AGENDA

Wednesday

July 06, 2016

TOWN OF EASTHAM
AGENDA
BOARD OF SELECTMEN
Wednesday, July 6, 2016
3:00 p.m.

Location: *Earle Mountain Room*

I. Affordable Housing Trust – Vacancy due to the resignation of Peter Wade
   a. Interview with applicant Carolyn McPherson - (confirmed)
   b. Interview with Joan Matern - (unconfirmed)

II. Discussion- Nauset Estuary Dredging Feasibility Assessment Report

III. Review & Approve Minutes:
   a. June 20, 2016 Regular Meeting
   b. June 20, 2016 Board of Water Commissioners
   c. June 20, 2016 Executive Session
   d. June 22, 2016 Work Session
   e. June 22, 2016 Executive Session

Upcoming Meetings

July 18, 2016	*5:00 p.m.*	*Earle Mountain Room*	*Regular Meeting*
July 20, 2016	*3:00 p.m.*	*Timothy Smith Room*	*Work Session*

The listing of matters includes those reasonably anticipated by the Chair which may be discussed at the meeting. Not all items listed may in fact be discussed and other items not listed may be brought up for discussion to the extent permitted by law.

This meeting will be video recorded and broadcast over Local Access Channel 18 and through the Town website at www.eastham-ma.gov

II.

WOODS HOLE GROUP

Nauset Estuary Dredging Feasibility Assessment

Prepared For:
Office of the Town Administrator
Town of Orleans
19 School Road
Orleans, MA 02653-3699

Prepared By:
Woods Hole Group &
Anderson Consulting Associates

February 2016

Nauset Estuary Dredging Feasibility Assessment

February 2016

Prepared for:
Town of Orleans
19 School Road
Orleans, MA 02653

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1.0 INTRODUCTION

This report describes a study conducted for the Town of Orleans into the feasibility of developing a dredging program for improved navigation in Nauset Estuary. Significant shoaling has resulted in major changes to the channel and mooring areas, and navigation is typically restricted to several hours on either side of high tide. Commercial fishing boats have been forced to moor in deeper areas of the channel immediately behind the barrier beach, and offload their catch and crew to nearby landings via skiff. This is a less efficient alternative to prior practices, which afforded the fleet the opportunity to moor directly offshore Snow Shore, Priscilla and Goose Hummock landings. These difficulties with navigation and the concerns over public safety prompted the Town of Orleans to commission this study to evaluate a potential dredging program for the estuary.

The Town's conceptual dredge plan focused on portions of Nauset Estuary that provide boat access to the public landings and commercial boating facilities (Figure 1). This includes the main channel starting at the inlet to the Atlantic Ocean and continuing approximately 4.2 miles to Town Cove. The Town Cove area supports public facilities at Goose Hummock, Cove Road, and Asa's Landing, as well as private facilities at Orleans Yacht Club, Nauset Marine, and the Goose Hummock Shop. Areas of the estuary southeast of the main channel providing access to Snow Shore and Priscilla Road Landings were included in the plan. These areas of the estuary are located in the Towns of Orleans and Eastham and a portion of the study area is also located in the Cape Cod National Seashore (Figure 1).

The feasibility of a dredging program will depend on a host of factors including environmental impacts, project lifetime, costs and schedule for permitting, and costs for project construction. The purpose of this study is to develop the necessary information to reliably address these factors. Once this information is known, the Town will be in a position to make an informed decision as to the overall feasibility of the project.

This study takes advantage of existing information and studies, and also leverages the valuable experience of Town officials and other local stakeholders. New data collected as part of this study add to an improved understanding of the Nauset Estuary system, particularly as related to the engineering, environmental, financial, and practical aspects of a dredge program. Section 2.0 provides information on the existing physical and ecological environment in the estuary that influence the dredge and disposal plan formulation described in Section 3.0. The primary factors that determine project feasibility are included in Section 4.0, and recommendations for consideration by the Town if the project is pursued are described in Section 5.0.

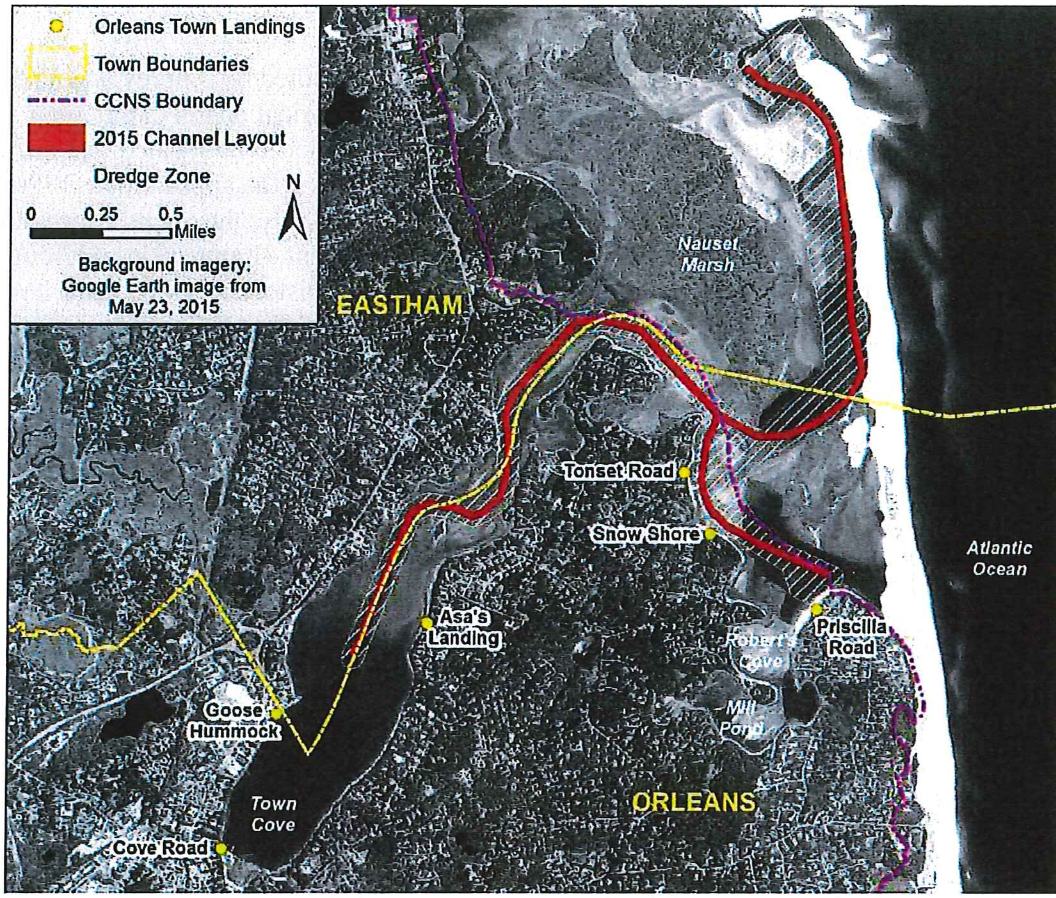

Figure 1. Nauset Estuary showing layout of conceptual dredge plan.

2.0 EXISTING ENVIRONMENT

An understanding of the existing environment in Nauset Estuary is critical to evaluating the feasibility of a dredging program. Data describing the quantity and type of sediment that will need to be dredged given current bathymetric and shoal conditions will control placement alternatives, construction methods, and also construction costs. A fundamental understanding of the changes in geomorphology of the barrier beach and Nauset Estuary inlet and the hydrodynamics of the system will provide valuable insight into areas of the channel that tend to shoal the fastest and will require frequent maintenance dredging. Information on ecological factors such as red tide cysts, shellfish, eelgrass, and other sensitive resources will help to identify potential environmental constraints on a dredging program.

For the purposes of this study the existing conditions of Nauset Estuary were documented through review of available information and limited collection and analysis of new data. The existing physical and ecological conditions of the estuary are described in the following report sections. Data sources are included and where new data were collected, the field and data analysis methods are described.

2.1 GEOMORPHOLOGY

This history of geomorphologic changes at Nauset Inlet was studied by Aubrey and Speer (1984) and more recently by Woods Hole Group (2006). Historical charts dating back to 1779 and aerial photography from 1938 and 1946, show the inlet to be located just north of Nauset Heights at the southeastern edge of the estuary. During the approximate 170-yr period that the inlet was located in the vicinity of Nauset Heights, spit formation extending to the north from the lower beach was non-existent (Figure 2). Although Aubrey and Speer (1984) agree that aperiodic coverage of historical maps may have undersampled previous episodes of inlet migration, they suggest that the persistence of a southern location suggests a historically stable inlet configuration at Nauset Heights.

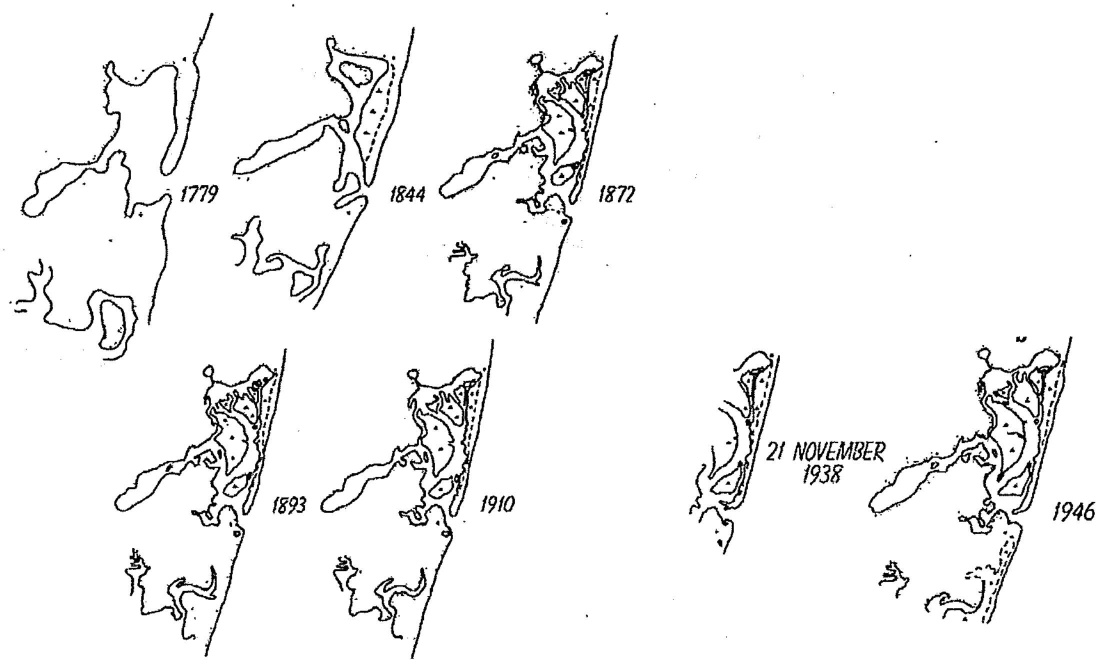

Figure 2. Representative charts and historical aerials from 1779 to 1946 showing stability of the Nauset Estuary inlet at Nauset Heights (Aubrey and Speer, 1984).

Inlet activity at Nauset Harbor has been distinctly more active during the last 70 years. Starting in the 1950s, the inlet experienced two distinct cycles of northward migration. During the first phase between 1950 and 1957, the length of the northern spit extending from Coast Guard Beach remained relatively stable, while the southern spit extending from Nauset Heights continually grew northward. A series of storms in the late 1950s and early 1960s re-established the inlet to its southernmost position immediately adjacent to Nauset Heights. The second cycle began in 1965 and lasted approximately 25 years until 1990. This period of northerly inlet migration was characterized by substantial erosion of the north spit along with northward growth and extension of the south spit (Figure 3). The distance of northerly inlet migration during this period was about 1.3 miles.

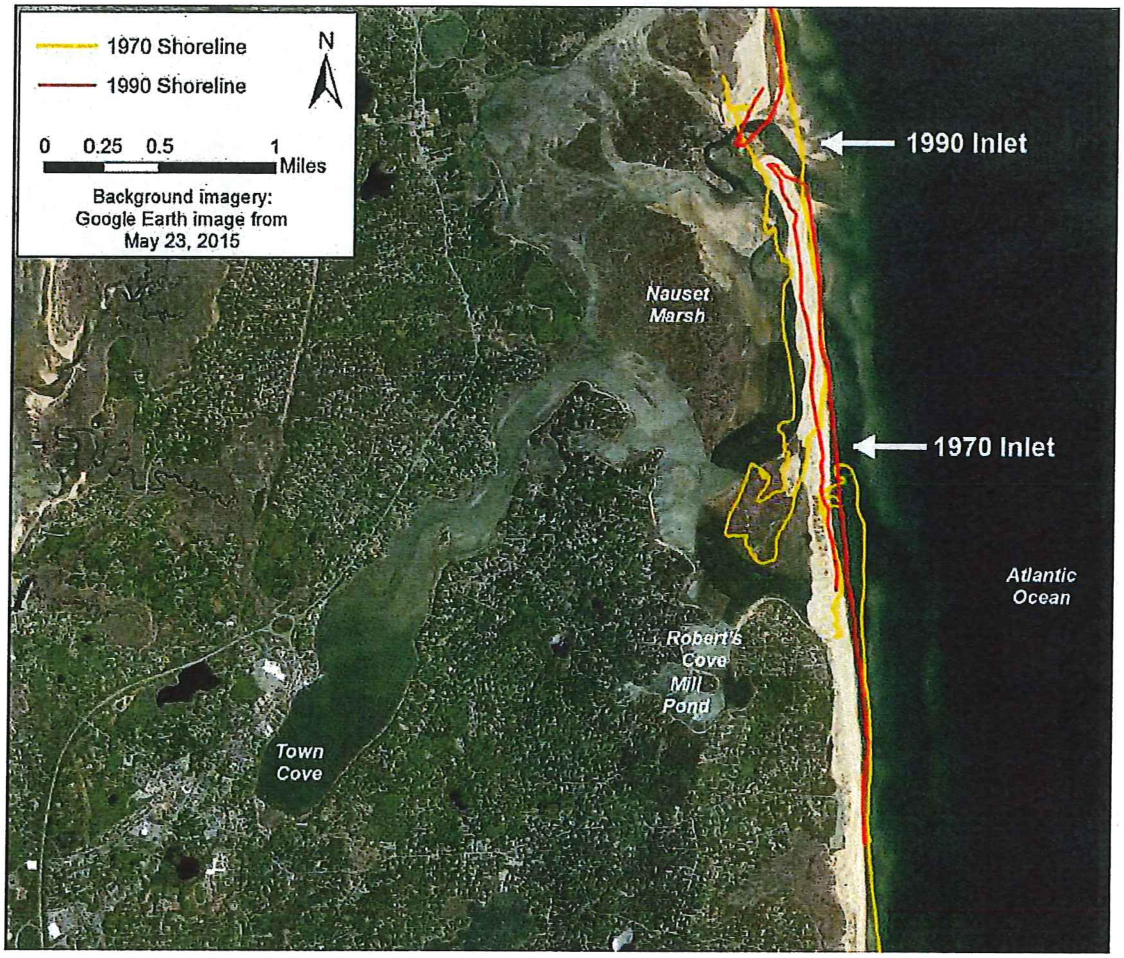

Figure 3. Northerly migration of Nauset Estuary inlet between 1970 and 1990.

Storm activity in the early 1990s caused a breach in the barrier beach near the north end of Tern Island. The system supported two inlets for a period of 2 to 4 years with a northern inlet in the vicinity of the 1990 opening, and a southern inlet at the location of the breach. Sometime after 1996 the northern inlet closed and the system began another cycle of northerly inlet migration. Between 1996 and 2015 the inlet migrated nearly 1.0 mile to the north, back to the location of the 1990 inlet (Figure 4). This represents the most northerly position of the inlet since the early record keeping in 1779.

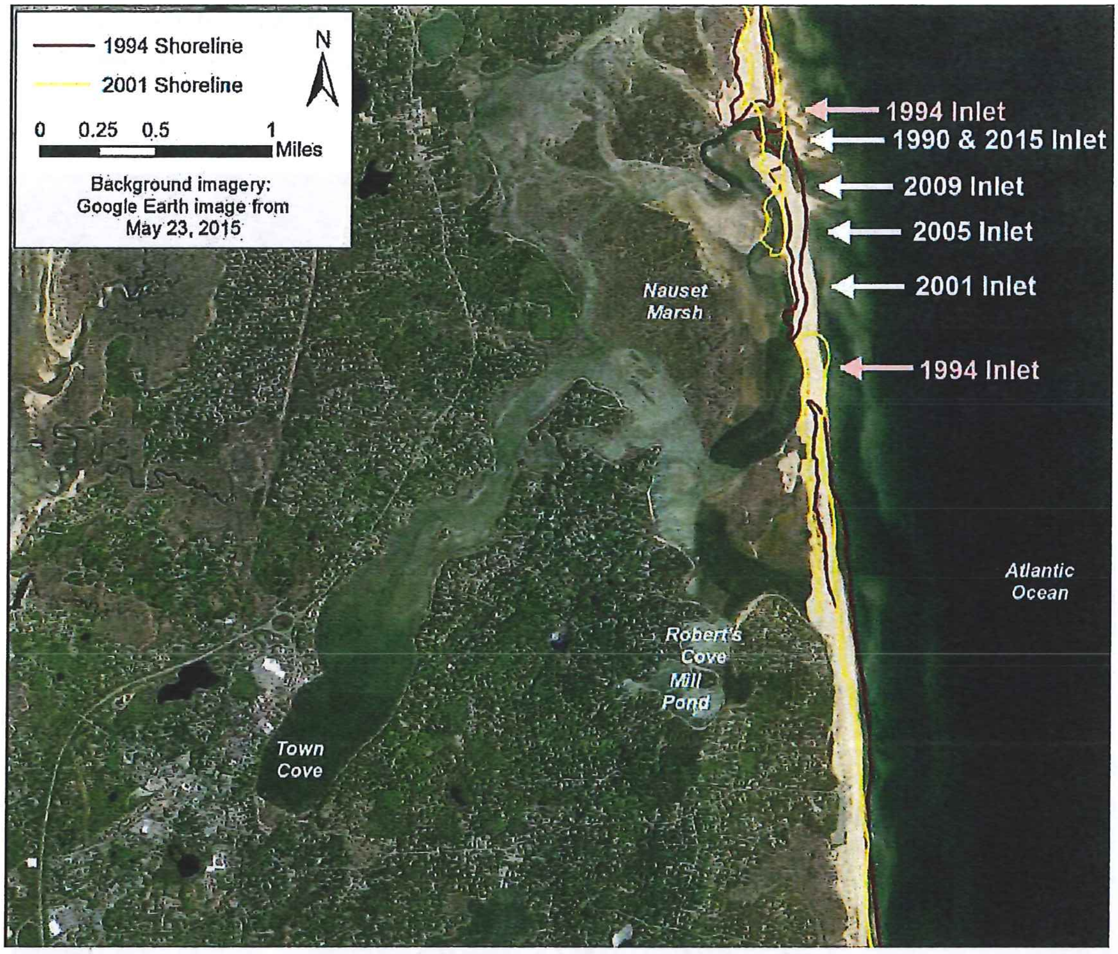

Figure 4. Nauset Estuary Inlet migration between 1990 and 2015.

These cycles of northerly inlet migration, punctuated by breaching to the south, have an influence on the location of the main channel in Nauset Estuary behind the barrier beach. As the spit lengthens to the north pushing the inlet further north, the channel becomes elongated and the hydraulic efficiency of the channel is reduced. Incoming tidal currents bring sediment from the ocean side to form flood shoals and overwash processes during storms deposit sediment in the channel along the west side of the barrier beach. These shoaling processes further reduce the efficiency of the channel. Eventually storms cause the formation of a new breach further to the south where the channel has a more direct link to the ocean. Historical breach locations just north of Tern Island are largely related to the location and orientation of the main channel which directs ebb currents towards the back side of the barrier beach. With enough hydraulic head between the estuary and the ocean, scouring on the west side of the barrier can result in the formation of a new breach from the estuary side. The scouring can also cause a thinning of the barrier beach just north of Tern Island, which weakens the barrier and increases the potential for overwash and breaching from the ocean side.

Historical data indicate that the Nauset Estuary channel between Tern Island and the current inlet location is highly dynamic and strongly influenced by the continuing geomorphologic evolution of the inlet and barrier beach. The data also suggest that a breach in the vicinity of Tern Island is likely to occur in the future. In fact, a washover just north of Tern Island was reported at high tide on February 9, 2016. Whether this develops into a full breach this winter is uncertain. What is clear however, is that a new inlet near Tern Island would allow the Town to temporarily abandon the northern section of channel behind the current barrier beach, in lieu of the more direct channel through the new inlet.

Longshore sediment transport rates and directions along the Eastham/Orleans ocean facing coastline have been studied by Zeigler (1954, 1960), US Army Corps of Engineers (1969) and by Geise (1988). The studies report a net southerly littoral drift with rates ranging between 230,000 and 250,000 cubic meters per year. Sediment is derived from erosion of coastal banks further to the north. The history of northerly inlet migration at Nauset Estuary, in a direction opposite the dominant longshore sediment transport, is contrary to patterns of migration at most other natural inlets. Aubrey and Speer (1984) analyzed historical charts, aerial photos, and storm histories from the area to develop a conceptual model that explains the inlet migration patterns.

The main channel in Nauset Estuary that runs along the west side of the barrier beach is the most dynamic part of the system and is subject to shoaling from inlet processes, barrier formation, and storm generated overwash. However, channel areas further inside the estuary are subject to shoaling as well. A qualitative assessment of channel shoaling was conducted using historical aerial photos from 1972 to the present. Areas of major shoaling were identified on the photos, digitized within a geographic information system (GIS), and then compared over time. This process is influenced by the stage of the tide at the time the photography was collected as well as the ability of the photo interpreter to utilize a consistent proxy for shoaling from one set of photography to the next. Despite these inaccuracies the method provides a reasonable first approximation of areas within the estuary that are prone to shoaling.

Results of the historical shoaling analysis are compared with shoal areas identified from a recent bathymetric survey conducted in November 2015 (Figure 5). The data show significant variability in channel shoaling immediately west of the barrier beach, caused by inlet and barrier migration and storm overwash processes. Patterns of channel shoaling are also evident further inside the estuary where the geometry changes from a narrow constricted channel to a wider configuration. This is consistent with typical flow dynamics where sediment moving with the higher velocity currents in the narrower channels, drops out of suspension when the channels widen and the current velocities decrease. In general the historical shoal locations correspond with current patterns of shoaling from the November 2015 survey, and also with problem areas identified by the Town of Orleans.

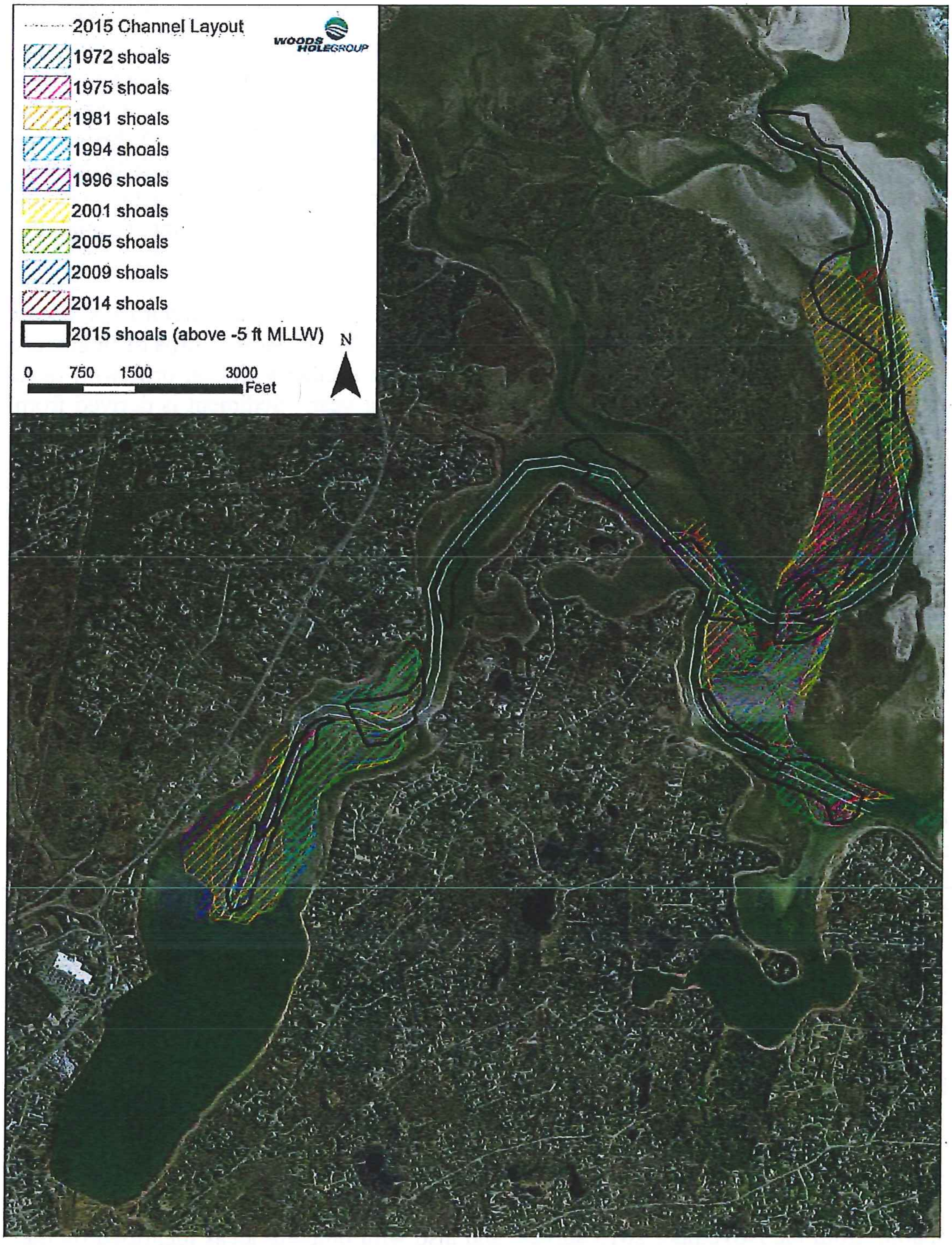

Figure 5. Patterns of historical shoaling in the Nauset Estuary channels compared with current shoal locations surveyed in November 2015.

2.2 BATHYMETRY

The current water depths and shoal locations in the Nauset Harbor estuary were documented via a bathymetric survey conducted on November 23 and 25, 2015. The purpose of the survey was to document existing conditions and to provide information needed to plan a dredge channel layout and compute dredge volumes.

The bathymetric survey was performed by a two-person survey crew including an ACSM/THSOA certified hydrographer. The crew was equipped with a Novatel RTK Global Positioning System with 20Hz update rate and an Innerspace Model "455" survey grade digital depth sounder with a narrow beach 200 kHz transducer and 20 depth/sec update rate. The Model 455 depth sounder incorporated transducer draft corrections, calibration for speed of sound through water and gain control. Calibration was accomplished by performing "bar checks" at the beginning and end of the survey day. Water level was continuously monitored during the survey using a VP electronic tide data recorder. As back-up the water levels were also monitored via the RTK GPS system. The recorded tidal data were used to correct the depth soundings to the NAVD88 vertical datum.

Since the bathymetric survey was collected to aid in channel design for navigation purposes, corrections from NAVD88 to the mean lower low water (MLLW) tidal datum were needed to compare with controlling water depths needed for safe navigation. Typically tidal datum corrections are derived from analyses of long-term tide gage data collected at nearby locations. However, in the case of Nauset Estuary, the closest long-term tide gage stations are in Boston Harbor and Chatham Harbor (Fish Pier), and these locations are not representative of tidal nonlinearities in the estuary. A 29-day tide gage deployment at various locations in the estuary in support of the Massachusetts Estuaries Program (MEP) during the fall of 2001 was identified as the best source of water level data for developing tidal datum corrections (Howes et al., 2012). The data show that MLLW in Nauset Harbor and Town Cove is approximately equal to zero NGVD29 (Figure 6). NOAA's VertCon program was used to determine that NGVD29 is 0.9 ft lower than NAVD88, and therefore a correction of 0.9 ft was used to convert the NAVD88 bathymetry to MLLW (ex. -5.0 ft NAVD88 depth equals -4.1 ft MLLW depth).

A color shaded map of the November 2015 bathymetric survey, with depths referenced to MLLW, is shown in Figure 7. Depths in the main channel range from -32.5 to 0.7 feet (MLLW). The shallowest areas of the channel are west of the barrier beach. A number of isolated shoals with depths less than -5.0 MLLW are located along the channel. These shoal locations correspond closely with the locations of historical shoaling shown in Figure 5.

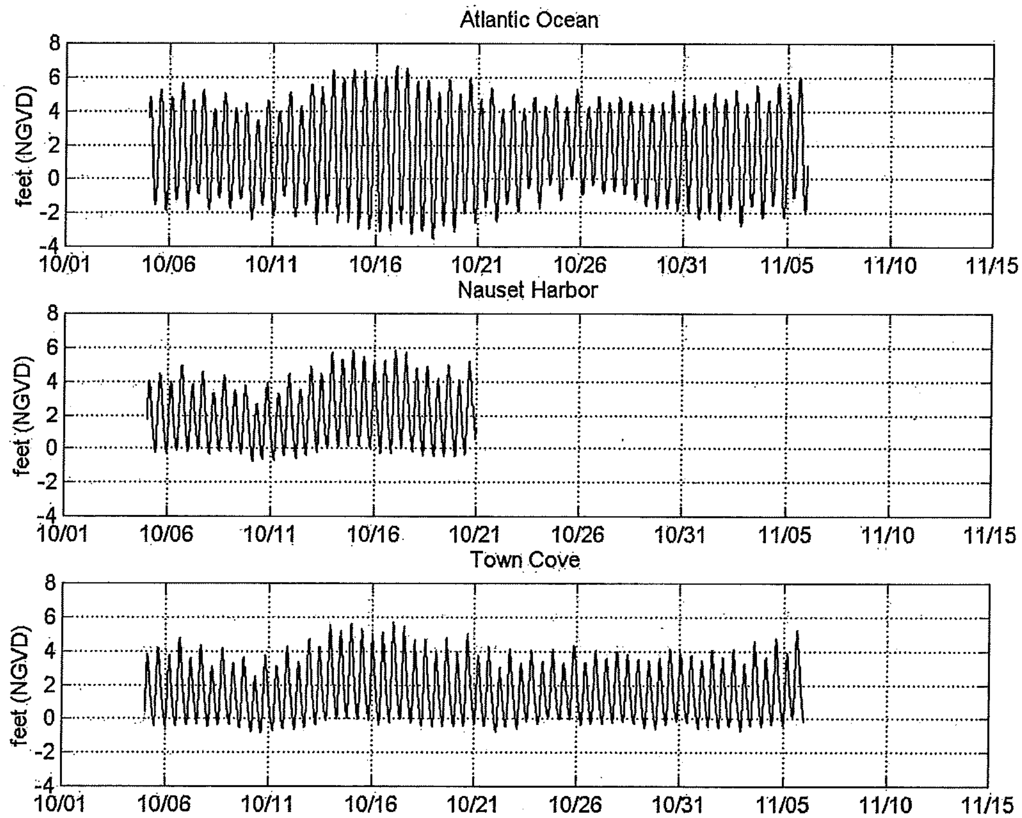

Figure 6. Water level measurements collected Nauset Estuary in support of the MEP in 2001 used to develop a tidal datum correction between NAVD88 and MLLW (Howes et al., 2012).

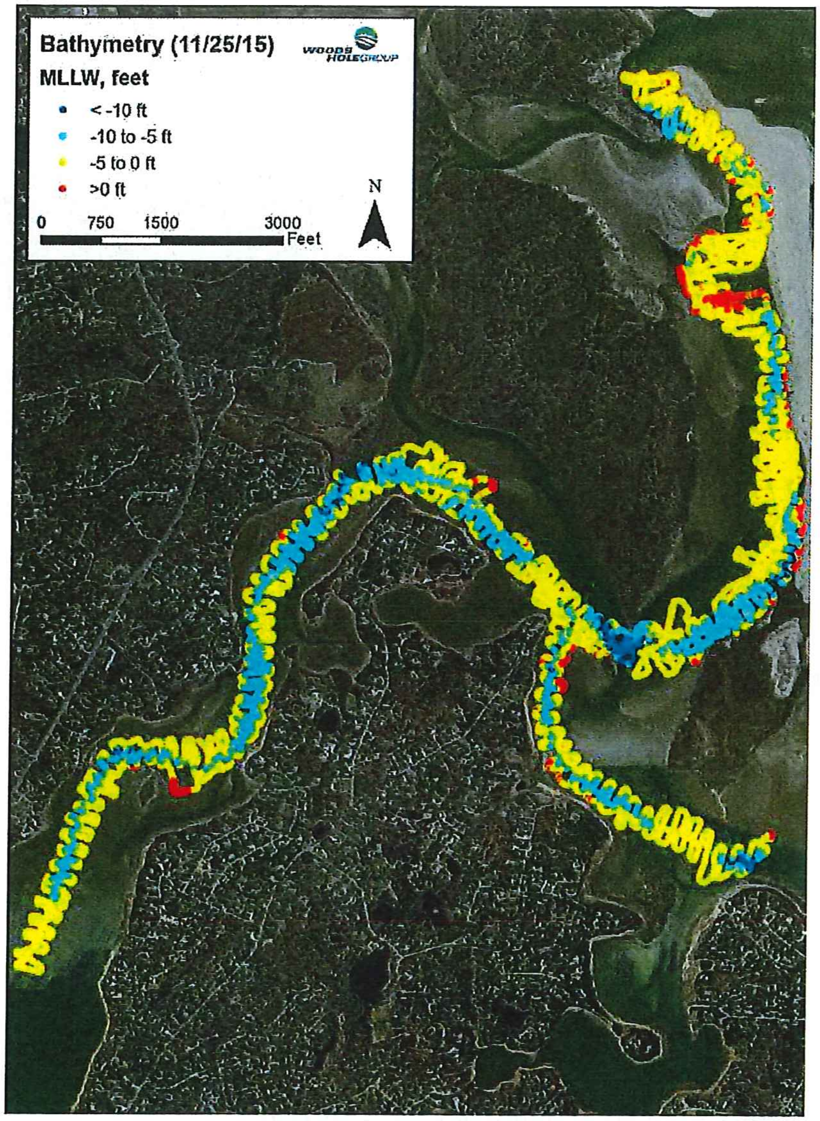

Figure 7. Color shaded map showing water depths referenced to MLLW from the November 2015 bathymetric survey.

2.3 HYDRODYNAMICS

A hydrodynamic model previously developed for Nauset Estuary was used to assess the current hydrodynamic conditions, as well as potential changes that may result from a dredging program. The Finite Volume Coastal Ocean Model (FVCOM) (Chen et al. 2003) used an unstructured grid with node spacing ranging from a minimum of less than 10 m in the estuary to 4 km on the open boundary (Fig. 8). High-resolution bathymetry was used for the model from LiDAR-derived topographic maps of Cape Cod National Seashore from the U.S. Geological Survey (USGS) (Brock et al. 2007). Bathymetry in subtidal regions too deep for LiDAR penetration was based on previous acoustic surveys and observations by investigators from the USGS (Cross et al. 2006) and Woods Hole Oceanographic Institution (WHOI) (Aubrey et al. 1997). The model was previously evaluated against observations of water level, salinity, temperature, and velocity from moored sensors at multiple locations around the estuary (Ralston et al. 2015).

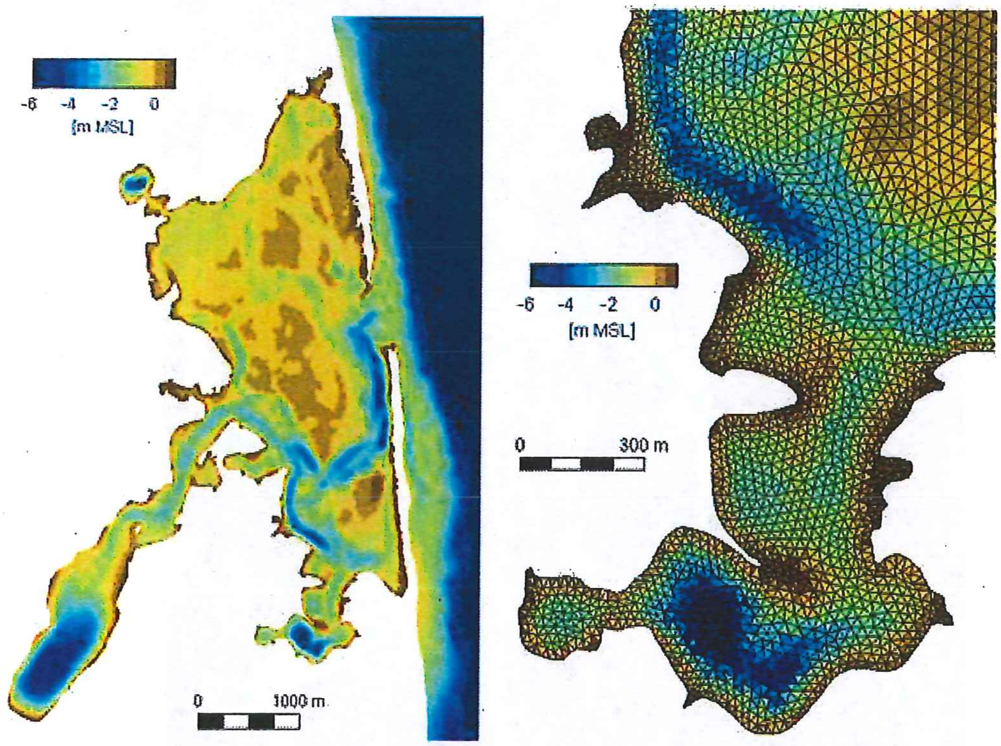

Figure 8. Model bathymetry, with a zoom on the unstructured grid configuration in the vicinity of Mill Pond. Model open boundaries (not shown) extend north, south, and offshore from the inlet approximately 15 miles in each direction.

For the current study the model grid bathymetry was updated based on data collected during the November 2015 bathymetric survey in the vicinity of the planned dredging program. Note that the 2015 configuration of the south spit is approximately 660 ft north of the previous model grid based on the inlet position in 2007. For this study no attempt was made to change the model grid to reflect the more northerly inlet location because the model was being used in a diagnostic sense to evaluate relative changes in flow patterns between the no dredge/dredge condition. Modeling shows that Nauset Estuary is a flood dominated inlet, meaning that peak incoming flood currents are stronger than peak outgoing ebb currents. Flood dominated systems tend to be sediment sinks, as more material is transported in during the flood tide than can be exported on the ebb tide.

2.4 SEDIMENTS

Sediment characteristics and distributions throughout Nauset Estuary were evaluated as part of this study to determine the quality of sediment required for dredging and to evaluate the feasibility of different placement alternatives. Two phases of sampling were conducted to help characterize the site and maximize use of available resources. The sampling methods and results are described in the following report section.

Initial confirmatory grab sampling was conducted within the planned dredge area to validate sediment characteristics documented by previous studies. The purpose of the confirmatory sampling was to gather information to identify targeted areas for subsequent vibracore sampling, with specific emphasis on identifying boundaries between sandy and fine-grained sediments. Confirmatory sediment grabs were collected at sixteen (16) sites on November 30, 2015. A Van Veen grab sampler was used to collect samples from the upper 6-12 inches of the sea floor. Sediment characterizations were conducted by a trained sedimentologist based on visual and textural observations. Results of the qualitative assessment shown in Figure 9 indicate that sediments in the main channel were mostly sand and silty sand. Samples from Town Cove and the southeast oriented channel leading to Priscilla Road Landing contained finer-grained materials characterized as sandy silt. While the confirmatory samples provided a qualitative measure of sediment characteristics at the near surface, core samples were subsequently collected to identify sediments at depth that would be more representative of the entire volume of material potentially removed via dredging.

Results of the confirmatory sediment sampling and the bathymetric survey were used to develop a plan for sediment coring at six (6) locations to quantify material that would need to be dredged from the primary shoal areas. The coring was conducted on December 10, 2015 using a shallow draft pontoon boat specially equipped with an A-frame, winch, anchoring spuds, and a vibracore unit. The coring was conducted to an approximate depth of -6.0 ft MLLW determined based on water depth, tide elevation and time of coring. The cores ranged in length from 2.7 to 6.6 ft depending on water depth at each site. Sample locations were recorded using a RTK GPS. The cores were collected in clear polycarbonate liners and transported to the Woods Hole Group office where they were split, photographed, described, and sub-sampled. The sub-samples were shipped to GeoTesting Express, Inc. in Acton, MA for grain size analyses. Results of the laboratory analyses show the sediments to be sand or silty sand (Figure 9). The only samples containing higher percentages of silt were in Town Cove and near Priscilla Road Landing where the upper 0.2 to 0.6 ft of sediment contained in excess of 30% silts and clays. The core log descriptions and photographs are provided in Appendix A and the laboratory grain size testing results are provided in Appendix B.

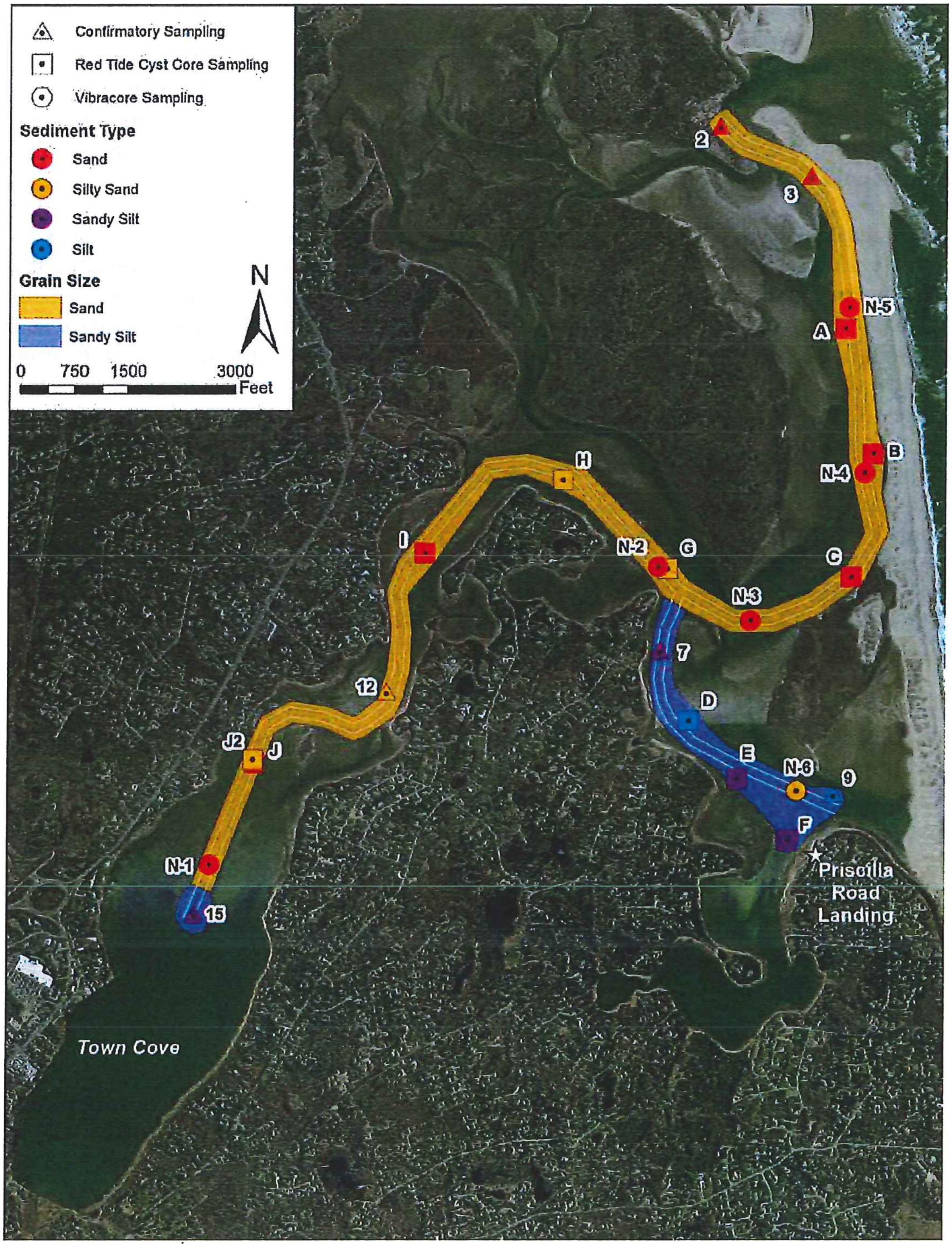

Figure 9. **Sample locations and sediment characteristics from 2015 based on a combination of qualitative assessment and laboratory analyses for grain size.**

2.5 ECOLOGICAL RESOURCES

SAV Resources

An eelgrass survey was performed as the same time as the confirmatory sediment sampling on November 30, 2015 (Figure 10). A video camera mounted atop the Van Veen sediment sampler was used to survey the bottom. Eelgrass surveys were conducted via passive drifting transects at approximately one foot above the seafloor. Due to decreased sunlight towards the end of the day, camera exposure caused a "washing out" effect of the image. However this did not significantly affect the ability to interpret the imagery. An example of the estuary bottom observed during the video surveys is presented in Figure 11.

Eelgrass video transects were analyzed for eelgrass presence or absence. Despite limitations in video quality, the presence of eelgrass was not observed at any of the sixteen site locations. This finding supports previous mapping efforts that have reported there was no eel grass in the study area.

An analysis of historical eelgrass data for Nauset Harbor was conducted by the Massachusetts Estuaries Project (MEP) (Howes et al. 2012). This analysis incorporated mapping done by the MassDEP Eelgrass Mapping Project, as well as aerial photographs from 1951 used to reconstruct the eelgrass distribution prior to substantial development in the Nauset Estuary watershed. At the time of the study, MassDEP's most recent year of eelgrass mapping was 2001. The 1951 data from the aerial photograph analysis were only anecdotally validated, while the 2001 map was field validated. The goal of the MEP analysis was to determine the stability of the eelgrass community in Nauset Estuary over time. Howes et al. (2012) found that by 2001, eelgrass had nearly disappeared from the Nauset Estuary, with most of the remaining eelgrass patches located just north of Tonset Road (Figure 12). The loss was found to be consistent with the level of high nitrogen concentrations in the water and the tidal flows within the system. Nutrient enrichment is known to cause a loss of eelgrass habitat in tidally restricted basins, such as Town Cove. Such areas also tend to be the main discharge points for watershed nitrogen inputs, which further exacerbate the problem. That high nitrogen levels and reduced tidal flushing have contributed to the loss of eelgrass is further supported by the fact that the only location observed to have eelgrass in 2001 was adjacent Tonset Road where these impacts are mitigated by high tidal exchange (Howes et al. 2012).

It should be noted that subsequent sampling in Nauset Estuary by MassDEP in 2012 did not observe the presence of eelgrass. This is supported by the field surveys conducted in 2015 as part of this study, which also found no evidence of eelgrass beds.

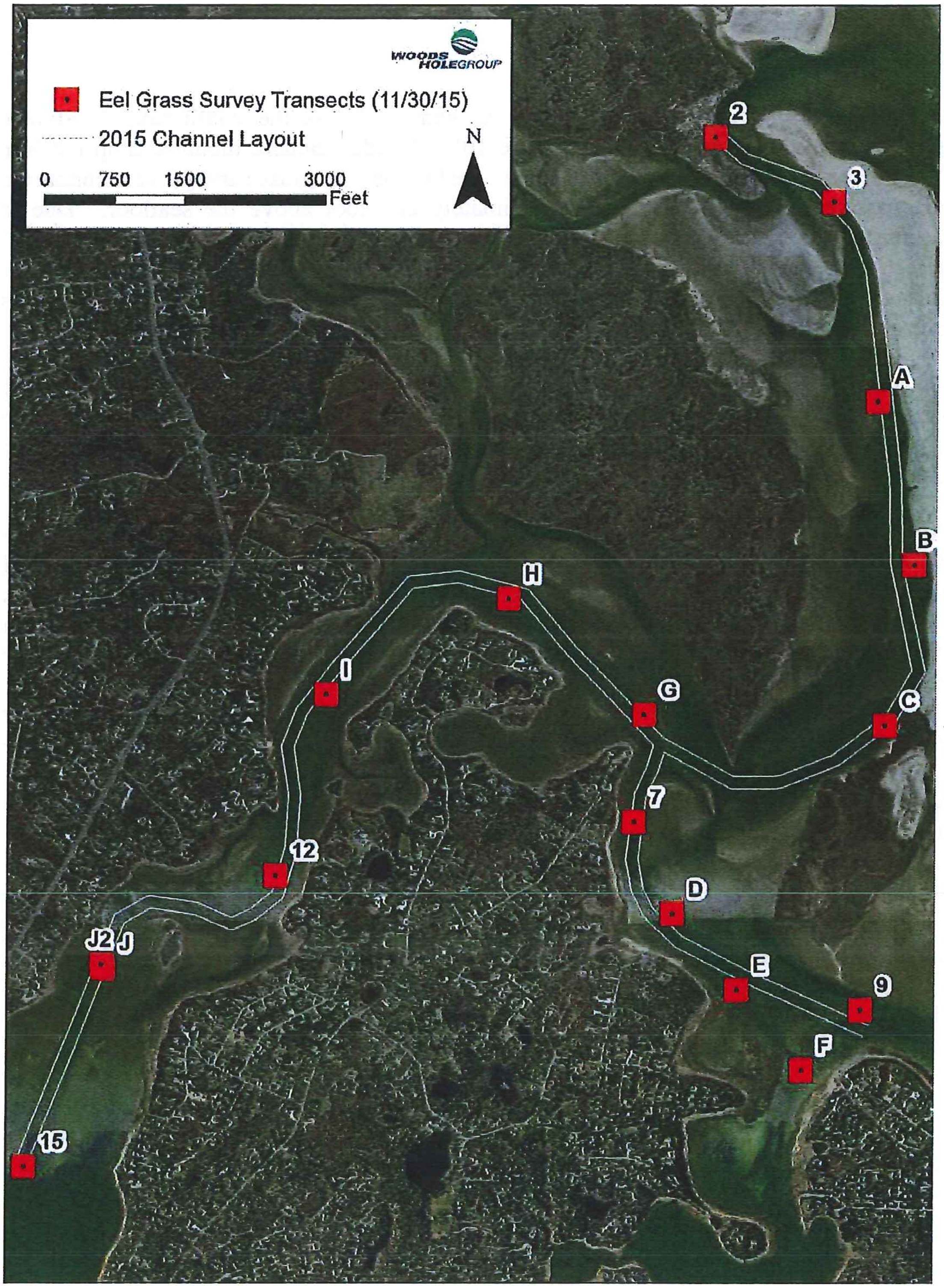

Figure 10. Eelgrass survey transect locations evaluated in November 2015.

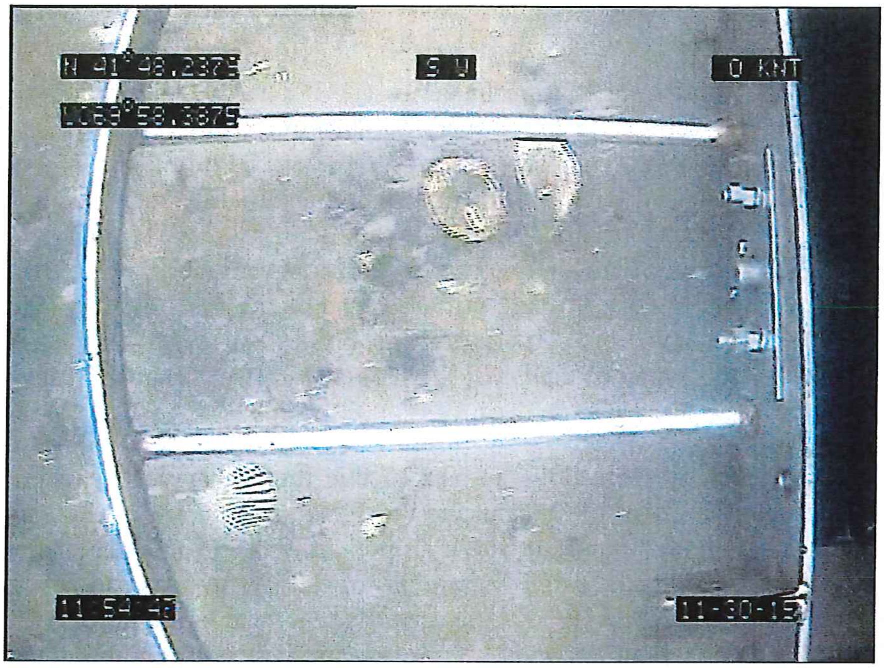

Figure 11. Example image from the November 2015 eelgrass video survey. Bottom cover was mostly sand with shell fragments.

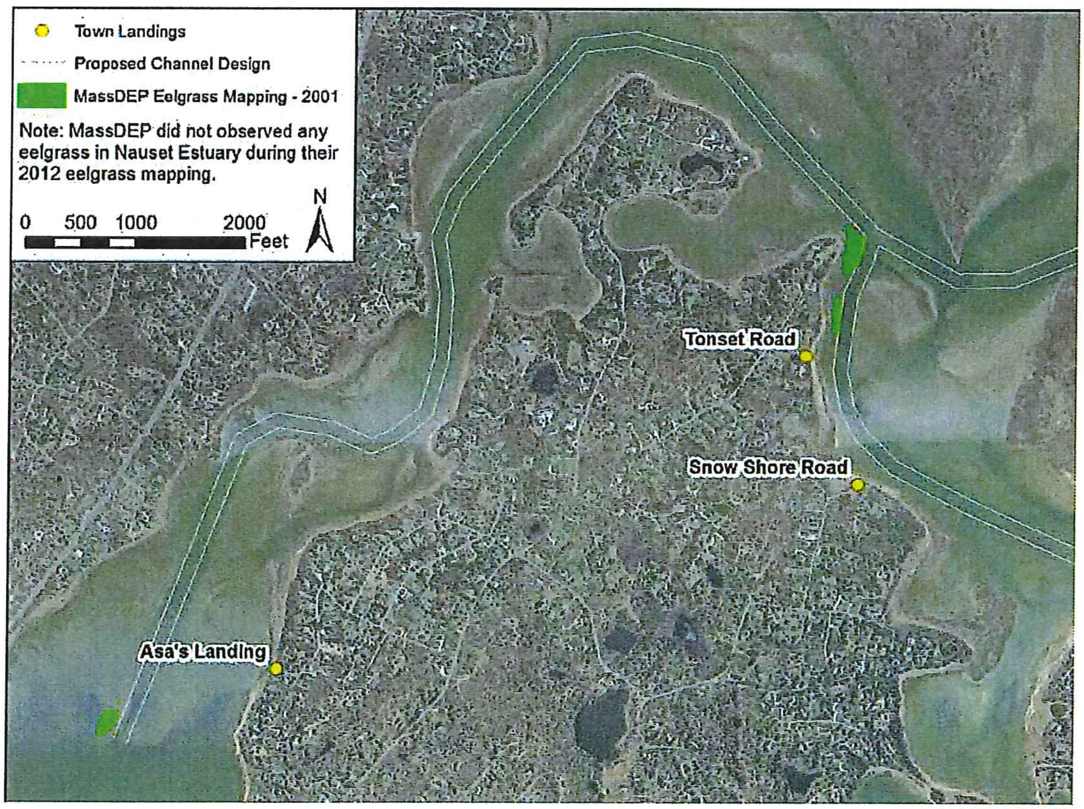

Figure 12. Historical eelgrass mapping results from MassDEP's Eelgrass Mapping Project.

Shellfish Resources

The Massachusetts Division of Marine Fisheries (DMF) has produced a map outlining areas that are believed to be suitable for specific types of shellfish, such as blue mussel, quahog, and soft-shelled clam. These areas are delineated based on the expertise of the DMF staff, in conjunction with input from local shellfish constables, commercial fishermen, and information contained in maps and studies of shellfish in Massachusetts. These areas include places where shellfish have been observed since the 1970s, and have a habitat that is suitable to support that particular type of shellfish, but there may not be any shellfish present at this time. Therefore, these shellfish suitability maps represent *potential* habitat areas. A map of the DMF shellfish suitability areas in Nauset Estuary is shown in Figure 13.

Although no field surveys were done as part of this preliminary assessment, shellfish constables from both the Town of Orleans and the Town of Eastham were interviewed to identify current locations of important shellfish populations. In Orleans, there are high densities of quahogs along the eastern shoreline of Town Cove, north to the area of Hopkins Island. There is also a set of blue mussels that establishes around the channel near Hopkins Island each year; however, the population has not been able to survive the winter during the last few years, either getting scoured by ice or predated by eiders, but has regularly recolonized the area each year. Most recently this blue mussel set was observed on the Eastham side of the channel.

Shellfish constables from both towns noted a high density of shellfish in some of the shoals that have developed. In Orleans, there have been significant quahog, soft-shell clam, and razor clam populations recently in the sandy shoals near Priscilla Road and Snow Shore Landings. While in Eastham, soft-shell clam and surf clam have been observed in the tidal flats near Nauset Inlet. In general, both shellfish constables noted no significant populations of shellfish within the majority of the historic navigation channel.

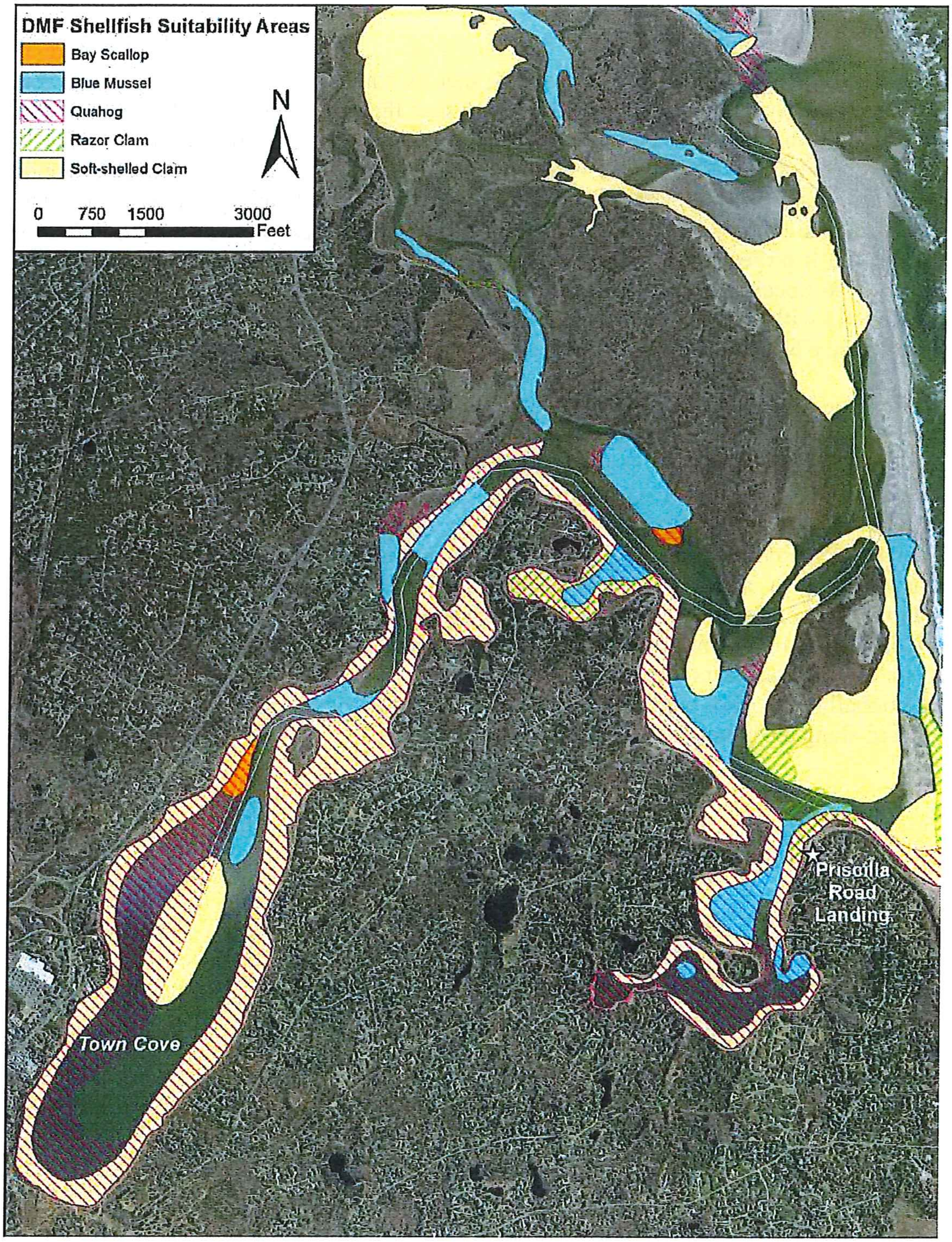

Figure 13. Mass DMF shellfish suitability map for Nauset estuary.

Endangered Species

The Estimated and Priority Habitats of rare species mapped by the Natural Heritage and Endangered Species Program (NHESP) represent the geographic extent of state-listed rare species in Massachusetts based on observations documented within the NHESP database. Estimated Habitats are a subset of the Priority Habitats, which do not include areas delineated for rare plants or wildlife with strictly upland habitat requirements. The Estimated and Priority Habitats within and around Nauset Estuary are presented in Figure 14. When a project falls within Priority Habitat and does not meet a Massachusetts Endangered Species Act (MESA) filing exemption (321 CMR 10.14), it is necessary to file directly with the NHESP pursuant to MESA. For projects within Estimated Habitats that require a Notice of Intent (NOI), a copy of the NOI must also be sent to NHESP.

While specific species driving the habitat designations shown in Figure 14 are not currently known because a MESA information request has not been submitted, other reports produced by NHESP provide some indication of which species might be present. Although, the Natural Heritage BioMap2 program serves only as a conservation tool, without any regulatory significance, and does not supplant the Estimated and Priority Habitats which do have regulatory significance, it does combine decades of documented rare species data, and can provide useful insight into species of concern that might be found in a particular area. For example, the entire ocean-side shoreline of the outer cape is identified as important nesting and foraging habitat for Piping Plovers and Least Terns, as well as an important staging area for Common and Roseate Terns (NHESP 2012). Additionally, the BioMap2 report indicates that American sea-blite is a species of concern along the eastern shore of Town Cove.

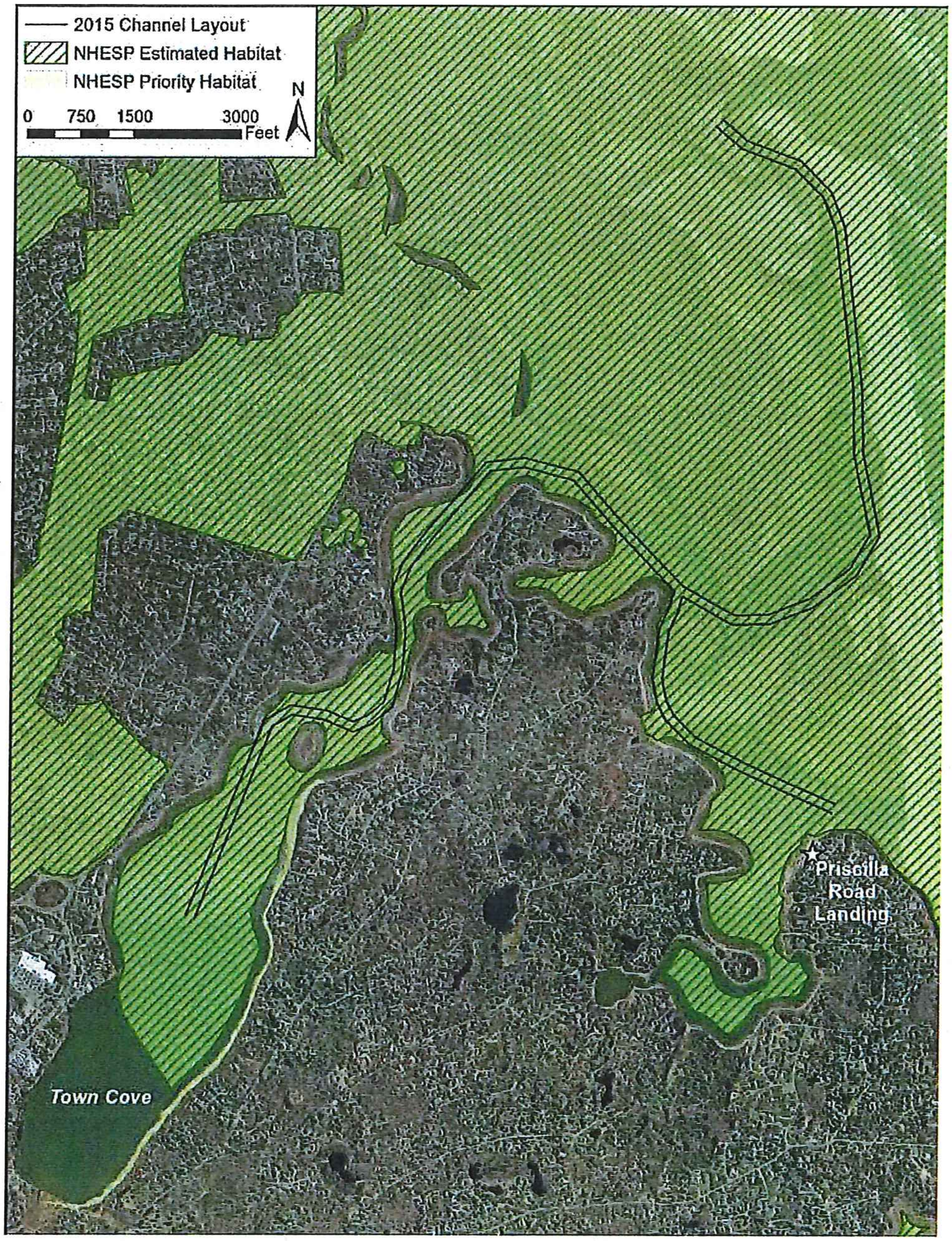

Figure 14. Natural Heritage and Endangered Species Program Estimated and Priority Habitats in Nauset Estuary.

2.6 RED TIDE

Background and past studies

Harmful algal blooms (HABs, commonly called "red tides") are a serious economic and public health problem throughout the world. In the U.S., the most serious and widespread manifestation is paralytic shellfish poisoning (PSP), a syndrome caused by human ingestion of shellfish that accumulate toxins from dinoflagellates, predominantly in the genus *Alexandrium.*

In many parts of the world, PSP is a recurrent and serious problem associated with blooms of toxic dinoflagellates in the genus *Alexandrium.* The potent neurotoxins produced by these organisms are accumulated by filter-feeding shellfish and other grazers and are passed on to humans and other animals at higher trophic levels, leading to illness, incapacitation, and even death. *Alexandrium* species cause toxicity in many different hydrographic and climatic regimes, from temperate to tropical. One reason for growth success across such a variety of habitats is that many species have a cyst stage in their life histories. This allows the organism to remain dormant in bottom sediments through temperature extremes (e.g., winter), with seasonal germination inoculating vegetative cells into the water column only during intervals where temperature and light are suitable for growth (Anderson et al., 2012). Population development is thus possible in more locations than would otherwise be the case if year-round persistence in the water column were the only means for survival.

There are two types of *Alexandrium* blooms in the New England region, both caused by the species *A. fundyense* (hereafter referred to simply as *Alexandrium*). One occurs along the open coast of the Gulf of Maine from the Bay of Fundy to Massachusetts and outer Cape Cod, and on rare occasions, this distribution stretches to the islands of Nantucket and Martha's Vineyard and occasionally, to Rhode Island (i.e., Anderson et al., 2005a; Anderson et al., 2005b; Borkman et al. 2014). Blooms in the coastal region of the Gulf of Maine can stretch over hundreds of miles and last for several months.

The second type of *Alexandrium* bloom in the region is much smaller in scale and is representative of the blooms that occur in the Nauset Estuary system. *Alexandrium* blooms occur, but those episodes are sporadic and highly independent of each other or of the large-scale coastal blooms described above. Instead, isolated and localized blooms occur in those areas, with very tight linkage in time and space to cyst populations in bottom sediments of the areas where toxicity occurs. These locations can be viewed as self-seeding "point sources", in that *Alexandrium* populations originate within the embayments or estuaries, with no input of cells from coastal waters, and they deposit cysts after those blooms, to "seed" future blooms. These "localized" or "point source" blooms have been well studied by D. M. Anderson and colleagues (e.g., Anderson et al. 1983; Anderson and Stolzenbach 1985; Crespo et al. 2011; Ralston et al. 2013, 2015; Brosnahan et al. 2014).

The distribution of the *Alexandrium* blooms within Nauset Estuary is not uniform. It has been well established that the hot spots of toxicity occur at the three distal end points of the system - namely Salt Pond, Town Cove, and Mill Pond (collectively termed salt ponds hereafter). Although the central marsh does occasionally show dangerous levels of toxicity, the highest and earliest levels are always recorded within these salt ponds, with the toxicity in the central marsh delivered there from the localized blooms. In all cases, the salt ponds have deeper central portions (kettle holes), with water exchange with the central marsh limited by shallow, restricted inlet channels. Figure 15 shows the distribution of cysts in Nauset Estuary in 2008, 2009, and 2011. Figure 16 shows a time series of *Alexandrium* cell abundance between March and May 2009. Clearly, there is a strong linkage between the location of the cyst accumulations and the origins of the Nauset blooms, with cells first appearing in Mill Pond, then Town Cove and Salt Pond, with low abundances observed in the central marsh, and no connectivity between the three salt ponds.

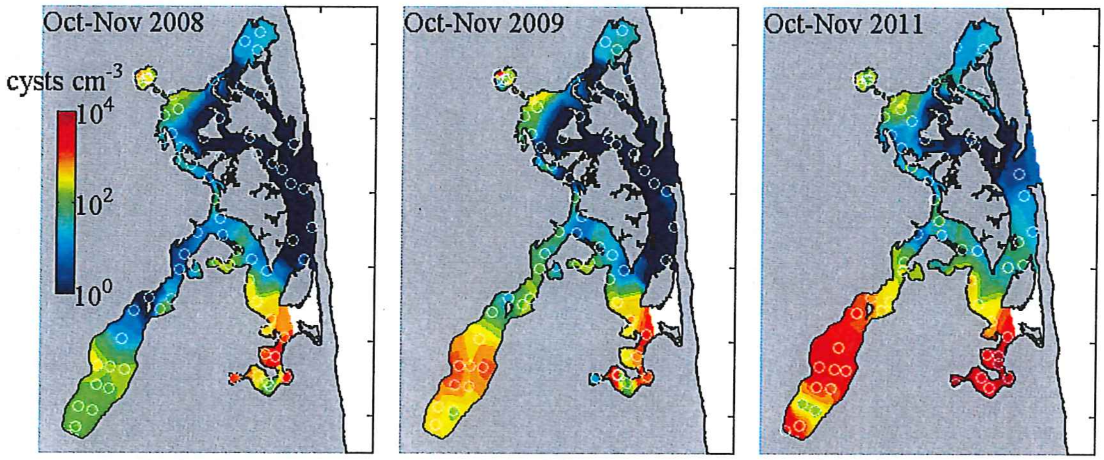

Figure 15. Contour maps of Nauset Estuary mean *A. fundyense* cyst concentrations (cysts/cm^3) in: (left) 2008, (center) 2009, and (right) 2011. Gray circles indicate sample sites (From Ralston et al., 2015).

There are two reasons why these three locations are persistent hot spots for *Alexandrium* and toxicity. The first is that they are accumulation zones for the cysts of *Alexandrium* because of their bathymetry and hydrography. As flood tide-dominated systems, Salt Pond, Mill Pond, and Town Cove accumulate fine sediments year after year, and cysts behave like that fine sediment fraction. Cysts that are formed within the central marsh tend to be disbursed with other fine sedimentary material, much of which ultimately accumulates in kettle holes like the salt ponds and the areas that have silted in near their inlets. The bulk of the *Alexandrium* cysts formed within Nauset Estuary are thus retained within the salt ponds.

The second mechanism that leads to the hotspots results from a combination of the bathymetry and configuration of the salt ponds and the behavior of *Alexandrium*. *Alexandrium* swims vertically in the water column, seeking the appropriate amount of sunlight for photosynthesis in surface waters, while also swimming downward to access nutrients that are often found in deeper waters. This is termed diel vertical migration. *Alexandrium*, however, does not swim to the very surface of the water, but instead finds suitable sunlight 1.5 - 2.5 meters deep (Anderson and Stolzenbach 1985). This means that the top of the vertical ambit of *Alexandrium* tends to be below the depth of the shallow inlet channel. Thus the water that leaves the salt ponds on ebb tides contains few cells compared to those retained within the ponds. The population is thus retained within the ponds, dividing and accumulating, and reaching dangerous levels of toxicity. For example, Salt Pond has had closures due to toxin levels above quarantine action limits in 23 of the past 26 years. Similar numbers hold for Mill Pond and Town Cove.

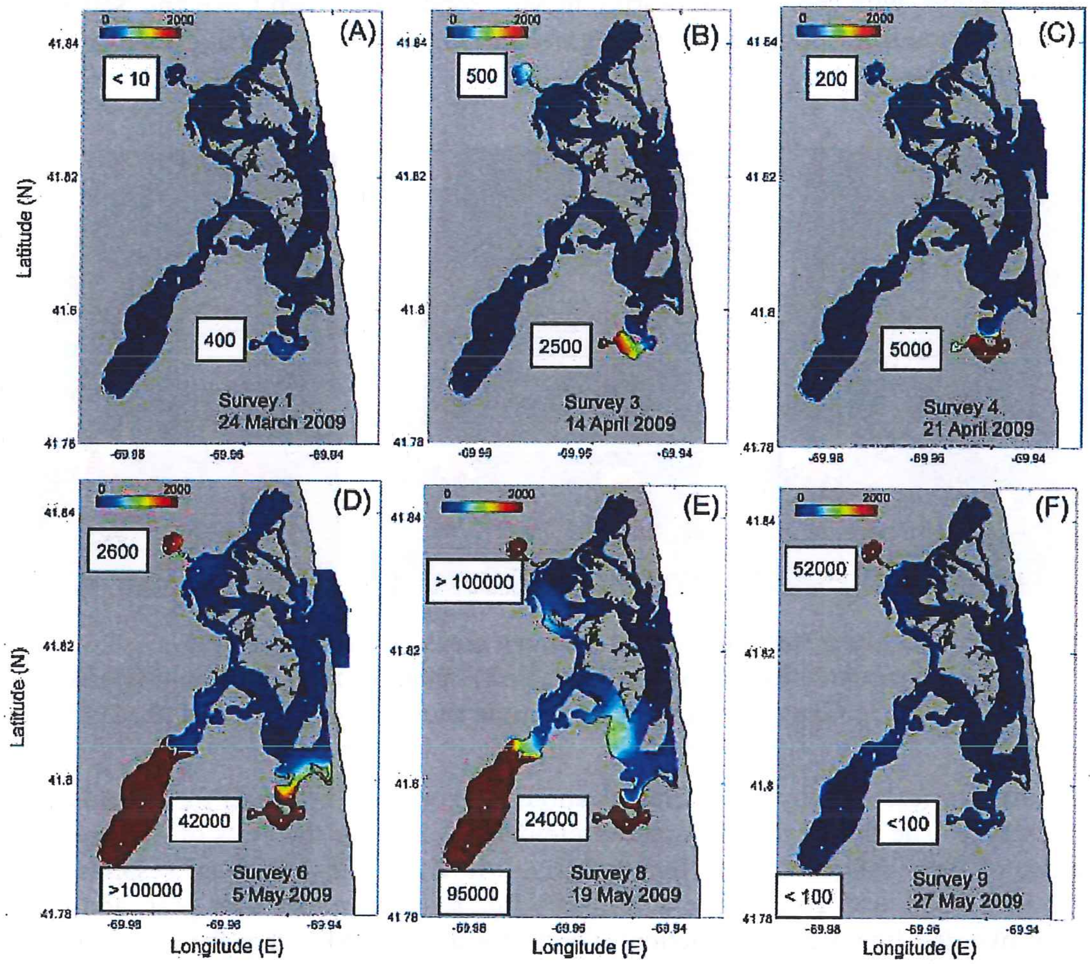

Figure 16. Distribution of Nauset Estuary *A. fundyense* cells (cells L^{-1}) between March 24 and May 27, 2009. Maximum number of cells for Mill Pond, Town Cove and Salt Pond indicated in the white squares. White dots indicate sample sites (From Crespo et al., 2011).

Another important feature of the *Alexandrium* bloom dynamics is that the cysts in bottom sediments do not just sit at the surface of those sediments. Bioturbation (i.e. mixing by worms and other bottom-dwelling animals) as well as physical mixing from storms and currents can bury the cysts. It is common to find more cysts a few centimeters below the surface than there are at the surface, as shown in a core profile taken in Roberts Cove, immediately adjacent to Mill Pond (Figure 17). However, dinoflagellate cysts require oxygen for germination (Anderson et al. 1987), and typically oxygen is only found in the top centimeter or less of bottom sediments. This means that cysts that are buried below that layer typically do not germinate and participate in the bloom formation in the spring. Instead, they remain dormant and either eventually die, or are mixed to the sediment surface or the water column by storms, bioturbation, or other disturbances. There are reports that *Alexandrium* cysts can live in anoxic sediments for decades (Keafer et al. 1992); there are even reports of successful cyst germination that were over 100 years old (Ribeiro et al. 2011). Clearly, activities that might resuspend deep cyst deposits (i.e., dredging) have the potential to introduce cysts that otherwise would not have germinated, into conditions that would be favorable for germination.

One important conclusion from Figure 17 and from many other cyst profiles in sediment cores is that in Nauset Estuary, *Alexandrium* cysts are quite low in abundance below 10 cm (D. M. Anderson, unpub. data). For this reason, the cyst abundance in the top 0-10 cm layer is most important when considering the impacts of dredging operations.

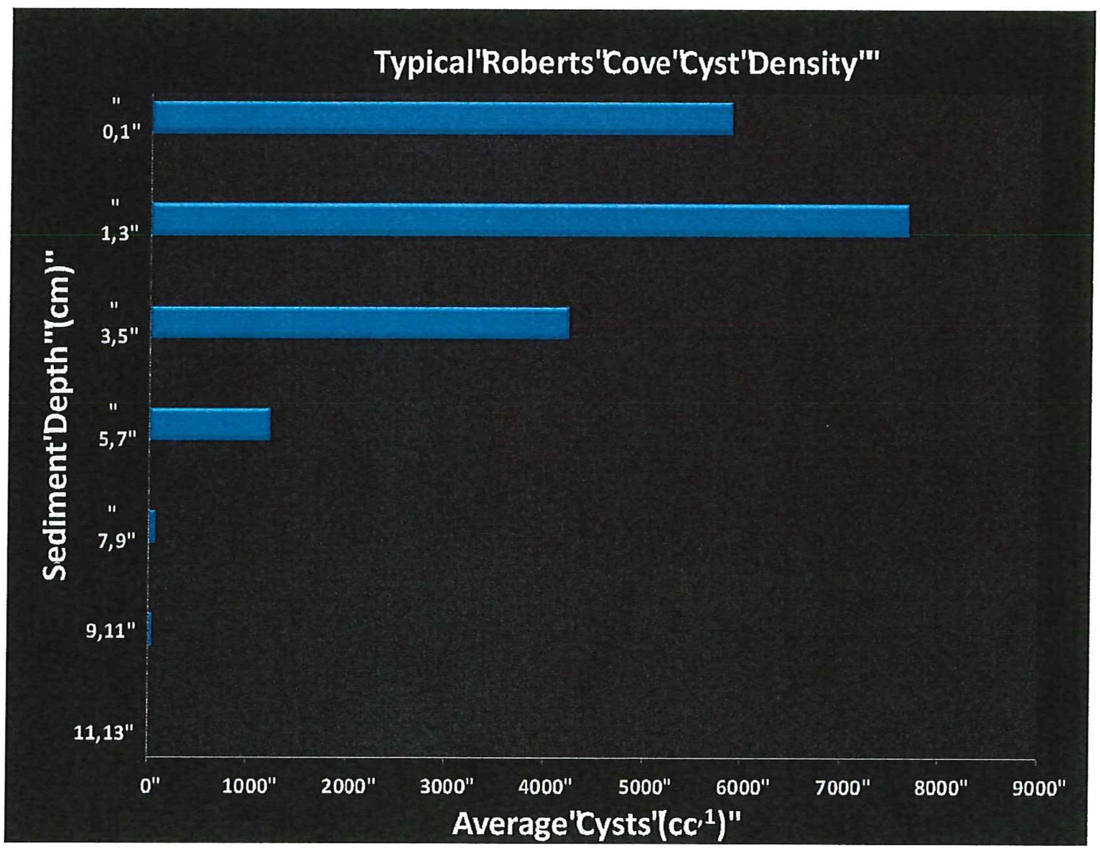

Figure 17. Vertical profile of *Alexandrium* cyst abundance (cysts/cm^3) from Roberts Cove in the Nauset Estuary.

It is also important to recognize other factors that regulate the timing and extent of *Alexandrium* cyst germination. Foremost among these is seasonality in germination that is internally controlled by a "clock" mechanism. The timing or phasing of this "endogenous clock" is in turn regulated by temperature. It is a complicated process that is still under active investigation, but for the purpose of this discussion, suffice it to say that most newly formed cysts that are deposited in the summer or fall from *Alexandrium* blooms typically cannot germinate during the early winter because of a combination of maturation processes and clock regulation. Germination is typically possible beginning in January or early February, but the rate of that germination is controlled by ambient temperatures. In very cold winters, germination is delayed until waters reach 4-6 °C. At those temperatures, the cysts can germinate, but the *Alexandrium* vegetative cells that are produced grow very slowly, if at all, again because of non-optimal temperatures. An indication of the growth potential of *A. fundyense* from Roberts Cove is described in a study by Watras et al. (1982). In general, a temperature range for survival and growth between 5.5 and 24 °C was observed. There was no growth at 5.5 °C, but the cells did not die. At 8.5 °C, the rate ranged from 0.08 to 0.2/day depending on salinity. The maximum growth rate was 0.44/day, at 22.5 °C. A broad optimum for growth occurred between 13 and 22.5 °C.

Interestingly, *Alexandrium* cells also do not germinate or grow when it becomes too warm (Anderson 1998). Typical summer temperatures of 23-28 °C are inhibitory in this regard.

Some useful information is presented in Figure 18, which shows multiple blooms of *Alexandrium* in Roberts Cove from 2009 to 2015, as well as the bottom temperature, and the rate of cyst germination at ambient temperatures. Bloom initiation tends to vary interannually, with the earliest cells seen in February, but more often, March. Peak motile cell concentrations occur in April and May, and the blooms terminate in late May and early June. Anomalous years like 2012 (yellow curve in Figure 18) show a shifted bloom dynamic, but otherwise the same general shape.

The middle panel of Figure 18 shows the germination success of cysts at ambient temperatures. This would be analogous to the situation if sediments containing cysts were resuspended or dumped into the oxygenated surface waters during a dredging operation. The pattern indicates that germination does occur in the fall and early winter, but is generally near zero in January and February, increasing thereafter. Note that the lack of germination in the mid- and late-summer months (June – September) is due to newly deposited cysts being immature at the time of the incubation. Cysts that were mature but buried in anoxic sediment layers would be expected to germinate at those times.

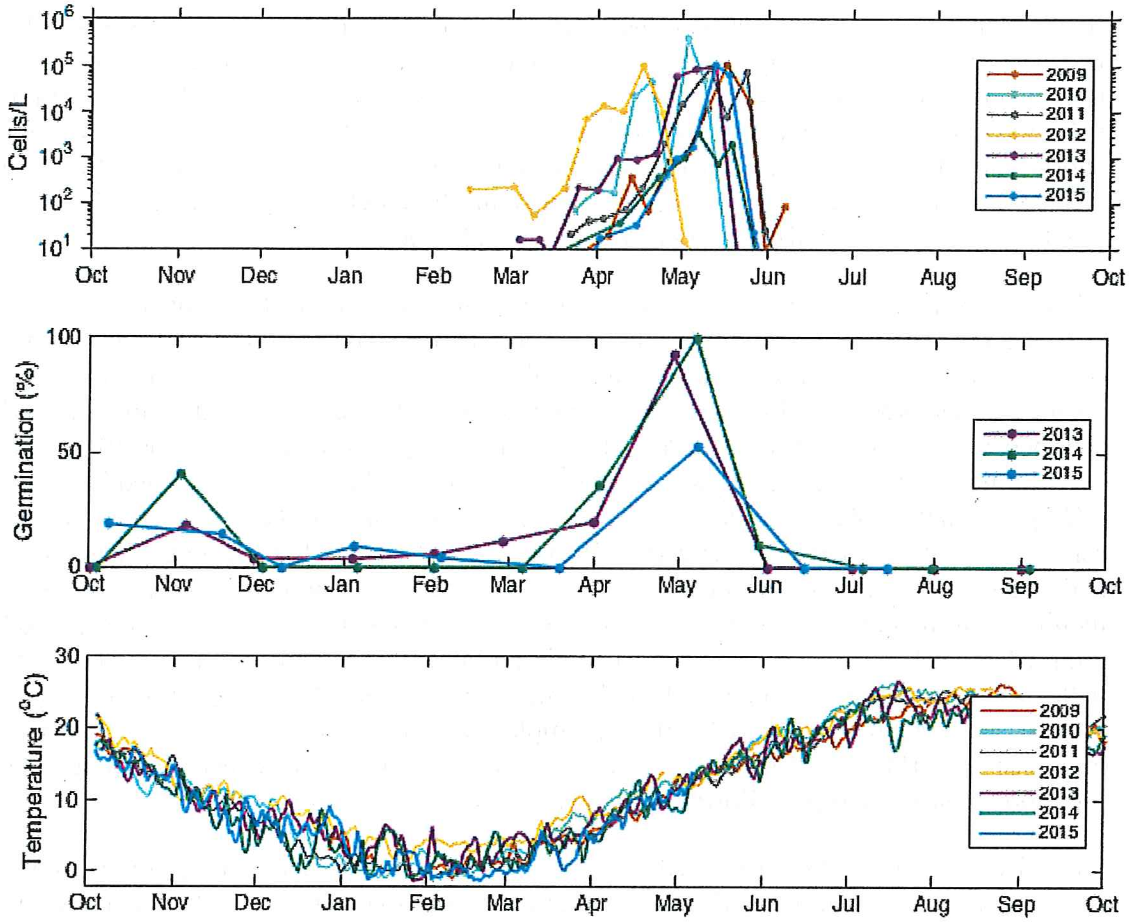

Figure 18. ***Alexandrium*** **motile cell and cyst dynamics from Roberts Cove in Nauset Estuary. Top panel:** ***A. fundyense*** **cell abundance by month. Middle panel: Cyst germination success in surface sediment samples collected and incubated at the ambient water temperature. Bottom panel: temperature (°C). (From A. Fischer, unpub. data).**

2015 red tide cyst assessment

To evaluate current red tide conditions in Nauset Estuary sediment cores were collected at 10 sites on December 10, 2015 for analysis of red tide cysts (Figure 19). The sample locations were planned to coincide with previous red tide cyst analyses conducted by others. A push-core sampling device equipped with a 2 5/8 inch inner diameter clear polycarbonate barrel was used to collect the cores. To ensure sufficient retrieval depth, the cores were pushed to a penetration depth of 1.5 feet. A piston assembly inside the core barrel was used to create suction, thereby preventing excessive compaction during core barrel penetration, and loss of sediment from the bottom of the barrel during recovery. This method provided an undisturbed sediment core of at least 10 cm in length. Upon collection, the cores were packed in ice and stored at 4 °C in the dark for a maximum of 36 hours prior to processing using standard techniques (Anderson et al., 1982, 2005a).

In brief, the cores were extruded such that the 0-1 cm sediment layer was carefully retained, and the 1–10 cm layer was collected into a plastic basin and completely homogenized by hand. From each layer, a well-mixed 5 cm^3 wet volume sediment subsample was taken and resuspended to 25 mL with filtered seawater. A 10 mL subsample of the 25 ml sediment slurry was sonified using a Branson Sonifier 250 affixed with a 1.25 cm disruptor horn at a constant 40-W output for 1 min, and sieved to yield a clean, 20–80μm size fraction (Anderson et al., 2005).

Alexandrium fundyense cysts were counted in a 1-ml Sedgewick Rafter slide according to standard methods for cyst identification and enumeration (Anderson et al., 2003) using primulin to stain the cysts (Yamaguchi et al., 1995). For this, 10 mL of processed sediment was preserved by the addition of 0.75 mL, 100% ACS grade formalin and returned to 4 °C for at least 60 min. This sample was then centrifuged for 10 min at 3000xg, the overlying water aspirated, and the sediment pellet was resuspended in 10 ml ACS grade methanol and stored at 4 °C for at least 48 h. The sample was centrifuged and aspirated as before, and resuspended in 10 mL Milli-Q water. Following centrifugation and aspiration, 2 mL of primuline stain (2 mg mL^{-1}) was added. The sample was incubated in the dark at 4 °C on a rotating mixer, centrifuged and aspirated, and washed with 10 mL Milli-Q water, centrifuged and aspirated again, and the stained sediment pellet was brought up to 3 to 14 mL with Milli-Q water depending on the volume of the stained sediment pellet. A one mL subsample was enumerated using a Zeiss Imager microscope at 100X total magnification under blue light epifluorescence (Chroma filter set 19002, Chroma Corp, Bellows Falls, VT).

Table 1 shows the results of the sediment coring and cyst analysis, and Figure 19 shows the location of the samples and the distribution of cyst abundance. Cyst concentrations ranged from 0 (central marsh sites) to values as high as 2,446 cysts/cm^3 in the top cm of sediment. The latter site was near Mill Pond and Roberts Cove. Other high values were also in the areas closest to the mouths of the salt ponds. Concentrations in the 1-10 cm fraction were generally much lower than the surface counts at each station, except at station F near Roberts Cove, where 2,941 cysts/cm^3 was measured. Note that these values represent the average cyst abundance over that 9 cm layer.

These 2015 cyst samples were collected and analyzed to allow comparisons between the limited number of samples collected now, and those collected in more extensive, marsh-wide system surveys in 2008, 2009 (Crespo et al., 2011) and 2011 (Ralston et al. 2015). Figure 20 compares cyst abundance at sampling sites from 2008, 2009, 2011, and 2015. It is immediately apparent that the general distribution of *Alexandrium* cysts in the area to be dredged has not changed over these years, and it is also clear that cyst abundance has a similar range to that measured in other years. This is an important observation, and the main justification for taking the samples, as it demonstrates that cyst abundance and distribution within the estuary are generally similar among years. Since the dredging program, if found feasible by the Town, will likely be several years from now, there is confidence that these measurements, and those in the recent past, are a realistic representation of the situation at the time the dredging may eventually occur.

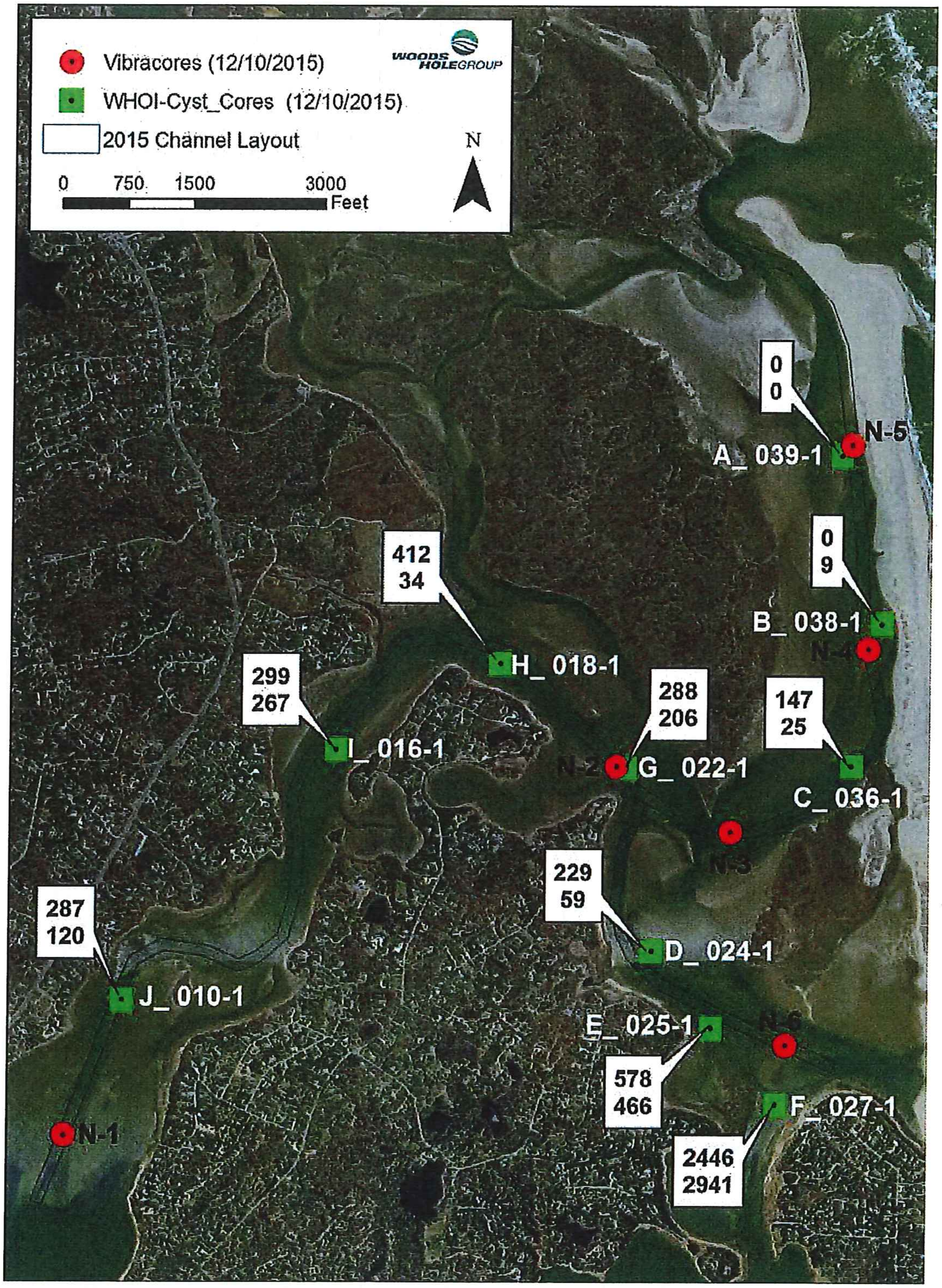

Figure 19. **Map showing cyst coring locations and cyst counts. White boxes near each station show the *Alexandrium* cyst abundances (cysts/cm^3) in the top cm (top line) and 1-10 cm layer (bottom line).**

Table 1. Summary of 2015 red tide cyst sampling and analysis.

Core ID	Latitude	Longitude	Core Recovery (ft)	Collection Date & Time	0-1 cm *Alexandrium* cysts/cm^3	1-10 cm *Alexandrium* cysts/cm^3	Sediment Type (visual)
A_ 039-1	41°49.256	69°56.544	1	12/10/15 11:30	0	0	Sandy
B_ 038-1	41°48.876	69°56.504	0.4	12/10/15 11:05	0	9	Course sand
C_ 036-1	41°48.657	69°56.556	1.2	12/10/15 12:22	147	25	Light sand to dark black
D_ 024-1	41°48.32	69°57.059	0.8	12/10/15 12:51	229	59	Dark silt
E_ 025-1	41°48.175	69°56.911	1	12/10/15 13:04	578	466	Mud
F_ 027-1	41°48.031	69°56.756	0.9	12/10/15 13:40	2446	2941	Light sandy silt
G_ 022-1	41°48.668	69°57.143	1.2	12/10/15 10:21	288	206	Sandy silt
H_ 018-1	41°48.86	69°57.437	0.8	12/10/15 14:07	412	34	Dark silt
I_ 016-1	41°48.709	69°57.841	0.8	12/10/15 14:22	299	267	Sandy silt
J_ 010-1	41°48.247	69°58.384	0.9	12/10/15 14:40	287	120	Sandy silt

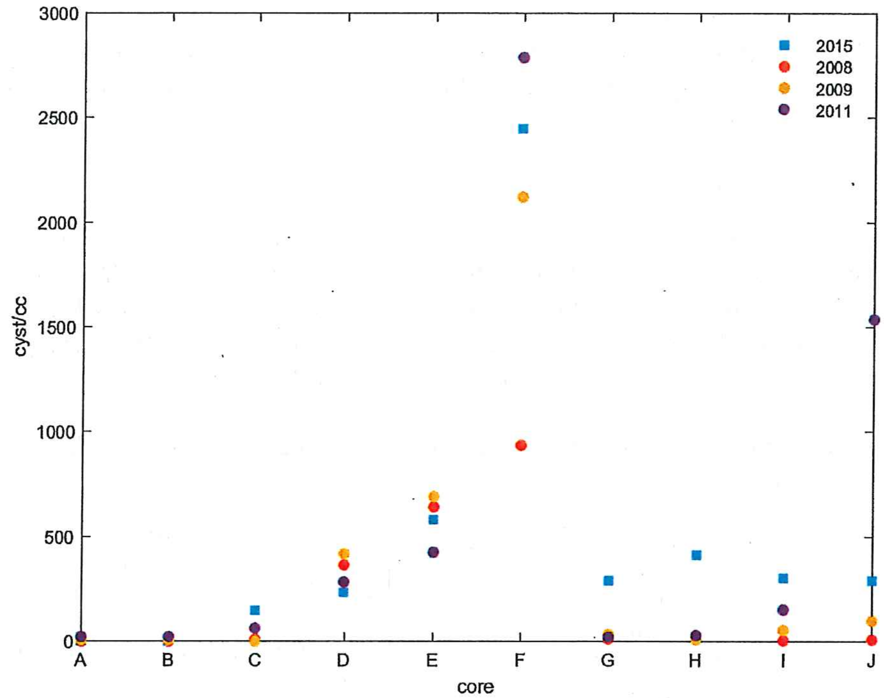

Figure 20. Comparison of cyst abundance at the 2015 core locations with data from previous cyst surveys in 2008, 2009, and 2011.

Red tide cysts in dredged sediments

Observed sediment cyst concentrations and information on the Town's conceptual dredging plan were used to estimate the abundance of red tide cysts in the dredge sediment. The FVCOM model grid bathymetry was used as the basis for the calculations. Cyst concentrations observed at the sample locations were interpolated to the model grid using an inverse-distance weighting approach. The near-surface (0-1 cm) cyst concentrations were used for the spatial distribution. To augment the 10 stations sampled in November 2015, additional near-surface samples (0-1 cm) from the most recent cyst survey of the full estuary during Nov 2011 were utilized (Figure 15). The approach is reasonable given the strong similarities in spatial distributions of cyst abundance across the multiple years of surveys, including those from November 2015 (Figure 20).

The total volume of dredged sediment was calculated by comparing the model grid for the 2015 bathymetry with the grid representing the dredged channel. The amount of material to be removed during the dredging was calculated to be about 73,000 cubic yards, similar to the volume calculated from the bathymetric surveys. The cysts associated with the dredged material were assumed to decrease linearly from the near-surface abundance mapped to the model grid to 0 cysts at 10 cm depth, and equal to 0 in any material below 10 cm. Cyst abundances typically decrease rapidly in the bed over depths of about 10 cm (Figure 17).

Assuming that the cyst concentrations decrease linearly from the surface concentration to 0 at 10 cm depth, and that there are no cysts below 10 cm, the total number of cysts to be removed during dredging was calculated to be 2.2×10^{12}. Dividing that by the dredge volume, an average of concentration in the dredged material of 40 cysts/$cm^3$was determined.

2.7 PAST DREDGING ACTIVITIES

Information on past dredging activities in Nauset Estuary was obtained from the Massachusetts Department of Environmental Protection (DEP) and the Division of Conservation and Recreation (DCR). A total of four (4) permits were identified with issue dates between 1924 and 1974 Table 2 provides a summary of the relevant permit information and Figure 21 shows the locations of the specific activities.

Table 2. Historical permits for Nauset Estuary dredging and associated placement.

Permittee	Permitted Activities	Permit/License No.	Issue Date
Mass DPW/ Waterways	Dredging at 3 sites with placement at 4 in-harbor sites	Contract No. 97	May 24, 1924
Town of Orleans	Maintain bulkhead, piers, dredged & fill	License No. 6256	Aug. 1, 1974
Goose Hummock Shop	Maintain bulkhead, piers, dredge & fill	License No. 5853	Dec. 22, 1971
Esther & Melville Richardson	Dredge & fill	License No. 4844	Jul. 28, 1964

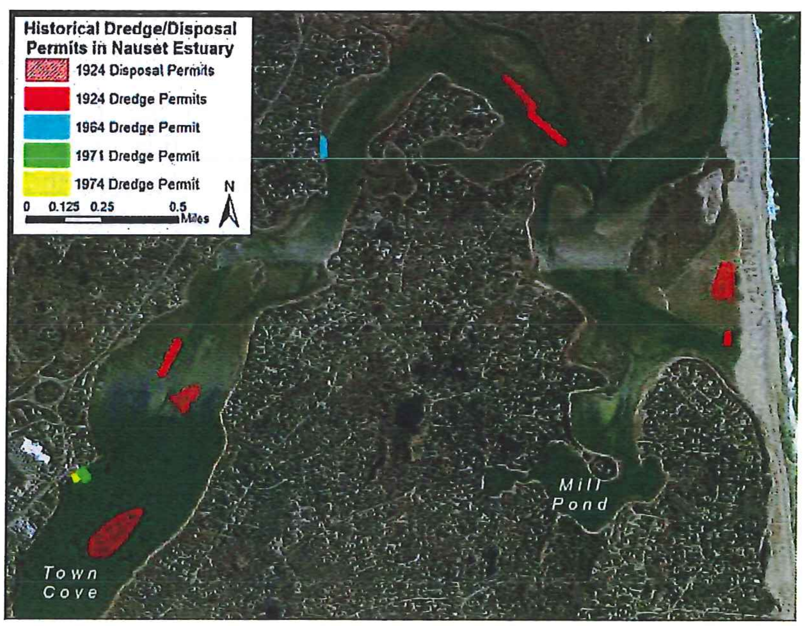

Figure 21. Historical dredging and disposal activities in Nauset Estuary.

3.0 DREDGE AND DISPOSAL PLAN FORMULATION

3.1 TOWN DREDGE CONCEPTUAL PLAN

The Town of Orleans is investigating the feasibility of a dredging program in Nauset Estuary that would improve navigation and public safety. Current shoaling in the channel makes access to the Town landings difficult and dangerous during certain tides. The conceptual channel layout, seen in Figure 1, would facilitate safe passage for navigation not only through the inlet and behind the barrier beach, but also to the key Town landings, such as Priscilla Road, Snow Shore Road, Tonset Road, Asa's Landing, Goose Hummock, and Cove Road, as well as other locations in Town Cove.

To accommodate local boating needs, the Town is investigating a channel design that is 100 feet wide at the base, with 1V:3H side slopes extending an additional 15 feet on each side. The main stem of the dredge channel would extend just over 4 miles from Nauset inlet to Town Cove. A secondary channel, approximately 4,500 feet long would extend south from the main channel towards Robert's Cove, to provide access to Tonset Road, Snow Shore Road and Priscilla Road Landings. The channel would be dredged to a depth of -5 ft at MLLW.

3.2 DREDGE ZONE LAYOUT

The conceptual layout takes advantage of the existing channel and will require significant sediment removal in only a few locations. Figure 5 shows the existing shoals, according to the 2015 bathymetric survey. The major shoal locations are near the inlet and behind the barrier beach, at the first bend in the channel to the south of Nauset Marsh, and towards the upstream end of the channel in Town Cove. However, due to the dynamic nature of the shifting inlet and the resulting change in currents, the exact locations of these shoals changes from year to year. Consequently, the specific areas that need to be dredged today may be different than the areas that need to be dredged a year from now. Given the current bathymetry an estimated total of 80,600 cubic yards of material would need to be removed from the channel to meet the conceptual design described in Section 3.1 (Figure 22). This includes approximately 68,000 cubic yards from the main channel and approximately 12,600 cubic yards from the southern channel.

Due to the dynamic nature of the estuary, the Town is considering an adaptive management approach that would permit a larger dredge zone, rather than a specific channel. This zone is wider than the specific channel layout, and allows flexibility in the future for choosing the optimum dredge route along the deepest part of the natural channel to minimize the volume of dredge material. As part of this feasibility study, a potential dredge zone was developed for Nauset Estuary based on historical variations in the natural channel (Figure 22). At minimum the dredge zone is 300 feet wide near the entrance to Town Cove, and increases to nearly 1,500 feet wide near the inlet. In total, the dredge zone covers approximately 390 acres. However, despite the much larger size of this zone, any particular dredge project would be limited to a 100-foot wide channel within that zone. The total area of dredging in the main channel would not exceed 66 acres and the total area in the channel leading to Priscilla Road Landing would not exceed 13.2 acres. This adaptive management approach would allow the Town to select a slightly different path for the dredged channel in order to capitalize on the existing channel thalweg, and to minimize costs by removing as little sediment as required.

Figure 22. Extent of dredge zone and 2015 channel layout.

3.3 POTENTIAL ALTERNATIVES FOR PLACEMENT

As with all dredge projects, one of the major factors in determining a project's feasibility is where to place the dredged material. Where material can be placed is driven by a number of factors, including distance from the dredging site, characteristics of the sediment being dredged, natural resources, such as eelgrass, shellfish, and salt marsh, feasibility/need to dewater the material, and ownership/size of the potential disposal site(s).

These factors were used as a guide to evaluate the range of possible placement alternatives for the Nauset Estuary dredge program. Unfortunately, the dense residential development, the paucity of shorefront public-owned parcels, and the close proximity to the Cape Cod National Seashore (CCNS) limited the available options for placement. Five potential placement sites/alternatives were identified; however, two of the alternatives are considered experimental due to the need to collect additional information regarding impacts, suitability, and regulatory review. Descriptions of the placement options are provided in the following section.

Dune restoration at Nauset Beach

Use of Nauset Beach as a dredged material placement site would be optimal for the Town, since the beach is currently experiencing significant erosion and the resilience of the site could be enhanced through dune restoration. In fact, in a study recently completed for the Town by Woods Hole Group (2016), a plan of phased retreat for Nauset Beach that included dune enhancement was recommended to protect valuable resources and extend the lifetime of the public beach. Beneficial reuse of sediment dredged from Nauset Estuary for dune enhancement at the public beach would result in a significant cost savings for the Town as the plan of phased retreat for Nauset Beach is implemented.

The most efficient method to use this site would be to contract with the Barnstable County dredge and hydraulically pump the sediment from the estuary directly to Nauset Beach. Because the beach is approximately one mile to the closest part of the estuary, it would be necessary to incorporate use of a booster pump to transport the material. The maximum pump distance for the County dredge with a booster pump is 11,000 ft. This distance would allow portions of Nauset estuary to be hydraulically dredged and the material directly pumped to Nauset Beach, but the ends of the dredge project near the inlet and towards Town Cove would still be too far (Figure 23). Dredge volume estimates from this section of the channel that could be pumped to Nauset Beach are approximately 45,100 cubic yards (channel area 1 in left panel of Figure 23).

It is estimated that Nauset Beach could hold approximately 80,000 cubic yards, and would likely be available for reuse as a placement site within 5 to 10 years if the estuary required maintenance dredging. A preliminary compatibility assessment indicates that the Nauset Estuary sediments have a median grain size between 0.2 and 0.6 mm (fine to coarse sand) and would therefore be suitable for use as dune enhancement at Nauset Beach.

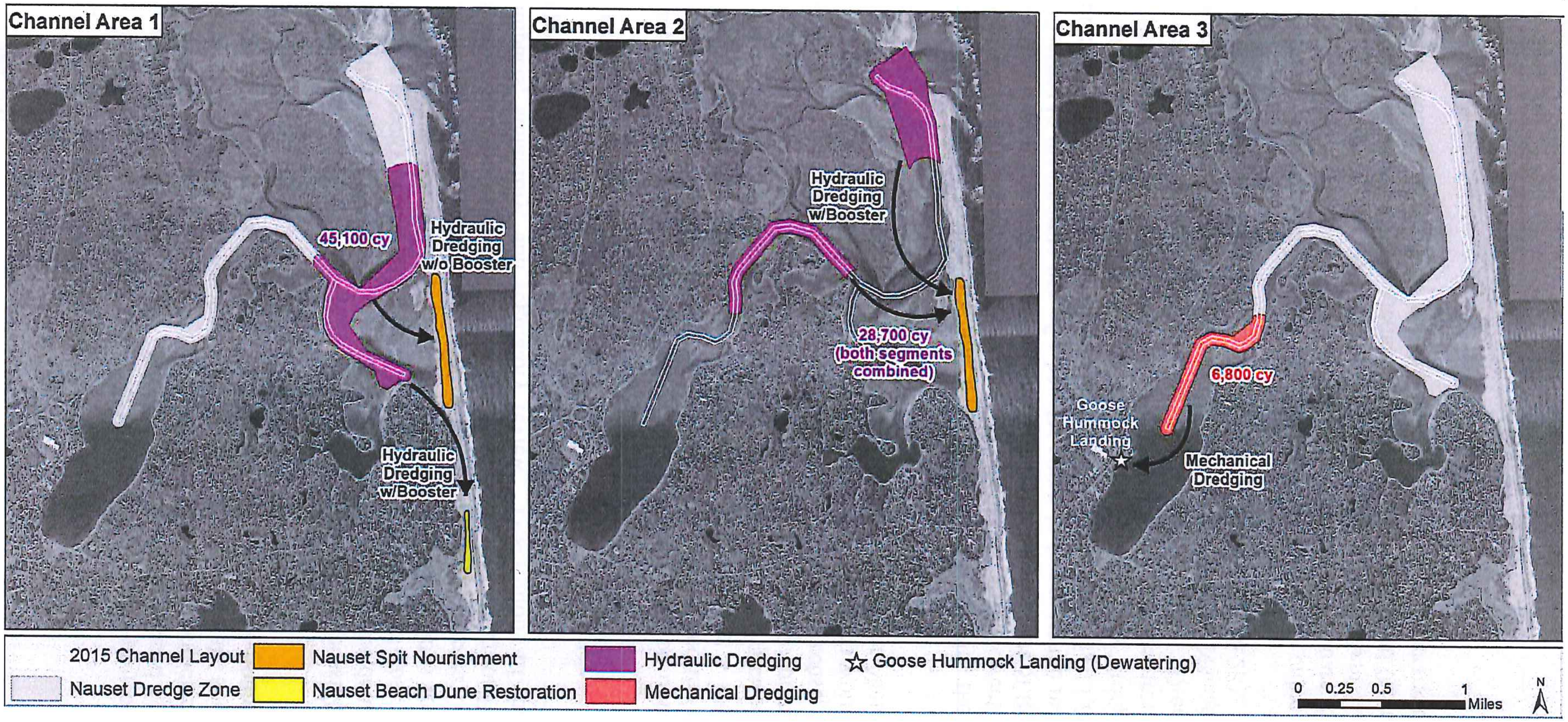

Figure 23. Dredging and placement options for Nauset Estuary.

Dune enhancement along Nauset Spit

The Town-owned portion of Nauset Spit could also be used as a placement site, and could accommodate material acquired through hydraulic dredging. Because of its proximity to the estuary, a good portion of the channel could actually be dredged and the material transported to Nauset Spit without a booster. The left panel of Figure 23 shows approximately 45,100 cubic yards from channel area 1 could be placed on Nauset Spit without the use of a booster pump. With the notable exception of the last mile of channel leading to Town Cove, the remaining portions of the channel would be within reach of Nauset Spit using a hydraulic cutterhead dredge equipped with a booster pump. Approximately 28,700 cubic yards of sand from channel area 2 could be used to enhance Nauset Spit if a booster pump is utilized (channel area 2 in center panel of Figure 23).

Capacity of this site is estimated at more than 100,000 cubic yards, and the site would likely be available for reuse as a placement site within 5 to 10 years. As with the Nauset Beach site, the dredged sediments would be compatible with existing material at Nauset Spit.

Upland/coastal beneficial reuse

There is also the option to beneficially reuse the dredged material at an upland site, or at a site farther away than a hydraulic dredge can pump the material. This option would likely require mechanical dredging with temporary storage, dewatering, and trucking of the dredged material. However, because there is very little upland open space around the estuary, options for dewatering locations are limited. This method is less efficient than hydraulic dredging and would only be recommended for the furthest upstream portion of the channel leading to Town Cove, where even hydraulic methods with the Barnstable County dredge are not feasible. This section of the channel currently requires dredging of approximately 6,800 cubic yards (channel area 3 in right panel of Figure 23).

One potential shorefront staging area in Town Cove is Goose Hummock Landing (Figure 23). In this scenario the material would be mechanically dredged and transported via small barge to Goose Hummock Landing. The sediment would be partially or totally dewatered in the barge (depending on the grain size), and then off loaded at the public bulkhead where it would be temporarily stored for further dewatering (if necessary) and then trucked to a pre-selected beneficial reuse site.

Subaqueous placement

An interesting option that might be considered is to spread sandy dredge material over the surface of the salt ponds, thereby burying the *Alexandrium* cysts that are present in these areas. Calculations performed as part of this study suggest that the dredged sediments will contain very few *Alexandrium* cysts (see Section 4.2 below). If a layer only a few cm thick were dispersed in this manner, and if this were done in the late winter, just before the time when the cysts begin germinating, the inoculum for that year's bloom could be substantially reduced. Not only will sediments quickly become anoxic below the sand layer, inhibiting germination, but the sand grains would make it very difficult for any germinated cells to successfully swim to the overlying water column.

This placement alternative would accommodate only a small fraction of the dredged material and should be considered experimental at this point. Further discussion with the stakeholders and regulatory officials would be required to evaluate the methods, sites, and potential benefits.

Marsh restoration

A second interesting option for beneficial reuse of dredged material would be to place the sediment in a thin layer over portions of the salt marsh to allow the marsh to keep pace with rising sea levels. This too should be considered experimental, since further data would be needed investigate response of the Nauset Estuary marshes to sea-level rise to see if the alternative is warranted. Additional discussions with the CCNS would be required since the large marsh areas in the estuary are owned by the National Park Service (NPS). The enacting legislation for the CCNS appears to prohibit this type of activity on the salt marsh; however, similar projects under consideration elsewhere may help to demonstrate important benefits of this approach that may allow its use.

4.0 PROJECT FEASIBILITY

The feasibility of establishing a dredging program in Nauset Estuary is described in the following sections in terms of potential environmental impacts, engineering constraints, regulatory requirements, and construction costs.

4.1 ENVIRONMENTAL FEASIBILITY

A dredging program in Nauset Estuary has the potential to have both positive and negative impacts. If the Town decides to pursue the project further it will be necessary to conduct more in-depth environmental impact analyses than were achievable with resources available for this study. However, data and tools developed for this project were used to the extent possible to evaluate potential impacts of the project.

Impacts on hydrodynamics

The FVCOM model described on Section 2.3 was used to evaluate potential changes to the estuary hydrodynamics caused by the dredge plan. The model grid was updated to reflect the 100 ft wide channel dredged to a depth of -5 ft MLLW (Figure 24). To allow comparison with previously validated model results, the model simulations were forced with conditions corresponding to a previous observational period in April 2011.

One of the more notable differences between model simulations with the current 2015 bathymetry and the proposed dredged channel was an increase in tidal amplitude. As the channel has shoaled in recent years and the inlet location has migrated to the north, the channel has become shallower and longer, and therefore more frictional. The added bottom friction causes a reduction in the amplitude of the tide propagating into the estuary from the ocean. Measured water level data from moorings deployed in Town Cove at various times since spring 2009 demonstrate that the tidal amplitude has been decreasing as the channel has lengthened and the friction increased (Figure 25). The data show a 20% decrease in tidal amplitude over the 5 year period of observation. A similar decrease in water level was observed in measurements from Salt Pond.

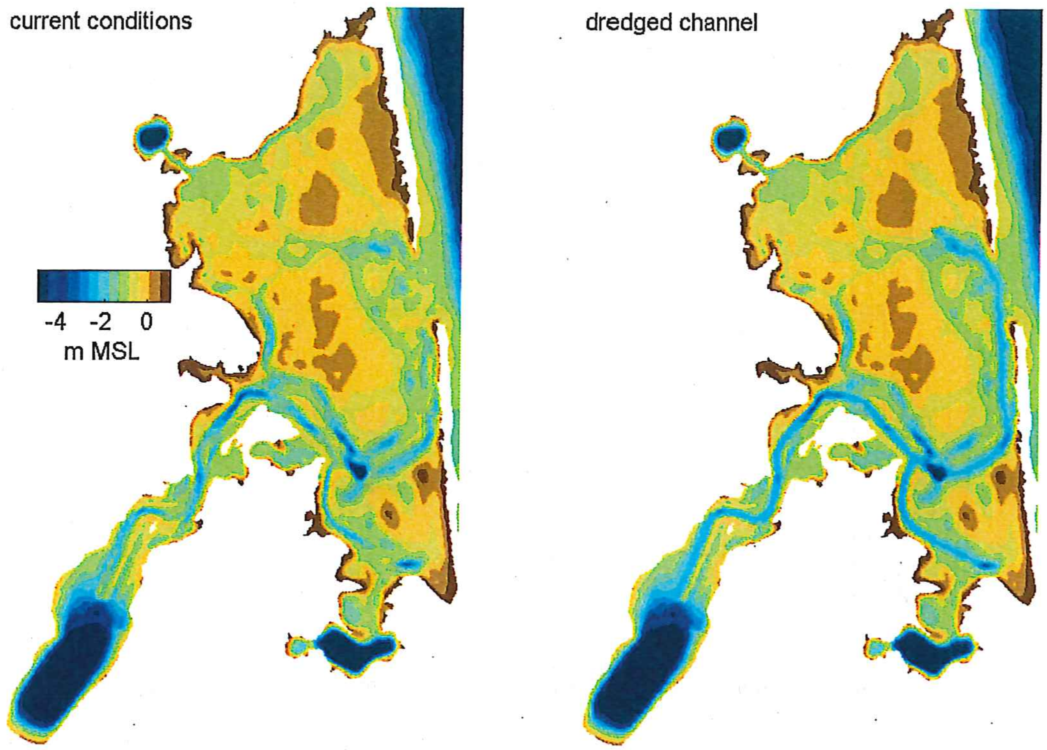

Figure 24. Model bathymetry based on (left) 2015 bathymetric soundings, and (right) channel dredged to -5 feet MLLW.

Model simulations are generally consistent with the observed trends. For example, simulations with the current 2015 bathymetry have a lower tidal amplitude in Town Cove (and the other ponds) than the previous model simulations based on bathymetry surveys through 2009 (Figure 25). In the model, the effect of dredging is to make the tidal flow less frictional, increasing conveyance into the ponds and increasing the tidal amplitude. Therefore, expected effects of the dredging are to restore tidal amplitude to values similar to the model results using the older bathymetry and the observations from 2009-2011.

In the model, tidal velocities and bottom stresses increase modestly in the vicinity of the proposed dredging (Figure 26). The changes in bottom stress, which are important for determining sediment transport, are due both to the increase in water depth and the increase in tidal amplitude. The estuary remains strongly flood dominant, continuing to favor sediment import and accretion. Bed stresses with the proposed dredging are greater in the current configuration only in a few locations, which likely correspond with regions that are currently depositional. In general, the dredging project is not expected to result in increased shoreline erosion within the estuary as the system is expected to return to conditions that existed previously. Longer term, shifts in tidal amplitude, bottom stress, and sediment transport depend as much on inlet position and dynamics as on the channel depth.

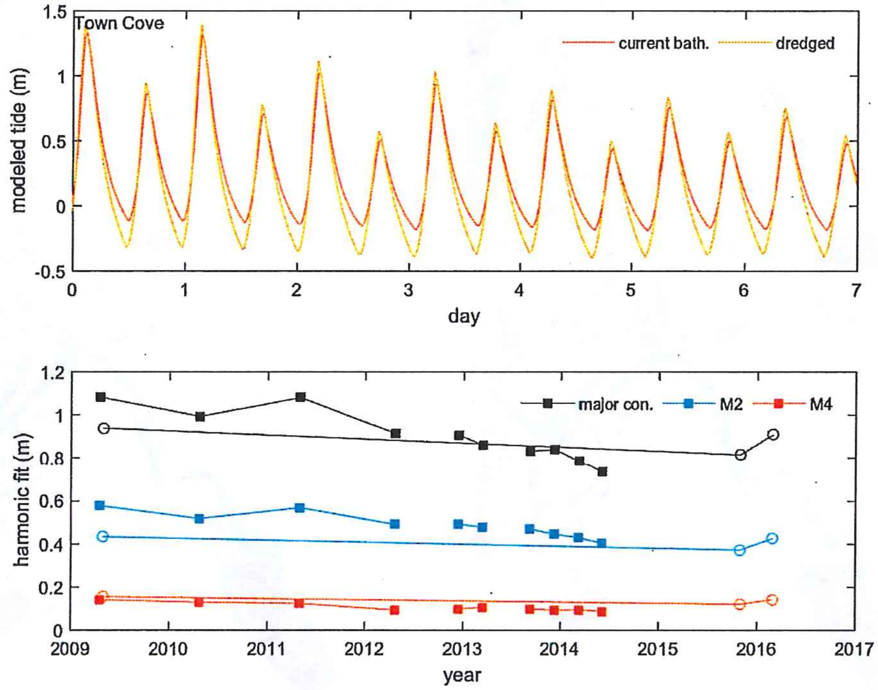

Figure 25. Modeled and observed tidal amplitudes in Town Cove. (top) Modeled water level using 2015 bathymetry vs. the dredge configuration. (bottom) Tidal harmonics based on observations (filled squares) and model results (open circles). Model results are based on simulations using bathymetry from 2009, 2015, and the dredged channel.

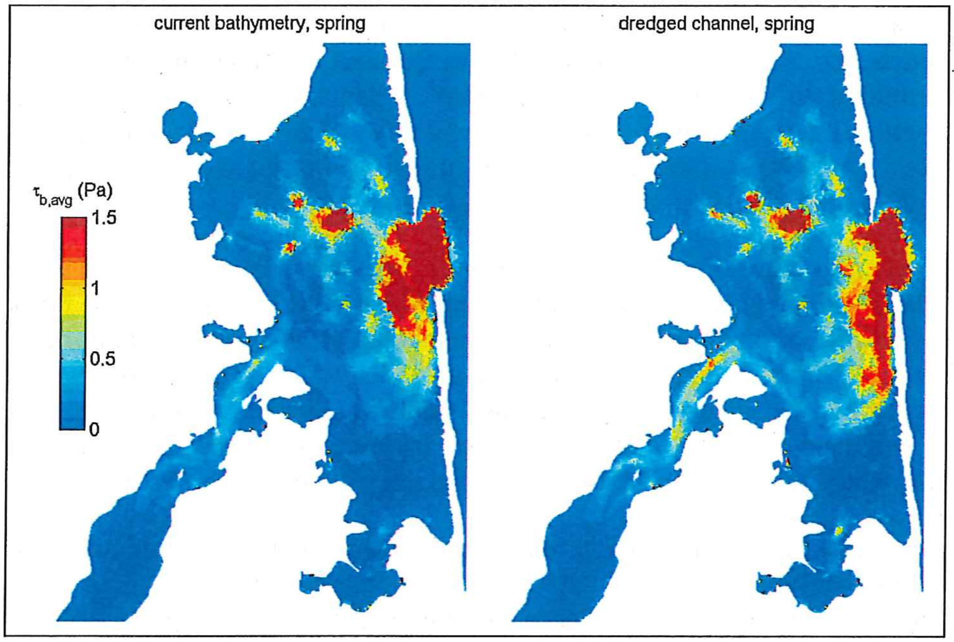

Figure 26. Modeled bottom stresses (average over 2 days) for the current bathymetry (left) and bathymetry with the proposed channel (right).

Impacts on distribution of red tide cysts

There are several ways that the dredging might alter the dynamics and distributions of *Alexandrium* blooms within Nauset Estuary. One is that the mechanical or hydraulic dredging operations will resuspend sediments that contain *Alexandrium* cysts, redistributing those cysts within the marsh, and, depending on the timing of the dredging, provide conditions that are suitable for germination. The latter concern can be eliminated by dredging between December and February when the cysts are generally incapable of germination.

The redistribution of cysts in also not a major concern based on the following reasoning. The estuary is strongly flood dominant and retentive, so resuspended sediment and cysts will likely deposit within the estuary, either on the marsh platform or in regions of lower velocity like shoals at the channel edges or in the salt ponds. It is, however, not possible to estimate the total number of cysts that will be resuspended during dredging, as this will not be constant across the marsh due to variable cyst abundances and sediment types in the areas to be dredged. Previous coring data have shown that cysts are most concentrated in the top few cm of the bed, and that concentrations decrease rapidly within about 10 cm from the surface. The dredging depth would generally be much deeper than 10 cm, and thus the cysts in the surface layer will be mixed and diluted with the deeper bed material. The calculation described in Section 2.6 estimated an average of 40 cyst/ cm^3 in the dredged material, and it is reasonable to assume that the sediment and cysts released to the environment during dredging will have a similar average concentration. Resuspension experiments in test plots in Roberts Cove found that cysts settled at rates similar to silt-sized sediment (Anderson and Ralston, unpublished data), so the cysts and silt can be expected to be transported in the estuary similarly. Silt is most commonly found in the lower energy regions of the system, including the salt ponds and shallow side embayments, and in these regions the background cyst concentrations range from several hundred to several thousand cysts/cm^3. The addition of newly remobilized material with an average concentration of around 40 cyst/cm^3 would not increase the cyst abundance at the bed surface in these depositional areas, nor would it be expected to increase the magnitude of *Alexandrium* blooms.

Alternatively, the total number of cysts in the dredge material is estimated to be 2.2 x 10^{12}. Using a similar approach, the total number of cysts in the estuary in the top 1 cm of the bed is estimated to be 6.6 x 10^{13}, and the total number in the top 10 cm of the bed as 3.3 x 10^{14}. Estimating that the loss rate of resuspended material during dredging operations to be 1% (Palermo, et al., 2008), the total number of cysts released during dredging would represent an addition of about 0.03% to the cysts in the surface layer. Again, this would not be expected to increase the magnitude of *Alexandrium* blooms.

The changes in tidal amplitude in the estuary associated with dredging that were calculated by the model may have impacts on red tide cysts that are difficult to quantify. An increase in tidal range could enhance flushing of the salt ponds, potentially reducing the accumulation rates of *Alexandrium* cells in the ponds and bloom intensity (Ralston et al. 2015). Larger tides may also increase bed stresses in the system, remobilizing and redistributing fine sediment and associated cysts. This could increase the population of cysts that are available to germinate, although as with the sediment released during dredging operations, the expectation is that the fine sediment and cysts would accumulate in regions that already have high cyst concentrations. An important point in assessing potential effects of a change in tidal amplitude is that the model predicts a return to tidal conditions similar to that of several years ago rather than a significant increase over the historical range. As the Nauset inlet has migrated north and the entrance channel both extended and shoaled, the estuary has become more frictional, accounting for the decrease in tidal range. The proposed dredging would reverse some of that decrease, but the tidal regime and any effects on the harmful algal bloom would be similar to conditions from a few years ago.

Red tide impacts associated with the various placement alternatives shown in Figure 23 present no major concerns or negative impacts. For the dune enhancement alternatives, most cysts in the sand will be buried in the dune, such that few, if any, will be washed back into the water. As the sand dries out, the cysts will desiccate and die. With the upland/coastal beneficial reuse alternative the primary concern with respect to *Alexandrium* cysts is that during the dewatering process, cysts might be carried into Town Cove with the water that drains from the sediment pile. But, sand and silt act as filters when piled in the holding area, so most cysts will be strained from the water as it drains through the tortuous path of the sand, silt, and clay particles. With the marsh restoration option, the dredged sediment and associated *Alexandrium* cysts will be trapped by the *Spartina* and other marsh grasses. The cysts will thus be placed in an environment where they are likely either to die, due to repeated cycles of inundation and drying with the tides, or to be buried into anoxic sublayers of sediment, where they will remain dormant until they die. The subaqueous placement alternative has considerable promise to be effective and environmentally benign, but it should be pursued as a pilot research study first to demonstrate the principle of using sand deposition to suppress cyst germination.

Impacts requiring further study

Given that FVCOM shows changes in tidal amplitude with the dredging project, it is likely that the project would also result in changes to tidal flushing and water quality. However, these impacts are not expected to result in significant harm since the system will be returning to conditions that existed previously. If the Town proceeds with the project it will be important to quantify these potential impacts. In terms of sediment transport and shoreline erosion, the dredging is not expected to result in significant differences. However, one area that requires further examination is the southern channel leading to Priscilla Road Landing. While the FVCOM model does not indicate significant changes to hydrodynamics in this area caused by dredging, the potential for an increased risk of breaching at the historical 1930's location near Nauset Heights should be evaluated further. If adverse impacts are noted, it may be possible to evaluate different dredging scenarios (narrower, shallower) that would reduce the potential for a breach in this location. If the Town proceeds with the project, it will also be necessary to evaluate potential impacts to existing resources such as shellfish, wetlands, shorebirds, etc. through more detailed surveys.

4.2 ENGINEERING FEASIBILITY

The engineering feasibility of the project was evaluated by looking at two primary aspects of the project. The first was the ability to maintain a dredged channel to the desired width and depth without frequent maintenance dredging. The second included an evaluation of viable construction methods given the dredge channel layout and available placement options. Although determining specific time frames for the former is difficult, based on preliminary hydrodynamic modeling and long-term knowledge of the geomorphology of Nauset Inlet and Nauset Estuary, rough projections of the lifetime of the dredged channel can be made. Because of the dynamic nature of the inlet and barrier beach, the portion of the channel immediately behind the barrier beach and near the inlet would likely require maintenance dredging every 1 to 3 years to maintain the channel design. In the event that a new breach forms to the south near Tern Island, the channel area behind the barrier beach would be abandoned, and maintenance dredging would only be required in the channel leading to the breach. Post-dredge shoaling rates in the interior channels are difficult to predict without a detailed sediment transport model; however, it is likely that these areas would receive small volumes of sedimentation and would require infrequent maintenance dredging.

The second engineering consideration involves which construction methods are viable given the channel layout, available placement options, and equipment limitations. Because there are technical limitations to how far dredged material can be hydraulically pumped, the limits on appropriate placement sites were assumed to the 4,000 and 11,000 ft from the dredge locations. These two distances coincide with the Barnstable County Dredge capabilities to pump dredge material without and with a booster pump. Because Nauset Beach is approximately one mile south of Nauset Estuary, material can only be hydraulically pumped there with a booster pump attached to the pipe (Figure 23). Alternatively, Nauset Spit is much closer to the proposed dredge areas, and could be used as a placement site for material pumped from within 4,000 feet using a hydraulic dredge, even without a booster. By adding a booster pump, material from much of the proposed dredge area could be pumped to this location.

Finally, due to the length of the dredging project, areas of the channel in the vicinity of Town Cove are more than 11,000 feet from either beach/dune disposal site. As such, the distance limitations of the County Dredge, even with an attached booster pump, rule out the possibility of utilizing a hydraulic dredge to remove the material from this portion of the channel (Figure 23, right panel). Instead, the material will need to be mechanically dredged, and barged to a shorefront location for offloading and trucking to an approved site. Water depths in the estuary would not allow for a fully loaded barge to be towed to the eastern side of the system so the material could be used on Nauset Spit. Instead, the likely destination for any mechanically dredged material, regardless of grain size, from the Town Cove portion of the channel would be Goose Hummock Landing. There, it could be offloaded at the existing bulkhead, dewatered in the parking lot if necessary, and then trucked to Nauset Beach for dune enhancement or some other approved location.

4.3 REGULATORY FEASIBILITY

Any dredging project in Massachusetts requires certain permits and certificates. Based on the 2015 channel layout, which includes removal of approximately 80,600 cubic yards of sediment from over 79 acres, regulatory review will be required by the Massachusetts Environmental Protection Act (MEPA) and the Cape Cod Commission in the form of an Environmental Impact Report (EIR) and District of Regional Impact (DRI). The current plan exceeds the regulatory threshold for the EIR, which is alteration of ten or more acres of a wetland (11.03(3)(a)1a). It may be possible to file an Expanded Environmental Notification Form (ENF) with MEPA requesting a waiver from the requirements of an EIR. This would reduce permitting costs and timing, but at this point it is unclear if MEPA would accept this request. It may also be possible to scale the project back so the EIR threshold is not triggered, but this would require a significant reduction in project scope which may not meet the objectives of improving navigation and public safety.

Since the channel layout includes sections in both the Town of Orleans and the Town of Eastham, a separate Notice of Intent will need to be filed with each town's Conservation Commission. In addition, other standard permits for dredge projects, such as a Massachusetts DEP Water Quality Certification, Chapter 91 Permit, Coastal Zone Consistency, and a USACE Individual Permit will also be required.

Although certain activities are prohibited or more strictly regulated within the Cape Cod National Seashore (CCNS), this dredge plan would not require additional federal permitting because of its location within the CCNS. However, close communication with the CCNS will be important if the project proceeds. Placement options on Town owned land, shown in Figure 23 in Section 3, also do not trigger the need for permitting with the CCNS.

Table 3 summarizes the list of permits that would be required to implement the dredge plan. The table details the type of application, agency responsible for issuing each permit, the duration of the permits, and the estimated cost associated with preparing and applying for each permit. Combined, the cost for all permits necessary for this project is estimated to be approximately $141,000. If the requirement for an EIR/DRI can be waived the cost for permitting could be reduced to approximately $75,400. Although an exact time line for applying for and receiving all the permits is not possible to develop at this time, it is likely to take between 2 and 3 years.

This feasibility study collected a limited amount of data, to help evaluate the feasibility of the project, but more detailed data will be required for actual permitting. Based on past experience from similar projects, a list of additional data needed to support the permit applications has been developed and is summarized along with associated costs in Table 4. To complete all the additional data collection would cost approximately $195,900 and would take approximately 1 year to complete.

Combined the cost of permitting and additional data collection would range between $271,300 and $336,900 depending on whether or not an EIR/DRI review is required.

Table 3. Required permits for the Nauset Estuary dredge project.

Application	Agency	Permit Duration	Cost
Expanded Environmental Notification Form	MEPA	Not Applicable	$17,400
Environmental Impact Report/ Development of Regional Impact Joint Filing	MEPA/ Cape Cod Commission	Not Applicable	$65,600
Notice of Intent	Orleans Conservation Commission	3-Years, possibly up to 10-Years	$15,000
Notice of Intent	Eastham Conservation Commission	3-Years, possibly up to 10-Years	$15,000
401 Water Quality Certification	MADEP Wetlands & Waterways	5-Years	$8,000
Chapter 91 Waterways Permit	MADEP/ Waterways	10-Years	$8,000
MCZM Federal Consistency Determination	MA Coastal Zone Management	Not Applicable	$5,000
MA Individual Permit	Army Corps of Engineers	10-Years	$7,000

Table 4. Data collection activities and estimated costs to support permit applications.

Data Collection Activity	Estimated Cost
Resource area surveys (wetlands, shellfish, eelgrass, shorebirds)	$23,000
Beach and dune topographic surveys	$7,800
Bathymetric surveys (Pre- and Post-Dredge)	$18,400
Placement site Monitoring	$9,100
Vibracoring and beach sampling for grain size	$42,500
Refined hydrodynamic modeling	$77,700
Engineering design and plans	$17,400
Total	**$195,900**

4.4 CONSTRUCTION COSTS

Construction costs are contingent on a number of factors, including mobilization costs, dredging costs, disposal costs (in the case of mechanical dredge), and whether or not a booster is utilized (in the case of hydraulic dredging). Mobilization costs to get the County Dredge to Nauset Estuary are approximately $25,000 per dredge event. The cost for actual dredging, however, depends on whether a booster pump is utilized. Without a booster pump, dredging costs $9 per cubic yard. With a booster pump, dredging costs $13 per cubic yard. There are no specific disposal costs associated with hydraulic dredging because the material is pumped to the placement site as it is being dredged, although some land-based, mechanical equipment such as bobcats and bulldozers may be required to spread and grade the material, which would add additional costs to this method.

Mechanical dredging is more costly. The mobilization cost for a mechanical dredge is approximately $150,000. The cost of actual dredging is $43 per cubic yard. Unlike hydraulic dredging, the mechanical dredging would also incur a rehandling and trucking fee of approximately $43 per cubic yard. If the material was not reused beneficially, and taken to a landfill for use as daily cover there would also be a tipping fee of about $37 per cubic yard.

Given the volumes of sediment present in different areas of the channel layout (Figure 22), and the limitations of what dredge method and placement site can be utilized for each of the areas (Figure 23), the cost of dredging each channel area has been calculated (Table 5). Assuming that the entire 80,600 cubic yards of material is dredged from all three channel areas in Nauset Estuary, the costs would range between $1.5 and $1.7 million. If sediment dredged from channel areas 1 and 3 (Figure 23) is used beneficially for dune restoration at Nauset Beach, it could save the Town between $900,000 and $1,200,000, which is the estimated cost for purchasing and spreading sand to restore the dune (Woods Hole Group, 2016).

Table 5. Estimated construction costs for dredging Nauset Estuary.

Dredge Method	Channel Area 1[1]	Channel Area 2[1]	Channel Area 3
Hydraulic w/o Booster	$430,900		
Hydraulic w/ Booster	$611,300	$398,100	
Mechanical			$734,800

1: Includes $25,000 mobilization/demobilization fee

4.5 SUMMARY OF FEASIBILITY FACTORS

Sections 4.1 to 4.4 describe the various feasibility considerations for the Nauset Estuary dredging project. These considerations encompass environmental, engineering, regulatory, and financial concerns involved with this project. To better facilitate an understanding of all these project components, the major findings from each feasibility category are summarized below in Table 6. The Town can use this summary, as well as the detailed information presented in this report, to determine the overall feasibility of this project, based on their needs, available funding, and required time frames.

Table 6. Summary of project feasibility.

Feasibility Category	Summary
Environmental	• No adverse impacts are expected due to dredging in areas with red tide cysts provided the work is done between December and February. • Potential impacts to shellfish and water quality will require further study to be determined. • Because no eelgrass is present in Nauset Estuary, no impacts are expected to this resource.
Engineering	• Combination of hydraulic and mechanical dredging • Placement can be through nearby beneficial reuse and offsite upland transport • Lifetime estimates for the dredged areas range from a low of 1 to 3 years immediately behind the barrier beach to higher lifetimes with infrequent maintenance dredging elsewhere.
Regulatory Constraints	• The total cost to complete all necessary additional data collection and prepare and submit all required permits is estimated to be $336,900. • It will take approximately 1 year to complete all additional necessary data collection, and an additional 2 to 3 years to apply for and acquire all permits necessary to commence work
Construction Costs	• Construction cost for the entire project range from $1.5 to $1.7 million. • Beneficial reuse of the dredged sand could offset the costs of dune enhancement and phased retreat at Nauset Beach by approximately $900,000 to $1,200,000.

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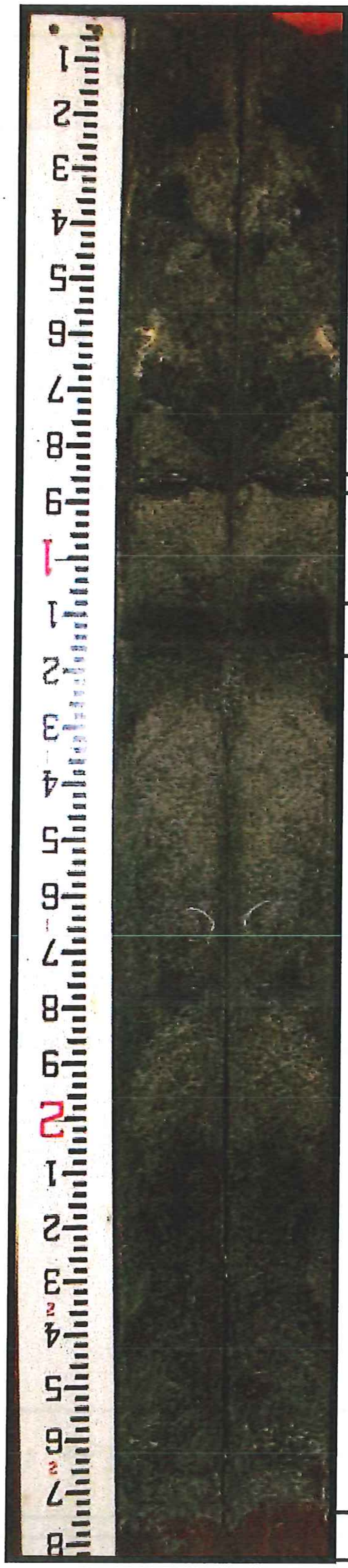
APPENDIX A. CORE LOG DESCRIPTIONS

Sediment Core Descriptions

N-1

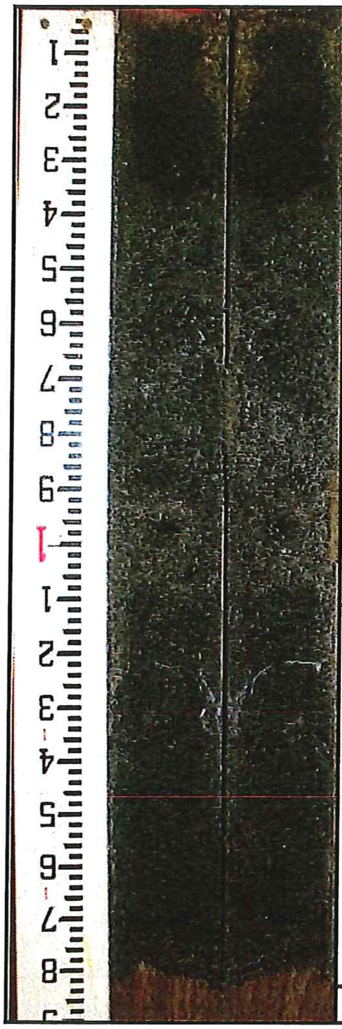
0.0-0.2’	Black sandy silt. Well sorted.
0.2-1.2’	Fine sand. Moderately-well to well-sorted. Color modeled brown to gray.
1.2-2.7’	Medium to fine sand. Moderately well-sorted. Gray.
2.7-2.9’	Fine sand. Moderately to well sorted.

N-2



0.0-0.4’	Medium to fine sand. Silty clay clast. Slipper snail shell on surface. Variable color. Modeled brown to black.
0.4-0.86’	Fine sand. Occasional shell fragments. Well-sorted. Color is gray/light gray.
↓ 0.86-0.88’	↓ Silt. Gray to dark gray. Crushed shell hash on top layer then silt.
0.88-1.08’	Fine to medium sand. Light brown to gray color. Moderately well sorted
1.08-1.16’	Sandy silt. Gray to dark gray. Well sorted.
1.16-2.78’	Sand. Grain-size coarsens with depth. Medium grained with occasional pockets of coarser sand. Organic material at 2.32’. Crushed shell hash at 2.6-2.62’. Silt content at 2.06-2.22’. Light gray to gray color.

N-3



0.0-0.36’	Medium to fine sand. Moderately sorted. Dark gray to dark olive gray.
0.36-1.1’	Sand. Poorly sorted. Fine to coarse sand. Small percentage gravel. Small to coarse gravel size. Organic content includes charcoal, woody debris and shell hash. Color variable light brown to gray.
1.1-1.86’	Medium to fine sand. Moderately sorted. Gray to dark gray.

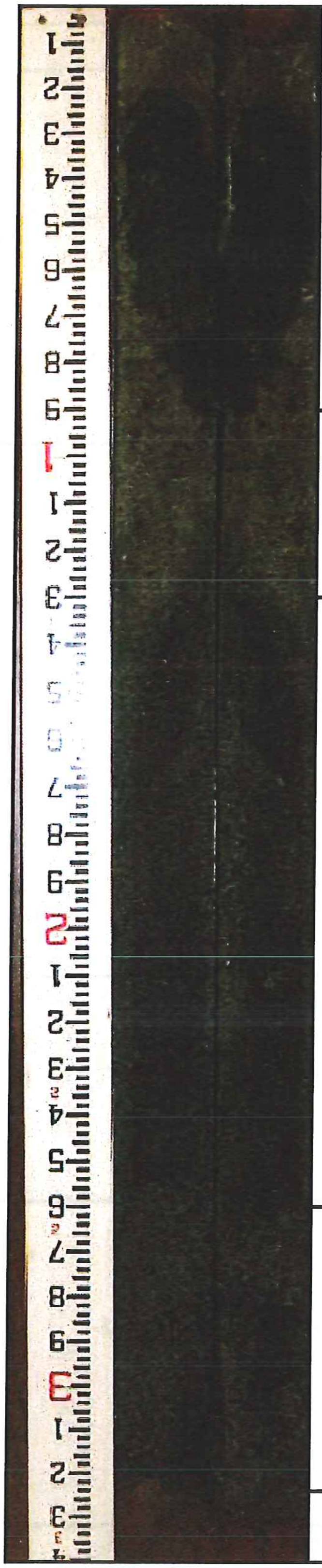
N-4

0.0-1.2'	Sand. Poorly sorted. Medium grained matrix with gravel. Light brown color.
1.2-1.6'	Top predominately quartz. Slightly coarser grained. Minerology is different. High content of darker sand grains.
1.6-1.98'	Gray to dark gray. Moderately well sorted.
1.98-2.2'	Well sorted. Fine sand. Very dark gray. Shell fragments. Occasional large gravel.
2.2-2.56'	Bimodal sand. Dark gray.
2.56-3.3'	Medium to coarse grained with gravel. Salt and pepper color. Predominately quartz. Medium to poorly sorted.

N-5

0.0-1.26’	Medium grained sand. Moderately sorted. Shell fragments. Low percentage gravel. Brown to light browns.
1.26-2.84’	Well sorted medium sand. Color variable light gray to dark gray.
2.84-3.52’	Well sorted medium sand. Color variable light gray to dark gray.
3.52-4.56’	Moderately sorted. Medium grained sand matrix. Occasional gravel. Color gray to dark gray.
4.56-4.84’	Poorly sorted sand with low percentage silt and gravel. High percentage organic material with shell hash. Gravel > 1 cm well rounded. Black color.

N-6



0.0-0.2’	Fine to medium sand with gravel. Light brown.
0.2-0.9’	Uniform texture. Fine sand and silt content. Bottom on transition zone on an angle. Sand content increases with depth. Dark olive gray to black.
0.9-1.3’	Moderate medium grained sand. Low percentage gravel fragments. Color light grayish to brown.
1.3-2.6’	Fine to medium grained sand. Well rounded gravel. Gray to dark gray. Well sorted.
2.6-3.24’	Medium grained. Slightly coarser than above. Moderately sorted. Gray.

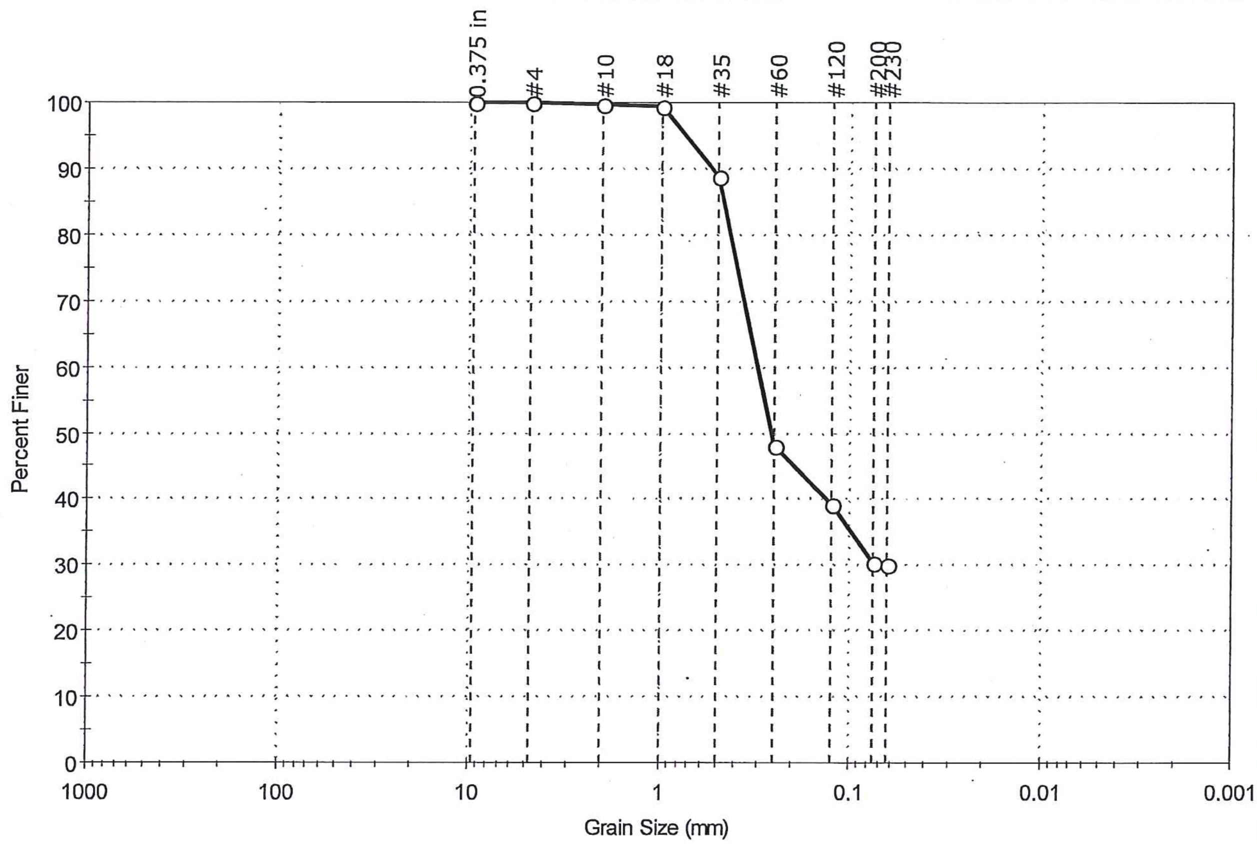
APPENDIX B. LABORATORY GRAIN SIZE RESULTS

GeoTesting EXPRESS

Client:	Woods Hole Group				
Project:	Orleans Nauset Estuary				
Location:	Nauset Inlet, MA			Project No:	GTX-304172
Boring ID:	2015-0121	Sample Type:	bag	Tested By:	jbr
Sample ID:	N-1	Test Date:	01/04/16	Checked By:	emm
Depth :	0-0.2 ft	Test Id:	359153		

Test Comment: ---
Visual Description: Moist, olive silty sand
Sample Comment: ---

Particle Size Analysis - ASTM D422



% Cobble	% Gravel	% Sand	% Silt & Clay Size
—	0.1	69.5	30.4

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
0.375 in	9.50	100		
#4	4.75	100		
#10	2.00	100		
#18	1.00	99		
#35	0.50	89		
#60	0.25	48		
#120	0.12	39		
#200	0.075	30		
#230	0.063	30		

Coefficients

D_{85} =0.4690 mm D_{30} =N/A
D_{60} =0.3059 mm D_{15} =N/A
D_{50} =0.2579 mm D_{10} =N/A
C_u =N/A C_c =N/A

Classification

ASTM N/A

AASHTO Silty Gravel and Sand (A-2-4 (0))

Sample/Test Description

Sand/Gravel Particle Shape : ---
Sand/Gravel Hardness : ---

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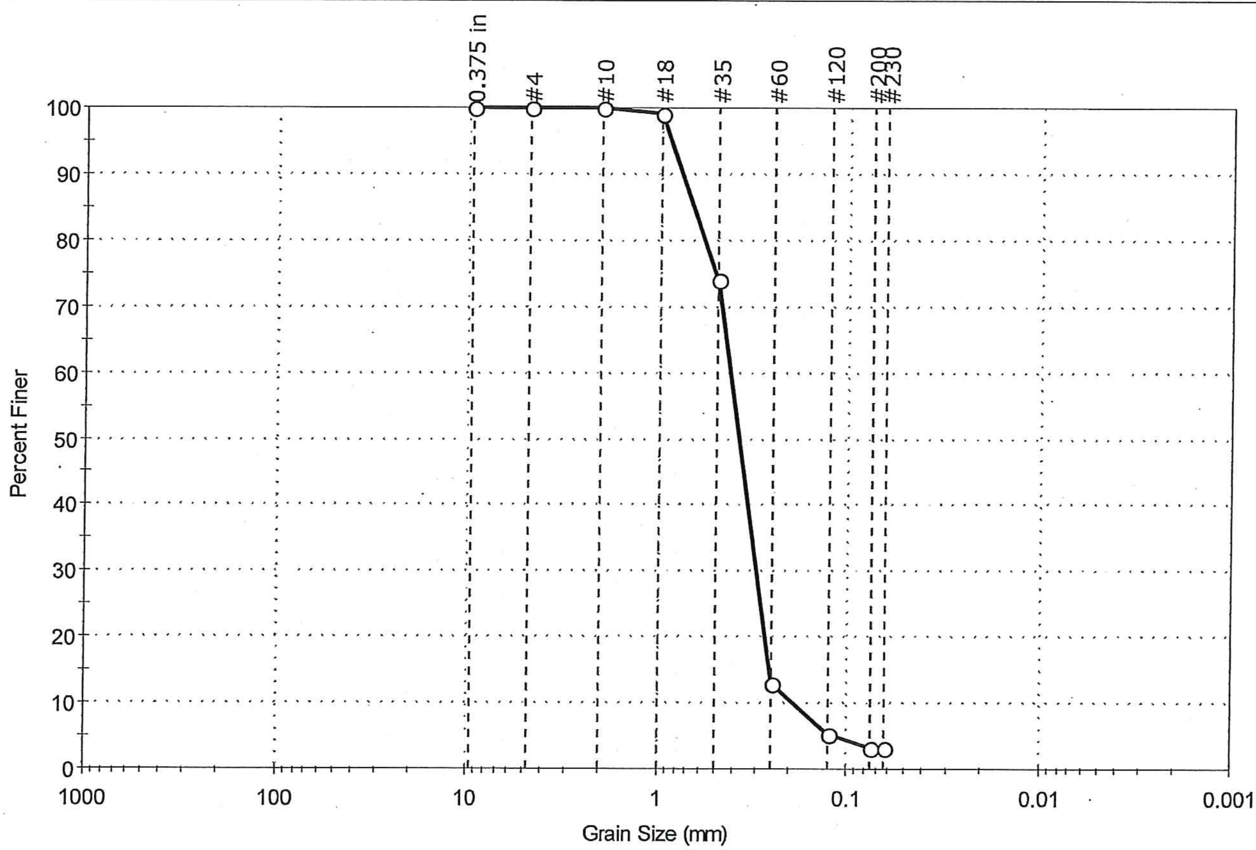
GeoTesting EXPRESS

Client:	Woods Hole Group		
Project:	Orleans Nauset Estuary		
Location:	Nauset Inlet, MA	Project No:	GTX-304172
Boring ID: 2015-0121	Sample Type: bag	Tested By:	jbr
Sample ID: N-1	Test Date: 01/04/16	Checked By:	emm
Depth : 0.2-2.3 ft	Test Id: 359154		
Test Comment:	---		
Visual Description:	Moist, gray sand		
Sample Comment:	---		

Particle Size Analysis - ASTM D422



% Cobble	% Gravel	% Sand	% Silt & Clay Size
—	0.0	96.8	3.2

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
0.375 in	9.50	100		
#4	4.75	100		
#10	2.00	100		
#18	1.00	99		
#35	0.50	74		
#60	0.25	13		
#120	0.12	5		
#200	0.075	3.2		
#230	0.063	3		

Coefficients

D_{85} =0.6765 mm — D_{30} =0.3031 mm

D_{60} =0.4262 mm — D_{15} =0.2556 mm

D_{50} =0.3804 mm — D_{10} =0.1901 mm

C_u =2.242 — C_c =1.134

Classification

ASTM — Poorly graded sand (SP)

AASHTO — Stone Fragments, Gravel and Sand (A-1-b (1))

Sample/Test Description

Sand/Gravel Particle Shape : ---

Sand/Gravel Hardness : ---

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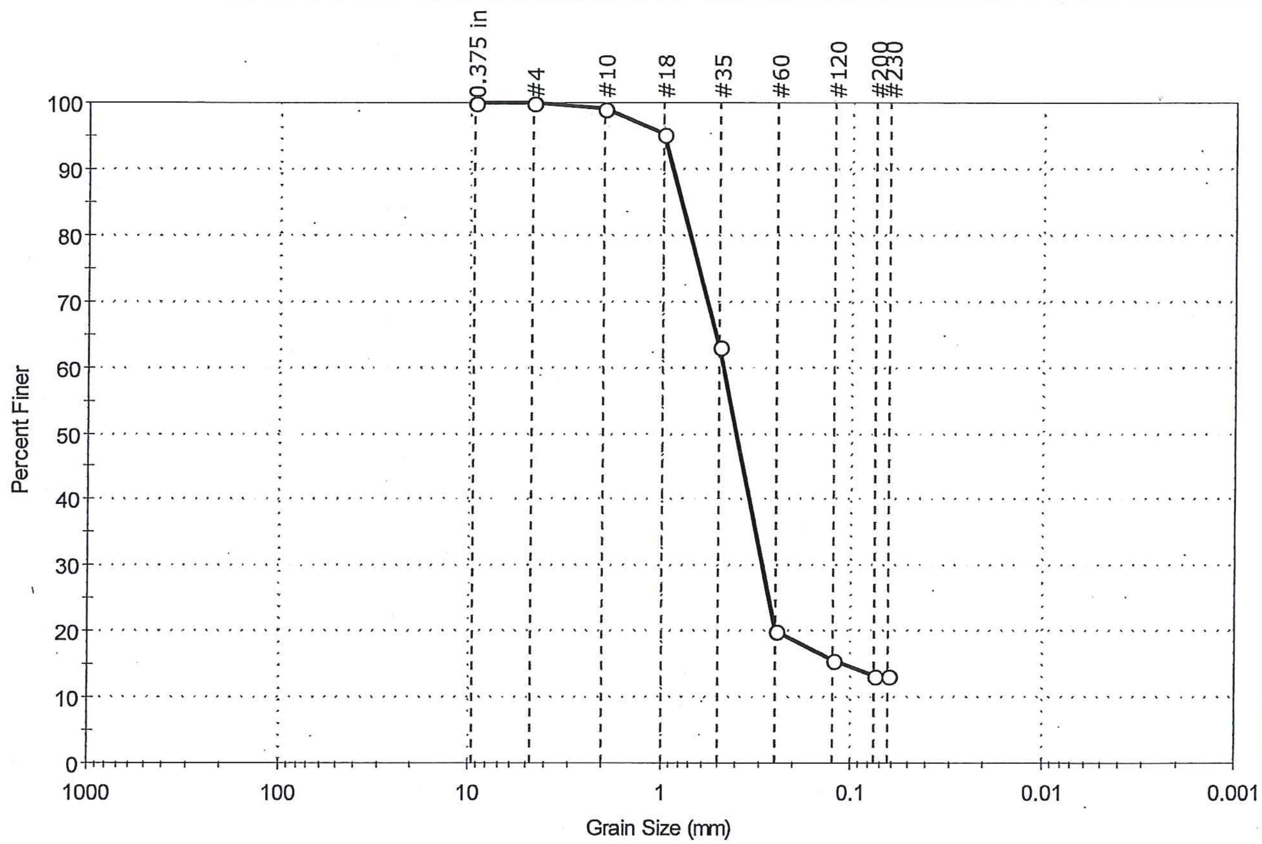
Client:	Woods Hole Group				
Project:	Orleans Nauset Estuary				
Location:	Nauset Inlet, MA			Project No:	GTX-304172
Boring ID:	2015-0121	Sample Type:	bag	Tested By:	jbr
Sample ID:	N-2	Test Date:	12/31/15	Checked By:	emm
Depth :	0-2.6 ft	Test Id:	359155		

Test Comment: ---
Visual Description: Moist, olive silty sand
Sample Comment: ---

Particle Size Analysis - ASTM D422



% Cobble	% Gravel	% Sand	% Silt & Clay Size
—	0.0	86.7	13.3

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
0.375 in	9.50	100		
#4	4.75	100		
#10	2.00	99		
#18	1.00	95		
#35	0.50	63		
#60	0.25	20		
#120	0.12	16		
#200	0.075	13		
#230	0.063	13		

Coefficients

D_{85} =0.8010 mm
D_{30} =0.2935 mm
D_{60} =0.4765 mm
D_{15} =0.1095 mm
D_{50} =0.4054 mm
D_{10} =N/A
C_u =N/A
C_c =N/A

Classification

ASTM N/A

AASHTO Stone Fragments, Gravel and Sand (A-1-b (0))

Sample/Test Description

Sand/Gravel Particle Shape : ---

Sand/Gravel Hardness : ---

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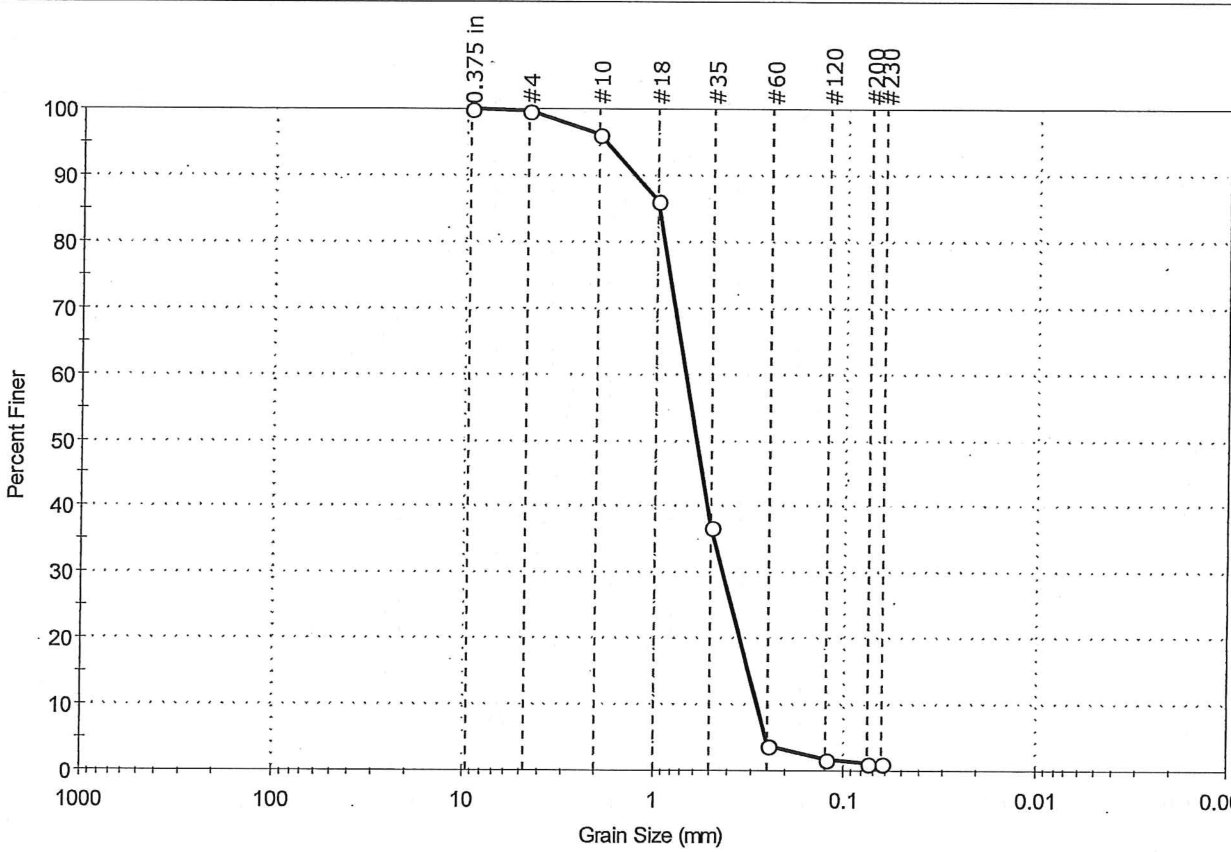
GeoTesting EXPRESS

Client:	Woods Hole Group				
Project:	Orleans Nauset Estuary				
Location:	Nauset Inlet, MA			Project No:	GTX-304172
Boring ID:	2015-0121	Sample Type:	bag	Tested By:	jbr
Sample ID:	N-3	Test Date:	12/31/15	Checked By:	emm
Depth :	0-1.8 ft	Test Id:	359156		
Test Comment:	---				
Visual Description:	Moist, pale brown sand				
Sample Comment:	---				

Particle Size Analysis - ASTM D422



% Cobble	% Gravel	% Sand	% Silt & Clay Size
---	0.4	98.3	1.3

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
0.375 in	9.50	100		
#4	4.75	100		
#10	2.00	96		
#18	1.00	86		
#35	0.50	37		
#60	0.25	4		
#120	0.12	2		
#200	0.075	1.3		
#230	0.063	1		

Coefficients

D_{85} =0.9840 mm D_{30} =0.4324 mm
D_{60} =0.6918 mm D_{15} =0.3163 mm
D_{50} =0.6009 mm D_{10} =0.2850 mm
C_u =2.427 C_c =0.948

Classification

ASTM Poorly graded sand (SP)

AASHTO Stone Fragments, Gravel and Sand (A-1-b (1))

Sample/Test Description

Sand/Gravel Particle Shape : ---

Sand/Gravel Hardness : ---

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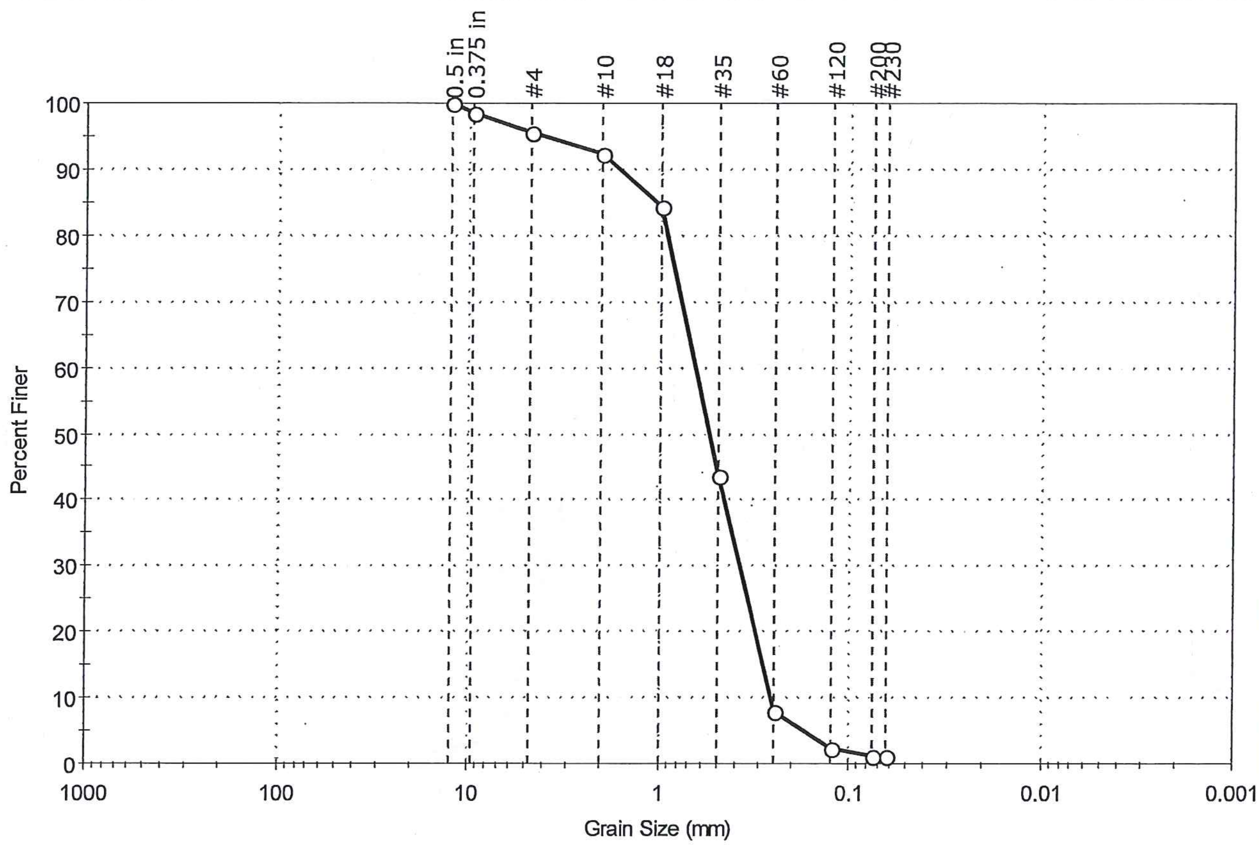
Client:	Woods Hole Group				
Project:	Orleans Nauset Estuary				
Location:	Nauset Inlet, MA			Project No:	GTX-304172
Boring ID:	2015-0121	Sample Type:	bag	Tested By:	jbr
Sample ID:	N-4	Test Date:	01/04/16	Checked By:	emm
Depth :	0-3.3 ft	Test Id:	359157		
Test Comment:	---				
Visual Description:	Moist, pale brown sand				
Sample Comment:	---				

Particle Size Analysis - ASTM D422



% Cobble	% Gravel	% Sand	% Silt & Clay Size
---	4.5	94.2	1.3

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
0.5 in	12.50	100		
0.375 in	9.50	99		
#4	4.75	95		
#10	2.00	92		
#18	1.00	84		
#35	0.50	44		
#60	0.25	8		
#120	0.12	2		
#200	0.075	1.3		
#230	0.063	1		

Coefficients

D_{85} =1.0677 mm D_{30} =0.3837 mm

D_{60} =0.6607 mm D_{15} =0.2872 mm

D_{50} =0.5568 mm D_{10} =0.2607 mm

C_u =2.534 C_c =0.855

Classification

ASTM   Poorly graded sand (SP)

AASHTO   Stone Fragments, Gravel and Sand (A-1-b (1))

Sample/Test Description

Sand/Gravel Particle Shape : ROUNDED

Sand/Gravel Hardness : HARD

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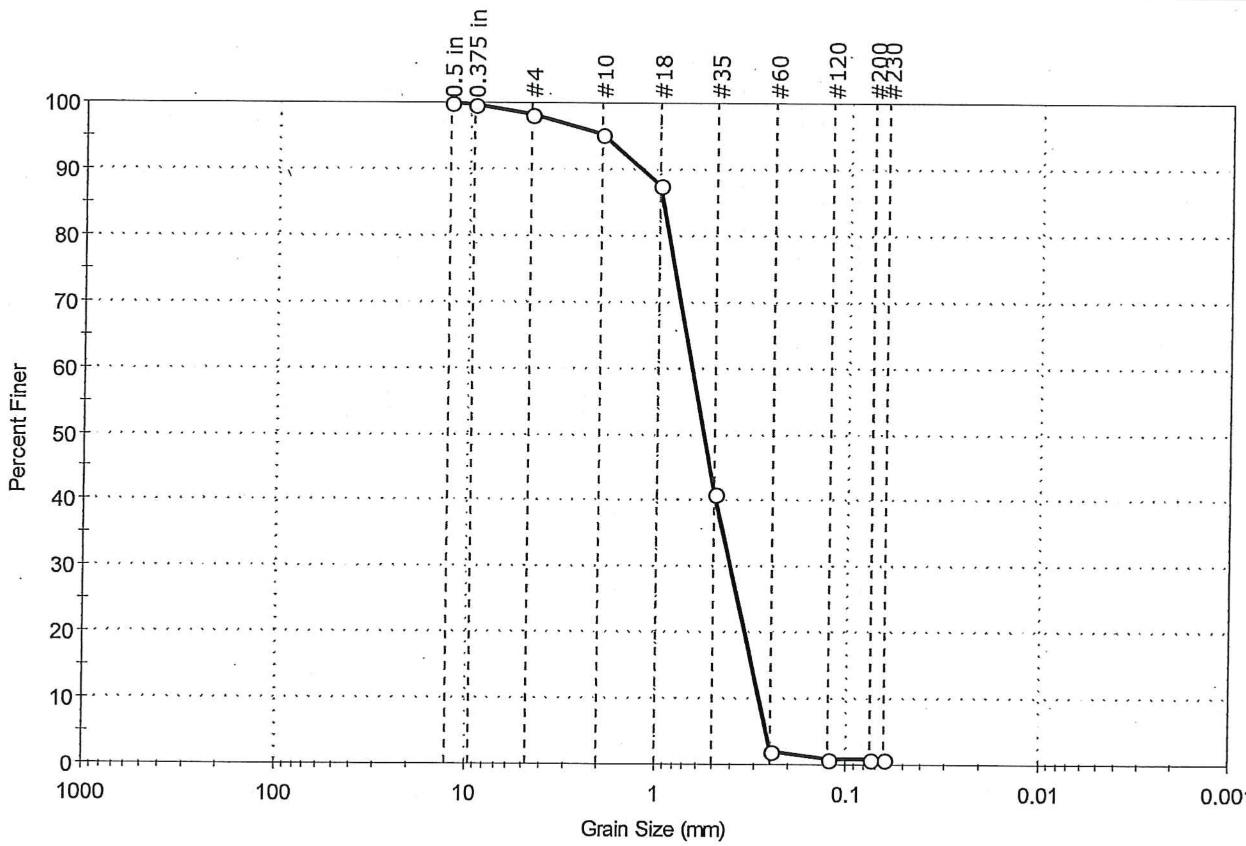
GeoTesting EXPRESS

Client:	Woods Hole Group				
Project:	Orleans Nauset Estuary				
Location:	Nauset Inlet, MA			Project No:	GTX-304172
Boring ID:	2015-0121	Sample Type:	bag	Tested By:	jbr
Sample ID:	N-5	Test Date:	12/31/15	Checked By:	emm
Depth :	0-4.5 ft	Test Id:	359158		
Test Comment:	---				
Visual Description:	Moist, pale brown sand				
Sample Comment:	---				

Particle Size Analysis - ASTM D422



% Cobble	% Gravel	% Sand	% Silt & Clay Size
—	1.9	97.3	0.8

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
0.5 in	12.70	100		
0.375 in	9.50	100		
#4	4.75	98		
#10	2.00	95		
#18	1.00	88		
#35	0.50	41		
#60	0.25	2		
#120	0.12	1		
#200	0.075	0.8		
#230	0.063	1		

Coefficients

D_{85} =0.9623 mm	D_{30} =0.4121 mm
D_{60} =0.6642 mm	D_{15} =0.3155 mm
D_{50} =0.5726 mm	D_{10} =0.2886 mm
C_u =2.301	C_c =0.886

Classification

ASTM Poorly graded sand (SP)

AASHTO Stone Fragments, Gravel and Sand (A-1-b (1))

Sample/Test Description

Sand/Gravel Particle Shape : ---

Sand/Gravel Hardness : ---

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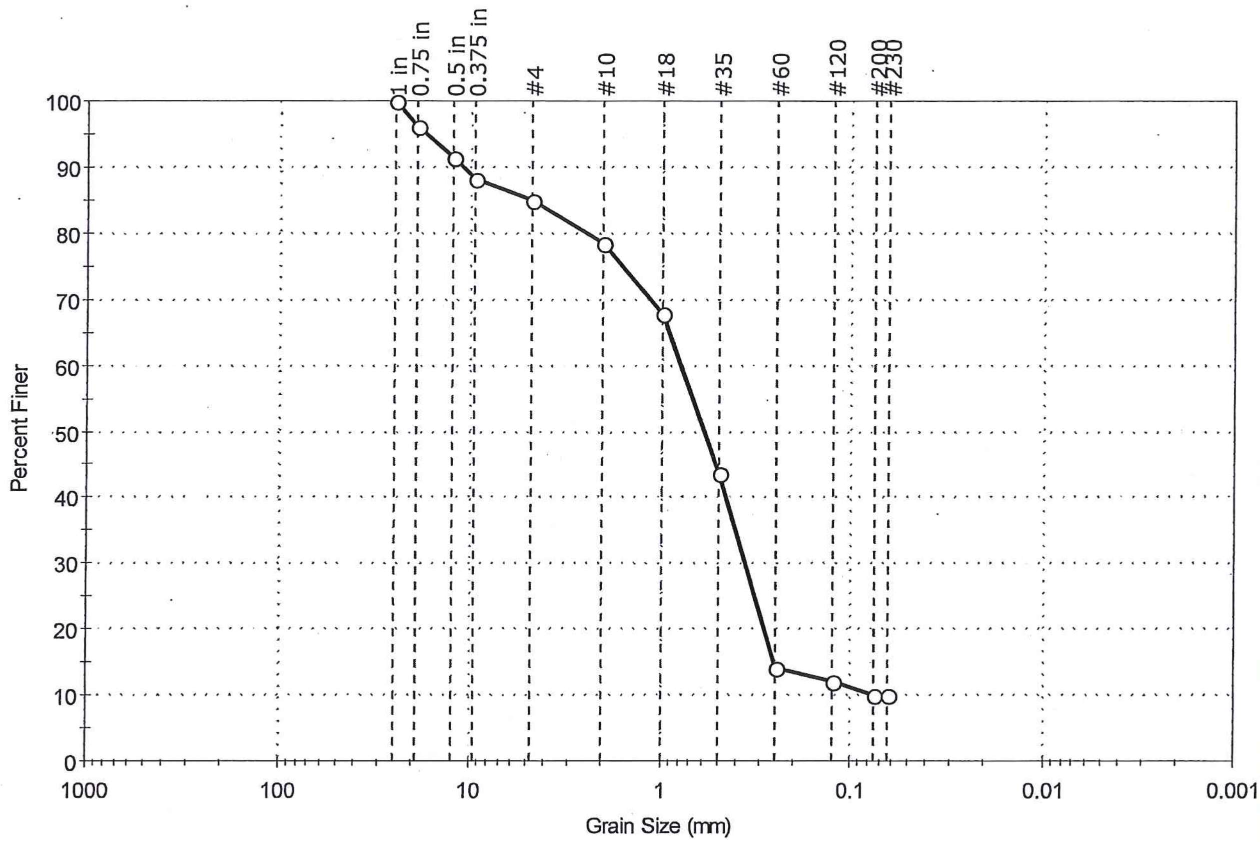
GeoTesting EXPRESS

Client:	Woods Hole Group				
Project:	Orleans Nauset Estuary				
Location:	Nauset Inlet, MA			Project No:	GTX-304172
Boring ID:	2015-0121	Sample Type:	bag	Tested By:	jbr
Sample ID:	N-5	Test Date:	01/04/16	Checked By:	emm
Depth :	4.56-4.84 ft	Test Id:	359159		

Test Comment: ---
Visual Description: Moist, brown sand with silt and gravel
Sample Comment: ---

Particle Size Analysis - ASTM D422



% Cobble	% Gravel	% Sand	% Silt & Clay Size
—	15.0	74.9	10.1

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
1 in	25.00	100		
0.75 in	19.00	96		
0.5 in	12.50	91		
0.375 in	9.50	88		
#4	4.75	85		
#10	2.00	78		
#18	1.00	68		
#35	0.50	44		
#60	0.25	14		
#120	0.12	12		
#200	0.075	10		
#230	0.063	10		

Coefficients

D_{85} =4.7159 mm	D_{30} =0.3619 mm
D_{60} =0.7966 mm	D_{15} =0.2543 mm
D_{50} =0.5982 mm	D_{10} =N/A
C_u =N/A	C_c =N/A

Classification

ASTM N/A

AASHTO Stone Fragments, Gravel and Sand (A-1-b (0))

Sample/Test Description

Sand/Gravel Particle Shape : ROUNDED

Sand/Gravel Hardness : HARD

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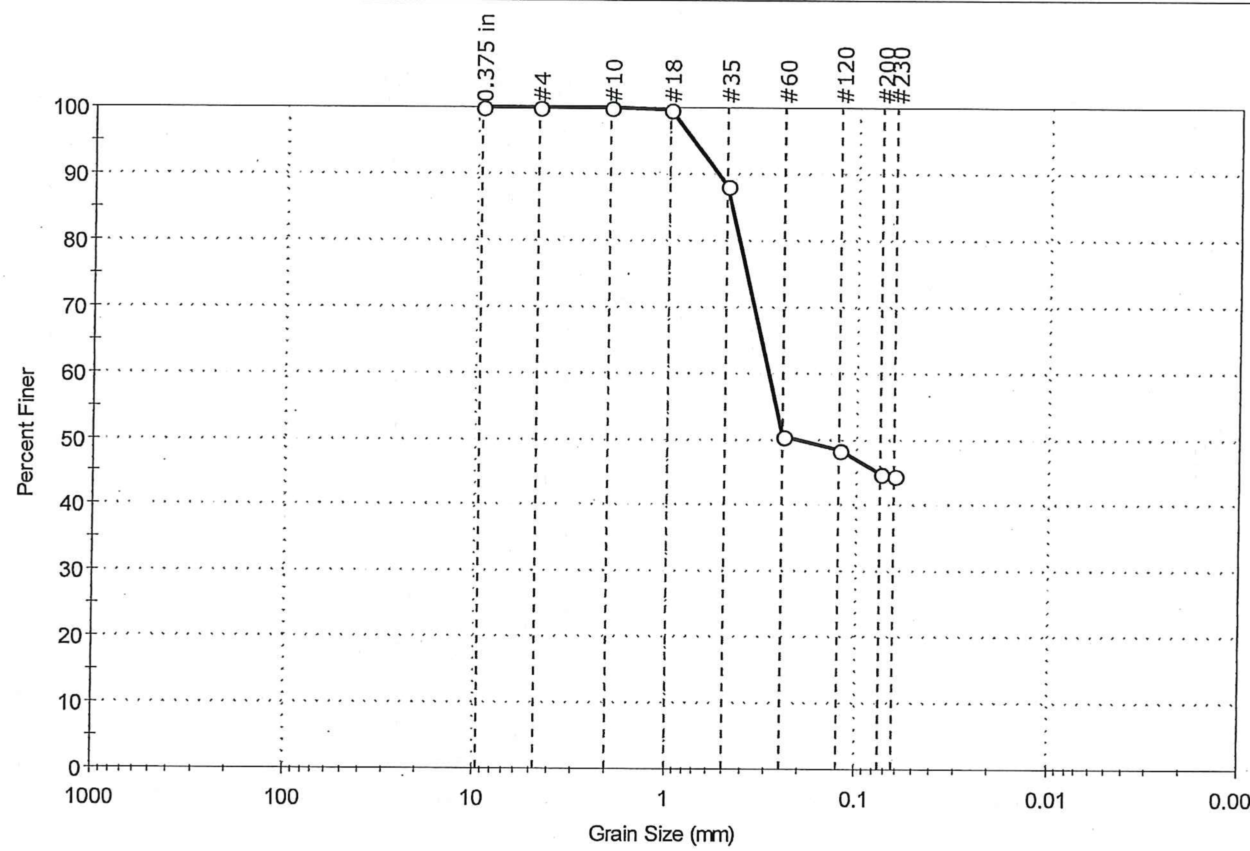
GeoTesting EXPRESS

Client:	Woods Hole Group				
Project:	Orleans Nauset Estuary				
Location:	Nauset Inlet, MA			Project No:	GTX-304172
Boring ID:	2015-0121	Sample Type:	bag	Tested By:	jbr
Sample ID:	N-6	Test Date:	01/04/16	Checked By:	emm
Depth :	0.2-0.6 ft	Test Id:	359161		
Test Comment:	---				
Visual Description:	Moist, olive silty sand				
Sample Comment:	---				

Particle Size Analysis - ASTM D422



% Cobble	% Gravel	% Sand	% Silt & Clay Size
—	0.0	55.3	44.7

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
0.375 in	9.50	100		
#4	4.75	100		
#10	2.00	100		
#18	1.00	100		
#35	0.50	88		
#60	0.25	51		
#120	0.12	48		
#200	0.075	45		
#230	0.063	44		

Coefficients

D_{85} =0.4722 mm D_{30} =N/A

D_{60} =0.2978 mm D_{15} =N/A

D_{50} =0.2097 mm D_{10} =N/A

C_u =N/A C_c =N/A

Classification

ASTM N/A

AASHTO Silty Soils (A-4 (0))

Sample/Test Description

Sand/Gravel Particle Shape : ---

Sand/Gravel Hardness : ---

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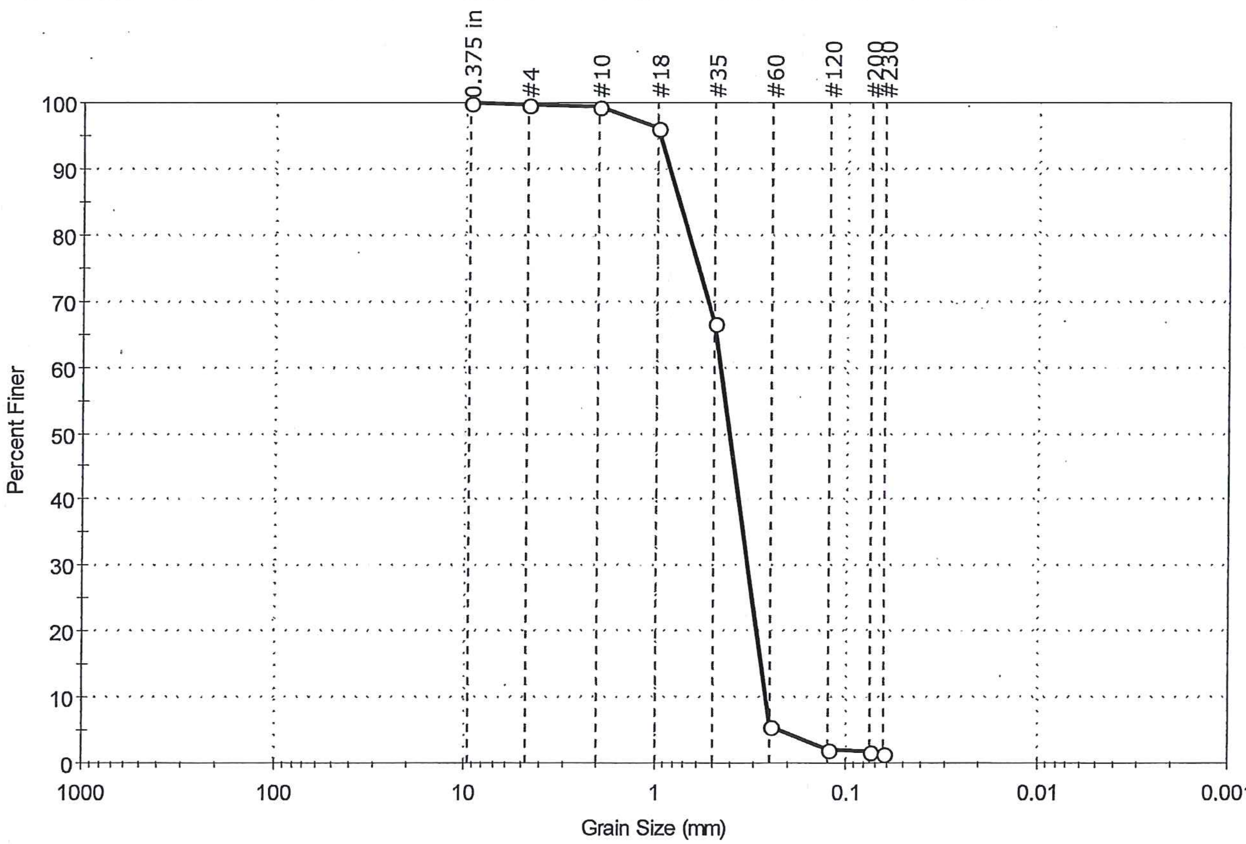
Client:	Woods Hole Group				
Project:	Orleans Nauset Estuary				
Location:	Nauset Inlet, MA			Project No:	GTX-304172
Boring ID:	2015-0121	Sample Type:	bag	Tested By:	jbr
Sample ID:	N-6	Test Date:	01/04/16	Checked By:	emm
Depth :	0.9-3.24 ft	Test Id:	359160		
Test Comment:	---				
Visual Description:	Moist, gray sand				
Sample Comment:	---				

Particle Size Analysis - ASTM D422



% Cobble	% Gravel	% Sand	% Silt & Clay Size
—	0.2	98.2	1.6

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
0.375 in	9.50	100		
#4	4.75	100		
#10	2.00	99		
#18	1.00	96		
#35	0.50	67		
#60	0.25	6		
#120	0.12	2		
#200	0.075	1.6		
#230	0.063	2		

Coefficients

D_{85} =0.7699 mm — D_{30} =0.3297 mm

D_{60} =0.4637 mm — D_{15} =0.2780 mm

D_{50} =0.4139 mm — D_{10} =0.2627 mm

C_u =1.765 — C_c =0.892

Classification

ASTM: Poorly graded sand (SP)

AASHTO: Stone Fragments, Gravel and Sand (A-1-b (1))

Sample/Test Description

Sand/Gravel Particle Shape : ---

Sand/Gravel Hardness : ---

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Sheila Vanderhoef

From: whswift@yahoo.com
Sent: Wednesday, April 27, 2016 3:35 PM
To: Sheila Vanderhoef
Cc: Jacqueline Beebe
Subject: Nauset Marsh Inlet; Thoughts for Consideration

Sheila, as you probably recall from previous discussions and emails, my educational background is geology (with some work in coastal processes, as noted at bottom of email) and I have worked as an environmental consultant from 1978 through present, although I am sending this email as a private citizen with no connection to my employer.

I have read in the Cape Codder, with some amusement I might add, of Orleans' initiatives towards evaluating feasibility of dredging the Nauset Inlet to (1) allow safer ingress/egress through the inlet, (2) remove shoaling within the marsh near the inlet to allow for mooring of commercial vessels, (3) increase tidal flow so that selective person(s) docks can be more functional, (4) stabilize the current inlet and thus prevent a breach closer to Orleans avoiding the loss of valuable land to Eastham, and (5) provide sand to nourish Nauset Beach. At each turn, I expected reasonable minds to wake up and smell the coffee, so to speak...

However, as that has not happened and to the contrary, there appears to be a bit of a steamroller mentality developing, I thought I would offer some general thoughts and opinions on the matter, backed by my geology background and my first-hand witnessing of the outer beach since the early 1960's.

- The shoaling in the inlet area is happening for a reason. It is different than what has happened in the past 50 years, in my opinion because the natural system has been driven out of that equilibrium by the increased rate of sea level rise. Therefore, recent past history cannot be used effectively as a predictor of future results. One process that has not significantly changed is the massive volume of sand transported from wave erosion at the escarpment in S. Wellfleet and Eastham in a southerly direction past the inlet. As this "river of transported sand" crosses the inlet , it is swept into the marsh on incoming "flood" tides and pushed offshore during outgoing "ebb" tides. Sand swept into the marsh is deposited in the much quieter marsh environment creating the shoaling we see today, which is greater because in my opinion there is more sand and the flood tidal velocities are greater due to sea level rise.
- The inlet area is a VERY DYNAMIC SYSTEM. I view it from my house, and the inlet width and apparent wave action there appear larger than I can recall. Aerial photos show a channel configuration quite different than typical for the past 50 years.
- There have been comparisons made in the Orleans dialog between Rock Harbor and Nauset Inlet. These locales have very little in common. Rock Harbor has quite small groundwater discharge feeding the marsh behind it, and the Cape Cod Bay environment is a very gentle one compared with the outer beach. The jetties further protect it. As a result, the tidal currents flowing into and out of Rock Harbor are relatively low, and the volume of sand transport (longshore drift) in this area is relatively small, compared to Nauset Inlet. Nauset Inlet, in comparison, has substantial groundwater discharge to it, creating greater dynamics by itself, and the ocean waves and their generated longshore transport of sand combine to make it a MUCH HIGHER ENERGY SYSTEM.
- What does that last conclusion mean (Rock Harbor does not equal Nauset Inlet)? In my opinion, that means that there can be no comparison in lifespan of dredging effectiveness from Rock Harbor to Nauset.
- Mother nature always wins. <u>Always</u>. If the spit is going to breach close to Nauset Heights (which has been the normal cycle under previous, more stable conditions) and then migrate slowly to the north, <u>then that is what it is going to do</u>, irrespective of efforts of some "big boys playing with their machines".
- Rising sea level is a game changer. Nauset Beach is losing sand, where it had been much more stable before. Nauset Marsh (including at the base of my property) was rich with sea lavender, now there is none, because it cannot dry out between high tides. Shoaling is more dominant because there are comparatively higher flood (incoming) tides allowing for slightly greater incoming net sand transport into the marsh. Could the over-accumulation of sand in the marsh be the reason that Nauset Beach has been starved of sand and is eroding? I pose that as a possibility; data would have to be evaluated to consider the hypothesis.
- Nature seeks equilibrium. Assuming sea level continues to rise (or even stabilizes at current level), what will nature seek to do with a newly dredged channel? That channel creates ideal conditions for increased deposition of sand and shoaling will increase.

Finally, I am concerned that, given the ill will between the towns of Orleans and Eastham over the location of the town line on the outer beach and the matter of enforcement of Eastham's no vehicles on beach by-law, Orleans could very well expect cost sharing by Eastham for any dredging performed at the inlet. I would suggest that the Selectmen consider this possibility (if they have not done so already) and form a position, that would include, I hope, refusal to allow dredging on Eastham's property, and if not successful, a demand to be compensated at going rates for sand "mined" from Eastham land for Orleans' benefit. I do not see a parallel with Rock Harbor where Eastham has a town landing and a dock that benefits from the dredging. In this situation, per my list of 5 "perceived benefits" that Orleans has touted in the press, none in my opinion actually benefit Eastham (dock issue notwithstanding, but why can't the dock be reconfigured to adjust to nature, as opposed to adjust nature to the dock?).

I offer 2 caveats before signing off. My specialty is groundwater contamination; however, I have more than a passing knowledge of coastal processes, having studied them at University, having conducted shoreline erosion surveys under the CZM Act during the 1970's for CT and NH, and having observed coastal processes on the outer beach of Eastham first hand since I was a young boy. Second, what I have expressed here are my independent opinions, and have no connection with my employer, ERM.

I would be pleased to come in and discuss further with you at your convenience.

Kind regards, Harrison

Harry Swift

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whswift@yahoo.com