PORTSMOUTH HARBOR AND PISCATAQUA RIVER
NEW HAMPSHIRE AND MAINE
NAVIGATION IMPROVEMENT STUDY
FEASIBILITY REPORT

APPENDIX M

BENTHIC COMMUNITY ANALYSIS
AND
SEDIMENT SEIVE ANALYSIS
OF THE
ISLES OF SHOALS NORTH
ALTERNATIVE OCEAN PLACEMENT SITE

This appendix presents data collected from the alternative ocean placement site Isles of Shoals North and consists of two parts:

1) Identification and Enumeration of Muddy Bottom Benthic Macrofauna from the Isles of Shoals Area, by Peter Larsen, Ph.D., Coastal Sciences, Boothbay, Maine

2) Sediment sieve analysis results from the Isles of Shoals North Alternative Ocean Placement Site

IDENTIFICATION AND ENUMERATION OF MUDDY BOTTOM BENTHIC MACROFAUNA FROM THE ISLES OF SHOALS-NORTH AREA, NORTHEAST GULF OF MAINE

Contract No. W912WJ-11-M-0020

SUBMITTED BY:

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This report represents analytical results of benthic samples received by Coastal Sciences on November 10, 2010 from the US Army Corps of Engineers.

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INTRODUCTION

The Gulf of Maine is one of the world's most productive fishing grounds and best-studied continental seas. Since the last glaciation, the Gulf has undergone a rapid and dynamic geological and oceanographic evolution that has produced the rich and intricate ecological system that we witness today (Bousfield and Thomas 1975, Shaw, *et al.*, 2002). Interest the benthic macrofauna of the Gulf began early and several investigations qualitatively documented the high invertebrate species richness of the region (Mighels, 1843; Stimpson, 1853; Verrill, 1872, 1874; and Webster and Benedict, 1887; Kinsley, 1901; others). In more recent times, the rich macrobenthos of the offshore Gulf has been documented quantitatively by Rowe, *et al.*, (1975), Theroux and Wigley (1998) and others. Likewise, the coastal embayments and estuarine bottoms of New England have also been sampled widely (Larsen, 1979; Larsen and Gilfillan, 2004); Hale, 2010; and many others). All these studies confirm the rich and complex zoogeography described by Bousfield and Thomas (1975).

In spite of the high level of investigative activity, there remain other areas and systems in the Gulf of Maine that are not adequately described. One of these is the muddy bottoms of the coastal region (Lewis Incze, Gulf of Maine Area Program, Census of Marine Life, personal communication). Such areas generally fall between the deeper waters sampled from large oceanographic vessels and nearshore environments sampled from smaller workboats. Nevertheless, increased knowledge of these mid-depth soft sediment patches is required by environmental managers as the proposed uses for the coastal margin are accelerating. In particular, several demonstration projects for the development of offshore wind power are now being planned. These projects could potentially disturb these stable depositional areas by the impact of cable footings to secure the floating turbine platforms and the passage of transmission lines to the coast. In this communication we describe the benthic community inhabiting a muddy bottom in 100m water off the coast of southern Maine.

METHODS

Sampling occurred at nine stations on November 1, 2010 within a 780m radius circle approximately 14 km east northeast of the Isles of Shoals in the northwestern Gulf of Maine (Fig. 1). This is the proposed Isles of Shoals-North disposal area. The sampling site is in an area known as the Bigelow Bight and lies between the shallow Jeffreys Ledge and the Maine coast. At each station, samples for fauna and sediment analyses were retrieved using a 0.04 m^2 modified Van Veen grab. The faunal samples were sieved on a 0.5 mm screen and fixed in 10% formalin solution with the vital stain Rose Bengal.

The nine faunal samples were transferred from the U.S. Army Corps of Engineers to Coastal Sciences on November 10, 2010. In the laboratory, the formalin was removed from the samples by gentle washing on a 0.5 mm sieve and the samples were preserved in 70% ethanol. The benthic macrofauna in each sample was separated from the limited inorganic debris and

sorted to major taxonomic categories. This process was accomplished by trained personnel using binocular dissecting microscopes. A subsample of the residue of each sample was reexamined to insure complete removal of the fauna. No problems were detected. Each taxonomic group was examined by an experienced marine taxonomist who identified each individual to the lowest practical taxonomic level, usually the species level, and enumerated the number of individuals in each taxon. Synonymies were made current using the World Register of Marine Species (www.marinespecies.org/).

Zoogeographic affinities and feeding types were determined using standard references such as Pettibone (1963), Gosner (1971), Bousfield (1973), Fauchald and Jumars (1979) and Watling (1979) as well as several websites including using the World Register of Marine Species (www.marinespecies.org/).

The numerical data were analyzed using the statistical package PRIMER v6 (Clarke and Gorley, 2006). Univariate community structure analyses performed include density (N), species richness (S), Shannon diversity (H^1, base *e*) and Pielou's Evenness (J^1). The faunal relationships were also investigated using numerical classification and ordination. Species data were square root transformed to moderate the influence of abundant species. A hierarchical agglomerative classification scheme was employed using the Bray-Curtis similarity index. The group-average linking method was used to produce a dendrogram of sample relatedness and a 2-dimensional ordination of stations was accomplished using the non-metric multidimensional scaling (MDS) technique found in PRIMER. Multivariate analyses were limited to species that occurred at two or more stations.

Species accumulation curves were utilized to assess the adequacy of the sampling and to estimate the unknown biodiversity of the northwestern Gulf of Maine community. The Chao 2 formula was chosen. This is a presence-absence measure that relies on the number of species that occur in one sample and the number that occur in two samples to calculate an estimate of the maximum number of species expected (Colwell and Coddington, 1994).

RESULTS

Abiotic Factors

Descriptive details of station location, depth and sediment type are presented in Table 1. The stations were in close proximity to one another; the maximum distance between any two stations being about 1.5 km. Depth was rather uniform as all stations occurred at depths between 95 and 100 m. The sediments can be characterized as fine. Seven of the nine stations exhibited silt/clay content in excess of 96%. Two stations, B and H, were somewhat coarser with silt/clay contents of 79.8 and 92.7%, respectively. The non-silt/clay fractions of all the samples consisted of sand. Moist, brown silty clay is the visual description of all of the samples. The Folk classification of these sediments is silt (Folk, 1968).

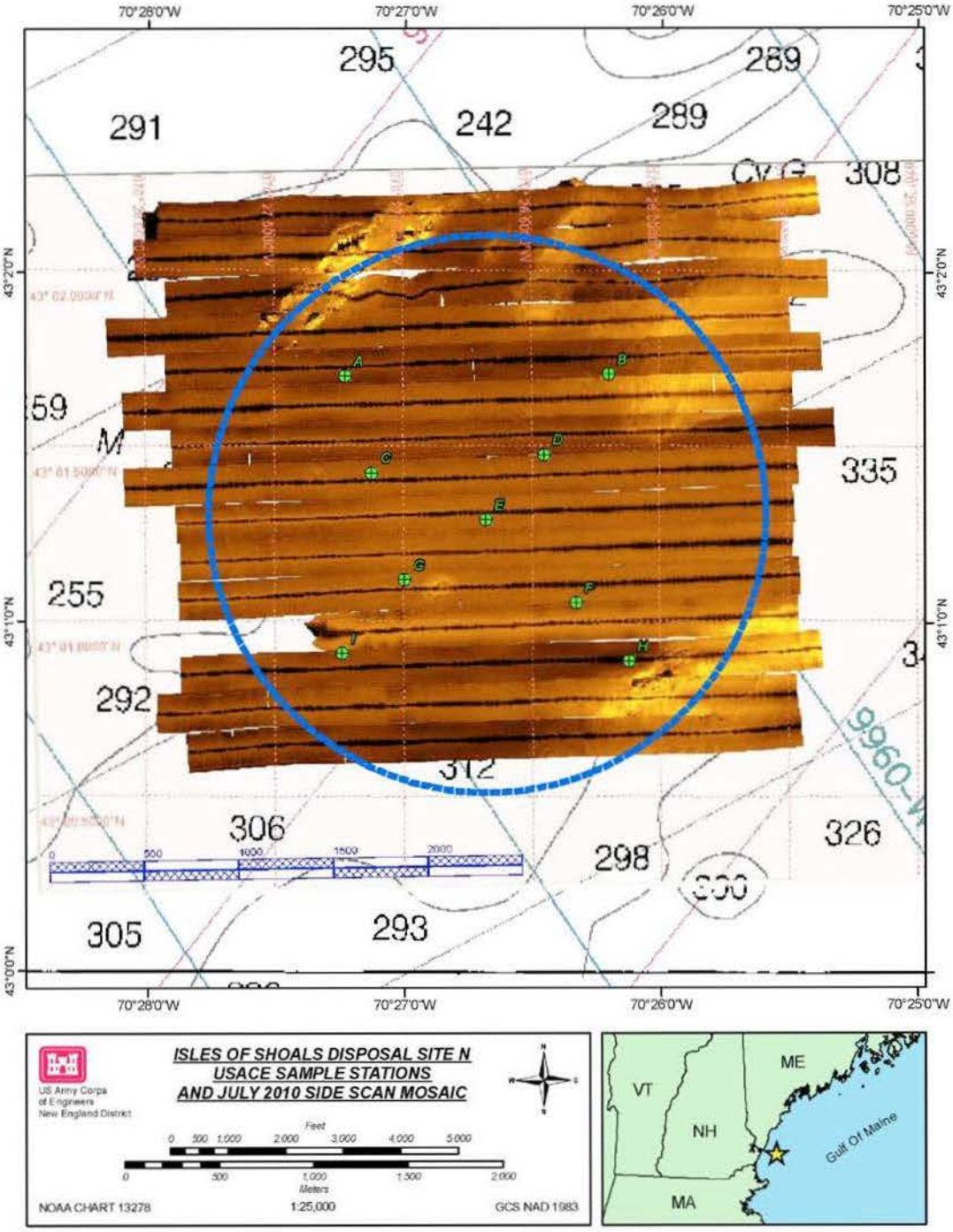

Figure 1. Isles of Shoals-North Station Locations with Side Scan Sonar Mosaic Superimposed. Depths are in Feet.

Faunal Composition, Abundance and Dominance

A total of 40 taxa from four phyla were identified from the nine samples (Table 2). Thirty-two taxa were identified to the species level. No colonial species were encountered. The number of taxa at the stations ranged from seven to 19 with a mean of 10.7 (Table 3). The fauna was dominated by polychaetes that accounted for 25 of the 40 taxa or 62.5% of the fauna. Percentage representation of other taxa was 17.5% Arthropoda, 15% Mollusca and 5% Rhynchocoela.

TABLE 1. Location and Environmental Characteristics of the Nine Benthic Stations from the Northwestern Gulf of Maine.

Station	Latitude	Longitude	Depth (m)	% Sand	% Silt & Clay
A	43.028412	-70.45389	97.2	2.1	97.9
B	43.028527	-70.43678	95.7	20.2	79.8
C	43.023773	-70.45215	96.0	2.4	97.6
D	43.024674	-70.44097	96.9	3.4	96.6
E	43.021569	-70.44474	96.3	3.7	96.3
F	43.017613	-70.43885	97.8	2.4	97.6
G	43.018689	-70.45004	96.6	3.9	96.1
H	43.014840	-70.43541	100.0	7.3	92.7
I	73.015181	-70.45402	95.4	2.1	97.9

Density at the stations ranged from 400 to 1,950 individuals/m^2 with a mean density of 1,055/m^2 (Table 3). The numerical dominance of polychaetes was very pronounced. Polychaetes represented 93.2% of all individuals. Percentage of total individuals of Mollusca, Arthropoda and Rhynchocoela were 2.6, 2.1 and 2.1 percent, respectively.

Numerical dominance of the most abundant species ranged from moderate to high (Table 3). The percentage of the fauna represented by the dominant species ranged from 14 to 51%. At eight of the nine stations the dominant species was the deposit feeding polychaete *Paraonis gracilis* that accounted for over 40% of the individuals at four of the nine stations. The only other species obtaining dominant status was another deposit feeder, the polychaete *Cossura longocirrata*.

Most of the Shannon informational diversity values (base log *e*) were constrained within a rather narrow range with the low species richness (Table 3). Station C was something of an outlier. Mean diversity was 1.811 and the range was 1.184 -2.367. Evenness also did not vary widely. Evenness values ranged from 0.6362 to 0.9182 with a mean of 0.8035.

Zoogeographic Affinities and Feeding Guilds

It was possible to assign zoogeographic affinities to 32 of the 40 identified taxa (Table 4).

Fifteen of the taxa, 47%, could be classified as Boreal in their distribution. Another 34% of the taxa were considered to have a Boreal-Virginian geographic range. Taxa characterized as being Arctic or Virginian in their zoogeographic affinities each represented nine per cent of the identified species.

TABLE 2. List of Taxa Collected During the Isles of Shoals-North Benthic Survey

Phylum	Species	Phylum	Species
Rhynchocoela		**Arthropoda**	
	Micrura sp. (Ehrenberg, 1971)		*Cyclaspis varians* Calman, 1912
	Nemertean		*Eudorella pusilla* Sars, 1871
Mollusca			*Harpinia propinqua* Sars, 1891
	Astarte undata (Gould, 1841)		*Leptocheirus plumulosus* Shoemaker, 1932
	Bivavle juv.		*Leptostylis longimana* (Sars, 1865)
	Parvicardium pinnulatum (Conrad, 1831)		*Paracaprella tenuis* Mayer, 1903
	Chaetoderma nitidulum (Loven, 1844)		*Photis* sp. Kroyer, 1842
	Thyasira gouldi (Philippi, 1845)		
	Thyasira sp. (Lamarck, 1818)		
Annelida			
	Aglaophamus neotenus (Noyes, 1980)		
	*Ampharete arctica (*Malmgrem, 1866)		
	Aricidea suecica (Eliason, 1920)		
	Ceratocephale loveni (Malmgren, 1867)		
	Chaetozone setosa (Malmgren, 1867)		
	Cossura longocirrata (Webster & Benedict, 1887)		
	Harmothoe extenuata (Grube, 1840)		
	Lepidonotus squamatus (Linnaeus, 1758)		
	Lumbrineris latreilli Audouin & Milne Edwards, 1834		
	Scoletoma tenuis Verrill, 1873		
	Maldane sarsi Malmgren, 1865		
	Mediomastus ambiseta (Hartman, 1947)		
	Nephtys incisa Malmgren, 1865		
	Ninoe nigripes Verrill, 1973		
	Owenia fusiformis Delle Chiaje, 1844		

	Paramphinome pulchella Sars, 1869		
	Paraonis gracilis (Tauber, 1879)		
	Praxillella gracilis (M. Sars, 1861)		
	Praxillella praetermissa (Malmgren, 1865)		
	Prionospio sp Malmgren, 1867.		
	Sabaco elongatus (Verrill, 1873)		
	Scalibregma inflatum Rathke, 1843		
	Syllid juvenile		
	Tharyx acutus Webster & Benedict, 1887		
	Unknown		

TABLE 3. Community Parameters and Numerical Dominance

Station	Species Richness	Density (m^2)	Evenness (J^1)	Diversity (H^1)	Numerical Dominance
A	11	775	0.8561	2.053	*Paraonis gracilis* 26%
B	7	400	0.9182	1.787	*Paraonis gracilis* 14%
C	6	825	0.6609	1.184	*Paraonis gracilis* 61%
D	14	825	0.875	2.309	*Cossura longocirrata* 31%
E	10	1,425	0.7059	1.625	*Paraonis gracilis* 37%
F	10	950	0.7556	1.740	*Paraonis gracilis* 42%
G	8	475	0.8195	1.704	*Paraonis gracilis* 42%
H	19	1,875	0.8039	2.367	*Paraonis gracilis* 26%
I	11	1,950	0.6362	1.526	*Paraonis gracilis* 60%

On the basis of abundance, the distribution among the zoogeographic provinces was much more skewed. A full 71% of the individuals encountered could be defined as Boreal in character. The remaining individuals were divided rather evenly between Arctic, Boreal-Virginian and Virginian affinities.

The taxa encountered were assigned to one of four feeding guilds for the purposes of analysis. Surface deposit feeders, subsurface deposit feeders and omnivores were grouped together as deposit feeders in this analysis. Deposit feeders were the most prevalent of the feeding guilds. Twenty-three of the 40 species, 59%, were classified as deposit feeders.

Carnivores accounted for 23% of the taxa while only 18% were considered suspension feeders. A different pattern emerged when the analysis was done on the basis of individuals. Here 88% of the community consisted of deposit feeders, nine per cent were carnivores and suspension feeders represented only three per cent of the fauna.

Multivariate Analyses

The dendrogram based on group-average sorting classification using the Bray-Curtis similarity measure on square-root transformed data did not present a clear-cut spatial pattern (Fig. 2). Only four stations were linked in pair-groupings. Stations C and F and stations H and I formed the two pair-groupings at a very high level of similarity. Station E was then linked to the C/F grouping and the five stations were joined at nearly 60% similarity. The remaining stations then were chain-linked to the five-station cluster, i.e. individual stations were sequentially added to the dendrogram singly. They were no higher level dichotomies indicating basic dissimilarities in the station array. The SIMPROF routine of PRIMER was run to test the null hypothesis that the set of samples do not differ from each other in the dendrogram structure. Groupings that do not reject the null hypothesis are connected with red lines in the test output. As indicated in Fig. 2, all samples are connected by red lines and, hence, it can be concluded that all of the samples came from the same community.

The biological relationships among the nine samples were further investigated using a two dimensional non-metric multi-dimensional scaling (MDS) ordination also with the Bray-Curtis similarity measure calculated on square root transformed abundance data. Similar to the cluster analysis, the MDS did not reveal any segregation of groups of stations (Fig. 3). Stations C, E, F, H and I were grouped towards the center while Stations A, B, D and G were spaced around the periphery. The stress level of 0.07 indicates that the MDS is “a good ordination with no real prospect of misleading interpretation; 3- or higher dimensional solutions will not add any additional information” (Clarke and Warwick, 2001).

TABLE 4. Zoogeographic Affinities and Feeding Guilds of Taxa Collected in a Mud Habitat, Northwestern Gulf of Maine.

Phylum and Species		Zoogeographic Affinity	Feeding Guild
Phylum Rhynchocoela			
	Micrura sp. Ehrenberg, 1971	BV	Carnivorous
	Nemertean		Carnivorous
Phylum Mollusca			
	Astarte undata Gould, 1841	B	Suspension
	Bivavle juv.		Suspension
	Parvicardium pinnulatum (Conrad, 1831)	BV	Suspension
	Chaetoderma nitidulum (Loven, 1844)	B	Omnivorous
	Thyasira gouldi (Philippi, 1845)	B+	Suspension
	Thyasira sp. Lamarck, 1818		Suspension
Phylum Annelida			
	Aglaophamus neotenus Noyes, 1980	B	Deposit
	Ampharete arctica Malmgrem, 1866	A+	Deposit
	Aricidea suecica (Eliason, 1920)	A+	Deposit
	Ceratocephale loveni Malmgren, 1867	B	Deposit
	Chaetozone setosa Malmgren, 1867	B	Surface deposit
	Cossura longocirrata Webster & Benedict, 1887	B	Surface deposit
	Harmothoe extenuata (Grube, 1840	B	Carnivorous
	Lepidonotus squamatus (Linnaeus, 1758)	B	Carnivorous
	Lumbrineris latreilli Audouin & Milne Edwards, 1834	BV	Carnivorous
	Scoletoma tenuis Verrill, 1873	BV	Carnivorous
	Maldane sarsi Malmgren, 1865	B	Subsurface deposit
	Mediomastus ambiseta (Hartman, 1947)		Deposit
	Nephtys incisa Malmgren, 1865	B	Deposit
	Ninoe nigripes Verrill, 1973	BV	Carnivorous
	Owenia fusiformis Delle Chiaje, 1844	BV	Surface deposit
	Paramphinome pulchella Sars, 1869	BV	Carnivorous
	Paraonis gracilis (Tauber, 1879)	B	Deposit
	Praxillella gracilis (M. Sars, 1861)		Subsurface deposit
	Praxillella praetermissa (Malmgren, 1865)	B	Subsurface deposit
	Prionospio sp Malmgren, 1867.		Surface deposit
	Sabaco elongatus (Verrill, 1873)	V	Subsurface deposit
	Scalibregma inflatum Rathke, 1843	BV	Subsurface deposit
	Syllid juvenile		Carnivorous
	Tharyx acutus Webster & Benedict, 1887	B+	Surface deposit
	Unknown		

Phylum Arthropoda			
	Cyclaspis varians Calman, 1912	V	Deposit
	Eudorella pusilla Sars, 1871	BV	Deposit
	Harpinia propinqua Sars, 1891	B	Surface deposit
	Leptocheirus plumulosus Shoemaker, 1932	V	Suspension
	Leptostylis longimana (Sars, 1865)	A+	Deposit
	Paracaprella tenuis Mayer, 1903	BV	Suspension/carnivorous
	Photis sp. Kroyer, 1842	BV	Deposit

Species Accumulation Analysis

The observed species accumulation curve (Sobs) and the calculated Chao 2 values are plotted in Figure 4. Tabulated values are presented in Table 5. The values are the product of 999 permutations at each step as the sample size is increased by adding samples randomly. The figure and table indicate that, while the Sobs curve continued to incline smoothly, the Chao 2 curve reached an asymptote when approximately six samples were accumulated. The Chao 2 estimator predicted that the number of species in this community is expected to be about 75 with a standard deviation of 20 under conditions of infinite sampling. The survey recovered slightly more than 50% of the theoretical total species number.

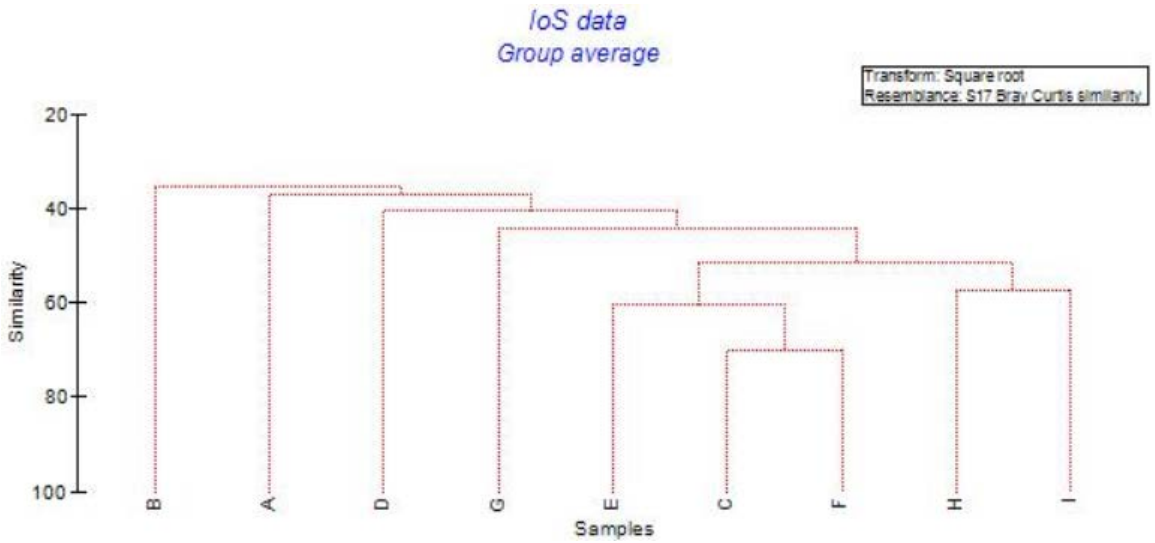

Figure 2. Dendrogram Based on a Group-Average Sorting Classification using the Bray-Curtis Similarity Measure on Square Root Transformed Data.

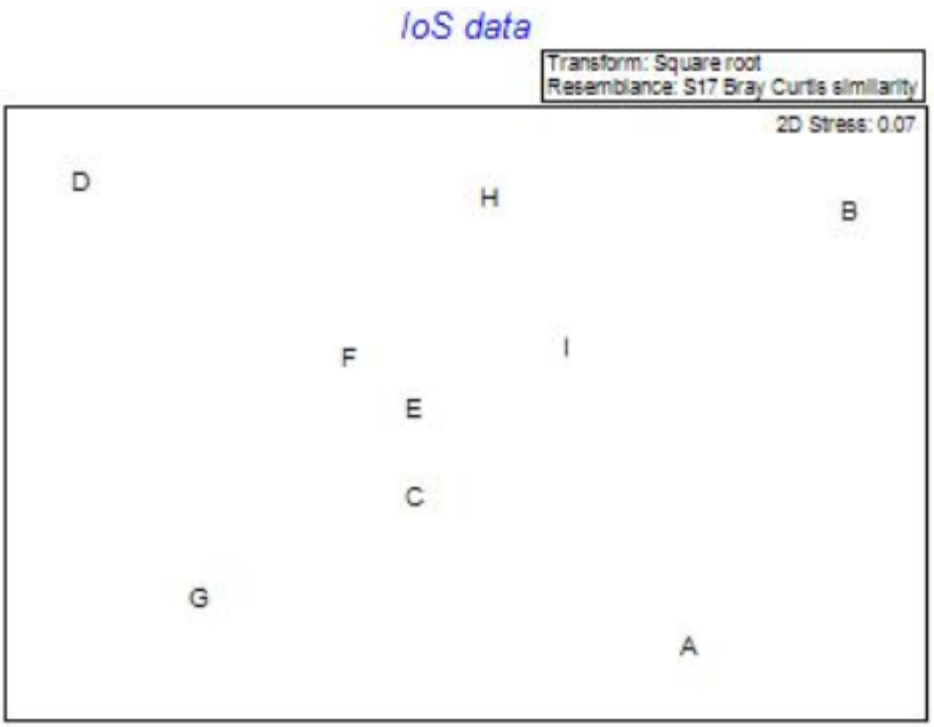

Figure 3. MDS Ordination of the Nine Samples Based on Square Root Transformed Species Abundances and Bray-Curtis Similarities (stress = 0.07).

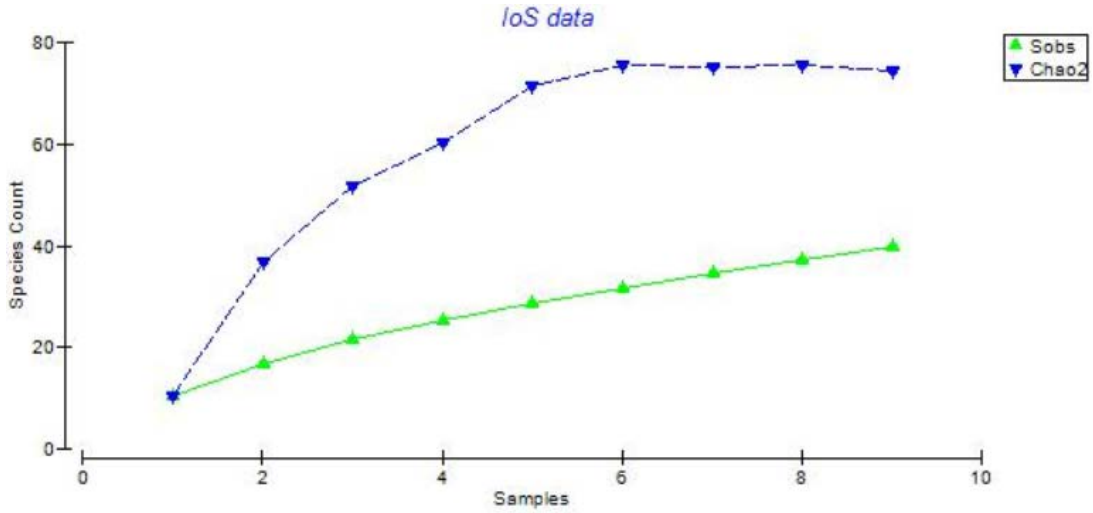

Figure 4. Plot of Observed Species Accumulation Curve (Sobs) and the Curve Predicted by the Chao 2 Extrapolator.

TABLE 5. Number of Observed Species (Sobs) and True Total Number of Species Predicted to be Found (Chao 2) with Infinite Sampling Following the Same Sampling Protocol

Station	Sobs	Sobs(SD)	Chao2	Chao2(SD)
1	10.62	3.66	10.62	12.69
2	16.65	3.91	36.05	15.56
3	21.42	3.91	50.39	24.20
4	25.43	3.54	60.79	28.43
5	28.89	3.28	70.93	33.98
6	32.07	2.85	76.53	33.15
7	34.85	2.31	75.54	27.57
8	37.54	1.56	76.50	24.95
9	40.00	0.00	74.57	20.56

DISCUSSION

The salient result of this benthic survey in the northwest Gulf of Maine is the uniformity of the environment both physically and biologically. The stations occur over a very narrow depth range and the sediments have a very high silt/clay content that can be described as silt (Table 1). In the limited area covered by the survey, there is no reason to suspect that temperatures and currents are not equally uniform.

The macroinvertebrate fauna at the site is limited. The benthic community consists of only 40 species representing just four phyla (Table 2). The assemblage is noteworthy for its lack of oligochaetes, nearly ubiquitous elsewhere, and the absence of echinoderms and colonial species. Polychaetes are the characteristic taxa overwhelmingly dominating the community in terms of numbers of species and individuals. Density is relatively low while the univariate statistics, species richness, diversity and evenness, are also at low to modest levels. One species, the polychaete *Paraonis gracilis*, is the numerical dominant at eight of the nine stations.

The zoogeographic affinities of the species that could be characterized range from Arctic to Virginian (Table 4). The largest group has a Boreal affinity followed by the Boreal-Virginian group accounting for about a third of the taxa. Fewer than one in ten of the taxa are considered to be either Arctic or Virginian. Numerically, however, individuals of the Boreal species make up nearly three-quarters of the community.

The functional group in this fine-grained habitat is overwhelmingly deposit feeders as would be expected. Species in this generalized feeding guild partition the environment by practicing several variations of obtaining nutrition from the sediments. Some, such as the four maldanid polychaete species, feed relatively deeply within the subsurface sediments. Other subsurface feeders, *Scalibregma inflatum*, feed higher in the sediment column while several other species, *Cossura longocirrata* and *Tharyx acutus*, feed on the very sediment surface.

Hence, a large number of deposit-feeders can be supported.

The biological homogeneity is confirmed by multivariate analyses of the community data. Cluster analysis does not dissect the stations into any discernible pattern. SIMPROF indicates that there are no statistically significant differences among the branches of the dendrogram (Figure 2). MDS analysis, likewise, shows no separation of samples that would indicate any coherent underlying biological divisions (Figure 3). It can be concluded that the samples were drawn from the same faunal community.

The species accumulation analyses are revealing. While the observed species curve climbs smoothly, the Chao 2 curve reaches an asymptote rather quickly (Figure 4, Table 5). This suggests that the true species complement would be reached with a finite amount of additional sampling. The Chao 2 estimate of the true species number is less than twice the number of species actually observed (Table 5) indicating that further sampling would add rare species to the species list while not affecting the numerical dominance observed (Appendix).

In summary, the study area is physically homogeneous and inhabited by a limited benthic invertebrate community. Richness, at the species and higher taxonomic levels, and density are low relative to both more inshore and more offshore habitats. Deposit-feeding polychaetes dominate the fauna qualitatively and quantitatively. The community can be considered Boreal in its zoogeographic affinity. Further sampling would undoubtedly add to the species total but would probably not modify the characterization of the community significantly. This communication helps to fill an identified gap in our knowledge of the Gulf of Maine ecosystem.

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APPENDIX

COMMUNITY STRUCTURE TABLES

TABLE 1A. Isles of Shoals-North Benthic Sample A

Species	Total	Cum. Tot.	%	Cum. %	Higher Taxon
Paraonis gracilis	8	8	25.8	25.8	Annelida
Lepidonotus squamatus	6	14	19.4	45.2	Annelida
Ampharete arctica	6	20	19.4	64.5	Annelida
Nemertean	3	23	9.7	74.2	Rhynchocoela
Cossura longocirrata	2	25	6.5	80.6	Annelida
Scoletoma tenuis	1	26	3.2	83.9	Annelida
Ceratocephale loveni	1	27	3.2	87.1	Annelida
Tharyx acutus	1	28	3.2	90.3	Annelida
Unknown	1	29	3.2	93.5	Annelida
Harpinia propinqua	1	30	3.2	96.8	Arthropoda
Eudorella pusilla	1	31	3.2	100.0	Arthropoda
Number of Species:	11				
Density (m^{-2}):	775				
Diversity (H'):	2.053				

TABLE 2A. Isles of Shoals-North Benthic Sample B

Species	Total	Cum. Tot.	%	Cum. %	Higher Taxon
Paraonis gracilis	4	4	13.8	13.8	Annelida
Ampharete arctica	4	8	13.8	27.6	Annelida
Ninoe nigripes	3	11	10.3	37.9	Annelida
Cossura longocirrata	2	13	6.9	44.8	Annelida
Sabaco elongatus	2	15	6.9	51.7	Annelida
Mediomastus ambiseta	1	16	3.4	55.2	Annelida
Maldane sarsi	1	17	3.4	58.6	Annelida
Aglaophamus neotenus	1	18	3.4	62.1	Annelida
Paraonis gracilis	4	22	13.8	75.9	Annelida
Ampharete arctica	4	26	13.8	89.7	Annelida
Ninoe nigripes	3	29	10.3	100.0	Annelida
Number of Species:	11				
Density (m^{-2}):	725				
Diversity (H'):	1.787				

TABLE 3A. Isles of Shoals-North Benthic Sample C

Species	Total	Cum. Tot.	%	Cum. %	Higher Taxon
Paraonis gracilis	20	20	60.6	60.6	Annelida
Cossura longocirrata	7	27	21.2	81.8	Annelida
Ampharete arctica	2	29	6.1	87.9	Annelida
Owenia fusiformis	2	31	6.1	93.9	Annelida
Ceratocephale loveni	1	32	3.0	97.0	Annelida
Paracaprella tenuis	1	33	3.0	100.0	Annelida
Number of Species:	6				
Density (m^{-2}):	825				
Diversity (H'):	1.184				

TABLE 4A. Isles of Shoals-North Benthic Sample D

Species	Total	Cum. Tot.	%	Cum. %	Higher Taxon
Cossura longocirrata	9	9	31.0	31.0	Annelida
Sabaco elongatus	4	13	44.8	44.8	Annelida
Mediomastus ambiseta	4	17	58.6	58.6	Annelida
Prionospio sp.	2	19	65.5	65.5	Annelida
Ceratocephale loveni	2	21	72.4	72.4	Annelida
Paramphinome pulchella	1	22	75.9	75.9	Annelida
Syllid juvenile	1	23	79.3	79.3	Annelida
Paraonis gracilis	1	24	82.8	82.8	Annelida
Owenia fusiformis	1	25	86.2	86.2	Annelida
Nephtys incisa	1	26	89.7	89.7	Annelida
Chaetozone setosa	1	27	93.1	93.1	Annelida
Leptocheirus plumulosus	1	28	96.6	96.6	Arthropoda
Astarte undata	1	29	100.0	100.0	Mollusca
Number of Species:	13				
Density (m^{-2}):	725				
Diversity (H'):	2.309				

TABLE 5A. Isles of Shoals-North Benthic Sample E

Species	Total	Cum. Tot.	%	Cum. %	Higher Taxon
Paraonis gracilis	22	22	38.6	38.6	Annelida
Cossura longocirrata	19	41	33.3	71.9	Annelida
Ampharete arctica	4	45	7.0	78.9	Annelida
Prionospio sp.	4	49	7.0	86.0	Annelida
Ceratocephale loveni	2	51	3.5	89.5	Annelida
Sabaco elongatus	2	53	3.5	93.0	Annelida
Ninoe nigripes	1	54	1.8	94.7	Annelida
Praxillella gracilis	1	55	1.8	96.5	Annelida
Thyasira sp.	1	56	1.8	98.2	Mollusca
Bivavle juv.	1	57	1.8	100.0	Mollusca
Number of Species:	10				
Density (m^{-2}):	1425				
Diversity (H'):	1.625				

TABLE 6A. Isles of Shoals-North Benthic Sample F

Species	Total	Cum. Tot.	%	Cum. %	Higher Taxon
Paraonis gracilis	16	16	42.1	42.1	Annelida
Cossura longocirrata	9	25	23.7	65.8	Annelida
Ampharete arctica	3	28	7.9	73.7	Annelida
Mediomastus ambiseta	3	31	7.9	81.6	Annelida
Ceratocephale loveni	2	33	5.3	86.8	Annelida
Praxillella gracilis	1	34	2.6	89.5	Annelida
Owenia fusiformis	1	35	2.6	92.1	Annelida
Micrura sp.	1	36	2.6	94.7	Rhynchocoela
Paracaprella tenuis	1	37	2.6	97.4	Arthropoda
Astarte undata	1	38	2.6	100.0	Mollusca
Number of Species:	10				
Density (m^{-2}):	950				
Diversity (H'):	1.740				

TABLE 7A. Isles of Shoals-North Benthic Sample G

Species	Total	Cum. Tot.	%	Cum. %	Higher Taxon
Paraonis gracilis	8	8	42.1	42.1	Annelida
Cossura longocirrata	4	12	21.1	63.2	Annelida
Owenia fusiformis	2	14	10.5	73.7	Annelida
Sabaco elongatus	1	15	5.3	78.9	Annelida
Aricidea suecica	1	16	5.3	84.2	Annelida
Prionospio sp.	1	17	5.3	89.5	Annelida
Chaetoderma nitidulum	1	18	5.3	94.7	Mollusca
Micrura sp.	1	19	5.3	100.0	Rhynchocoela
Number of Species:	8				
Density (m^{-2}):	475				
Diversity (H'):	1.704				

TABLE 8A. Isles of Shoals-North Benthic Sample H

Species	Total	Cum. Tot.	%	Cum. %	Higher Taxon
Paraonis gracilis	20	20	26.3	26.3	Annelida
Sabaco elongatus	15	35	19.7	46.1	Annelida
Ampharete arctica	7	42	9.2	55.3	Annelida
Praxillella gracilis	5	47	6.6	61.8	Annelida
Cossura longocirrata	4	51	5.3	67.1	Annelida
Prionospio sp.	4	55	5.3	72.4	Annelida
Scoletoma tenuis	3	58	3.9	76.3	Annelida
Mediomastus ambiseta	3	61	3.9	80.3	Annelida
Owenia fusiformis	2	63	2.6	82.9	Annelida
Ninoe nigripes	2	65	2.6	85.5	Annelida
Scalibregma inflatum	1	66	1.3	86.8	Annelida
Paramphinome pulchella	2	68	2.6	89.5	Annelida
Ceratocephale loveni	1	69	1.3	90.8	Annelida
Tharyx acutus	1	70	1.3	92.1	Annelida
Harmothoe extenuata	1	71	1.3	93.4	Annelida
Astarte undata	1	72	1.3	94.7	Mollusca
Thyasira gouldi	1	73	1.3	96.1	Mollusca
Parvicardium pinnulatum	1	74	1.3	97.4	Mollusca
Cyclaspis varians	1	75	1.3	98.7	Arthropoda
Leptostylis longimana	1	76	1.3	100.0	Arthropoda
Number of Species:	20				
Density (m^{-2}):	1900				
Diversity (H'):	2.367				

TABLE 9A. Isles of Shoals-North Benthic Sample I

Species	Total	Cum. Tot.	%	Cum. %	Higher Taxon
Paraonis gracilis	47	47	59.5	59.5	Annelida
Sabaco elongatus	7	54	8.9	68.4	Annelida
Cossura longocirrata	5	59	6.3	74.7	Annelida
Ampharete arctica	4	63	5.1	79.7	Annelida
Ninoe nigripes	3	66	3.8	83.5	Annelida
Mediomastus ambiseta	3	69	3.8	87.3	Annelida
Nemertean	3	72	3.8	91.1	Rhynchocoela
Praxillella praetermissa	2	74	2.5	93.7	Annelida
Owenia fusiformis	2	76	2.5	96.2	Annelida
Lumbrineris latreilli	1	77	1.3	97.5	Annelida
Lepidonotus squamatus	1	78	1.3	98.7	Annelida
Photis sp.	1	79	1.3	100.0	Arthropoda
Number of Species:	12				
Density (m^{-2}):	1975				
Diversity (H'):	1.526				

SEDIMENT SEIVE ANALYSIS RESULTS

ISLES OF SHOALS NORTH

ALTERANTIVE OCEAN PLACEMENT SITE

GeoTesting
EXPRESS

1145 Massachusetts Avenue
Boxborough, MA 01719
978 635 0424 Tel
978 635 0266 Fax

Transmittal

TO:
Richard Heidebrecht
U.S. Army Corps of Engineers
696 Virginia Road
Concord, MA 01742

DATE: 12/21/2010	GTX NO: 10463
RE: Isles of Shoals Site N	

COPIES	DATE	DESCRIPTION
	12/21/2010	**December 2010 Laboratory Test Report**

REMARKS:

SIGNED: Joe Tomei, Laboratory Manager

CC:

APPROVED BY: Nancy Hubbard, Project Manager

GeoTesting
EXPRESS

Boston
Atlanta
New York
www.geocomp.com/geotesting

December 21, 2010

Richard Heidebrecht
U.S. Army Corps of Engineers
696 Virginia Road
Concord, MA 01742

RE: Isles of Shoals Site N, (GTX-10463)

Dear Richard:

Enclosed are the test results you requested for the above referenced project. GeoTesting Express, Inc. (GTX) received nine samples from you on 12/15/2010. These samples were labeled as follows:

Boring Number	Sample Number	Depth
Site N	A	319 ft
Site N	B	314 ft
Site N	C	315 ft
Site N	D	318 ft
Site N	E	316 ft
Site N	F	321 ft
Site N	G	317 ft
Site N	H	328 ft
Site N	I	313 ft

GTX performed the following test on each of these samples:

ASTM D 422 – Grain Size Analysis with Hydrometer

A copy of your test request is attached.

The results presented in this report apply only to the items tested. This report shall not be reproduced except in full, without written approval from GeoTesting Express. The remainder of these samples will be retained for a period of sixty (60) days and will then be discarded unless otherwise notified by you. Please call me if you have any questions or require additional information. Thank you for allowing GeoTesting Express the opportunity of providing you with testing services. We look forward to working with you again in the future.

Respectfully yours,

Joe Tomei
Laboratory Manager

GeoTesting Express, Inc. | 1145 Massachusetts Ave. | Boxborough, MA 01719 | Toll Free 800 434 1062 | Fax 978 635 0266

GeoTesting
EXPRESS

1145 Massachusetts Avenue
Boxborough, MA 01719
978 635 0424 Tel
978 635 0266 Fax

Geotechnical Test Report

12/21/2010

GTX-10463
Isles of Shoals Site N
Project

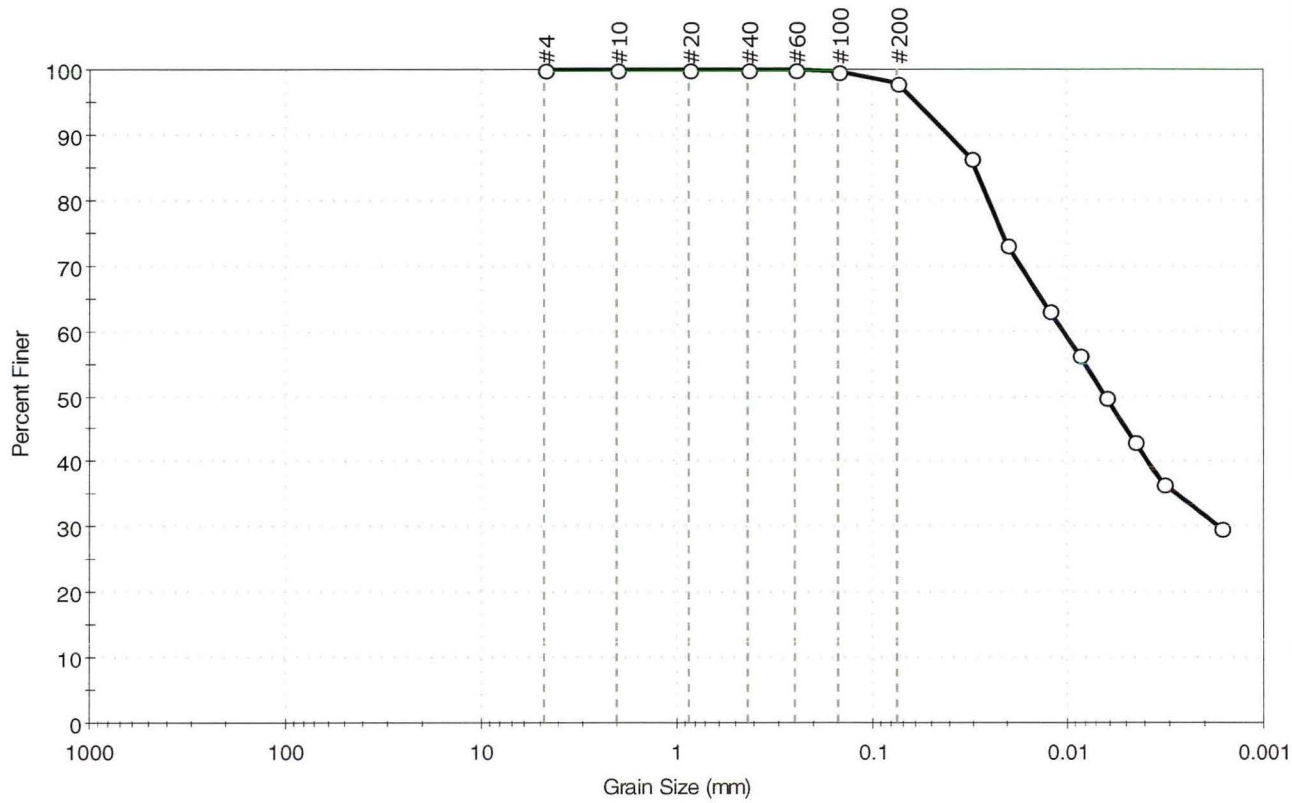
Client Project No.: Call #13

Prepared for:

U.S. Army Corps of Engineers

Client:	U.S. Army Corps of Engineers		
Project:	Isles of Shoals Site N		
Location:	---	Project No:	GTX-10463
Boring ID: Site N	Sample Type: bag	Tested By:	jbr
Sample ID:A	Test Date: 12/17/10	Checked By:	jdt
Depth : 319 ft	Test Id: 201085		
Test Comment:	---		
Sample Description:	Moist, brown silty clay		
Sample Comment:	---		

Particle Size Analysis - ASTM D 422-63 (reapproved 2002)



% Cobble	% Gravel	% Sand	% Silt & Clay Size
--	0.0	2.1	97.9

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
#4	4.75	100		
#10	2.00	100		
#20	0.85	100		
#40	0.42	100		
#60	0.25	100		
#100	0.15	100		
#200	0.075	98		
---	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0308	86		
---	0.0202	73		
---	0.0122	63		
---	0.0086	56		
---	0.0062	50		
---	0.0045	43		
---	0.0032	37		
---	0.0016	30		

Coefficients

D_{85} = 0.0295 mm	D_{30} = 0.0017 mm
D_{60} = 0.0103 mm	D_{15} = N/A
D_{50} = 0.0063 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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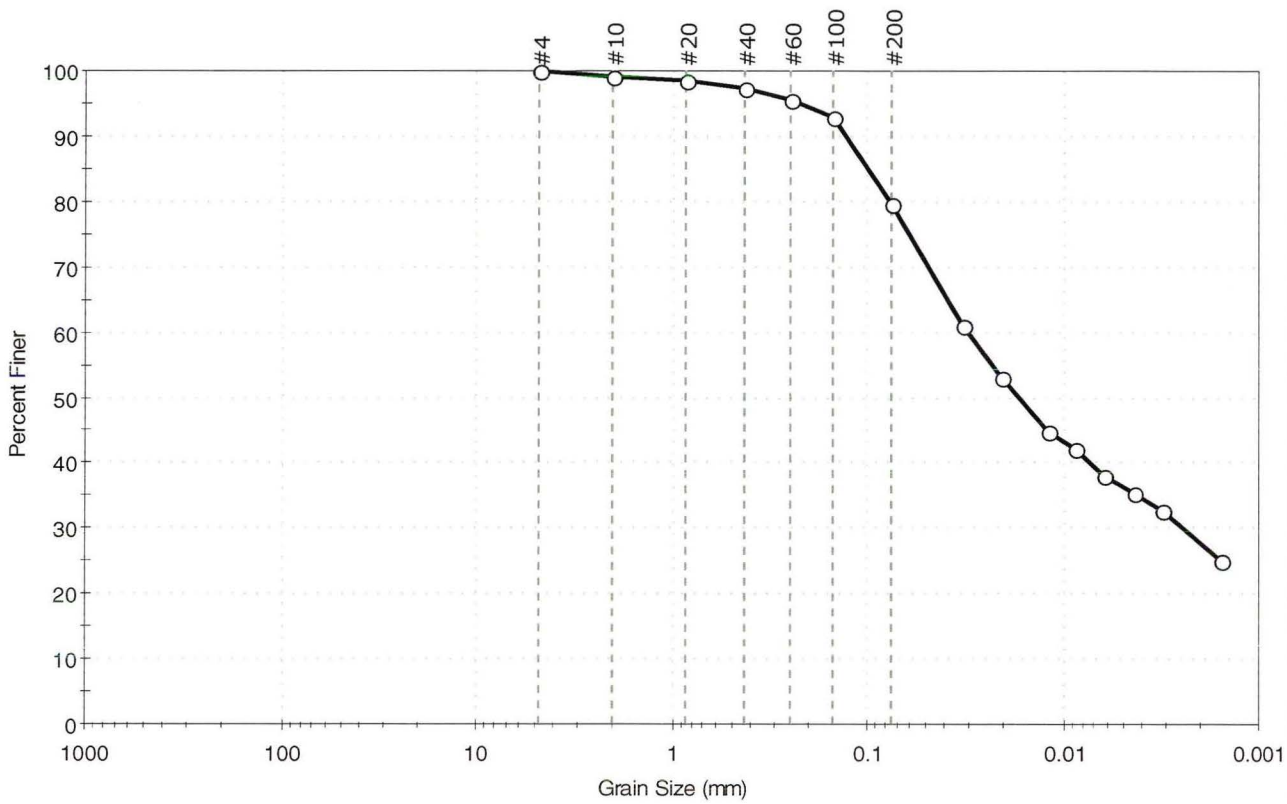
Client:	U.S. Army Corps of Engineers		
Project:	Isles of Shoals Site N		
Location:	---	Project No:	GTX-10463
Boring ID: Site N	Sample Type: bag	Tested By:	jbr
Sample ID:B	Test Date: 12/17/10	Checked By:	jdt
Depth : 314 ft	Test Id: 201086		
Test Comment:	---		
Sample Description:	Moist, brown silt with sand		
Sample Comment:	---		

Particle Size Analysis - ASTM D 422-63 (reapproved 2002)



% Cobble	% Gravel	% Sand	% Silt & Clay Size
--	0.0	20.2	79.8

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
#4	4.75	100		
#10	2.00	99		
#20	0.85	99		
#40	0.42	97		
#60	0.25	96		
#100	0.15	93		
#200	0.075	80		
---	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0328	61		
---	0.0209	53		
---	0.0121	45		
---	0.0087	42		
---	0.0062	38		
---	0.0044	35		
---	0.0032	33		
---	0.0016	25		

Coefficients

D_{85} = 0.0988 mm D_{30} = 0.0025 mm
D_{60} = 0.0307 mm D_{15} = N/A
D_{50} = 0.0170 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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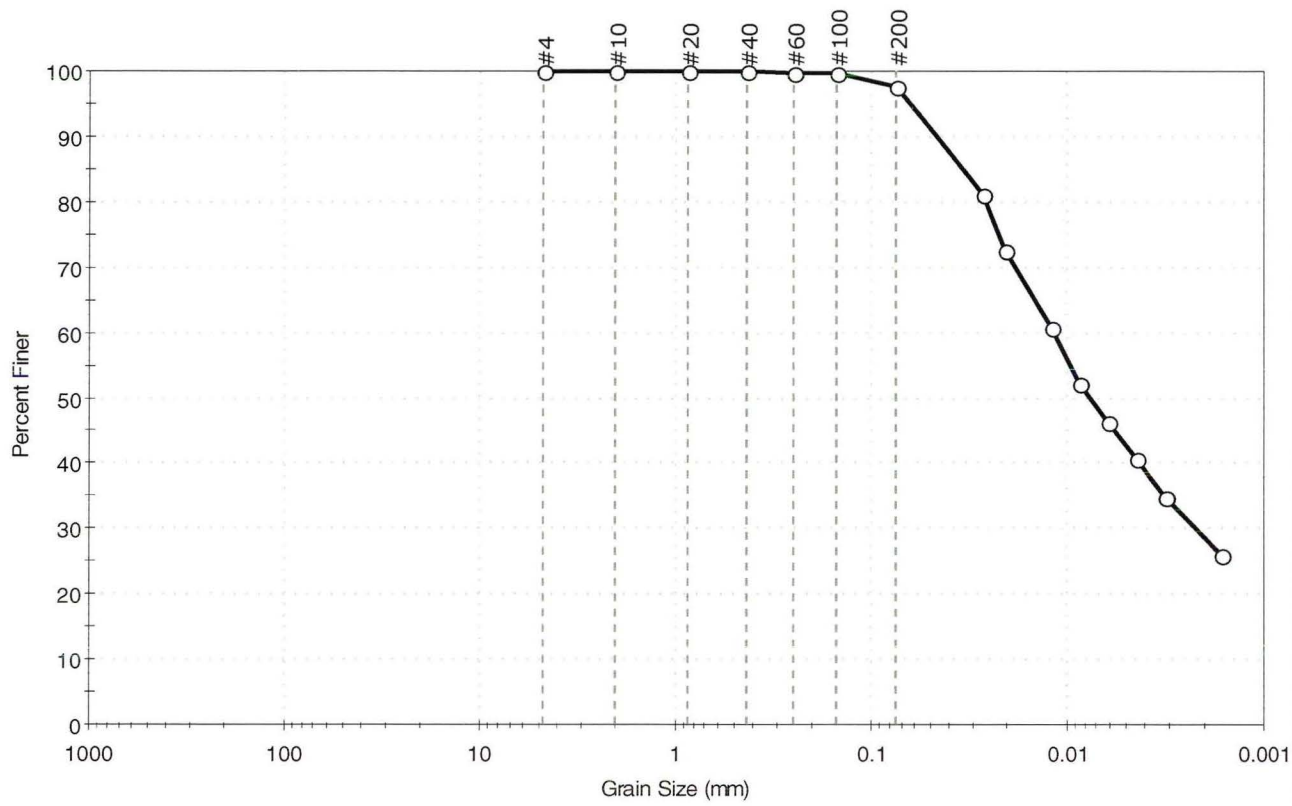
Client:	U.S. Army Corps of Engineers		
Project:	Isles of Shoals Site N		
Location:	---	Project No:	GTX-10463
Boring ID: Site N	Sample Type: bag	Tested By:	jbr
Sample ID:C	Test Date: 12/17/10	Checked By:	jdt
Depth : 315 ft	Test Id: 201087		
Test Comment:	---		
Sample Description:	Moist, brown silty clay		
Sample Comment:	---		

Particle Size Analysis - ASTM D 422-63 (reapproved 2002)



% Cobble	% Gravel	% Sand	% Silt & Clay Size
--	0.0	2.4	97.6

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
#4	4.75	100		
#10	2.00	100		
#20	0.85	100		
#40	0.42	100		
#60	0.25	100		
#100	0.15	100		
#200	0.075	98		
---	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0269	81		
---	0.0205	72		
---	0.0120	61		
---	0.0086	52		
---	0.0062	46		
---	0.0044	41		
---	0.0032	35		
---	0.0016	26		

Coefficients

D_{85} = 0.0341 mm D_{30} = 0.0022 mm
D_{60} = 0.0116 mm D_{15} = N/A
D_{50} = 0.0076 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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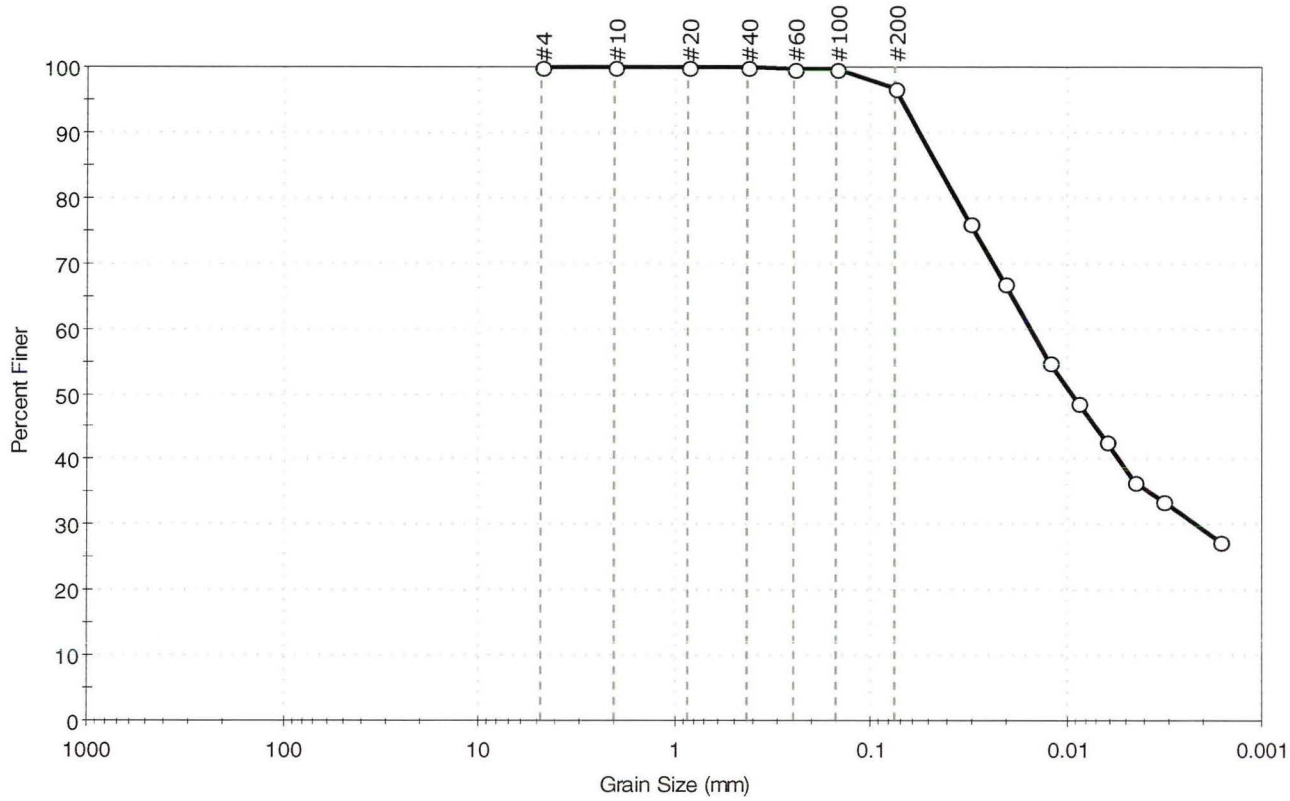
Client:	U.S. Army Corps of Engineers		
Project:	Isles of Shoals Site N		
Location:	---	Project No:	GTX-10463
Boring ID: Site N	Sample Type: bag	Tested By:	jbr
Sample ID:D	Test Date: 12/17/10	Checked By:	jdt
Depth : 318 ft	Test Id: 201088		
Test Comment:	---		
Sample Description:	Moist, brown silty clay		
Sample Comment:	---		

Particle Size Analysis - ASTM D 422-63 (reapproved 2002)



% Cobble	% Gravel	% Sand	% Silt & Clay Size
---	0.0	3.4	96.6

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
#4	4.75	100		
#10	2.00	100		
#20	0.85	100		
#40	0.42	100		
#60	0.25	100		
#100	0.15	100		
#200	0.075	97		
---	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0314	76		
---	0.0207	67		
---	0.0121	55		
---	0.0088	49		
---	0.0062	43		
---	0.0045	37		
---	0.0032	34		
---	0.0016	27		

Coefficients

D_{85} = 0.0456 mm D_{30} = 0.0022 mm
D_{60} = 0.0152 mm D_{15} = N/A
D_{50} = 0.0093 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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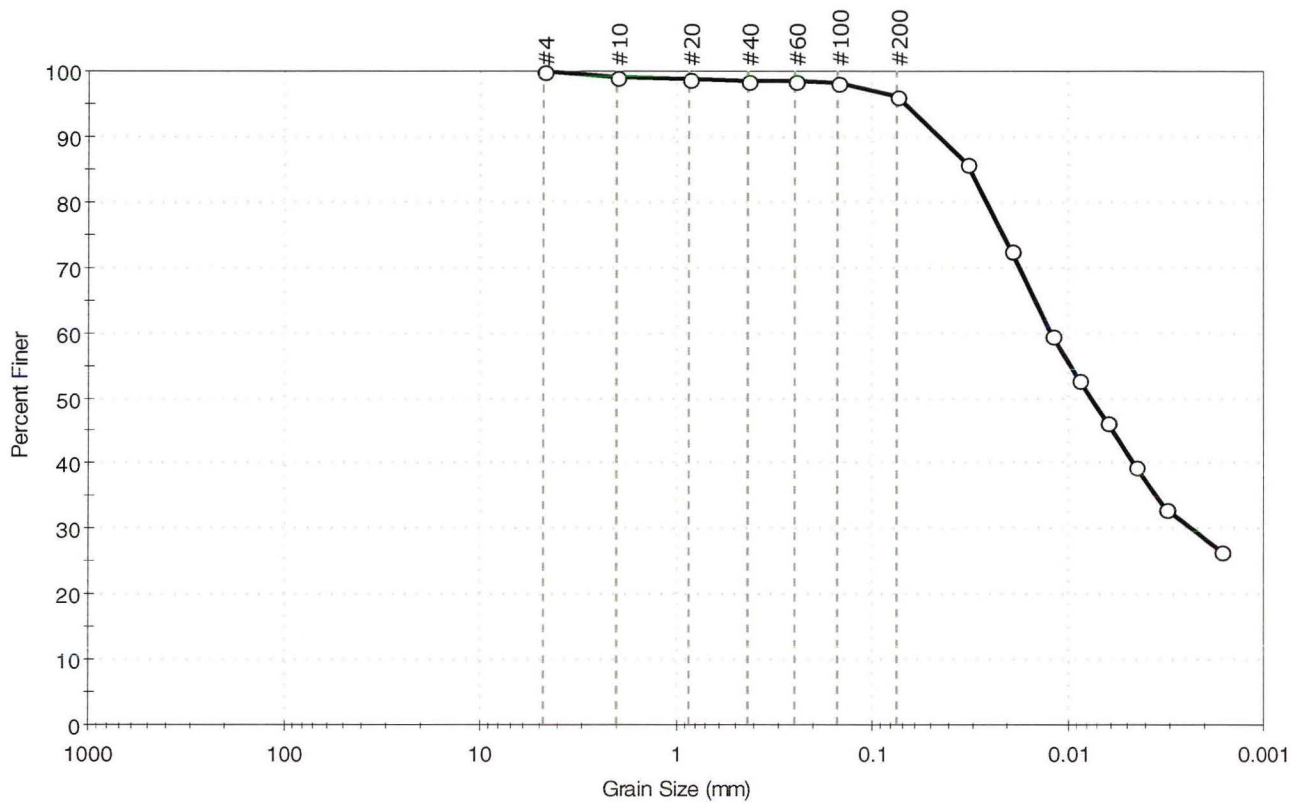
Client:	U.S. Army Corps of Engineers		
Project:	Isles of Shoals Site N		
Location:	---	Project No:	GTX-10463
Boring ID: Site N	Sample Type: bag	Tested By:	jbr
Sample ID:E	Test Date: 12/17/10	Checked By:	jdt
Depth : 316 ft	Test Id: 201089		
Test Comment:	---		
Sample Description:	Moist, brown silty clay		
Sample Comment:	---		

Particle Size Analysis - ASTM D 422-63 (reapproved 2002)



% Cobble	% Gravel	% Sand	% Silt & Clay Size
---	0.0	3.7	96.3

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
#4	4.75	100		
#10	2.00	99		
#20	0.85	99		
#40	0.42	99		
#60	0.25	99		
#100	0.15	98		
#200	0.075	96		
---	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0328	86		
---	0.0191	73		
---	0.0120	59		
---	0.0087	53		
---	0.0062	46		
---	0.0045	40		
---	0.0032	33		
---	0.0017	26		

Coefficients

D_{85} = 0.0316 mm D_{30} = 0.0024 mm
D_{60} = 0.0122 mm D_{15} = N/A
D_{50} = 0.0075 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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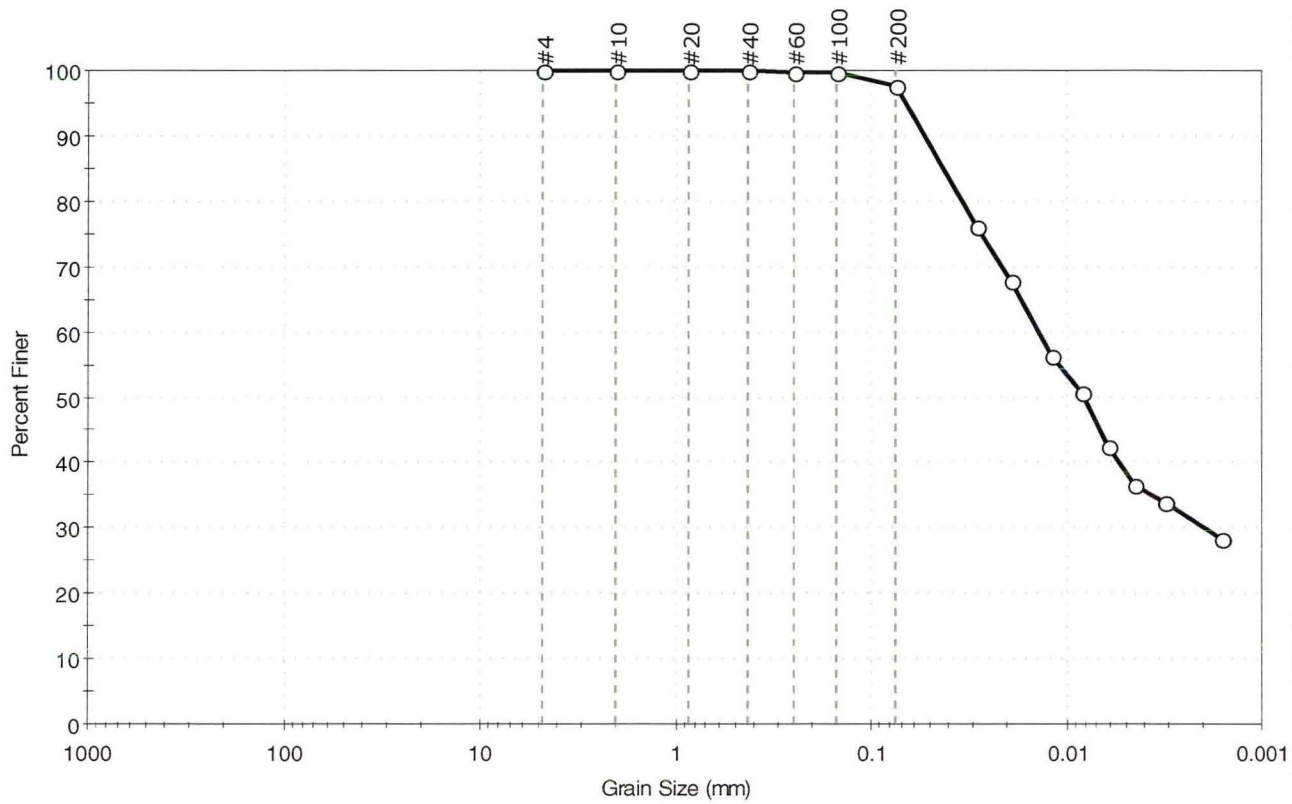
Client:	U.S. Army Corps of Engineers		
Project:	Isles of Shoals Site N		
Location:	---	Project No:	GTX-10463
Boring ID: Site N	Sample Type: bag	Tested By:	jbr
Sample ID:F	Test Date: 12/17/10	Checked By:	jdt
Depth : 321 ft	Test Id: 201090		
Test Comment:	---		
Sample Description:	Moist, brown silty clay		
Sample Comment:	---		

Particle Size Analysis - ASTM D 422-63 (reapproved 2002)



% Cobble	% Gravel	% Sand	% Silt & Clay Size
---	0.0	2.4	97.6

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
#4	4.75	100		
#10	2.00	100		
#20	0.85	100		
#40	0.42	100		
#60	0.25	100		
#100	0.15	100		
#200	0.075	98		
---	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0286	76		
---	0.0191	68		
---	0.0119	56		
---	0.0084	51		
---	0.0062	42		
---	0.0045	37		
---	0.0032	34		
---	0.0016	28		

Coefficients

D_{85} = 0.0425 mm	D_{30} = 0.0020 mm
D_{60} = 0.0138 mm	D_{15} = N/A
D_{50} = 0.0082 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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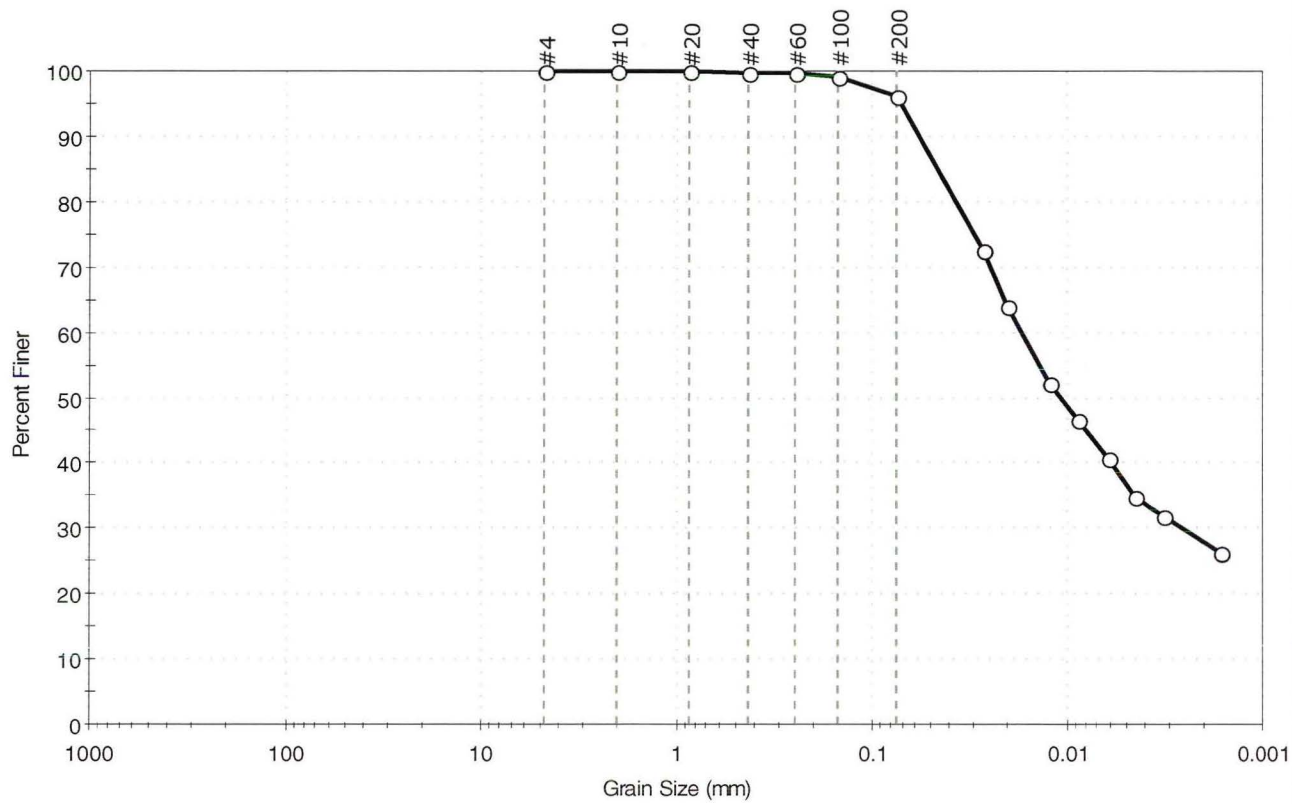
Client:	U.S. Army Corps of Engineers		
Project:	Isles of Shoals Site N		
Location:	---	Project No:	GTX-10463
Boring ID: Site N	Sample Type: bag	Tested By:	jbr
Sample ID:G	Test Date: 12/17/10	Checked By:	jdt
Depth : 317 ft	Test Id: 201091		
Test Comment:	---		
Sample Description:	Moist, brown silty clay		
Sample Comment:	---		

Particle Size Analysis - ASTM D 422-63 (reapproved 2002)



% Cobble	% Gravel	% Sand	% Silt & Clay Size
--	0.0	3.9	96.1

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
#4	4.75	100		
#10	2.00	100		
#20	0.85	100		
#40	0.42	100		
#60	0.25	100		
#100	0.15	99		
#200	0.075	96		
---	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0268	73		
---	0.0203	64		
---	0.0122	52		
---	0.0088	46		
---	0.0062	41		
---	0.0045	35		
---	0.0032	32		
---	0.0016	26		

Coefficients

D_{85} = 0.0461 mm D_{30} = 0.0026 mm
D_{60} = 0.0171 mm D_{15} = N/A
D_{50} = 0.0107 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

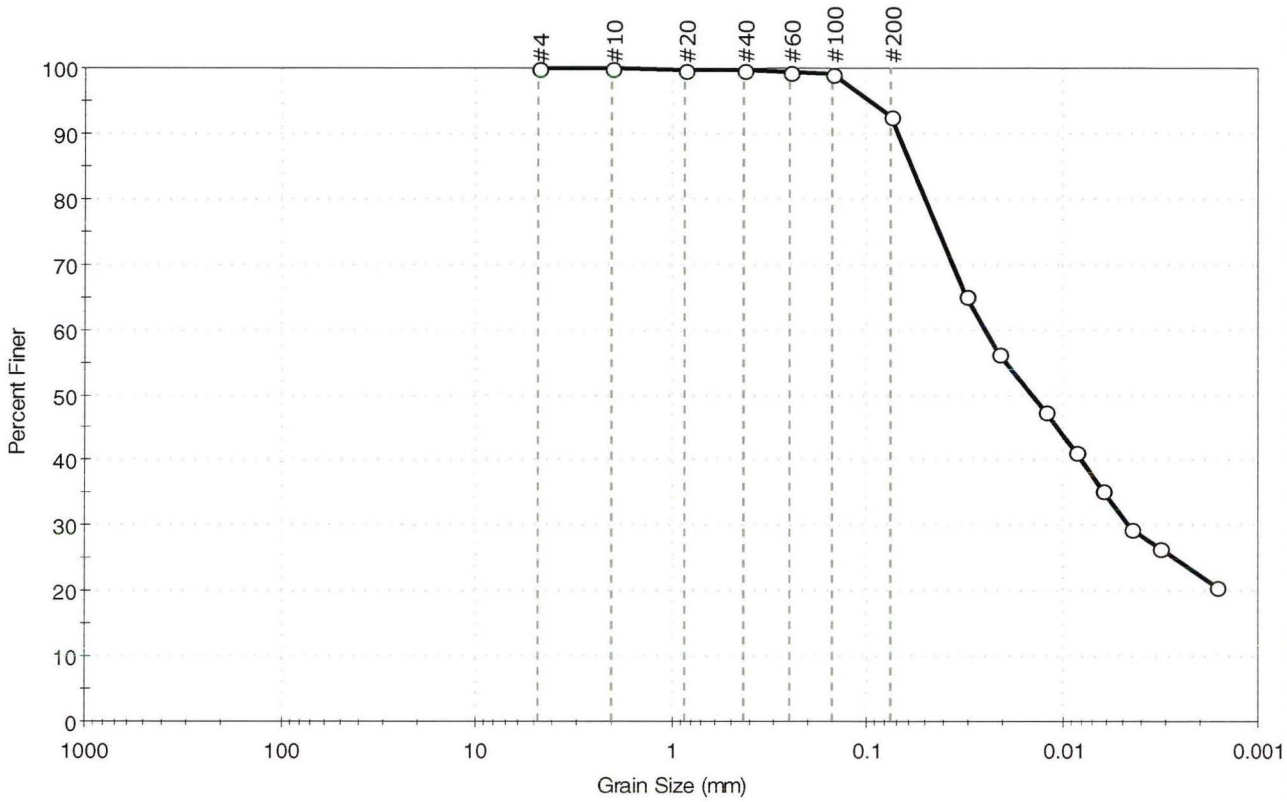
Sand/Gravel Particle Shape : ---

Sand/Gravel Hardness : ---

printed 12/21/2010 11:11:59 AM

Client:	U.S. Army Corps of Engineers		
Project:	Isles of Shoals Site N		
Location:	---	Project No:	GTX-10463
Boring ID: Site N	Sample Type: bag	Tested By:	jbr
Sample ID:H	Test Date: 12/17/10	Checked By:	jdt
Depth : 328 ft	Test Id: 201092		
Test Comment:	---		
Sample Description:	Moist, brown silt		
Sample Comment:	---		

Particle Size Analysis - ASTM D 422-63 (reapproved 2002)



% Cobble	% Gravel	% Sand	% Silt & Clay Size
--	0.0	7.3	92.7

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
#4	4.75	100		
#10	2.00	100		
#20	0.85	100		
#40	0.42	100		
#60	0.25	99		
#100	0.15	99		
#200	0.075	93		
---	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0311	65		
---	0.0213	56		
---	0.0124	47		
---	0.0085	41		
---	0.0063	36		
---	0.0045	30		
---	0.0032	27		
---	0.0017	21		

Coefficients

D_{85} = 0.0586 mm D_{30} = 0.0046 mm
D_{60} = 0.0250 mm D_{15} = N/A
D_{50} = 0.0146 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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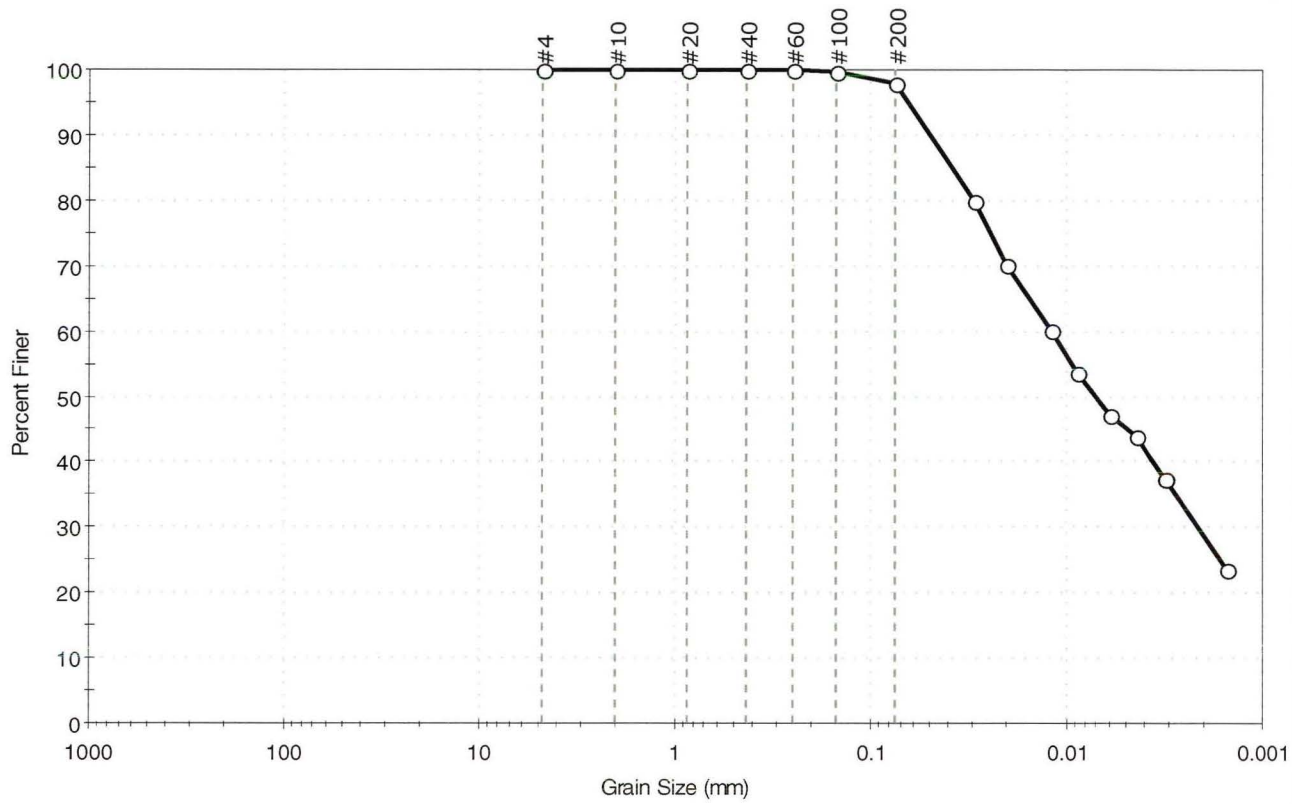
Client:	U.S. Army Corps of Engineers		
Project:	Isles of Shoals Site N		
Location:	---	Project No:	GTX-10463
Boring ID: Site N	Sample Type: bag	Tested By:	jbr
Sample ID:I	Test Date: 12/17/10	Checked By:	jdt
Depth : 313 ft	Test Id: 201093		
Test Comment:	---		
Sample Description:	Moist, brown silt		
Sample Comment:	---		

Particle Size Analysis - ASTM D 422-63 (reapproved 2002)



% Cobble	% Gravel	% Sand	% Silt & Clay Size
--	0.0	2.1	97.9

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
#4	4.75	100		
#10	2.00	100		
#20	0.85	100		
#40	0.42	100		
#60	0.25	100		
#100	0.15	100		
#200	0.075	98		
---	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0293	80		
---	0.0204	70		
---	0.0121	60		
---	0.0087	54		
---	0.0060	47		
---	0.0044	44		
---	0.0031	37		
---	0.0015	24		

Coefficients

D_{85} = 0.0383 mm D_{30} = 0.0021 mm
D_{60} = 0.0119 mm D_{15} = N/A
D_{50} = 0.0070 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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U.S. ARMY CORPS OF ENGINEERS

Richard Heidebrecht 978-318-8513 **CHAIN OF CUSTODY RECORD**

PROJ. NO.	PROJECT NAME: Isles of Shoals Site N
SAMPLERS: *(Signature)* Todd Randall	

STA. NO.	DATE	TIME	COMP.	GRAB	STATION LOCATION	NO. OF CONTAINERS	Wet Sieve Hydrometer						REMARKS
A	11/1			/	Site N	1	/						319' Depth
B	11/1			/	↓	1	/						314' Depth
C	11/1	940		/		1	/						315' Depth
D	11/1			/		1	/						318' Depth
E	11/1	1200		/		1	/						316' Depth
F	11/1	1040		/		1	/						321' Depth
G	11/1	1015		/		1	/						317' Depth
H	11/1	1115		/		1	/						328' Depth
I	11/1	1140		/		1	/						313' Depth

Relinquished by: *(Signature)*	Date / Time	Received by: *(Signature)*	Relinquished by: *(Signature)*	Date / Time	Received by: *(Signature)*
R. W. Heidebrecht	12/15/10 9:50	[illegible]			
Relinquished by: *(Signature)*	Date / Time	Received by: *(Signature)*	Relinquished by: *(Signature)*	Date / Time	Received by: *(Signature)*
Relinquished by: *(Signature)*	Date / Time	Received for Laboratory by: *(Signature)*	Date / Time	Remarks: Cal #13	

Distribution: Original Accompanies Shipment; Copy 1 to Sample Custodian; Copy 2 to Coordinator Field Files

GeoTesting EXPRESS

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GTX may report engineering parameters that require us to interpret the test data. Such parameters are determined using accepted engineering procedures. However, GTX does not warrant that these parameters accurately reflect the true engineering properties of the *in situ* material. Responsibility for interpretation and use of the test data and these parameters for engineering and/or construction purposes rests solely with the user and not with GTX or any of its employees.

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Commonly Used Symbols

A	pore pressure parameter for $\Delta\sigma_1 - \Delta\sigma_3$
B	pore pressure parameter for $\Delta\sigma_3$
CIU	isotropically consolidated undrained triaxial shear test
CR	compression ratio for one dimensional consolidation
C_c	coefficient of curvature, $(D_{30})^2 / (D_{10} \times D_{60})$
C_u	coefficient of uniformity, D_{60}/D_{10}
C_c	compression index for one dimensional consolidation
C_α	coefficient of secondary compression
c_v	coefficient of consolidation
c	cohesion intercept for total stresses
c'	cohesion intercept for effective stresses
D	diameter of specimen
D_{10}	diameter at which 10% of soil is finer
D_{15}	diameter at which 15% of soil is finer
D_{30}	diameter at which 30% of soil is finer
D_{50}	diameter at which 50% of soil is finer
D_{60}	diameter at which 60% of soil is finer
D_{85}	diameter at which 85% of soil is finer
d_{50}	displacement for 50% consolidation
d_{90}	displacement for 90% consolidation
d_{100}	displacement for 100% consolidation
E	Young's modulus
e	void ratio
e_c	void ratio after consolidation
e_o	initial void ratio
G	shear modulus
G_s	specific gravity of soil particles
H	height of specimen
PI	plasticity index
i	gradient
K_o	lateral stress ratio for one dimensional strain
k	permeability
LI	Liquidity Index
m_v	coefficient of volume change
n	porosity
PI	plasticity index
P_c	preconsolidation pressure
p	$(\sigma_1 + \sigma_3) / 2$, $(\sigma_v + \sigma_h) / 2$
p'	$(\sigma'_1 + \sigma'_3) / 2$, $(\sigma'_v + \sigma'_h) / 2$
p'_c	p' at consolidation
Q	quantity of flow
q	$(\sigma_1 - \sigma_3) / 2$
q_f	q at failure
q_o, q_i	initial q
q_c	q at consolidation
S	degree of saturation
SL	shrinkage limit
s_u	undrained shear strength
T	time factor for consolidation
T	temperature
t	time
U, UC	unconfined compression test
UU, Q	unconsolidated undrained triaxial test
u_a	pore gas pressure
u_e	excess pore water pressure
u, u_w	pore water pressure
V	total volume
V_g	volume of gas
V_s	volume of solids
V_v	volume of voids
V_w	volume of water
V_o	initial volume
v	velocity
W	total weight
W_s	weight of solids
W_w	weight of water
w	water content
w_c	water content at consolidation
w_f	final water content
w_l	liquid limit
w_n	natural water content
w_p	plastic limit
w_s	shrinkage limit
w_o, w_i	initial water content
α	slope of q_f versus p_f
α'	slope of q_f versus p_f'
γ_t	total unit weight
γ_d	dry unit weight
γ_s	unit weight of solids
γ_w	unit weight of water
ε	strain
ε_{vol}	volume strain
ε_h, ε_v	horizontal strain, vertical strain
μ	Poisson's ratio, also viscosity
σ	normal stress
σ'	effective normal stress
σ_c, σ'_c	consolidation stress in isotropic stress system
σ_h, σ'_h	horizontal normal stress
σ_v, σ'_v	vertical normal stress
σ_1	major principal stress
σ_2	intermediate principal stress
σ_3	minor principal stress
τ	shear stress
φ	friction angle based on total stresses
φ'	friction angle based on effective stresses
φ'_r	residual friction angle
φ_{ult}	φ for ultimate strength