Mitsch and Gosselink 2007; NJDEP 2007; Narayan et al. 2017). However, the long-term resiliency of New Jersey's coastal tidal wetlands is threatened by a variety of factors, including historic alterations, such as ditching and diking, and ongoing stressors, such as accelerating sea-level rise, severe storms, and subsidence (Bertness et al. 2002; Hartig et al. 2002; Church and White 2011; Partnership for the Delaware Estuary 2012).

To offset the effects of sea-level rise and subsidence, salt marshes must receive sufficient sediment and organic matter to gain elevation and maintain a hydroperiod (duration of tidal flooding) that is optimal for or at least tolerated by salt marsh plants (Nyman et al. 2006; Mitsch and Gosselink 2007; Kirwan and Megonigal 2013; Fig. 6). Sediment accretion on a marsh is a function of both sediment budget and plant root growth (Nyman et al. 2006; Linhoss et al. 2015). A marsh with a healthy sediment supply receives sediment not only at a rate that exceeds what it loses to erosion (i.e., net positive deposition rate), but at

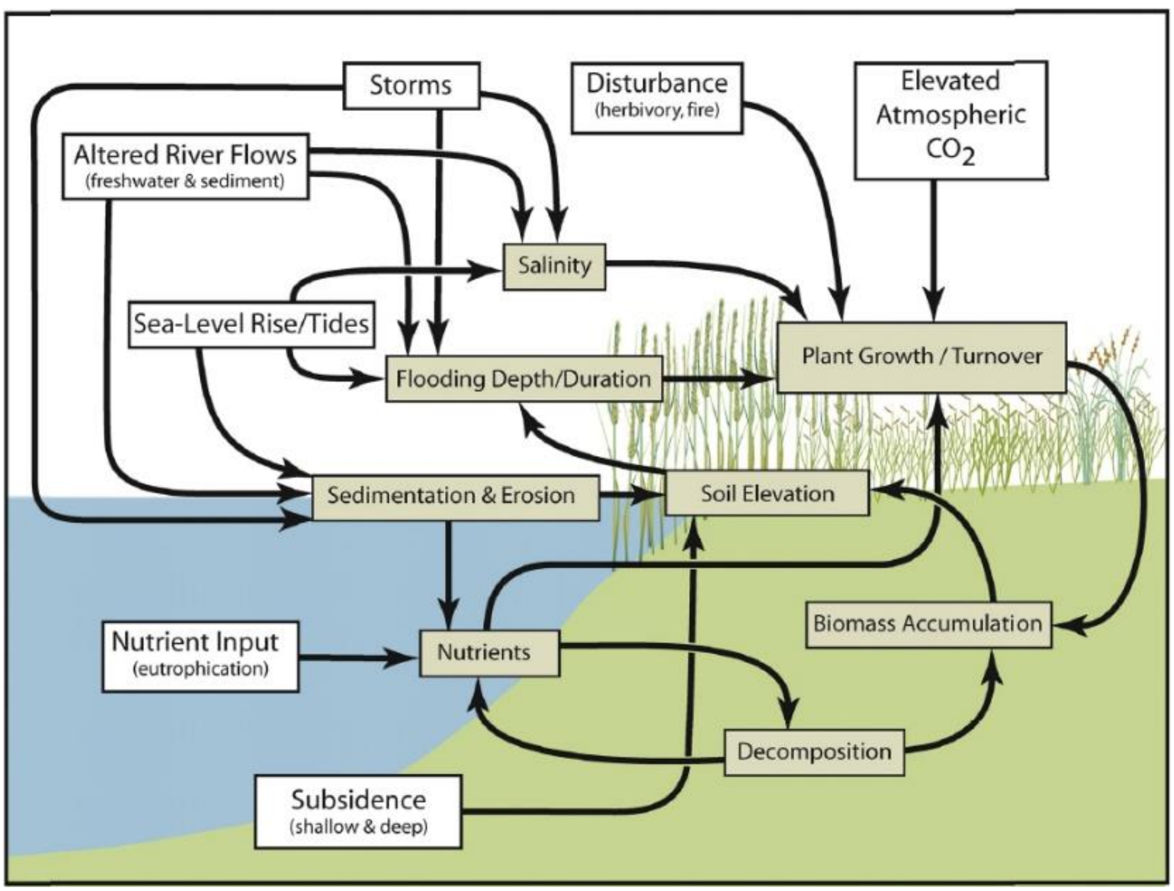

Figure 6. *This conceptual model of a tidal marsh shows how substantial tidal inputs of mineral sediment are influenced by environmental drivers and factors affecting accretion processes (Cahoon et al. 2009).*

a rate that allows a net increase in marsh elevation (Nyman et al. 2006; Mitsch and Gosselink 2007; Cahoon et al. 2009; Kirwan and Megonigal 2013).

Historically, the natural rate of accretion in marshes has usually been able to keep pace with sea-level rise (Cahoon and Gunterspergen 2010). However, sea level is rising at the fastest rate in at least 2,000 years (Horton 2017), averaging 4 mm/year in New Jersey between 1911 and 2018 (Fig. 7; NOAA 2019). As the rate of sea-level rise accelerates, some marshes have been unable to maintain the elevation they need to survive (Wamsley et al. 2010), and there is growing concern that marshes will be lost at increasing rates (Hartig et al. 2002; Kennish et al. 2012).

As we understand more about the important roles that marshes play in the biosphere, we are focusing more on enhancing their resiliency (Lotze et al. 2006). **Ecological resiliency** is the capacity of an ecosystem to maintain or recover its normal functions in response to disturbances (Cahoon and Gunterspergen 2010). It may be possible to increase the resiliency of a **stressed marsh** by placing sediment, such as dredged material, on it. This action may help additional sediment and organic matter accrete on the marsh at a rate that can maintain marsh elevation as sea level rises (Ray 2007).

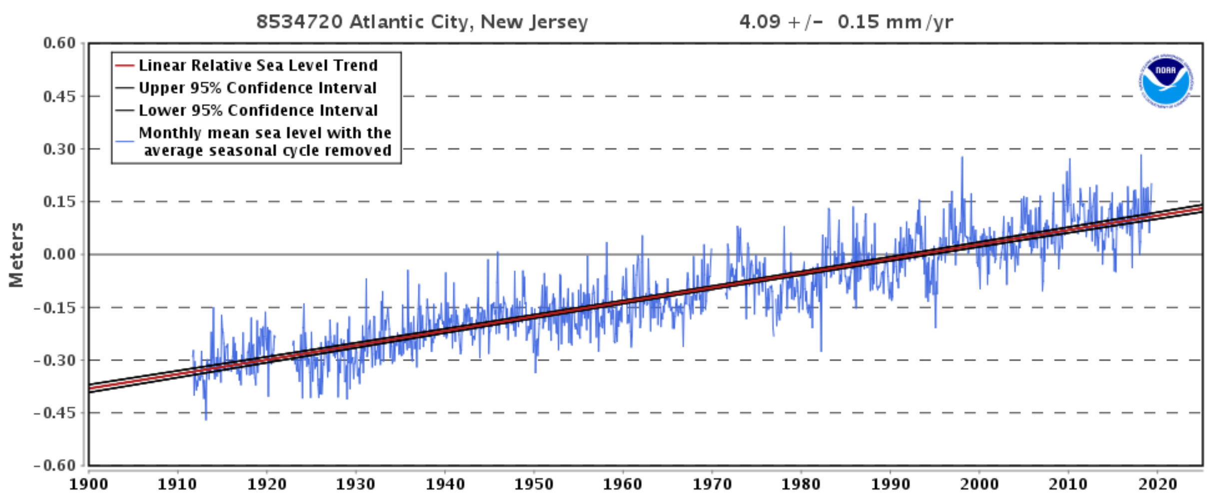

Figure 7. *The relative sea-level trend is an increase of 4.09 mm/year, with a 95% confidence interval of +/- 0.15 mm/year, based on monthly mean sea-level data from 1911 to 2018. This is equivalent to a change of 1.34 feet in 100 years (NOAA. https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=8534720. July 1, 2019).*

New Jersey's navigation channels and marinas require regular dredging to maintain safe passage. However, the state has a dearth of CDFs with capacity to accept additional dredged material; this has become a major problem for coastal communities, as well as the agencies that need to maintain navigation channels. As a result, within the state and the larger Mid-Atlantic region, there is great interest in restoring and enhancing salt marshes using material dredged from channels. This activity combines routine maintenance and post-storm dredging with wetland enhancement. The combined cost of the two types of projects could potentially be less than if the dredging and salt marsh enhancement projects were implemented separately.

One of Superstorm Sandy's many impacts was major shoaling of navigation channels along New Jersey's Coast. Traditionally in New Jersey, dredged sediments have been placed in confined disposal facilities (CDFs), effectively removing from estuaries the sediment needed by tidal wetlands. However, New Jersey has a dearth of CDFs with capacity to accept additional dredged material; this has become a major problem for coastal communities, as well as State and federal agencies, that need to maintain navigation channels.

In addition, increasing the resiliency of a salt marsh may produce significant socioeconomic and ecological benefits for coastal communities (McDonough et al. 1999). Although this beneficial use of dredged material is considered a pilot method in New Jersey, it is being used in other areas of the country. Stakeholders, including the NJDEP and The Nature Conservancy (TNC), are further refining the development, permitting, and implementation of these types of projects.

Project Background

In 2013, the New Jersey Department of Environmental Protection-Division of Fish and Wildlife (NJDEP-DFW) partnered with the USACE-Philadelphia District Operations Division (USACE-OP), the USACE Engineer Research and Development Center (USACE-ERDC), NJDOT-OMR, The Nature Conservancy (TNC), and the Green Trust Alliance (GTA) to initiate three pilot projects to enhance salt marshes. The projects sought to determine whether beneficially using dredged material to increase the elevation on existing, but stressed, salt marshes could increase the abundance of native salt marsh vegetation and result in ecological uplift compared with their baseline condition. The ultimate goal was to increase their resiliency to accelerating sea-level rise. All parties acknowledged that this was an opportunity to explore a paradigm shift from treating dredged material as waste to treating it as a valuable environmental resource. The NJDEP, USACE-OP, and NJDOT-OMR agree that retaining sediment within estuaries provides more environmental benefits than disposing of it in CDFs. In addition, many CDFs are filled to capacity, and there are no CDFs within a reasonable pumping distance of many navigation channels and marinas. Thus, dredging sediment from these sites and disposing of it can be very costly. In addition to improving sediment management practices, the USACE-OP and NJDOT-OMR expected that beneficially using dredged material for marsh enhancement projects could decrease overall project costs.

To evaluate and further develop this method of marsh enhancement in New Jersey, it was important to carry out pilot projects. Pilot projects would demonstrate that the beneficial use of dredged material for salt marsh enhancement could provide the expected benefits, while not damaging coastal habitats, by providing local proof-of-concept examples.

The total cost of the pilot projects was $8 million, including $3.4 million from the Hurricane Sandy Coastal Resiliency Competitive Grant Program awarded to NJDEP-DFW and remaining funds provided by the USACE-OP and NJDOT-OMR. The grant period was August 2014 through October 2017 (Table 3). The pilot projects included three main components:

1. Demonstrate the use of dredged material to enhance approximately 90 acres of salt marsh (and associated restoration of dune, beach, and avian nesting habitats).
2. Analyze the effects of dredged material placement on the marsh ecosystem and the resiliency of nearby coastal communities.
3. Develop an interactive web-based mapping tool to provide data and information for developing future marsh enhancement projects in New Jersey.

The goals of these pilot projects were as follows:

1. Improve existing dredged material management practices.
2. Increase the technical and scientific knowledge behind these innovative beneficial use projects.
3. Change standard dredged material management practices in New Jersey.
4. In the aftermath of Superstorm Sandy, promote these practices to enhance coastal resiliency.

The overall goal for the marsh enhancement pilot projects was to advance the concept that placing dredged material on stressed salt marshes would provide ecological uplift and increased resiliency of the habitat, helping the marshes persist despite accelerating sea-level rise, increased storms, and subsidence. The projects would evaluate the use of a variety of different sediment types (predominantly sandy and fine-grained material), dredged material placement methods (spraying and direct pumping) and placement thickness on a range of salt marsh conditions. The pilot projects would be monitored comprehensively to evaluate how the ecosystem responded to dredged material placement in the near term, identify factors that negatively impacted recovery, and determine whether the structure and functions of the marsh were improved.

The long-term objectives for the marsh enhancement components of the pilot projects were the following:

1. Increase and maintain the optimal tidal elevation and hydroperiod for native salt marsh biota.
2. Increase the abundance and vigor of native salt marsh plants.
3. Return all other parameters to pre-construction conditions unless they were expected to change from the conversation of habitat.

In order to use enough dredged material to make the dredging projects economically viable, additional project components were added at Ring Island and Fortescue. At Ring Island, a sandy **Elevated Nesting Habitat (ENH)** was created for the state-endangered black skimmer (*Rynchops niger*) and other colonial nesting shorebird species of concern. At Fortescue, a nearby beach was restored and a constructed dune was enhanced to provide protection for the marsh and boat launch in Fortescue Creek.

Table 3. Pilot Project Timeline		
2012	October	Superstorm Sandy
2013	March	USACE begins development of the Environmental Assessment and awards dredging contracts
	Summer to Fall	Project conceptual development (NJDEP, USACE, and TNC)
	October	NFWF grant announcement
Late 2013 to early 2014		USACE NJIWW channel sediment sampling and bathymetric surveys

2014	January	NJDEP NFWF grant application submission
	July	USACE NEPA EA/FONSI (Avalon, Ring Island)
	Summer	Ring Island and Avalon (site assessment and baseline monitoring for placement areas A, B, and C)
	August 7	NJDEP permits issued for Ring Island pilot projects
	September	Fortescue site assessment visits (marsh, beach, dune)
	September	Ring Island dredged material placement
	December 23	NJDEP permits issued for Avalon Phase 1 (placement areas A and C)
2014 to 2015	December to January	Avalon Phase 1 dredged material placement
2015	March to October	Ring Island post-construction monitoring
	May, June, & July	Avalon site assessment (placement areas D, E, F, G, H, and I)
	July	Fortescue site assessment visits (marsh, beach, dune)
	October	NJDEP and USACE permits issued for Fortescue pilot projects
	November	NJDEP permits issued for Avalon Phase 2
2015 to 2016	December to March	Avalon Phase 2 dredged material placement
2016	January to March	Fortescue dredged material placement (marsh, beach)
	March to October	Ring Island, Avalon, and Fortescue post-construction monitoring
	May & June	Fortescue site assessment visits (dune only)
	November 21	NJDEP and USACE permit modifications; Fortescue dune redesign
2017	January to March	Fortescue dredged material placement (dune)
	May & June	Vegetation planting (Avalon, Ring Island, Fortescue)
	March to September	Ring Island, Avalon, and Fortescue post-construction monitoring
2018 to 2022	March to September	Ring Island, Avalon, and Fortescue post-construction monitoring

Project Implementation

The pilot projects at each of the three locations followed seven phases:

- Phase 1: Site Identification and Placement Area Selection
- Phase 2: Project Design
- Phase 3: Permitting
- Phase 4: Bidding and Contracting
- Phase 5: Construction
- Phase 6: Post-Construction Adaptive Management
- Phase 7: Project Assessment

Here, we summarize the major steps undertaken by the project team during each phase.

Phase 1: Site Identification and Placement Area Selection

In Phase 1, the team identified salt marsh sites that were stressed due to an elevation deficit, identified an appropriate dredging project near the stressed marsh, selected the specific dredged material, or beneficial use, placement areas at those sites for habitat enhancement, and identified control areas. Control areas were sites that represented the baseline condition of the sites that received treatment. They represented what the placement areas would have looked like if sediment was not placed on them. They also helped to capture natural variation in the monitoring metrics.

All three of the marsh enhancement projects discussed in this report were developed using the same general four-step site identification and placement area selection process. The timeline specified by the NFWF grant and the USACE-OP dredging schedule limited both the time available for this phase and the collection of baseline monitoring data to characterize each site. However, with each successive project, more time was available to collect and analyze baseline data. In addition, the experience we gained developing the early projects was invaluable for selecting the placement areas for the subsequent projects. It is also important to note that we did not follow the four-step process sequentially in each project. In some projects, the steps were implemented concurrently, while in others they were implemented iteratively.

Four-Step Process for Site Identification and Placement Area Selection

- Step 1: Project Conception
- Step 2: Collection of Data for Dredging Project
- Step 3: Marsh Enhancement/Placement Area Selection
- Step 4: Project Design and Construction

Step 1: Project Conception. This first step in the site identification process included a series of meetings between NJDEP-DFW, USACE-OP, NJDOT-OMR, TNC, and GTA.

Early in the development of these pilot projects, a diverse project team was established, which was one of the keys to project success. The project team consisted of land managers, navigation managers, state regulators, engineers, dredge contractors, dredging experts, senior environmental scientists, biologists, bio-environmental engineers, and hydraulic engineers. These technical experts focused on implementing a systems approach to use sediment dredged from navigation channels to restore/enhance marshes.

The team included a dredging team (NJDOT-OMR or USACE-OP, USACE ERDC scientists and engineers, and dredging and engineering contractors) and a marsh team (NJDEP, TNC, GTA, Princeton Hydro [PH] and The Wetlands Institute [TWI]). The dredging team's primary responsibility was to ensure that the channels would be cleared for safe navigation and that the dredged material would be placed on the marsh following the marsh enhancement project design plans. The marsh team's primary responsibility was to ensure the ecological success of the projects. Regular communication and cooperation between the two teams was critical to initiating, planning, and constructing these projects.

The NJDEP and conservation organizations were interested in experimenting with new ways of enhancing stressed salt marshes. The USACE-OP and NJDOT-OMR were interested in developing these types of pilot projects because managing dredged material can be both difficult and costly. The USACE-OP is also committed to the efficient use of dredged material and to rebuilding and supplementing coastal marshes and beaches wherever possible. It has demonstrated this commitment by hosting USACE's Regional Sediment Management Program since 2002 and by being designated an Engineering with Nature Program Proving Ground in 2016.

Marsh enhancement beneficial use projects are an innovative and proactive regional sediment management approach that retains sediment in the estuarine system and potentially can have socioeconomic and ecological benefits. All parties recognized that combining dredging and marsh enhancement projects may decrease project costs compared with conducting these efforts independently. During the initial meetings in 2013 and 2014, the team identified potentially stressed or degraded marshes, potential funding sources for marsh enhancement, dredging projects that needed alternative ways to dispose of dredged material, and possible timelines for all phases of the projects.

At Ring Island and Avalon, conceptual plans were developed to use sediment dredged from the nearby NJIWW for marsh enhancement and habitat creation. These areas were selected for evaluation because NJDEP-DFW owns large tracts of potentially stressed salt marsh in proximity to critical channel shoals in the NJIWW that the USACE-OP would be dredging.

At Fortescue, three potential habitat projects near the Fortescue Creek navigation channel were identified: enhancement of a portion of a historically ditched marsh adjacent to the channel, restoration of the eroding dune fronting the marsh along Delaware Bay, and restoration of an eroding natural beach. These areas were selected for evaluation because New Jersey manages large areas of salt marsh near a navigation channel (Fortescue Creek) that NJDOT-OMR considers to be in critical need of dredging. Managing the associated dredged material from this channel has been a longtime problem for the state. The channel requires dredging every three to five years, and traditional management options for the dredged material are not available locally.

Next, implementation timelines were developed for each project. In spring and early summer 2014, the team developed contracts, collected baseline data and further evaluated the potential marsh enhancement sites, developed marsh enhancement designs, obtained permits, and developed monitoring plans. Construction was scheduled for the fall of 2014, with the possibility of completing construction in the fall of 2015. Post-construction monitoring was planned for the five years after construction. These timelines considered the USACE-OP's dredging schedule under an existing maintenance dredging contract, as well as environmental timing restrictions (i.e., "dredging windows") for winter flounder, marsh nesting birds, and other potential species of concern.

In January 2014, NJDEP-DFW applied to NFWF for a grant to pay for the design and monitoring of the projects, using the cost of the USACE-OP and NJDOT-OMR dredging projects to meet NFWF's matching fund requirement.

Step 2: Collection of Data for Dredging Project. The dredging project managers provided the project team with information about when and where they planned to dredge, the estimated volume of sediment to be dredged, the available sediment characterization data, and how far the dredged material could be pumped. The USACE-OP and NJDOT-OMR also worked with the NJDEP Office of Dredging and Sediment Technology (ODST) to develop Sediment Sampling and Analysis Plans to collect and analyze the channel sediment for physical characteristics, including grain size, total organic carbon, and potential contaminants. These data were needed to determine whether the dredged material was suitable for the proposed projects.

Ring Island: The USACE-OP studies of the nearby NJIWW channel confirmed that the sediment was 96% fine sand and the estimated volume of sediment to be dredged was 7,000 CY. Because of the high percentage of sand, NJDEP-ODST confirmed that additional testing for contaminants was not needed.

Avalon: The USACE-OP studies of the nearby NJIWW channel revealed that the sediment was primarily fine-grained silt and clay, the estimated volume of sediment to be dredged was 75,000 CY, and dioxins/furans were present at potential levels of concern in some sections of the channel. The USACE-OP also worked with their dredging contractor to better determine the maximum distance that the hydraulically dredged sediment could be pumped, given its physical characteristics, from each of the channels.

Fortescue: The analysis of sediment in Fortescue Creek channel indicated that it was a heterogenous mix of coarser-grained (sand) and fine-grained (silt and clay) material, the estimated volume of sediment to be dredged was 83,000 CY, and contaminants in the sediment to be dredged did not present an ecological concern and were generally present at lower levels than in the surface sediment of the Fortescue marsh.

Step 3: Marsh Enhancement/ Placement Area Selection. To preliminarily identify stressed marshes and delineate marsh enhancement and control areas, the project team evaluated all marshes within the pumping distances of the USACE-OP and NJDOT-OMR dredging projects. To determine which marshes within pumping range would benefit from sediment addition, the sites were assessed through desktop analyses, site visits, and marsh enhancement project feasibility evaluations.

Site assessment through desktop analysis consisted of reviewing readily available information about the condition of the marshes, evaluating maps of marsh elevation, and conducting various modeling analyses. Due to limitations in the distance that dredged material could be economically pumped, a first round of analysis evaluated marshes that were within approximately 1 mile of the planned dredging projects. LiDAR (Light Detection and Ranging) data were used to identify low-lying marsh platforms. Historic aerial photographs available through Google Earth and the NJDEP's GIS website were used to assess marsh stability, considering features such as expanding and contracting pools, shoreline erosion, tidal creeks, and mosquito control ditches. The project team also looked for marshes that might buffer communities from waves and storms, using TNC's Risk Explorer app for NJ (The Nature Conservancy n.d.). This information was used preliminarily to select portions of the marsh that might benefit from the addition of a thin layer of sediment. It was also used to help select control areas with similar conditions to the placement areas. Additional analysis and modeling were usually conducted after the initial site visits.

Ring Island: The marsh team and the USACE-ERDC conducted desktop studies to identify potential marsh sites that would benefit from the placement of the sandy sediment to be dredged from the Ring Island section of the NJIWW. Figure 8 shows a LiDAR map of the marsh areas within pumping distance of the channel. This map was used both to preliminarily identify low-elevation areas of the marsh and to guide initial site visits. In addition, potential areas of the marsh for ENH for colonial shorebirds were identified. Several locations for both types of habitat enhancement projects were initially identified for further study using current and historic aerial photos, maps of elevation, and erosion rates (Fig. 9). However, because birds were nesting on the preferred locations for marsh enhancement and ENH, new sites had to be selected.

Avalon: The marsh team and USACE-ERDC performed desktop analyses to identify sites that could benefit from the placement of sediment. Several locations were identified for further evaluation based on current and historic aerial photos, maps of elevation, erosion rates, and tidal connectivity. As at Ring Island, a LiDAR map (Fig. 10) was used to preliminarily identify low-elevation areas of the marsh and to guide initial site assessment visits. The project team considered a variety of options for beneficially using the dredged material, including TLP on low-lying marsh areas, filling expanding pools near the eroding marsh edge, recreating and stabilizing eroded marsh edge, and restoring part of an island that was lost to erosion. Once the project team decided to focus on filling expanding pools and enhancing the surrounding marsh platform at the Avalon site, USACE-ERDC performed a drainage analysis to identify pools that appeared to experience restricted tidal flow conditions.

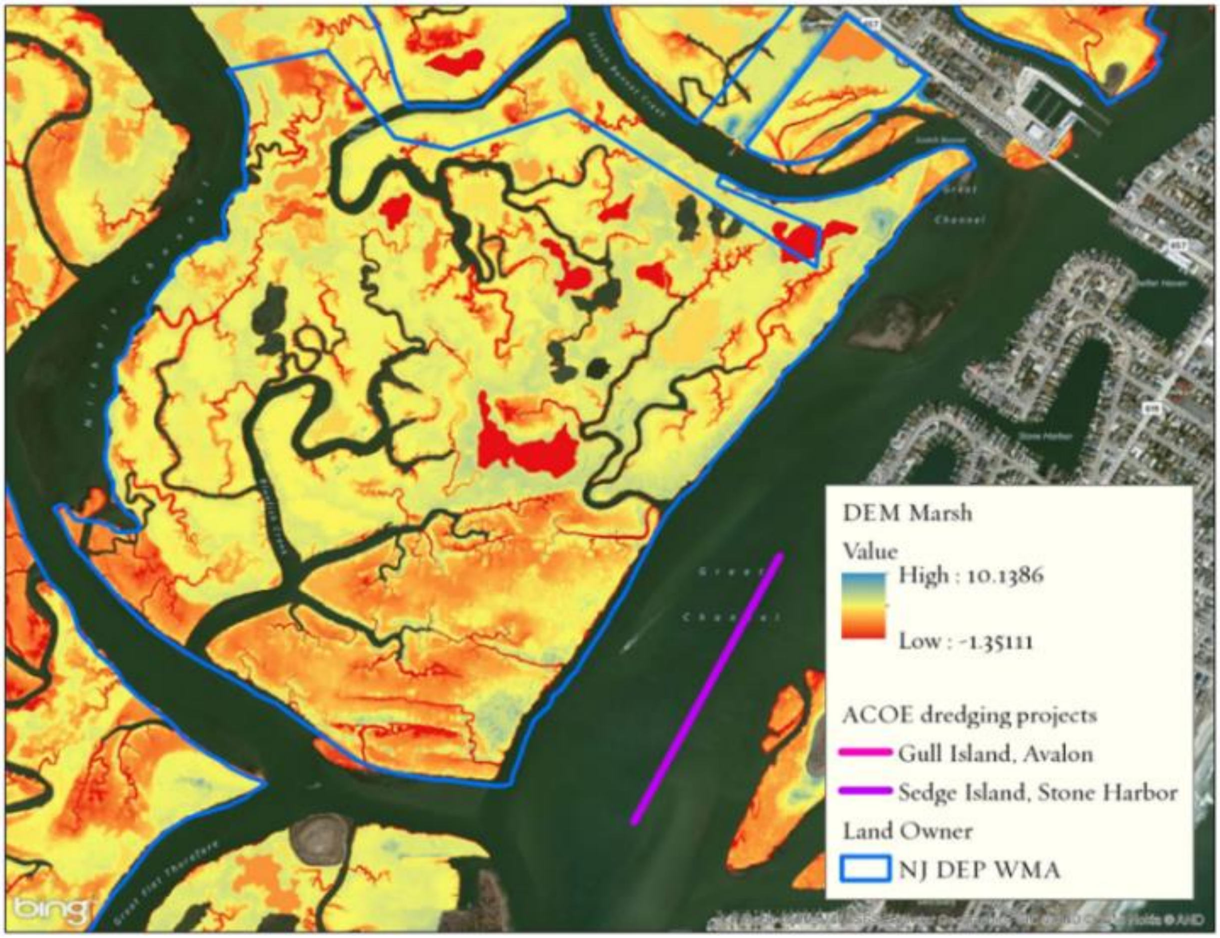

Figure 8. *This LiDAR map of Ring Island shows the relative elevation of salt marsh sites. Areas in red were especially low elevation and were selected for further evaluation.*

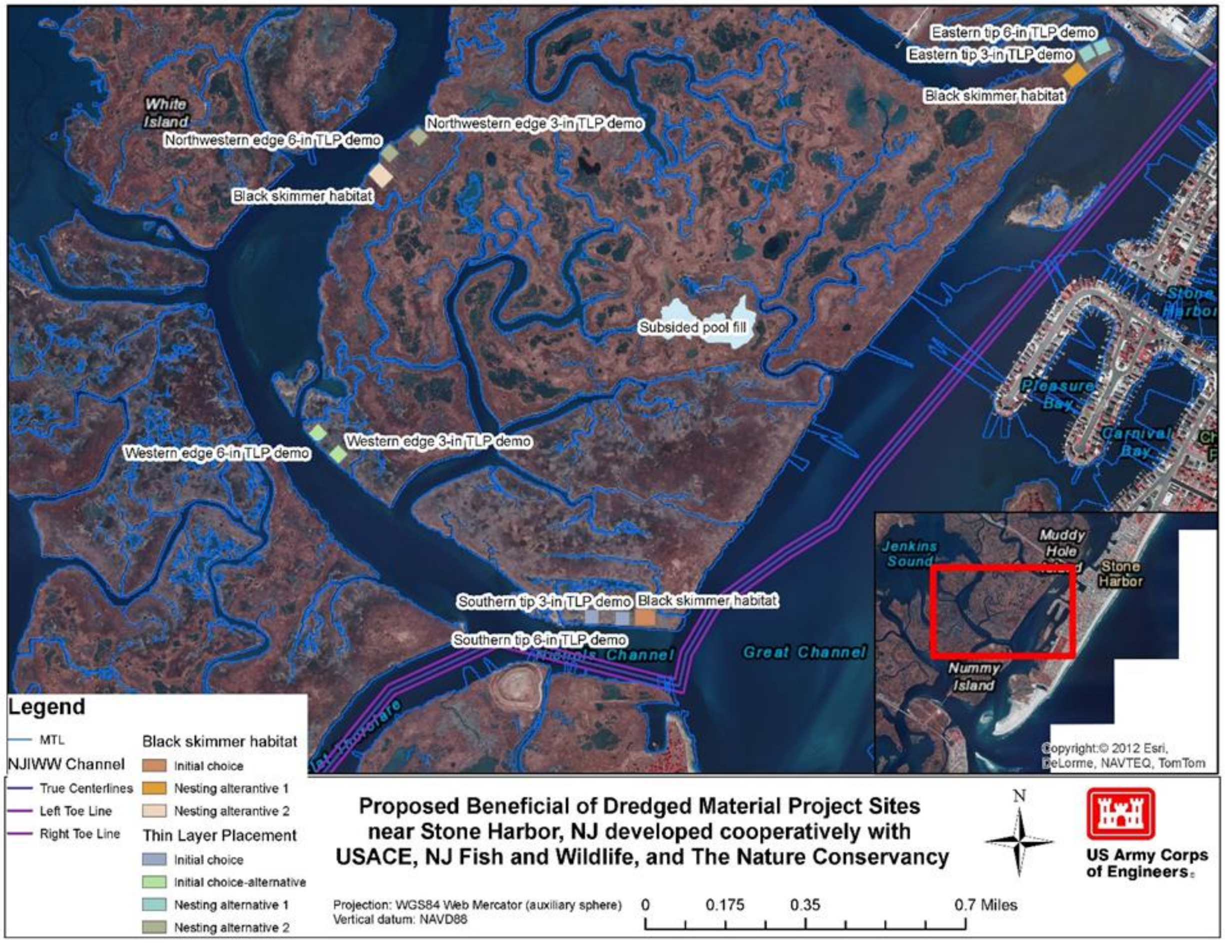

Figure 9. *This map shows the initial potential sites on Ring Island, with priority and secondary choices for the creation of black skimmer habitat and marsh enhancement. None of these areas were used because birds were nesting there during the scheduled construction time.*

Fortescue: The marsh team conducted desktop analyses to identify marsh sites that would potentially benefit from the placement of dredged material and that were within the estimated pumping distance from the Fortescue Creek channel. Using recent and historic aerial photos, maps of elevation, erosion rates, and tidal connectivity, several locations were identified for further evaluation. For example, a LiDAR map (Fig. 11) and topographic surveys were used to preliminarily identify low-elevation areas of the marsh and to guide site assessment visits. The marsh team also used a Marsh Futures report (Kreeger et al. 2015), which stated that the salt marshes next to Fortescue Creek were vulnerable to die-off due to their low elevation within the tidal spectrum. This report also recommended TLP of dredged material to raise the marsh platform to the proper tidal range for native salt marsh plants. During this phase of marsh assessment, the marsh team was primarily considering TLP on low-elevation areas of the marsh directly adjacent to Fortescue Creek, particularly a depression that contained abandoned

Figure 10. *This LiDAR map of the marsh at Avalon shows the relative elevations of state-owned marsh near planned dredging and was used in combination with other information to preliminarily select marsh enhancement areas.*

mosquito ditches. In addition, an eroding beach and a *P. australis*–dominated constructed dune were identified as potential recipients of the sandy sediment to be dredged from the channel.

Site visits were conducted to evaluate vegetation health, pool condition, platform stability, faunal (primarily bird and fish) use, and enhancement feasibility. The project team visited the potential marsh enhancement and control areas selected through the desktop analyses several times. These site visits allowed the marsh team to narrow down the potential marsh enhancement areas to those that were clearly stressed and likely to benefit from the placement of dredged material.

Ring Island: The areas that were initially identified (Fig. 11) were heavily used by nesting birds or were too far away from the dredging area in the NJIWW. The project team conducted several site visits before selecting the final marsh enhancement and ENH areas shortly before dredged material placement began (Fig. 12). The selected marsh enhancement area had stunted, sparse vegetation (Fig. 13) and higher elevations than the originally selected areas. The project team decided to move forward with a dredged material TLP trial in two 0.5-acre areas at Ring Island, even though these areas were not the team's original choice, because of what could be learned from this pilot project.

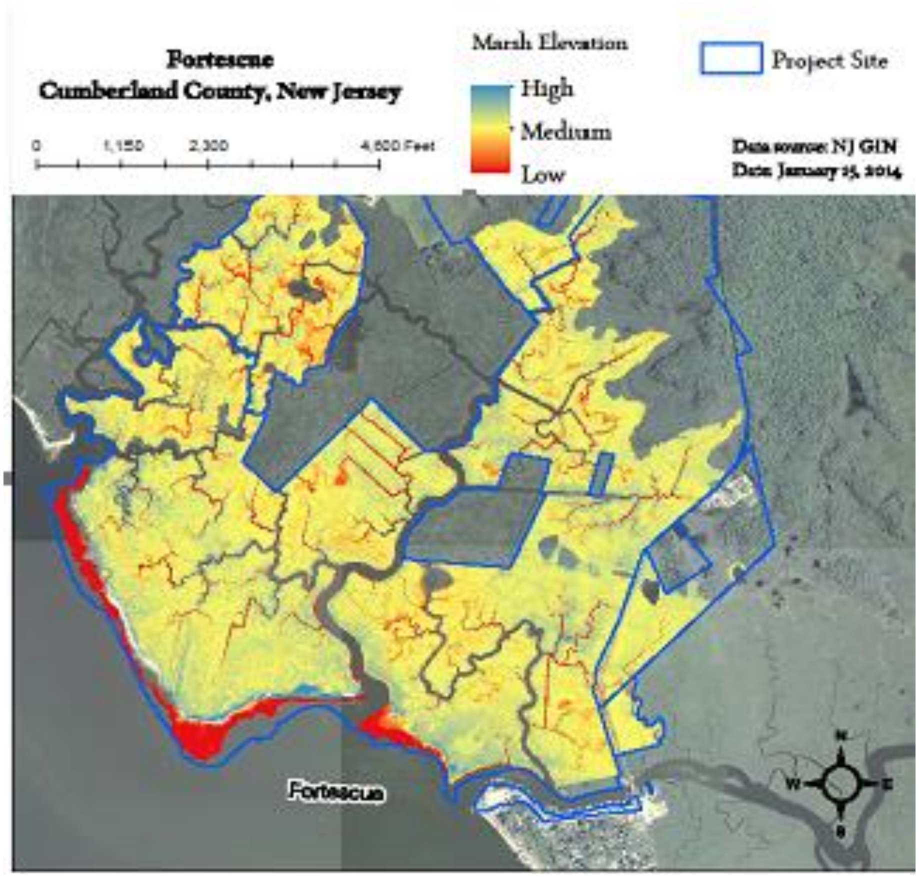

Figure 11. *This LiDAR map of the Fortescue site shows the relative elevations of state-owned marsh near the planned dredging area. This map was used in combination with other information to preliminarily select marsh enhancement areas.*

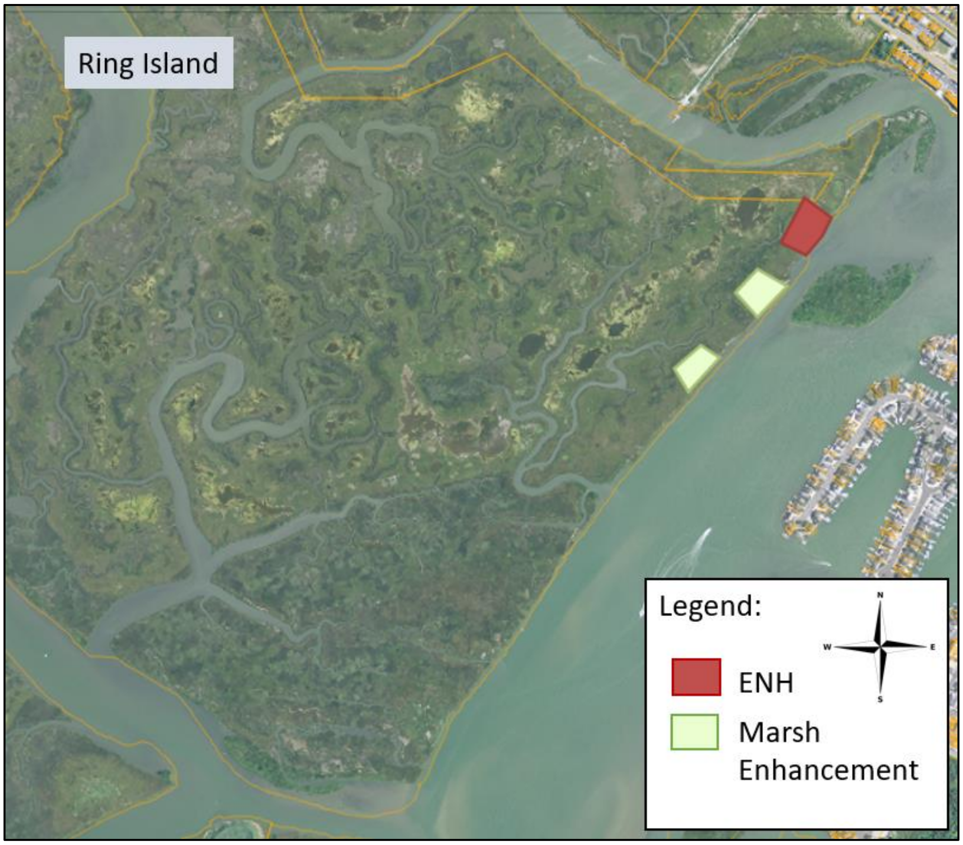

Figure 12. *This map shows the final placement sites at Ring Island. Elevated Nesting Habitat is marked in red and thin-layer placement areas are in green.*

Figure 13. *Sparse and stunted vegetation was characteristic of the areas of the marsh at Ring Island selected for enhancement via thin-layer placement of dredged material.*

Avalon: Site visits conducted by the marsh team considered marsh vegetation, hydrology, faunal use (particularly bird nesting), and marsh platform stability (particularly around the edges of pools). These observations helped the team identify stressed areas of the marsh for enhancement as well as areas of the marsh that were healthy and probably would not benefit from the addition of dredged material. Ultimately, the selected placement areas at Avalon had multiple characteristics typical of stressed marshes, including eroding edges, expanding and degrading pools with undercut banks (Fig. 14), sparse and stunted vegetation (Fig. 15), and minimal faunal usage.

For marsh enhancement at the Avalon site, the marsh team selected expanded and degraded pools that were surrounded by sparsely vegetated marsh platform. Most of these pools were also near an eroded marsh edge. The team predicted that as the marsh edge continued to erode and pools continued to expand, they would essentially coalesce, resulting in a "blowout," and a large area of the marsh would be lost and become open water. This prediction was supported by observations of remnant pools in open water adjacent to the marsh (Fig. 16). For the small Avalon Phase 1 project, three placement areas were chosen for construction in fall 2014 and winter 2015, and the edge of the marsh near those areas was evaluated for creation of a living shoreline. In 2015, a larger area of the marsh was evaluated, first by desktop analysis and then with site visits. Several additional placement areas were selected for the larger Avalon Phase 2 project.

Figure 14. *Expanded and degraded pools were present at the Avalon marsh. The white wrack in the picture is dried algae from the pond.*

Figure 15. *Vegetation at the Avalon marsh was sparse.*

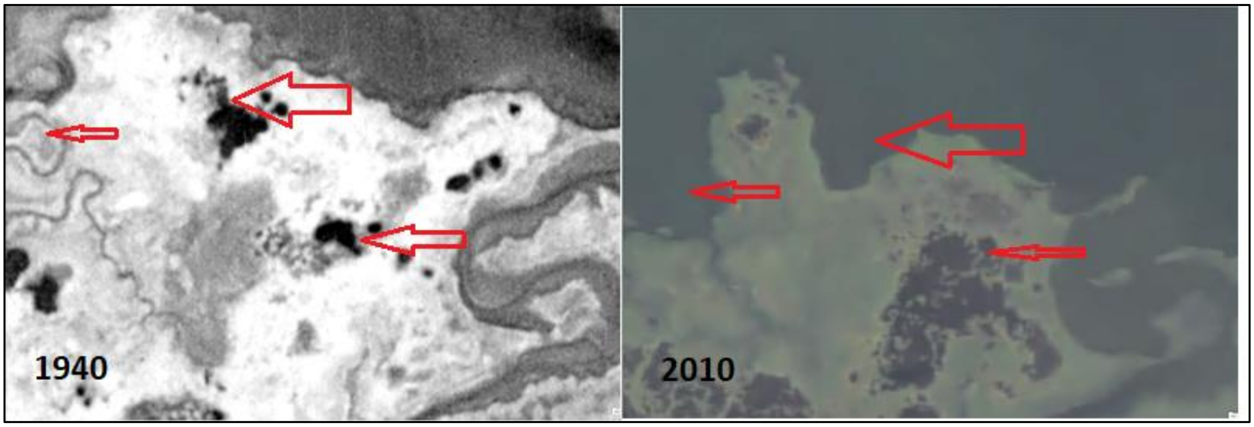

Figure 16. *These aerial photos of Avalon Area C in 1940 and 2010 reveal conversion of the marsh platform to open water, which was caused by a combination of expanding pools that eroded the marsh edge.*

Fortescue: As at Avalon, the marsh team performed site assessment visits to identify stressed areas of marsh that could benefit from the placement of dredged material and to narrow the list of potential dredged material placement areas. The team considered vegetation, hydrology, faunal use (particularly bird nesting), and marsh platform stability (particularly around the edges of pools). The selected enhancement areas exhibited multiple characteristics typical of stressed marshes, including undulating terrain, mosquito ditches, erosion, an unstable marsh platform (wobbly hummocks of *Spartina* spp. surrounded by unconsolidated mud), minimal faunal use, and sparse and stunted vegetation (Fig. 17).

Figure 17. *At Fortescue, the team noted stunted vegetation on an unstable marsh platform (wobbly hummocks of* Spartina *spp. surrounded by unconsolidated mud).*

During site assessment visits to the proposed beach restoration area in Fortescue, the team confirmed that the area was eroding and was highly utilized by birds. As a result of the site visits, the size and configuration of the proposed dune restoration was changed in order to preserve a valuable patch of mature trees, which was used by many herons.

Many additional factors informed the final selection of enhancement areas at each site. These included the grain size distribution of channel sediment, the chemical composition of channel and marsh surface sediment, the distance from the marsh edge to the placement areas, the contours of dredged material placement areas (surface area and thickness required to achieve the target dredged material placement elevation and respective placement constraints), and timing restrictions for dredging and dredged material placement ("dredging windows"). Because these factors also affected the design of the projects, they are discussed in more detail in Phase 2: Project Design [Step 3].

At the Avalon site, the sediment to be dredged from the NJIWW was, on average, comprised of 27% fine sand, 53% silt, and 19% clay. The project team had originally planned to use some of the dredged material to restore part of the eroded marsh edge; however, it would have been very difficult and expensive to design, place, and stabilize the fine-grained sediment. Therefore, the team abandoned this plan. Based on the project team's experience placing and spreading sandy material at Ring Island, the team decided that the sand–silt mix available at Avalon was ideal for filling marsh pools, with the overflow resulting in TLP of sediment on the existing marsh platform surrounding the pools. For additional information, see Phase 2: Project Design.

The Fortescue Creek navigation channel contained a heterogenous mix of fine-grained sediment, sand, and some gravel. After its experience at Ring Island, the project team knew that it would be difficult to place sandy dredged material evenly over large areas of marsh. Because the navigation channel needed to be dredged completely to make the dredging project economically viable, the team decided to use the coarser-grained dredged material to restore the adjacent dune and a natural beach. Dredging and placing the sandy dredged material for the dune and beach components could also be done faster than applying TLP on the marsh. These project components were added to help contain costs and increase the probability that the project could be completed before dredging was stopped by seasonal restrictions.

Step 4: Project Design and Construction. The team made final refinements to the selection and delineation of the marsh enhancement/dredged material placement areas during the design and construction phases (discussed in Phase 2: Project Design and Phase 5: Construction). This was an iterative process involving coordination and adaptive management of the project designs with the dredging and dredged material placement.

Phase 2: Project Design

After the dredged material placement areas had been selected at each site, the project design (Phase 2) was initiated. Project design included developing the target dredged material placement elevations and target ecological elevations (or thickness of placed dredged material), grading plan, planting plan, dredge pipe layout, and sediment erosion and control plans and specifications.

In salt marshes, the depth and duration of tidal inundation, which is controlled by elevation and topography, is one of the most important determinants of the habitat present at a site. The target ecological elevation is the elevation at which the depth and duration of flooding would be expected to create a specific type of salt marsh habitat, which is characterized by the predominant plant species. These elevations can be based on either biological benchmark data (the elevation at which a species is typically found) or on data from a reference site. These elevations, in combination with tidal datums, can be used to select target ecological elevations for a project. To accommodate future sea levels at the project sites, the team selected target ecological elevations at the higher end of the elevation range within which a target plant species occurred.

If the marshes are going to undergo manual revegetation, biological benchmarks and hydrology from a reference site can also be used to draft planting plans. To obtain the needed quantities of plants for large sites, specialty nurseries may require orders far in advance (likely at least 6 months), so creating a draft planting plan is helpful. However, to allow for elevation changes from dewatering and consolidation of the placed sediment, the planting plan cannot be finalized until the elevation stabilizes and the topographic survey has been completed.

The target dredged material placement elevation is the elevation to which dredged material should be placed on the enhancement project site. After dewatering and consolidation of the dredged material, the surface elevation should decrease to achieve the target ecological elevation. Hydraulically dredged sediment is mixed with water to form a slurry, which increases its volume. This increase in sediment water content and volume is called the sediment “bulking factor” and was estimated on the basis of USACE-ERDC research in the Gulf of Mexico. The bulking factor is then used in combination with the target dredged material placement and ecological elevations to estimate the volume of sediment needed for each enhancement area.

Another option for determining the volume of dredged material needed on the marsh is to select a target thickness of placed dredged material. This target could be based on what would be expected to accrete during a large storm, or on the thickness of placed dredged material that marsh vegetation would be expected to quickly grow through and recover (based on the scientific literature, expert interviews, or personal experience).

Sediment erosion and control plans for the pilot projects were based on the grain size of the sediment, the contours of the marsh, the elevation gain to achieve the target dredged material placement elevation, and the need to protect tidal creeks. Fine-grained sediment will disperse farther across the marsh and take longer to dewater than coarser-grained sediment, potentially requiring more containment.

At each project site, the project design was created through a collaboration of the dredging team and the marsh team, with each contributing extensive expertise and resources to the design process. The four general steps to design of the marsh enhancement components of the pilot projects were:

- **Design Step 1:** Complete assessment of biological benchmarks and tidal datums to establish target ecological elevations.
- **Design Step 2:** Conduct baseline topographic survey and map tidal creeks.
- **Design Step 3:** Review potential design constraints.

- **Design Step 4:** Develop the target dredged material placement elevations and enhancement design plan.

Design Step 1: Complete assessment of biological benchmarks and tidal data to establish target ecological elevations.

At **Ring Island, TLP:** The biological benchmark and tidal data (Table 4) were collected only a few days prior to construction and were not used to guide project design. Instead, design was based on the detailed literature review of Ray (2007), which indicated that plants recovered best after placement of 2–6 inches of material. In addition, Reimold et al. (1978) found excellent vegetation recovery after placement of up to 9 inches of sandy material. Based on these two studies, the team selected placement area depths of 3 and 6 inches. Because the dredged material was sprayed from the edge of the marsh, no pipe layout on the marsh was needed for this site.

Biological benchmark information was collected using real-time kinematics global positioning system (RTK-GPS), and tidal data for the sites were based on the nearest National Oceanic and Atmospheric Administration (NOAA) or U.S. Geological Survey (USGS) tide gauge. This information was also used after construction to develop the planting plan for the site and to identify a threshold elevation to be avoided, above which *P. australis* could potentially colonize. Biological benchmarks and tidal datums are presented in Table 4.

The Ring Island colonial shorebird ENH was designed so that the central area of the created mound would be above the spring high-tide line (the elevation that ensures nests will not be flooded during storms), with the majority of the surrounding area below the elevation at which *P. australis* can colonize. A detailed dredge pipe layout was not needed because the dredge pipe was cribbed into place on the marsh only a short distance from the marsh edge, and the dredged material was pumped directly onto the ENH site.

Table 4. Ring Island Marsh Enhancement Biological Benchmarks and Tidal Datums

Vegetation Zone/ Tidal Datum	Elevation (ft.; NAVD88)
Elevation above which *Phragmites australis* and *Iva frutescens* dominate	2.90+
Spring High Tide	**3.60**
Spartina patens* with lowest reaches of *Phragmites australis* and *Iva frutescens	2.76
Spartina patens	2.63
Short-form *Spartina alterniflora* with *Distichlis spicata*, *Limonium carolinianum*, and *Salicornia* spp.	2.52
Panne surrounded by stunted short-form *Spartina alterniflora*	2.16
Mean Higher High Water (MHHW)	**2.14**

Avalon Phase 1: As at Ring Island, the biological benchmark and tide data were collected only a few days prior to construction and were not used to guide the project design. In addition, because water-level loggers were not installed prior to construction, the design was based on filling targeted pools to the same elevation as the surrounding marsh plain and adding 3–6 inches of sediment onto the surrounding marsh plain.

Avalon Phase 2: For this phase, target elevations were based primarily on the need to restore high marsh habitat as well as on the surrounding topography of each placement area. Biological benchmark data were collected at 21 locations on the site prior to construction. A range of vegetation types (including *S. alterniflora* tall and short forms and *D. spicata)* were found. The benchmarks were synthesized into three habitat designations (Table 5).

Table 5. Vegetation Zones at Avalon	
Vegetation Zone/ Tidal Datum	Elevation (ft.; NAVD88)
Mean Higher High Water (MHHW)	**2.39**
Lower limit of high marsh (*Distichlis spicata* dominated)	2.20
Mean High Water (MHW)	**2.03**
Upper limit of *Spartina alterniflora* tall form and lower limit of intermediate and short form *Spartina alterniflora*	1.90
Lower limit of low marsh (*Spartina alterniflora* tall form)	0.00
Mean Low Water (MLW)	**-2.00**
Mean Lower Low Water (MLLW)	**-2.61**

In each placement area, the mean elevation of the marsh platform surrounding the pools was determined based on the topographic survey. Then, based on the selected target ecological elevations (Table 6), an elevation of approximately 6 inches above that elevation was chosen for both the pools and marsh plain in each area. This increase in elevation would ensure that the enhanced marsh would be higher than the surrounding areas, facilitating drainage off the site to avoid waterlogging of the sediments and vegetation.

Table 6. Target Ecological Elevations (feet NAVD88) for Placement Areas at Avalon					
	Avalon Placement Areas				
	A	**C**	**D**	**E**	**F**
Target Ecological Elevations (ft.; NAVD88)	2.50	2.11	2.50	1.89	2.50

At Avalon, two months prior to design, water-level loggers were installed in wells on the marsh and in a tidal creek. NOAA VDatum[8] program was used on site-specific data combined with long-term data from tide gauges in Atlantic City (NOAA 2012; Table 6).

Fortescue: The project involved the enhancement of high and low marsh, a coastal dune, and a natural beach. Biological benchmarks were chosen to represent each type of marsh habitat and were evaluated to determine the upper and lower elevation tolerances for the target plant communities. The biological benchmarks were then used to select the target ecological elevations. In general, the upper elevation of the target plant community was used as the target ecological elevation. In addition, it was important to keep these elevations below those at which *P. australis* would colonize the site. To increase ecosystem resilience and habitat diversity, enhancement in some areas converted the existing habitat into another habitat, which was the case for creating high marsh and restoring the dune.

Biological benchmark data were collected at 33 locations on this site prior to the placement of dredged material. A range of plant species (*S. alterniflora*, *I. frutescens*, *D. spicata*, and *P. australis)* exhibited low, intermediate, and high vigor, and the benchmarks were summarized into vegetation zones (Table 7). In January 2015, a tide gauge was installed in Fortescue Creek to collect baseline data. Because the data of the tide range on-site were from a relatively short time span (five months), data from other tide gauges were also considered during the design process. However, just as in the Avalon Phase 2 project, the tide information used to set the target dredged material placement and ecological elevations was taken from the NOAA VDatum (Table 7).

For the Fortescue dune restoration, no biological benchmark data were used in the design. The restoration project was designed to create a more stable dune that would protect the marsh from the high wave energy in Delaware Bay. The original dune crest elevation was designed to be +6 feet NAVD88 with a 5:1 (horizontal to vertical) slope. This plan had to be modified because the shoreline eroded during the time between the initial design and construction. The modified design had a dune crest elevation of 10 feet NAVD88 with a 4:1 slope.

For the Fortescue beach restoration, no biological benchmark or water level data were used in the design. An 80-foot-wide, 5-foot-high (NAVD88) berm was designed for the marsh-beach interface (landward edge of the beach). From the berm waterward, sand was placed at an approximate slope of 15:1 (horizontal to vertical). The entire beach restoration area was in the intertidal zone.

[8] https://www.vdatum.noaa.gov/about.html

Table 7. Biological Benchmark Range Summaries, Tidal Datums, and Target Placement Elevations for the Fortescue Marsh Enhancement Project		
Vegetation/ Tidal Datum	Lower Limit (ft.; NAVD88)	Upper Limit (ft.; NAVD88)
High Tide Level (HTL)		**4.53**
Upper elevation of high marsh target placement elevation range		4.00
Phragmites australis	2.29	3.72
***Spartina alterniflora* tall form**	-0.75	3.69
***S. alterniflora* intermediate form**	2.18	3.69
Iva frutescens	3.18	3.65
High marsh	2.47	3.35
Lower elevation of high marsh and upper elevation of low marsh target placement elevation range		3.30
***S. alterniflora* short form**	2.47	3.08
Mean Higher High Water (MHHW)		**3.08**
Mean High Water (MHW)		**2.66**

Design Step 2: Topographic Survey

Baseline topographic surveys were collected at all sites except the ENH. These data were used in combination with biological benchmarks and tide range data to design the Avalon Phase 2 and Fortescue projects.

The topographic data were collected using permanent transects established at intervals of at least 50 feet, spanning the entire project area and the control areas. Within each project site, the limits of the areas to be surveyed were determined based on the results of Phase 1: Site Identification and Placement Area Selection, which established the potential treatment areas. The topographic surveys were conducted by NJ-licensed professional land surveyors using RTK-GPS survey equipment to capture point-by-point data with both horizontal (x, y) and vertical (z) information assigned to each point (horizontal and vertical accuracies were set at 0.1 feet). Qualitative descriptors for each point were also identified to generate topographic base maps that contained identifying information for the surface features, such as pools, platforms, channels, top of the bank, and bottom of the bank. The density of data points varied depending on the accessibility of the marsh. For example, because there was standing water in the pools and working conditions were unsafe, they were not surveyed in as much detail as the marsh platform, which was more accessible.

Ring Island: The topography of the existing marsh enhancement area and the control area were surveyed, but the data were not used to inform project design because they were not available before the project was constructed. Baseline topographic data were not obtained from in the area where the ENH was sited. Topographic information, including LiDAR information, from available online sources was also reviewed; however, it was not deemed accurate enough for design purposes.

Avalon Phase 1: The existing topography was surveyed in 2014 for marsh enhancement areas A, B, and C and at the control areas, but the data were not used for project design purposes because they were not available prior to construction. Topographic information from available online sources, including LiDAR information, was also reviewed; however, it was not deemed accurate enough for design purposes.

Avalon Phase 2: The existing topography was surveyed in July and August 2015. Some pools could not be surveyed because the conditions were too dangerous to traverse on foot. Because of this lack of data, some generalized assumptions were made about the depth of the pools. Project design was driven primarily by three factors related to site topography: (1) specific dredged material placement areas were selected in Phase 1, (2) a specified (and potentially limiting) volume of sediment was available to be dredged for this project and (3) the volume of dredged material was needed to achieve the target ecological elevation in each dredged material placement area. To aid in the design, estimates of the volume of dredged material needed in each placement area were made using the topographic data and observations of the marsh platform surrounding the placement areas.

Fortescue: Topographic surveys were performed in 2015 by the dredging team. To estimate the volume of dredged material needed for each of the three project components (marsh, beach, and dune restoration) the data from these surveys were used along with data for the distribution of grain size in the sediment to be dredged. Because a portion of the shoreline along the existing dune was eroded by a storm in January 2016, an additional topographic survey of the dune was completed prior to the dune restoration.

Design Step 3: Review Design Constraints

The designs of the Ring Island, Avalon, and Fortescue marsh enhancement projects were closely coordinated with the design and implementation of the associated dredging projects. A variety of potential site-specific constraints were considered regarding the design of each project, including:

- the distance between the dredging site and the dredged material placement areas,
- practical dredged material spraying and/or pumping distances,
- existing marsh elevations in relation to the location of tidal creeks, pools, pannes, and other potential obstacles to site access, as well as the need to place and move the dredge discharge pipe on the marsh,
- tidal creeks in the marsh,
- the need to minimize adverse impacts to the marsh from the use of heavy construction equipment,
- the volume of sediment to be dredged and its estimated bulking factor,
- the grain size distribution and chemical characteristics of the sediment to be dredged and the existing marsh surface sediment, and
- project-specific scheduling limitations.

To varying degrees, these factors interacted to affect how and where the sediment was used for habitat enhancement.

The goal of the design process was to develop feasible projects that focused on the delivery and placement of the dredged material to achieve the desired marsh enhancement objectives while minimizing both dredging costs and construction-related damage to the marsh. Potential obstacles to marsh access and positioning the dredge discharge pipe on the marsh were identified and addressed.

The distance between the dredging site and the dredged material placement areas was a design constraint that was addressed mostly during the Phase 1: Site Identification and Placement Area Selection and was a problem only for the Avalon Phase 2 project (discussed below). In general, the dredging projects were located within typical hydraulic dredging pumping distances of the marsh enhancement sites, and therefore booster pumps were not needed.

The grain size of the dredged material and obstacles such as tidal creeks and large pools can limit where the outlet pipe can be placed and moved on the marsh. The grain size of the dredged material affects how it will move and settle as it is placed. In general, the greater the proportion of silt and clay, the farther the dredged material will travel across the marsh; the longer it will take to settle, dewater, and consolidate; and the more even the application will be. The grain size of the dredged material will affect the number and locations of the dredge discharge pipe, which is further affected by the limited spraying and pumping distances.

One of the objectives of the projects was to maintain existing tidal creeks. To identify all the regulated channels and ditches on the marsh at each project site, the team reviewed the New Jersey Tidelands Claim Map. To avoid encroaching on Tidelands claim areas, general project limits-of-disturbance and limits-of-dredged-material-placement were established. The design and placement of perimeter containment was also based, in part, on the location of these creeks. To minimize the formation of new pools, target placement elevations should be high enough to ensure positive drainage off the marsh platform.

A dredged material slurry is the mixture of sediment and water transported in a pipeline by a hydraulic dredge. The sediment from a navigation channel increases in volume as it is dredged and mixed with water. This estimated bulking factor was used to determine the volume of dredged material needed to achieve the target ecological elevations. The typical percentage of solids (weight of dry solids divided by weight of wet slurry) varies in a hydraulic pipeline, but usually ranges from 10% to 20%; this variability causes errors in the estimates of the volume of dredged material needed.

Sediment composition, including grain size distribution and chemical characteristics, was a key factor in designing the Avalon and Fortescue projects; it was not a design consideration at Ring Island, where the dredged material was 96% fine sand. Hydraulically dredged sand (coarse-grained dredged material) will quickly settle and accumulate near the outlet of the dredge discharge pipe, leading to uneven placement depths and requiring the pipe to be frequently moved. In contrast, finer grained (predominantly silt and clay) dredged material will disperse farther from the pipe across the marsh. Thus, grain size of the dredged material is a prime consideration when selecting placement areas and enhancement activities.

One of the design objectives was to use dredged material that had physical and chemical characteristics similar to the existing marsh surface sediment. From a physical standpoint, the grain size distribution of the sediment to be dredged from the channel was integral to the overall designs of these three pilot projects. The site-specific importance of sediment composition to project design is discussed in more detail in Phase 3: Permitting.

The size and type of marshes selected for enhancement were influenced, in part, by two scheduling factors: (1) seasonal restrictions ("dredging windows") for dredging and material placement to minimize potential impacts to species of concern, and (2) availability of dredge contractors. At each site, project construction was planned to start soon after marsh nesting birds had fledged (typically, September) and needed to be completed by the following December to March to prevent potentially negative impacts to winter flounder, anadromous fish, and other species of concern. It was also highly desirable to complete construction in one continuous work period because it is expensive to re-mobilize dredging equipment. In addition, the TLP method is generally slower and pumps fewer cubic yards of sediment per day than other types of dredged material management operations, such as placement in a CDF. Combining marsh enhancement projects with other types of habitat projects with higher production rates, such as the beach nourishment and dune restoration at Fortescue and the ENH at Ring Island, allowed more sediment to be dredged from the navigation channels during the available "dredging windows."

The following examples show how these constraints impacted the pilot projects.

Ring Island, TLP: The two major design constraints for this project were the maximum distance (150–200 feet) that the dredged material could be sprayed from the marsh edge to the placement areas and the sandy texture (96% fine sand) of the dredged sediment. This sediment was deemed suitable for construction of the colonial shorebird ENH (discussed below). However, the project team was unsure how sand would spread when it was sprayed on the marsh or how the marsh sediment, which is composed of highly organic and silty soils, would respond to placed sand. So, the team conducted a test using a small volume of sandy dredged material to determine whether and how far it could be sprayed onto the marsh platform and whether its placement would enhance the marsh.

In addition, USACE-OP's dredging contractor built and modified the dredged material spray equipment during placement to improve its performance. Access to and across the marsh site was not a problem and no heavy equipment was used on the marsh. The dredged material was homogenous (96% fine sand), but only a limited volume was designated for TLP on the marsh.

The selection of the TLP site at Ring Island was also heavily influenced by environmental timing restrictions. The dredge contractor was on a fixed schedule, but birds were still nesting in the selected placement area during the planned construction time, so new sites had to be selected. This limited timeframe also influenced the decision to use most of the dredged material to create a sandy ENH.

Ring Island, ENH: The TLP and ENH sites had permit conditions to minimize dispersal of the dredged material from the placement area, particularly into creeks, and to otherwise minimize impacts to the surrounding marsh. To address these conditions, the TLP areas were set back from creeks and the heavy machinery used to grade the ENH site was kept within the footprint of the ENH.

Avalon Phase 1: Chemical analysis of the sediment to be dredged from the NJIWW and proposed for use in marsh enhancement showed the presence of contaminants in some samples, particularly dioxins and furans, at concentrations greater than the existing marsh surface sediment in dredged material placement areas A, B, and C. In addition, a limited time remained in the USACE-OP dredging contract to complete the work. These two factors reduced the scope of the Avalon Phase 1 project to dredging a limited section of the NJIWW that had physical and chemical sediment characteristics comparable with those in dredged material placement areas A and C (see Phase 3: Permitting).

Another consideration at Avalon was the limited distance (150–200 feet) that the dredged material could be sprayed from the marsh edge; however, the finer-grained material was expected to fill pools and pannes and to disperse throughout placement areas A and C. Site access was not a problem, and no heavy equipment was used on the marsh.

Avalon Phase 2: This marsh had many pannes and pools that affected access and placement of the dredge pipe. This project design constraint was integrated with the sediment composition design constraints discussed below. In addition, containment was needed to allow sediment to reach the target dredged material placement elevations and prevent sediment from running into creeks.

In the Avalon Phase 2 project, the grain size of the dredged material played a major role in the design. Given the grain size variability of both the marsh surface sediment and the sediment to be dredged from the NJIWW, one objective of the design was to place the dredged material on areas of the marsh with similar grain size.

The chemical characteristics of the dredged material also greatly influenced the design of the Avalon Phase 2 project. The USACE-OP's initial testing of the sediment to be dredged from the NJIWW near Avalon found dioxins and furans at potential levels of concern in some of the sediment. To further evaluate the potential to use the dredged material for marsh enhancement, the project team tested the marsh surface sediment in the placement areas and also tested samples of the sediment to be dredged from the NJIWW. The samples were analyzed for dioxins, furans, PCB congeners, pesticides, and metals.

The dredged material to be used in each placement area was required to have contaminant concentrations similar to or less than those of the existing marsh surface sediment. For this project, placing such dredged material on the Avalon marsh posed a minimal potential risk to human health and the ecosystem. The suitability of the dredged material for marsh enhancement was also evaluated considering the Effects Range-Low (ER-L) and Effects Range-Medium (ER-M) Sediment Quality Guideline values of Long et al. (1995). The testing results indicated that the range of contaminant concentrations in the sediment of the Avalon marsh and the NJIWW were similar and were usually less than their ER-L values. Further, it was decided that the more contaminated dredged material would be placed on areas of the marsh with existing sediment of similar concentration. See Phase 3: Permitting.

The placement of dredged material on placement areas A, C, D, E, and F was further limited by the volume of sediment, plus an estimated bulking factor of two in each reach of the NJIWW placement areas. The contract expired before the dredging team finished placing sediment in all placement areas, and the team was unable to complete the dredging.

Fortescue: The main factor affecting the design of the Fortescue marsh enhancement project was the heterogeneous composition of the sediment to be dredged from the channel. Although sediment contamination was not a problem, as the sediment to be dredged was overall less contaminated than the marsh surface sediment, its grain size limited the amount of predominantly fine-grained dredged material that was available for marsh enhancement. This reduced the area of marsh that could be enhanced and prompted the team to design the dune and beach restoration components that would accept the sandier portions of the channel sediment.

The NJ Tidelands Claim Map was used to set the limits for dredged material placement on the marsh and for the beach and dune project components. However, avoiding and protecting Tidelands-regulated channels and creeks posed a challenge for the containment design.

Fortescue Beach and Dune Restoration: Design of the beach restoration component followed typical beach nourishment guidelines. A major design constraint for the dune restoration component was to minimize encroaching upon and impacting the surrounding salt marsh during construction. This constraint became more significant when the team needed to redesign the dune after a January 2016 storm eroded part of its shoreline.

In addition to sediment grain size, the dune and beach restoration project components were influenced by biological timing restrictions and the need to dredge the entire reach of the Fortescue Creek channel to make the project cost-effective for NJDOT-OMR.

Design Step 4: Develop Target Elevations, Grading, and Planting

The target dredged material placement elevations were based on the estimated dredged material bulking factor and anticipated rates of consolidation of the dredged material after dewatering. The team assumed that the predominantly fine-grained dredged material to be placed on the marsh would likely have a bulking factor of two and would consolidate by approximately 50% after dewatering.

The project designs for the marsh enhancement projects did not include any provisions for post-construction grading of the placed dredged material. The Fortescue dune and beach restoration components and the Ring Island ENH project component were not expected to consolidate by 50% due to the sandy nature of the dredged material. To reach the specified target ecological elevations, the placed dredged material was graded during and after construction.

Perimeter containment was the primary sediment erosion and control technique evaluated and designed for all the projects, except the Ring Island marsh enhancement and Fortescue beach nourishment projects, where containment was not needed. To reduce sediment release into government-protected waters, some locations were identified where containment could be placed. These were typically low-lying areas where water concentrated for discharge off the marsh platform. During the design process, several containment products were evaluated. To avoid removing containment after the dredged material was placed, the marsh team preferred containment products that were composed of biodegradable materials. Containment products were available in a limited set of diameters and lengths, which were not necessarily consistent with the target dredged material placement elevations and the existing marsh elevations. As a result, in some locations, containment was considerably higher than the target dredged material placement elevation.

Containment design typically included a plan for securing the containment through staking and trenching and for stacking containment in areas where the channels, pannes, or pools were exceptionally deep. One problem was obtaining the quantity of containment needed for the Avalon Phase 2 and Fortescue projects. The team had to order it months in advance for the supplier to produce such large quantities. This was one reason why Filtrexx SiltSoxx™ was used instead of coconut-fiber logs at Fortescue.

Technical specifications associated with the site plan were prepared during Phase 4: Contract and Bidding and were included on the engineering drawings prepared for the projects.

Avalon Phase 1 Marsh Enhancement: The analysis of sediment for the Avalon Phase 1 project revealed that the portion of the NJIWW to be dredged near Shark Island had a much lower percentage of sand (34%) than that used at Ring Island (96%). This was expected to provide a more even and dispersed application of the dredged material. Given the high percentage of silt (49%) in the dredged material, some containment was installed to minimize the dispersal of this finer-grained sediment from the placement areas. The project team did expect, however, that the pools into which the dredged material would be sprayed would retain much of the material. The containment structures consisted of coconut-fiber logs, which are made of baled coconut fibers that slow and filter the water passing through them.

Avalon Phase 2 Marsh Enhancement: In general, target dredged material placement elevations were approximately 12 inches above the existing marsh elevation. The team expected the placed dredged material to settle and consolidate, resulting in an elevation of approximately 6 inches across most of the site, which would achieve the target ecological elevations. The selected target dredged material placement and ecological elevations for each placement area can be seen in Table 8.

Table 8. Target Dredged Material Placement Elevations and Ecological Elevations for Placement Areas

Placement Area	**Placement Elevation** (ft. NAVD88)	**Ecological Elevation** (ft. NAVD88)
A	3.00	2.50
C	2.61	2.11
D	3.00	2.50
E	2.39	1.89
F	3.00	2.50

After their experience with the Avalon Phase 1 project, the team decided that in order to keep the dredged material within its boundaries as much as possible, each dredged material placement area would be completely enclosed by containment. To achieve the target dredged material placement elevations, biodegradable coconut-fiber logs of various diameters were used for containment. At each placement area, the arrangement of containment was designed based on the local topography. Special emphasis was placed on identifying low points along the placement area perimeter toward which the slurry was predicted to flow. The containment slowed and filtered the slurry, allowing the sediment to fall out of suspension, and resulted in relatively clean water flowing through or over the containment.

A general layout of the dredge pipe from the NJIWW to each placement area is shown in Figure 18. The layout directed dredged material from each reach of the NJIWW to areas of the marsh with similar chemical characteristics to meet the “like-on-like" permit conditions. This approach minimized the distance the dredge pipe had to be pulled into the marsh and the number of times the pipe had to be moved during placement.

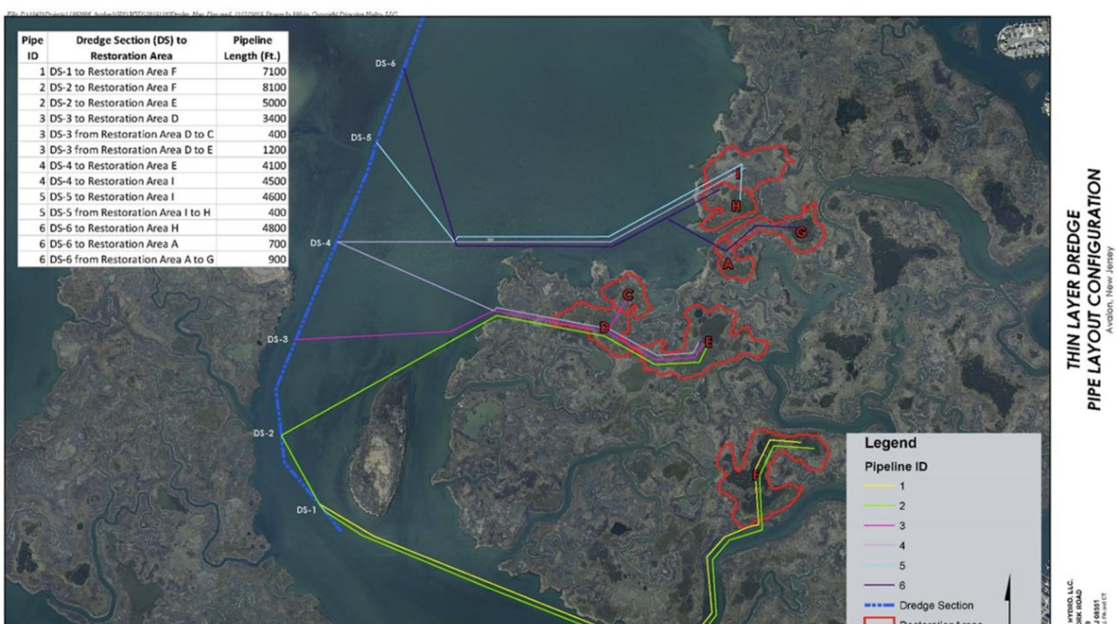

Figure 18. This figure shows the planned dredge pipe layout for the Avalon Phase 2 marsh enhancement. Only one pipe was used, so each pipeline ID represents a repositioning of the pipe.

Fortescue Marsh Enhancement: The selected target dredged material placement elevation was 3.3 feet (NAVD88), which was approximately 9 inches (on average) higher than the existing marsh platform. The team expected the dredged material to settle and consolidate, resulting in a final height of approximately 4–6 inches above most of the marsh. This placement depth was consistent with the target ecological elevation and would result in the desired low- and high-marsh plant communities based on biological benchmarks.

Each dredged material placement area was surrounded by a double row of non-biodegradable, but photodegradable, Filtrexx SiltSoxx™ that required removal once the dredged sediment stabilized. Primary (interior) containment consisted of 12-inch diameter Filtrexx SiltSoxx™. A secondary containment (6-inch diameter Filtrexx SiltSoxx™) was installed approximately 7 feet outside the primary containment. A minimum 50-foot buffer from the containment was established around larger creeks, and a 10-foot buffer was established around smaller internal creeks. Special emphasis was given to identifying low points along the placement area perimeters toward which the slurry was predicted to flow and where additional or stacked containment was needed. The containment was designed to slow and filter the slurry, allowing the sediment to fall out of suspension and resulting in relatively clean water flowing through or over the containment.

The dredge discharge pipe layout for placing dredged material on the marsh accounted for the grain size of the dredged material. In general, it was assumed that the coarser-grained sand would settle out more quickly than the silt and clay, which would disperse farther from the pipe outlet across the marsh. Therefore, the pipe layout was designed with a central “trunk line” with "branches" extending out from the trunk into the center of each dredged material placement area (Fig. 19). Multiple discharge points were positioned so that the sand fraction would accumulate to high marsh elevation and the finer-grained dredged material would disperse to the outer portions of the placement areas, where it would settle out of suspension. The size of the placement areas and the volume of material that could be placed in them were determined by the dredged material characteristics and existing site topography. In addition, at each discharge point, an on–off valve would allow continuous dredging and placement. In theory, this would more likely achieve the target dredged material placement elevations and allow the project to be completed within one season, eliminating the need to remobilize and finish the project the following year. However, in practice, the system did not operate as planned (see Phase 5: Construction).

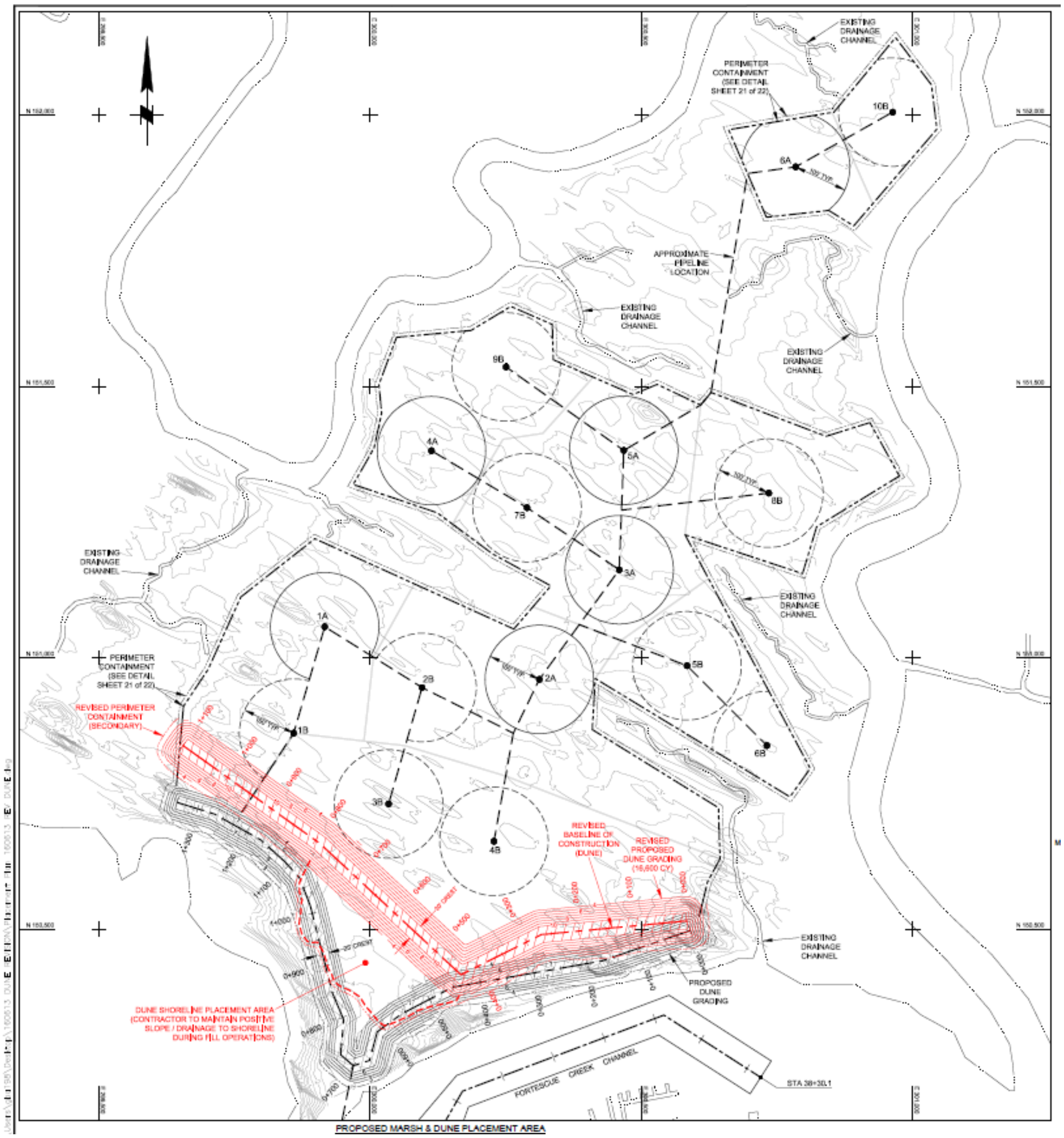

Figure 19. *This was the original design of the dredge discharge pipe system for the Fortescue marsh enhancement project component. The dune design is in red. The dashed lines represent the pipe layout across the marsh. Circles represent discharge areas where sand was expected to create high marsh. Black dash and dotted lines represent containment around placement areas.*

Fortescue Dune Restoration: The dune restoration component was designed to protect a municipal marina and the adjacent marsh from storms and waves. The height of the dune was established to minimize overtopping by waves. Target ecological elevations were not developed for the dune restoration project, although the constructed elevations were used to develop the planting plan for the dune. The dune was designed to allow the dredged sand to dewater and then graded to reach target elevations and desired slopes. A major design consideration was the need to minimize the impacts from dune construction to the adjacent marsh. To help stabilize the dune and minimize the dispersal and erosion of the placed dredged material, the dune footprint was enclosed by a single line of staked Filtrexx SiltSoxx™.

Phase 3: Permitting

This section summarizes the NJDEP and USACE regulatory processes as they were applied to the Ring Island, Avalon, and Fortescue projects. The Division of Land Use Regulation (NJDEP-DLUR) reviewed the state permit applications, and the USACE-Philadelphia District Regulatory Branch (USACE-RB) reviewed the federal permits applications. Pursuant to the New Jersey Coastal Zone Management (CZM) Rules (N.J.A.C. 7:7), the NJDEP regulates wetlands, dredging, and the management of dredged material. Specifically, Appendix G of the CZM Rules addresses *The Management and Regulation of Dredging Activities and Dredged Material in New Jersey's Tidal Waters*. Appendix G was developed to reflect the NJDEP policy that dredged material is a resource and that acceptable beneficial uses of dredged material should be encouraged and given priority over the disposal of dredged material.

Dredging projects not conducted by the USACE-OP (i.e., Fortescue) require permits from both the NJDEP-DLUR and the USACE-RB. A Waterfront Development Permit is required by the NJDEP, together with the associated Federal Consistency Determination and Clean Water Act Section 401 Water Quality Certificate (WQC). In areas where the dredged material is to be used beneficially, an Acceptable Use Determination (AUD) for the dredged material is also required from the NJDEP. The federal permits were issued pursuant to Section 404 of the Clean Water Act (33 U.S.C. 1344) and Section 10 of the Rivers and Harbors Act of 1899 (33 U.S.C. 403).

CZM General Permit 24 (N.J.A.C. 7:7-6.24; formerly GP29) addresses habitat creation, restoration, enhancement, and living shoreline activities. This general permit applies to a habitat project, not to the associated dredging activities, and does not speak to the appropriateness of using dredged material to meet the habitat project objectives.

Dredging projects undertaken by the USACE-OP (i.e., Ring Island and Avalon) must receive a Federal Consistency Determination and a Section 401 WQC from the NJDEP; the USACE-OP applies to the NJDEP for these regulatory approvals. Because the USACE cannot issue permits to itself for its dredging projects, it undertakes a rigorous public Environmental Impact Assessment that evaluates projects for consistency with Section 404(b)1 of the Clean Water Act.

In order to address its National Environmental Policy Act (NEPA) requirements, in July 2014 the USACE issued an Environmental Assessment (EA) for "Channel Maintenance and Beneficial Use of Dredged Material Projects – New Jersey Intracoastal Waterway – Ocean and Cape May Counties, New Jersey." This NEPA EA evaluated the Ring Island and Avalon dredging and habitat enhancement projects. The USACE NEPA requirements for the Fortescue dredging and habitat enhancement projects were addressed as part of the Section 10 and Section 404 individual permit regulatory review of these projects.

For the three pilot projects (Ring Island, Avalon, and Fortescue), both the NJDEP and USACE regulatory review processes were coordinated and iterative. Prior to formally submitting permit applications to the NJDEP and USACE, the NJDEP-DFW worked with both agencies (as well as the U.S. Fish and Wildlife Service, NOAA, and the NJDOT-OMR) to develop the projects that met all the potential regulatory requirements. NJDEP-DFW started this coordinated process by requesting a Joint Permit Processing (i.e., pre-application) meeting with the USACE and NJDEP.

The proposed habitat enhancement projects had to meet two critical requirements:

- The regulatory agencies had to determine that the habitat was structurally or functionally in need of restoration or enhancement.
- The beneficial use of dredged material had to address the causes of stress to the habitat (i.e., provide ecological uplift).

If the regulatory agencies are satisfied that the permit applicant has demonstrated the habitat is stressed, then the beneficial use of dredged material can be evaluated and the habitat enhancement project can be designed to meet its objectives, consistent with all applicable regulations. The evaluation of dredged material acceptability includes consideration of both its physical and chemical characteristics (including contaminant concentrations), which requires a comprehensive sediment sampling and analysis plan (discussed below in Sediment Sampling and Testing).

The major components of the permit application submitted to NJDEP and USACE for the three pilot projects were:

- Analyses and evaluations, including a variety of qualitative and quantitative data, to support the conclusion that the proposed marsh enhancement/dredged material placement areas at each project site were stressed and needed enhancement or restoration
- A dredging plan identifying the source and volume of sediment to be dredged and how the sediment would be dredged and placed on the project sites, including the type and size of equipment to be used, dredge pipeline layout, etc.
- A habitat enhancement plan identifying the source and volume of dredged material to be placed, the target dredged material placement elevation, and the ecological elevation in the habitat enhancement areas. Habitat enhancement objectives and best management practices were developed to minimize potential adverse impacts of dredged material placement.
- A Coastal Zone Management Rules Compliance Statement
- Dredged material and marsh surface sediment data and evaluation (physical characteristics, bulk sediment chemistry, elutriate contaminant concentrations)
- A monitoring program for use during and after construction
- An adaptive management plan for use during and after construction, including provisions for planting and other methods to mitigate potential adverse impacts

NJDEP and USACE Permits

The dredging for the Ring Island and Avalon projects was conducted by the USACE-OP, which applied to NJDEP-DLUR for a Federal Consistency Determination and Section 401 Water Quality Certificate. The marsh enhancement and ENH creation components were managed by the NJDEP-DFW, which applied to NJDEP-ODST for the GP29 and Acceptable Use Determination for these projects (Table 9).

For the Fortescue project, the USACE-RB considered the dredging and the material placement to be one combined project requiring a single permit applicant. The dredging and dredged material placement were managed by NJDOT-OMR, and the marsh enhancement and dune and beach restoration components were managed by NJDEP-DFW. After much interagency discussion, NJDEP-DFW applied for and received the required permits – Coastal GP29 (currently redesignated as Coastal GP 24)/AUD – from the USACE-RB for both the dredging and dredged material placement (marsh, dune, and beach) components. NJDOT-OMR applied for and received a Waterfront Development Permit for the dredging projects (Table 9).

After the NJDEP and USACE permits were issued, storms in the winter of 2015–2016 eroded a section of the Fortescue Creek shoreline within the footprint of the dune restoration component. As a result, the dune restoration had to be redesigned and relocated, and the permits from both NJDEP-ODST and the USACE-RB had to be modified.

Ring Island: Although NJDEP-DLUR issued the GP29 for this project within two days after the initial application was submitted, the project development and regulatory review timeframes for the marsh enhancement and shorebird ENH projects is better represented by the USACE-OP application process (to NJDEP-ODST) for the CZM Consistency Determination and Section 401 WQC for the dredging (Table 9). Throughout the summer of 2014, multiple draft plans for dredging, dredged material placement, marsh enhancement, and ENH creation were developed by NJDEP-DFW and the USACE-OP, reviewed by NJDEP, and revised by NJDEP-DFW and the USACE-OP. Ultimately, NJDEP-DFW and the USACE-OP formally submitted the final permit applications to NJDEP-ODST, which approved them on August 7, 2014.

The dredged material to be placed on Ring Island was 96% fine sand, which NJDEP considers unlikely to be contaminated at levels of concern, so it was excluded from additional testing for contaminants (see Appendix G-Chapter III-C of the New Jersey Coastal Zone Management Rules, N.J.A.C. 7:7).

Table 9. State and Federal Permits Issued for the Ring Island, Avalon, and Fortescue Projects

<table>
<tr><th>Project</th><th>NJDEP*</th><th>USACE**</th><th>Notes</th></tr>
<tr><td>Ring Island Marsh and Elevated Nesting Habitat</td><td>● GP29 and AUD (combined); CZM Consistency and Section 401 WQC</td><td>Not required</td><td rowspan="2">● Dredging and dredged material placement conducted by USACE
● NJDEP GP29 and 24 permits issued to NJDEP-DFW
● NJDEP CZM and Section 401 WQC issued to USACE</td></tr>
<tr><td>Avalon Marsh</td><td>● 2014 Phase 1 Project – GP29 and AUD; CZM Consistency and Section 401 WQC
● 2015 Phase 2 Project – GP24 and AUD; CZM Consistency and Section 401 WQC</td><td>Not required</td></tr>
</table>

Fortescue Marsh Fortescue Beach Fortescue Dune	● Combined GP29 and AUD, CZM Consistency and Section 401 WQC issued to NJDEP-DFW for habitat enhancement ● Combined Waterfront Development Permit, AUD, CZM Consistency and Section 401 WQC issued to NJDOT-OMR for the dredging and material placement	Combined Individual Section 404 permit for dredging and habitat enhancement issued to NJDEP-DFW	● Dredging and dredged material placement conducted by NJDOT-OMR ● Dune restoration redesign and permit modification required due to shoreline erosion after permit issued ● Adaptive management plan required as a condition of the USACE permit

* NJDEP: New Jersey Department of Environmental Protection (state permit)

** USACE: U.S. Army Corps of Engineers (federal permit)

Note: During the project, the NJ CZM regulations were revised and NJ GP29 was renumbered to be GP24.

Avalon Phase 1: The time available to implement this project, from fall 2014 to winter 2015, was limited by the USACE-OP dredging schedule, because a number of dredging projects needed to be completed that winter. In addition, the results of testing the sediment in the channel to be dredged and the sediment of the marsh surface in placement areas A, B, and C raised concerns (see Phase 2: Project Design [Step 3: Review Design Constraints] and Sediment Sampling and Testing below). It took several weeks to design the Avalon Phase 1 project, develop the required documentation, and submit the final permit applications to NJDEP-ODST. The NJDEP-ODST review of the permit application package for this project, which included coordination with other NJDEP programs to ensure consistency with the CZM Rules, took approximately seven weeks.

Avalon Phase 2: It took approximately four months to design the Avalon Phase 2 project, develop the required documentation, and submit the final permit applications to NJDEP-ODST. To ensure consistency with the CZM Rules, the NJDEP-ODST review of the application included coordination with other NJDEP programs and was completed in approximately seven weeks.

Fortescue: As previously discussed, it took time to develop the interagency agreement that allowed NJDEP-DFW to apply for the required permits from the USACE-RB for both the dredging and habitat enhancement. Designing the three components of the Fortescue project and the associated dredging project, developing the required documentation, and submitting the final permit applications to NJDEP-ODST and the USACE-RB took about three months. The NJDEP-ODST review of the Waterfront Development Permit application for the Fortescue dredging project was completed in approximately two months, while review of the GP29 application for the three associated dredged material beneficial use projects (which included more extensive coordination with other NJDEP programs to ensure consistency with the CZM Rules) was completed in approximately three months. The USACE-RB review of the application for a combined dredging–habitat enhancement Section 404 individual permit was completed in about three and a half months. To evaluate the potential impacts of these alternatives to the adjacent marsh, the redesign of the dune restoration component considered a variety of alternatives and an additional topographical survey. This work and the development of the documentation to apply for a permit modification was completed in approximately six weeks. Since the dune redesign was closely coordinated with NJDEP-ODST and the USACE-RB, these agencies completed their review of the request to modify the permits relatively quickly, in approximately one month.

Sediment Sampling and Testing

To evaluate the suitability of the sediment for the various habitat enhancement and restoration projects, the team tested the sediment to be dredged. Both physical and chemical (including contaminant concentrations) characteristics were tested, which required the implementation of a comprehensive Sediment Sampling and Analysis Plan approved by NJDEP-ODST. Likewise, to ensure that the placed dredged material would have similar physical and chemical characteristics, samples of the marsh surface sediment were tested at each project site, except Ring Island.

Ring Island: The test of the sediment to be dredged from the NJIWW revealed that it was comprised of 96% fine sand; thus, testing for contaminants was not required. In addition, because the marsh enhancement project was a pilot to evaluate whether such coarse-grained sandy dredged material could be sprayed onto the marsh, the Ring Island marsh surface sediment was not sampled and tested.

Avalon Phase 1: Both the sediment to be dredged from the NJIWW and the marsh surface sediment in placement areas A, B, and C were predominantly fine-grained silt–clay. In addition, both contained several contaminants at different levels of concern. After extensive analyses, NJDEP-ODST determined that the sediment from one section of the NJIWW had contaminants, including dioxins and furans, at similar concentrations to those in the surface sediment of dredged material placement areas A, B, and C. Thus, the project team decided to limit dredging for the Avalon Phase 1 project to that one section of the channel and to limit marsh enhancement/dredged material placement to placement areas A and C.

Avalon Phase 2: Both the sediment to be dredged from the NJIWW and the marsh surface sediment in placement areas A, C, D, E, and F were predominantly fine-grained silt–clay. In addition, both contained several contaminants at different levels of potential concern. The main factor affecting the Avalon Phase 2 project was the presence of this suite of contaminants, particularly dioxins and furans, in both the sediment to be dredged from the NJIWW and the marsh surface sediment. After extensive analyses, NJDEP-ODST determined that the sediment from multiple sections of the NJIWW contained contaminants (including dioxins and furans) at similar concentrations to those in the surface sediment of placement areas A, C, D, E, and F. The sediment from each section of the channel was directed to that placement area (A, C, D, E, or F) with similar contaminant concentrations.

Fortescue: The sediment from both Fortescue Creek channel and the marsh surface were analyzed for physical and chemical characteristics. The dredged material was found to be heterogenous in grain size with distinct areas of predominantly coarser-grained sandy and finer-grained silt–clay material. Overall, contaminant concentrations in the sediment to be dredged were lower than those in the Fortescue marsh surface sediment, so contaminants were not a problem. The dredging and habitat enhancement projects were designed to use the finer-grained dredged material on the marsh and the coarser-grained dredged material on the dune and beach restoration components.

Permit Conditions

A significant factor impacting the dredging and dredged material placement projects was timing restrictions due to ecological factors. To minimize the adverse impacts to fish, shellfish, and birds, these "dredging windows" were included as permit conditions.

Ring Island: Dredged material placement was limited to time periods when colonial shorebirds were not actively nesting at the proposed placement areas and was subject to consultation with the NJDEP Endangered and Nongame Species Program. Nesting birds were present into August 2014 at the southern and western preferred placement locations (Fig. 9). So rather than not implementing the Ring Island projects in 2014, NJDEP-DFW decided to use the selected sites on the northern end of Ring Island for the dredged material marsh enhancement and ENH projects. Additional practical limitations to implementing the projects included the original two-year project implementation timeframe of the NFWF grant and the dredging schedule and availability of the USACE-OP's dredge contractor.

Avalon Phase 1: No ecological timing restrictions were placed on the Avalon Phase 1 project. However, the project had to be completed in fall 2014/winter 2015 due to USACE-OP scheduling and contractual limitations with the dredge contractor (see Phase 2: Project Design [Step 3: Review Design Constraints]).

Avalon Phase 2: To minimize impacts to nesting ospreys (*Pandion haliaetus*), gull-billed terns (*Gelochelidon nilotica*), and common terns (*Sterna hirundo*), dredging and dredging material placement for the larger Avalon Phase 2 project were prohibited from April 1 through August 31. USACE-OP dredged during the winter of 2015–2016.

Fortescue: To protect several marine species, including winter flounder (*Pseudopleuronectes americanus*) and Atlantic sturgeon (*Acipenser oxyrhynchus oxyrhynchus*), dredging and dredged material placement were originally prohibited from January 1 through September 30. This limited dredging to October 1 through December 31 each year. As a result of ongoing review by the NOAA Fisheries, in 2016 the dredging and material placement prohibition for winter flounder was rescinded, reducing the restriction for dredging to April 15 through September 15.

Although the Avalon Phase 2 and Fortescue projects were designed to be completed within the allowable time periods specified in the permits, inclement weather and equipment problems affected the construction of these projects (see Phase 5: Project Construction).

Additional permit conditions included best management practices designed to limit the dispersal of the dredged material from the placement areas to (1) increase the probability of placing dredged material to the established target elevations and (2) protect the marsh, particularly creeks, outside the placement areas. In addition, a permit condition restricted dredged material placement when the placement areas were not covered by surface water (i.e., at lower tides). This could have had a significant impact on the dredging and dredged material placement, but in actual practice it did not.

As a condition of the permit for the Fortescue dredging/habitat enhancement project, the USACE-RB required an adaptive management plan and associated monitoring program. While NJDEP did not require a monitoring program for the Ring Island and Avalon Phase 1 projects, it did require monitoring of the Avalon Phase 2 and Fortescue projects. A comprehensive monitoring program was a major requirement of the NFWF grant and was implemented for all the projects (Phase 7: Project Assessment - Monitoring and Data Evaluation). Finally, an adaptive management approach was used throughout the projects.

Phase 4: Bidding and Contracting

The Ring Island and Avalon projects were completed as part of a contract that the USACE-OP awarded for maintenance dredging to remove critical shoals from the NJIWW following Hurricane Irene and Superstorm Sandy. A lease-of-plant contract was utilized whereby the dredge contractor bids required line items and then conducts work by priority assignment along the channel, paid by the day and not according to the specific quantity of sediment dredged. This type of contract allowed greater flexibility for the USACE-OP and the project team to adaptively manage dredged material placement on the marshes, with USACE-OP absorbing the costs of downtime.

The Fortescue beneficial use projects were managed by NJDOT-OMR. Its engineering contractors created the engineering and dredging design plans, while the construction specifications were prepared by the NJDOT-OMR design team. The NJDOT-OMR solicited bids for construction and the contract was awarded to a NJ-based dredging company. Under the NJDOT-OMR contract, the contractor was paid by the volume (cubic yard) dredged and placed and had very specific requirements for the dredging and material placement, which made adaptive management of the construction difficult.

Phase 5: Construction

After the marsh enhancement design was finalized and the permits for the dredging and marsh enhancement were obtained from the regulatory agencies, construction began. This phase varied somewhat among the sites, but for documentation purposes, it involves three stages: (1) pre-placement, (2) dredging and dredged material placement, and (3) post-placement.

The pre-placement stage included several phone calls and in-person meetings of the marsh team to discuss construction before the official pre-construction meetings. Discussions focused on pre-construction activities and site preparation. The subsequent pre-construction meetings included both the marsh team and the dredging team and covered the placement of dredged material on the marsh. Given that the marsh enhancement technique was new to the marsh team and that the dredged material placement technique was new to the dredging team, these meetings were a critical first step in the construction process. The other major component of the pre-placement stage was site preparation, which was site specific but generally involved installing containment, setting grade stakes, and staging the pipes for dredged material placement.

For all the projects, the dredging and dredged material placement stage (i.e., actual construction) consisted of the simultaneous hydraulic dredging of sediment from the channel, pumping the dredged material to the project site, and placing the dredged material onto the marsh. Tentative dredging and dredged material placement strategies were determined beforehand, but placement was predominantly performed using hands-on, real-time adaptive management. The keys to successfully implementing this stage of construction were (1) the marsh team's ability to constantly observe dredged material placement as it was happening, (2) clear communication between the marsh team and the dredging team, and (3) the ability to adjust the dredging and material placement during construction to achieve the target elevations. During dredged material placement, the marsh team had an inspector on the marsh and the dredging team had an inspector on the dredge. Communication between the teams occurred daily, and project status meetings occurred weekly.

The post-placement stage of construction was the short period immediately after cessation of dredging and placement. It involved a final inspection by representatives of both the marsh and dredging teams, clean-up of the project site, and as-built elevation surveys of the dredged material placement areas.

Ring Island Marsh Enhancement Project

This was the first marsh enhancement project implemented under the NFWF grant. The goal of the project was to test a method for placing a thin layer of sandy dredged material on to the marsh. The dredging team sprayed the material on the marsh surface in two areas, attempting to place homogeneous 3- or 6-inch thick layers. In addition, on a 1-acre section of marsh, an ENH was constructed for colonial shorebirds (Fig. 2). The dredged material came from a small stretch of the NJIWW maintained by the USACE-OP. The dredging and dredged material placement were implemented by a NJ-based dredging company overseen by the USACE-OP. The placement of dredged material on the marsh was overseen by the marsh team.

Ring Island Marsh Enhancement Project Construction Summary

Placement area: 0.89 acres (two areas)
Placement volume: 1,000 cubic yards
Placement depth: Average 6 inches
Sediment composition: 96% fine sand
Containment type: None
Distance from NJIWW to marsh edge: 2,000–3,000 feet
Dredge type: 14-inch (inside diameter of discharge pipeline) cutterhead dredge
Placement technique: Spray from discharge pipe mounted on a pontoon at the marsh edge
Shore construction machinery: None
Timing of placement: August 2014

Pre-placement: To communicate the project objectives and to refine the plans for dredged material placement, the marsh team and dredging team held a pre-construction meeting. Given the composition (96% fine sand) of the dredged material and topography of the marsh, the teams determined that containment was not needed.

Construction was originally scheduled for September 2014; however, dredging was moved to August to fit the USACE-OP dredging schedule for the NJIWW. This was a problem because, in August, laughing gulls (*Leucophaeus atricilla*) were still nesting on parts of the Ring Island marsh, and their chicks had not yet fledged. In response to this schedule change, the marsh team assessed the three areas for nesting chicks (Fig. 9) and selected the one area without chicks for marsh enhancement.

To prepare the site, the team marked the outer limits of the dredged material placement areas and installed grade stakes. Each grade stake was marked with a line to indicate the target elevations of 3 or 6 inches above the marsh surface.

Dredging and dredged material placement: During a few days in August 2014, the dredging and dredged material placement was completed. Sediment was hydraulically dredged from the NJIWW, transported as a slurry (a mix of sediment and bay water) and sprayed on the marsh (Fig. 20). The discharge end of the dredge pipe was mounted on a pontoon that was stationed at the edge of the marsh. The pipe was mounted at approximately a 45-degree angle to spray the dredged material in a high arc above and onto the marsh. The discharge pipe was also outfitted with a reducer, which narrowed the outlet diameter and increased the velocity of the slurry, allowing it to reach farther into the marsh.

Figure 19. *This photo shows the dredged material spray operation at the Ring Island marsh enhancement project.*

Almost immediately after placement of the dredged material began, the project team realized that simply spraying the slurry did not effectively spread the sand over the marsh. Initially, the dredge contractor tried to spread the material evenly by alternating between spraying the material and spraying water onto the same spot, but this did not accomplish the desired effect. Next, the dredge contractor tried increasing the velocity at the pipe outlet by compressing the reducer's diameter. This increased the spray distance to a maximum of about 150 feet from the marsh edge, allowing the slurry to cover more of the marsh platform, but it did not result in more even dispersal of the sand across the marsh platform.

Because of the way the dredge pipe reducer was compressed and due to the weight of the sand in the slurry, the spray separated into two streams and the dredged material was placed unevenly. Sand accumulated on the marsh directly under the two streams, leaving an area between them in which no material was placed. In an attempt to correct this, the dredge contractor tried moving and rotating the pontoon on which the dredge pipe was mounted, but movement of the pontoon was limited, especially during lower tide.

As a result of these difficulties and the high sand content (96% fine sand) of the dredged material, placement was patchy and the depth, or thickness, of placed sediment was not uniform as originally planned. The sand fell out of suspension rapidly and did not disperse across the marsh platform. The only way to achieve an even application of dredged material was to (1) continually move the dredging discharge pipe, which was not possible due to the limited mobility of the pontoon, or (2) grade the sand after it was placed. Grading would have required using heavy machinery on the marsh, which could have negatively impacted it.

In total, on the Ring Island marsh, about 1,000 cubic yards of sand was placed at an uneven depth in two small, irregularly shaped areas (0.40 and 0.49 acres) (Fig. 21).

Shortly after construction was completed, the USACE-OP performed an as-built survey of the site and removed the grade stakes. The marsh team measured and recorded the depth of the placed sand across the placement areas. The data showed that although the average placement depths were within the 3- and 6-inch targets, placement was uneven, ranging from 0 to 9 inches.

Figure 21. *Dredged material was placed on the Ring Island Marsh Enhancement site (left). An aerial view shows the placement area TLP-1 after placement (right).*

Ring Island Elevated Nesting Habitat Project Construction Summary

Placement area: 1 acre
Placement volume: 6,000 cubic yards
Placement depth: Up to 6 feet after grading (variable)
Sediment composition: 96% fine sand
Containment type: Straw bales, silt fence, and sand berm
Distance from NJIWW to marsh: Approximately 3,500 feet
Dredge type: 14-inch cutterhead dredge
Placement technique: Direct pumping
Shore construction machinery: CAT 459 tracked front-end loader
Timing of placement: August 2014

Figure 22. *Dredged material was placed on the Ring Island Enhanced Nesting Habitat site.*

Pre-placement: Prior to construction, the marsh team and dredging team met to review project objectives and to refine the plans for building the ENH. Given the composition of the dredged material (96% fine sand) and topography of the project site, they determined that containment measures were not needed. Site preparation consisted of marking the outer limits of the ENH dredged material placement area.

Dredging and Dredged Material Placement: Construction of the Ring Island ENH was completed during two weeks in August 2014. This project was built by cribbing the dredge discharge pipe in the approximate center of the site and directly pumping the hydraulically dredged sand onto the site (Fig. 22). As the sand slurry dewatered and accumulated, the cribbing was moved to direct the slurry to different sections of the placement area (Fig. 23). In addition, a baffle plate was attached to the end of the dredge discharge pipe to help spread the sand slurry more evenly. A small-tracked front-end loader moved the sand both during pumping and after dewatering to grade the sand into the final mound with the desired shape, height, and contours (Fig. 24).

The team expected that the dredged sand would rapidly fall out of suspension and containment measures would not be needed. However, this was not the case. Within hours after placement started and established a small mound of sand on the site, the slope of the mound was steep enough to cause some of the sand slurry to erode into adjacent tidal creeks. The team responded by enclosing the perimeter of the ENH with a silt fence and straw bales. As the sand mound grew and the slope became steeper, they also needed to construct a sand berm around the project area to adequately contain the dredged material. However, the team had to maintain an opening in the perimeter containment to allow dewatering, so dredged material flowed out of this opening and deposited onto a small area of the marsh south of the site.

Figure 23. *Containment measures were placed around the Ring Island Enhanced Nesting Habitat site.*

Post-placement: Shortly after construction, the USACE-OP performed an as-built survey of the site and the dredging contractor removed the silt fence and sand berm. The team expected that the straw bales would decompose, but because mats could smother marsh vegetation and attract predators, NJDEP-DFW later removed the bales.

Figure 24. *A front-end loader was used to move the sand during pumping and after dewatering.*

Avalon Phase 1 Marsh Enhancement Project

In late 2013, the Avalon project site was identified as a candidate for marsh enhancement via beneficial use of dredged material. The goal of this project was to enhance the marsh by filling large, expanding pools and providing a thin layer of dredged material over the surrounding marsh platform. The material to be dredged from the NJIWW contained a much lower percentage of sand than the sediment used at

Ring Island, so Avalon was a very different project in nature. The dredging and dredged material placement of both projects was conducted by the same dredging contractor, with oversight by the USACE-OP. The marsh team collaborated with USACE-OP to oversee the placement of dredged material on the marsh.

Avalon Phase 1 Marsh Enhancement Project Construction Summary

Placement area: 6.9 acres
Placement volume: ~6,000 cubic yards
Placement depth: Average 6 inches (excluding pools)
Sediment composition: 49% silt, 34% fine sand, 16% clay
Containment type: Partial containment with 6" diameter coconut-fiber logs
Distance from NJIWW to marsh edge: 3,500 feet
Distance from marsh edge to placement area: 100–150 feet
Dredge type: 10-inch cutterhead dredge
Placement technique: Spray from discharge pipe
Shore construction machinery: None
Timing of placement: December 29, 2014 to January 7, 2015

Pre-placement: During the pre-placement stage of construction of the Avalon Phase 1 project, the marsh and dredging teams had many conference calls and meetings to discuss how dredged material placement would be implemented. Dredged material placement areas A, B, and C had already been identified and staked out during the site selection process (Fig. 3), and area B was ultimately eliminated as a placement option during the project design phase (Phase 2: Project Design).

To minimize the potential for dredged material to run off placement area C and into the adjacent bay, 6-inch diameter coconut-fiber logs were installed in a few low-lying areas of the marsh and creeks (Fig. 25). To minimize the dispersal of dredged material beyond specified boundaries, additional logs were brought on-site for use as needed (i.e., adaptive management) during dredged material placement at both placement areas. To indicate elevations of 3 and 6 inches above the marsh surface, the marsh team installed grade stakes in the placement areas (Fig. 26).

At placement area C, the dredge discharge pipe was staged at the edge of the marsh, propped on a large float in the water with about 50 feet of pipe extending into the marsh. The pipe was laid directly on the marsh surface and a spray nozzle was attached to the pipe with an elbow (Fig. 26). At placement area A, the dredge pipe was extended farther into the marsh and cribbed into place.

Dredging and Dredged Material Placement: Avalon Phase 1 dredging and dredged material placement began on December 29, 2014, and these activities were completed on January 7, 2015. Representatives from the marsh team were stationed on the marsh, and the dredging team was stationed on the dredge. As soon as placement began at placement area C, the marsh team realized that the dredge pipe outlet was located much too close to the edge of the marsh. Because the dredged material was predominantly fine-grained, the slurry quickly ran off the marsh edge into nearby creeks and the bay, so dredging was stopped. To ensure that the slurry spray would land in the large pool, the dredge discharge pipe was moved farther into the marsh and the pipe outlet was elevated on a wooden crib. To prevent the slurry from running back toward the water, coconut-fiber logs were installed in a line behind the dredge pipe outlet. After spraying resumed, the marsh team noticed that any slurry that landed outside the pool overflowed from the pool, followed marsh drainage paths into creeks. To protect the creeks and to keep the dredged material within the placement area, they added containment to block these drainage paths. To help direct the slurry toward the pool, they added coconut-fiber logs and adjusted the angle of the dredge pipe outlet.

Figure 25. *At Avalon, a coconut-fiber log containment was installed to minimize the dispersal of the dredged material.*

Figure 26. *At Avalon, grade stakes helped indicate elevations about the marsh surface during dredged material spraying.*

The placement of dredged material in placement area A was implemented using the lessons learned from work at placement area C. Thanks to those lessons, the dredge pipe outlet was cribbed in place farther into the marsh and angled so that the spray landed in the large pool (Fig. 27). To minimize the dispersal of the slurry into nearby creeks, coconut-fiber logs were placed behind the dredge pipe outlet and in low-lying areas. To determine whether the placement in area A was increasing turbidity in the creeks, the team sampled the discharge water around the placement area and in creeks to which it was draining. By the time the discharge water passed through the containment and the narrow strips of tall-form *S. alterniflora* that lined the creek banks (Fig. 28), its turbidity was similar to that of the bay and neighboring creeks. The containment and the creek-bank vegetation, combined, effectively trapped suspended sediment before the discharge water reached the creeks.

Post-placement: In March 2015, the USACE-OP attempted an as-built survey of the Avalon Phase 1 project site. However, large portions of both placement areas were still dewatering and unconsolidated, making it very difficult (and dangerous) to walk there. Therefore, the surveyors could not completely survey either placement area. To document the application depth (thickness) and to verify the prior observation that the dredged material sorted (by grain size) during the placement process, the marsh team measured the placed material. Their measurements showed that in both areas, the marsh plain received an average of 6 inches of material. Placement depth in the pool areas ranged from 6 inches to more than 36 inches. In addition, the sediment analysis confirmed that the sand component of the material was deposited nearer to the place where the spray contacted the marsh (largely in the pools) and the finer-gained material (silt and clay), which stayed in suspension longer, was transported farther across the marsh plain.

Figure 27. *At Avalon, dredged material spraying in placement area A used the lessons learned from work at placement area C.*

Figure 28. *At Avalon, coconut-fiber log containment was installed to minimize the dispersal of the dredged material.*

Avalon Phase 2 Marsh Enhancement Project

After the Avalon Phase 1 project was completed in early 2015, it was clear that a larger marsh enhancement project could be implemented at the site using different construction methods. In addition, after observing how much the dredged material consolidated in Avalon Phase 1, the team decided to add more dredged material to areas A and C, as well as to several additional sites.

The Avalon Phase 2 placement areas selected (Areas A, C, D, E, and F) were large, expanding pool–panne complexes typical of the marsh on Shark Island. There was insufficient time to place dredged materials in Areas G, H, and I.

The design of Avalon Phase 2 focused on target dredged material placement and ecological elevations. This was a different focus from the Ring Island and Avalon Phase 1 projects, which attempted to place material to specific depths. The dredged material available for use in the Avalon Phase 2 project had slightly higher percentages of silt (53%) and clay (19%) than the Avalon Phase 1 material (49% silt, 16%

clay). Therefore, a condition of the permit for the Avalon Phase 2 project was the extensive use of containment. With oversight from the USACE-OP, the dredging contractor dredged the NJIWW. The marsh team oversaw the placement of dredged material on the marsh by the contractor.

Avalon Phase 2 Marsh Enhancement Project Construction Summary

Placement area: 45 acres
Placement volume: ~49,300 cubic yards
Placement depth: Average 9 inches (on marsh areas but not pools)
Sediment composition: 27% sand, 53% silt, 19% clay
Containment type: Full containment with (6- to 20-inch diameter) coconut-fiber logs
Distance from NJIWW to marsh edge: 3,500 to 5,000 feet
Distance from marsh edge to placement site: 150 to 875 feet
Dredge type: 14-inch cutterhead dredge
Placement technique: Spray and direct pumping
Shore construction machinery: Marsh Master and trailer
Timing of placement: November 23, 2015 to February 20, 2016

Pre-placement: During the pre-placement stage of the Avalon Phase 2 project, the marsh team and dredging team discussed how dredged material placement would be conducted, using both the lessons learned from the Ring Island and Avalon Phase 1 projects and the new permit conditions for the Avalon Phase 2 project. In the discussions, the teams determined exactly where on the marsh the dredged material would be placed, agreed on the order of operations for the dredging and placement, and finalized the target placement elevations for the dredged material. These meetings ensured that the dredge contractor fully understood the objectives and critical design elements of the project.

Site preparation was much more extensive for the Avalon Phase 2 project than for Ring Island or Avalon Phase 1. At four of the five dredged material placement areas, containment was installed around the full perimeter. Placement area E was only partially contained because some of the surrounding marsh was at an elevation equal to or greater than the target dredged material placement elevation, forming natural containment. Containment was critical to ensuring that the target dredged material placement elevations were effectively and efficiently achieved (by providing adequate time for the dredged material to settle within the placement areas) and to ensure that the dredged material did not disperse into creeks.

To guide containment installation, a surveyor staked out the perimeter of each area. For containment, the team used coconut-fiber logs ranging from 6 to 20 inches in diameter, depending on the thickness of the planned fill in a given location (the difference between the elevation of the marsh and the target dredged material placement elevation; Fig. 29). For the Avalon Phase 2 project, a crew of 8–10 people spent five weeks installing 15,300 linear feet of containment. The coconut-fiber logs were transported across the marsh and around the staked-out perimeter of each placement area using a low-pressure Marsh Master with a trailer (Fig. 30), the tracks of which inadvertently created unvegetated paths around the placement areas (Fig. 31).

Figure 29. *This photo of Avalon Phase 2 shows the containment area immediately after installation.*

Figure 30. *A Marsh Master and trailer were used to transport the coconut-fiber logs for containment.*

Figure 31. *At Avalon Phase 2, the Marsh Master used to transport the coconut-fiber logs inadvertently created tracks in the marsh.*

To guide dredged material placement in the Avalon Phase 2 project, grade stakes were installed at the site, marking the target dredged material placement elevation. The main purpose of the grade stakes was to avoid placing dredged material to an elevation greater than the target elevation. When dredged material reached the specified elevation, operations ceased, and the dredge pipe outlet was moved to a new location within the placement area. As this was a pilot project, the NJDEP-ODST did not set any regulatory thresholds for the target elevation, and there was no regulatory requirement to meet the target elevations.

Dredging and Dredged Material Placement: The Avalon Phase 2 dredging and dredged material placement began on November 23, 2015 and continued until February 20, 2016. During this time, dredging and placement was conducted 24 hours per day and six days per week. During daylight hours, a representative of the marsh team inspected placement on the marsh, and a USACE-OP inspector oversaw the dredge plant; the two teams communicated by radio and cell phone. At the beginning of each day of placement, the marsh team member on duty contacted the dredge operator or the USACE-OP project inspector to review the operations plan for the day, which had been developed the previous night, and to discuss any potential issues with wind and tide conditions and the condition of the placement area. For example, if a high tide was expected to overtop containment, placement would be prohibited for some time before and after high tide, as any dredged material placed during high tide would not be adequately contained.

During placement, the marsh team member walked around the placement area and communicated issues to the USACE-OP inspector. The most frequent reason for communication was that the dredged material was overtopping placement area containment. When this happened, the marsh team member would ask the USACE-OP to stop dredging in order to adjust the containment, dredge pipe outlet position, or dredged material placement operation. If overtopping was limited to a small stretch of containment and material still needed to be placed near the pipe outlet, dredging would be paused until additional containment was added and, if needed, the pipe outlet was adjusted to change the direction of flow, which would reduce pressure on the affected section of containment. If containment overtopping was extensive and the target dredged material placement elevation was nearly achieved near the pipe outlet, placement would cease to allow the material to dewater and consolidate, after which more material would be added ("interval pumping").

At the end of each day, the on-site marsh team member would assess the condition of the placement area and, with the dredging team, develop a schedule for dredging and placement for the next 12–15 hours (i.e., overnight and into the next morning). Depending on conditions in the placement area, one of three options would be implemented: (1) dredging would continue through the night (provided there was no threat of overnight high tides over-topping or breaching the containment), (2) dredging would not be conducted through the night (usually because of the high potential to overtop or breach containment), or (3) "interval pumping" would be used.

Each week, the marsh team and dredging team met to review recently completed work, assess current work needs, and formulate the next steps considering the site constraints and field conditions. These meetings helped the dredging contractor understand how the marsh team used observations of the marsh to make decisions. These meetings also allowed the two teams to reach consensus and jointly develop solutions and plans so they could achieve their main objectives of careful placement of dredged material on the marsh (marsh team) and efficient dredging and placement (dredging team).

The dredge pipe outlet was fitted with either a spreader plate or a spray nozzle (Fig. 32). By reducing the energy of the sediment slurry as it was discharged, the spreader plate dispersed the slurry in multiple directions. Meanwhile, the spray nozzle increased the velocity of the slurry from the outlet so that it could be sprayed farther. In both cases, the pipe outlet was cribbed about 3–4 feet above the marsh surface.

Within each dredged material placement area, the dredge pipe outlet was positioned near the edge of a large pool (Fig. 33). If the dredged material was overtopping its containment and overtopping could not be stopped, the dredge pipe was moved within the placement area. In each placement area, the outlet usually needed to be moved two or three times to achieve the target elevation across the full extent of the area.

Figure 32. *The dredge pipe outlet at Avalon, Phase 2, was fitted with either a spreader plate (left) or a spray nozzle (right).*

In most cases, placed material reached the target dredged material placement elevations near the dredge pipe outlet before it reached that target in areas farther from the outlet. This outcome was not expected when the Avalon Phase 2 project was designed. Given the large proportion of silt and clay in the dredged material, the team expected that the dredged material would disperse evenly within the placement areas. However, the pools contained “bathtubs” (especially deep areas) that tended to hold the slurry and prevent it from dispersing. Once a "bathtub" was full, the dredged material spilled out though its lowest point, which was either predictable (e.g., an existing marsh drainage path) or unpredictable (with the slurry flowing along the path of least resistance created around mounds of dredged material). Frequently, the drainage path led directly to the containment, causing it to be overtopped. Although moving the pipe outlet more frequently could have resolved this problem, frequent moves were not possible for the reasons discussed below.

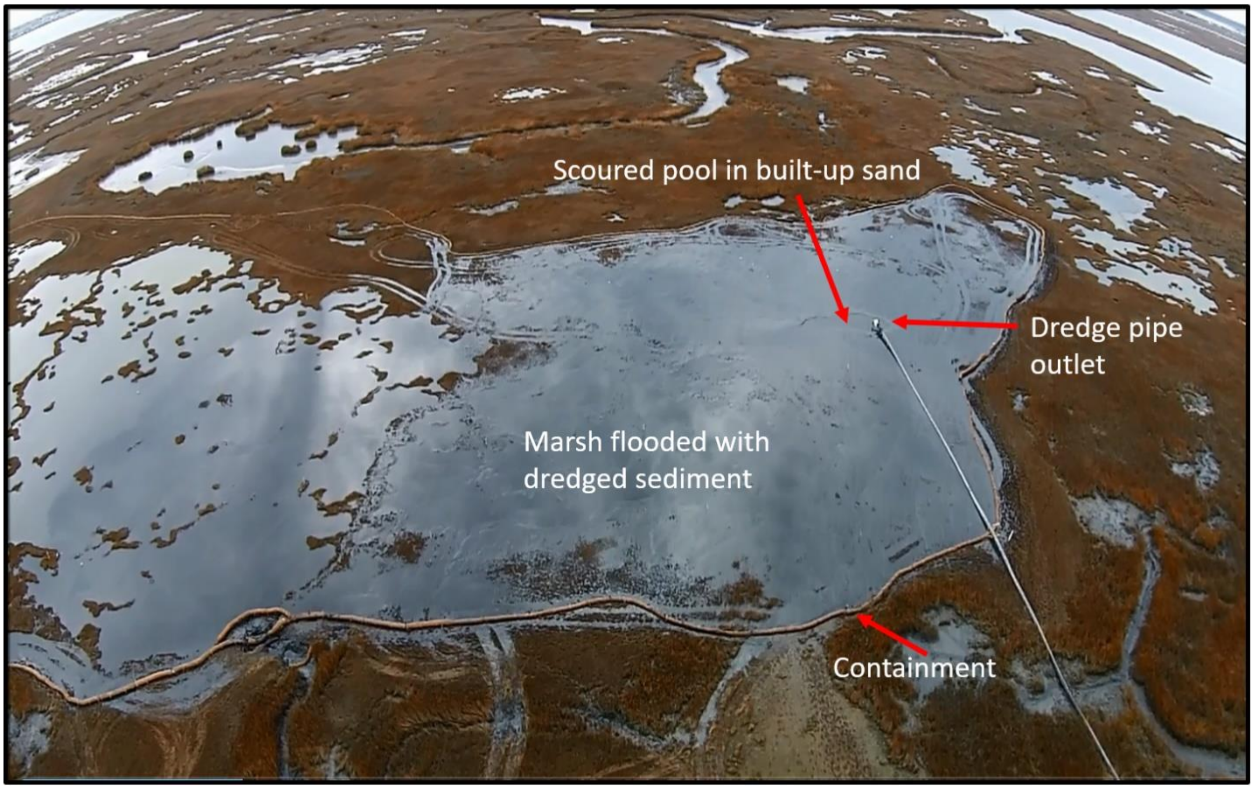

Figure 33. *This aerial view shows the dredged material being placed in the Avalon Phase 2 project. Source: TNC*

The accumulation of sand around the dredge pipe outlet often limited the dispersal of dredged material in placement areas. The sand fraction of the dredged material rapidly segregated and fell out of suspension, creating a mound near the dredge pipe outlet. Then, the dredged material carved into this sand mound, creating a pool with a berm edge (Fig. 33). Eventually the slurry in the pool broke through the berm and was funneled in one direction, which usually limiting its dispersal. Again, moving the dredge pipe outlet more frequently could have resolved this problem.

However, moving the dredge pipe was difficult, which limited the number of pipe outlet locations within each dredged material placement area. The location of the pipe and the ability to move it frequently were restricted by a number of factors:

- the amount (length) of available pipe
- the rigidity of the pipe, which was made of high-density polyethylene that could not be bent at sharp angles
- the marsh landscape (the pipe was moved by a Marsh Master, which could not traverse all areas, especially large deep pools)
- the short window of time for moving the pipe (a boat supported and moved the pipe at the marsh edge, which was only accessible at high tide)
- the difficulty of moving the pipe within unconsolidated dredged material, and
- the high cost of pausing the dredge (i.e., “downtime”) as the pipe was moved.

The limited mobility of the pipe greatly affected day-to-day operations and the outcome of the dredged material placement. Ultimately, the placement areas contained sandy humps near the dredge pipe outlets and predominantly silt–clay at lower elevations that were farther from the outlets. Thus, the placement areas varied in elevation, grain-size composition, dewatering rates, and placed volumes.

Construction at the Avalon Phase 2 project during the winter was also problematic. For example, at placement area C, only one pipe outlet location was used because Winter Storm Jonas hit during placement. The storm-driven waters removed half the perimeter containment. Because it was not possible to re-install containment, work in this placement area ceased. In addition, the storm waters sank one of the dredge contractor's boats and damaged the dredge plant's engine, halting work for about two weeks while repairs were made.

During the project, team members generated daily field reports and took photographs of the work in progress. GreenVest, a marsh team member, periodically provided updates to the team regarding the overall construction process, methods, and progress to date.

Post-placement: With the USACE-OP and its dredge contractor, the marsh team inspected the site immediately after placement was completed. Next, the dredge contractor removed as much of the wood cribbing used for the dredge pipe as possible. However, unconsolidated dredged material made access difficult and dangerous, so some pieces could not be removed from the placement area and had to be removed by the marsh team at a later date.

Sediment placement resulted in an average increase of 9.4 inches in marsh elevation across the entire area, excluding areas that started as pools. The placement depth on the marsh platform ranged from 0.9 to 19 inches and exceeded 36 inches in former pools.

Another important component of the post-placement period in the Avalon Phase 2 project was the completion of as-built topographic surveys of each dredged material placement area. Ideally, surveys are completed almost immediately after placement to determine the bulking factor and the extent of consolidation. Originally the project team planned to complete these surveys on foot, using RTK-GPS survey equipment. However, because the material was still unconsolidated, the placement areas were difficult and dangerous to traverse, and the team quickly realized that surveying was not a viable option in placement areas. Fortunately, in March 2015, the USACE-Engineer Research and Development Center (ERDC) was able to survey the site using ground-based LiDAR survey equipment (a RIEGL VZ-400 V-Line 3D Terrestrial Laser Scanner). This equipment produces a high density of highly accurate elevation measurements. However, a major limitation of this survey technique is the inability to measure through water to ascertain the elevation of the land below, which resulted in data gaps. In addition, using different survey equipment (RTK-GPS before construction and LiDAR after construction) added variability to the data, making it difficult to perform between-year comparisons.

Fortescue Project Marsh Enhancement Component

The pre-placement stage of the construction phase of this project began on January 29, 2016 (Table 3). Both the design and construction of the Fortescue marsh enhancement were based on the lessons learned from construction of the Avalon Phase 2 project, particularly those lessons associated with the placement of fine-grained dredged material and the limited mobility of the dredge pipe. Originally, the design of the Fortescue marsh enhancement involved a complex, branching system of pipes and valves (Fig. 19). This would have enabled the dredging team to place material in different parts of the marsh, without moving and repositioning the dredge pipe (see Phase 2: Project Design). In theory, this design would avoid the costly downtime that was experienced during the Avalon Phase 2 project when discharge was stopped to prevent containment overflow and reposition the dredge pipe. However, at Fortescue, the dredge discharge pipe was not installed as designed (see below).

For the Fortescue marsh enhancement, the dredging and dredged material placement was performed by a New Jersey-based contractor with oversight by NJDOT-OMR. The oversight of the dredged material placement on the marsh was performed by Princeton Hydro, a member of the marsh team.

Fortescue Marsh Enhancement Component Construction Summary

Placement area: 6.6 acres
Placement volume: 6,490 cubic yards
Placement depth: Average 6 inches
Sediment composition: 70% sand, 15% silt, 15% clay
Containment type: Full containment with Filtrexx SiltSoxx™
Distance from channel to marsh: 1,000 to 1,280 feet
Distance from marsh edge to placement site: 400 to 3,050 feet
Dredge type: 12-inch hydraulic cutterhead dredge (12-inch diameter intake pipe and 12-inch diameter discharge pipe)
Placement technique: Direct pumping
Shore construction machinery: Marsh Master, skid steer, excavator
Timing of placement: March 5 to March 20, 2016

Pre-placement: During the pre-placement stage, as NJDOT-OMR prepared the bid package for dredging and dredged material placement, the marsh team provided input. Specific areas of concern were limiting heavy equipment on the marsh, installing adequate containment, not exceeding target dredged material placement elevations, marsh team oversight of dredged material placement, and adding elevation while avoiding the creation of upland. After the dredger was under contract, the marsh team reiterated the goals of the project and the sensitive nature of the marsh to the dredging team.

In January 2016, the site was prepared by the dredge contractor or another NJDOT-OMR subcontractor overseen by a member of the marsh team. The site was prepared by installing containment, laying the dredge pipe, and installing grade stakes. The project design called for complete containment around the perimeter of each placement area. The team installed an inner perimeter and a second, outer perimeter, both consisting of Filtrexx SiltSoxx™ fabric tubes filled with hardwood chips (Fig. 34). Like the coconut-fiber logs used at Avalon, the Filtrexx SiltSoxx™ contained the dredged material as the suspended sediment settled out and allowed water to drain through, filtered by the fabric and woodchips. Although the marsh team had requested fully biodegradable Filtrexx SiltSoxx™ (cotton tubes), the manufacturer could not provide the required quantity prior to construction, so photodegradable polypropylene geotextile tubes were used instead. The inner perimeter consisted of 12-inch diameter tubes, most of which were stacked in a pyramid to the appropriate target elevation. The outer perimeter consisted of a single layer of 6-inch diameter tubes. Due to their buoyancy, the stacked tubes slipped out of alignment at channel crossings during high tide.

Because each Filtrexx SiltSoxx™ tube was so long (100 feet) and heavy (1500 pounds), they could not be moved by hand. Therefore, a Marsh Master fitted with a trailer was used to transport the tubes and aid in their installation. During installation, the Marsh Master used the same route across the marsh repeatedly, causing unanticipated damage (Figs. 35 and 36).

Figure 34. *At Fortescue, the team installed Filtrexx SiltSoxx™ containment in two concentric rows along the perimeter of the dredged material placement areas.*

Figure 35. At Fortescue, damage to the marsh is evident in the right foreground area (darker ground) of this picture. This was caused by repeated travel and other activity over the same area.

Grade stakes were installed in a 100 x 100-foot grid across the dredged material placement areas. Each grade stake was marked at the target dredged material placement elevation and at 6 inches above and below this elevation. Due to their experience with the Avalon Phase 2 project, the marsh and dredging teams concluded that it would be difficult to consistently place dredged material at more than one elevation (i.e., the high- and low-marsh target elevations specified in the design plans). Therefore, they

Figure 36. This long pool was created accidentally by driving an excavator on the marsh at Fortescue.

decided to use a single target dredged material placement elevation for the entire marsh: 3.3 feet NAVD88, which was the elevation at the upper end of the range of high marsh bio-benchmarks.

Dredging and Dredged Material Placement: From March 5 to March 20, 2016, the dredging and dredged material placement at the Fortescue marsh continued for 12 hours per day and 6 days per week. During this project component, material was placed in three general areas. A marsh team inspector from Princeton Hydro was always present on the marsh and the NJDOT-OMR resident engineer was stationed at an office in a nearby marina during the operation. The marsh team's inspector communicated to the dredge contractor through the NJDOT-OMR engineer. In general, the NJDOT-OMR resident engineer and inspectors were focused on maintaining the dredging schedule and maximizing the volume of dredged material placed, while the marsh team inspectors were focused on the marsh enhancement objectives of the project. To document work progress, the dredging team created daily field reports with photographs, and Princeton Hydro periodically updated to the marsh team about the overall construction process, methods, and progress.

The design plans, as permitted by the NJDEP-ODST and USACE-RB, consisted of a branched system of dredge pipes, valves, and sections made of more flexible pipe to allow easy movement (see Phase 2: Project Design). Instead of using this design, six branches were installed utilizing y-valves (Fig. 37) and the flexible pipe was never installed. The average length of pipeline across the marsh was 3,050 feet.

Figure 37. *This y-valve allowed the team to change the location of sediment placement without moving the pipe. Photo from Dewberry Engineers Inc., courtesy of NJDOT.*

Placement started in dredged material placement area 2 (Fig. 4). Immediately, the project team realized that the higher-than-expected amount of sand in the dredged material was a problem (Fig. 38). The sand mounded and blocked the dredge pipe outlet, which was lying directly on the marsh surface (in contrast with Avalon, where it was raised off the surface with cribbing). To resolve this problem, the dredge contractor used an excavator on the marsh to raise and move the pipe as material was being pumped (Fig. 39) and to knock down high mounded areas.

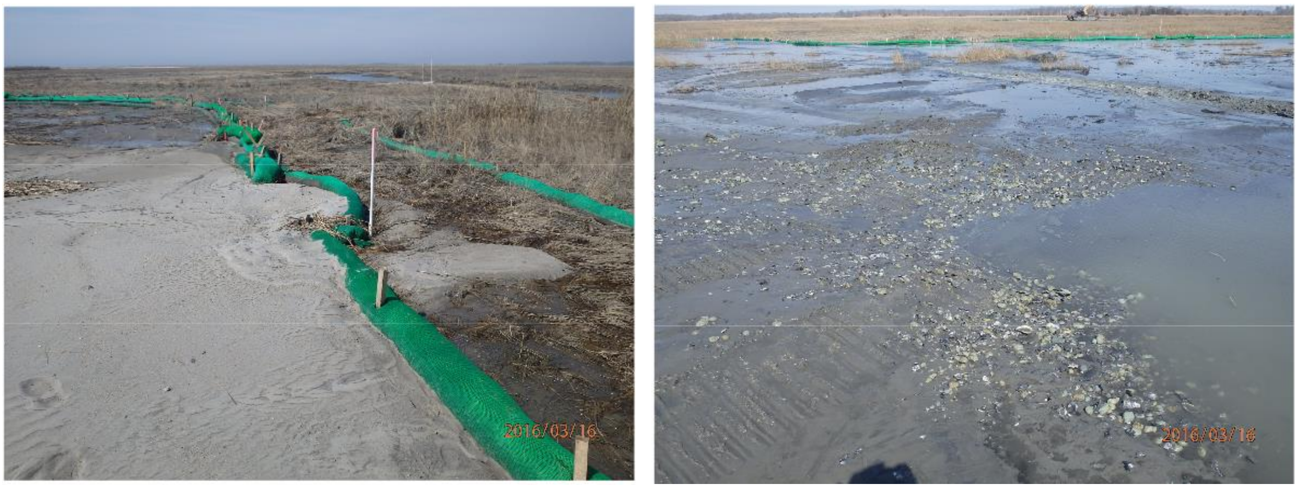

Figure 38. *The dredged material was sandier than expected at Fortescue.*

Figure 39. *At Fortescue, an excavator held and repositioned the dredge discharge pipe outlet.*

As at Avalon, the finer-grained dredged material flowed to the edge of dredged material placement area 2 and began to overtop the containment. To resolve this issue, the dredge contractor did not use the system of pipes and valves as originally intended. Instead, dredging was paused while the Filtrexx SiltSoxx™ containment was reinforced, sediment dewatered, and the dredge pipe outlet was moved.

After the work in placement area 2 was complete, placement began in placement area 1 (Figs. 4 and 40). Again, the pipe-and-valve system was not fully utilized, and sand mounding and limited pipe mobility were problematic. Because progress on the marsh was too slow, NJDOT-OMR redirected dredging and dredged material placement to the beach restoration project component. As a result, only two small sections of placement area 1 received material.

To allow the dredge contractor to complete placement in placement area 1, the permit was modified to extend the work on the marsh to April 15. However, weather prevented this work from continuing. Ultimately, 6,490 CY of dredged material were placed on 6.6 acres, compared with 11,350 CY on 22.4 acres specified in the design.

Post-placement: After the dredged material placement was completed on March 20, 2016, NJDOT-OMR performed an as-built survey of the placement areas in the marsh. A post-construction survey in permanent monitoring plots found that the average placement depth was 6 inches with a range of 0–18 inches. All the containment and grade stakes were left on the marsh because the project team intended to place more dredged material in fall 2016. However, this second placement of dredged material never occurred because the remaining material to be dredged from the channel was mostly sand, and the team wanted to prevent additional impacts of equipment use on the marsh. Containment and grade stakes were later removed from the site by NJDEP-DFW and GreenVest.

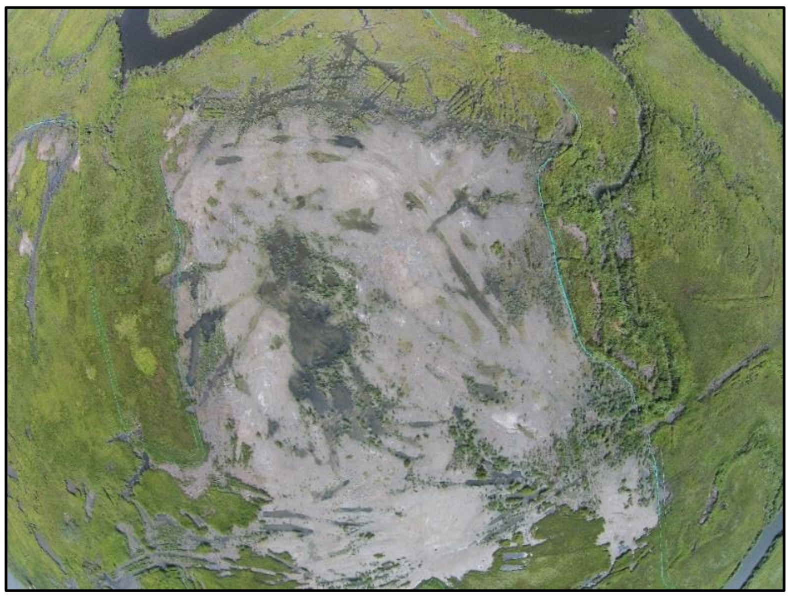

Figure 40. *This aerial view shows Fortescue placement area 1 immediately after placement was completed. Note the Filtrexx Siltsoxx™ containment (bright green lines) near the perimeter.*

Fortescue Dune Restoration Component

The Fortescue dune restoration component was designed and permitted together with the marsh and beach projects (note that all three components were needed so that the associated NJDOT-OMR dredging project could be completed). Unlike the pilot marsh enhancement projects, dune restoration and creation projects were well understood. The sand used for the dune restoration project was dredged from the Fortescue Creek channel.

Pre-placement: The marsh team stressed to the dredge contractor that protecting the marsh habitat was important. Site preparation started on January 18, 2017, and consisted of staking out the dune boundary, installing containment, laying out the dredge pipe, and excavating the dewatering pits where sand (dredged material) would be stockpiled. Prior to construction, to prevent the placed dredged material from migrating outside the dune footprint and into the adjacent marsh, containment (8-inch-diameter Filtrexx SiltSoxx™) was installed along the north and east perimeter of the proposed dune. Likewise, to provide some protection from onshore waves, containment was installed along the west and south perimeter of the placement area. All site preparation was performed by the dredge contractor or another NJDOT-OMR subcontractor, with input from the marsh team.

Fortescue Dune Restoration Component Construction Summary

Placement area: 2.25 acres
Placement volume: Approximately 18,355 cubic yards
Sediment composition: Primarily sand
Containment type: Partial perimeter, with Filtrexx SiltSoxx™
Distance from channel to dune: 2,000 feet
Dredge type: 12-inch hydraulic cutterhead dredge
Placement technique: Direct pumping into excavated dewatering pits, grading with bulldozer
Shore construction machinery: Marsh Master, skid steer, excavator, bulldozer
Timing of construction: February 15 to April 12, 2017

Dredging and Dredged Material Placement: Channel dredging and dune construction began on February 15 and continued until April 12, 2017. The sandy dredged material was pumped into dewatering pits within the dune. To contain the dredged material and to divert the dewatering discharge to the center of the placement area, the dredge contractor constructed sand berms around the dewatering pits (Fig. 41). To prevent the flow of water and dredged material from the placement area to the marsh, additional sand berms were built and Filtrexx SiltSoxx™ were used as needed during the construction.

Once it dewatered, the dredged material was moved into the dune footprint and then graded into a dune by a bulldozer. The marsh team and NJDOT-OMR resident engineer monitored the placement of the dredged material into the dune footprint. High winds frequently created unsafe working conditions, which temporarily halted dredging and placement.

Work progress was documented by the dredging team in daily field reports. Princeton Hydro (the marsh team member that was onsite during construction) provided periodic updates to the project team, discussing the overall construction process, methods, and progress.

Figure 41. *At the Fortescue dune restoration, berms were constructed from the first dredged sediment to create dewatering pits to retain the dredged material and to direct the dewatering discharge to the center of the placement area. Photo from NJDOT.*

Post-placement: After placement, NJDOT-OMR performed an as-built survey of the restored dune (Fig. 42). The final dune measured 900 feet long (~200 feet shorter than designed), 40 feet wide at the top and 80 feet wide at the base, with a dune crest elevation of 10 feet NAVD88 (5–6 feet above the marsh surface). The side of the dune graded to a slope of 4:1 (horizontal to vertical). Immediately after placement, the dredge contractor removed the dredge pipe and other construction equipment from the site. The placement area boundary stakes were removed, but the Filtrexx SiltSoxx™ containment was left in place to support the restored dune and minimize erosion into the marsh.

Figure 41. This photo of the Fortescue dune restoration shows the bay side of the dune immediately after placement.

Fortescue Beach Restoration Component Construction Summary

Placement area: 1.3 acres
Placement volume: 7,245 cubic yards
Sediment type: Sand
Containment type: None
Distance from channel to dune: 1,800 feet
Dredge type: 12-inch hydraulic cutterhead dredge
Placement technique: Direct pumping, grading with bulldozer
Shore construction machinery: Marsh Master, skid steer, excavator, bulldozer
Timing of construction: March 26 to April 14, 2016

The Fortescue beach restoration component was designed and permitted together with the marsh enhancement and dune restoration components. Unlike the pilot marsh enhancement/dredged material placement projects, beach restoration was well understood, and the dredging team had experience with such projects. The sand used for the Fortescue beach restoration component was dredged from the Fortescue Creek channel.

The dredging team provided daily field reports of work progress, including photographs. Princeton Hydro (the marsh team member onsite during construction) periodically provided the project team with updates of the overall construction process, methods, and progress.

Pre-placement: Prior to pumping material into this area, the topography of the existing beach was surveyed, and the limits of the placement area ("beach fill") were delineated with 1-inch PVC pipes marked with the target elevation. Additional stakes were added around a 25-foot offset from the beach fill area.

Dredging and Dredged Material Placement: The beach restoration followed standard methodologies. The dredged material was hydraulically pumped to the placement area and the slurry was directed into a created trench, which allowed the sand to settle out while the finer material and water flowed back to the bay (Fig. 43). The approximate dimensions of the trench were 100 feet long by 30 feet wide and 4 feet deep. The trench was surrounded by approximately 200-foot long "training" dikes, which prevented dredged material from flowing directly into the bay or across the beach into the adjoining marsh. As dredged material exited the pipe, it flowed through the trench, giving sand the opportunity to settle out. The trench was regularly cleared by an excavator and the accumulating sand was used to maintain the training dikes and restore the beach. Then, the sand on the beach was distributed and graded to design specifications using a small bulldozer.

Figure 43. *During the beach restoration component at Fortescue, dredged material flowed in a created trench surrounded by training dikes. Photo from NJ DOT.*

Post-placement: After placement, the grade stakes were removed and an as-built survey was completed.

Phase 6: Post-Construction Adaptive Management

This project phase addresses post-construction monitoring, adaptive management, and associated lessons learned at the three project sites. It is important to note that adaptive management was employed throughout the project implementation process, particularly in response to lessons learned as implementation proceeded from one project to the next.

It is well known that many years (possibly decades) are required for enhanced marshes to develop the structural and functional characteristics typical of "reference" (i.e., "healthy," natural) marshes (Mitsch and Wilson 1996; Zedler and Callaway 1999; Williams and Faber 2001; Moreno-Mateos et al. 2012). In addition, the three pilot marsh enhancement projects—Ring Island, Avalon, and Fortescue—employed techniques that were new to New Jersey. Therefore, the trajectory of the marsh response was not predictable.

In the first few weeks after construction, the marsh team realized that the comprehensive monitoring plan was not tracking some elements of these projects. For example, the monitoring plan did not include the effects of containment on marsh recovery. Therefore, to better understand conditions in the dredged material placement areas, the marsh team developed and implemented a number of additional monitoring parameters, using an adaptive management approach. They also tested a variety of management techniques (e.g., planting test plots and removing some containment) intended to improve marsh recovery.

In April 2016, at the beginning of the first growing season post-construction, the marsh team performed the first formal post-construction inspections of the Avalon and Fortescue projects. These inspections raised many questions about how the sites were recovering. The comprehensive monitoring plan focused on quantitatively measuring single parameters, collected over the length of the growing season (April to October); thus, the data were not often analyzed and interpreted in "real time," but long after they were collected. The main purpose of the additional inspections was to make qualitative real-time observations, including interactions between parameters, to guide adaptive management decisions and identify significant issues that the marsh team needed to address.

The marsh team's monthly inspections, which occurred only during the growing season, observed changes in the marsh, the placed dredged material, and biological activity. Marsh team members walked the perimeter and interior (to the extent possible) of each placement area and made a variety of qualitative observations. In 2016, these observations focused on documenting the vegetation response, vegetation die-off areas, containment integrity, and containment impacts on marsh response and dynamics of the placed dredged material (e.g., dewatering, consolidation, erosion). In 2017, the team also began recording planting success and failure. The full list of parameters monitored are listed in Table 10. (For a detailed description of the monthly monitoring methods, see the Project Monitoring Protocols located at XX-LINK.)

Table 10. Site Features Monitored During Monthly Post-construction Site Inspections			
Vegetation Recovery/ Die Off	**Planting**	**Containment**	**Dredged Material**
Species present	Species present	Issue (e.g., blocking tidal flow, wildlife hazard, wrack collection)	Cracking or drying
Sediment characteristics (texture, colors, etc.)	Sediment characteristics (texture, colors, etc.)	Difference in sediment elevation inside and outside containment	Sediment characteristics (texture, colors, etc.)
Method of growth (recovery or recruitment)		Biodegradation	Consolidation

Ring Island Marsh Enhancement Adaptive Management

In September 2014, dredged material placement for the Ring Island marsh enhancement project was completed.

Initial Observations: Although the monthly site inspection program was not formally in place until July 2016, during the intervening months the site was qualitatively inspected by marsh team members who were conducting vegetation and avian surveys and during visits by marsh team members. Although there were almost no gains in vegetation cover during the 2015 growing season (Fig. 44), no adaptive management actions were considered until spring 2016. Because the dredged material placement areas were small (less than 0.5 acres), there was little risk associated with leaving the areas unvegetated, and leaving them alone offered an opportunity to learn about natural re-vegetation and colonization. During early post-construction visits, the marsh team noticed several things:

- The placed dredged material was heterogenous and its thickness varied across the placement areas.
- Plants that survived the initial placement senesced and died early.
- As birds began to use the placement areas for feeding, shell piles formed.

Figure 44. *At the Ring Island marsh enhancement site in October 2015, there was minimal vegetation recovery and colonization.*

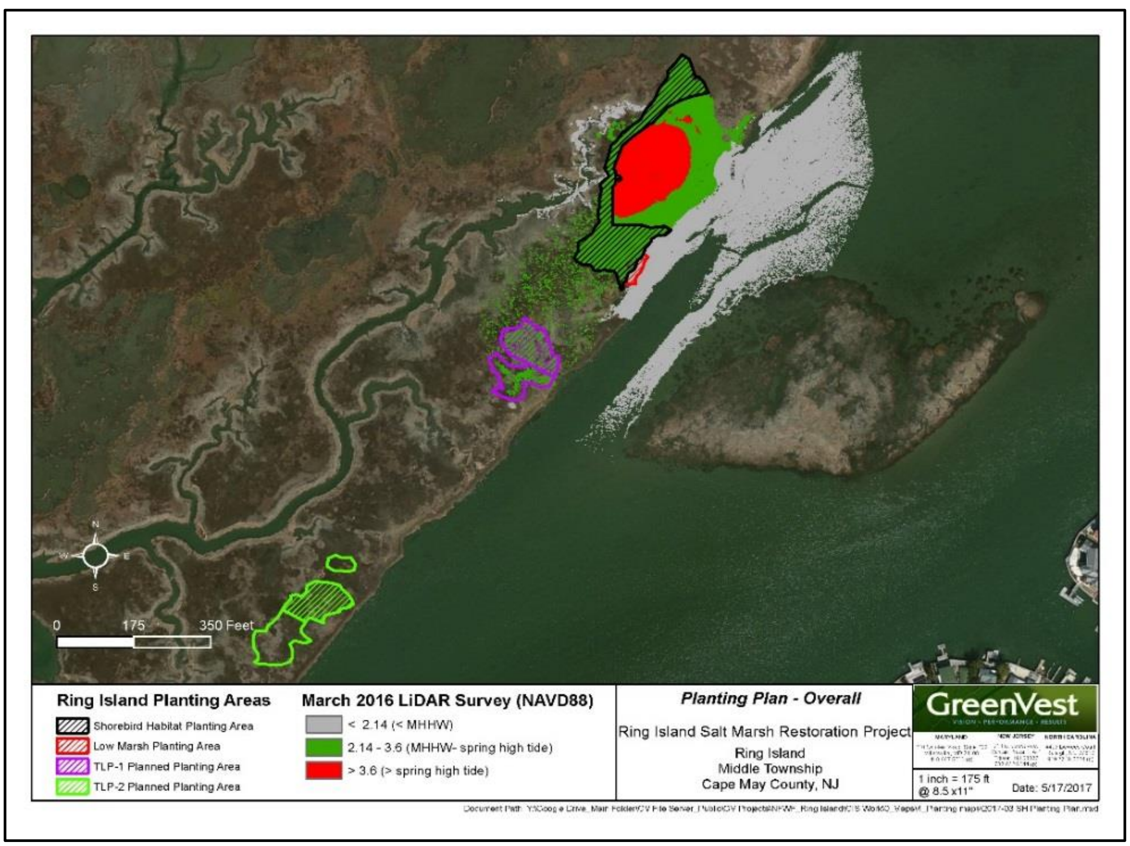

Figure 45. *This image shows the planting plan for the Ring Island marsh enhancement project.*

Using biological benchmarks (Table 4), tidal range, and topography, the team developed plans to plant half of each of the two dredged material placement areas (Fig. 45) at Ring Island. The elevations of the two placement areas differed, so different plant communities were chosen in the plan, as follows:

- **TLP-1 Planting Area**: 25% *S. alterniflora*, 50% *S. patens*, and 25% *D. spicata*, all spaced at 3-foot centers
- **TLP-2 Planting Area**: 50% *S. alterniflora*, 25% *S. patens*, and 25% *D. spicata*, all spaced at 3-foot centers

On March 30, 2017, a crew of 10 people planted approximately 2,200 plugs on half of each placement area (0.46 acres in total). At the Ring island marsh enhancement project site, no other post-construction adaptive management actions were implemented.

Avalon Phase 1 Adaptive Management

Dredged material placement for the Avalon Phase 1 project was completed in January 2015.

Initial Observations: Although the formal monthly site inspection program did not begin until July 2016 (after construction of the Phase 2 project), the project team visited the site in April, June, September, and October 2015. The 2015 visits revealed that the placed dredged material had dewatered and consolidated to varying degrees, with significant consolidation and potential subsidence occurring in areas that were previously pools. The lesson learned from these observations was that placed dredged material may consolidate more than anticipated, particularly in former pools, and the final elevation may be lower than the target ecological elevation.

To achieve the desired marsh enhancement project objectives—the conversion of degraded pools to stable marsh plain—the marsh team decided to place additional dredged material in Avalon Phase 1 placement areas A and C.

Planting: Based on their observations from site visits, the marsh team implemented a small-scale test planting in placement area A. The purpose of this planting was to help inform future planting in the larger Avalon Phase 2 project.

According to the as-built survey, the elevation range for placement area A was approximately 2.0 to 2.4 feet NAVD88 and the Avalon biological benchmarks suggested that this was the elevation range of *S. alterniflora* and *D. spicata* (Table 5). However, *D. spicata* was not available from the local nursery at the time of planting, so *S. patens* was used in its place. The planting plan was implemented on July 21, 2015, and consisted of 12 plots with the following treatments: planting vs. no planting (i.e., natural recovery and recolonization), planting at 2-foot centers vs. planting at 3-foot centers, planting *S. alterniflora* vs. *S. patens*, and planting with goose netting versus no netting. By September 2015, only a few *S. alterniflora* plants survived (Fig. 46).

Figure 46. *By October 2015, few plants survived at Avalon in dredged material placement area A.*

The marsh team presumed that plant survival was poor because conditions in the middle of the growing season (late July) are not conducive to plant establishment. Other possible contributing factors include the chemical composition of the dredged material and lack of adequate pore space in the tightly consolidated fine-grained sediment.

Despite the failure of the experimental planting, by September 2015, *S. alterniflora* grew vigorously through the placed dredged material at some locations in placement area A (Fig. 47). However, recovery was patchy, and in some areas, vegetation died. Overall, vegetation recovery during the 2015 growing season was too variable to draw any firm conclusions about the marsh response.

Containment: During construction of the Avalon Phase 1 project, little containment was used, and what was used (coconut-fiber logs) was biodegradable. The marsh team left these logs in place to observe how long it would take for them to break down.

Figure 47. *At Avalon, existing marsh plants grew through placed dredged material in April (left) and June 2015 (right).*

Avalon Phase 2 Adaptive Management

On February 19, 2016, dredged material placement for the Avalon Phase 2 project was completed.

Initial Observations: During the first site visit on April 25, 2016, the project team observed the following:

- During the two months since construction had been completed, the extent of consolidation for the dredged material was highly variable.
- Due to dewatering and drying, the dredged material had formed thick plates in a number of areas (Fig. 48).
- At some locations, *S. alterniflora* was growing through the cracks in the dredged material (Fig. 49).
- Vegetation did not recover in the tracks left by the Marsh Master (Fig. 31).
- Water created drainage paths through some of the placement areas.
- It was difficult or impossible to walk across both former pools and sediment dominated by fine-grained material.

After this first site visit, the marsh team began formal monthly site inspections (described in the Phase 6 introduction) and decided not to attempt a large-scale planting in 2016 due to the difficulty of walking across the placement areas. There were additional reasons to delay a large-scale planting until 2017:

- There was not enough lead time for a nursery to grow the amount and species of plants needed (at least six months' notice would be required).
- There was not enough information on how much, if any, natural plant colonization would occur during the first growing season (e.g., if by the end of 2016, the site was significantly covered by plants, then planting in spring 2017 would be unnecessary).

- There was uncertainty about the consolidation and elevation loss of the placed dredged material (which would impact plant selection) and the re-formation of pools (in which plants would not survive).

Figure 48. *At Avalon, Phase 2, thick plates of drying and cracking dredged material were present in April 2016 (two months after construction was completed).*

Planting: The team planned to conduct a small-scale test planting in late spring/early summer 2016 at Avalon to examine the recovery of planted and unplanted areas and to plan for the 2017 planting. However, as happened at Ring Island, American oystercatcher and other birds used the new patches of bare sediment for nesting, so this planting could not be implemented.

In summer 2016, the team developed the draft planting plan that would be implemented in 2017. To delineate elevation zones and the corresponding plant communities, the team conducted a thorough review of the Avalon biological benchmarks (Table 5) and tidal datums. The plan involved the following elevation zones and plant community compositions:

- **<2.03 NAVD88 (MHW)**: 100% *S. alterniflora*
- **2.03–2.39 NAVD88 (MHHW)**: 50% *S. alterniflora*, 25% *S. patens* and 25% *D. spicata*
- **2.39–2.85 NAVD88**: 50% *S. patens* and 50% *D. spicata*
- **2.85–3.03 NAVD88**: 50% *S. patens* and 50% *D. spicata*; a 50:50 ratio of *I. frutescens* and *Baccharis halimifolia* covering only 50% of the area
- **>3.03 NAVD88**: 50% *I. frutescens* and 50% *B. halimifolia*
- **Pooling areas**: 100% *S. alterniflora*

Figure 49. *At Avalon, Phase 2,* S. alterniflora *grew through some of the cracks in the dredged material.*

Based on the scientific literature, the marsh team hypothesized that the original marsh vegetation covered with less than 6 inches of dredged material would recover naturally during the first few growing seasons, growing through the dredged material. Therefore, only areas covered with 6 or more inches of dredged material were planted. Because the island had no natural seed source for the selected species and because the team wanted to prevent colonization by *P. australis*, they decided to plant 100% of the two highest elevation zones and lower three elevation zones (with one-third left unplanted as a control), and 50% of the re-formed pools (Fig. 50). The as-built elevation survey from March 2016 was used to map and quantify areas that had received less than 6 inches of dredged material, identify areas of pooling water, and delineate the different plant communities.

The monthly inspection prior to the May 2017 planting revealed that the dredged material had consolidated, which would impact the original planting plan. Therefore, the plant community boundaries (based on elevation) were re-delineated. The team decided to plant two-thirds of the placement areas and leave the rest unplanted to compare the effects of planting with natural recruitment. A NJ-licensed surveyor staked out the planting areas based on horizontal data, not elevation data. To test the concept that clumped plantings would reduce environmental stresses and improve plant survival and growth (Silliman et al. 2015), the lowest two elevation zones were planted in clumps while the higher zones were planted in a grid pattern. Pools were not planted.

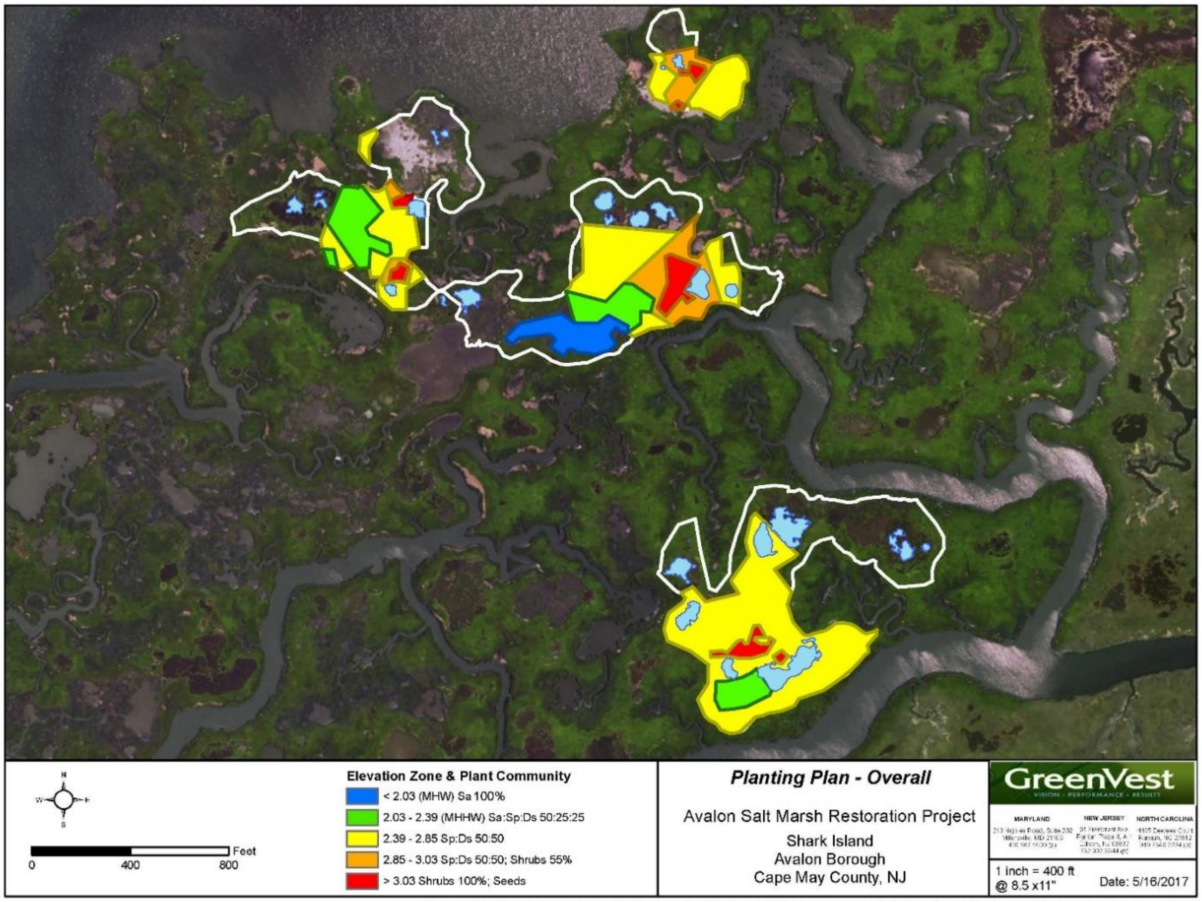

Figure 50. *Species selected in the Avalon Phase 2 planting plan were* Spartina alterniflora *(Sa),* S. patens *(Sp),* Distichlis spicata *(Ds),* Iva frutescens *(If), and* Baccharis halimifolia *(Bh).*

Over the course of nine days in early May 2017, eight people planted 106,708 plugs in 18.57 acres of the marsh; however, the actual planting deviated from the approved plan. In the field, it was apparent that the dredged material had consolidated even farther, as large areas of the marsh—mostly former pools—were at much lower elevations than recorded in the topographic survey from 10 months prior. In addition, healthy patches of *S. alterniflora* had colonized some areas. Using adaptive management in the field, the marsh team amended the planting plan to accommodate the elevation changes, gauging by eye, and to avoid existing vegetation.

Vegetation Die-Off Areas: Through spring and early summer 2016, the placement area seemed to be responding as expected, showing continued dewatering and plant growth. However, during the monthly inspection in July 2016 (five months after construction), the marsh team observed several patches of dead plants outside some of the placement areas that were directly adjacent to the containment (Fig. 51).

Figure 51. *At Avalon Phase 2, vegetation die-off (brown areas outside containment) occurred (top). The containment restricted tidal flow, keeping water higher outside the placement area than inside it. Photos from NJDEP.*

To understand why this vegetation die-off occurred and to evaluate its potential implications for plant growth throughout the site, the marsh team immediately delineated the affected areas and characterized them. It was important to understand whether the observed vegetation die-off areas indicated poor conditions in those areas only or throughout the site.

The bulk of the subsequent adaptive management at the Avalon project site was spurred by observations that the marsh team made during the July 2016 monthly site inspection:

- Areas where vegetation had died received only a very thin layer of dredged material and were 4–6 inches lower and, therefore, wetter than the adjacent placement area.
- Die-off occurred only adjacent to intact containment, and live plants occurred where containment was missing or severed.
- Patches of vegetation die-off seemed to occur at creek heads and along drainage pathways, but not elsewhere.
- Within the placement area, vegetation die-off occurred in areas of pooled water.
- There were also areas of vigorous plant growth both inside and outside the placement areas.

In light of these observations, the marsh team created several (not mutually exclusive) hypotheses to explain the cause of vegetation die-off and developed adaptive management actions to address the problem:

- **The containment acts as a physical barrier to surface water flow.** Water is retained outside or inside the placement area because it is either not flowing through the containment or flows through it very slowly, resulting in prolonged inundation.
    - **Adaptive management:** Remove the containment.
- **The placed dredged material acts as a physical barrier to surface and subsurface water flow.** The hydraulic spreading of dredged material from a stationary pipe likely caused sediments to sort by grain size, such that some areas of the placement area received material of homogenous composition. Areas dominated by silt or clay, which was observed adjacent to containment outside the placement area, could contain tightly packed material that either impeded the flow of subsurface water or impaired the function of plant roots. It is also possible that water was retained outside the placement area because the dredged material was blocking water flow.
    - **Adaptive management:** Dig runnels to improve drainage.
- **Altered sediment and water chemistry is inhibiting plant growth.** The chemical composition of the placed dredged material may be adversely affecting vegetation. The dredged material that was placed in the areas now experiencing vegetation die-off was predominantly composed of silt and clay, which may contain elevated concentrations of contaminants. Chemical factors of potential concern include metal toxicity, salt concentration, and highly acidic conditions that are created when mono-sulfidic sediment is exposed to oxygen (which were documented in the Avalon placement areas after construction). Alternatively, water flowing over and through the dredged material within the adjacent placement area carried solutes (e.g., salts, metals, acidic water) that concentrated in some areas, causing plant mortality.
    - **Adaptive management:** Investigate potential solutions or develop and implement a monitoring plan to answer questions about the problem (e.g., Why is it happening? Will it resolve without intervention? If so, within what timeframe? What does this mean for future projects?).
- **The weight of the placed dredged material is impacting plant survivorship.** The placed dredged material may have compacted the marsh substrate, including both the sediment and peat layer, impacting subsurface water flow or plant root function.
- **Site hydrology was altered by the elevation of the placed dredged material**. Site hydrology was altered simply as a function of the elevation of the placed dredged material.
- **Meteorological conditions killed plants.** Extreme short-term weather, such as drought and high temperatures during summer 2016, may have caused the plants to die around the marsh.

Before any adaptive management actions were implemented at Avalon, the marsh team conducted a variety of studies to investigate the potential cause(s) of the problem:

- **Die-off area characterization and mapping.** To evaluate the problem, the team first documented observations of the vegetation die-off areas during monthly site visits throughout 2016 and the following 2017 growing season. For each die-off area, they noted depth (thickness) of dredged material, presence of pooled water, presence (alive and dead) of plants and species, containment condition, presence of a drainage path, and color of the placed dredged material or sediment. Each die-off area was photographed and its limits were mapped using a Trimble GPS unit. To determine below-ground vegetation biomass, core samples were collected and permanent vegetation monitoring plots were established in the die-off areas. To observe water flow throughout the tidal cycle, trail cameras were set up to take photos of the die-off area and containment every 30 minutes.

- **Groundwater and surface water monitoring.** After the team observed unusual salinity and pH of ponded water and acidic soils, they began to monitor water chemistry in 2017. Their approach was to characterize surface water chemistry in salt marsh pannes and pools following placement of dredged material. Monitoring sites were chosen to test the effect of containment on vegetation, so sites were located both inside and outside containment and in die-off areas. The sampling frequency and timing were designed to capture the range of conditions post-placement, to understand the role of surface water chemistry in vegetation recovery, survival of plantings, and/or die-off. To determine the potential cause for surface water chemistry, the monitoring program also documented the water chemistry in groundwater within the emplaced dredged material. Surface and ground water in placement areas were compared with control sites and the reference site located at The Wetlands Institute.
- **Experimental removal of containment.** During the monthly site inspections, the marsh team often observed that water was retained directly outside or inside the containment surrounding the placement areas. They suspected that containment could be restricting the flow of surface water. However, immediate removal of all containment was not possible because of its high cost, the equipment needed (which could damage the marsh), and concerns that removing containment could jeopardize the integrity of the placed dredged material. Therefore, in November 2016, the team removed approximately 214 linear feet of containment from two die-off areas in order to answer key questions, such as: Is the die-off mitigated by containment removal? Is water still retained? Does the placed dredged material erode? What is the effort and cost to remove containment?

Based on initial results of the experimental removal of containment as well as observations of additional vegetation die-off areas, the marsh team determined that containment was inhibiting tidal flow and was a potential risk to new plantings. Therefore, prior to the 2017 planting, the team removed as much containment as the project maintenance budget would allow. They started removing it from the priority sections: those that bordered vegetation die-off areas and that crossed drainage paths. After they removed the priority sections, they created small openings in long continuous sections of containment in the non-priority areas to encourage drainage (Fig. 52). In March 2017, a crew of eight people, using no machinery, completed this work over three days. They removed or dismantled approximately 1,849 linear feet of containment. Segments of containment were either hauled off the marsh intact or cut open in place, allowing the coconut-fiber stuffing to loosen and spread over the marsh, while the netting was removed from the marsh. In September 2017, the team removed an additional several hundred linear feet of containment. Many of the wooden stakes that held containment down could not be efficiently removed from the marsh and were left in place. In later years, the stakes have been observed as places where wrack builds up.

Figure 52. *Avalon Phase 2: Containment was removed from this section (dark line curving from bottom center to upper left) and the biodegradable coconut fibers (right of line) from the containment were spread over the marsh. The elevated placement area is to the right.*

Figure 53. *Acid sulfate soils with a pH below 3.8 appeared reddish and were found in the higher, drier, and sandier portions of the Avalon placement area. Photo from NRCS.*

Acid sulfate soils: To further investigate soil chemistry at the Avalon site, soil scientists from the U.S. Department of Agriculture Natural Resources Conservation Service (NRCS) tested the placed dredged material in June 2017. They confirmed that the top layer of the higher, drier, and sandier sediments had acid sulfate conditions, with the pH in some areas falling below the detection limits (3.8) of their soil test. Sulfuric acid is produced when anoxic sulfidic sediments, like those found in the NJIWW channels, are exposed to oxygen (Natural Resources Conservation Service 2019). The areas of low pH were found within the rust-colored layer on top of some placement areas (Fig. 53). It was unknown how long these low pH conditions would last, but it was expected that the acids would be washed away by the tides over time. It was also unknown the degree to which low pH conditions might have prevented vegetation from establishing or led to the death of existing vegetation inside the placement areas or outside containment.

Fortescue Marsh Enhancement Project

For the Fortescue marsh enhancement component, dredged material placement was completed on March 20, 2016.

Initial Observations: During a site visit one month later (April 25, 2016), the marsh team observed vigorous patches of *S. alterniflora,* areas of pooled water inside and outside the placement area, and some areas of the marsh damaged by equipment.

Planting: As the project team planned to do a second round of dredged material placement in fall 2016, the marsh team decided not to plant the dredged placement areas in spring 2016. In the summer of that year, they created a draft planting plan to be implemented in 2017 (Fig. 54). To create the plan, the team thoroughly reviewed biological benchmarks (Table 6) and tidal datums to delineate elevation zones and the corresponding plant communities. The planting plan consisted of the following elevation zones and plant communities:

- **2.0–3.0 NAVD88**: 100% *S. alterniflora*
- **3.0–4.0 NAVD88**: 20% each *S. patens, D. spicata, Juncus gerardii, S. cynosuroides*, and *Solidago sempervirens*
- **3.5–4.0 NAVD88**: 33% *I. frutescens* and 67% *B. halimifolia*

The planting elevation zones were drawn using the as-built elevation survey from June 2016. Once they were drawn, the areas of each planting zone were calculated.

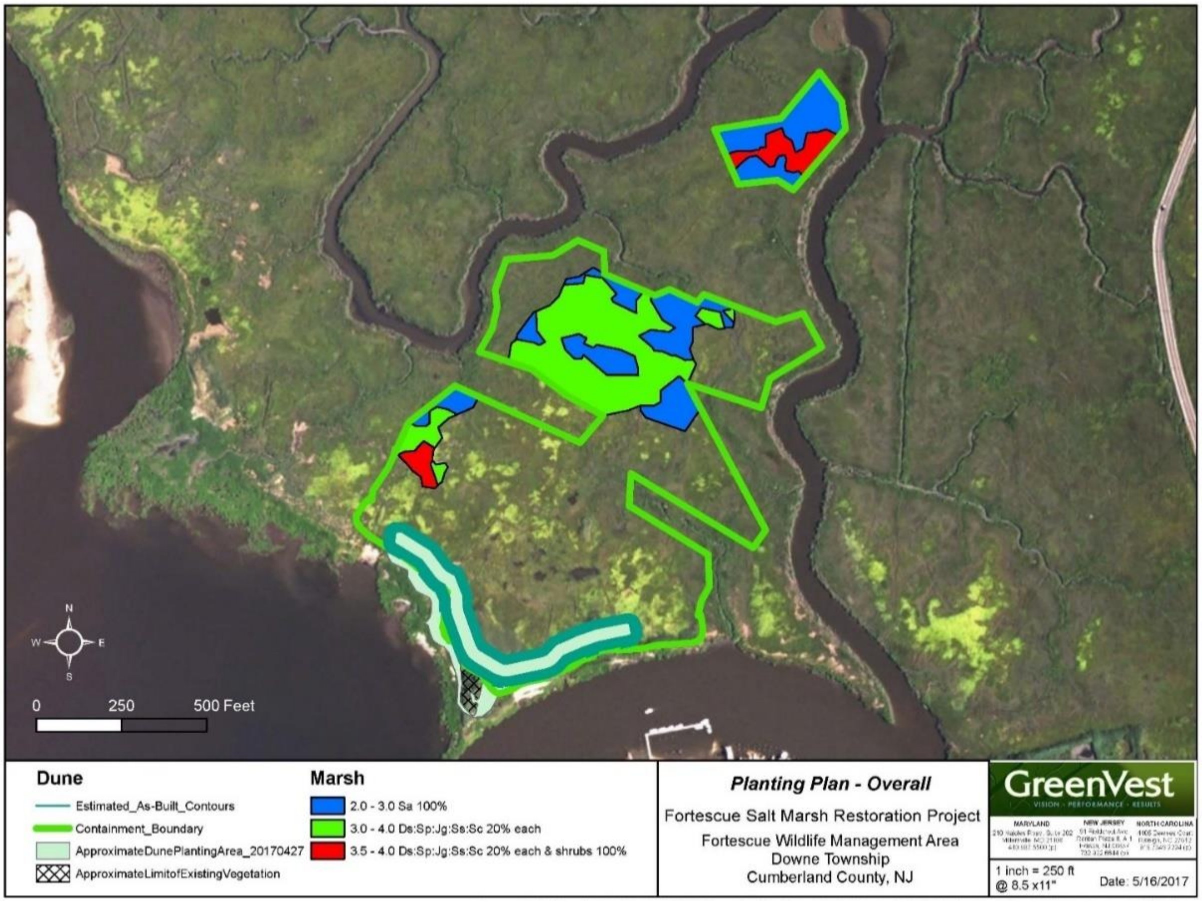

Figure 54. *Species selected for the Fortescue marsh enhancement component were* Spartina alterniflora *(Sa),* S. patens *(Sp),* Distichlis spicata *(Ds),* Juncus gerardii *(Jg),* S. cynosuroides *(Sc),* Solidago sempervirens *(Ss),* Iva frutescens *(If), and* Baccharis halimifolia *(Bh).*

In preparation for planting, the planting zones were staked out in April 2017. (Although a year had passed since the most recent elevation survey, the project team decided it was not necessary to conduct another one because, unlike at Avalon, the dredged material had a high sand content that would prevent it from consolidating very much.) In May 2017, the planting plan was implemented. However, because *S. alterniflora* colonized some of the planting areas and only unvegetated areas were planted, the plants were installed at a greater density than in the planting plan. Over the course of three days, eight people planted 27,765 plugs.

Containment: The Filtrexx SiltSoxx™ geotextile fabric would eventually break down into microplastics that are noxious in the aquatic environment; therefore, the team had decided at the outset to remove it entirely after placement. (The marsh team also wanted to remove it because they suspected that containment negatively affected hydrology at the site.) In May 2016, small sections of containment in placement area 2 were disassembled. The objectives of this management action were to: (1) determine whether removing some containment alleviated pooling inside the placement area, (2) evaluate the feasibility of removing containment on a larger scale, and (3) determine whether the placed dredged material would rapidly erode once it was no longer contained. The geotextile fabric was easy to cut and remove, and its woodchip mulch contents were dispersed across a small area of the marsh.

In early 2017, the marsh team weighed the potential outcomes of removing the rest of the containment versus leaving it in place. They determined that the potential risk of the containment to adversely impact site hydrology and the upcoming planting was greater than the risk of the dredged material eroding if the containment was removed. Therefore, over five days in March 2017, a crew of eight people disassembled approximately 14,816 linear feet of containment. In September 2017, the remaining containment on the site was broken down.

Fortescue Dune Restoration Component

On April 12, 2017, dredged material placement and grading for this project were completed.

Initial Observations: The ends of the dune were quickly eroded by storm-driven waves.

Planting: In early May 2017, immediately after construction, the dune was planted. Because the dune was constructed with dredged material that had a high sand content and was graded to design specifications, dewatering and consolidation were not expected to affect final elevations. Therefore, the planting plan could be implemented with much more certainty and without significant modifications. However, the final planting area was only 2.55 acres instead of the expected 2.90 acres, so the planting density was increased to accommodate this change. The dune was divided into four different areas for planting purposes:

- **Dune crest:** *Ammophila breviligulata* and *Panicum amarum* in a grid at 3-foot centers; *Myrica pensylvanica, Prunus maritima, Celtis occidentalis, Rhus copallinum*, and *Juniperus virginiana* at 8-foot centers.
- **Dune front face:** *A. breviligulata, P. amarum*, and *S. sempervirens* in a grid at 3-foot centers; *M. pensylvanica* and *B. halimifolia* at 8-foot centers.
- **Dune back face:** *P. amarum* in a grid at 3-foot centers; *P. maritima*, *C. occidentalis*, and *J. virginiana* at 8-foot centers
- **Phragmites treatment area:** *A. breviligulata* and *S. sempervirens* in a grid at 3-foot centers; *B. halimifolia* at 8-foot centers.

Aside from slightly modifying the dune planting plan, no other post-construction adaptive management was implemented for this project component.

Phase 7: Project Assessment

Monitoring and Data Evaluation

To document the initial response of salt marsh to dredged material placement, as well as to track and assess the trajectory of marsh response over the subsequent five years, a comprehensive monitoring plan was developed. The plan included collecting data on the placed dredged material, elevation, depth of placement, surface water elevation, vegetation, epifaunal macroinvertebrates, benthic infauna, fish, crabs, and birds. When possible, monitoring was initiated before the placement of dredged material at the marsh enhancement areas and control areas and utilized a BACI analysis design. The monitoring plan (and subsequent additional modeling and post-placement adaptive monitoring) was designed to answer specific research questions and to be useful to future similar projects in New Jersey. The complete monitoring plan is available as Appendix 1.

The monitoring used widely accepted, scientifically sound methods. Where possible, methods were adapted from the Salt Marsh Integrity Index Protocols used by U.S. Fish and Wildlife Service Region 5. The National Wildlife Refuges in New Jersey intended to use these protocols to monitor similar projects, and the project team intended the data from both the NJDEP and USFWS projects to be comparable.

Based on its experience and literature reviews, the project team knew that these types of projects generally do not show definitive trends until much longer than the two years of the NFWF grant period, which covered monitoring from 2015 to the summer of 2017. Therefore, they created the monitoring plan and secured the funds to extend beyond the end of the NFWF grant reporting period, through 2019, with some parameters monitored through 2021. To track the trajectory of marsh response, the project team prioritized the future monitoring of site elevation, vegetation, soil and water chemistry, benthic infauna, and avian surveys. A companion monitoring document (in preparation) will present the results of the monitoring of these projects through 2019.

Cost Analysis

This cost analysis is intended to provide those who are interested in developing similar projects with a general idea of the costs of the development, design, construction, and monitoring phases of the three pilot projects: Ring Island, Avalon (both Phase I and Phase 2) and Fortescue. Due to the complexity of these projects and the multiple partners involved, precise cost tracking was not possible, so the costs presented are approximate. They can be used to guide the development of future projects that use dredged material to enhance or restore salt marshes, as well as to inform the potential cost difference of traditional dredging projects that do not include marsh enhancement. The analysis does not include NJDEP staff time and other resources expended in project development, monitoring, data analysis, report preparation, and post-construction adaptive management.

It was not possible to separate the costs of the different project components at Ring Island (marsh enhancement and ENH creation), Avalon (Phase I and Phase 2 marsh enhancement), and Fortescue (marsh enhancement, dune restoration, and beach nourishment). In fact, the marsh enhancement projects could not have been implemented (nor could the channels have been dredged) without including these other project components. This may be characteristic of future projects that combine dredging and marsh projects: additional management alternatives for dredged material may be needed to make the projects viable.

Total Project Cost Comparisons

The total costs per CY of placed dredged material and per acre of habitat enhanced were the highest at Fortescue ($151 per CY and $467,000 per acre). Costs were lowest at Avalon ($45 per CY and $55,600 per acre; Table 11).

The largest portions (62.6% to 80.5%) of the costs were for construction, and the smallest portions (6.1% to 12.1%) were for development and design. Total costs varied among the projects by a factor of 3.4 per CY dredged ($151 vs. $45) and by a factor of 8.4 per acre of habitat enhanced ($467,000 vs. $55,600).

Table 11. Comparison of Total Project Costs ($)

	Ring Island	Avalon	Fortescue
Development and Design	42,000	302,000	479,000
Construction	428,000	1,762,000	3,913,000
Monitoring	214,000	439,000	469,000
Total Cost	**$684,000**	**$2,503,000**	**$4,861,000**
Total Volume Dredged	7,000 CY	55,300 CY	32,100 CY
Cost per CY	**$98**	**$45**	**$151**
Total Area Enhanced	2 acres	45 acres	10.4 acres
Cost per Acre Enhanced	**$342,200**	**$55,600**	**$467,000**

Project Development and Design Costs

For the purpose of this analysis, project development and design costs (Table 12) include costs associated with the initial ecological assessment of marsh condition, sediment sampling (navigation channel and marsh surface), engineering, and permitting. Within these categories, engineering costs were the highest percentage for the projects at Ring Island (59.5%; conducted by the USACE-OP) and Fortescue (49.2%; conducted by GreenVest). Sediment analysis costs were the highest portion (48.9%) for the Avalon project, where two rounds of sampling were conducted.

Table 12. Comparison of Project Development and Design Costs

	Ring Island	**Avalon**	**Fortescue**
Ecological Assessment (Initial Marsh Condition)	n/a	$31,000	$17,000
Sediment Sampling	$5,000	$147,000	$149,000
Engineering	$25,000	$93,000	$235,000
Permitting	$12,000	$31,000	$77,000
Total	**$42,000**	**$302,000**	**$478,000**
Total Volume Dredged	7,000 CY	55,300 CY	32,100 CY
Cost per CY	**$6.00**	**$5.50**	**$15.00**
Total Area Enhanced	2 acres	45 acres	10.4 acres
Cost per Acre Enhanced	**$21,000**	**$6,700**	**$46,000**

Costs of the Ecological Assessment of Initial Marsh Condition: As a percentage of the total project costs, these costs were negligible across the project sites, with a maximum of 1.2% at Avalon. However, these costs do not include the considerable time spent by the TNC-NJ staff to initially identify the three marsh enhancement sites *via* desktop analyses and site visits, NJDEP's costs to evaluate the project sites, and initial staff coordination of the marsh enhancement pilot projects with their associated dredging projects prior to the formal start of the grant period. For future similar projects, these costs will likely be higher both in absolute terms and as a percentage of total project costs.

The Ring Island placement areas were small test plots, so no formal ecological assessment of marsh condition was completed prior to construction. However, prior to final site selection, qualitative information was collected *via* desktop analysis and site visits to evaluate the condition of the marsh and document the location of nesting birds. More comprehensive ecological assessments were completed at Avalon and Fortescue, including multiple site visits to collect baseline information on several site characteristics. In addition, as required by the National Environmental Policy Act (NEPA), USACE completed an Environmental Assessment in July 2014 for the Ring Island and Avalon projects. The NEPA requirements for the Fortescue project were addressed as part of the USACE regulatory review of the project's permit application.

Costs of Sediment Sampling: At Avalon and Fortescue, sediment sampling costs were similar and accounted for 48.9% and 31.2%, respectively, of project development and design costs, and 5.9% and 3.1%, respectively, of total project costs. In order for dredged material to be used for marsh enhancement, both the sediment to be dredged from the channels and the existing marsh surface sediment had to be tested to determine their physical and chemical composition. The cost for this evaluation depended on the types of analyses conducted on the samples and the number of samples collected, which varied with the size of the placement areas and the volume of sediment to be dredged from the channels. Chemical analysis is not required when dredged material is greater than 90% sand, as at Ring Island.

Costs of Engineering: Engineering costs include any expenditure associated with creating the designs and specifications for each project. As a percentage of total project costs, engineering costs were similar for all three projects: 3.7% for Ring Island and Avalon, and 4.8% for Fortescue.

Costs of Permitting: As a percentage of total project costs, the permitting cost for all three projects was low (similar to ecological assessment costs), ranging between 1.2% and 1.8%.

Construction Costs

Construction costs for the three pilot projects included the oversight and implementation of the dredging and dredged material placement operations, and the installation and removal of containment (Table 13). Construction costs ranged from 62.6% to 80.5% of total project costs, with dredging (including dredged material placement onto the marsh) accounting for 52.7% to 60.2% of total project costs. Construction costs per CY dredged varied by a factor of 3.8 among the projects and by a factor of 9.6 per acre of habitat enhanced. Dredging costs (including dredged material placement) were the most expensive part of the construction costs for all three projects (92% at Ring Island, 75% at both Avalon and Fortescue). The cost of containment was negligible at Ring Island and accounted for 12.4% and 14.9%, respectively, of the construction costs at Avalon and Fortescue.

Costs of Oversight: Oversight costs included the staff time from the USACE-OP, NJDOT-OMR, and marsh team members who served as on-site inspectors during construction. This staff time accounted for 4.9% of total construction costs at Ring Island, 10.3% at Fortescue, and 12.8% at Avalon. Oversight costs were highest for the Fortescue project ($12.60 per CY dredged and $39,000 per acre of habitat enhanced). The oversight and management costs were similar per CY dredged and acre of habitat enhanced at Ring Island ($3.00 per CY and $10,500 per acre) and Avalon ($4.07 per CY and $5,000 per acre).

Table 13. Comparison of Construction Costs

	Ring Island	**Avalon**	**Fortescue**
Oversight/Management	$21,000	$225,000	$405,000
Dredging	$395,000	$1,319,000	$2,925,000
Containment	$13,000	$218,000	$583,000
Total	**$429,000**	**$1,762,000**	**$3,913,000**

Total CY Dredged	7,000 CY	55,300 CY	32,100 CY
Cost per CY	**$61.00**	**$32.00**	**$122.00**
Total Acres Enhanced	2 acres	45 acres	10.4 acres
Cost per Acre Enhanced	**$214,500**	**$39,000**	**$376,000**

Costs of Containment: At Ring Island, containment was limited to straw bales and silt fence (costing approximately $500) around the ENH component, including the use of a small compact track loader with operating personnel to construct a sand berm; the dredged material placement areas were not contained. Containment accounted for only 3% of the Ring Island construction costs. At Avalon, the marsh team installed, and eventually removed, coconut-fiber logs around most of the placement areas. At Fortescue, Filtrexx SiltSoxx™ were installed, and eventually removed, around most of the designed placement areas (but ultimately only 6.6 acres of the planned 22 acres received sediment, which increased the ultimate cost per acre enhanced).

Containment accounted for 12.4% of the construction costs at Avalon and 14.9% of the construction cost at Fortescue. At Fortescue, containment costs per CY dredged ($18.20) and per acre of habitat enhanced ($56,000) were substantially greater than at Ring Island and Avalon ($1.80 and $3.90 per CY; $4,800 and $6,500 per acre, respectively). This was at least partly because the placement areas in the design for Fortescue were almost four times greater in area than the placement areas that ultimately received dredged material. Had all of the designed placement areas at Fortescue received dredged material, the relative costs of containment would have been much lower.

Costs of Dredging. The cost of dredging for each project differed significantly. Dredging costs ranged from 52.7% to 60.2% as a percentage of total project costs, and 74.8% to 92.0% as a percentage of total construction costs. Also, while there were major differences in the cost of dredging per CY (which varied by a factor of 3.8 among the projects), the dredging cost per acre habitat enhanced varied among the projects by even more: a factor of 9.6. The dredging at Fortescue ($91.00 per CY) cost more per CY than at Ring Island ($56.40 per CY) and Avalon ($23.90 per CY), while the costs per acre habitat enhanced also varied considerably (at Fortescue, $281,000 per acre; at Ring Island, $197,500 per acre; and at Avalon, $29,300 per acre).

Monitoring Costs

As a percentage of total project costs, monitoring costs (Table 14) ranged from a low of 9.7% (Fortescue) to a high of 31.3% (Ring Island). While each of the three pilot projects were monitored for the three-year NFWF grant period, Ring Island and Avalon were also monitored for topography and some vegetation metrics in 2014, prior to the start of the grant. Per acre of enhanced habitat, monitoring costs were highest at Ring Island and lowest at Fortescue. Note that these costs do not include the additional monitoring conducted by USACE-ERDC to expand the understanding of projects that use dredged material to restore marshes.

Monitoring included topographic surveys that were conducted before construction, immediately after construction (as-built surveys), and after construction once the placed dredged material had time to settle and consolidate. Topographic survey costs per acre of habitat enhanced were much lower at Avalon ($2,360 per acre) and were higher at Fortescue ($14,970 per acre) and Ring Island ($17,200 per acre).

Some the reasons for the difference in the cost of monitoring per acre were that the time and expense of getting to the sites was the same regardless of whether a full day of sampling was needed. Another reason was that a minimum number of samples were required to capture variability at the smaller sites and to cover a control site. In addition, nesting success of birds was monitored at Ring Island, and not at the other sites.

Table 14. Comparison of Monitoring Costs

	Ring Island	Avalon	Fortescue
Topography	$34,000	$106,000	$156,000
Water Level	n/a	$55,000	$55,000
Plants	$31,000	$44,000	$33,000
Birds	$81,000	$54,000	$60,000
Benthic Infauna & Soil Properties	$67,000	$70,000	$67,000
Fish and Crabs	n/a	$101,000	$99,000
Total	**$213,000**	**$430,000**	**$479,000**
Total Acres Enhanced	2 acres	45 acres	10.4 acres
Cost per Acre Enhanced	**$107,000**	**$9,764**	**$45,135**

Post-construction Planting and Adaptive Management Costs

Planting costs consist of the costs of purchasing plant plugs from a nursery and hiring a crew to plant them (Table 15). These costs are not included in the total project costs (Table 11) because planting may not be necessary for other similar projects if plants naturally recolonize the placement areas. Per acre of enhanced habitat, the planting costs increased the total project costs by 4.6% at Ring Island, 3.4% at Fortescue, and 26.7% at Avalon.

Table 15. Comparison of Planting Costs

	Ring Island	Avalon	Fortescue
Planting	$19,000	$280,000	$142,000
Acres Planted	1.2 acres	18.86 acres	8.9 acres
$ per Acre	**$15,700**	**$14,850**	**$16,000**

Post-construction (non-monitoring) adaptive management activities were limited at the marsh enhancement sites and consisted of adjusting the planned planting design in the field in response to altered conditions on the marsh. Adaptive management/maintenance activities at the Ring Island ENH included vegetation removal and the placement of additional sandy dredged material; the costs of these activities are not available.

Discussion of Cost Analysis

The primary goal of this cost analysis was to help inform the development of similar future projects. While it would be useful to determine whether combining the two types of projects—dredging and habitat enhancement—would cost less than implementing them separately, this comparison is difficult because a wide range of site and project conditions affect project costs. In addition, total project costs are affected by project-specific objectives and, potentially, multiple project habitat components. These factors make it difficult to draw definitive conclusions about the costs of marsh enhancement/dredged material beneficial use projects. In addition, because pilot projects like these tend to be more expensive, future projects would cost less as they become more common and as dredged material placement volumes increase, due to factors such as less dredge downtime, more accurate placement procedures, and the ability to work safely at night.

However, the cost of these three pilot projects in New Jersey can be compared with the cost of other similar marsh enhancement projects elsewhere in the country. For all three pilot projects in New Jersey, the total project costs were $56,000 per acre at Ring Island, $342,200 per acre at Avalon, and $467,365 per acre at Fortescue (Table 11). In a recent paper, Bayraktarov et al. (2016) reported total restoration costs of salt marshes in developed countries in 2010 U.S. dollars (median: $61,160 per acre; average: $421,730 per acre), equivalent to 2017 U.S. dollars (median: $69,581 per acre; average: $479,800 per acre). However, it is unknown whether dredged material was used in the projects analyzed in that paper. The Nature Conservancy in Rhode Island (TNC-RI) recently completed a project along the Narrow River Inlet that used dredged material to increase the elevation of 30 acres of salt marsh. Unlike the New Jersey pilot projects, which were managed by multiple entities, TNC-RI was the sole project manager and contracting entity for the major project activities. To design, construct, and monitor that project, the estimated costs were $63.74 per CY dredged and $43,399 per acre restored (S. Cummings, personal communication). In another Rhode Island project at Ninigret Pond, about 20 acres of salt marsh were restored using dredged material at a cost approximately $24 per CY dredged and $80,978 per acre restored (C. Chaffee, RI Coastal Resources Management Council, personal communication).

Dredging in New Jersey, which is conducted by the state, USACE, municipalities, and private entities, also incurs a broad range of costs. Based on estimates from the NJDOT-OMR, traditional dredging projects, in which dredged material is pumped to a confined disposal facility (CDF), cost an average of $45 per CY (W. Douglas, personal communication). The costs of a recent dredging project conducted by the Borough of Avalon in New Jersey ranged between $33 per CY (excluding the cost to first empty the CDF) and $76 per CY (including the cost to empty a portion of the CDF). Dredging projects conducted by the USACE-OP typically cost $15 to $18 per CY dredged, not including any fees to empty an CDF, which can make a project prohibitively expensive (M. Chasten, personal communication). Although the per-CY total project costs of the Ring Island and Fortescue projects were significantly higher ($98 per CY and $152 per CY, respectively) they included all aspects of dredge material placement—design, construction, and monitoring—which are not part of a typical dredging-only project.

The question remains: Will combining dredging projects and marsh enhancement projects result in net cost savings, compared with separately implementing the projects? Also, would the marsh enhancement projects even be constructed if an associated dredging project did not need a non-traditional dredged material management option?

Since this is not an analysis comparing benefits and costs, the estimates of the benefits achieved (beyond acres of marsh enhanced) do not include the full economic value of the beneficial use of dredged material for salt marsh enhancement. Marshes provide many monetary benefits that are difficult to measure, including water filtration, nursery habitat for most commercially and recreationally harvested fish and shellfish, wave attenuation, and storm-surge reduction. These ecosystem services would be lost—and the coastal ecosystem would be less resilient—if stressed marshes were not restored and ultimately disappeared. Also, similar projects in the Gulf of Mexico show that as more coastal restoration projects are implemented, they have the potential to support businesses and could lead to the creation of new jobs, opportunities for workforce development, and innovation (Lowe et al. 2011; Stokes et al. 2012).

Factors Influencing New Jersey Pilot Project Costs. A variety of factors influenced the difference in cost among the three pilot projects, especially between Fortescue and Avalon. However, the project team cannot definitively state the extent to which each factor affected the total cost of the projects. Total project costs, development and design costs, and construction costs per CY dredged varied among the projects by a factor of 2.7 to 3.8, but varied by a factor of 6.9 to 9.6 per acre of habitat enhanced (Table 10). In addition, while the dredging cost per CY varied by a factor of 3.8, the dredging cost per acre of habitat enhanced varied among the projects by a much larger factor (9.6). This suggests that the major cost variables for these types of projects are not the volume of dredged material placed, but instead site- and design-specific characteristics, as well as the objectives, of the marsh enhancement projects. Several differences in scope, design, and contracting between Avalon and Fortescue may have contributed to the higher relative costs at Fortescue (Table 16). These differences include:

- *Number of Design Elements.* The Fortescue project consisted of three components: marsh enhancement, dune restoration, and beach restoration. This required additional costs in design and engineering, project oversight and management, and mobilization of the dredging equipment.
- *Sediment Analysis.* The sediment sampling costs were likely lower at Fortescue because (1) the volume of sediment to be dredged was smaller, (2) some of the sediment samples from the navigation channel were greater than 90% sand and thus needed no additional chemical testing, and (3) the placement areas were smaller so fewer samples were needed from the marsh. In addition, at Avalon there were two separate rounds of sampling and analysis of sediments from both the NJIWW and the marsh.

- *Engineering.* At Fortescue, more designs were needed, one for each of the three components: marsh, dune and beach. In addition, the marsh enhancement component had more design elements than the marsh enhancement designs for the Ring Island and Avalon projects. Also, Winter Storm Jonas eroded the existing shoreline, resulting in the need to update the dune restoration design.
- *Permitting.* The USACE does not issue permits to itself for dredging navigation channels, so the permitting costs were lower for the Ring Island and Avalon projects than for the Fortescue project. Note, however, that the permitting costs for these two sites did not include the cost to the USACE of preparing the NEPA Environmental Assessment for the projects. The Fortescue project required permits from both the NJDEP and USACE (which would be the case for most future similar projects). In addition, the re-design of the Fortescue dune restoration required permit modifications.
- *Designed vs. As-Built.* The Fortescue marsh enhancement project was expected to be approximately 22 acres in size and, therefore, the initial monitoring, design, and containment was for this area. However, weather and contracting delays reduced the final placement area to only 6.6 acres; thus, the final per-CY and per-acre costs were much higher.
- *Type of Dredging Contract.* The cost of projects can be greatly influenced by the type of contract used, the contracting process, the assumption of cost risks, and the design of the project. For the Avalon project, the dredge was leased on a per-day basis. Therefore, the USACE-OP absorbed the cost of dredge downtime (these costs are included in the cost analysis) when dredging was stopped (e.g., to let the dredged material settle, during inclement weather). For the Fortescue project, the dredging contractor was under NJDOT-OMR's performance-based contract, which paid by dredged material volume and some other line-item project expenses (e.g., containment). Therefore, to be paid the total contract amount, the dredge contractor needed to complete the entire job. Thus, while the USACE-OP assumed some of the "risk" and associated costs of the Avalon project (lowering the costs to an unknown degree), these "risks" were assumed by the dredge contractor at Fortescue (increasing the costs to an unknown degree). In the proof-of-concept stage of projects that use dredged material to enhance salt marshes, a per-day lease-of-plant dredging contract, rather than the typical performance-based contract, may be more economical. With the per-day contract at Avalon, the risk of unexpected costs was borne by USACE-OP; with the performance-based contract at Fortescue, the risk was borne by the dredge contractor. Many factors remain unknown for these types of projects, such as design costs, dredged material placement duration, and dredged material settlement time. At Avalon, because the dredge company was paid regardless of whether it was dredging, the company was willing to stop dredging when needed and let the project team experiment with a variety of placement methods at locations within the larger placement area. This also led to a more collaborative relationship between the dredge company and the project team, further fostering innovation.
- *Containment*. At Fortescue, containment costs per CY dredged ($18.16) and per acre of habitat enhanced ($56,060) were substantially greater than at Avalon ($3.90 per CY and $4,840 per acre). At Fortescue, containment consisted of a double row (with some stacking) that was installed around a 22-acre placement area, but only 6.6 acres received sediment. At Avalon, containment

consisted of only a single row, and it was not needed around the entire perimeter because the existing topography and vegetation in some areas of the Avalon site provided a natural barrier to slurry runoff.

Costs of Each Project Phase Compared with Total Project Costs (Table 17). Construction was the greatest cost (63%–80% of total project costs), with dredging and dredged material placement, combined, accounting for 52%–60% of total project costs. As a percentage of the total project costs, sediment sampling, containment, and planting varied with each project. However, at most, any one of these activities accounted for no more than 12% of the total project costs.

Table 16. Comparison of Design and Construction Costs for Avalon and Fortescue			
Factor	**Avalon**	**Fortescue**	**Notes**
Amount of dredged material	55,300 CY	32,100 CY	Larger projects potentially cost less per CY than smaller projects
Area of habitat enhanced	~45 acres	~10.4 acres	Fortescue: did not construct all that was designed and prepared
Project components	Marsh only	Marsh, dune, and beach	Fortescue: more designs and equipment mobilizations
Engineering	Marsh only	Marsh, dune, and beach	Fortescue: additional design components
Permitting	NJDEP only*	NJDEP and USACE permits	Fortescue: permit modification needed for dune
Type of dredging contract	Lease-of-plant (USACE-OP)	"Typical" (NJDOT-OMR)	USACE-OP: $/day NJDOT-OMR: $/CY dredged
Dredge mobilization	Coordinated with other projects	Multiple mobilizations	Avalon: dredge "shared" with 5 other USACE-OP projects
Containment	Single row Coconut-fiber logs	Double row Filtrexx SiltSoxx™	Fortescue: fewer acres contained. Avalon: more linear feet

*Environmental Assessment conducted by USACE pursuant to NEPA.

Table 17. Comparison of Total Project Costs for Marsh Enhancement/Dredged Material Beneficial Use Pilot Projects			
PROJECT PHASE			
	Ring Island	**Avalon**	**Fortescue**
Total Costs	$684,000	$2,503,000	$4,861,000
Phases 1, 2 & 3: Development, Design, and Permitting	6%	12%	10%
Phase 5: Construction	63%	70%	80%
Phase 7: Monitoring	31%	18%	10%
PHASE SUB-COMPONENTS			
Sediment Sampling	0.7%	6%	3%
Dredging	58%	52%	60%
Containment	2%	9%	12%
Planting	3%	11%	3%

Supplemental Cost Analysis: Mordecai Island

Another project conducted by the USACE-OP offers additional insights into the costs of using dredged material for marsh enhancement/restoration. Mordecai Island is a 45-acre uninhabited coastal salt marsh island located in Barnegat Bay (Ocean County, NJ). It supports a variety of breeding and migratory bird species, including American oystercatchers and black skimmers. The western shorelines of the island have eroded significantly, and a large cut has formed on the northwestern section, dividing the island into two segments. The island is adjacent to a section of the NJIWW that required dredging. Although this project differs from the three pilot projects in that dredged material was not placed on an existing marsh, it is nevertheless useful for comparing costs.

Led by the USACE-OP in 2015, the Mordecai Island project aimed to restore the island by connecting its two segments. Approximately 25,000 CY of sandy dredged material from the NJIWW channel was used to bring the gap between the two sections up to the elevation of the adjacent marsh. To hold the placed dredged material in place during construction, the dredging contractor used project-specific placement techniques, a small track loader, and a turbidity curtain along the along the eastern side of the placement area to protect submerged aquatic vegetation. (The curtain was jetted into the bay bottom and floated with the tides.) No containment was used on the western edge of the placement area, allowing water from the hydraulically placed dredged material to drain from the site. The placed dredged material raised the elevation approximately 3.5 ft (a range of -1 ft to +2.5 feet MLW) to better stabilize the placement area. The site was planted in May 2016.

Compared with the three pilot projects, the Mordecai Island project cost less ($33) per CY dredged, but the range of costs per acre of marsh enhanced were comparable ($277,800) (Table 18). The use of less containment at Mordecai Island contributed to this difference. Factoring in an additional $85,000 in planting costs on Mordecai Island, the cost of the project was approximately $37 per CY dredged and $305,200 per acre enhanced. As was the case for the three pilot projects, construction accounted for the highest percentage (82%) of total project costs, with the primary construction cost being dredging and dredged material placement. The cost per CY dredged and per acre restored for the Mordecai Island project are comparable with both routine dredging and marsh enhancement projects.

At Mordecai Island, many cost efficiencies were realized due to the design of the project, contracting strategies, and the dredging and dredged material placement techniques. Pre-construction data were collected (i.e., baseline monitoring), including marsh biological benchmarks (elevation of plant communities), physical and chemical characteristics of sediment, topography, and hydrography. Additional data from a separate USACE planning study of the island (USACE 1135 Ecosystem Restoration Investigation) also informed the design; this study provided most of the ecological assessment data that were used to support permitting for the project. Post-construction monitoring, which is ongoing, includes topography, hydrography, and bird nesting, as well as other data collected by other agencies and partners.

Table 18. Total Costs of the Mordecai Island Project	
Development and Design	
Ecological Assessment (Initial Marsh Condition)	$0
Sediment Sampling	$90,000
Engineering Design	$15,000
Permitting	$20,000

Total	***$125,000***
Construction	
Oversight/Management	$31,000
Dredging	$558,000
Containment	$91,000
Total	***$680,000***
Monitoring	
Topography, Avian, Vegetation	**$25,000**
Total	***$25,000***
Total Cost	**$830,000**
Total Volume Dredged	25,000 CY
Cost per CY	**$33**
Total Area Enhanced	3 ac.
Cost per Acre Enhanced	**$277,833**

Cost Analysis Summary

The project team conducted this high-level cost analysis to better understand the major costs of projects that use dredged material to enhance salt marshes and to inform discussions about the possible cost savings of combining dredging projects with marsh enhancement or restoration projects. Costs are unique to each individual project and are affected by many variables, some of which cannot be controlled (e.g., weather). As more projects like these are implemented in New Jersey and throughout the Northeast, more information-sharing may reduce the costs of design, permitting, construction, and monitoring. Additional research into the costs and benefits of these types of projects may inform decisions about the value of restoring and enhancing salt marshes, and reveal whether combining project types is a more cost-efficient way to accomplish multiple ecological, economic, and social goals.

References

Bayraktarov, E., M.I. Saunders, S. Abdullah, M. Mills, J. Beher, H.P. Possingham, P.J. Mumby, and C.E. Lovelock (2016). The cost and feasibility of marine coastal restoration. *Ecological Applications,* 26: 1055–1074. doi:10.1890/15-1077

Berkowitz, Jacob F., Candice Piercy, Tim Welp, and Christine VanZomeren (2019). Thin Layer Placement: Technical Definition for U.S. Army Corps of Engineers Applications. ERDC TN-19-1. ERDC Vicksburg United States, 2019.

Bertness, M. D., P.J. Ewanchuk, and B.R. Silliman (2002). Anthropogenic modification of New England salt marsh landscapes. *Proceedings of the National Academy of Sciences*, 99(3): 1395–1398.

Cahoon, D.R. and G.R. Guntenspergen (2010). Climate change, sea-level rise and coastal wetlands. *National Wetlands Newsletter*, 32(1): 8–12.

Cahoon, D.R., D.J. Reed, A.S. Kolker, M.M. Brinson, J.C. Stevenson, S. Riggs, R. Christian, E. Reyes, C. Voss, and D. Kunz (2009). Coastal wetland sustainability. In: Titus, J.G. (lead author) *Coastal Sensitivity to Sea-level Rise: A Focus on the Mid-Atlantic Region,* pp. 57–72. U.S. Climate Change Science Program, Washington, D.C.

Church, J.A. and N.J. White (2011). Sea-level rise from the late 19th to the early 21st century. *Surveys in Geophysics*, *32*(4–5): 585–602.

Daiber, F.C. (1986). *Conservation of Tidal Marshes*. New York. Van Nostrand Reinhold. Print.

Ganju, N.K., Z. Defne, M.L. Kirwan, S. Fagherazzi, A. D'Alpaos, and L. Carniello (2017). Spatially integrative metrics reveal hidden vulnerability of microtidal salt marshes. *Nature Communications,* 8(1): 1–7.

Hartig, E.K., V. Gornitz, A. Kolker, F. Mushacke, and D. Fallon (2002). Anthropogenic and climate-change impacts on salt marshes of Jamaica Bay, New York City. *Wetlands*, 22(1): 71–89.

Kennish, M.J., B.M. Fertig, and G. Petruzzelli (2012). Emergent Vegetation: NERR SWMP Tier 2 Salt Marsh Monitoring in the Jacques Cousteau National Estuarine Research Reserve. *National Estuarine Research Reserve Program (NOAA) Report, Institute of Marine and Coastal Sciences, Rutgers University, New Brunswick, New Jersey*.

Kirwan, M.L. and J.P Megonigal (2013). Tidal wetland stability in the face of human impacts and sea-level rise. *Nature*, 504(7478): 53–60.

Kreeger, D., J. Moody, M. Katkowski, M. Boatright, and D. Rosencrane (2015). Marsh futures: Use of scientific survey tools to assess local salt marsh vulnerability and chart best management practices and interventions. Partnership for the Delaware Estuary, Wilmington, DE. PDE Report No. 15-03.

Linhoss, A.C., G. Kiker, M. Shirley, and K. Frank (2015). Sea-level rise, inundation and marsh migration: Simulating impacts on developed lands and environmental systems. *Journal of Coastal Research*, 31(1): 36–46.

Long, E.R., D.D. MacDonald, S.L. Smith, and F.D. Calder (1995). Incidence of adverse biological effects within ranges of chemical concentrations in marine and estuarine sediments. *Environmental Management,* 19(1): 81–97.

Lotze, H.K., H.S. Lenihan, B.J. Bourque, R.H. Bradbury, R.G. Cooke, M.C. Kay, S.M. Kidwell, M.X. Kirby, C.H. Peterson, and J.B.C. Jackson (2006). Depletion, degradation and recovery potential of estuaries and coastal seas. *Science,* (5781): 1806.

Lowe, M., S. Stokes, and G. Gereffi (2011). New Markets for Established Firms. Duke University Center on Globalization, Governance and Competitiveness.

McDonough, F.M., G.A. Boehm, and W.S. Douglas (1999). Dredged material management in New Jersey: A multifaceted approach for meeting statewide dredging needs in the 21st century. *In Proceedings of the 31st Annual Dredging Seminar, Western Dredging Association*, pp. 15–18. https://www.nj.gov/dep/passaicdocs/docs/NJDOTSupportingCosts/HIST-PAPER-MCDONOUGH-DOUGLAS-DREDGEMATMGMTNJ.pdf

Mitsch, W.J. and J.G. Gosselink (2007). *Wetlands*. Hoboken. ed: John Wiley & Sons, Inc.

Mitsch, W.J. and R.F. Wilson (1996). Improving the success of wetland creation and restoration with know-how, time and self-design. *Ecological Applications,* 6(1): 77–83.

Moreno-Mateos, D., M.E. Power, F.A. Comín, and R. Yockteng (2012). Structural and functional loss in restored wetland ecosystems. *PLoS Biology* 10(1), e1001247.

Narayan, S., M.W. Beck, P. Wilson, C.J. Thomas, A. Guerrero, C.C. Shepard, B.G. Reguero, G. Franco, J.C. Ingram, and D. Trespalacios (2017). The value of coastal wetlands for flood damage reduction in the Northeastern USA. *Scientific Reports,* 7: 9463.

National Oceanographic and Atmospheric Administration (2019). Relative Sea Level Trend: 8534720 Atlantic City, New Jersey. https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=8534720 Accessed July 1st, 2019.

National Oceanographic and Atmospheric Administration (2012). VDatum Manual for Development and Support of NOAA's Vertical Datum Transformation Tool, VDatum. Version 1. 01, June 2012.

Neckles, H.A. and M. Dionne (2000). Regional standards to identify and evaluate tidal wetland restoration in the Gulf of Maine. Wells National Estuarine Research Reserve Technical Report, Wells, ME, 21.

New Jersey Department of Environmental Protection (2007). Valuing New Jersey's Natural Capital: An Assessment of the Economic Value of the State's Natural Resources.

Niedowski, N.L. (2000). New York State salt marsh restoration and monitoring guidelines. New York State Department of State, Division of Coastal Resources.

Natural Resources Conservation Service (2019). Soil Survey Technical Note 430-SS-11: Acid Sulfate Soils in the Coastal and Subaqueous Environment.

Nyman, J.A., R.J. Walters, R.D. Delaune, and W.H. Patrick Jr. (2006). Marsh vertical accretion via vegetative growth. *Estuarine, Coastal and Shelf Science*, 69: 370–380.

Partnership for the Delaware Estuary (2012). The Technical Report for the Delaware Estuary and Basin. Partnership for the Delaware Estuary (*Chapter 5—Intertidal Aquatic Habitats).* PDE Report No. 12-01, 255 pages.

Ray, G.L. (2007). Thin layer placement of dredged material on coastal wetlands: A review of the technical and scientific literature. ERDC/EL TN-07-1.

Reimold, R. J., M. A. Hardisky and P. C. Adams (1978). The effects of smothering a *Spartina alterniflora* salt marsh with dredged material. *Dredged Material Research Program Technical Report D-78-38.* Vicksburg, MS: U.S. Army Engineer Waterways Experiment Station.

Silliman, B.R., E. Schrack, Q. He, R. Cope, A. Santoni, T. van der Heide, R. Jacobi, M. Jacobi, and J. van de Koppel (2015). Facilitation shifts paradigms and can amplify coastal restoration efforts. *Proceedings of the National Academy of Sciences*, 112(46): 14296–14300.

Stokes, S., S. Wunderink, M. Lowe, and G. Gereffi (2012). Restoring gulf oyster reefs: Opportunities for innovation. Duke University Center on Globalization, Governance and Competitiveness. Retrieved from http://www.cggc. duke.edu/pdfs/CGGC_Oyster-Reef-Restoration.pdf

The Nature Conservancy. (n.d.). Coastal Resilience Mapping Portal: New Jersey Regional Planning App. https://maps.coastalresilience.org/newjersey/

The Nature Conservancy. *Coastal Resilience: Priority conservation areas for New Jersey Shore*. Layers used: Risk Explorer and priority conservation areas where habitats likely reduce risk now. [map scale 1:63,360]. Map generated by Metthea Yepsen: using "Coastal Resilience Mapping Portal: New Jersey." <https://maps.coastalresilience.org/newjersey/> (accessed Fall 2013 and Spring 2014).

Wamsley, T.V., M.A. Cialone, J.M. Smith, J.H. Atkinson, and J.D. Rosati (2010). The potential of wetlands in reducing storm surge. *Ocean Engineering,* (37): 59–68.

Watson, E.B., K.B. Raposa, J.C. Carey, C. Wigand, and R S. Warren. (2017) Anthropocene survival of southern New England's salt marshes. *Estuaries and Coasts* 40(3): 617–625.

Watson, E.B., C. Wigand, E.W. Davey, H.M. Andrews, J. Bishop, and K.B. Raposa (2017). Wetland loss patterns and inundation-productivity relationships prognosticate widespread salt marsh loss for southern New England. *Estuaries and Coasts*, 40(3): 662–681.

Weston, N.B. (2014). Declining sediments and rising seas: an unfortunate convergence for tidal wetlands. *Estuaries and Coasts,* 37(1): 1–23.

Williams, P. and P. Faber (2001). Salt marsh restoration experience in San Francisco Bay. *Journal of Coastal Research,* 27: 203–211.

Wolanski, E., M.M. Brinson, D.R. Cahoon, and G.M. Perillo (2009). Coastal wetlands: a synthesis. *Coastal wetlands an integrated ecosystem approach. Elsevier. Amsterdam, Países Bajos.* pp. 1–62.

Zedler, J.B. (2000). Handbook for Restoring Tidal Wetlands. CRC Press.

Zedler, J.B. and J.C. Callaway (1999). Tracking wetland restoration: do mitigation sites follow desired trajectories? *Restoration Ecology*, 7(1): 69–73.