APPENDIX D

EROSION PROTECTION LAYER / ARMOR LAYER DESIGN

REPORT

ARMOR LAYER DESIGN APPENDIX
ONONDAGA LAKE

Prepared for

Honeywell
PARSONS

Prepared by

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December 2009

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LIST OF ACRONYMS AND ABBREVIATIONS

Abbreviation	Definition
2-D	2-dimensional
ACES	Automated Coastal Engineering System
CEM	Coastal Engineering Manual
cfs	cubic feet per second
COCs	chemicals of concern
CRREL	Cold Regions Research and Engineering Laboratory
°F	degrees Fahrenheit
FEMA	Federal Emergency Management Agency
fps	feet per second
IDA	instantaneous data archive
IRM	Interim Remedial Measure
Lake	Onondaga Lake
LP3	Log-Pearson Type III
mph	miles per hour
NAVD88	North American Vertical Datum of 1988
NGVD29	National Geodetic Vertical Datum of 1929
NOAA	National Oceanic and Atmospheric Administration
NYSCC	New York State Canal Corporation
NYSDEC	New York State Department of Environmental Conservation
pdf	probability distribution functions
ROD	Record of Decision
SMS	Surface Water Modeling System
SMU	Sediment Management Unit
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
Wastebed	WB

1 INTRODUCTION

As described in the Record of Decision (ROD), the multi-component sediment cap portion of the Onondaga Lake (Lake) remedial design will consist of separate layers to provide specific functions:

- Chemical isolation from chemicals of concern (COCs) in the underlying sediment (i.e., "chemical isolation layer")
- Protection from physical forces causing erosion (i.e., "armor layer")
- Suitable substrate to promote habitat reestablishment (i.e., "habitat layer")

This report details the design of the sediment cap armor layer; other technical documents present the design of the chemical isolation and habitat layers.

The primary objective of the armor layer is to prevent exposure and erosion of the chemical isolation layer. The potential for erosion of the sediment cap depends on the erosive processes that are likely to occur in Onondaga Lake as well as the materials comprising the cap layers. Potential erosive processes that may act on the sediment cap within Onondaga Lake include:

- Wind-induced waves due to storm events
- Currents in the Lake resulting from discharge of tributaries and other discharges as well as from typical lake circulation conditions
- Localized propeller wash from vessels
- Waves generated by passing vessels
- Winter ice buildup and resulting scour processes

Each of these potential erosion processes was evaluated independently to determine the design requirements for the cap armor component. The cap armor layer was then designed to withstand erosion under the range of anticipated conditions for each. This appendix presents the results of this armor layer design analysis. The appendix is divided into the following sections:

- Section 2 summarizes the armor layer design for each Remediation Area
- Section 3 describes the armor layer design and performance criteria

- Section 4 presents the evaluation of historical Onondaga Lake water levels to determine the water level to be used for design of the armor layer
- Section 5 presents the wind-generated waves analysis
- Section 6 presents the tributary and lake currents analysis
- Section 7 presents the vessel-impacts analysis (propeller scour and boat wakes)
- Section 8 presents the ice analysis
- Section 9 presents the Sediment Management Unit (SMU) 3 shoreline enhancement analysis
- Section 10 presents the evaluation of the relative stability of littoral zone sediments in water depths from 20 to 30 feet (6 to 9 meters)

2 ARMOR LAYER PRELIMINARY DESIGN FOR ONONDAGA LAKE

Table 2-1 presents a summary of the preliminary sediment cap armor layer design.

Table 2-1

Summary of Sediment Cap Armor Layer Design by Remediation Area

Range of Water Depths Based on Baseline Lake Level (feet)	A		B		C and D		E	
	Particle Size	Minimum Thickness (inches)	Particle Size	Minimum Thickness (inches)	Particle Size	Minimum Thickness (inches)	Particle Size	Minimum Thickness (inches)
40.5 to 30.5	Fine Sand	3	Fine Sand	3	Fine Sand	3	Fine Sand	3
30.5 to 20.5	Fine Sand	3	Fine Sand	3	Fine Sand	3	Medium Sand	3
20.5 to 15.5	Fine Sand	3	Fine Sand	3	Medium Sand	3	Fine Gravel	3
15.5 to 10.5	Fine Sand	3	Medium Sand	3	Medium Sand	3	Fine Gravel	3
10.5 to 8.5	Medium Sand	3	Coarse Sand	3	Fine Gravel	3	Coarse Gravel	3
8.5 to 6.5	Coarse Sand	3	Fine Gravel	3	Fine Gravel	3	Coarse Gravel	3
6.5 to surf zone	Fine Gravel	3	Fine Gravel	3	Fine Gravel	3	Cobbles	6
Within surf zone	Coarse Gravel	3	Coarse Gravel	3.5	Coarse Gravel	4	Cobbles	6

Notes:
1. Sediment type was classified using the Unified Soil Classification System.
2. The surf zone begins at a depth approximately equal to the breaking wave height.
3. The breaking wave depth (surf zone) is approximately 3.5 feet in Remediation Area A and B, 4 feet in C and D, and 7 feet in E.
4. Range of water depths referenced to the Onondaga Lake baseline water level of 362.5 ft (see Section 4 of this appendix). The water level used for the armor layer design is 0.5 feet (362.0 feet) lower than the baseline water level.
5. The erosion protection layer thickness will be the greater of either 1.5 times the largest particle diameter, or 2 times the median particle diameter. For practical application considerations for construction, the minimum erosion protection layer thickness will be 3 inches (0.25 feet).

The armor layer thickness will be the greater of either 1.5 times the largest particle diameter or 2 times the median particle diameter. For practical application considerations for construction, the minimum armor layer thickness will be 0.25 feet.

The tributary analysis resulted in stable particle sizes of fine gravel for the portions of the cap near the discharge of Ninemile Creek (Remediation Area A) and Onondaga Creek (Remediation Area E) . The required particle sizes are less than or equal to the stable particles computed from the wind-wave results. Ninemile Creek and Onondaga Creek are the two largest inflows to the Lake. Evaluation of erosive forces from other tributaries and discharges, such as from stormwater and other outfalls, to the Lake will be evaluated as part of future design efforts, but is not anticipated to result in significant design revisions. The assessment of typical current velocities measured in the Lake (away from the influence of tributary flows) indicated a stable particle size of fine sand, which is less than or equal to the stable particles computed from the wind-wave results.

Based on a review of the types of vessels and operating procedures for these vessels in Onondaga Lake, there will generally be two types of vessel operations over the cap: 1) commercial and recreational vessels operating frequently in the New York State Canal Corporation (NYSCC) navigation channel to the Inner Harbor in Remediation Area E, and 2) recreational vessels operating randomly in shallower water depths. The propeller wash analysis indicates that particle sizes in the coarse gravel range (1 to 2 inches) would be required for the armor layer in the NYSCC navigation channel. For the other areas of the cap, recreational vessels will likely operate randomly; that is, these vessels will not start and stop or pass over the same location on a regular basis. Due to the limited area impacted by propeller wash from an individual vessel, significant movement of armor layer is not expected from propeller wash. In addition, in shallow water, a dedicated 1.5- to 2-foot-thick habitat layer is planned above the armor and chemical isolation layers. Any potential disturbance to particles within a localized area is expected to "self-level" soon after disturbance due to natural hydrodynamic conditions within the Lake.

Ice freezing to the bottom of Onondaga Lake is expected in shallow water at the shoreline. In such cases, it is expected that the normal thickening of ice will encounter the bed and freezing will continue. It was determined that the freezing of ice to the lake bottom is limited to water depths of less than 1.5 feet. To protect the chemical isolation layer for the cap, the armor layer and chemical isolation layer will be placed below the ice freezing zone described above. Using a low lake water level of 362.0 feet, the ice freezing zone would be

360.5 feet. The top of the armor layer and chemical isolation layer will be placed below an elevation of 360.5 feet to protect against ice scour.

The final armor layer median particle size (D_{50}) and gradation (such as for the sands and gravels) will be selected during the intermediate design phase with consideration of constructability and availability of materials.

3 DESIGN AND PERFORMANCE CRITERIA

Setting performance standards for the sediment cap is a necessary first step in developing the design requirements for isolation caps. As described in the United States Environmental Protection Agency's (USEPA's) and the United States Army Corps of Engineers' (USACE's) "Guidance for In-Situ Subaqueous Capping of Contaminated Sediments" (Palermo et al. 1998):

> *"The cap component for stabilization/erosion protection has a dual function. On the one hand, this component of the cap is intended to stabilize the contaminated sediments being capped, and prevent them from being resuspended and transported offsite. The other function of this component is to make the cap itself resistant to erosion. These functions may be accomplished by a single component, or may require two separate components in an in-situ cap."*

In addition, USEPA's "Contaminated Sediment Remediation Guidance for Hazardous Waste Sites" (USEPA 2005) states that:

> *"[t]he design of the erosion protection features of an in-situ cap (i.e., armor layers) should be based on the magnitude and probability of occurrence of relatively extreme erosive forces estimated at the capping site. Generally, in-situ caps should be designed to withstand forces with a probability of 0.01 per year, for example, the 100-year storm."*

As described in the ROD, the sediment cap will be a multi-component cap designed with separate layers to provide chemical isolation of underlying sediment, protection from erosive forces, and suitable substrate for habitat restoration. The erosion protection, or armor layer, is designed to protect the chemical isolation layer (which will be comprised primarily of sand) from erosional processes such as waves, ice, tributary flows, and propeller wash. The armor layer will be included in the cap design/construction, where needed, above the chemical isolation layer and below the habitat restoration layer. In select locations, a single layer of material may be designed to function as both the armor layer and habitat restoration layer.

The armor layer is designed to provide long-term protection of the chemical isolation layer using methods developed by the USEPA and the USACE specifically for in-situ caps. This includes the methods included in "Armor Layer Design of Guidance for In-Situ Subaqueous Capping of Contaminated Sediments" (Maynord 1998). The armor layer design presented herein involved evaluating the particle size (ranging from sand to cobbles) required to resist a range of erosive force expected on Onondaga Lake.

Consistent with USEPA guidance and based on ROD requirements and other project-specific considerations, design and performance criteria for the armor layer are listed below:

- The armor layer will be physically stable under conditions predicted to occur based on consideration of 100-year return-interval waves. The 100-year wave is the highest wave that would be expected to occur, on average, once every 100 years.
- The armor layer, specifically the areas potentially impacted by influent from tributaries, will be physically stable under conditions predicted to occur during a 100-year flood flow event.
- The sediment cap will be designed such that the chemical isolation layer will not be negatively impacted by ice.
- The sediment cap will be designed such that the chemical isolation layer is not negatively impacted by erosive forces resulting from propeller scour.

4 ONONDAGA LAKE WATER LEVELS

This section provides a summary of the analysis of historical Onondaga Lake water levels for determining an appropriate water level to use for armor layer design.

Onondaga Lake is part of the Erie (Barge) Canal system, and the elevation of the Lake is controlled by a dam on the Oswego River at Phoenix, New York, downstream of the Lake. The United States Geological Survey (USGS) maintains a water level gage on Onondaga Lake at the Onondaga Lake Park Marina Basin in Liverpool, New York (USGS Gage 04240495). Daily mean (average) water level data are available since October 1970 are available online and can be accessed at http://waterdata.usgs.gov/ny/nwis/dv/?site_no=04240495&agency_cd=USGS&referred_module=sw. It should be noted that the water level data were reported to the National Geodetic Vertical Datum of 1929 (NGVD29). These water levels were converted to the project datum, the North American Vertical Datum of 1988 (NAVD88), by subtracting 0.59 feet.

A frequency analysis was performed on the daily mean water level data from October 1, 1970 to April 1, 2009 (approximately 38 years). Table 4-1 presents the minimum, maximum, mean (average), and median water levels by month. Figure 4-1 presents a time series of Onondaga Lake water levels. Figure 4-2 presents the cumulative frequency distribution. Figure 4-3 presents monthly median water levels for Onondaga Lake.

Based on the measurements collected over the past 38 years, the following observations can be made:

- The mean and median waters level for the Lake were similar and 362.85 feet and 362.58 feet, respectively (Table 4-1)
- The highest lake level was 369.18 feet (on April 28, 1993)
- The lowest lake level was 361.00 feet (on March 12, 1978)
- The median water levels for the late winter/spring months (reflecting higher water levels due to rainfall and snowmelt) are 363.35 feet (April) and 363.20 feet (March)
- The median water levels for summer months (reflecting drier conditions and lower lake levels) are 362.31 feet (August) and 362.30 feet (September)

Table 4-1

Monthly Minimum, Average, and Maximum Onondaga Lake Water Levels

Month	Minimum Water Level (feet)	Mean Water Level (feet)	Median Water Level (feet)	Maximum Water Level (feet)
January	361.63	362.87	362.70	366.64
February	361.33	362.87	362.68	366.74
March	361.00	363.39	363.20	367.88
April	361.83	363.66	363.35	369.18
May	361.44	362.98	362.63	368.33
June	361.68	362.61	362.49	368.55
July	361.70	362.51	362.37	368.55
August	361.73	362.35	362.31	364.58
September	361.64	362.38	362.30	366.33
October	361.65	362.60	362.44	366.17
November	361.85	362.86	362.73	365.78
December	361.56	363.07	362.97	366.33
Yearly (January to December)	361.00	362.85	362.58	369.18

Notes:

1. Daily mean water levels from October 1, 1970 through April 1, 2009 obtained from http://waterdata.usgs.gov/ny/nwis/uv/?site_no=04240495&agency_cd=USGS.
2. Water levels referenced to the NAVD88 vertical datum.

For the design of the habitat modules, a baseline water level of 362.5 feet is being used. This water level represents the mean water level in Onondaga Lake during the plant growing season (May through October). Based on the analysis above, it can be seen that Onondaga Lake water levels have rarely dropped below 362.0 feet since the mid-1990s (see Figure 4-1). Further, this lake elevation of 362.0 feet also represents an elevation which has been exceeded approximately 99.6% of the analyzed time period. A lake level of 362.0 feet is being used for the armor layer design. In principle, lower water levels correlate to greater forces exerted by storm events on the lake bottom. Therefore, selection of a lake level of 362.0 feet represents a conservative assumption for armor layer design.

5 WIND-WAVE ANALYSIS

This section summarizes the wind-wave analysis that was used to determine the 100-year design wave for each of the Remediation Area and the resultant particle size(s) necessary for providing stability for the sediment cap armor layer. To resist wind-generated waves, stable particle sizes were computed at various water depths within and outside of the surf zones for each Remediation Area where sediment caps will be constructed as part of the Lake remedy.

5.1 Introduction

Meteorological factors such as changes in barometric pressure and the uneven heating and cooling of the earth produce pressure differences that result in winds. Winds blowing across the surface of bodies of water transmit energy to the water, and waves are formed. The size of these wind-generated waves depends on the wind velocity, the length of time the wind is blowing, and the extent of open water over which it blows (fetch) (USACE 1991).

For the Onondaga Lake wind-generated wave analysis, a return period for episodic events of 100 years has been utilized in the design evaluations of the armor layer to provide a high degree of protection to the sediment cap. Even though higher return frequencies for wind-wave analysis could be considered, the incremental benefits of using a return frequency higher than 100 years is minimal, since the changes in forcing conditions are minimally incremental over frequencies of 100 years, as opposed to those under the 100-year event. The use of 100-year return frequency for erosion protection of contaminated sediment site cap/armor design is also consistent with past practices at national contaminated sites under USEPA-/USACE-/ State-led programs. The wind-wave analysis summarized herein was conducted for the following Remediation Areas (Figure 5-1):

- Remediation Area A
- Remediaiton Area B
- Remediation Area C and D
- Remediation Area E

The wind-wave analysis consisted of the following major components:

1. Obtaining historical wind speeds and directions proximal to Onondaga Lake
2. Conducting a statistical analysis of wind data to estimate the 100-year return-interval wind speed (i.e., the highest wind speed that would be expected to occur once, on average, every 100 years) for each Remediation Area
3. Estimating the 100-year wave height and period from the 100-year return-interval wind data
4. Computing the particle size necessary to withstand the erosive forces associated with the 100-year wave outside the surf zone
5. Computing the particle size necessary to resist the erosive forces associated with the 100-year breaking wave within the surf zone

In general, within each Remediation Area, the sediment cap armor layer size will increase as the water depth decreases due to increasing wave energy. The details of the methodology are presented in Section 5.3. A detailed example calculation is included as Attachment A.

5.2 Summary

The wind-wave analysis was conducted to determine armor stone sizes for the sediment cap in Remediation Areas A, B, C , D, and E based on the 100-year design wave. Design wave heights were computed using a statistical analysis of 68 years of wind records collected at Hancock International Airport (formerly Syracuse Municipal Airport). The airport is located approximately five miles east of Onondaga Lake. Wave-induced horizontal orbital velocities generated by the 100-year wave were computed at different water depths before wave-breaking.

Stable sediment particle sizes were computed for the sediment cap for various water depths both prior to, and following, wave-breaking (in the surf zone). In general, the armor layer size increases as the water depth decreases. The size of the armor layer predicted for Onondaga Lake is generally gravel- to cobble-sized in the surf zone (shallower depths) and sand-sized materials in the deeper zones. Table 5-1 summarizes the particle size for each Remediation Area.

Table 5-1
Summary of Sediment Cap Armor Layer Design by Remediation Area

Range of Water Depths based on Baseline Lake Level (feet)	A		B		C and D		E	
	Particle Size	Minimum Thickness (inches)	Particle Size	Minimum Thickness (inches)	Particle Size	Minimum Thickness (inches)	Particle Size	Minimum Thickness (inches)
40.5 to 30.5	Fine Sand	3	Fine Sand	3	Fine Sand	3	Fine Sand	3
30.5 to 20.5	Fine Sand	3	Fine Sand	3	Fine Sand	3	Medium Sand	3
20.5 to 15.5	Fine Sand	3	Fine Sand	3	Medium Sand	3	Fine Gravel	3
15.5 to 10.5	Fine Sand	3	Medium Sand	3	Medium Sand	3	Fine Gravel	3
10.5 to 8.5	Medium Sand	3	Coarse Sand	3	Fine Gravel	3	Coarse Gravel	3
8.5 to 6.5	Coarse Sand	3	Fine Gravel	3	Fine Gravel	3	Coarse Gravel	3
6.5 to surf zone	Fine Gravel	3	Fine Gravel	3	Fine Gravel	3	Cobbles	6
Within surf zone	Coarse Gravel	3	Coarse Gravel	3.5	Coarse Gravel	4	Cobbles	6

Notes:
1. Sediment type was classified using the Unified Soil Classification System.
2. The surf zone begins at a depth approximately equal to the breaking wave height.
3. The breaking wave depth (surf zone) is approximately 3.5 feet in Remediation Area A and B, 4 feet in C and D, and 7 feet in E.
4. Range of water depths referenced to the Onondaga Lake baseline water level of 362.5 feet (see Section 4 of this appendix). The water level used for the armor layer design is 0.5 feet (362.0 feet) lower than the baseline water level.
5. The erosion protection layer thickness will be the greater of either 1.5 times the largest particle diameter, or 2 times the median particle diameter. For practical application considerations for construction, the minimum erosion protection layer thickness will be 3 inches (0.25 feet).

5.3 Methodology

This section describes the methodology used to estimate the 100-year return-interval wind speed, the 100-year design wave height and period, and the size and thickness of the armor layer for the sediment cap. The results of the analyses are presented in Section 5.4 below.

5.3.1 Wind Analysis Methodology

Hourly wind measurements (speeds and direction) from 1942 to 2009 were obtained from Hancock International Airport. The airport is located approximately five miles east of Onondaga Lake. The winds were measured at the following heights above the ground:

- 1942 to 1949: 57 feet
- 1949 to 1962: 72 feet
- 1962 and 1963: 84 feet
- 1963 to 2009: 21 feet

A wind rose diagram for the data, illustrating how wind speed and direction are typically distributed for the site, is shown on Figure 5-1. As can be seen in this figure, the prevailing winds in the area are from the westerly direction.

The methodology used to estimate winds speeds for wave prediction were consistent with that described in Part II – Chapter 2 of the USACE's *Coastal Engineering Manual* (CEM; USACE 2006). In accordance with the CEM, the measured wind speeds were first converted to hourly-averaged wind speeds at heights of 32.8 feet (10 meters) above the ground for predicting waves (USACE 2006). The hourly-averaged wind speeds were then converted to 15-minute-averaged wind speeds using procedures outlined in the CEM. In large lakes, the wave generation process tends to respond to average winds over a 15- to 30-minute interval (USACE 2006), because shorter duration gusts are generally not sufficient for significant wave generation. It is assumed that Onondaga Lake represents fetch-limited conditions and not duration-limited conditions for wave growth. Using 15-minute averages produces higher wind speeds than 30-minute averages, so the more conservative 15-minute averaging interval was used in this analysis.

A statistical analysis was then performed on the maximum annual 15-minute-averaged wind speeds to estimate the 100-year return-interval wind speeds (the 100-year design wind speed). For each Remediation Area, those winds blowing primarily toward the shoreline for that Remediation Area (i.e., along the possible fetch radials) were considered in each analysis. The following ranges of wind directions were used (where 360° represents due north; see Figure 5-1):

- A: 330° to 100°
- B: 330° to 130°
- C: 0° to 130°
- D: 320° to 30°
- E: 280° to 340°

Five candidate probability distribution functions (pdf's) were fitted to the maximum 15-minute-averaged annual winds during the 68-year period of record to develop representative wind speeds with different return periods, including the 100-year wind speed. The candidate distribution functions evaluated were Fisher-Tippet Type I and Weibull distributions with the exponent k varying from 0.75 to 2.0. The 100-year wind speed to be used in the design was chosen from the distribution that best fit the data.

In addition to the data available from Hancock Airport, data is also available from two meteorological stations installed at Onondaga Lake as part of the Pre-Design Investigation (PDI) studies to measure wind speeds and directions near the Lake. One station was installed at Wastebed (WB) 13 (WB 13 Site) in November 2005, and another was installed along the Lake shore at Willis Avenue (Lakeshore Site) in November 2006 (Parsons 2007a, 2007b). Hourly-averaged wind speed and directions were measured at both sites at an elevation of 10 meters above the ground. Attachment B presents a comparison performed by Parsons of the monthly average and monthly maximum wind speeds between Hancock International Airport, the WB 13 Site, and the Lakeshore Site for 2006 to 2009. The comparisons indicate that the monthly average and monthly maximum wind speeds are higher at Hancock International Airport than at the Lake. In addition, it appears that there is a stronger east-to-west wind at the airport than at the lakeshore. In summary, the 10-meter wind velocities measured at the Lakeshore Site from the north/northwest (which has a long overwater fetch distance) are less than the adjusted wind velocities from the airport, indicating that no important transitional effects have been ignored by using the airport data. Therefore, the long-term measurements collected at Hancock Airport were used for the wind-wave evaluations at Onondaga Lake.

5.3.2 Wind-Generated Wave Analysis and Armor Layer Sizing Methodology

The Onondaga Lake shoreline and bathymetry data used to estimate the longest fetch distance and bathymetric profile for each Remediation Area were obtained from the proposed restored slopes and from C.R. Environmental as part of the *Onondaga Lake Phase I Pre-Design Investigation Geophysical Survey Report* (C.R. Environmental 2007). Along with the computed 100-year design winds described above, this information was used to estimate the 100-year wave heights and horizontal orbital water velocities at various depths and nearshore slopes. The USACE Automated Coastal Engineering System (ACES) computer program was used to model wave growth and propagation due to winds (USACE 1992). The ACES program was developed in 1992 by the USACE and is an accepted worldwide reference for modeling water wave mechanics and properties. To compute the 100-year design wave height for each Remediation Area, the 100-year wind was applied along the longest fetch distance for each Remediation Area.

For each Remediation Area, the 100-year wave was determined using the ACES Wave Prediction Module and was then transformed along the longest fetch's bathymetric profile using the ACES Wave Transformation Module. This module was used to determine wave heights and horizontal orbital velocities at different water depths and the breaking wave depth. These wave characteristics were then used to determine appropriate stable particle sizes within and outside of the "surf zone." The surf zone is defined as the region in the Lake extending from the location where the waves begin to break to the limit of wave run-up on the shoreline slope. Within the surf zone, wave-breaking is the dominant hydrodynamic process. Outside of the surf zone, the wave-induced horizontal orbital velocities are the dominant force. In general, the surf zone begins at a depth approximately equal to the breaking wave height.

The USEPA's "Armor Layer Design for the Guidance for In-Situ Subaqueous Capping of Contaminated Sediment" (Maynord 1998) was used to compute a representative particle size (diameter) to resist erosion associated with the wave-induced horizontal orbital velocities. This estimate was compared with the following two other methods:

- The commonly-used Shields diagram presented in Vanoni (1975), which presents stable particle sizes under different flow velocities measured parallel to the particle bed.
- A model for sediment initiation under non-breaking waves on a horizontal bed developed by You (2000). This model was based on experimental data collected for oscillatory flows.

The maximum particle size obtained from these three methods was conservatively selected as the stable sediment particle for the sediment cap armor layer outside of the surf zone.

Due to the amount of turbulence generated by breaking waves in the surf zone, the sediment cap armor layer was modeled as a rubble mound berm (or revetment) in the surf zone. The berm or revetment was assumed to be composed of a rock layer (equivalent to the armor layer) on the top of a chemical isolation layer that would serve as an interface between the revetment core (i.e., the sediment to be capped) and the rock surface (armor layer). The physical properties (e.g., grain size distribution) of the chemical isolation layer (below the armor layer) will be selected to prevent wave-induced turbulence from moving the chemical isolation layer materials into or through the armor layer (i.e. "piping"). Such effects could be minimized by either providing a separate filter layer in-between the armor and isolation cap, or through coarsening of the isolation cap material, and/or fine-grading the overall gradation of the armor layer. These options will be reviewed and addressed as part of the future design process.

The ACES Rubble Mound Revetment Design Module was used to compute the armor stone gradation and thickness in the surf zone. ACES assumes that the waves would propagate and break on the slope of the armor layer. The structure is assumed to be permeable, thereby minimizing wave reflection. Stable particle sizes (i.e., armor sizes) for of the restored slopes (that are being currently considered for each Remediation Area) were evaluated using the model.

Revetments used for coastal protection projects are often designed allowing for some maintenance of the armor layer. The revetment design methodology allows varying amounts of displacement (movement) of the armor layer. The amount of displacement considered can be categorized as:

- No displacement – No armor stone displacement (note that this does not account for settlement)
- Minor displacement – Few armor stones displaced (less than 5 percent) and potentially redistributed within or in the near vicinity of the armor layer
- Intermediate displacement – Ranging from moderate to severe; armor stones are displaced without causing exposure of filter layer to direct wave attack

Allowable movement or rocking of armor stones (minor displacement) in the ACES revetment design methodology is based on steeper slopes (from 1.5H:1V to 6H:1V) that are typically used for coastal revetments than the relatively milder slopes that are being considered for Onondaga Lake (50H:1V). Since the proposed slopes are milder than the slopes typically evaluated, only the minor displacement maintenance scenario was considered in the analysis.

5.4 Results

This section summarizes the results of the wind-wave analysis and armor layer sizing for each Remediation Area. A detailed example calculation is included as Attachment A. Table 5-2 presents a summary of the 100-year design wind speeds based on various return-interval periods for each Remediation Area. The 100-year design wind speed varies from 45.0 miles per hour (mph) at Remediation Area C to 60.0 mph at Remediation Area E.

Table 5-2
100-Year Design Wind Speed by Remediation Area

	A	B	C	D	E
Wind Direction (degrees)	330° to 100°	330° to 130°	0° to 130°	320° to 30°	280° to 340°
Wind Speed (mph)	47.7	47.9	45.0	46.5	60.0

Using the 100-year design wind speed shown in Table 5-2, Table 5-3 presents a summary of the fetch length, the 100-year significant wave height (H_s), the 100-year significant wave period (T_s), and the corresponding breaking wave height and depth for each Remediation

Area. The 100-year design wave heights ranged from 2.6 feet in Remediation Area A to 5.2 in Remediation Area E. In general, the 100-year wave breaks in depths of 3.4 to 6.7 feet.

Table 5-3
100-Year Design Wave Summary by Remediation Area

Remediation Area	Longest Fetch (miles)	Significant Wave Height (feet)	Significant Wave Period (seconds)	Breaking Wave Height (feet)	Breaking Wave Depth (feet)
A	2.01	2.6	2.7	2.6	3.4
B	2.43	2.8	2.9	2.9	3.6
C	3.57	3.2	3.2	3.3	4.2
D	3.39	3.2	3.2	3.3	4.2
E	4.66	5.2	3.9	5.3	6.7

In the sediment cap design, the effects of wind and wave setup were not included so that the resultant design will be more conservative in terms of armor protection. An analysis was performed to evaluate the setup across the surf zone to evaluate the level of conservatism. In addition to the creation of wind-waves, wind can also cause a condition known as "setup" or “setdown.” Wind stress on the water surface can result in a pushing or piling up of water in the downwind direction and a lowering of the water surface in the upwind direction. When the wind blows, water will set up against the land. This setup, superimposed on the normal water level, causes apparent higher-than-normal water levels at the shoreline. When the wind stops, the setup or setdown water surface will return to normal levels (USACE 1991). Wind setup at the shoreline at each Remediation Area as a result of the 100-year design wind was estimated using two methods: Ippen (1966) and USACE (1997).

In addition to wind setup at the shoreline, as waves shoal and break, the momentum flux in the onshore direction is reduced and results in compensating forces on the water column (Dean and Dalrymple 1991). Wave setup is the superelevation of mean water level in the surf zone caused by wave action (Smith 2003). Similar to wind setup, wave setup causes apparent higher-than-normal water levels at the shoreline. The wave setup for the 100-year design waves was computed using Dean and Dalrymple (1991).

Table 5-4 presents the wind and wave setup in each Remediation Area. Estimates of the wind setup at the shoreline varies between methods but ranges between 1 and 6 inches in Remediation Areas A and B, 2 to 7 inches in Remediation Areas C and D, and 4 to 8 inches in Remediation Area E. The wave setup across the surf zone ranges from 6 inches in Remediation Area A to 1 foot in Remediation Area E.

Table 5-4
100-Year Wind and Wave Setup Calculations by Remediation Area

Remediation Area	Longest Fetch (miles)	100-Year Design Wind Speed (mph)	Wind Setup at Shoreline using USACE (1997) (feet)	Wind Set-up at Shoreline using Ippen (1966) (feet)	Wave Setup at Shoreline (feet)
A	2.01	47.7	0.1	0.5	0.5
B	2.43	47.9	0.1	0.5	0.5
C	3.57	45.0	0.1	0.5	0.6
D	3.39	46.5	0.1	0.6	0.6
E	4.66	60.0	0.3	0.7	1.0

Stable sediment particle sizes for the sediment cap armor layer outside of the surf zone were calculated in accordance with the procedure presented in Section 5.3.2 and are presented in Table 5-5. Attachment C presents the calculations (including the computed median particle size, D_{50}) for each Remediation Area. Since Remediation Areas C and D have the same design wave height, they have the same stable particle size and therefore have been presented together in the table. As can be seen from the calculations, the stable particle sizes for the sediment cap predicted to resist the 100-year wind-induced wave would generally consist of sand-sized particles in water depths deeper than 15 feet. However, gravel-sized particles are predicted in water depths ranging from about 15 feet to the surf zone. Maynord (1998) recommends that the thickness of the armor layer be 1.5 times the maximum particle diameter ($1.5D_{100}$) or twice the median particle diameter ($2D_{50}$), whichever is greater. Due to the relatively small median particle diameter of these materials, it would not be practical to place such a small armor layer thickness consistent with Maynord's recommendations. Therefore, based on constructability considerations the armor layer outside of the surf zone has been designed with a minimum thickness of three inches. It is recognized that this three-inch design thickness represents a conservative thickness relative to the erosion protection evaluation.

Table 5-5
Summary of Sediment Cap Armor Layer Design by Remediation Area
(Outside of Surf Zone)

Range of Water Depths (feet)	A	B	C and D	E
40 to 30	Fine Sand	Fine Sand	Fine Sand	Fine Sand
30 to 20	Fine Sand	Fine Sand	Fine Sand	Medium Sand
20 to 15	Fine Sand	Fine Sand	Medium Sand	Fine Gravel
15 to 10	Fine Sand	Medium Sand	Medium Sand	Fine Gravel
10 to 8	Medium Sand	Coarse Sand	Fine Gravel	Coarse Gravel
8 to 6	Coarse Sand	Fine Gravel	Fine Gravel	Coarse Gravel
6 to surf zone	Fine Gravel	Fine Gravel	Fine Gravel	Cobbles

Notes:
1. Sediment type was classified using the Unified Soil Classification System.
2. The surf zone begins at a depth approximately equal to the breaking wave height.
3. The breaking wave depth (surf zone) is approximately 3.5 feet in Remediation Area A and B, 4 feet in C and D, and 7 feet in E.

Table 5-6 presents a summary of the median (D_{50}) armor stone size and minimum thickness layer for the sediment cap in the surf zone for each Remediation Area for a restored slope of 50 horizontal:1 vertical (50H:1V). The design armor layer thicknesses presented in Table 5-6 are based on the same criteria summarized above for the areas outside of the surf zone (1.5 times D_{50} or 2 times D_{100}, whichever is greater).

Table 5-6
Armor Stone Size (D_{50}) and Thickness
with a Restored Slope of 50H:1V (For Surf Zone Regime)

Remediation Area	D_{50} Stone Size (inches)	Thickness of Armor Layer (inches)
A	1.5	3.0
B	1.7	3.4
C and D	1.9	3.8
E	3.0	6.0

Notes:
1. D50 = median grain size.
2. Computed using minor displacement (S=3). Minor displacement refers to minimal movement of armor stones and could be related to "rocking" of the armor under extreme wave action. Repairs associated with such events (if any) will be handled as part of a maintenance program.

5.4.1 Assessment of Rubble-Mound Revetment Approach in Surf Zone

As described in Section 5.3.2, the rubble-mound revetment methodology used for assessing stability within the surf zone is based on steeper slopes (from 1.5H:1V to 6H:1V; typical for coastal revetments) than the relatively mild slopes that are being considered for Onondaga Lake (50H:1V). A detailed assessment was performed to verify the use of this method for estimating stable particle sizes in the surf zone for the Onondaga Lake armor layer design.

The ACES methodology is based on van der Meer's (1988) paper titled "Deterministic and Probabilistic Design of Breakwater Armor Layers". van der Meer suggested using the method for slopes flatter than 4H:1V. The van de Meer method uses wave period, structure permeability, damage, and storm duration. The ACES program assumes an event (N) of 7,000 waves. The equations are valid in the range 1,000< N <7,000, so N = 7, 000 represents the limiting value that is used in this ACES application and is conservative. In addition, the typical revetment design and application (in which ACES is often used) involves the revetment extending from below the normal water level to above the normal water level. Waves typically break on the revetment itself. In the Onondaga Lake application, the armor layer will always be <u>below</u> the water level with a 1.5- to 2-foot dedicated habitat layer placed above the armor layer in the surf zone.

The waves in Onondaga Lake are fetch-limited and the surf similarity parameter (ξ_β) ranges between 0.06 and 0.07, which would indicate that the waves are spilling breakers. In spilling breakers, the wave crest becomes unstable and cascades down the shoreward face of the wave, thus producing a wave that can be characterized as "foamy water." Spilling breakers tend to occur for high-steepness waves on gently sloping beaches. Spilling breakers differ little in fluid motion from unbroken waves and generate less turbulence near the bottom and thus tend to be less effective in suspending sediment than plunging or collapsing breakers (Smith 2003). Since spilling breakers have a similar effect on stone stability as non-breaking waves, a comparison was made with the stable particle size recommended by Maynord (1998) and You (2000) for non-breaking waves, which would be a lower bound for the stable particle size estimate (Figure 5-2). As can been seen on Figure 5-2, the van de Meer method predicts larger stable particle sizes than Maynord (1998) and You (2000). Since the method needs to be extrapolated for flatter slopes (flatter than 6H:1V), only allowing for minor displacement was recommended to be conservative.

Based on this analysis, the use of the rubble-mound revetment equations are appropriate to assess stable particles sizes within the surf zone for Onondaga Lake.

5.4.2 Wave Refraction

As waves approach the shoreline, it is possible for wave orthogonals (i.e., paths) of wave crests to converge or diverge if the water depth varies laterally in the direction of the wave crests. The shallower water depths tend to slow down the wave phase speed and give the impression that waves are "turning" toward the shallower parts of the shoreline. This turning or bending is known as wave refraction.

The restored slopes in each Remediation Area will generally be parallel with the shoreline and therefore significant wave refraction is not anticipated for the majority of the cap areas within the Lake. However, one area where there may be some wave refraction is in the vicinity of the boundary between Remediation Area A and Remediation Area B. There may some wave refraction around the "headland" feature at this location for waves approaching from the northeast. However, for the purpose of evaluating the stable particle sizes for the sediment cap, the design wave height was computed by applying the maximum wind speed along the maximum fetch distance for each Remediation Area. The computed stable particle size was then applied to the entire Remediation Area (not just portions of the Remediation Area); that is, larger waves that may impact only a portion of the Remediation Area that may "bend" toward another portion within the Remediation Area were not ignored. The maximum 100-year waves that could be generated for the Remediation Area were applied to cap armor design for the Remediation Area. Therefore, a wave refraction analysis was not necessary for the cap armor design.

6 TRIBUTARY ANALYSIS

This section summarizes the analysis used to evaluate the stable particle sizes for the armor layer of sediment caps to resist currents generated by the tributaries flowing into Onondaga Lake. High flows resulting from rainfall runoff can occur in the tributaries that discharge into Onondaga Lake. These high flows can result in elevated velocities (and associated bed shear stress) near the mouths of these tributaries and have the potential to erode and/or resuspend sediments. This analysis was conducted to refine and optimize cap designs for long-term stability and performance by evaluating the size of armor stone that would resist the erosive forces from the tributary flows (under high-flow events) entering into Onondaga Lake.

6.1 Summary

Velocity fields generated by the 100-year flows from Ninemile Creek and Onondaga Creek were modeled using a 2-dimensional (2-D) hydrodynamic model. Particle sizes necessary to withstand the 100-year flood flow were computed for the 100-year flood flow from Ninemile Creek and Onondaga Creek.

As expected, the influence of the tributaries decreases with distance from the tributary mouth into the Lake. The tributary analysis resulted in a stable particle size of fine gravel for the portions of the cap near the discharge of Ninemile Creek (Remediation Area A) and Onondaga Creek (Remediation Area E). In comparison, the assessment of typical current velocities measured in the Lake (away from the influence of tributary flows) indicated a stable particle size of fine sand. In summary, the stable particle sizes were smaller than the stable particles required to resist the 100-year wind-generated waves (see Section 5). In fact, the armor layer protection based on wind waves is predicted to withstand bottom velocities up to 4 feet per second (fps) and 6 fps at the mouths of Ninemile Creek and Onondaga Creek, respectively.

Honeywell is currently working with the New York State Department of Environmental Conservation (NYSDEC) in realigning Harbor Brook as part of the WB B upland remediation. The East Flume is also being realigned as part of the East Flume Interim Remedial Measure (IRM). These tributaries will be evaluated in the Intermediate Design

Submittal once the design specifications (e.g., alignment, channel cross-section and depth) have been determined. However, based on the relatively small discharge of these tributaries, the stable particle sizes will likely be smaller than those predicted for Ninemile Creek and Onondaga Creek.

6.2 Introduction

Seven creeks and two industrial conveyances discharge to Onondaga Lake. They include:

- Tributary 5A
- Ninemile Creek
- Sawmill Creek
- Bloody Brook
- Ley Creek
- Onondaga Creek
- Harbor Brook
- Metropolitan Syracuse Wastewater Treatment Plant (Metro)
- East Flume

Of the seven creeks and two industrial conveyances, sediment caps are proposed at three of the tributary mouths and one outfall. Honeywell evaluated the water current velocities resulting from the tributary and outfall flows as a potential mechanism for cap erosion. These tributaries/outfalls and the respective remediation area they enter include:

- Ninemile Creek in Remediation Area A
- Harbor Brook in Remediation Area D
- Onondaga Creek in Remediation Area E
- East Flume in Remediation Area D

Onondaga Creek and Ninemile Creek are the main contributors to the total freshwater input flow into Onondaga Lake (Exponent 2002), representing 34 percent and 33 percent, respectively, of the total flow. Harbor Brook is a minor tributary contributing only 2.1 percent of the total flow (Exponent 2002). The East Flume is an industrial conveyance that contributes a small percentage of surface water. Although Metro discharges into a remediation area, the discharge is located in an area where only dredging is proposed. For the Onondaga Lake tributary analysis, the design evaluations of the armor layer used a 100-year return period for tributary and outfall flood flows, which provides a high degree of protection to the sediment cap. The analysis presented herein consists of determining the particle size required to resist erosive forces from Ninemile Creek and Onondaga Creek. Honeywell is currently working with the NYSDEC in realigning Harbor Brook as part of the WB B upland remediation. The East Flume is also being realigned as part of the East Flume IRM. These tributaries will be evaluated in the Intermediate Design Submittal once the design specifications (e.g., alignment, channel cross-section and depth) have been determined. However, based on the relatively small discharge of these tributaries, the stable particle sizes will likely be smaller than those predicted for Ninemile Creek and Onondaga Creek.

In addition to the tributary and outfall flow analyses, the stable particle size was evaluated for typical Lake currents.

6.3 Methodology

This section presents the methods used to compute a stable particle size to resist erosive forces from tributary flood flows. Section 6.3.1 presents the hydrodynamic model used to compute the velocity fields generated by the 100-year flows from Ninemile Creek and Onondaga Creek. Section 6.3.2 presents the methods used to compute stable particle size for the estimated velocity fields associated with tributary flows as well as current velocities observed within the Lake.

Each of these methods is described below. A detailed example calculation is presented in Attachment C.

6.3.1 Estimating Current Velocities Using Hydrodynamic Modeling

To determine the stable armor layer particle size in Onondaga Lake, it is necessary to understand the velocity field generated by each tributary to the Lake. The velocity fields generated by the 100-year flows from Ninemile Creek and Onondaga Creek were modeled using the USACE hydrodynamic model, RMA2. The RMA2 model is a 2-D, depth-averaged (i.e., the model computes lateral, not vertical variations in flows), finite-element, hydrodynamic numerical model routinely used by the USACE for hydrodynamic studies and was previously used to estimate stable armor layer sediment size for Onondaga Lake during the Feasibility Study (FS) (Parsons 2004). The RMA2 model was used in conjunction with the Surface Water Modeling System (SMS) for RMA2, which is a pre- and post-processor that includes a graphical interface for display of inputs and results.

The following data were used to develop the hydrodynamic models for Ninemile Creek and Onondaga Creek:

- Creek bathymetry and floodplain topography (within the 100-year flood elevation) for Ninemile Creek and Onondaga Creek
- Estimations of predicted post-remediation bathymetry in Onondaga Lake
- Upstream 100-year Creek flood flow conditions
- Downstream 100-year Onondaga Lake water surface elevations
- Channel and lake bed material types/distributions
- Hydrodynamic calibration parameter values, such as the Peclet number (estimated based on published literature)

Table 6-1 summarizes the input parameters for each model. Each of the inputs is described below.

Table 6-1
Summary of RMA2 Input Parameters

	Upstream BC	Downstream BC	Manning's Roughness Coefficient		
Tributary	Flow (cubic fps [cfs])	Water Surface Elevation (feet, NAVD88)	Lake	Tributary	Floodplain
Ninemile Creek	3,756	366.96	0.03	0.035	0.1
Onondaga Creek	4,890	366.96	0.03	0.03	NA

Notes:
a. NA = not applicable.
b. Peclet numbers between 15 and 40 were used for both hydrodynamic models.

The hydrodynamic models were applied for steady-state flow conditions to provide conservative assumptions of flow and velocity.

6.3.1.1 Model Grid

Two-dimensional, finite-element model grids were developed for the tributary analysis that extended from the mouths of the tributaries into Onondaga Lake. The Ninemile Creek model grid extended approximately 2,700 feet into the Lake and 5,600 feet along the shore. Figure 6-1 presents the Ninemile Creek model grid, which consists of 2,351 elements and 7,026 nodes. The sediment cap in Remediation Area A extends from approximately 250 to 1,450 feet into the Lake near the mouth of Ninemile Creek, and therefore the Ninemile Creek model grid extends approximately 1,250 feet beyond the proposed sediment cap. The Onondaga Creek model grid extended approximately 2,700 feet into the Lake and 3,900 feet along the shore. Figure 6-2 presents the Onondaga Creek model grid, which consists of 1,098 elements and 3,073 nodes. The sediment cap in Remediation Area E extends approximately 1,840 feet into the Lake near the mouth of Onondaga Creek, and therefore the Onondaga Creek model grid extends approximately 860 feet beyond the proposed sediment cap.

The bed elevations at each node of the grid were interpolated from bathymetric contour maps comprised of the proposed restored bathymetry in remediation areas and existing bathymetry measurements collected in 2006 by CR Environmental in remaining areas of Onondaga Lake. Limited bathymetry from the National Oceanic and Atmospheric Administration (NOAA) map was applied to Onondaga Creek (NOAA 2001), while the bathymetry and topography collected in 2009 by Thew Associates was applied to Ninemile Creek. Figures 6-3 and 6-4 present the bathymetry used in the hydrodynamic model grids for Ninemile Creek and Onondaga Creek, respectively.

6.3.1.2 Model Boundary Conditions

The model boundary conditions consisted of upstream 100-year flood flows from the respective tributaries and a downstream 100-year flood water surface elevation in Onondaga Lake.

Upstream Flow

The 100-year flood flows were computed for each tributary using peak streamflow data acquired directly from a USGS website (http://nwis.waterdata.usgs.gov/usa/nwis/peak) or computed using the annual peak streamflow from USGS instantaneous data archive (IDA; http://ida.water.usgs.gov/ida/). Streamflow data was gathered from USGS gage titled Ninemile Creek at Lakeland Station (USGS #04240300) for Ninemile Creek and Onondaga Creek at Spencer Street (USGS #04240010) for Onondaga Creek. The 100-year flood flows were estimated using three methods/sources. These three values were reviewed and compared, and the most conservative value was used as the upstream boundary condition. The three methods/sources used were:

- Fitting a Log-Pearson Type III (LP3) probability distribution to the data and estimating the return flow based on the expected value of the distribution at the 99% exceedance level
- Using the USGS flood frequency analysis PeakFQ Program (where peak streamflow data were available from USGS)
- Obtaining 100-year flood flow estimates from a USGS report of flood flows for streams in New York State (USGS 2006)

Table 6-2 presents a summary of the estimated 100-year flood flows.

Table 6-2
Computed 100-year Tributary Flows

	Peak Discharge (cfs) for 100-year Return Frequency Flood Flow			
Tributary[1]	LP3 Calculation[2]	PeakFQ Calculation (adjusted)[3]	USGS Flood Report[4]	Select 100-year Flood Flow
Ninemile Creek	3,202 (3,700)	NA[5]	2,260	3,756[6]
Onondaga Creek	4,641	4,620	4,890	4,890

Notes:

1. Streamflow data was gathered from USGS gage titled Ninemile Creek at Lakeland Station (USGS #04240300) for Ninemile Creek and Onondaga Creek at Spencer Street (USGS #04240010) for Onondaga Creek.
2. Calculated using Log Pearson Type 3 distribution method. (Values in parentheses represent adjusted value based on review of graphical distribution fit).

3. Calculated using USGS's PeakFQ software adjusted to allow for inclusion of records designated as "All or part of the record affected by Urbanization, Mining, Agricultural changes, Channelization, or other," and "Discharge affected by Regulation or Diversion." PeakFQ typically excludes entries flagged with these qualifiers.
4. Taken from Table 9 of USGS Scientific Investigations Report 2006-5112, *Magnitude and Frequency of Floods in New York.* Page 131.
5. NA – PeakFQ calculations not made due to the USGS peak streamflow data for this gage comprised of only maximum daily average streamflow measurements as opposed to instantaneous peak flow measurements. Annual peak streamflow data based on maximum daily averages was not considered to be representative of actual peak streamflow conditions and was therefore not used for 100-year flood calculations.
6. A previous 100-year return flow for Ninemile Creek at Lakeland was developed by Limno-Tech, Inc. and presented in the April 2005 *HEC-RAS Model Calibration for Current Conditions and Remedial Scenario Forecasts for Ninemile Creek.* In that document, the 100-year flood flow was presented as 3,756 cfs (Table 6 and Table 8). Associated discussion stated that this was determined via use of the Log Pearson Type 3 method using available USGS data from the period 1990-2004.

Downstream Water Surface Elevations

Onondaga Lake level was assessed as part of the Supplemental FS for Geddes Brook/Ninemile Creek, Operable Unit 1 (Parsons 2008). Upper and lower bound values, representing the range of estimates from two difference data sources (Federal Emergency Management Agency [FEMA] and USGS), were computed as 371.23 feet NAVD88 and 366.96 feet NAVD88, respectively. The lower value of 366.96 feet NAVD88 was conservatively selected for use as the downstream boundary condition in both hydrodynamic models. A sensitivity analysis on the water surface elevation was performed and is described in Section 6.5 below.

6.3.1.3 Bed Roughness and Turbulent Exchange Coefficient

The Manning's roughness coefficient (Manning's *n*) value is used to represent the bed roughness in the hydrodynamic model. The visual observations of bed materials as well as input values from previous hydraulic analyses were used to assign the bed roughness in the model grids (Parsons 2008). Bounding values of Manning's roughness coefficient were evaluated for the channel and floodplains of Ninemile Creek as part of the Supplemental FS (Parsons 2008). The midpoint of the bounding values was selected for application to the RMA2 model. Therefore, Manning's roughness coefficients of 0.035 (range from 0.03 and 0.04) and 0.1 (range of 0.05 and 0.15) were used for the channel and floodplains, respectively, in the Ninemile Creek model. Since the bed of Onondaga Creek and Onondaga Lake are comprised of sand and clay, a Manning's roughness coefficient of 0.03, based on published values (such as presented in Chou 1959 and USACE 1996), was used in the model. A sensitivity analysis on the Manning's roughness coefficient was performed and is described in Section 6.5 below.

Turbulence may be defined generally as the effect of temporal variations in velocity and the momentum exchange associated with their spatial gradients. In particular, turbulence is viewed as the temporal effects occurring at time scales smaller than the model time step. The eddy viscosity terms in the governing equations used in RMA2 actually represent the molecular viscosity and the effects of turbulence from the Reynolds stress terms. The eddy viscosity controls the numerical stability of the solution and the variation of velocities through a cross-section. Turbulence was accounted for in RMA2 by allowing the model to automatically adjust the turbulence exchange coefficient (E) after each solution iteration, based on a provided Peclet number. The Peclet number, which is based on the unique size and calculated velocity within each element, defines the relationship between the average elemental velocity magnitude, elemental length, fluid density, and E. The Peclet number (non-dimensional) is recommended to be between 15 and 40 (USACE 1996). Peclet numbers within this range were selected for the flow simulations.

6.3.2 Stable Particle Size to Resist Current Velocities

Representative particle sizes (diameters) to resist erosion associated with current velocities were estimated using two methods:

- The Armor Layer Design for the Guidance for In-Situ Subaqueous Capping of Contaminated Sediment (Maynord 1998), which uses current velocity and water depth
- The commonly used Shields diagram presented in Vanoni (1975), which presents stable particle sizes under different flow velocities measured parallel to the particle bed

Stable particles sizes at the mouths of Onondaga Creek and Ninemile Creek were computed using estimated velocities and water depths from the hydrodynamic models. Additionally, the stable particle size necessary to resist typical Lake current velocities was assessed using current velocities measured in the littoral zone (<9 meters) in 1987 by Effler et al. (1996).

The maximum particle size obtained from these two methods was conservatively selected as the stable sediment particle for the sediment cap armor layer due to current velocities.

6.4 Results

This section summarizes the results of the tributary analysis and associated armor layer sizing for each tributary. A detailed example calculation is included as Attachment C.

6.4.1 Ninemile Creek

Figure 6-5 presents the 100-year flood flow velocity magnitude for Ninemile Creek. Additionally, Figure 6-6 presents the 100-year flood flow velocity along the approximate discharge centerline from Ninemile Creek into Onondaga Lake. The predicted velocities decrease almost linearly with distance from the mouth of Ninemile Creek. Velocities along the discharge centerline where a sediment cap is proposed ranged from 0.7 to 2.5 fps.

Stable sediment particle sizes for the sediment cap armor layer were calculated in accordance with the procedure presented in Section 6.3.2 and are presented in Table 6-3. The sediment type required to resist the 100-year flood flow ranges from fine gravel at the nearshore edge of the sediment cap to medium sand at the offshore edge of the sediment cap.

Table 6-3
Stable Particle Sizes along the Discharge Centerline from Ninemile Creek

Distance Offshore (feet)	Computed Velocity (fps)	Median Particle Diameter (inches)		Design Median Particle Size (inches)	Design Median Particle Size (millimeters)	Sediment Type
		Maynord (1998)	Vanoni (1975)			
0	4.1	1.13	0.83	1.13	28.6	coarse gravel
79	3.5	0.77	0.63	0.77	19.5	coarse gravel
251	2.5	0.35	0.31	0.35	8.8	fine gravel
363	2.4	0.36	0.30	0.36	9.2	fine gravel
551	1.7	0.16	0.14	0.16	4.0	coarse sand
749	1.4	0.08	0.08	0.08	2.1	coarse sand
1038	1.0	0.03	0.05	0.05	1.3	medium sand
1466	0.7	0.01	0.02	0.02	0.6	medium sand
1529	0.7	0.01	0.02	0.02	0.6	medium sand
1922	0.6	0.01	0.02	0.02	0.4	fine sand

Notes:
a. Sediment cap extends approximately 250 to 1,450 feet offshore from Ninemile Creek (indicated with shading).
b. Sediment type was classified using the Unified Soil Classification System.

6.4.2 Onondaga Creek

Figure 6-7 presents the 100-year flood flow velocity magnitude for Onondaga Creek. Additionally, Figure 6-8 presents the 100-year flood flow velocity along the approximate discharge centerline from Onondaga Creek into Onondaga Lake. As with Ninemile Creek, the predicted velocities decrease almost linearly with distance from the mouth of Onondaga Creek. In areas where a sediment cap is proposed as the remedy for Remediation Area E, velocities along the discharge centerline ranged from 0.9 to 2.7 fps.

Stable sediment particle sizes for the sediment cap armor layer were calculated in accordance with the procedure presented in Section 6.3.2 and are presented in Table 6-4. The sediment type required to resist the 100-year flood flow ranges from fine gravel near the mouth of Onondaga Creek to medium sand at the offshore edge of the sediment cap.

Table 6-4
Stable Particle Sizes along the Discharge Centerline from Onondaga Creek

Distance Offshore (feet)	Computed Velocity (fps)	Median Particle Diameter (inches)		Design Median Particle Size (inches)	Design Median Particle Size (millimeters)	Sediment Type
		Maynord (1998)	Vanoni (1975)			
0	2.7	0.36	0.33	0.36	9.2	fine gravel
206	2.1	0.19	0.24	0.24	6.0	fine gravel
382	1.9	0.14	0.18	0.18	4.5	coarse sand
744	1.5	0.09	0.11	0.11	2.8	coarse sand
1100	1.3	0.06	0.08	0.08	2.0	medium sand
1785	0.9	0.02	0.04	0.04	1.0	medium sand
1990	0.8	0.02	0.03	0.03	0.8	medium sand
2590	0.7	0.01	0.02	0.02	0.6	medium sand

Notes:
a. Sediment cap extends approximately 1,840 feet offshore from Onondaga Creek (indicated with shading).
b. Sediment type was classified using the Unified Soil Classification System.

6.4.3 Onondaga Lake Current Velocities

In addition to evaluating the influence of the tributaries on the stable particle size, the particle size needed to resist current velocities in Onondaga Lake under typical weather conditions were also assessed. Current velocities range from 0.02 to 0.25 fps in the littoral zone (<9 meters) as measured in 1987 by Effler et al. (1996). Using the methods presented in Section 6.3.2, these measured velocities result in a stable particle size less than fine sands (Table 6-5).

Table 6-5
Stable Particle Sizes for Typical Onondaga Lake Current Velocities

Measured Velocity (fps)[a]	Median Particle Diameter (inches)		Design Median Particle Size (inches)	Sediment Type
	Maynord (1998)	Vanoni (1975)		
0.17	<0.001	<0.004	0.004	fine sand
0.02	<0.001	<0.004	0.004	fine sand
0.25	0.001	<0.004	0.004	fine sand
0.04	<0.001	<0.004	0.004	fine sand
0.18	<0.001	<0.004	0.004	fine sand
0.03	<0.001	<0.004	0.004	fine sand

Notes:
a. Measured velocities include values reported by Effler et al. (1996) in the littoral zone (<9 meters).
b. Sediment type was classified using the Unified Soil Classification System.

6.5 Sensitivity Analyses

Sensitivity analyses were performed by varying Manning's roughness coefficient and downstream (e.g., lake) water surface elevation. Table 6-6 presents the various input parameters for the sensitivity simulations. The downstream water surface elevation was varied between 366.96 feet NAVD88 (lower bound 100-year flood level) and 371.23 feet NAVD88 (upper bound 100-year flood level). Manning's roughness coefficient was varied for each material type as shown below:

- Ninemile Creek Channel: 0.03 to 0.04
- Ninemile Creek Floodplains: 0.05 to 0.15
- Onondaga Creek Channel and Onondaga Lake: 0.025 to 0.035

Table 6-6
Summary of Input Parameters for Sensitivity Simulations

		Upstream BC	Downstream BC	Manning's Roughness Coefficient		
Tributary	Simulation	Flow (cfs)	Water Surface Elevation (feet, NAVD88)	Lake	Tributary	Floodplain
Onondaga Creek	Base Run	4,890	366.96	0.03	0.03	NA
	A	4,890	366.96	0.035	0.035	NA
	B	4,890	366.96	0.025	0.025	NA
	C	4,890	371.23	0.03	0.03	NA
Ninemile Creek	Base Run	3,756	366.96	0.03	0.035	0.1
	A	3,756	366.96	0.035	0.04	0.15
	B	3,756	366.96	0.025	0.03	0.05
	C	3,756	371.23	0.03	0.035	0.1

Note:
a. NA = Not applicable

Tables 6-7 and 6-8 present the results of the sensitivity analysis for Ninemile Creek. A comparison of velocities and stable particle sizes for the range of Manning's roughness coefficients shows the Base Run predicts generally the same material necessary for the armor layer when comparing the Base Run with Simulations A and B (Table 6-7). A slightly coarser material (medium sand vs. fine sand) is predicted at the outer edge of the sediment cap with the Base Run as compared with Simulation A. A comparison of stable particle sizes for differing water surface elevations indicates a larger material would be required near the mouth of Ninemile Creek using the Base Run (lower bound) as compared to Simulation C (upper bound). Furthermore, this particle size is below the particle size required to resist wind-generated waves.

Table 6-7

Summary of Sensitivity Analysis for Ninemile Creek - Manning's Roughness Coefficient

Distance Offshore (feet)	Manning's Roughness Coefficient						Sediment Type from Wind-Wave Analysis [a]
	Base Run - Mid Values		Simulation A - Upper Values		Simulation B - Lower Values		
	Velocity (fps)	Sediment Type	Velocity (fps)	Sediment Type	Velocity (fps)	Sediment Type	
0	4.1	coarse gravel	4.4	coarse gravel	3.6	coarse gravel	NA
79	3.5	coarse gravel	3.7	coarse gravel	3.2	fine gravel	NA
251	2.5	fine gravel	2.5	fine gravel	2.4	fine gravel	1.5-inch stone
363	2.4	fine gravel	2.4	fine gravel	2.4	fine gravel	1.5-inch stone
551	1.7	coarse sand	1.7	coarse sand	1.8	coarse sand	1.5-inch stone
749	1.4	coarse sand	1.2	medium sand	1.5	coarse sand	fine gravel
1038	1.0	medium sand	0.8	medium sand	1.1	medium sand	medium sand
1466	0.7	medium sand	0.6	fine sand	0.8	medium sand	fine sand
1529	0.7	medium sand	0.6	fine sand	0.7	medium sand	NA
1922	0.6	fine sand	0.4	fine sand	0.6	fine sand	NA

Notes:
a. See Section 5 for description of wind-wave analysis and results.
b. Sediment cap extends approximately 250 to 1,450 feet offshore from Ninemile Creek (indicated with shading).
c. Sediment type was classified using the Unified Soil Classification System.

Table 6-8

Summary of Sensitivity Analysis for Ninemile Creek – Water Surface Elevation

Distance Offshore (feet)	Water Surface Elevation (feet, NAVD88)				Sediment Type from Wind-Wave Analysis [a]
	Base Run - Lower Bound 100-year Flood		Simulation C - Upper Bound 100-year Flood		
	Velocity (fps)	Sediment Type	Velocity (fps)	Sediment Type	
0	4.1	coarse gravel	2.0	fine gravel	NA
79	3.5	coarse gravel	1.8	coarse sand	NA
251	2.5	fine gravel	1.4	coarse sand	1.5-inch stone
363	2.4	fine gravel	1.3	medium sand	1.5-inch stone
551	1.7	coarse sand	1.0	medium sand	1.5-inch stone
749	1.4	coarse sand	0.8	medium sand	fine gravel
1038	1.0	medium sand	0.6	fine sand	medium sand
1466	0.7	medium sand	0.4	fine sand	fine sand
1529	0.7	medium sand	0.4	fine sand	NA
1922	0.6	fine sand	0.4	fine sand	NA

Notes:

a. See Section 5 for description of wind-wave analysis and results.

b. Sediment cap extends approximately 250 to 1,450 feet offshore from Ninemile Creek (indicated with shading).

c. Sediment type was classified using the Unified Soil Classification System.

Tables 6-9 and 6-10 present the results of the sensitivity analysis for Onondaga Creek. A comparison of velocities and stable particle sizes for the range of Manning's roughness coefficients shows similar results for the all three simulations (i.e., Base Run, Simulation A, and Simulation B; Table 6-9). A comparison of stable particle sizes for differing water surface elevations indicates a slightly larger material would be required near the mouth of Onondaga Creek using the Base Run (lower bound) as compared to Simulation C (upper bound). Furthermore, the particle size is below the necessary particle size required to resist wind-generated waves.

Table 6-9
Summary of Sensitivity Analysis for Onondaga Creek – Manning's Roughness Coefficient

Distance Offshore (feet)	Manning's Roughness Coefficient						Sediment Type from Wind-Wave Analysis a
	Base Run - Mid Values		Simulation A - Upper Values		Simulation B - Lower Values		
	Velocity (fps)	Sediment Type	Velocity (fps)	Sediment Type	Velocity (fps)	Sediment Type	
0	2.7	fine gravel	2.7	fine gravel	2.7	fine gravel	fine gravel[b]
206	2.1	fine gravel	2.0	fine gravel	2.1	fine gravel	fine gravel[b]
382	1.9	coarse sand	1.8	coarse sand	1.9	coarse sand	fine gravel[b]
744	1.5	coarse sand	1.5	coarse sand	1.6	coarse sand	fine gravel
1100	1.3	medium sand	1.2	medium sand	1.4	coarse sand	fine gravel
1785	0.9	medium sand	0.8	medium sand	1.0	medium sand	medium sand
1990	0.8	medium sand	0.8	medium sand	0.9	medium sand	fine sand
2590	0.7	medium sand	0.6	fine sand	0.8	medium sand	fine sand

Notes:
a. See Section 5 for description of wind-wave analysis and results.
b. A median stone size of 3 inches is proposed throughout the navigation channel, as it is necessary on the side slopes for protection from wind-waves.
c. Sediment cap extends approximately 1,840 feet offshore from Onondaga Creek (indicated with shading).
d. Sediment type was classified using the Unified Soil Classification System.

Table 6-10

Summary of Sensitivity Analysis for Onondaga Creek – Water Surface Elevation

Distance Offshore (feet)	Water Surface Elevation (feet, NAVD88)				Sediment Type from Wind-Wave Analysis [a]
	Base Run - Lower Bound 100-year Flood		Simulation C - Upper Bound 100-year Flood		
	Velocity (fps)	Sediment Type	Velocity (fps)	Sediment Type	
0	2.7	fine gravel	2.1	fine gravel	fine gravel[b]
206	2.1	fine gravel	1.7	coarse sand	fine gravel[b]
382	1.9	coarse sand	1.5	coarse sand	fine gravel[b]
744	1.5	coarse sand	1.3	medium sand	fine gravel
1100	1.3	medium sand	1.1	medium sand	fine gravel
1785	0.9	medium sand	0.8	medium sand	medium sand
1990	0.8	medium sand	0.8	medium sand	fine sand
2590	0.7	medium sand	0.7	medium sand	fine sand

Notes:

a. See Section 5 for description of wind-wave analysis and results.
b. A median stone size of 3 inches is proposed throughout the navigation channel, as it is necessary on the side slopes for protection from wind-waves.
c. Sediment cap extends approximately 1,840 feet offshore from Onondaga Creek (indicated with shading).
d. Sediment type was classified using the Unified Soil Classification System.

7 VESSEL EFFECTS ANALYSIS

This section summarizes the analysis used to evaluate the stable particle sizes to resist propeller wash from commercial and recreational vessels that might operate in Onondaga Lake. In addition, an analysis was performed to evaluate the potential for vessel-generated wake waves associated with the vessels that may operate on Onondaga Lake. The analysis was conducted to refine and optimize cap designs for long-term stability and performance by evaluating the size of armor stone that would resist the erosive forces from the propeller wash generated by boats operating on Onondaga Lake.

7.1 Summary

A propeller wash and vessel wake analysis was conducted to evaluate the stable particle sizes to resist propeller wash from commercial and recreational vessels that currently, or may in the future, use Onondaga Lake. Both commercial and recreational vessels were evaluated over a range of water depths and operating conditions.

The results of the analysis were compared with the stable particle sizes to resist erosion by wind-generated waves. Based on the analysis, 1- to 2-inch coarse gravel is recommended for the armor layer in the NYSCC navigation channel to resist propeller wash. Outside of the navigation channel, the particle sizes necessary to withstand the wind-generated waves are protective against the expected frequency and magnitude of propeller wash expected under typical operating conditions. In the event that a disturbance to the surface of the cap from localized propeller wash or boat anchor occurs, the disturbed area is expected to "self-level" following removal of the anchor from deposition and redistribution of the habitat layer.

The results of the vessel wake analysis indicate that designing the armor layer to protect the chemical isolation layer from 100-year wind-generated waves will also protect against vessel-generated waves.

7.2 Propeller Wash

As a vessel or boat moves through the water, the propeller produces an underwater jet of water. This turbulent jet is known as propeller wash (or propwash). If this jet reaches the bottom, it can contribute to resuspension or movement of bottom particles. Based on a review of the types of vessels and operating procedures for these vessels in Onondaga Lake, there will generally be two types of vessel operations over the sediment cap:

1. Commercial and recreational vessels operating frequently in the NYSCC navigation channel to the Inner Harbor in Remediation Area E
2. Recreational vessels operating randomly in shallower water depths

The propeller wash analysis consisted of the following major components:

1. Obtaining information of the types of commercial and recreational vessels that use Onondaga Lake and their operating characteristics
2. Obtaining the vessel characteristics (such as draft, engine horsepower)
3. Selecting representative vessels to be used in the design
4. Computing the particle size necessary to withstand the erosive forces associated with propeller wash at various water depths

The details of the methodology are presented in Section 7.3. A detailed example calculation is included as Attachment D.

7.3 Propeller Wash Methodology

This section describes the methodology used to estimate the particle size that will withstand the erosive forces associated with propeller wash. The results of the analyses are presented in Section 7.3 of this appendix.

7.3.1 Design Vessels

A variety of vessels operate in Onondaga Lake, including tugboats, a passenger vessel, and a variety of private recreational vessels. The first step in the analysis was to gather information about these vessels including specific design characteristics and typical operating procedures. The characteristics of various vessels were considered, and representative recreational design vessels were selected for analysis.

There are two types of commercial vessels that use Onondaga Lake – tugboats and a passenger vessel. Discussions with NYSCC representatives and barge operators indicate that

Pellegrino Marine operates two tugs on the Lake: the *Sean* and the *Mavret H*. Mid-Lake Navigation Corporation operates the *Emita II*, a 42-person passenger vessel. Previous discussions with tug operators indicate that their vessels operate in the deeper portion of the Lake and use an average of 25 percent of their horsepower (Parsons 2004). Table 7-1 shows the pertinent dimensions used in the propeller wash for these vessels. These vessels are considered representative of the types of commercial vessels that may use the Lake in the future.

Table 7-1
Commercial Vessel Characteristics

Vessel Class	Vessel	Propeller Shaft Depth (feet)	Number of Engines	Engine Horsepower	Propeller Dimensions (feet)	Ducted Propeller
Passenger Vessel	Emita II	5.5	1	200	3.5	No
Tugboat	Mavret H	3	1	800	4.67	Yes
	Sean	3	2	600 total	2.2	No

In addition to these commercial-type vessels, several different types of recreational vessels operate on Onondaga Lake. The various types of recreational vessels that currently use the Lake and their operational parameters were determined based on discussions with Onondaga County personnel. In general, the vessels can be organized into six general categories:

- Ski and fishing boats
- Bass boats
- High performance/power boats
- Sail boats
- Sports yachts
- Others (pontoon boats/jet skis)

Table 7-2 summarizes the types of vessels from annual tenets from the Onondaga Lake Marina located on the eastern shore of the Lake in Liverpool.

Table 7-2
Types of Recreational Vessels from Onondaga Lake Marina

Category	Number of Vessels	% of Total
Ski/Fishing Boat	30	26
Bass Boat	29	26
Sail Boat	22	19
Sports Yacht	20	18
Other (inflatable, pontoon, jetski)	7	6
High Performance/Power Boats	6	5
Total	114	100

The majority (over 50 percent) of vessels surveyed are characterized as ski/fishing boats and bass boats. Based on discussions with Onondaga County, fishing boats are the primary users of the Lake with sailboats using the Lake frequently on weekends. The larger vessels (high performance power boats and sports yachts) are limited in number and are not frequently used on the Lake. As opposed to these larger vessels, smaller vessels (such as ski/fishing boats and bass boats) can operate in shallower water and may use a significant amount of their available horsepower.

Representative vessels from the ski/fishing, bass boat, and high performance power boat category were used in this propeller wash analysis. Table 7-3 summarizes those characteristics.

Table 7-3
Representative Recreational Vessel Characteristics

Vessel Class	Vessel	Propeller Shaft Depth (feet)	Number of Engines	Engine Horsepower	Propeller Dimensions (inches)
Bass Boat	Nitro 929	1.17	1	270	14.625
Ski and Fishing Boat	Triumph 191	2.5	1	150	16
High Performance Boat	Baja Outlaw 23	2.75	1	375	17

7.3.2 Design Approach

The propeller wash analysis for the commercial vessels operating in deeper waters was conducted using the methods presented in USEPA's "Armor Layer Design for the Guidance for In-Situ Subaqueous Capping of Contaminated Sediment" (Maynord 1998). These methods are based on the relationships developed by Blaauw and van de Kaa (1978) and Verhey (1983). This USEPA model considers physical vessel characteristics (e.g., propeller diameter, depth of propeller shaft, and total engine horsepower) and operating/site conditions (applied horsepower, water depth, etc.) to estimate propeller-induced bottom velocities at various distances behind the propeller. The model can be used to predict the particle size that would be stable when subjected to the steady-state (i.e., maneuvering vessel where the speed of the vessel is essentially zero) propeller wash from the modeled vessel. In the case of non-steady-state conditions (i.e., moving vessel), the use of this model is conservative since the propeller wash force is transient in nature, only impacting a fixed point on the bottom for a short time.

Certain model components are based on large ocean-going vessels operating at very slow speeds (e.g., maneuvering operations), and therefore are not applicable to much smaller recreational vessels. The methods presented in the USEPA guidance (Maynord 1998) and technical literature (Verhey 1983, Blaauw and van de Kaa 1978) are based on large ocean-going vessels operating at very slow speeds (e.g., maneuvering operations), and therefore are not fully applicable to the smaller, fast-moving recreational vessels that typically operate in the shallower waters of Onondaga Lake. Specifically, the model does not properly consider the angle of the propeller (the propeller angling downward toward the bed as the boat is starting up) or the transient (i.e., moving vessel) nature characteristic of recreational propeller wash. A more detailed analysis of the propeller wash from recreational vessels was conducted using a refined modeling framework specifically developed for evaluating recreational propeller wash.

The refined modeling approach for evaluating the propeller wash from recreational vessels involved adapting the predictive equations developed for the larger vessels (based on USEPA guidance) to address smaller recreational vessels under moving conditions. The refinements were based, in part, on results of a field study where bottom-mounted current meters were used to measure actual bottom velocities of maneuvering and passing recreational vessels in the Fox River. This refined approach was successfully applied and accepted by USEPA (Region V) for the design of the Lower Fox River remediation to evaluate the effects of propeller wash for the design of the armor layer of a sediment isolation cap (Shaw and Anchor 2007).

Both of the approaches (for maneuvering commercial vessels and transient recreational vessels) summarized above were utilized to evaluate stable particle sizes to resist propeller wash from a range of vessel and operating/site conditions.

7.4 Propeller Wash Results

This section summarizes the results of the propeller wash analysis. As described above, a detailed example calculation is included as Attachment D. Based on previous discussions with tugboat operators and Mid-Lakes Navigation representatives, these vessels operate primarily in the deeper portion of the Lake and at 25 percent of their horsepower (Parsons 2004). One area in the future where these types of vessels may operate more frequently is the NYSCC navigation channel leading to the Inner Harbor in Remediation Area E. The navigation channel is authorized by the State of New York. At the time of dredging plan development, the authorized channel depth was unknown, and Honeywell awaits confirmation of the authorized channel depth as well as the side slope configuration from the NYSCC. For the propeller wash analysis, a water depth of 14 feet was used (an authorized depth of 12 feet plus 2 feet below authorized dredge depth to prevent dredge-induced damage to the cap associated with future navigational dredging). To assess the range of particle sizes that would be stable under varying propeller wash events from large commercial vessels, calculations were made using the USEPA guidance (Maynord 1998) method for a range of applied horsepower (10, 25, and 50 percent of the total installed power) as well as a range of water depths (14 feet, 20 feet, and 30 feet) for the Emita II passenger vessel and the Mavret H tugboat (representing these vessel classes). These operating conditions are considered conservative since most of the Lake is deeper than 30 feet and these vessels would be limited in operating in the nearshore regions due to their draft. Table 7-4 presents a summary of the stable median particle sizes (D50) for various water depths and applied horsepower for the Emita II passenger vessel and the Mavret H tugboat.

Table 7-4
Stable Particle Sizes for Commercial Vessels

Vessel Class	Representative Vessel	Water Depth (feet)	Applied Horsepower (Percent)	Median Particle Size D_{50} (inches)	Median Particle Size D_{50} (millimeters)	Particle Size Type
Commercial Passenger Vessel	Emita II	14	10	0.5	13	Fine Gravel
			25	0.9	23	Coarse Gravel
			50	1.5	37	Coarse Gravel
		20	10	0.2	4	Coarse Sand
			25	0.3	8	Fine Gravel
			50	0.5	13	Fine Gravel
		30	10	0.1	2	Medium Sand
			25	0.1	3	Coarse Sand
			50	0.2	4	Coarse Sand
Tugboat	Mavret H	14	10	1.1	27	Coarse Gravel
			25	1.9	49	Coarse Gravel
			50	3.1	78	Cobbles
		20	10	0.4	11	Fine Gravel
			25	0.8	21	Coarse Gravel
			50	1.3	33	Coarse Gravel
		30	10	0.2	4	Coarse Sand
			25	0.3	8	Fine Gravel
			50	0.5	13	Fine Gravel

Notes:
1. Water depth of 14 feet represents operation in the NYSCC navigation channel.
2. Sediment type was classified using the Unified Soil Classification System.

To assess the range of particle sizes that would be stable under varying propeller wash events for recreational vessels, calculations were made using the refined USEPA methodology for a range of applied horsepower (25, 50, 75, and 100 percent of total installed power) as well as a range of water depths to the top of the underlying armor layer for the three representative vessels outlined in Table 7-3. The minimum water depth for vessel operation that was evaluated was approximately 1 foot off each vessels propeller to the top of the cap (i.e. habitat layer). In shallow water, a dedicated 1.5- to 2-foot-thick habitat layer is planned for placement above the armor and chemical isolation layer. The analysis was performed for water depths to as much as 10 feet. These scenarios represent the range of typical recreational vessels operating in shallow water. Table 7-5 presents a summary of the stable particle sizes for various water depths and applied horsepower for these vessels.

Table 7-5
Stable Particle Sizes for Recreational Vessels

Vessel Class	Representative Vessel	Water Depth to Armor Layer (feet)	Applied Horsepower (Percent)	Median Particle Size D_{50} (inches)	Median Particle Size D_{50} (millimeters)	Particle Size Type
Bass Boat	Nitro 929	4	25	0.4	10	Fine Gravel
			50	0.6	15	Fine Gravel
			75	0.7	18	Fine Gravel
			100	0.9	23	Coarse Gravel
		5	25	0.1	3	Coarse Sand
			50	0.1	3	Coarse Sand
			75	0.2	5	Coarse Sand
			100	0.2	5	Coarse Sand
		10	25	0.003	0.1	Fine Sand
			50	0.004	0.1	Fine Sand
			75	0.005	0.1	Fine Sand
			100	0.007	0.2	Fine Sand
Ski and Fishing Boat	Triumph 191	5	25	0.7	18	Fine Gravel
			50	0.8	20	Coarse Gravel
			75	0.9	23	Coarse Gravel
			100	1.1	28	Coarse Gravel
		6	25	0.1	3	Coarse Sand
			50	0.2	5	Coarse Sand
			75	0.2	5	Coarse Sand
			100	0.2	5	Coarse Sand
		10	25	0.005	0.1	Fine Sand
			50	0.007	0.2	Fine Sand
			75	0.007	0.2	Fine Sand
			100	0.008	0.2	Fine Sand

Vessel Class	Representative Vessel	Water Depth to Armor Layer (feet)	Applied Horsepower (Percent)	Median Particle Size D_{50} (inches)	Median Particle Size D_{50} (millimeters)	Particle Size Type
High Performance Boat	Baja Outlaw 23	6	25	0.2	5	Coarse Sand
			50	0.3	8	Fine Gravel
			75	0.4	10	Fine Gravel
			100	0.5	13	Fine Gravel
		10	25	0.01	0.2	Fine Sand
			50	0.01	0.3	Fine Sand
			75	0.01	0.3	Fine Sand
			100	0.02	0.4	Medium Sand

Notes:
1. Sediment type was classified using the Unified Soil Classification System.
2. The shallowest water depth analyzed for each vessel was approximately 1 foot below the depth of the propeller.

7.5 Assessment of Propeller Wash for the Onondaga Lake Cap Design

The propeller wash analysis performed for Onondaga Lake indicates that particle sizes in the coarse gravel range (1 to 2 inches) would be stable in the NYSCC navigation channel when subjected to propeller wash forces from larger commercial vessels operating under the range of potential conditions identified above.

For the other areas of the cap (primarily in the nearshore areas), recreational vessels will likely operate randomly; that is, these vessels will not start and stop or regularly pass over the exact same location on a regular basis, and therefore the cap armor layer will not be subjected to repeated unidirectional propeller wash. Table 7-6 presents a comparison of the stable particle sizes at depths up to 8.5 feet in each Remediation Area to resist the 100-year wind-generated wave and propeller wash. As can be seen from the table, the particle size(s) predicted to be stable under the propeller wash are comparable to the particle sizes designed to resist wind waves. Due to the limited area impacted by propeller wash from an individual vessel, significant movement of armor layer is not expected from propeller wash. Only three percent (approximately 10 acres) of the sediment cap area in Remediation Areas A through D have water depths between the surf zone and 5.5 feet. In addition, in shallow water, a dedicated 1.5- to 2-foot-thick habitat layer is planned for placement above the armor and chemical isolation layer. In the event that the habitat materials are disturbed by propeller wash, the disturbed area(s) are expected to "self-level" shortly thereafter due to the natural hydrodynamic process of the Lake, which tends to level out discontinuities in the bottom.

Table 7-6
Comparison of Stable Particle Sizes for Recreational Vessels and Wind-Waves

Range of Water Depths Based on Baseline Lake Level (feet)	Remediation Area A	Remediation Area B	Remediation Area C and D	Remediation Area E	Range of Stable Particle Sizes for Recreational Vessels
8.5 to 6.5	Coarse Sand	Fine Gravel	Fine Gravel	Coarse Gravel	Coarse Sand
6.5 to 5.5	Fine Gravel	Fine Gravel	Fine Gravel	Cobbles	Coarse Sand to Fine Gravel
5.5 to 4.5	Fine Gravel	Fine Gravel	Fine Gravel	Cobbles	Coarse Sand to Coarse Gravel
4.5 to surf zone	Fine Gravel	Fine Gravel	Coarse Gravel	Cobbles	Coarse Sand to Coarse Gravel
Within surf zone	Coarse Gravel	Coarse Gravel	Coarse Gravel	Cobbles	Fine to Coarse Gravel

Notes:
1. Sediment type was classified using the Unified Soil Classification System.
2. The surf zone begins at a depth approximately equal to the breaking wave height.
3. The breaking wave depth is approximately 3.5 feet in RA A and B, 4 feet in RA C and D, and 7 feet in RA E.
4. Range of water depths referenced to the Onondaga Lake baseline water level of 362.5 feet (see Section 4 of this appendix). The water level used for the armor layer design is 0.5 feet (362.0 feet) lower than the baseline water level.

7.6 Vessel Wake

As indicated in Section 5 of this appendix, wind-generated waves are the dominant waves in Onondaga Lake. Waves can also be generated by a boat moving through the water. These vessel-generated waves are often referred to as wakes. An analysis was performed to evaluate the potential vessel-generated wake wave heights associated with the vessels that may operate on Onondaga Lake. The results of the analysis indicate that designing the armor layer to protect the chemical isolation layer from 100-year wind-generated waves will also protect against vessel-generated waves.

7.6.1 Design approach

Two methods were used in estimating potential vessels wakes:

- Sorensen-Weggel method (Sorensen and Weggel 1984; Weggel and Sorensen 1986) for tugboats and passenger vessels
- Bhowmik et al. (1991) for recreational vessels

The Sorensen-Weggel method is an empirical model (developed from available laboratory and field data on vessel-generated waves) to predict maximum wave height as a function of vessel speed, vessel geometry, water depth, and distance from the sailing line. This model is applicable for various vessel types (ranging from tugboats to large tankers), vessel speeds, and water depths. The method calculates the wave height generated at the bow of a vessel as a function of the vessel speed, distance from the sailing line, water depth, vessel displacement volume, and vessel hull geometry (i.e., vessel length, beam, and draft). The method has been widely tested on different vessels and is recommended for use with vessels having a Froude number between 0.2 and 0.8. The non-dimensional Froude number used in this method is defined as:

$$Fr = \frac{\text{vessel speed}}{\sqrt{\text{g} \times \text{water depth}}}$$

This method is not applicable for vessels moving with higher speeds at smaller water depths (e.g., recreational vessels) because the Froude number is outside the recommended range (0.2 to 0.8).

The Bhowmik et al. (1991) predictive model is based on measurements of waves generated by 12 different recreational boats ranging in length from approximately 11 to 45 feet, with a maximum draft of 2.4 feet in the Illinois and Mississippi Rivers. Vessels included in the Bhowmik et al. studies were a flat-bottom johnboat, a pontoon, a tri-hull, and various V-hulls. Two wave gages were deployed at each of four distances from the sailing line and 246 test runs were conducted. Vessel speeds ranged from 6.2 knots (7.2 mph) to 39.5 knots (45.4 mph). The empirical model relates maximum vessel-generated wave height as a function of vessel speed, draft, length, and distance from the sailing line. The maximum wave height was found to be proportional to the vessel length and vessel draft, and inversely and weakly proportional to the vessel speed. This is a result of the smaller recreational vessels planing at high speeds. The water depth was not found to be significant in the regression analysis, so it was not included in the empirical equation. Because this model is based on measurements of waves generated by 12 different recreational boats, this method was only used for simulations of recreational vessels traveling at various speeds throughout the Lake.

7.6.2 Results

Vessel wakes for a range of vessel operating speeds for representative commercial vessels are presented in Table 7-7. For these calculations, the wave characteristics were estimated at distances of 25, 50, and 100 feet from the sailing line (essentially the centerline) of the vessel. In actuality, distances may be well over 1,000 feet for vessels operating in deeper portions of the Lake. These close distances are considered to be conservative, since wave heights decrease the further you are from the vessel sailing line due to wave propagation and energy dissipation. A detailed example calculation is included as Attachment E. Details are presented below:

Table 7-7
Vessel-Generated Wave Heights for Commercial Vessels

Vessel Class	Representative Vessel	Water Depth (feet)	Vessel Speed (mph)	Distance from Sailing Line (feet)	Wave Height (feet)
Commercial Passenger Vessel	Emita II	14	8	25	1.0
				50	0.8
				100	0.6
			11	25	1.6
				50	1.3
				100	1.0
		30	8	25	1.3
				50	1.0
				100	0.8
			11	25	2.0
				50	1.7
				100	1.4

Vessel Class	Representative Vessel	Water Depth (feet)	Vessel Speed (mph)	Distance from Sailing Line (feet)	Wave Height (feet)
Tugboat	Mavret H	14	4	25	0.2
				50	0.1
				100	0.1
			10	25	2.5
				50	2.0
				100	1.6
		30	4	25	*
				50	*
				100	*
			10	25	3.2
				50	2.6
				100	2.1

Note:
* - Froude number < 0.2 for this case.

Commercial Passenger Vessels: The *Emita II* passenger vessel-generated wave heights were predicted using the Sorensen-Weggel method to range between 0.6 feet to 2.0 feet. These predicted heights were generated in water depths of 14 and 30 feet, and at speeds of 7.0 knots (8 mph) and 9.6 knots (11 mph). Based on conversations with Mid-Lakes Navigation representatives, these are the typical and maximum speeds that the *Emita II* travels in Onondaga Lake. The wave heights were predicted to decrease as the distance from the sailing increases. At a distance of 100 feet from the vessel, the maximum wave height is predicted to be approximately 1.4 feet.

Tugboats: The Sorensen-Weggel method was used to predicted wave height generated by the *Mavret H* tugboat ranging between 0.1 feet to 3.2 feet. These predicted heights were generated in similar water depths of 14 and 30 feet, and at speeds of 3.5 knots (4 mph) and 8.7 knots (10 mph). These speeds were considered the range of typical speeds that tugboats would operate at on Onondaga Lake. As described above, these vessels typically operate in the deeper portion of the Lake and at 25 percent of their horsepower. At a distance of 100 feet from the tugboat, the maximum wave height is predicted to be approximately 2.1 feet.

Predicted vessel wakes for a range of vessel operating speeds for representative recreational boats are presented in Table 7-8. Similar to the commercial vessels, the wave characteristics were calculated at distances of 25, 50, and 100 feet from the sailing line (essentially the centerline) of the vessel.

Table 7-8
Vessel-Generated Wave Heights for Recreational Vessels

Vessel Class	Representative Vessel	Vessel Speed (mph)	Distance from Sailing Line (feet)	Wave Height (feet)
Bass Boat	Nitro 929	8	25	1.3
			50	1.0
			100	0.8
		12	25	1.2
			50	0.9
			100	0.7
Ski and Fishing Boat	Triumph 191	8	25	1.0
			50	0.8
			100	0.6
		12	25	0.9
			50	0.7
			100	0.6
High Performance Boat	Baja Outlaw 23	8	25	1.7
			50	1.3
			100	1.0
		12	25	1.5
			50	1.2
			100	0.9
Sports Yacht	SeaRay Sundancer	8	25	2.8
			50	2.2
			100	1.7
		12	25	2.4
			50	1.9
			100	1.5

The Bhowmik et al. method was used to predict waves generated by the Nitro 929 bass boat, one of the smaller vessels in this class. The predicted wave heights generated by the Nitro 929 ranged between 0.7 feet to 1.7 feet. These predicted heights were generated at speeds of 7.0 knots (8 mph) and 10.4 knots (12 mph). Likewise, wave heights predicted to be generated by the SeaRay Sundancer sports yacht, which is the largest vessel analyzed in this class, ranged between 1.5 feet to 2.8 feet. As described above, the wave heights are inversely proportional to vessel speed. At a distance of 100 feet from the boats, the maximum wave height is predicted to be approximately 1.7 feet.

The 100-year design wind-generated wave heights range from 2.6 feet in Remediation Area A to 5.2 feet in Remediation Area E. Therefore, our wave analysis will focus on wind-generated waves and not vessel-induced waves.

7.7 Anchor Drag and Wading

Commercial vessel anchoring is not expected to occur over the sediment cap and is expected to be controlled via institutional controls to be implemented as part of the remedy which will dissuade such anchoring over the capped areas. Recreational vessel anchoring over the sediment cap is likely, but will not be subject to the institutional control applicable to commercial vessel anchoring. However, the armoring component of the sediment cap that underlies the habitat layer and overlies the chemical isolation layer will provide penetration resistance from recreational boat anchors from disturbing the underlying cap. In the event that a disturbance to the surface habitat layer of the cap from a boat anchor occurs, the disturbed area is expected to "self-level" following removal of the anchor as a result of redistribution of the habitat layer caused by the natural hydrodynamics of the Lake.

An analysis was performed to evaluate the sediment cap's ability to support human foot traffic (such as wading into shallow water for fishing or entering or exiting a boat). Shallow water ISCs were designed to support the weight of an individual walking on the surface, consistent with USEPA and USACE cap design guidance. The safety factor for the sediment cap is 5 to 15 times greater than the required safety under the range of nearshore cap thicknesses, and thus will be stable under worst-case bearing loads. An example calculation is included in Attachment F.

8 ICE ANALYSIS

Due to the cold temperatures that occur in Central New York in the winter months, Onondaga Lake typically freezes over in the winter. As a result, the potential effects of ice on the sediment cap were evaluated as part of the armor layer design. This section provides a summary of the analysis of icing conditions on Onondaga Lake and the design of the sediment cap armor layer to resist ice impacts.

Ice engineering is a highly specialized field, and it is important that ice processes be evaluated by an experienced professional. A leading technical center of expertise on ice engineering is the USACE Cold Regions Research and Engineering Laboratory (CRREL), located in Hanover, New Hampshire. The evaluation of ice processes for Onondaga Lake was performed by Dr. George Ashton, former Chief of Research and Engineering Directorate at CRREL, who has over 35 years of experience with ice processes. Dr. Ashton's evaluation was based on a field site visit, reviews of published literature on ice processes, review of historical water temperature measurements, observations of ice formation at Onondaga Lake, and evaluation of data from other lakes. The record of ice cover on the Lake from the winter of 1987/1988 through 2002/2003 was examined (16 years). Dr. Ashton's evaluation was included in Appendix H of the FS and is included as Attachment G to this Appendix.

The primary ice scour mechanism of concern for lakes such as Onondaga Lake is the expansion and contraction of ice associated with temperature changes through the winter and spring before breakup and the subsequent movement and pilings of ice at the shoreline due to wind. Occasional ice pilings along the shore of Onondaga Lake have been observed, but these are of limited height (less than 5 feet) and were not considered severe. In the 16 years of observation, only two cases of ice pilings on the shore were noted.

Formation of frazil or anchor ice is not likely to occur at Onondaga Lake due to the size of the Lake and the low exposure to supercooling. Frazil is ice in very small crystals formed in supercooled (below 32 degrees Fahrenheit [°F]) water. While in the supercooled matrix, it can adhere to most materials. In some cases, this frazil can adhere to the bottom sediments. When attached to the bottom, it is often termed anchor ice. Conditions favoring the formation of frazil ice include cooling of the water to below 32°F and sufficient turbulent mixing (e.g., rapids within a river) to entrain the water and crystals to depth. In Onondaga Lake, it is probable that neither condition occurs. The Lake is not of sufficient size and exposure to develop large wind-driven currents, and it is doubtful that the majority of the Lake becomes supercooled. There may be some limited supercooling of the top surface water during the time of initial ice formation, but this will only occur in the absence of mixing with the warmer water below.

Ice freezing to the bottom of the Lake is expected in shallow water at the shoreline of Onondaga Lake. In such cases, it is expected that the normal thickening of ice will encounter the bed, and freezing will continue. Reported ice thicknesses were sparse in the 16 years of record and rarely greater than 8 inches. Estimates of potential ice thickness (based on the degree–day calculation) ranged from 12 to 18 inches. It was determined by Dr. Ashton that the freezing of ice to the Lake bottom is limited to water depths of less than 18 inches (1.5 feet).

To protect the chemical isolation layer of the sediment cap, dredging and capping have been delineated such that the armor layer and chemical isolation layer will be placed below the ice freezing zone described above. Using a low-lake water level of 362.0 feet (see Section 4), the ice freezing zone would be 360.5 feet. The armor layer and chemical isolation layer will be placed below an elevation of 360.5 feet to protect against ice scour.

In summary, the sediment cap has been designed to protect the chemical isolation layer from ice scour.

9 SMU 3 SHORELINE ENHANCEMENT

This section provides a summary of the analysis of the stable particle size that is proposed for the habitat enhancement activities along the SMU 3 shoreline in Remediation Area B. The purpose of these activities along the estimated 1.5 miles of SMU 3 shoreline is to assist in stabilizing calcite deposits, which will reduce the ongoing periodic resuspension and turbidity in the nearshore areas. The shoreline stabilization activities in this area will be integrated with the remedy for the WBs 1-8 site.

SMU 3 (Remediation Area B) is located adjacent to WBs 1-8 in a medium-energy environment. The remedy specified in the ROD for area consists of dredging and capping of select areas as well as with stabilization of the shoreline. It is anticipated that the shoreline stabilization will use a combination of bioengineering techniques to provide a natural shoreline area to create transition zones from the low lying area or WBs 1-8 and SMU 3. However, the FS has not been completed, and no remedial approach has been identified for WB 1-8 at this time.

9.1 Summary

The surf zone associated with the 1-year return period was selected as the basis of design for defining the treatment area. This is the area with a 100% probability of receiving wave action of the specified size in any year. The short term, periodic events that cause daily or weekly resuspension of materials that impact aquatic plants are the main focus for these stabilization activities. Larger wave events that occur much less frequently do not have the ongoing, periodic impacts to the offshore area.

The treatment area for stabilizing the substrate will be set at the 1.5-foot contour within SMU 3 (361.0 feet) and will extend up the slope to a higher water level elevation of 365.0 feet (see Section 4). The design event for determining the stable particle size should be greater than the design event used to define the surf zone so that the material placed within the surf zone will be stable. However, the design event should not be so conservative as to require unnecessarily large stone sizes that could limit the habitat suitability of the material. As a result, the 10-year return period was used as the basis of design for determining the stable particle size to balance between stability and particle size. Based on this analysis, graded gravel with a median particle size (D_{50}) of 1.3 inches will be placed within the surf zone to stabilize the substrate to reduce resuspension, and at the toe of the slope where bioengineering treatments are anticipated. It should be noted that this material will be placed along the entire SMU 3 shoreline to a water depth of 1.5 feet (based on the baseline Lake water level of 362.5 feet), coincident with the depth that demarks the shallow edge of Module 3. As such, there is no overlap of the shoreline stabilization areas with the limited area of Modules 1, 2, or 3 currently planned for Remediation Area B.

9.2 Design Wave Heights and Stable Particle Size

The 1-year and 10-year return interval wind-generated wave heights were computed for the SMU 3 shoreline (in Remediation Area B) following the methodology outlined in Section 5. The 1-year return interval event was used to determine the offshore extent of the shoreline treatment. The 10-year return interval event was used to determine the stable particle size. Table 9-1 summarizes the 1-year design wind speed, computed wave height, and breaking wave height and depth.

Table 9-1
Design Wave Summary for SMU 3 Shoreline

Event	Wind Speed (mph)	Significant Wave Height (feet)	Significant Wave Period (seconds)	Breaking Wave Height (feet)	Breaking Wave Depth (feet)
1-year	22.0	1.1	2.1	1.2	1.4

The armor stone size and gradation for the surf zone for the 10-year wave was computed using the methods summarized in Section 5. The gradation is summarized in Table 9-2.

Table 9-2
Armor Stone Size (D_{50})
with a Slope of 50H:1V (For Surf Zone Regime)

Gradation	Stone Size (inches)
D_0	0.6
D_{15}	1.0
D_{50}	1.3
D_{85}	1.6
D_{100}	2.0

Notes:
1. Computed using minor displacement (S=3). Minor displacement refers to minimal movement of armor stones and could be related to "rocking" of the armor under extreme wave action. Repairs associated with such events (if any) will be handled as part of a maintenance program.
2. The 10-year design wave height and period are 2.1 feet and 2.6 seconds, respectively.

10 EVALUATION OF 6 TO 9 METER ZONE

This section provides a summary of the analysis of relative stability of littoral zone sediments in water depths from 20 to 30 feet (6 to 9 meters). This stability evaluation is utilized in the IDS to evaluate the appropriate sediment depth to consider in defining remedial boundaries and to support technical evaluations related to evaluating the potential placement of a thin layer cap in this zone.

The first step in the evaluation is to evaluate the stability of the existing sediments in the 20- to 30-foot water depth portions of RAs A, B, C and at the RA E/SMU 5 boundary. This evaluation included a review of the lake morphology, sediment texture data, and the stability of the bed under extreme wave events. This section summarizes these analyses.

10.1 Summary

Based on a review of lake morphology, wind-generated waves, and resuspension potential, the 20- to 30-foot water depth region of RAs A, B, and C are net depositional (e.g., new sediments are expected to accumulate over time). Therefore, surficial sediment concentrations in these areas could be used to delineate the remedial boundaries.

In the 20- to 30-foot water depth region in the vicinity of the RA E/SMU 5 boundary, the analysis suggests that resuspension of the existing fine-grained sediments under an extreme wave event would be generally limited to the surface sediments (within the top 1 foot). Therefore, surficial sediment concentrations in this area could be used to delineate the remedial boundaries.

10.2 Evaluation of Potential Bed Stability

As described by Downing and Rath (1988), many studies have demonstrated that the likelihood of sediment accumulation increases with depth in lakes. Lakebed materials are typically coarser in the high-energy, shallow environments and are usually more fine-grained and flocculated in the deeper water. Effler et al. (1996) reviewed available sediment data in Onondaga Lake and suggested that sediment resuspension would be expected to occur in water depths less than 6 meters (20 feet). Based on their analysis, Effler et al. (1996)

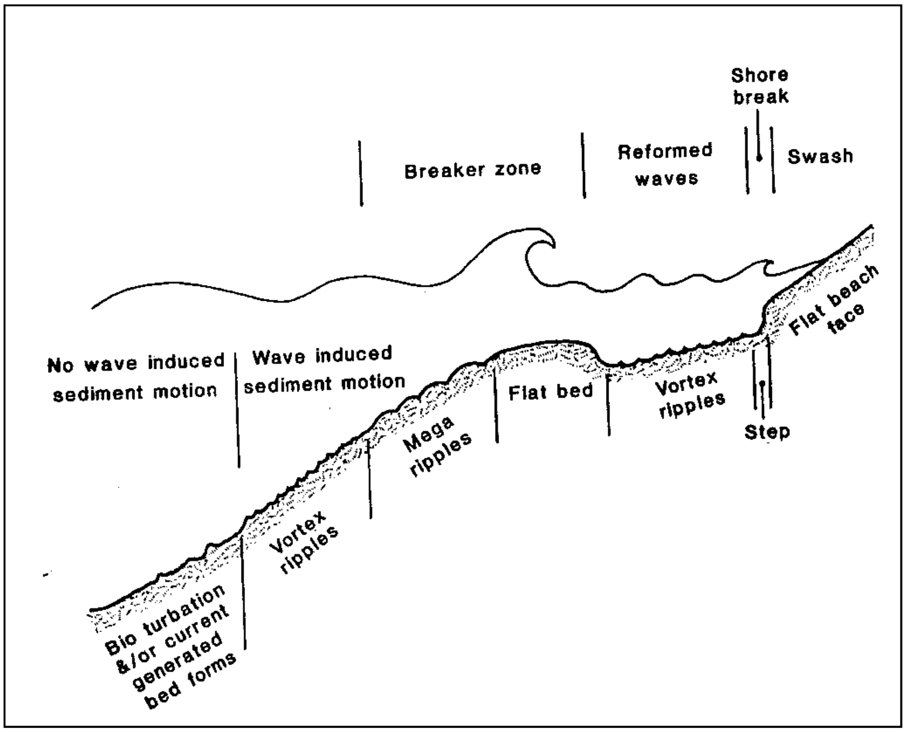
concluded that Onondaga Lake regions with depths in excess of 6 to 8 meters (20 to 26 feet) represent the depositional basin of the Lake.

As described in Section 5, the size of wind-generated waves in each RA depends on the wind velocity and the fetch distance. To evaluate the relative stability of the existing sediments in the 20- to 30-foot water depth region of each RA, an analysis was performed on a RA basis for RAs A, B, C, and the RA E/SMU 5 boundary. The analysis involved:

1. Reviewing existing sediment texture data in the 20- to 30-foot water depth region to determine the particle size of the sediments.
2. Comparing the horizontal orbital velocities for the 2-year, 10-year, and 100-year design waves in each RA to the commonly-used Shields diagram presented in Vanoni (1975), which presents stable particle sizes under different flow velocities measured parallel to the particle bed. The comparison was performed to determine if the existing sediments could potentially be resuspended by wave action.

Details of the wave height and horizontal orbital velocities calculation are presented in Section 5 and Attachment A. It should be noted that Rowan et al. (1992) suggests that critical wave heights to evaluate the mud depositional boundary layer in lakes (i.e. the boundary between the high-energy erosive environment and the low energy depositional areas where fine-grained sediment accumulate) is approximately 77 percent of the maximum wave heights that occur during the one or two largest storms that occur annually. Therefore, for the purpose of this analysis, the 2-year, 10-year, and 100-year extreme event were evaluated.

In addition, in a wave dominated environment such as Onondaga Lake, the sediment bed outside of the surf zone may move based on a wave's ability to form bedforms. Bedforms are sedimentary structures found on a sediment bed, which may have a large range of sizes and shapes (Nielsen 1992). Examples include bars, dunes, and ripples. The illustration below shows an example bedform distribution on a barred shoreline.



Example of Bedform Distribution (adapted from Figure 3.2.1 of Nielsen 1992)

In addition to evaluating the potential for the existing sediments to be resuspended by wave action, an additional evaluation was also performed to determine if the bedforms could develop as a result of wave action in these water depths. In the 20- to 30-foot water depth region, if the wave action is strong enough, vortex ripples can form (see figure above). Vortex ripples are unique to the wave environment, and their scaling is closely tied to wave motion. The size of the vortex ripples is closely linked to the orbital length of the wave-induced fluid motion near the bed. Suspended sediment distribution also tends to scale on ripple height (Nielsen 1992). Therefore, if sediment could be resuspended (i.e., if the maximum wave orbital velocities during an extreme wave event exceed the threshold velocities for resuspension of sediments), then the size of the bedforms would suggest the depth at which the bed may be mixed or resuspended.

Sediment texture (i.e. grain size) measurements in the 20- to 30-foot water depth region were available in RAs A, B, and C from the various phase of the PDI. The core locations where measurements were collected in RAs A, B, and C are shown in Figures 10-1, 10-2, and

10-3, respectively. The grain size analysis from Core OL-VC-60054 was used in the analysis for the RA E/SMU 5 boundary.

Table 10-1 presents the percentage of fine-grained sediments (defined herein as those materials passing the U.S. no. 200 sieve [0.075 millimeters]) in each segment measured.

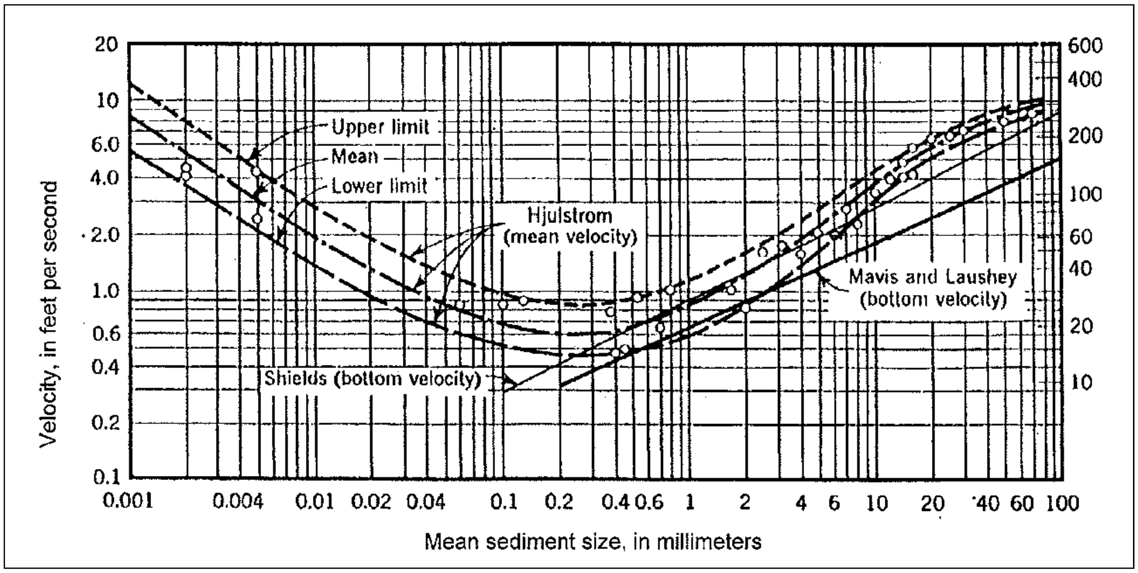
Table 10-1
Percentage of Fine Grained Sediments in the 6 to 9 Meter Zone

Remediation Area	Core	Depth Interval (ft)	Percent Silt and Clay Size
A	OL-VC-40016	9.9-13.2	99.2
		13.2-16.4	99.4
		16.5-19.8	99.5
	OL-VC-40017	0.5-3.3	99.8
		6.6-9.9	99.1
	OL-VC-40018	0-3.3	99.0
		6.6-9.9	99.9
		16.5-18.6	99.2
	OL-VC-40019	0.5-3.3	98.5
		9.9-13.2	99.0
		16.5-19.8	99.4
	OL-VC-40021	0.5-3.3	98.3
		3.3-6.6	98.8
		13.2-16.5	83.5
	OL-VC-40022	0.5-3.3	98.4
		13.2-16.5	87.9
	OL-VC-40023	3.3-6.6	99.6
		13.2-16.5	90.8

Remediation Area	Core	Depth Interval (ft)	Percent Silt and Clay Size
A	S302	0.3-0.59	94.4
		0.59-1.59	99.3
		1.59-2.59	98.5
		2.59-3.59	99.0
		3.59-4.59	98.4
		4.59-5.59	98.4
		5.59-6.59	98.7
		6.59-7.61	98.2
B	OL-VC-30034	0.5-3.3	82.2
		9.9-13.2	99.1
	OL-VC-30035	6.6-9.9	99.1
		16.5-19.6	97.9
	OL-VC-30036	0.5-3.3	97.1
		16.5-17.3	99.5
	OL-VC-30037	0.5-3.3	92.6
		9.9-13.2	96.9
		13.2-16.5	98.9
C	OL-VC-20067	0-3.3	97.8
		6.6-9.9	87.9
	OL-VC-20073	3.3-6.6	97.7
		13.2-16.5	97.4
		16.5-19.3	98.5
	OL-VC-20074	0-3.3	98.4
		9.9-13.2	98.7
		13.2-16.5	99.0
	OL-VC-20076	0-3.3	98.3
		9.9-13.2	90.2

Remediation Area	Core	Depth Interval (ft)	Percent Silt and Clay Size
C	OL-VC-20077	0-3.3	96.4
		13.2-16.5	99.1
RA E/SMU 5 Boundary	OL-VC-60054	0.5-3.3	97.8
		3.3-6.6	95.8
		6.6-9.9	98.3
		16.5-18.5	99.2
		Minimum	**82.2**
		Maximum	**99.9**
		Average	**97.0**

The grain size curves for each core are included in Attachment H. The grain size data indicate that the sediments in the 20- to 30-foot water depth region consist of thick deposits of primarily fine-grained sediments, which is consistent with depositional areas. The percentage of fine-grained sediments ranged from 82.2 to 99.9 percent, with an average of 97.0 percent). As shown on the Shields Diagram for Initiation of Motion (included as Figure A-8 of Attachment A and reproduced below), the velocity required to resuspend fine-grained sediments (with particle sizes of 0.075 millimeters or less) ranges between 0.6 fps (the lower limit) to 1.0 fps (the upper limit). It should be noted that the velocity required to resuspend the fine-grained sediments per the Shields Diagram is greater than that for fine sands due to the typical cohesive nature of these sediments which provides resistance to erosion. As can be seen from the Shields Diagram, the smaller the particle size in the silts and clay region, the higher the velocity required to resuspend the sediments due to the increasing cohesion. For example, as can been seen from the grain-size analysis, the median particle diameter (D_{50}) generally ranges from 0.0021 to 0.0257 millimeters. Based on the Shields Diagram, velocities greater than 1 to 3 fps would be necessary to resuspend particles of these sizes due to cohesion.



Shields Diagram for Initiation of Motion (from Vanoni 1975)

Tables 10-2, 10-3, and 10-4 present the maximum orbital velocity for the 2-year, 10-year, and 100-year wave for each RA in the 20- to 30-foot water depth region. The potential lengths of the vortex ripples for each wave event were also computed using Equation 3.4.1 from Nielsen (1992). Overall, the results of the analysis are consistent with Effler et al. (1996). An evaluation of the wind-generated waves and sediment texture data suggest that Onondaga Lake regions with depths in excess of 6 to 8 meters (20 to 26 feet) represent the depositional basin of the Lake.

Table 10-2

Horizontal Orbital Velocities and Bedforms in 6 to 9 Meter Zone for the 2-year Wave Event

Remediation Area	Water depth (feet)	Maximum Orbital Velocity (fps)	Bedform Length (feet)
A	20	0.02	0.01
	30	0.00	0.00
B	20	0.04	0.02
	30	0.00	0.00
C	20	0.08	0.04
	30	0.01	0.01
RA E/SMU 5 Boundary	20	0.30	0.18
	30	0.07	0.05

Note:
The 2-year significant wave height and period for the RA E/SMU 5 boundary is 2.4 ft and 2.9 seconds, respectively. This is based on a fetch distance of 4.1 miles and a 2-year wind speed of 34.8 mph.

Table 10-3

Horizontal Orbital Velocities and Bedforms in 6 to 9 Meter Zone for the 10-year Wave Event

Remediation Area	Water depth (feet)	Maximum Orbital Velocity (fps)	Bedform Length (feet)
A	20	0.07	0.03
	30	0.01	0.00
B	20	0.13	0.07
	30	0.02	0.01
C	20	0.24	0.14
	30	0.05	0.03
RA E/SMU 5 Boundary	20	0.65	0.46
	30	0.22	0.15

Note:
The 10-year significant wave height and period for the RA E/SMU 5 boundary is 3.4 feet and 3.3 seconds, respectively. This is based on a fetch distance of 4.1 miles and a 10-year wind speed of 45.2 mph.

Table 10-4
Horizontal Orbital Velocities and Bedforms in 6 to 9 Meter Zone for the 100-year Wave Event

Remediation Area	Water depth (feet)	Maximum Orbital Velocity (fps)	Bedform Length (feet)
A	20	0.21	0.11
	30	0.04	0.02
B	20	0.32	0.18
	30	0.08	0.04
C	20	0.54	0.35
	30	0.17	0.11
RA E/SMU 5 Boundary	20	1.30	1.01
	30	0.56	0.43

Note:
The 100-year significant wave height and period for the RA E/SMU 5 boundary is 4.9 feet and 3.7 seconds, respectively. This is based on a fetch distance of 4.1 miles and a 100-year wind speed of 60 mph.

The results of the analysis indicate that the maximum wave orbital velocities during extreme wave events (the 2-year, 10-year, and 100-year) are less than the threshold velocities for resuspension of fine grained sediments in RAs A, B, and C. The results also indicate that waves do not have the potential to develop significant bedforms in these RAs. This would suggest that the 20 to 30 feet water depth region is net depositional.

At the RA E/SMU 5 boundary where the fetch wave energy is greater than in the RAs A, B, and C, the results indicate that during the 2-year and 10-year wave events, the maximum wave orbital velocities are less than the threshold velocities for resuspension of fine grained sediments. This would suggest fine-grained sediment would accumulate as suggested by Rowan et al. (1992) as the mud depositional boundary for lakes. The results also indicate that at the 20-foot water depth, the maximum wave orbital velocity during the 100-year extreme wave exceeds the threshold velocity for resuspension of fine grained sediments. At the 30-foot depth, the maximum wave orbital velocity is less than the threshold velocity for resuspension of fine grained sediments. Based on a bedform analysis, the results indicate that resuspension or movement of sediments during an extreme event would be limited to the top foot in this location during the 100-year event. Sediments buried below these surficial sediments are expected to be stable.

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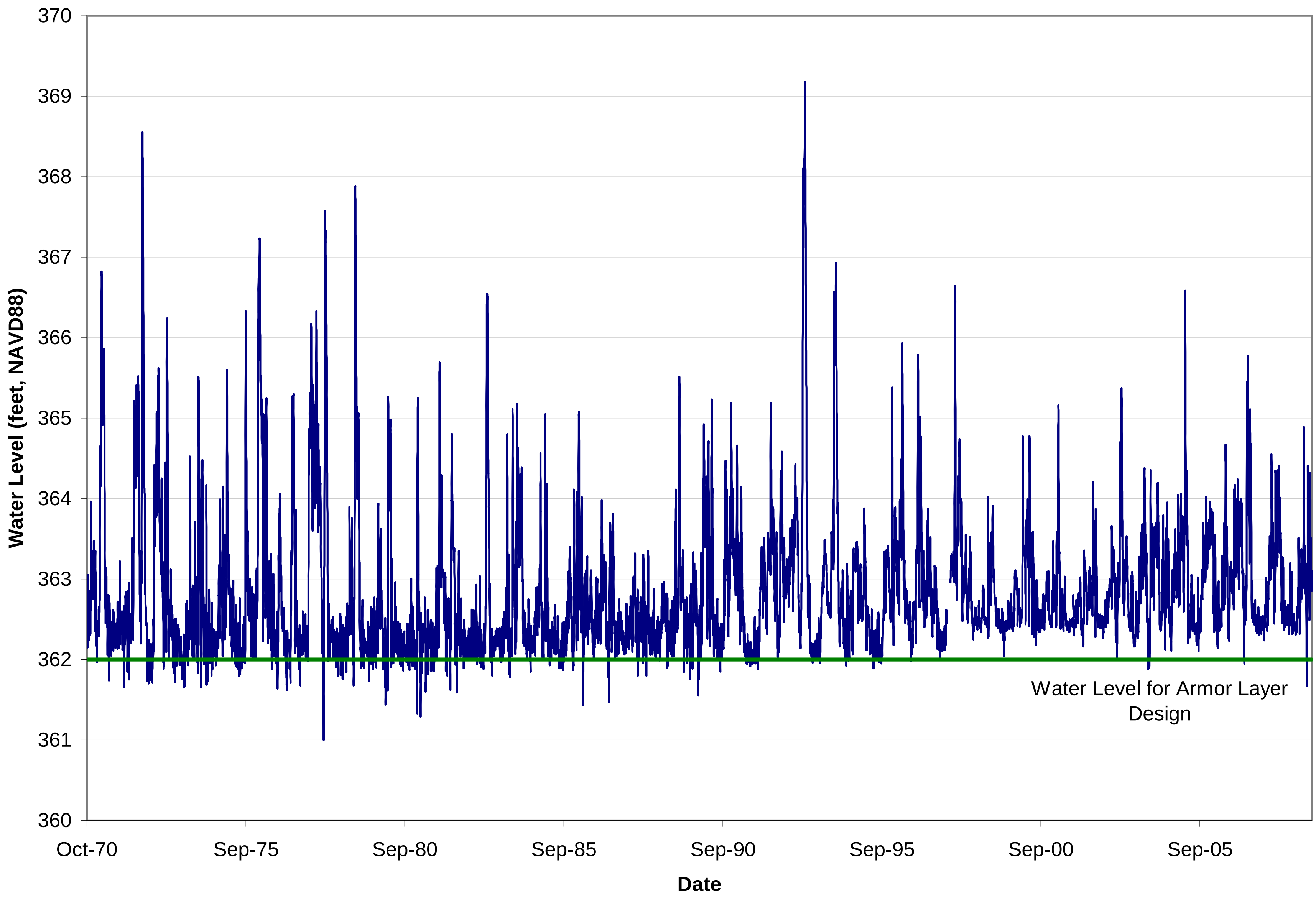
FIGURES



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Honeywell
PARSONS

Figure 4-1
Time Series of Onondaga Lake Water Levels 1970-2009
Armor Layer Design Appendix
Cap and Dredge Area and Depth Initial Design Submittal/Honeywell

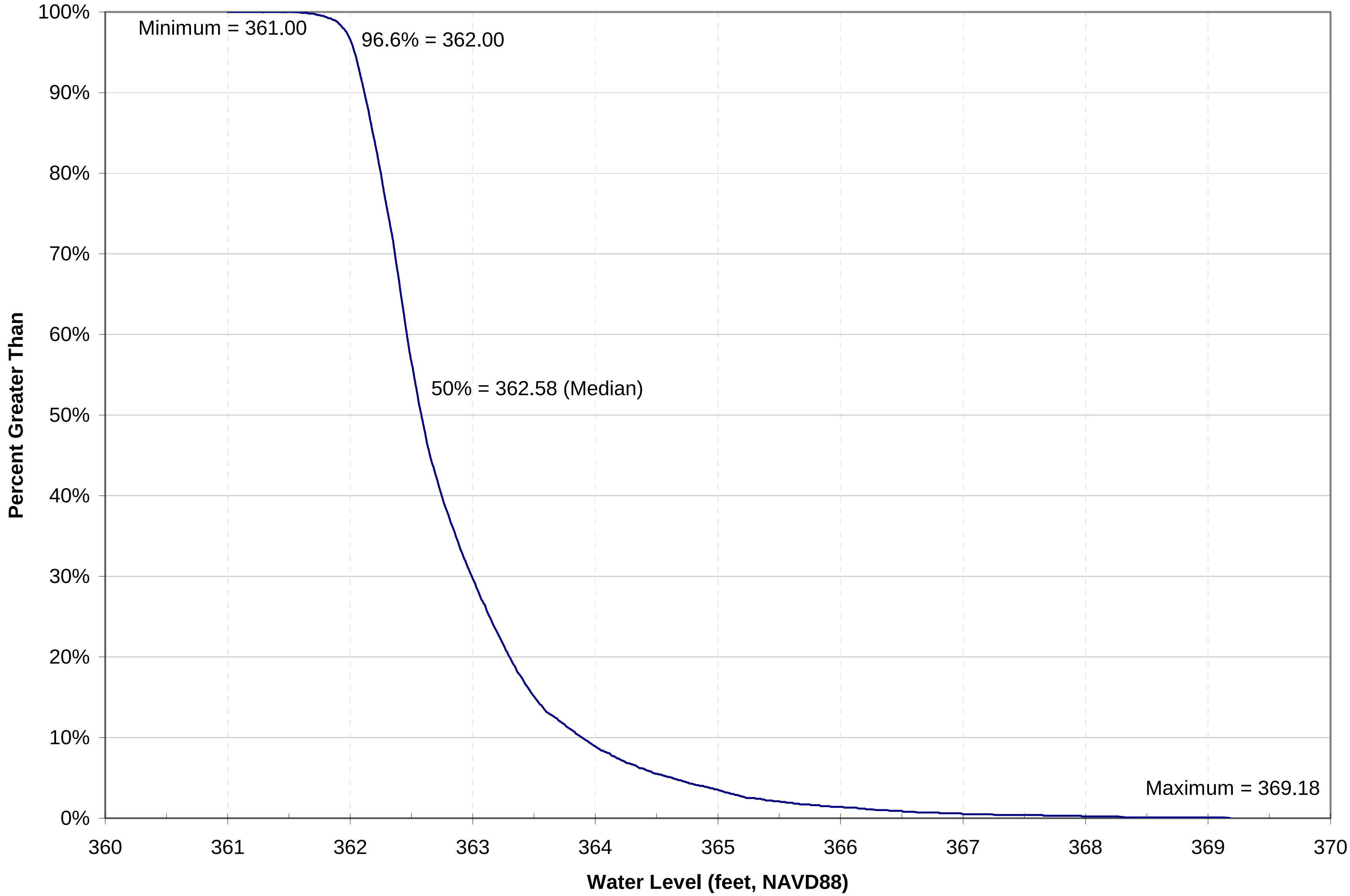

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Figure 4-2
Cumulative Frequency Distribution of Onondaga Lake Water Levels 1970-2009
Armor Layer Design Appendix
Cap and Dredge Area and Depth Initial Design Submittal/Honeywell

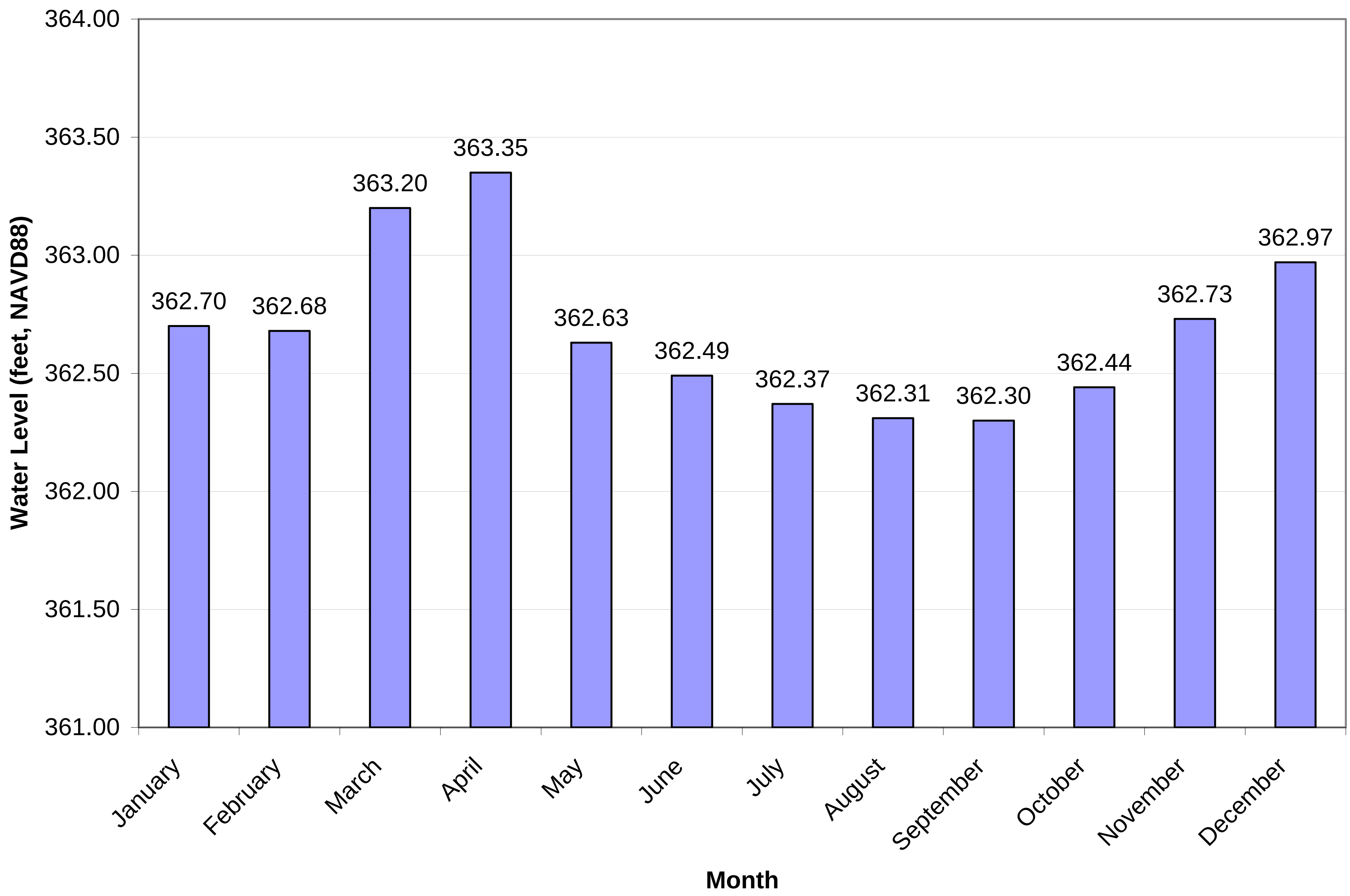

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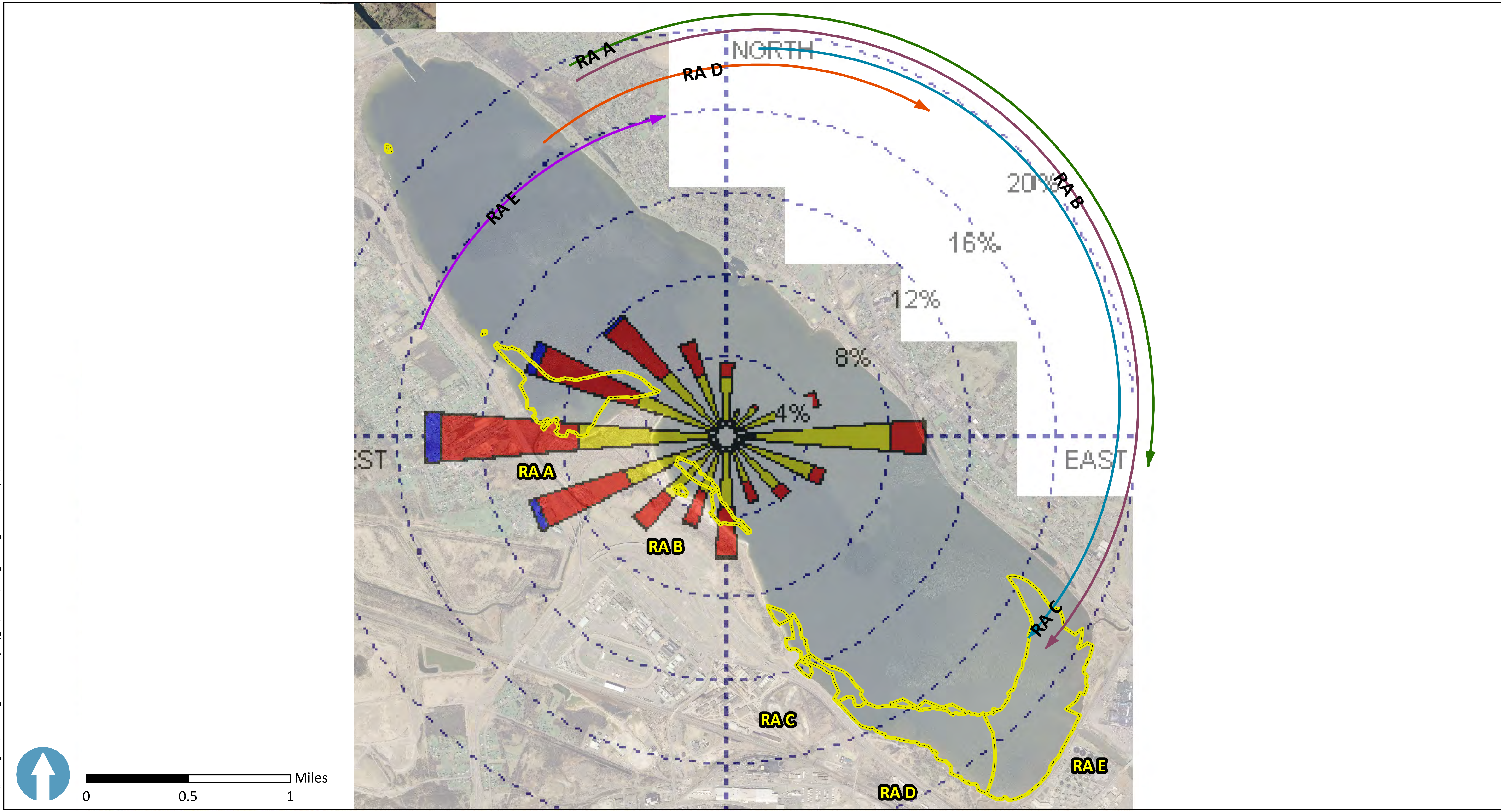
Figure 4-3
Monthly Median Onondaga Lake Water Levels 1970-2009
Armor Layer Design Appendix
Cap and Dredge Area and Depth Initial Design Submittal/Honeywell



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New York State

Legend

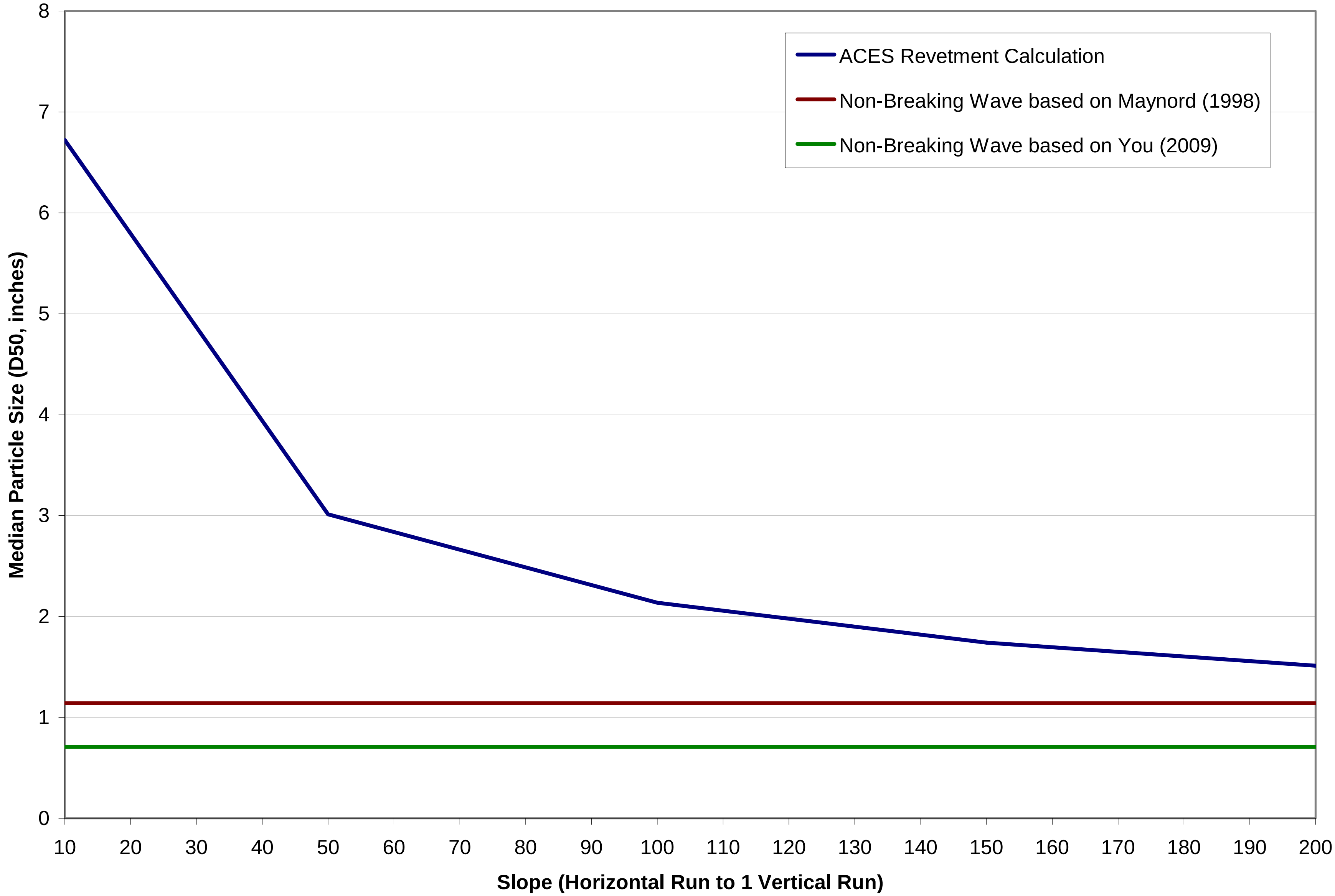
Remediation Areas

Wind speed (meters / second)

>= 25
20 - 25
15 - 20
10 - 15
5 - 10
2 - 5
1 - 2
Calms: 0.27%

Onondaga County, NY

Figure 5-1
Wind Rose for Onondaga Lake
Armor Layer Design Appendix
Cap and Dredge Area and Depth Initial Design Submittal



Note: Assumes "Minor Displacement" of Armor Layer (S=3)

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Figure 5-2
Sensitivity of Median Armor Stone Size (D50) to Slope in RA E
Armor Layer Design Appendix
Cap and Dredge Area and Depth Initial Design Submittal/Honeywell

Figure 6-1
Ninemile Creek Model Grid
Armor Layer Design Appendix
Cap and Dredge Area and Depth Initial Design Submittal/Honeywell

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Figure 6-2
Onondaga Creek Model Grid
Armor Layer Design Appendix
Cap and Dredge Area and Depth Initial Design Submittal/Honeywell

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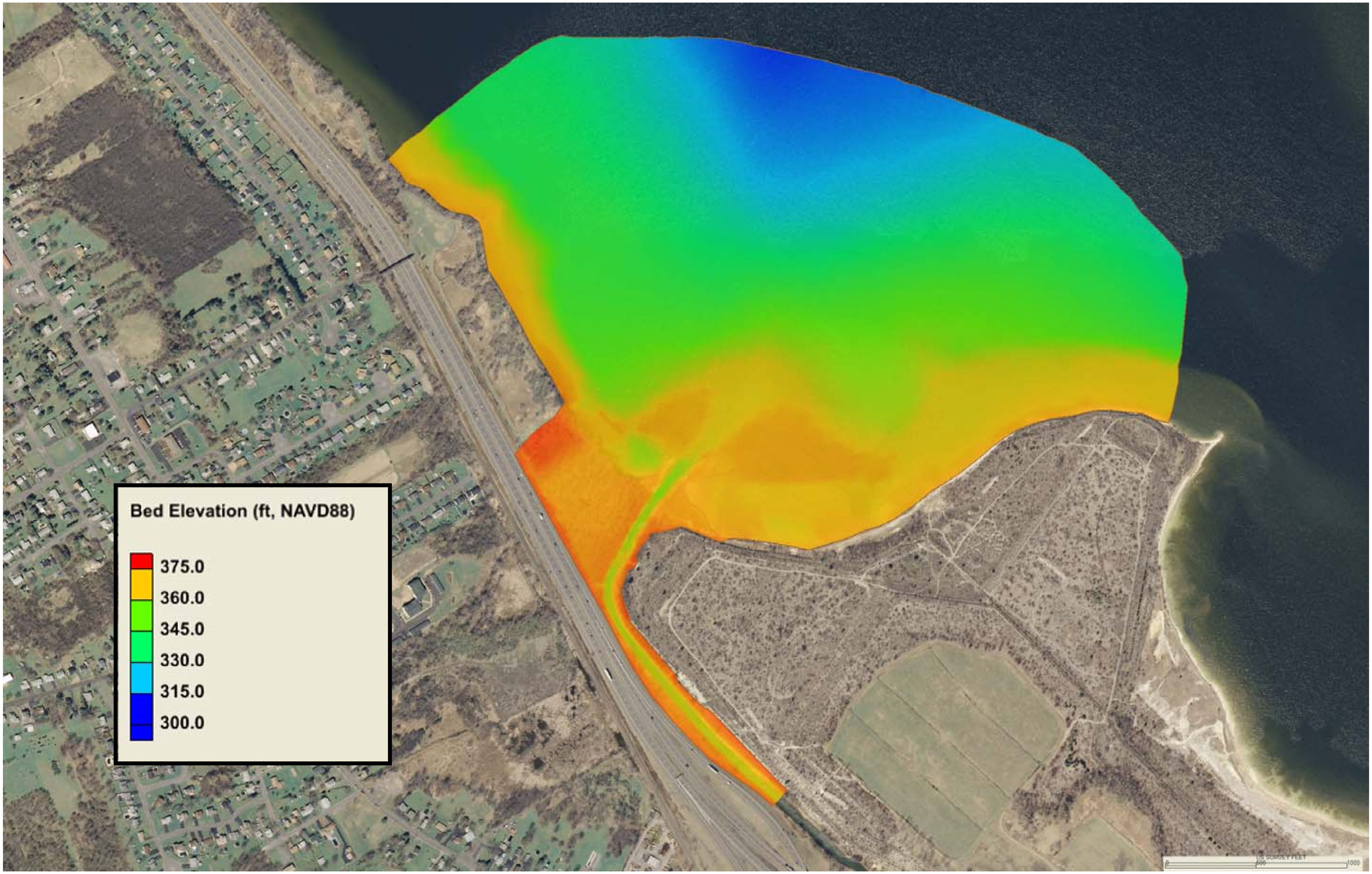
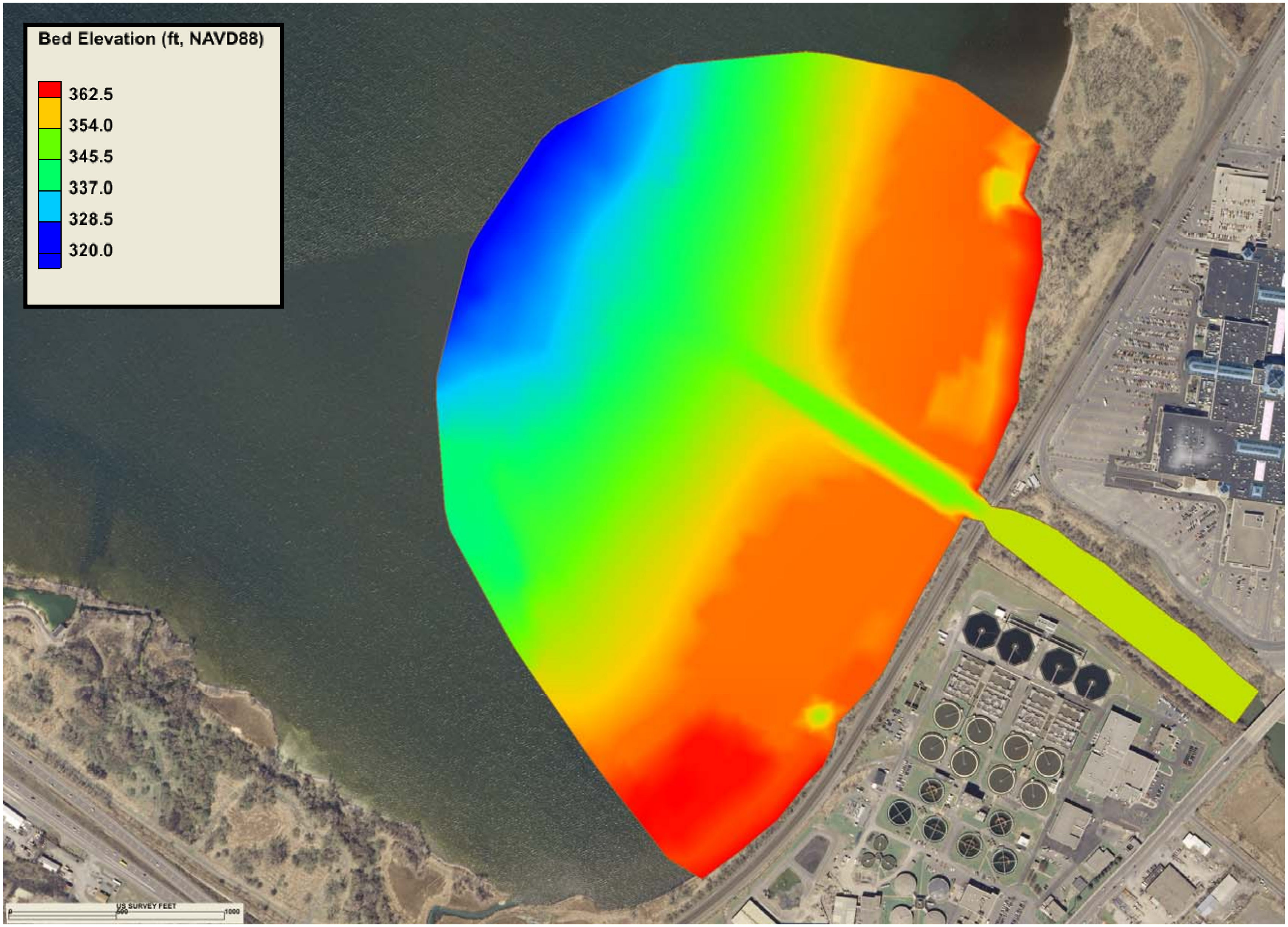


Note: Bathymetry presented as restored bathymetry after 2 years of settlement in water depths >3 feet.

Figure 6-3
Model Grid Bathymetry – Ninemile Creek
Armor Layer Design Appendix
Cap and Dredge Area and Depth Initial Design Submittal/Honeywell



Note: Bathymetry presented as restored bathymetry after 2 years of settlement in water depths >3 feet.

Figure 6-4
Model Grid Bathymetry – Onondaga Creek
Armor Layer Design Appendix
Cap and Dredge Area and Depth Initial Design Submittal/Honeywell

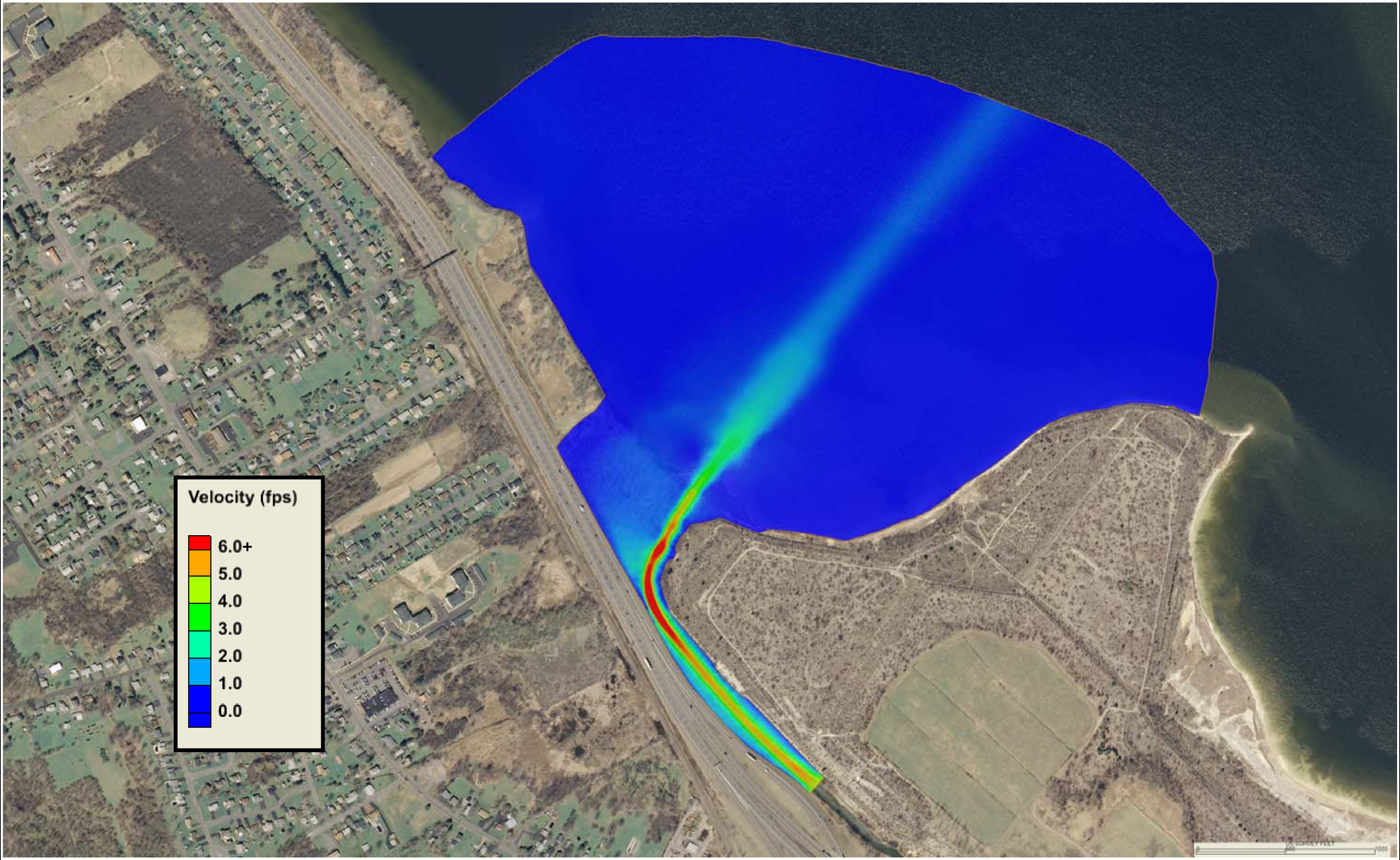


Figure 6-5
Computed Velocity Magnitude in Remediation Area A
Armor Layer Design Appendix
Cap and Dredge Area and Depth Initial Design Submittal/Honeywell

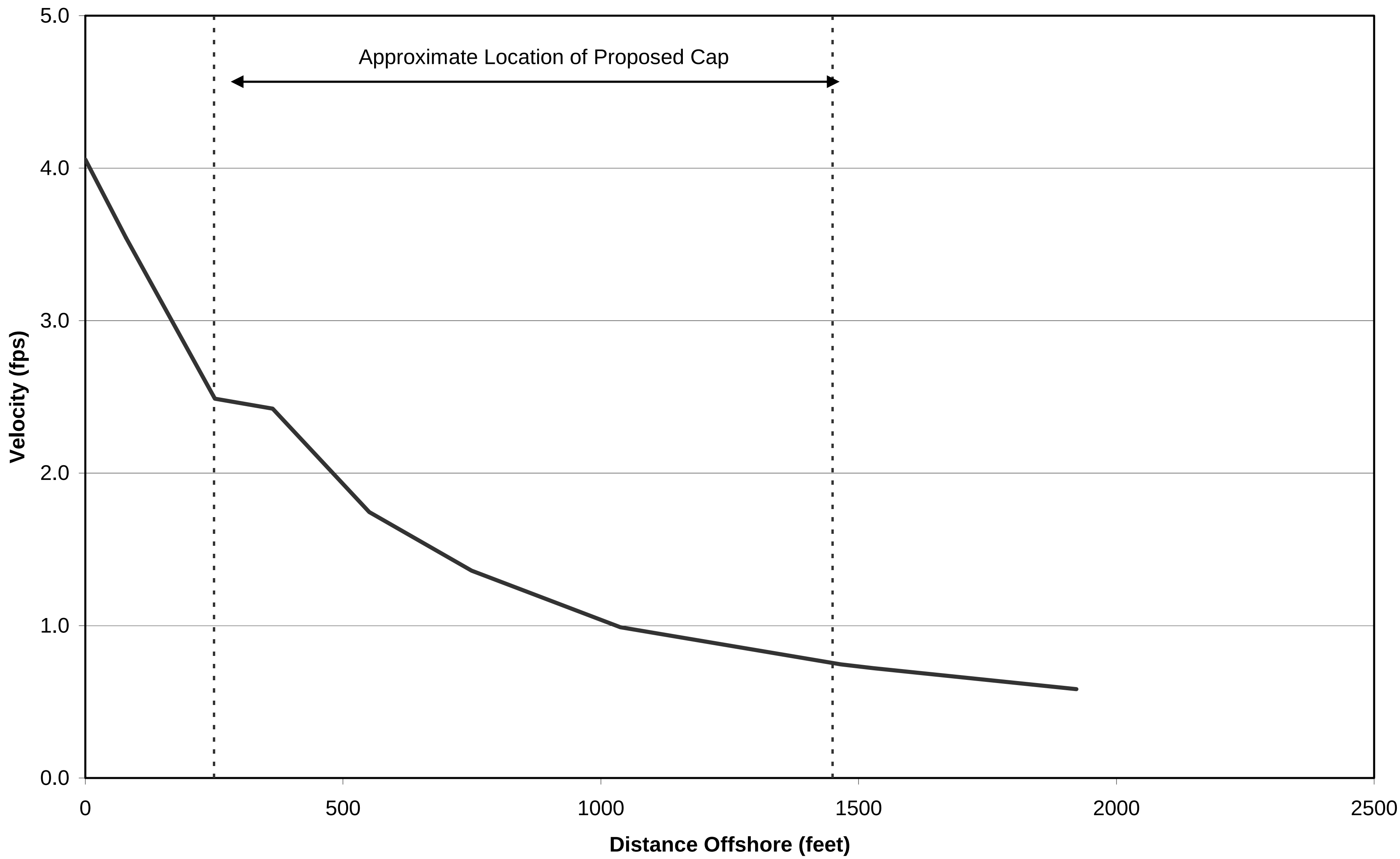


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Figure 6-6
Computed Velocity along Discharge Centerline from Ninemile Creek
Armor Layer Design Appendix
Cap and Dredge Area and Depth Initial Design Submittal/Honeywell

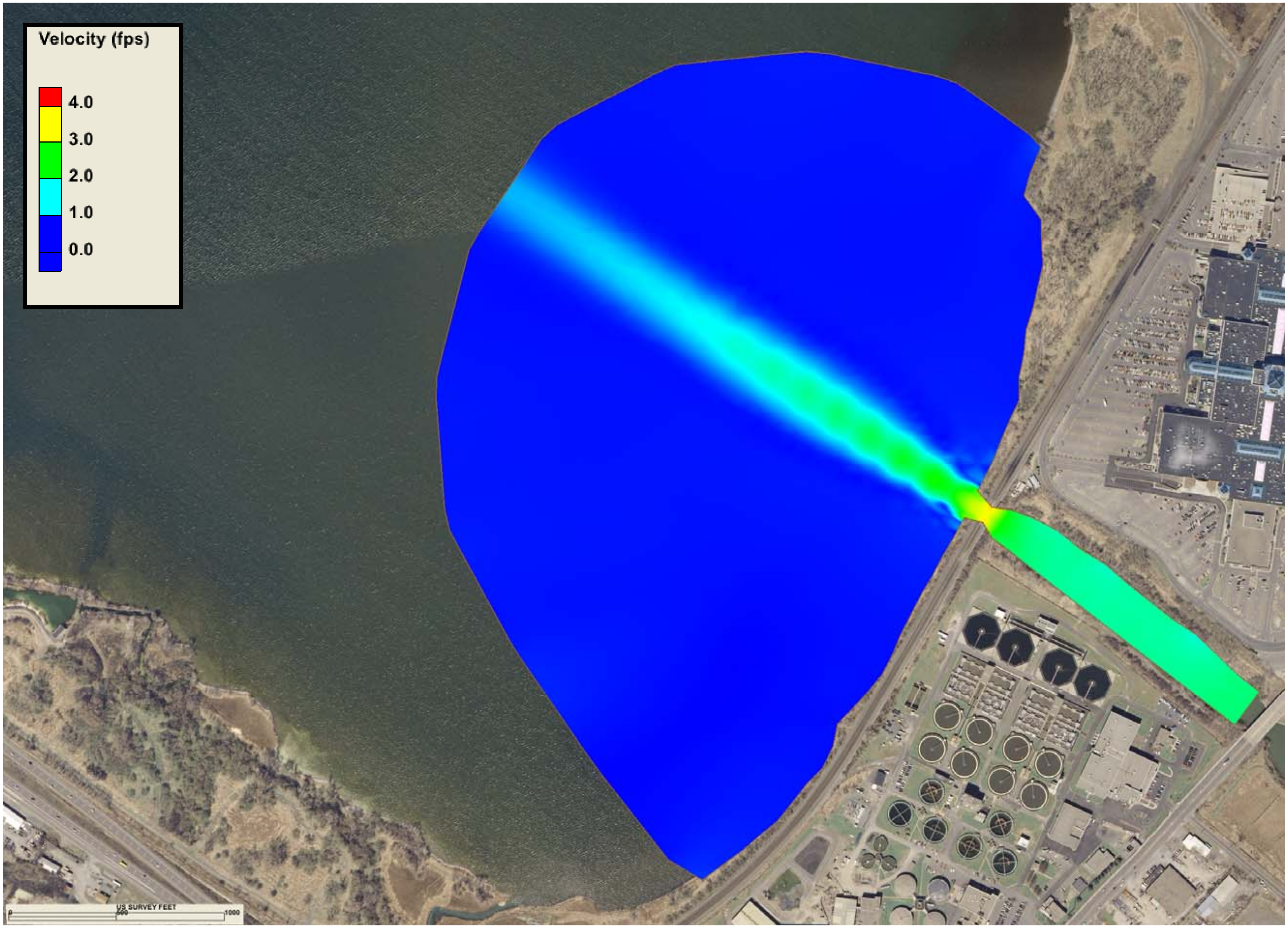


Figure 6-7
Computed Velocity Magnitude in Remediation Area E
Armor Layer Design Appendix
Cap and Dredge Area and Depth Initial Design Submittal/Honeywell

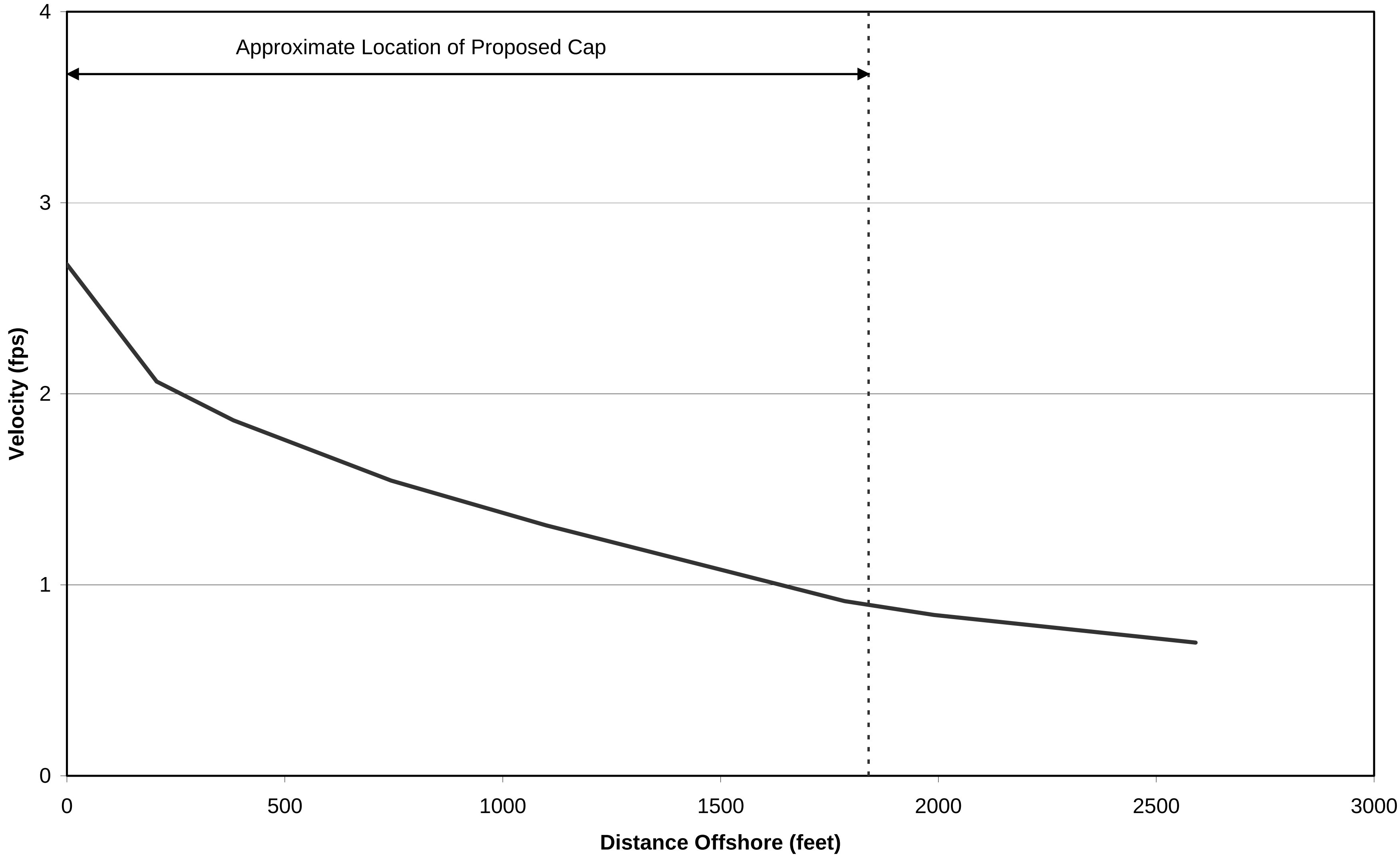


Figure 6-8
Computed Velocity along Discharge Centerline from Onondaga Creek
Armor Layer Design Appendix
Cap and Dredge Area and Depth Initial Design Submittal/Honeywell

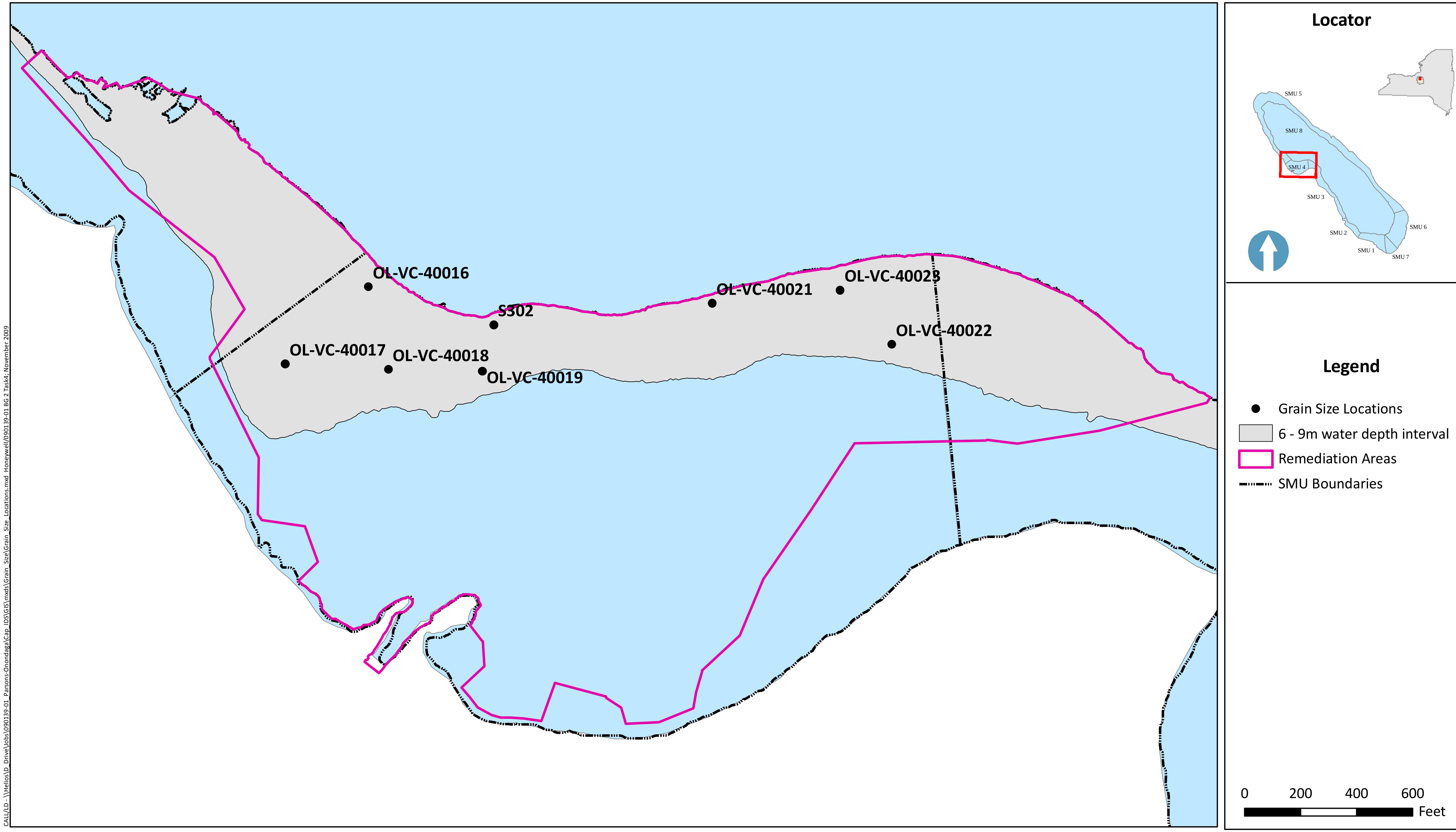
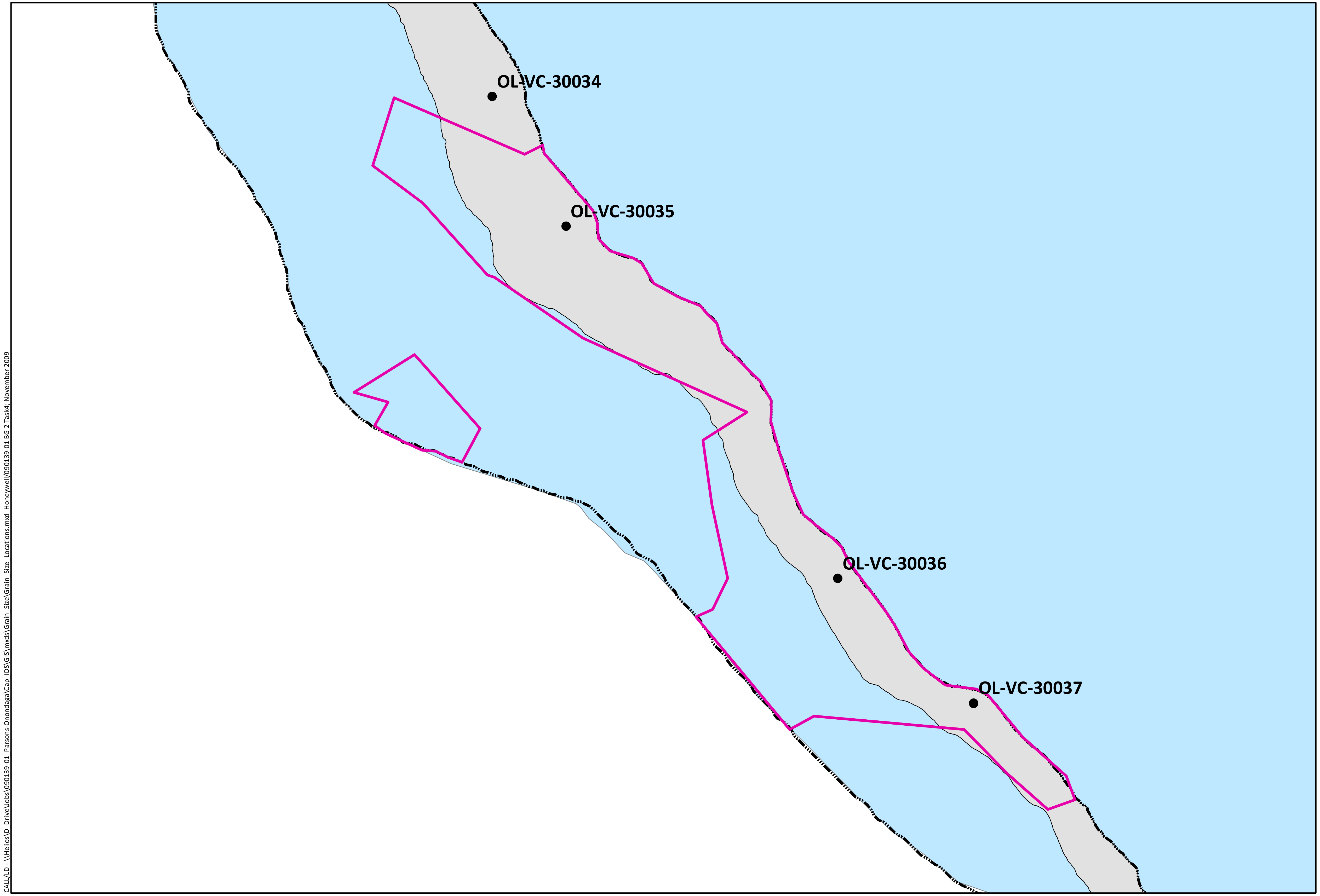


Figure 10-1
Grain Size Locations
Remediation Area A
Armor Layer Design Appendix
Cap and Dredge Area and Depth Initial Design Submittal



Legend

- Grain Size Locations
- 6 - 9m water depth interval
- Remediation Areas
- SMU Boundaries

0 200 400 600 Feet

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Figure 10-2
Grain Size Locations
Remediation Area B
Armor Layer Design Appendix
Cap and Dredge Area and Depth Initial Design Submittal

Legend

- Grain Size Locations
- 6 - 9m water depth interval
- Remediation Areas
- SMU Boundaries

0 200 400 600 Feet

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Figure 10-3
Grain Size Locations
Remediation Area C
Armor Layer Design Appendix
Cap and Dredge Area and Depth Initial Design Submittal

ATTACHMENTS

ATTACHMENT A
WIND-GENERATED WAVE EXAMPLE CALCULATION

CALCULATION COVER SHEET

PROJECT: Onondaga Lake	**CALC NO. 1**	**SHEET** 1 of 13
SUBJECT: Attachment A – Wind-Wave Analysis for Sediment Cap Armor Layer Designs - Example Calculation		

Objective: To determine the 100-year design wave for each of Onondaga Lake's Remediation Areas and the resultant particle size(s) necessary for stability of the sediment cap.

This document presents an example calculation for Remediation Area E as well as the results of the analysis for each Remediation Area.

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Dean, R.G. and R.A. Dalrymple. 1991. *Water Wave Mechanics for Engineers and Scientists*. World Scientific.

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USACE. 2006. *Coastal Engineering Manual*. Engineering Manual EM 1110-2-1100, U.S. Army Corps of Engineers, Washington, D.C. (in 6 volumes).

Vanoni, V.A. 1975. *Sedimentation Engineering*. ASCE Manuals and Reports on Engineering Practice – No. 54, 730 pp.

You. 2000. "A simple model of sediment initiation under waves." *Coastal Engineering* 41 (2000). pp 399-412

Computation of 100-year design wave and resultant particle size(s): The following presents a detailed summary and example calculation for the Onondaga Lake wind-wave analysis. The numbered list below outlines the general approach used for the calculation and defines specific parameters used in the calculations. To efficiently facilitate computations for multiple cases, all calculations were carried out using a spreadsheet and the *Automated Coastal Engineering System (ACES)* software. Subsequent sections below illustrate a step-by-step calculation for the example case of Remediation Area E.

1. Estimate the 15-minute averaged 100-year return interval wind speed

For the 68-years of one-hour averaged wind data, only the winds blowing from 280 to 340 degrees (clockwise from North) were considered for this Remediation Area. These are the winds blowing primarily toward the shoreline for this Remediation Area (i.e., along the possible fetch radials). The first step in computing the 15-minute averaged 100-year return interval wind speed was to determine the wind speed at an elevation of 10-meters above the ground (U_{10}) for each measurement. Equation II-2-9 from USACE (2006) was used:

$$U_{10} = U_z \left(\frac{10}{z} \right)^{\frac{1}{7}}$$

For example, wind speeds were measured at 21 feet (6.4 meters) above the ground from 1963 to 2009. Thus, for a one-hour averaged wind speed of 55.3 miles per hour (24.7 meters per second), the wind speed at 10-meters would be:

$$U_{10} = 24.7\ \text{m/s} \left(\frac{10\ \text{m}}{6.4\ \text{m}} \right)^{\frac{1}{7}} = 26.3\ \text{m/s} = 58.9\ \text{mph}$$

Figure A-1 was used to determine the estimated time to achieve fetch-limited conditions as a function of wind speed and fetch length. For a wind speed of 58.9 mph (26.3 m/s) and a fetch length of 4.66 miles (7.4 kilometers) for Remediation Area E, the time to achieve fetch-limited conditions is approximately 60-minutes. Therefore, using 15-minute averaged wind speeds would be conservative.

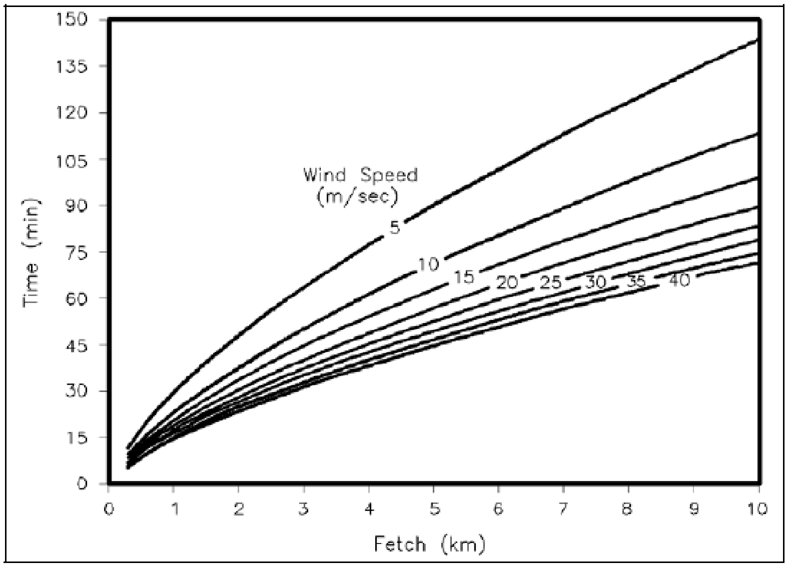

Figure A-1. Equivalent Duration for Wave Generation as a Function of Fetch and Wind Speed (adapted from Figure II-2-3 from USACE 2006)

After converting all of the maximum annual one-hour averaged wind data into winds speed at the 10-meter elevation, the wind data were converted to 15-minute averaged intervals (U_{900}) using Figure A-2.

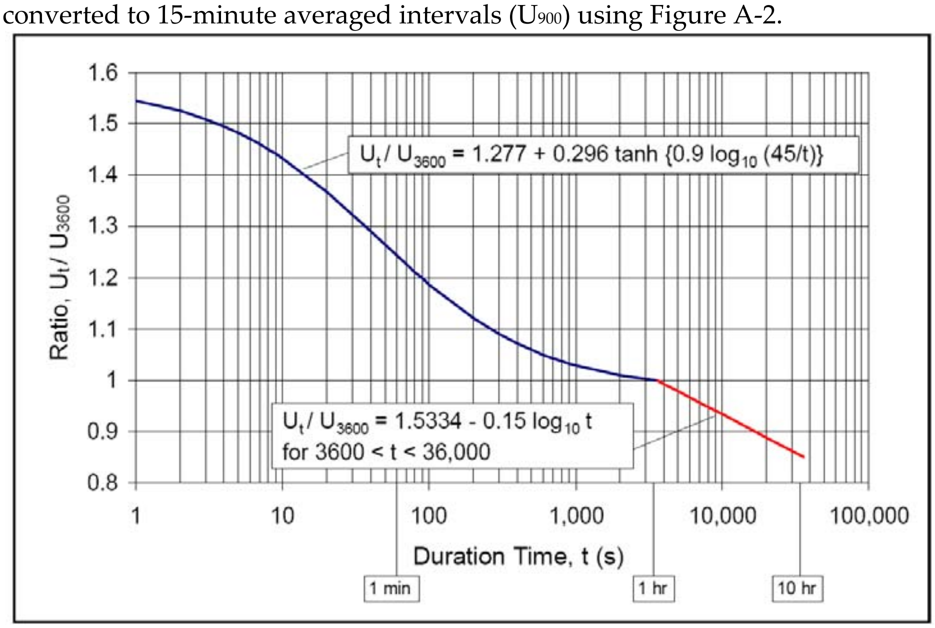

Figure A-2. Ratio of Wind Speed of any Duration U_t to the 1-hr wind speed U_{3600} (adapted from Figure II-2-1 from USACE 2006)

Using the above figure:

$$U_{900} = 1.03(58.9 \text{ mph}) = 60.6 \text{ mph}$$

The maximum annual 15-minute averaged wind speeds were analyzed using the ACES *Extremal Analysis Module* to estimate the various return periods. A review of the ACES results indicated that a Weibull Distribution (k=1) was found to be the best fit for the wind records from Remediation Area E. Figure A-3 shows the plot of computed return interval wind speeds based on Weibull Distribution.

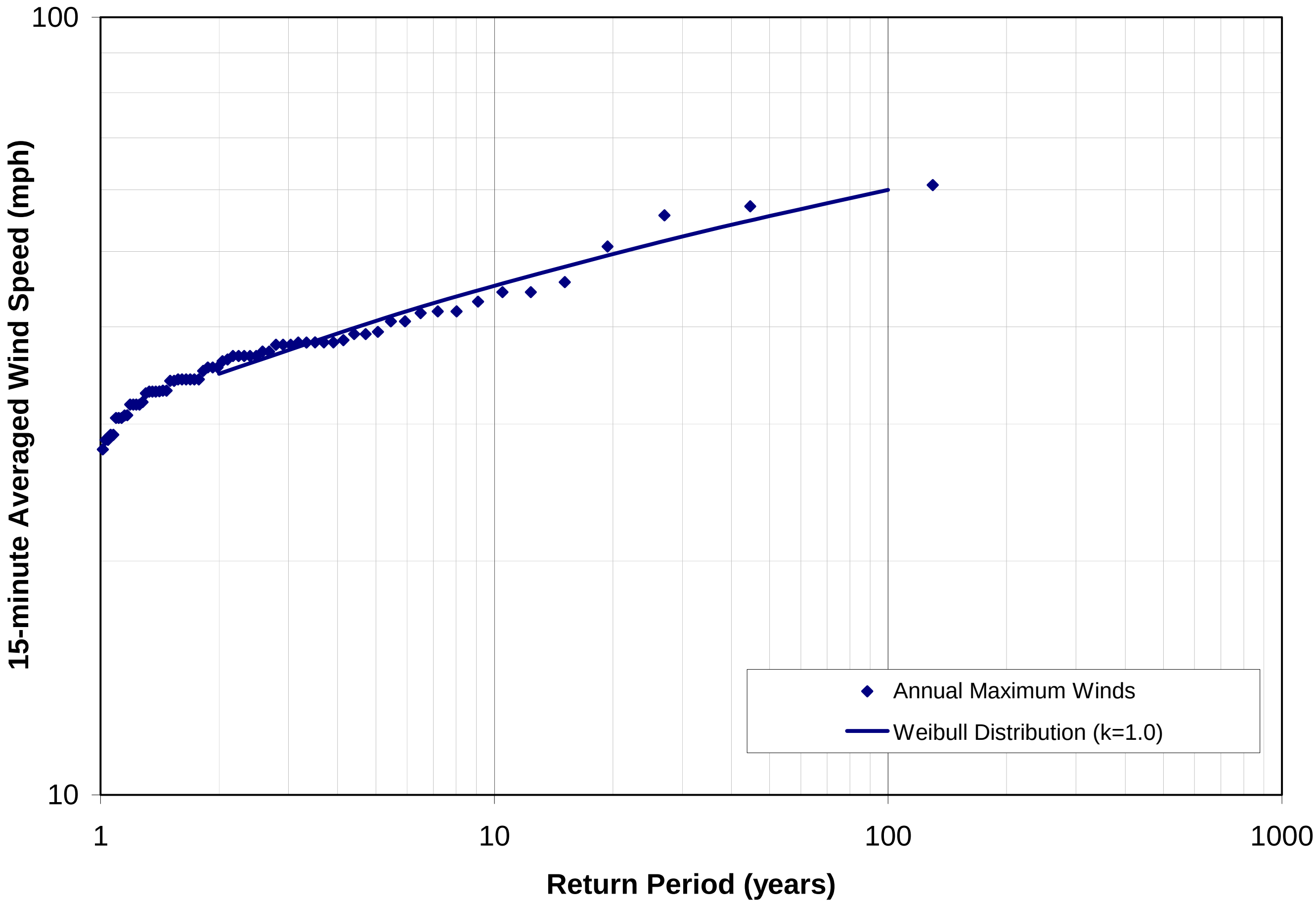

Figure A-3. Computed Return Interval Wind Speeds for Remediation Area E

Table A-1 shows the computed 15-minute averaged return interval wind speeds used for the sediment cap design.

Table A-1
Return Interval Wind Speeds for Remediation Area E

Return Period (years)	15-minuted Average Wind Speed (mph)
2	34.8
5	40.7
10	45.2
25	51.1
50	55.5
100	60.0

Therefore, the 100-year return interval wind speed was **60.0 mph**.

The analysis for Remediation Areas A, B, C and D followed a similar approach (i.e., use of the ACES *Extremal Analysis Module*). However, a review of the corresponding ACES results indicated that the Fisher - Tippet Type I Distribution was found to be the best fit for the wind records from A and C, while the Weibull Distribution (k=1.4) was found to be the best fit for B and D. Figures A-4 through A-7 shows the plots of computed return interval wind speeds based on for A, B, C, and D, respectively.

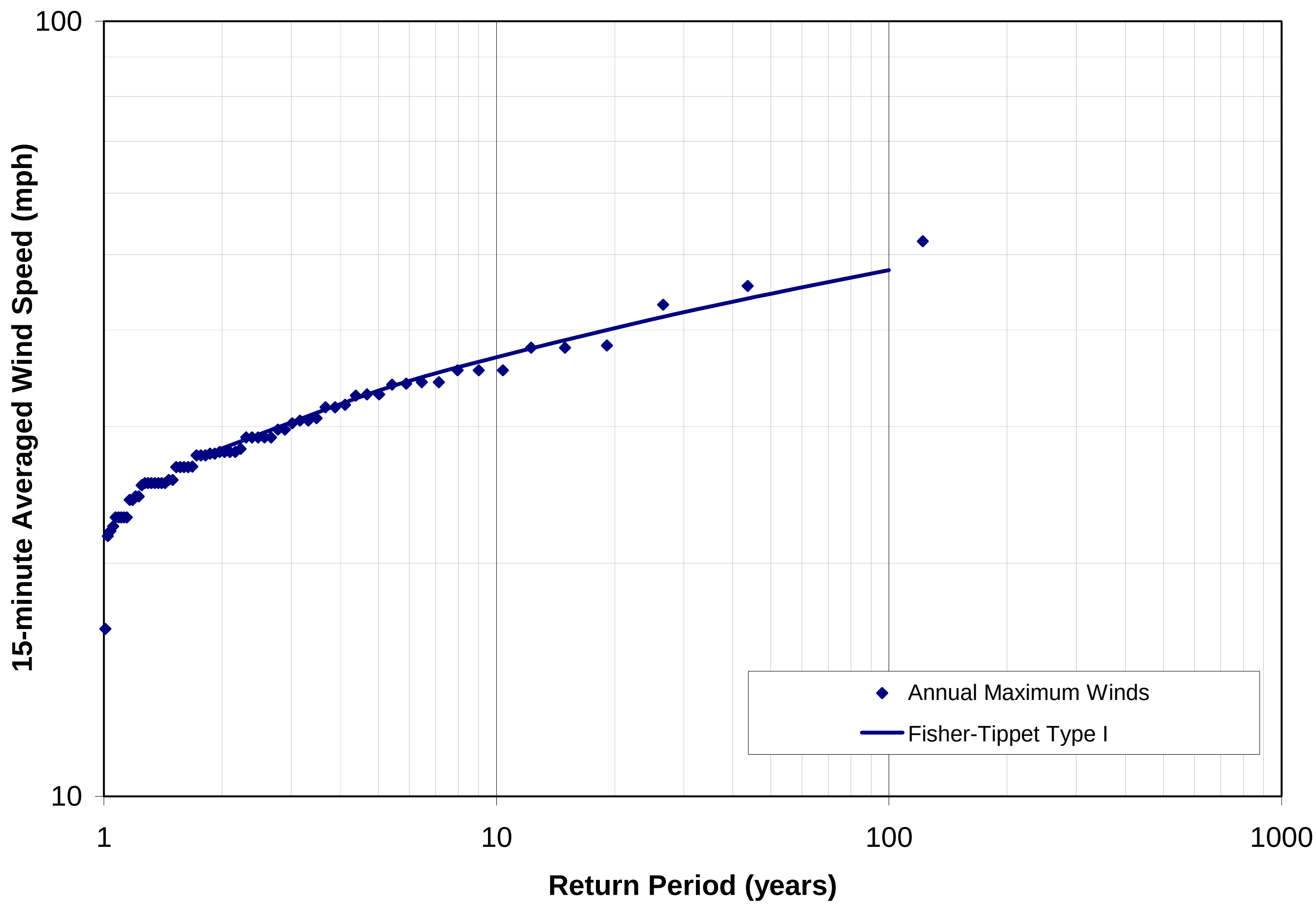

Figure A-4. Computed Return Interval Wind Speeds for Remediation Area A

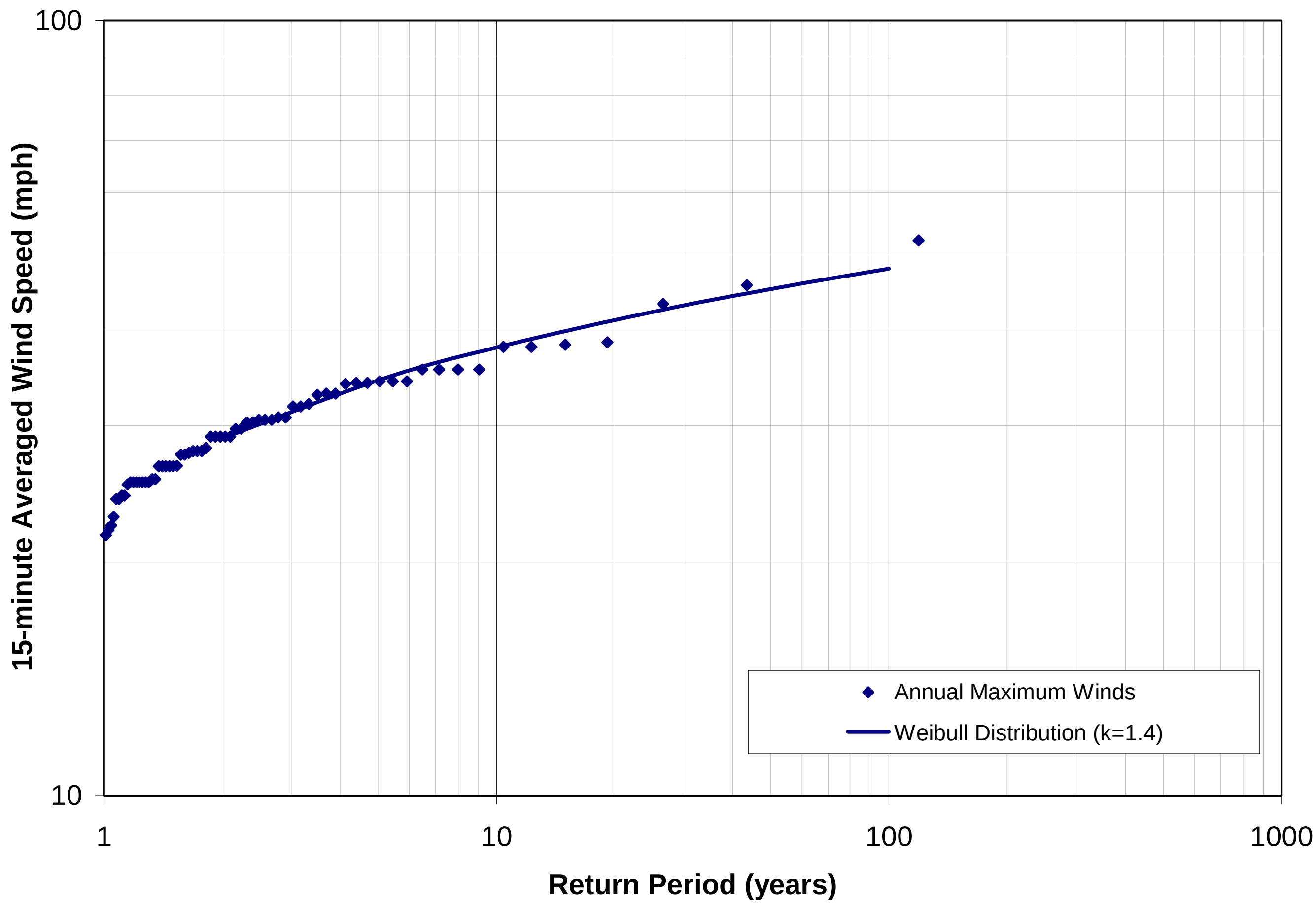

Figure A-5. Computed Return Interval Wind Speeds for Remediation Area B

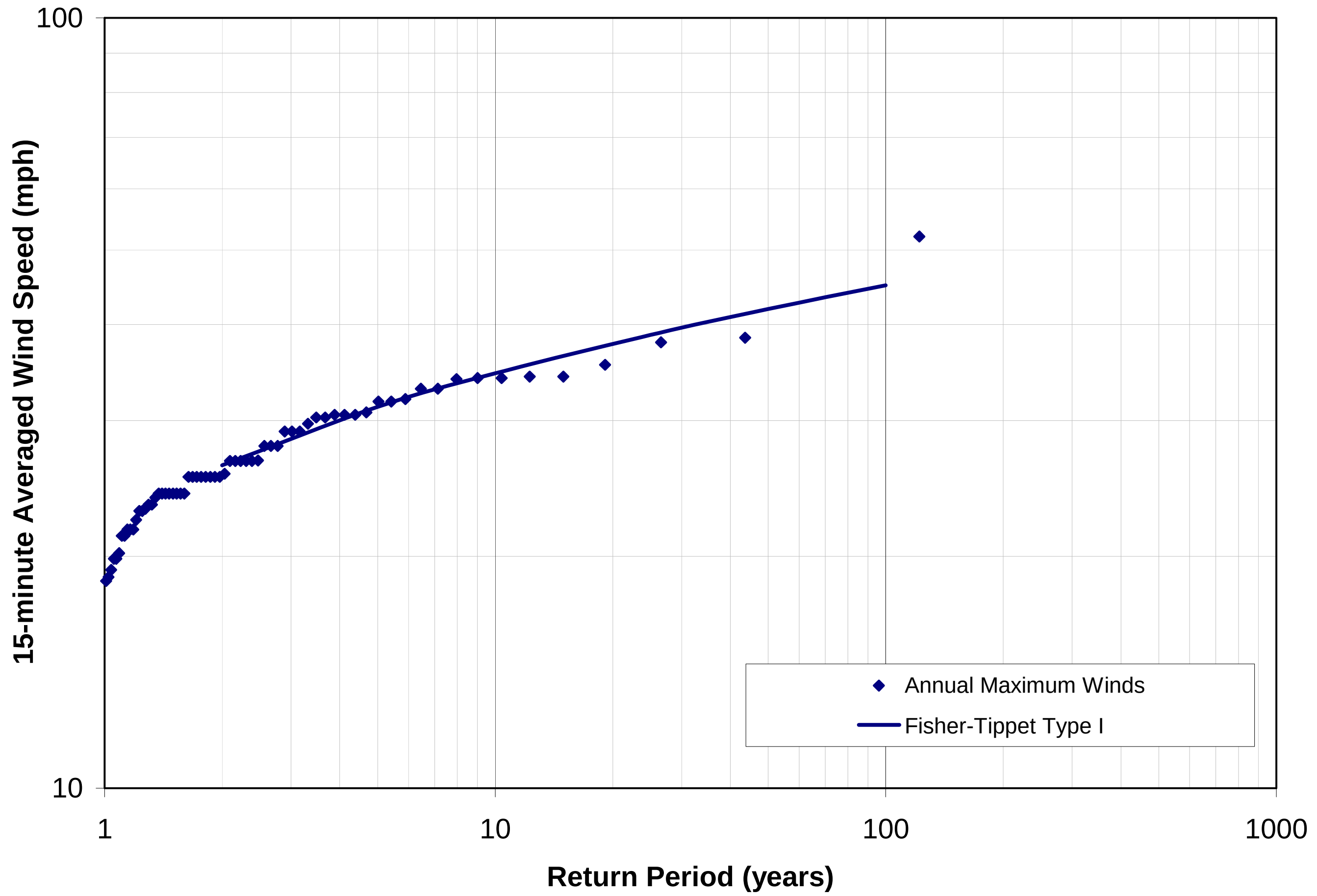

Figure A-6. Computed Return Interval Wind Speeds for Remediation Area C

DESIGNER:	KDP/MRH	**DATE:**	6-01-09	**CALC. NO.:** 1	**REV.NO.:** 1
PROJECT:	Onondaga Lake			**CHECKED BY:** RKM	**CHECKED DATE:** 6-08-09
SUBJECT:	Wind-Wave Analysis for Sediment Cap Armor Layer Designs - Example Calculation				

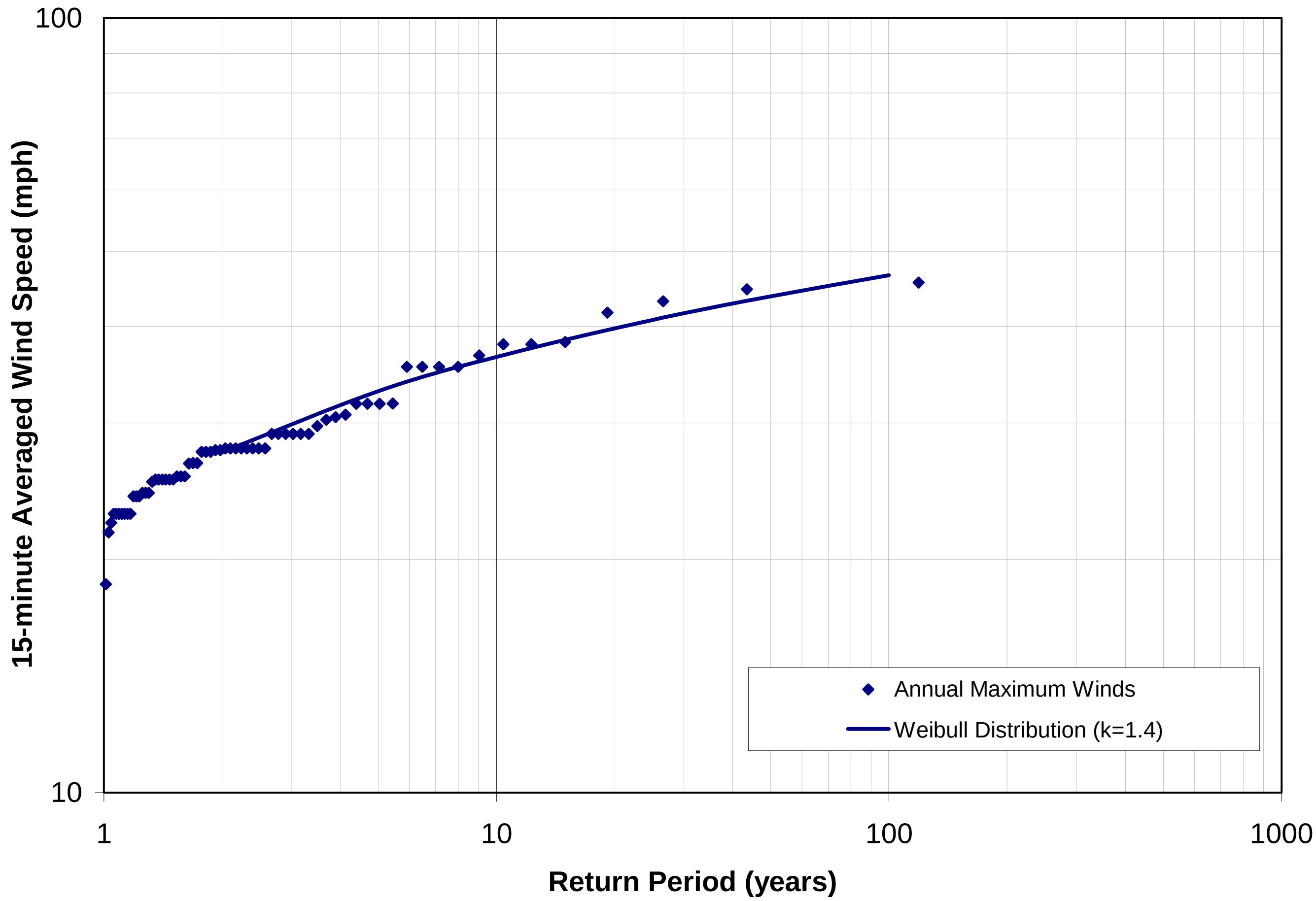

Figure A-7. Computed Return Interval Wind Speeds for Remediation Area D

2. Estimate the 100-year return interval significant wave height and period

For Remediation Area E, the longest fetch distance is 4.66 miles. The 100-year return interval wind speed was applied along this fetch using the *Wave Prediction Module* in ACES with the following parameters:

- 15-minute 100-year Return Interval Wind Speed = 60.0 mph (computed above)
- Wind Fetch Length = 4.66 miles (longest fetch distance)
- Fetch Depth = 65 feet (which is the maximum depth along the 4.66 mile fetch transect, and thus conservative)

Using the shallow openwater wind fetch method in the *Wave Prediction Module*, the significant wave height (H_s) and period (T_P) were:

H_s = 5.2 feet
T_P = 3.9 seconds

Sensitivity analyses:
A sensitivity analysis was performed on the Air-Water Temperature Difference. The Air-Water Temperature Difference in the calculation above was 0 degrees Celsius (^{0}C) (0 degrees Fahrenheit [^{0}F]). The Air-Water Temperature Difference was varied between -4 ^{0}C and 4 ^{0}C (-39.2 to 39.2 ^{0}F). The computed wave heights and periods varied from 5.4 feet and 4.0 seconds to 5.1 feet and 3.9 seconds. Therefore, it is evident that the wave heights for Onondaga Lake are not extremely sensitive to the Air-Water Temperature Difference. Thus, a design wave height of 5.2 feet and period of 3.9 seconds was selected for this analysis.

3. Compute the Stable Sediment Sizes at Various Depths Outside of the Surf Zone

The *Linear Wave Theory/Snell's Law Wave Transformation Module* in ACES was used to estimate wave shoaling, bottom orbital velocities at different depths, and the breaking wave height and depth using the cotangent of the nearshore slope = 45.5 and a crest angle of 0 degrees. Maximum bottom orbital velocities were computed using the *Linear Wave Theory Module* in ACES and the results are presented in Table A-2.

Table A-2
Design Wave Heights and Bottom Orbital Velocities at Various Depths for Remediation Area E

Water Depth (feet)	Wave Height (feet)	Maximum Orbital Velocity (feet per second)	Notes
40	5.2	0.33	Computed in Step 2
30	5.1	0.71	
20	4.9	1.5	
15	4.8	2.1	
10	4.8	3.1	
8	4.8	3.8	
6.7	5.3	Wave Breaking	Wave Breaking Depth

The stable sediment size under a progressive wave was estimated using the following three methods, for comparative purposes:

- Equation 5 from Appendix A – Armor Layer Design from the Guidance for In-Situ Subaqueous Capping of Contaminated Sediments (Maynord 1998).
- Shields Diagram (Vanoni 1975) (see Figure A-8)
- You (2000)

Using Equation 5 from Maynord (1998) for waves at a water depth of 10 feet, the D_{50} is approximately 0.75 inches (1.9 mm):

$$D_{50} = \frac{\left(\frac{V}{C_3}\right)^2}{g\left(\frac{\gamma_s - \gamma_w}{\gamma_w}\right)} = \frac{\left(\frac{3.1\,\text{ft/s}}{1.7}\right)^2}{32.2\,\text{ft/s}^2\left(\frac{165 - 62.4\,\text{lbs/ft}^3}{62.4\,\text{lbs/ft}^3}\right)} = 0.063\,\text{ft} = 19\,\text{mm}$$

Where,

V = maximum horizontal bottom velocity from the wave
C_3 = 1.7 for orbital velocities beneath waves (page A- 13 from Maynord 1998)
γ_s = unit weight of stone = 165 lbs/ft^3 (page A-6 of Maynord 1998)
γ_w = unit weight of water = 62.4 lbs/ft^3
g = 32.2 ft/s^2

Using the Shields Diagram, the D_{50} is approximately 0.5 inches (13 mm).

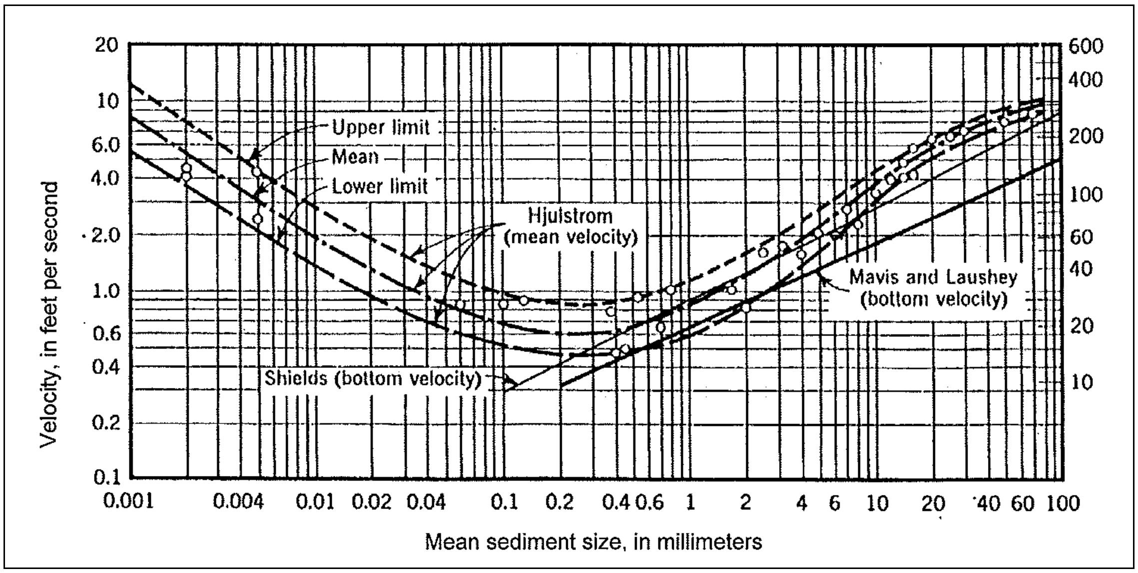

Figure A-8. Shields Diagram for Initiation of Cap Material Movement (from Vanoni 1975)

Using Equations 20 and 6 from You (2000), the D_{50} is approximately 0.4 inches (11 mm):

$$U_{max} = 3.97\sqrt{(s-1)gd}\,s_*^{-0.08}$$

Where,

U_{max} = nearbed wave orbital velocity from the wave for sediment onset velocity
s = particle specific gravity = 2.65 for sands
g = 9.81 m/s^2
d = particle diameter

and

$$s_* = \frac{d\sqrt{(s-1)gd}}{4\nu}$$

ν = kinematic viscosity of water = 1.139 x10^{-6} m^2/s at 15^{0}C (59 ^{0}F)

For a given nearbed wave orbital velocity, compute the stable particle size d using simple iteration (Solver in Microsoft Excel was used in this application). For U_{max} = 3.1 fps, d is approximately = 11 mm (10.5 mm):

$$s_* = \frac{d\sqrt{(s-1)gd}}{4\nu} = \frac{0.0105m\sqrt{(2.65-1)(9.81m/s^2)(0.0105m)}}{4(1.139x10^{-6}\,m^2/s)} = 950$$

$$U_{max} = 3.97\sqrt{(2.65-1)(9.81m/s^2)(0.0105m)}(950)^{-0.08} = 0.95m/s = 3.1\,fps$$

The results for selected water depths are summarized in Table A-3 below.

Table A-3
Armor Layer Size Calculations at Various Depths in Remediation Area E

Water Depth (ft)	Wave Height (ft)	Maximum Orbital Velocity (ft/s)	D_{50} (Maynord) (mm)	D_{50} (Shield's) (mm)	D_{50} (You) (mm)	Design D_{50} (mm)	Design D_{50} (inches)	Sediment Type
40	5.2	0.33	0.22	0.15	0.1	0.2	0.008	FINE SAND
30	5.1	0.71	1	0.6	0.2	1	0.04	MEDIUM SAND
20	4.9	1.5	4	3	2	4	0.2	FINE GRAVEL
15	4.8	2.1	9	5	4	9	0.4	FINE GRAVEL
10	4.8	3.1	19	13	11	19	0.75	COARSE GRAVEL
8	4.8	3.8	29	19	18	29	1.1	COARSE GRAVEL
6.7	5.3	*Wave Breaking **						

** see Section 4 below for Armor design for the Surf Zone (i.e., breaking wave condition)*

The results for selected water depths for A, B, and C and D are summarized in Tables A-4 to A-6 below.

Table A-4
Armor Layer Size Calculations at Various Depths in Remediation Area A

Water Depth (ft)	Wave Height (ft)	Maximum Orbital Velocity (ft/s)	D_{50} (Maynord) (mm)	D_{50} (Shield's) (mm)	D_{50} (You) (mm)	Design D_{50} (mm)	Design D_{50} (inches)	Sediment Type
30	2.6	0.038	0.003	0.1	0.1	0.1	0.004	FINE SAND
20	2.6	0.21	0.09	0.1	0.1	0.1	0.004	FINE SAND
15	2.5	0.45	0.4	0.3	0.1	0.4	0.02	FINE SAND
10	2.4	1.0	2	1	0.6	2	0.08	MEDIUM SAND
8	2.4	1.3	3	3	1	3	0.1	COARSE SAND
6	2.4	1.8	7	5	3	7	0.3	FINE GRAVEL
4	2.4	2.6	13	8	7	13	0.51	FINE GRAVEL
3.4	2.6	*Wave Breaking*						

Table A-5
Armor Layer Size Calculations at Various Depths in Remediation Area B

Water Depth (ft)	Wave Height (ft)	Maximum Orbital Velocity (ft/s)	D_{50} (Maynord) (mm)	D_{50} (Shield's) (mm)	D_{50} (You) (mm)	Design D_{50} (mm)	Design D_{50} (inches)	Sediment Type
30	2.8	0.076	0.01	0.1	0.1	0.1	0.004	FINE SAND
20	2.8	0.32	0.21	0.13	0.1	0.2	0.008	FINE SAND
15	2.7	0.63	0.79	0.55	0.2	0.8	0.03	MEDIUM SAND
10	2.6	1.2	3	2	1	3	0.1	COARSE SAND
8	2.6	1.6	5	3.5	2	5	0.2	FINE GRAVEL
6	2.6	2.1	9	5	4	9	0.4	FINE GRAVEL
4	2.6	3.0	17	12	10	17	0.67	FINE GRAVEL
3.6	2.9	*Wave Breaking*						

Table A-6
Armor Layer Size Calculations at Various Depths in Remediation Areas C and D

Water Depth (ft)	Wave Height (ft)	Maximum Orbital Velocity (ft/s)	D_{50} (Maynord) (mm)	D_{50} (Shield's) (mm)	D_{50} (You) (mm)	Design D_{50} (mm)	Design D_{50} (inches)	Sediment Type
40	3.2	0.052	0.01	0.1	0.1	0.1	0.004	FINE SAND
30	3.2	0.17	0.06	0.1	0.1	0.1	0.004	FINE SAND
20	3.1	0.54	0.57	0.35	0.1	0.6	0.02	FINE SAND
15	3.0	0.95	2	1	0.4	2	0.08	MEDIUM SAND
10	2.9	1.6	5	4	2	5	0.2	FINE GRAVEL
8	2.9	2.0	8	5	3	8	0.3	FINE GRAVEL
6	3.0	2.6	13	8	7	13	0.52	FINE GRAVEL
4.2	3.3	*Wave Breaking*						

4. Compute the Armor Stone Size within the Surf Zone

The *Rubble Mound Revetment Design Module* in ACES was used to compute the required armor layer size (gradation and thickness) in the surf zone to resist the forces generated by turbulence from breaking waves. The following parameters were used in the computation:

- Significant wave height = 5.2 feet (computed above)
- Significant wave period = 3.9 seconds (computed above)
- Breaking criteria = 0.78 (Dean and Dalrymple 1991)
- Water depth at toe of the structure = 10 feet (used a water depth slightly deeper than the beginning of the surf zone depth of 6.7 feet in E)
- Cotangent of nearshore slope = 45.5 (the slope of the bed offshore of the surf zone in Remediation Area E)
- Unit weight of rock = 165 lbs/ft^3 (page A-6 of Maynord 1998)
- Permeability coefficient = 0.4 (Figure 4-4-2b of USACE 1992)
- Cotangent of structure (revetment) slope = 50 (restored slope in surf zone for Remediation Area E)
- Minor Displacement Level (S) = 3 (from Table VI-5-21 of USACE 2006 and Table 4-4-1 of USACE 1992)

Table A-7 presents the armor layer gradation results for the minor displacement level for a 50H:1V slope computed by ACES.

Table A-7
Cap Armor Gradation for Minor Displacement for Remediation Area E

Gradation and Thickness	Stone Size (inches) for Minor Displacement (S=3)
D_0	1.4
D_{15}	2.2
D_{50}	3.0
D_{85}	3.7
D_{100}	4.7
Thickness of Armor Layer	6

Sensitivity analyses:
A sensitivity analysis was performed on the permeability coefficient. Variations in water depth at the toe of the structure and breaking criteria do not affect the armor stone size or gradation just the wave runup distance. In Onondaga Lake, the sediment cap is always submerged and does not extend above the lake surface; thus the wave run-up estimate in the revetment design methodology is not used. The permeability coefficient was varied between 0.6 (a homogeneous structure, consisting only of armor stones as shown in Figure 4-4-2d of USACE 1992) and 0.5 (two-diameter-thick armor layer on a permeable core with a ratio of armor/core stone diameter was 3.2 as shown on Figure 4-4-2c). The median stone size varied between 2.8 inches for P=0.6 and 2.9 inches for P=0.5. Therefore, the approach presented above and summarized in Table A-7 (i.e., a P=0.4) was used in this design.

Table A-8 presents the armor layer gradation results for the minor displacement level for a 50H:1V slope computed by ACES for the other Remediation Areass.

Table A-8
Cap Armor Gradation for Minor Displacement for Remediation Areas

Gradation and Thickness	Particle Size (inches)			
	A	B	C and D	E
D_0	0.7	0.8	1.0	1.5
D_{15}	1.1	1.2	1.4	2.2
D_{50}	1.5	1.7	1.9	3.0
D_{85}	1.8	2.1	2.4	3.8
D_{100}	2.3	2.6	3.0	4.8
Minimum Thickness of Armor Layer	3	3.5	4	6

RECORD OF REVISIONS

NO.	REASON FOR REVISION	BY	CHECKED	APPROVED/ ACCEPTED	DATE
1	Revise the calculation to include wind data from 2007 to 2009 and to address NYSDEC's comments	MRH	RKM		

ATTACHMENT B
COMPARISON OF WIND DATA

Comparative Monthly Average Wind Speeds (in mph) for Syracuse Airport, Wastebed 13 Site, and Lakeshore Site - December 2006 through February 2009

Month	Syracuse Hancock Int'l Airport	WB13	Lake Shore
January	11.1	8.3	8.2
February	11.7	9.3	8.5
March	11.4	8.3	7.5
April	10.9	8.0	7.4
May	8.6	6.1	6.0
June	8.5	5.5	5.8
July	7.6	5.2	5.4
August	8.0	5.1	5.4
September	7.8	5.2	5.3
October	8.8	6.5	6.0
November	9.5	6.5	6.9
December	11.4	8.5	8.4

Comparative Monthly Maximum Wind Speeds (in mph) for Syracuse Airport, Wastebed 13 Site, and Lakeshore Site - December 2006 through February 2009

Month	Syracuse Hancock Int'l Airport	WB13	Lake Shore
January	46	30	26
February	33	35	24
March	34	30	22
April	37	26	25
May	28	19	19
June	33	19	19
July	29	17	14
August	33	16	14
September	34	29	29
October	28	27	18
November	33	26	24
December	66.7*	25	23

Note:

* The maximum value of 66.7 mph for December measured at Syracuse Airport may have been an anomalous or erroneous measurement. This maximum value occurred on December 19, 2008. The maximum wind was 66.7 mph blowing from the southwest (200 degrees). At the same day and hour, the maximum winds at WB13 and the Lakeshore were both 9.0 mph and from the east. At the airport, the wind speed one hour before and one hour after this measurement were 17 and 16 mph respectively, and from the east (100 degrees). Therefore, this value appears inconsistent with other measurements. The maximum windspeed for December excluding this value is 40.3 mph.

ATTACHMENT C
TRIBUTARY EXAMPLE CALCULATION

Objective: To determine the particle size necessary to prevent erosion of sediment cap due to the 100-year flood flows from tributaries to Onondaga Lake. This document presents an example calculation for Onondaga Creek as well as the results of the analysis for Ninemile Creek.

References:

Effler, S. 1996 Limnological and Engineering Analysis of a Polluted Urban Lake: Prelude to Environmental Management of Onondaga Lake, New York. Springer-Verlag, New York.

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United States Geological Survey (USGS). 2006. Magnitude and Frequency of Floods in New York. Scientific Investigations Report 2006-5112.

Vanoni, V.A. 1975. *Sedimentation Engineering*. ASCE Manuals and Reports on Engineering Practice – No. 54, 730 pp.

Computation of 100-year flood flows for tributaries and resultant particle size(s): The following presents a detailed summary and example calculation for the Onondaga Lake tributary analysis. The numbered list below outlines the general approach used for the calculation and defines specific parameters used in the calculations. Subsequent sections below illustrate a step-by-step calculation for the example case of Onondaga Creek.

1. Estimate the 100-year return interval flood flow

Estimation of peak discharge for the 100-year return interval flood flow was based on three different methods/sources. These values were reviewed and compared and the most conservative value was recommended for utilization in the design. The methods/sources included:

- Fitting a Log-Pearson Type III (LP3) probability distribution to the data and estimating the return flow based on the expected value of the distribution at the 99% exceedance level.
- Using the United States Geological Survey (USGS) flood frequency analysis PeakFQ program (also based on the LP3 method).
- Obtaining 100-year flood flow estimates from a USGS report of flood flows for streams in New York State (USGS 2006).

2. Predict velocity flow fields using USACE's RMA2

The velocity fields generated by the 100-year flows from Onondaga Creek were modeled using the USACE hydrodynamic model, RMA-2. The RMA2 model is a 2-dimensional, depth-averaged (i.e., the model computes lateral, not vertical variations in flows), finite element, hydrodynamic numerical model routinely used by the USACE for hydrodynamic studies. The RMA2 model was used in conjunction with the Surface Water Modeling System (SMS) for RMA2, which is a pre- and post-processor that includes a graphical interface for display of inputs and results. A detailed description of the model input parameters is provided in Section 6 of Appendix D.

Current velocities along the centerline of the tributary discharge were extracted from the model and used for determination of stable particle size. Table C-1 presents the computed velocities along the centerline of the Onondaga Creek.

Table C-1
Predicted Velocities along the Discharge Centerline from Onondaga Creek

Distance Offshore (feet)	Computed Velocity (fps)
0	2.7
206	2.1
382	1.9
744	1.5
1100	1.3
1785	0.9
1990	0.8
2590	0.7

Notes:
a. Sediment cap extends approximately 1,840 feet offshore from Onondaga Creek (indicated with shading).
b. fps = feet per second

The analysis for Ninemile Creek followed a similar approach (i.e., use of the RMA2 model). Table C-2 presents the computed velocities along the centerline of the Ninemile Creek

Table C-2
Predicted Velocities along the Discharge Centerline from Ninemile Creek

Distance Offshore (feet)	Computed Velocity (fps)
0	4.1
79	3.5
251	2.5
363	2.4
551	1.7
749	1.4
1038	1.0
1466	0.7
1529	0.7
1922	0.6

Notes:
a. Sediment cap extends approximately 250 to 1450 feet offshore from Ninemile Creek (indicated with shading).
b. fps = feet per second

3. Compute the Stable Sediment Sizes at Various Depths along the Centerline Discharge of the Tributary

The stable sediment size for maximum current velocities or a flood flow was estimated using the following two methods, for comparative purposes:

- Equation 2 from Appendix A – Armor Layer Design from the Guidance for In-Situ Subaqueous Capping of Contaminated Sediments (Maynord 1998).
- Shields Diagram (Vanoni 1975) (see Figure C-1).

Using Equation 2 from Maynord (1998) for a current velocity of 0.9 fps at a water depth of 32 feet located approximately 1,800 feet offshore, the D_{50} is approximately 0.02 inches (0.51 mm):

$$D_{50} = S_f C_s C_v C_T C_G d \left[\left(\frac{\gamma_w}{\gamma_s - \gamma_w} \right)^{1/2} \frac{V}{\sqrt{K_1 g d}} \right]$$

$$D_{50} = 1.1 * 0.375 * 1.25 * 1 * 1.52 * 32\,ft \left[\left(\frac{62.4 \frac{ft}{s^3}}{165 \frac{ft}{s^3} - 62.4 \frac{ft}{s^3}} \right)^{1/2} \frac{0.9 \frac{ft}{s}}{\sqrt{0.99 * 32.2 \frac{ft}{s^2} * 32\,ft}} \right]^{2.5}$$

$$D_{50} = 0.002\ ft = 0.02\ inches$$

Where,

S_f = safety factor = 1.1 (page A-6 from Maynord 1998)
C_s = stability coefficient for incipient failure = 0.375 for rounded rock (page A-6 from Maynord 1998)
C_V = velocity distribution coefficient = 1.25 (page A-6 from Maynord 1998)
C_T = blanket thickness coefficient (typically 1 for flood flows)
C_G = gradation coefficient = $(D_{85}/D_{15})^{1/3}$
D_{85}/D_{15} = gradation uniformity coefficient (typical range = 1.8 to 3.5) = 3.5 (page A-6 from Maynord 1998)
d = depth = 32 feet
γ_s = unit weight of stone = 165 lbs/ft^3 (page A-6 of Maynord 1998)
γ_w = unit weight of water = 62.4 lbs/ft^3
V = maximum depth-averaged velocity = 0.9 fps
K_1 = side slope correction factor = $\sqrt{1 - \frac{\sin^2 \theta}{\sin^2 \phi}}$ (page 3-7 from USACE 1994)

Where,
Θ = angle of side slope with horizontal = 50 horizontal:1 vertical for restored slopes
ϕ = angle of repose of riprap material (normally 40 deg) (page 3-7 from USACE 1994)

g = 32.2 ft/s^2

Using the Shields Diagram, the D_{50} is approximately 0.04 inches (1 mm).

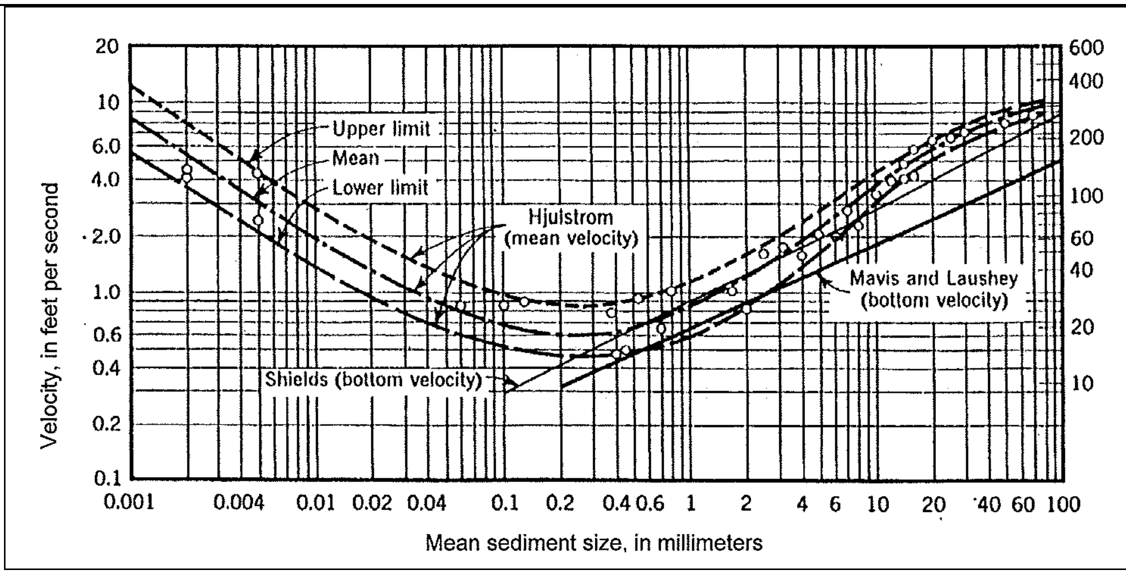

Figure C-1. Shields Diagram for Initiation of Cap Material Movement (from Vanoni 1975)

The results for the discharge along the centerline are presented in Table C-3 below.

Table C-3
Stable Particle Sizes along the Discharge Centerline from Onondaga Creek

Distance Offshore (feet)	Computed Velocity (fps)	Median Particle Diameter (inches)		Design Median Particle Size (inches)	Design Median Particle Size (mm)	Sediment Type
		Maynord (1998)	Vanoni (1975)			
0	2.7	0.36	0.33	0.36	9.2	fine gravel
206	2.1	0.19	0.24	0.24	6.0	fine gravel
382	1.9	0.14	0.18	0.18	4.5	coarse sand
744	1.5	0.09	0.11	0.11	2.8	coarse sand
1100	1.3	0.06	0.08	0.08	2.0	medium sand
1785	0.9	0.02	0.04	0.04	1.0	medium sand
1990	0.8	0.02	0.03	0.03	0.8	medium sand
2590	0.7	0.01	0.02	0.02	0.6	medium sand

Notes:
a. Sediment cap extends approximately 1,840 feet offshore from Onondaga Creek (indicated with shading).
b. Sediment type was classified using the Unified Soil Classification System.

The results for the discharge along the centerline of Ninemile Creek are presented in Table C-4 below.

Table C-4
Stable Particle Sizes along the Discharge Centerline from Ninemile Creek

Distance Offshore (feet)	Computed Velocity (fps)	Median Particle Diameter (inches)		Design Median Particle Size (inches)	Design Median Particle Size (mm)	Sediment Type
		Maynord (1998)	Vanoni (1975)			
0	4.1	1.13	0.83	1.13	28.6	coarse gravel
79	3.5	0.77	0.63	0.77	19.5	coarse gravel
251	2.5	0.35	0.31	0.35	8.8	fine gravel
363	2.4	0.36	0.30	0.36	9.2	fine gravel
551	1.7	0.16	0.14	0.16	4.0	coarse sand
749	1.4	0.08	0.08	0.08	2.1	coarse sand
1038	1.0	0.03	0.05	0.05	1.3	medium sand
1466	0.7	0.01	0.02	0.02	0.6	medium sand
1529	0.7	0.01	0.02	0.02	0.6	medium sand
1922	0.6	0.01	0.02	0.02	0.4	fine sand

Notes:
a. Sediment cap extends approximately 250 to 1450 feet offshore from Ninemile Creek (indicated with shading).
b. Sediment type was classified using the Unified Soil Classification System.

Additionally, the stable particle size to resist current velocities in Onondaga Lake under typical weather conditions were assessed using current velocities reported in Effler (1996). The results are presented in Table C-5.

DESIGNER:	KDP	DATE:	11-20-09	CALC. NO.:	1	REV.NO.:	1
PROJECT:	Onondaga Lake			CHECKED BY:	MRH	CHECKED DATE:	07-08-09
SUBJECT:	Tributary Analysis for Sediment Cap Armor Layer Designs - Example Calculation						

Table C-5
Stable Particle Sizes for Typical Onondaga Lake Current Velocities

Measured Velocity (fps)[a]	Median Particle Diameter (inches)		Design Median Particle Size (inches)	Sediment Type
	Maynord (1998)	Vanoni (1975)		
0.17	<0.001	<0.004	0.004	fine sand
0.02	<0.001	<0.004	0.004	fine sand
0.25	0.001	<0.004	0.004	fine sand
0.04	<0.001	<0.004	0.004	fine sand
0.18	<0.001	<0.004	0.004	fine sand
0.03	<0.001	<0.004	0.004	fine sand

Notes:
a. Measured velocities include values reported by Effler (1996) in the littoral zone (<9 meters).
b. Sediment type was classified using the Unified Soil Classification System.

RECORD OF REVISIONS

NO.	REASON FOR REVISION	BY	CHECKED	APPROVED/ ACCEPTED	DATE
1	Updated post-remediation bathymetry	KDP	MRH		11-24-09

ATTACHMENT D
PROPELLER WASH EXAMPLE CALCULATION

CALCULATION COVER SHEET

PROJECT: Onondaga Lake	**CALC NO. 1**	**SHEET** 1 of 11
SUBJECT: Attachment D – Propeller Wash Analysis for Sediment Cap Armor Layer Designs - Example Calculation		

Objective: To determine the propeller wash velocities from commercial and recreational vessels that may operate in Onondaga Lake's Remediation Areas and the resultant particle size(s) necessary for stability of the sediment cap subject to these propeller wash flows.

This document presents an example calculation for a commercial and recreational vessel.

References:

Albertson, M.L. et al. 1948. "Diffusion of Submerged Jets." *Proceedings ASCE Transactions*. Volume 115. Paper no. 2409. pp. 639-664.

Blaauw, H.G., and E.J. van de Kaa. 1978. "Erosion of Bottom and Sloping Banks Caused by the Screw Race of Maneuvering Ships." Paper presented at the 7th International Harbour Congress, Antwerp, Belgium. May 22-26, 1978.

Francisco, M. D. 1995. *Propeller Scour of Contaminated Sediments on the Seattle Waterfront* by Michael D. Francisco 1995, a draft of a thesis for the degree of Master of Marine Affairs, University of Washington.

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Saffman, P.G. 1965 and 1968. "The Lift on a Small Sphere in a Slow Shear Flow." *Journal of Fluid Mechanics*. Volume 22 (1965) and Volume 31 (1968).

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Vanoni, V.A. 1975. *Sedimentation Engineering*. ASCE Manuals and Reports on Engineering Practice – No. 54, 730 pp.

Van Rijn, L.C. 1984. "Sediment Transport, Part I: Bed Load Transport." American Society of Civil Engineers. *Journal of Hydraulic Engineering.* Volume 110, No. 10, pp. 1431-1456.

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Computation of commercial vessel propeller wash and resultant particle size(s): The following presents a detailed example calculation for a commercial vessel operating on Onondaga Lake. The numbered list below outlines the general approach used for the calculation and defines specific parameters used in the calculations. Subsequent sections below illustrate a step-by-step calculation for the example case. The example calculation is provided for the *Mavret H* tugboat operating in 14 ft of water at 25 percent of the installed engine power.

1. Select representative vessel for analysis

The *Mavret H* tugboat was the example vessel used in the calculation to represent tugboats operating on the Lake. Based on previous discussions with the vessel owner, the tugboat has the following characteristics:

- Number of engines: One
- Propeller shaft depth: 3 feet (ft)
- Total installed engine horsepower: 800 horsepower (hp)
- Propeller diameter: 4.67 ft
- Ducted propeller: Yes

2. Determine the maximum bottom velocities in the propeller wash of a maneuvering vessel

Equation 4 from Maynord (1998) is used to first determine the jet velocity exiting a propeller (U_0) in feet per second (fps):

$$U_0 = C_2\left(\frac{P_d}{D_p^{\,2}}\right)^{\frac{1}{3}}$$

where

C_2 = 7.68 for ducted propellers (page A-10 from Maynord 1998)
P_d = applied engine horsepower
D_p = Propeller diameter = 4.67 ft (from above)

Previous discussions with tug operators indicate that their vessels operate in the deeper portion of the Lake and use an average of 25 percent of their horsepower. For this example calculation, P_d = 0.25x800 hp = 200 hp. Therefore,

$$U_0 = C_2\left(\frac{P_d}{D_p^{\,2}}\right)^{\frac{1}{3}} = (7.68)\left(\frac{200}{4.67^2}\right)^{\frac{1}{3}} = 16.1\ \text{fps}$$

The resulting maximum bottom velocities, $V_{b(maximum)}$, in the propeller wash of a maneuvering vessel is computed using Equation 3 from Maynord (1998):

$$V_{b(maximum)} = C_1U_0D_p/H_p$$

where
C_1 = 0.30 for a ducted propeller
Hp = distance from propeller shaft to channel bottom in ft

In this example calculation, the tugboat operating in a depth of 14 ft of water is being evaluated. Therefore, Hp = 14 ft-3 ft = 11 ft. The maximum bottom velocity for this case is:

$$V_{b(maximum)} = C_1U_0D_p/H_p = 0.30(16.1)(4.67)/11 = 2.0\ \text{fps}$$

3. Compute the Stable Sediment Sizes to resist the propeller wash of a maneuvering vessel

Equation 5 from Maynord (1998) is used to compute the Stable Sediment Sizes to resist the propeller wash of a maneuvering vessel:

$$V_{b(maximum)} = C_3\left[g\left(\frac{\gamma_s - \gamma_w}{\gamma_w}\right)D_{50}\right]^{\frac{1}{2}}$$

where

C_3 = 0.7 for small transport (page A-10 from Maynord 1998)
D_{50} = median particle size
γ_s = unit weight of stone = 165 pounds per cubic foot (lbs/ft^3) (page A-6 of Maynord 1998)
γ_w = unit weight of water = 62.4 lbs/ft^3

Solving for D_{50}:

$$D_{50} = \frac{\left(\frac{2.0}{0.7}\right)^2}{32.2\left(\frac{165-62.4}{62.4}\right)} = 0.15\text{ ft} = 1.9\text{ inches}$$

The computed particle size for the *Mavret H* operating in 14 ft of water at 25 percent power is **1.9 inches** (coarse gravel). It should be noted that this method provides a conservative estimate of stable particle size for the low bottom velocities when compared with other methods used to compute a representative particle size to resist erosion associated with current velocities. For example, the stable particle size to resist a 2 fps bottom current velocity using Shields diagram presented in Vanoni (1975) is 0.2 inches (5 millimeters).

Computation of recreational vessel propeller wash and resultant particle size(s): The following presents a detailed example calculation for a recreational vessel operating on Onondaga Lake at high speeds in shallow water. This approach for evaluating the propeller wash from recreational vessels involved adapting the predictive equations developed for the larger vessels (based on Maynord 1998) to address smaller recreational vessels under moving conditions. The refinements were based, in part, on results of a field study where bottom-mounted current meters were used to measure actual bottom velocities of maneuvering and passing recreational vessels in the Fox River (Wisconsin). This refined approach was successfully applied and accepted by USEPA (Region V) for the design of the Lower Fox River remediation to evaluate the effects of propeller wash for the design of the armor layer of a sediment isolation cap (Shaw and Anchor 2007).

The example calculation is provided for the Triumph 191 FS boat operating at 50 percent power at 5 ft above the sediment cap armor layer.

1. Select representative vessel for analysis

The Triumph 191 FS boat was the example vessel used in the calculation to represent ski and fishing boats operating on Onondaga Lake. Based on discussions with and specifications provided by the manufacturers and boat dealers, the

Triumph 191 FS has the following characteristics:

- Number of engines: One
- Propeller shaft depth: 2.5 ft
- Total installed engine horsepower: 150 hp
- Propeller diameter: 1.33 ft (16 inches)
- Ducted propeller: No

2. Compute jet velocity for the moving vessel

The thrust, T, generated by the propeller is computed based on the applied engine horsepower at a given time during the start-up (e.g., period during which vessel accelerates from a stand still). A relationship between engine power and thrust (T in pounds force [lb_f]) for a range of applied power was previously compiled and presented in Shaw and Anchor (2007) and is utilized to compute the thrust for this example as follows:

$$T[lb_f] = 10.3(P_d) + 370$$

Blaauw and van de Kaa (1978) is used to first determine the jet velocity exiting a propeller (U_0) in meters per second (m/s) based on the thrust:

$$U_0 = \frac{1.6}{D_p}\left(\frac{T}{\rho_w}\right)^{1/2}$$

Where ρ_w = density of water (in slugs per cubic foot)

For this example, the maximum applied engine power is assumed to be 50 percent of 150 hp (or 75 hp). The applied engine power is assumed to increase linearly between zero at t=0 and 75 hp at the end of the engine power dwell time. The engine power dwell time ranges between approximately 1 and 3 seconds (Shaw and Anchor 2007). A value of 3 seconds was used in this analysis. Therefore, the power applied at time t = 1 second, would be the final applied power of 75 hp divided by engine power dwell time (i.e., 25 hp). Similarly, 50 hp would be applied at time t=2 seconds.

For the Triumph 191 FS operating at 50 percent power at 0.5 seconds after start-up:

$$T = 10.3\left(0.5 \times 150 \times \frac{0.5}{3}\right) + 370 = 498.8 \text{ lbf } = 2219 \text{ Newtons (N)}$$

$$U_0 = \frac{1.6}{1.33}\left(\frac{498.8}{1.94}\right)^{1/2} = 19.3 \text{ fps (in English Units) or}$$

$$U_0 = \frac{1.6}{0.406}\left(\frac{2219}{1000}\right)^{1/2} = 5.87 \text{ meters per second (in SI Units)}$$

This jet velocity behind the stationary propeller is converted to a velocity for the moving vessel relative to a fixed point using the boat speed, as described below.

The increase in boat speed during start-up conditions is assumed to be linear from zero at time zero (t=0) to maximum speed at the end of the boat speed dwell time. For the Onondaga Lake propeller wash evaluation, it was assumed that maximum boat speed will be dependent on propulsion parameters (e.g. applied engine power). The maximum boat speed, $V_{w(max)}$, for use in calculating the speed at each time step for a given set of operating conditions is estimated using a regression equation developed from values for boat speed (in miles per hour) and applied engine power (in hp) from field measurements reported by engine manufacturers (Shaw and Anchor 2007):

$$V_{w(\max)} = 2.0229(P_d)^{0.4568}$$

The boat speed dwell time is assumed to be 1.5 x engine power dwell time (Shaw and Anchor 2007). Therefore , $t_{(max)}$ is defined as follows

$t_{(max)}$ = 1.5 x engine power dwell time

Based on the assumed linear increase in boat speed between t=0 and $t_{(max)}$, the boat speed at time t, $V_{w(t)}$, is computed as follows:

$$V_{w(t)} = V_{w(\max)}\left(\frac{t}{t_{(\max)}}\right)$$

For the example calculation at time t=0.5 seconds:

$$V_{w(\max)} = 2.0229(0.5\times150)^{0.4568} = 14.5 \text{ mph}$$

$t_{(max)}$ = 1.5 x 3 = 4.5 seconds

$$V_{w(t)} = 14.5\left(\frac{0.5}{4.5}\right) = 1.61 \text{ mph} = 2.36 \text{ fps}$$

The method used to compute the relative near bottom velocity from a moving vessel is to first compute the jet velocity exiting a propeller (U_0) and the subtract the vessel speed from U_0. The adjusted X is then used to compute the near bottom velocity. For this example, the jet velocity exiting a propeller (U_0) for the moving vessel relative to a fixed point is

U_0 = 19.3 fps – 2.36 fps = 16.9 fps

The instantaneous fluid velocity (V_x) at a given point in the velocity jet relative to the propeller is computed using the Equation 6 from Maynord (1998) but modified to include the effects of propeller pitch (i.e. jet angle with respect to horizontal):

$$V_x = 2.78\times U_0 \times \frac{D_0}{x}\exp\left(-15.43\left(\frac{z}{x}\right)^2\right) + V_\theta$$

where

V_x = Instantaneous fluid velocity at coordinate x and z in fps

X = Horizontal distance aft of propeller in ft

Z = Radial distance from axis of propeller in ft (see attached sketch)

$D_0 = 0.71\,D_p$ for non-ducted propeller

V_θ = Velocity adjustment at point of calculation to account for jet angle with respect to horizontal. Note: this velocity adjustment is included in the computation of the radial distance from the jet centerline to the point of interest, z_r (see Figure D-1)

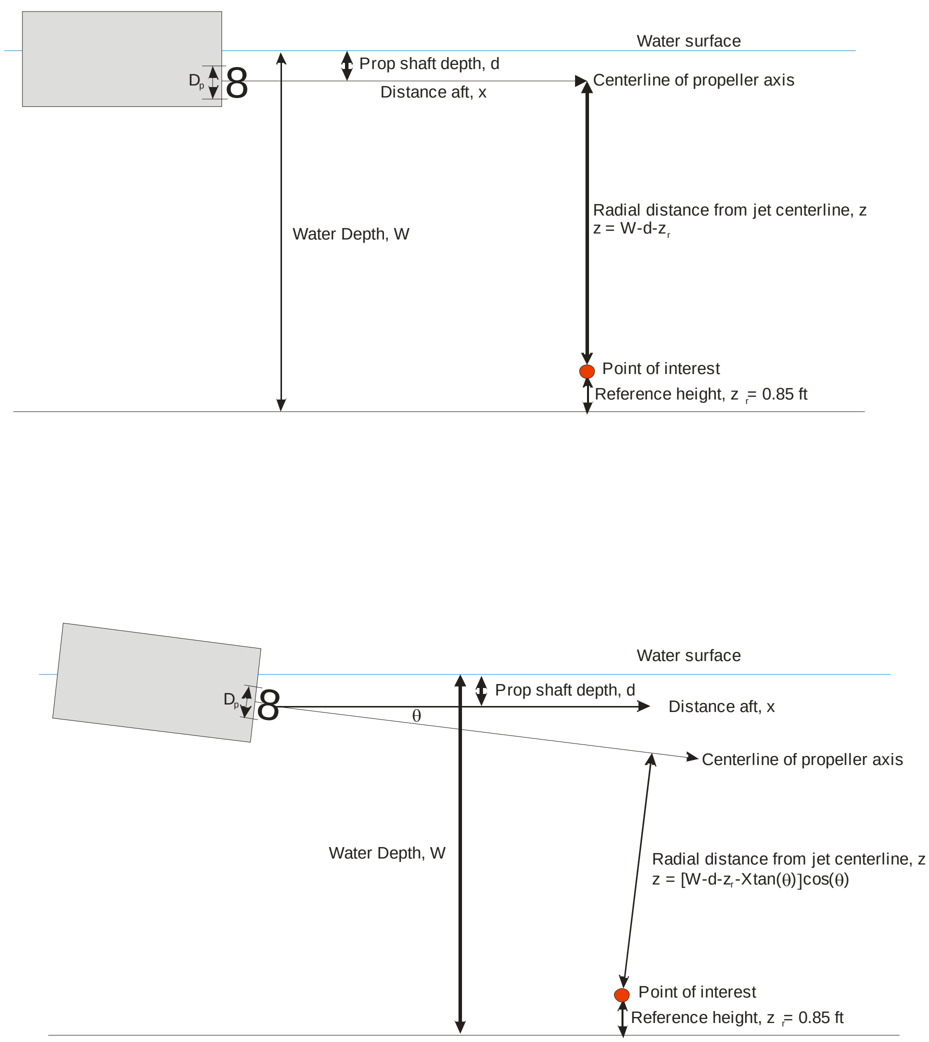

Figure D-1. Illustration of factors accounted for in V_θ

The flow pattern behind a stationary propeller is typically divided into a zone of flow establishment and a zone of established flow (Albertson et al. 1948). The zone of flow establishment typically occupies the distance 4 propeller diameters downflow from the propeller (Francisco 1995). Within the zone of flow establishment, momentum has not diffused away from the jet to the extent of affecting the core velocity, and bottom velocities are less than at the same elevation at the start of the zone of established flow. Therefore, for this evaluation, the horizontal distance, x, is selected as multiples of the propeller diameter beginning at a distance of 4Dp. The peak bottom velocities can occur at a distance greater than $4D_P$. Based on discussions with boat representatives and manufacturers, a propeller pitch angle of 7.5 degrees was used for this analysis for recreational boats.

For example, for $x = 5D_P = 5(1.33) = 6.65$ ft

$$z = [5 - 2.5 - 0.85 - 6.65 \times \tan(7.5)]\cos(7.5) = 0.77 \text{ ft}$$

$$V_x = 2.78 \times 16.9 \times \frac{0.71 \times 1.33}{6.65} \exp\left(-15.43\left(\frac{0.77}{6.65}\right)^2\right) = 5.42 \text{ fps}$$

Figure D-2 presents the instantaneous fluid velocity (Vx) relative to the propeller for this example.

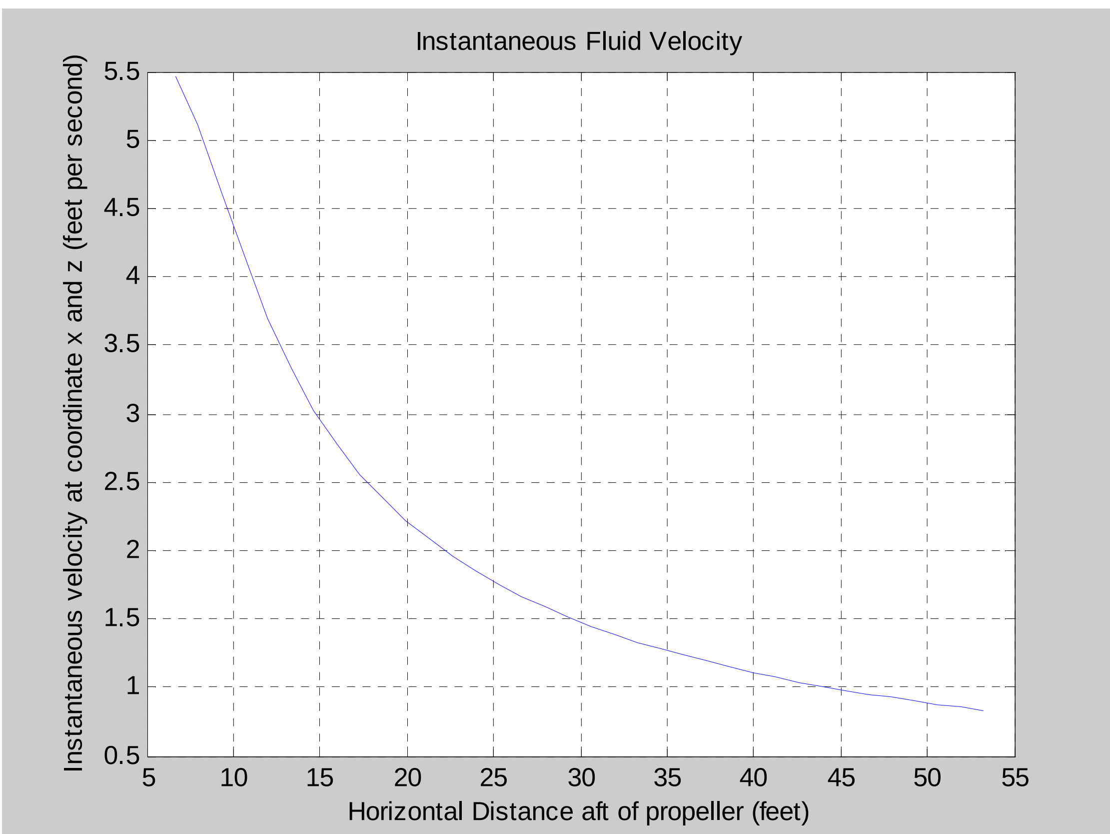

Figure D-2. Instantaneous fluid velocity (Vx) relative to the propeller

3. Compute propeller wash time series for a moving vessel

The velocity pattern at the reference height above the bottom (0.85 ft) behind the stationary propeller is converted to a time series of velocity for the moving vessel relative to a fixed point using the boat speed computed above. The reference height of 0.85 feet was selected as it corresponds to the minimum height above the bottom at which reliable measurements could reasonably be collected during previous field experiments. Previous propeller wash evaluations and particle sizes at the threshold of motion were compared to field measurements of velocities collected at this elevation (Shaw and Anchor 2007). To do so, the velocity vs. distance values (Figure D-2) are "translated" using the speed of the boat for the time step of interest. For example:

$$T = \frac{x}{V_{w(t)}} = \frac{6.65\,ft}{2.36\,fps} = 2.82\,\text{sec}$$

For the cases where the peak of the relative velocity time series is not well defined, the time T for x=0 is computed as one half of the time computed for the peak velocity. Figure D-3 presents the propeller wash time series for this example.

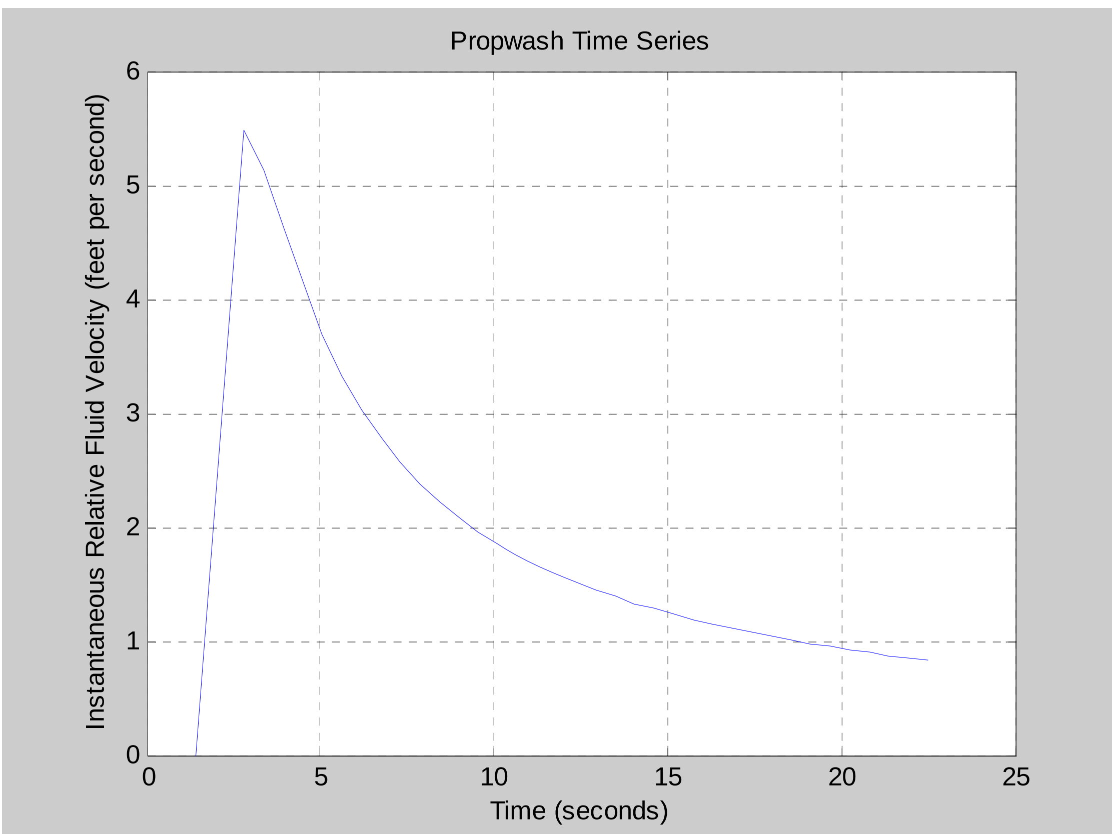

Figure D-3. Propeller Wash Time Series

Instantaneous velocities are calculated at intermediate points by linear interpolation between the points defining the curve in Figure D-3 using the procedures described in (Shaw and Anchor 2007). The effective velocity at each step in the velocity time series is computed as the average of a given instantaneous velocity and the peak instantaneous velocity. The duration corresponding to this effective velocity (ΔT) is conservatively assumed to be equal to the duration at the given instantaneous velocity:

$$\Delta T_{(VR)} = T_{2(VR)} - T_{1(VR)}$$

where

$\Delta T_{(VR)}$ = duration of time for which fluid velocity exceeds a given instantaneous relative velocity. Computed by interpolating between points on the velocity time series

$T_{1(VR)}$ = time within propeller wash time series that given instantaneous relative velocity is first exceeded (see Figure D-3)

$T_{2(VR)}$ = time within propeller wash time series that given instantaneous relative velocity is no longer exceeded (see Figure D-3)

For example, for the peak instantaneous relative velocity = 5.42 fps from Figure D-3 and for V_x = 3.0 fps:

$$V_{eff} = \frac{3.0 + 5.42}{2} = 4.2\ fps$$

$$\Delta T_{(3\ fps)} = 6.25 - 2.17 = 4.08\ \text{sec}$$

4. Compute Particle Size at Threshold of Motion

This step presents the estimation of particle size at threshold of motion using two methods, including a momentum based approach that considers both duration and magnitude of the flow as well as empirical data presented by Neill (1973) for a duration unlimited case as an upper bound of particle instability. The methods presented in the USEPA guidance (Maynord 1998) and technical literature (Blaauw and van de Kaa 1978) are based on large ocean-going vessels operating at very slow speeds (e.g., maneuvering operations), and therefore are not fully applicable to the smaller, fast-moving recreational vessels that typically operate in the shallower waters of Onondaga Lake. Specifically, the model does not properly consider the angle of the propeller (the propeller angling downward toward the bed as the boat is starting up) or the transient (i.e., moving vessel) nature characteristic of recreational propeller wash. In addition, as shown above, the USEPA guidance provides a conservative estimate of stable particle size for the low bottom velocities.

The threshold particle size was computed using the following equation that considers of both velocity and duration (Shaw and Anchor 2007).

$$D_{50} = \frac{3}{4} C_D \frac{V_{eff}^{\ 2}}{\frac{\rho_s}{\rho_{fluid}}\left(gC_F + \frac{\alpha V_{eff}}{\Delta t} \right) - gC_F}$$

where

ρ_{fluid} = fluid density in lbs/ft^3 = 62.4 lbs/ft^3

$\rho_{sediment}$ = particle density in lbs/ft^3 = 165 lbs/ft^3

C_D = Drag and lift combined coefficient. The lift and drag coefficients empirically account for two forces, lift and drag, that are exerted on a particle resting on the bed as a result of passing flow and contribute to the initiation of motion of the particle. The drag and lift coefficient of 0.35 is used in this analysis based on a review of published literature (van Rijn 1993; Saffman 1965, 1968; and others).

V_{eff} = effective fluid velocity in fps

C_F = Coefficient of friction (tan ϕ). The coefficient of friction here relates to a combination of friction (resistance to movement) forces acting on a single particle on a horizontal bottom, stochastically bounded with other particles. The friction angle of 45.67 degrees is used in this analysis based on a range of values reported in literature (Middleton and Southard 1984).

α = ratio of particle speed to fluid speed at initial motion. A value of 0.86 was used in this analysis (based on van Rijn 1984).

D_{50} = particle diameter, in ft

For the effective velocity of 4.2 fps and ΔT= 4.08 sec:

$$D_{50} = \frac{3}{4}(0.35)\frac{4.2^2}{\frac{165}{62.4}\left((32.2)\tan 45.67 + \frac{(0.86)(4.2)}{4.08}\right) - (32.2)\tan 45.67} = 0.082\,ft = 0.98\,inches$$

The threshold particle size was also computed for each effective velocity value assuming a duration unlimited condition according to the following relationship based on Neill (1973).

$$\mathrm{D}_{50} = (\mathrm{V}_{eff})^{3.5432} \times 0.002$$

where

D_{50} = median particle size in inches at threshold of motion

V_{eff} = velocity specific to reference point of interest, z_r (0.85 ft)

$$\mathrm{D}_{50} = (4.2)^{3.5432} \times 0.002 = 0.32\,inches$$

Both threshold particle size curves are plotted on Figure D-4. The particle size at threshold of motion is selected as the peak of the momentum equation curve if that peak plots to the right of (or below) the Neill curve. If the peak of the momentum equation curve plots to the left the Neill curve, the particle size at threshold of motion is defined as the intersection point of the momentum equation curve and the Neill curve.

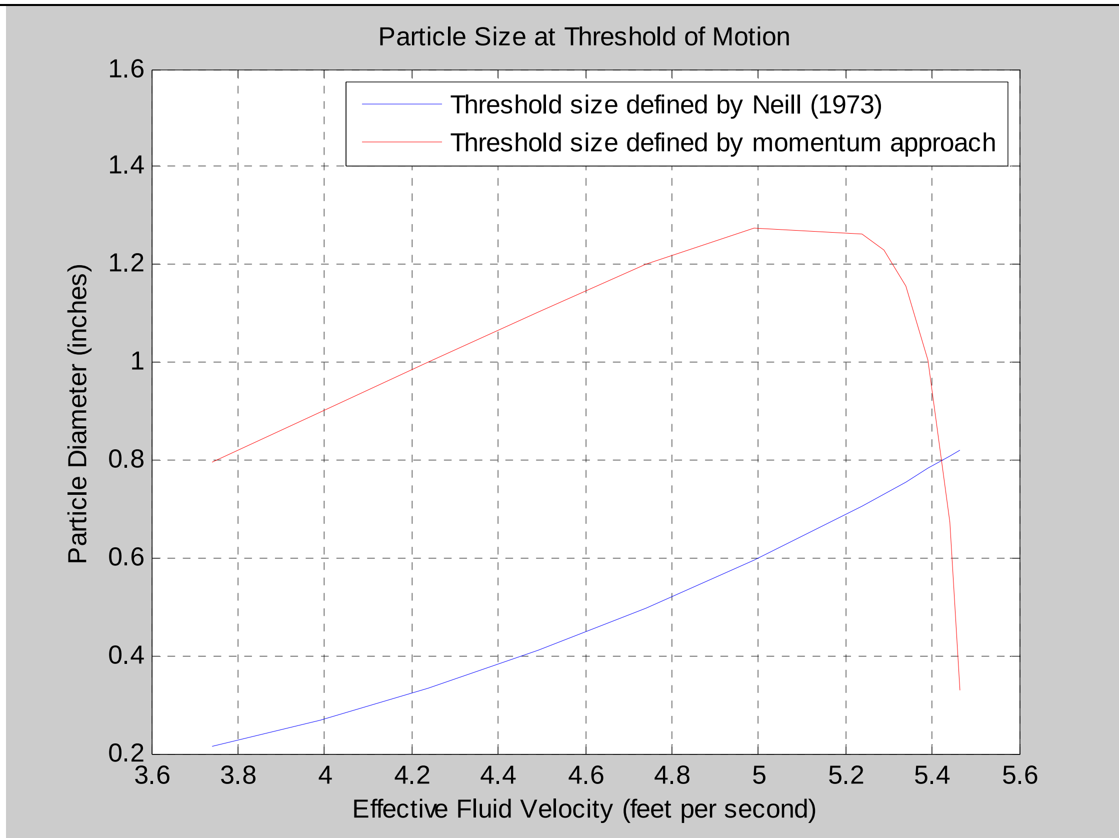

Figure D-4. Particle Size at Threshold of Motion

In this case, the peak of the momentum equation curve plots to the left the Neill curve, so the particle size at threshold of motion is defined as the intersection point of the momentum equation curve and the Neill curve. Therefore, the stable particle size for a Triumph 191 FS boat operating at 50 percent power 5 feet above the sediment cap armor layer is **0.8 inches** (coarse gravel).

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ATTACHMENT E
VESSEL WAKE EXAMPLE CALCULATION

CALCULATION COVER SHEET

PROJECT: Onondaga Lake	**CALC NO. 1**	**SHEET** 1 of 6
SUBJECT: Attachment E – Vessel Wake Analysis for Armor Layer Designs - Example Calculation		

Objective: To determine the wave height and period generated by a vessel traveling through Onondaga Lake's Remediation Areas.

References:

Bhowmik, N.G., Soong, T.W., Reichelt, W.F., and Seddik, N. M. L. 1991. *Waves generated by recreational traffic on the Upper Mississippi River System*. Research Report 117, Department of Energy and Natural Resources, Illinois State Water Survey, Champaign, IL.

Sorensen, R., 1997. *Prediction of Vessel-Generated Waves with Reference to Vessels Common to the Upper Mississippi River System.* Lehigh University and Coastal Hydraulics Laboratory of the US Army Engineer Waterways Experiment Station. ENV Report 4. December.

Weggel, J.R. and R.M. Sorensen. 1986. "Ship wave prediction for port and channel design." Proceedings of the Ports '86 Conference, Oakland, CA, May 19-21, 1986. Paul H. Sorensen, ed., American Society of Civil Engineers, New York, pp. 797-814.

Sorensen, R.M. and J.R. Weggel. 1984. "Development of ship wave design information." Proceedings of the 19th Conference of Coastal Engineering, Houston, Texas, September 3-7, 1984., Billy Ledge, ed., American Society of Civil Engineers, New York, III, pp 3227-43.

Determination of wake wave height and period for a tugboat: The following presents a detailed summary and example calculation to determine the wave height and period of a wake wave generated by a tugboat traversing Onondaga Lake. The approach was developed by Weggel and Sorensen (1986) and Sorensen and Weggel (1984). The numbered list below outlines the general approach used for the calculation and defines specific parameters used in the calculations.

1. Obtain vessel characteristics (model input parameters) for the vessel in question, in this case the *Mavret H*, a tugboat. Also, determine water depth and distance to sailing line, where wave characteristics will be assessed. These parameters are provided in the following table:

Table A-1
Vessel Characteristics and Input Parameters (Tugboat)

Parameter	Value	Units
Length	70	feet
Vessel Displacement	24	metric tons
Vessel Speed	10	mph
Water Depth	14	feet

2. Relating maximum wave height, H_m, to the vessel speed, distance from the sailing line, water depth, and the vessel displacement yields four dimensionless variables (equations 1 through 4) with their corresponding values for this calculation:

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$$F = \frac{V}{\sqrt{gd}}$$

$$x^* = \frac{x}{W^{0.33}}$$

$$d^* = \frac{d}{W^{0.33}}$$

$$H_m{}^* = \frac{H_m}{W^{0.33}}$$

where

F = Froude number
V = vessel speed
g = acceleration of gravity
d = water depth
x* = dimensionless distance from vessel sailing line to point of interest
x = distance from vessel sailing line to point of interest measured perpendicular to the sailing line
W = vessel displacement = 24 metric tons x 2,204 lbs/metric ton/62.4 lbs of water per ft^3 = 850 ft^3
H_m* = dimensionless maximum wave height
H_m = maximum wave height in a vessel wave record
d* = dimensionless water depth

3. The basic initial model, in terms of these dimensionless variables, is given by (equation 5):

$$H_m{}^* = \alpha(x^*)^n$$

Where α and n are a function of the Froude number and dimensionless depth as follows (equation 6):

$$n = \beta(d^*)^{\delta}$$

Where (equation 7):

$\beta = -0.342 \quad 0.55 < F < 0.8$
$\beta = -0.225\,F^{-0.699} \quad 0.2 < F < 0.55$

$\delta = -0.146 \quad 0.55 < F < 0.8$
$\delta = -0.118\,F^{-0.356} \quad 0.2 < F < 0.55$

and (equation 8):

$$\log(\alpha) = a + b\log(d^*) + c(\log(d^*))^2$$

where (equation 9):

$$a = \frac{-0.6}{F}$$

$$b = 0.75F^{-1.125}$$

$$c = 2.653F - 1.95$$

4. Using Equations 5 through 9, H_m can be determined given the vessel speed, displacement, water depth, and distance from the sailing line. These equations are valid for vessel Froude numbers from 0.2 to 0.8, which are common for most vessel operations, and in this case is 0.69 as defined in equation 1 above (and shown in the calculation below).

$$F = \frac{V}{\sqrt{gd}} = \frac{10\ \frac{\text{miles}}{\text{hr}} \times 5{,}280\ \frac{\text{ft}}{\text{mile}} \times \frac{1}{3{,}600}\ \frac{\text{hr}}{\text{sec}}}{\sqrt{32.2\ \frac{\text{ft}}{\text{s}^2} \times 14\ \text{ft}}} = 0.69$$

Where,
F = Froude number
V = vessel speed = 10 miles per hour
g = 32.2 ft/s^2
d = water depth = 14 feet

Given F = 0.69, β = -0.342 and δ = -0.146 and the value of H_m = 1.5 ft

equation 2:

$$x^* = \frac{x}{W^{0.33}} = \frac{25\ \text{ft}}{\left(850\ \text{ft}^3\right)^{0.33}} = 2.7$$

equation 3:

$$d^* = \frac{d}{W^{0.33}} = \frac{14\ \text{ft}}{\left(850\ \text{ft}^3\right)^{0.33}} = 1.5$$

equation 4:

$$H_m^* = \frac{H_m}{W^{0.33}} \Rightarrow H_m = \left(H_m^*\right)\left(W^{0.33}\right) = 0.16 \times \left(850\ \text{ft}^3\right)^{0.33} = 1.5\ \text{ft}$$

equation 5:

$$H_m^* = \alpha(x^*)^n = 0.21 \times (2.7)^{-0.3} = 0.16$$

equation 6:

$$n = \beta (d^*)^{\delta} = -0.342 \times (1.5)^{-0.146} = -0.3$$

equation 8:

$$\log(\alpha) = a + b\log(d^*) + c(\log(d^*))^2 = -0.87 + 1.1\log(1.5) + -0.12(\log(1.5))^2 = -0.68$$

$$\alpha = 10^{-0.53} = 0.21$$

equation 9:

$$a = \frac{-0.6}{F} = \frac{-0.6}{0.69} = -0.87$$

$$b = 0.75F^{-1.125} = 0.75(0.69)^{-1.125} = 1.1$$

$$c = 2.653F - 1.95 = 2.653 \times 0.69 - 1.95 = -0.12$$

Where,
F = Froude number = 0.69 (per equation 1 above)
V = vessel speed = 10 miles per hour
g = acceleration of gravity = 32.2 ft/s^2
d = water depth = 14 feet
x* = Dimensionless distance from vessel sailing line to point of interest
x = Distance from vessel sailing line to point of interest measured perpendicular to the sailing line = 25 feet
W = vessel displacement = 850 ft^3
H_m* = Dimensionless maximum wave height
H_m = maximum wave height in a vessel wave record
d* = Dimensionless water depth

5. The wave height is subsequently adjusted by modifying the value of H_m by the following relationship (equation 10):

$$H_m = A'H_m - B' = 1.73 \times 1.5\text{ ft} - 0.015 = 2.58\text{ ft}$$

Where,
A' and *B'* = coefficients to account for hull geometry = 1.73 and 0.015 (Equation 14 and Table 2 of Weggel and Sorensen 1986)

6. In order to determine the wave period, the diverging wave direction is determined with respect to the sailing line, by the following equation (equation 15):

$$\theta = 35.27 - 35.27^{(12F-12)} \qquad F<1$$

$$\theta = a\sin\left(\frac{1}{F}\right) \qquad F>1$$

In this example calculation where F= 0.69:

$$\theta = 35.27 - 35.27^{(12*0.69-12)} = 34.4 \text{ degrees, or } 0.6 \text{ radians}$$

And the diverging wave celerity, *C* is determined by the following (equation 16):

$$C = V\cos(\theta) = 10\frac{\text{miles}}{\text{hr}} \times 5{,}280\frac{\text{ft}}{\text{mile}} \times \frac{1}{3{,}600}\frac{\text{hr}}{\text{sec}} \times \cos(0.6) = 12.1\frac{ft}{\text{sec}}$$

Where,
V = vessel speed = 10 mph

And the period is calculated as (equation 17):

$$T = 2\pi(C/g) \qquad \text{F<0.7}$$

$$T = \frac{L^*}{C} \qquad \text{F>0.7}$$

Where L* is determined through an iterative process, to match *C* with *C**, where C* is defined as (equation 18):

$$C^* = \frac{\sqrt{32.2 \times L^* \times 0.5}}{\pi \times \tanh\left(2\pi\frac{d}{L^*}\right)}$$

In this example F < 0.7, and the first part of equation 17 is used to determine T:

$$T = 2\pi\left(\frac{12.1\frac{ft}{\text{sec}}}{32.2\frac{ft}{\text{sec}^2}}\right) = 2.4\text{sec}$$

Determination of wake wave height and period for a ski and fishing boat: The following presents a detailed summary and example calculation to determine the wave height and period of a wake wave generated by a ski and fishing boat traversing Onondaga Lake. The approach was developed by Bhowmik et al. (1991). The numbered list below outlines the general approach used for the calculation and defines specific parameters used in the calculations.

1. Obtain vessel characteristics (model input parameters) for the vessel in question, in this case the *Triumph 191*, a ski and fishing boat. These parameters are provided in the following table:

Table A-2
Vessel Characteristics and Input Parameters (Ski and Fishing Boat)

Parameter	Value	Units
Length	18.5	feet
Draft	1.17	feet
Vessel Speed	8	mph

2. Compute maximum wave height, H_m, using vessel length, vessel draft, vessel speed, and distance from the sailing line using Bhowmik et al. (1991):

$$H_m = 0.537 V^{-0.346} x^{-0.345} L_v^{0.56} D^{0.355}$$

$$H_m = 0.537 \left(3.6 \frac{\mathrm{m}}{\mathrm{s}}\right)^{-0.346} (7.6\,\mathrm{m})^{-0.345} (5.6\,\mathrm{m})^{0.56} (0.36)^{0.355} = 0.31\,\mathrm{m}, \text{or } 1\,\text{foot}$$

Where,
V = vessel speed = 8 mph, or 3.6 m/s
x = Distance from vessel sailing line to point of interest measured perpendicular to the sailing line = 25 feet, or 7.6 meters
L_v = vessel length = 18.5 feet, or 5.6 meters
D = vessel draft = 1.17 feet, or 0.36 meters

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ATTACHMENT F
BEARING CAPACITY CALCULATION

CALCULATION COVER SHEET

PROJECT: Onondaga Lake	**CALC NO. 1**	**SHEET** 1 of 4
SUBJECT: Attachment F – Sediment Cap Bearing Capacity Analysis – Example Calculation		

Objective: To determine the factor of safety relative to bearing capacity for human foot traffic on the nearshore sediment caps.

References:

Das, B.M. 1999. *Shallow Foundations Bearing Capacity and Settlement*. CRC Press.

Das, B.M. 1990. *Principles of Geotechnical Engineering*. Second Edition. PWS-Kent Publishing Company.

Determination of bearing loads due to human foot traffic: The following presents a detailed summary and example calculation to determine the factor of safety relative to bearing capacity for human foot traffic on the nearshore sediment caps in Onondaga Lake. The calculation was performed by assuming human foot traffic is similar to a shallow foundation that rests on a layered material (the sand and gravel cap over the softer, fine grained sediments in Onondaga Lake). The Terzaghi-Meyerhof method was used to compute the general bearing capacity of the cap. The sediment cap (i.e. top layer) was conservatively assumed to be comprised of sand only with the following soil properties:

Cohesion (c) = 0 pounds per square foot (psf)
Soil friction angle (ϕ) = 32 degrees
Submerged unit weight (γ) = 125 pounds per cubic foot (pcf) for sand – 62.4 pcf for water = 62.6 pcf

The Bearing Capacity Factors for general shear failure are:

N_c = 35.49 (from Table 10.1 of Das 1990)
N_q = 23.18 (from Table 10.1 of Das 1990)
N_γ = 30.22 (from Table 10.1 of Das 1990)

Approximating a human foot as a rectangular footing with a width (B) of 4 inches (0.33 ft), a length (L) of 10 inches, (0.83 ft), and a footing depth (D_f) of 0 ft.

For the sediment cap, the general bearing capacity using Equation 10.37 from Das 1990 is:

$$q_n = cN_c + qN_q + \frac{1}{2}\gamma BN_\gamma = (0)(35.49) + 0 + \frac{1}{2}(62.6)(0.33)(30.22) = 312 \text{ psf}$$

Note: since the foot traffic is at the top of the cap, there is no surcharge contribution to the general bearing capacity.

The bottom layer (i.e. the native sediments below the sediment cap) is assumed to consist of cohesive, fine-grained sediments with the following properties:

Cohesion (c) = 25 psf (representing the softest sediments in the upper one foot)
soil friction angle (ϕ) = 0 degrees
Submerged unit weight (γ) = 30 pcf (an average value of the sediments based on Pre-Design Investigations)

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DESIGNER: MRH **DATE:** 11-24-09 **CALC. NO.:** 0 **REV.NO.:** 0

PROJECT: Onondaga Lake **CHECKED BY:** PTL **CHECKED DATE:** 11-24-09

SUBJECT: Sediment Cap Bearing Capacity Analysis – Example Calculation

The Bearing Capacity Factors for general shear failure are:

$N_c = 5.14$
$N_q = 1.00$
$N_\gamma = 0.00$

For the underlying sediments, the general bearing capacity using Equation 10.37 from Das 1990 is:

$$q_n = cN_c + qN_q + \frac{1}{2}\gamma BN_\gamma = (25)(5.14) + 0 + \frac{1}{2}(30)(0.33)(0.00) = 129 \text{ psf}$$

Equation 4.32 from Das (1999) was used to determine the ultimate bearing capacity (q_u). The subscript 1 refers to the sediment cap (the top layer) and the subscript 2 refers to the underlying, native sediments (bottom layer). The thickness (H) of the sediment caps in the nearshore region can range from 2.75 ft to 5 ft in thickness.

$$q_u = q_b + \left(\frac{2c_a H}{B}\right) + \left(\gamma_1 H^2\right)\left(1 + \frac{2D_f}{H}\right)\left(\frac{K_s \tan\phi_1}{B}\right) - \gamma_1 H$$

Equation 4.29 from Das (1999) was used to determine q_b:

$$q_b = c_2 N_{C2} + \gamma_1\left(D_f + H\right)N_{q2} + \frac{1}{2}\gamma_2 BN_{\gamma 2} = (25)(5.14) + (62.6)(0 + 2.75)(1) + \frac{1}{2}(30)(0.33)(0) = 301 \text{ psf}$$

For a 5 ft thick cap, q_b = 442 psf.

K_s was determined from Figure 4.15 of Das (1999) below:

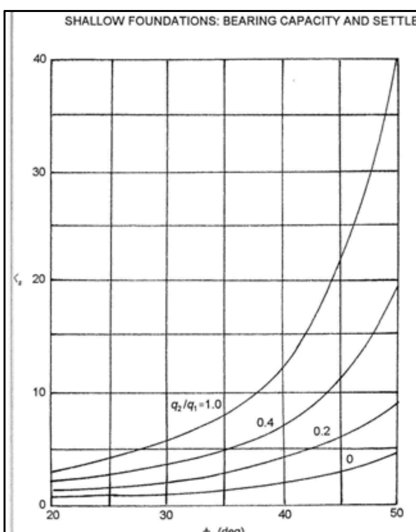

FIGURE 4.15 Meyerhof and Hanna's theory — variation of K_s with ϕ_1 and q_2/q_1

For $\phi_1 = 32$ degrees and $\frac{q_2}{q_1} = \frac{129}{312} = 0.41$, $K_s = 4$

c_a was estimated as 1 using Figure 4.23 from Das (1999) below:

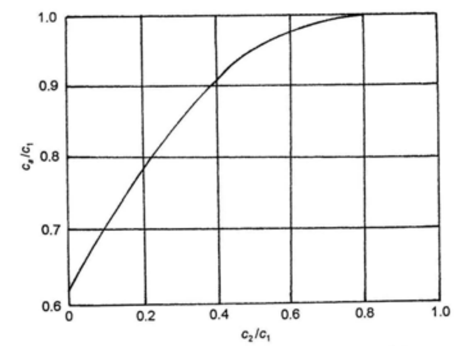

FIGURE 4.23 Analysis of Meyerhof and Hanna for the variation of c_a/c_1 with c_2/c_1

Since $\frac{c_2}{c_1} = \frac{25}{0}$, a value of 1 was selected for c_a

For a 2.75 thick nearshore cap:

$$q_u = 301 + \left(\frac{(2)(1)(2.75)}{0.33}\right) + (62.6)(2.75)^2\left(1 + \frac{2(0)}{2.75}\right)\left(\frac{4\tan 32}{0.33}\right) - (62.6)(2.75) = 3{,}730 \text{ psf}$$

For a 5 ft thick nearshore cap, q_u = 12,000 psf

The applied load for a 200 lb person on the cap is estimated as:

$$q = \frac{200}{(0.83)(0.33)} = 730 \text{ psf}$$

Note: this is conservative as it does not consider the submerged weight of the person.

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Therefore, the Factors of Safety (FOS) for the 2.75- and 5-thick caps are:

$$FOS_{\text{2.75-ft thick cap}} = \frac{3,730}{730} = 5.11$$

$$FOS_{\text{5-ft thick cap}} = \frac{12,000}{730} = 16.4$$

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ATTACHMENT G
ASHTON ICE EVALUATION

ICE EFFECTS ON SEDIMENTS ONONDAGA LAKE

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March 2004

BACKGROUND

As part of the effort to assess remediation of contaminated sediments in Onondaga Lake in New York, there was concern as to whether or not ice effects would influence various remedies being proposed, in particular capping of the existing bottom sediments. This report discusses the nature of the ice cover on Onondaga Lake and associated ice processes that could conceivably interact with the sediments. The conclusions below are based on a site visit to Onondaga Lake on 18 November 2003, on published literature dealing with ice and sediments, and some 35 years of personal experience examining river and lake ice behavior.

ONONDAGA LAKE

Onondaga Lake is a small to medium-sized lake located near Syracuse, New York. It is approximately 5 miles long and 1 mile wide with an orientation in the NW to SE direction. For a lake of this size, it is fairly deep with maximum depth of about 20 meters. The near shore areas slope gradually in a terrace to about 4 meters depth and then more steeply to near the maximum depth. Typically the ice cover forms in late December to early January and melts out near the latter part of March or the first part of April. Because of its depth, the temperature cools beneath the maximum density temperature of 4º C but does not cool down to the freezing point, since the surface ice cover forms before that occurs. In the 2002-2003 winter the coldest temperature at 14 feet depth near the site was about 2º C. From a water temperature record provided by Tim Johnson of Parsons Company, it is estimated that the first substantial ice cover occurred about 15 January and disappeared about 2 April. The winter 2002-2003 was extremely cold in the northeastern U.S. and maximum level ice thicknesses in the lake, based on a degree-days freezing algorithm using an air temperature from the site, were between 12 and 16 inches. Most likely there are years in which complete freeze over does not occur, although the usual scenario is one in which the lake is more or less completely ice covered.

ICE OBSERVATIONS

There are no known regular and/or historical ice thickness observations for Onondaga Lake. Onondaga County made almost daily observations of the extent of ice cover on the lake from the winter of 1987-88 through the winter of 2002-03. The lake was actively used in the late 1800's for iceboating which implies a more or less complete ice cover in most years. In an interview with Tim Johnson (Parsons), he suggested it is not used regularly by snowmobiles. In a telephone interview with Bob Halbritter of O'Brien and Gere, he stated that there are occasional ice pilings along the shore but these are of limited height (less than 5 feet) and were not considered severe. There are almost no residential or camp docks along the lake's shoreline and only a very small marina for boating access. Ordinarily damage (or not) to such docks provide indications of ice action. An inspection of the shoreline at several places by the writer showed no obvious signs of ice damage such as tree scars, except possibly some abrasion of shoreline trees at the very water's edge and at the water level. These abrasions could also have been caused by wave action on littoral debris near the shoreline.

The record of observations by Onondaga County was examined in detail. While providing a good record of surface ice coverage, measurements of ice thickness were infrequent. The surface ice coverage typically occurs in stages with initial ice formation along the shores and in protected inlets but eventually covering the entire lake. Often there are large open areas, particularly near the center of the lake. When the ice begins to melt, it first becomes clear of ice by enlargement of the open areas where tributaries enter, followed by an overall pattern that tends in most years to melt out the south basin first followed by the north basin. In those sixteen years of observation only two cases of shore ice piling was noted and they both occurred during the 1989-90 winter. On 1 February 1989 a photograph of thin ice piled on the eastern shore near French Fort was included with the caption stating "strong winds and temperatures that reached a high of 52 degrees combined to cause the ice to break up on Onondaga Lake. The ice was piled up in sheets on the eastern shore near the French Fort about 2:30 p.m. Tuesday." The ice appeared to consist of quite thin plates and no apparent damage could be observed from the photograph. On the calendar notes of that year for 19 January 1989 is a notation "heavy winds separated the South …pushed it ashore as shown (in cove near the south side of the lake).

Reported ice thicknesses were sparse in the record and rarely greater than 8 inches except for the years 1993-94 and 2002-03. During the 1993-94 year there are two notations: on 16 February 94: "+/- 20.5 inches at North Deep" and on 4 March 94: "+/-19.5 inches at North end." The month of January 1994 was the coldest of record for the Syracuse area, with an average air temperature of 12.6 °F. A degree-day calculation provided an estimate of expected thicknesses between 12 and 18 inches, so these two measurements are not inconsistent with the temperature record or other reported thicknesses that year. In the 2002-03 winter there were a series of thickness measurements with the maximum reported thickness 15 inches on 13 March 2003. The overall record that year is more detailed than usual and this thickness is consistent with other measurements through the season and a calculation based on freezing degree-days.

MECHANISMS OF ICE INTERACTION WITH BOTTOM SEDIMENTS

There are few studies of lake ice interaction with bottom sediments. However, several mechanisms of ice action are known and can be assessed for Onondaga Lake.

Frazil and Anchor Ice

Formation of frazil or anchor ice is not likely to occur at Onondaga lake due to the size of the lake and the low exposure to supercooling. Frazil is ice in very small crystals formed in supercooled (below 0º C) water. While in the supercooled matrix water it is adhesive to most materials. In some cases this frazil can adhere to the bottom sediments. When attached to the bottom, it is often termed anchor ice. When the water warms, or the deposit becomes large, the mass of frazil can rise and bring with it a quantity of sediment to which it had adhered.

Two conditions are necessary for this frazil formation at depth. They are cooling of the water to below 0º C and sufficient turbulent mixing to entrain the water and crystals to depth. In the Great Lakes both occur with the turbulent mixing due to both wind and current action, and the extended period of open water to achieve the necessary cooling associated with the difficulty in forming an intact ice cover over such a large surface area. In Onondaga Lake, neither condition occurs. The lake is not of sufficient size and exposure to develop large wind-driven currents, and it is doubtful that the majority of the lake becomes supercooled. There will be some limited supercooling of the top surface water during the time of initial ice formation but this will only occur in the absence of mixing with the warmer water below.

Wave Action

During the initial period of ice formation there may be very short periods when the wind and wave action will prevent an intact ice cover from forming. This will manifest itself in accumulations of very thin plates of ice accumulating in the surface waters at the downwind shorelines. This is expected to persist only until the winds subside. The interaction with the sediments below are considered to be equivalent to similar wave actions during open water periods with the exception that the surface layer of ice accumulation has a damping effect on the wave action.

Thermal Expansion

During the winter the ice cover expands and contracts in response to changes in air temperature. Associated with this expansion and contraction are formation and refreezing of cracks in the ice cover and the net effect usually is to push the ice edges in the shoreward direction. These pushes can move the top layers of the shoreline materials away from the lake. Personal observations of these by the writer suggests the disturbance to the top layers of soil are of limited depth, since the ice tends to “ride up” the shore. The forces, however, may be substantial and are limited by the strength of the ice.

Ice Ridging

Ice ridging of any significant degree is not expected to occur in Onondaga Lake due to its size. On the surface such ridges are easily observed because of their size. Descriptions of the ice cover of Onondaga Lake and other similar and even much larger lakes strongly suggest moving ice ridges do not occur. Undoubtedly there are smaller ridging features observed from time to time on Onondaga Lake but these are most likely due to local buckling resulting from thermal expansion and contraction, and are of limited vertical extent.

Shoreline Ice Piling

On large lakes such as the Great Lakes large ice pilings occur along the shorelines driven by winds and currents. On small lakes such as Onondaga Lake there is little literature and experience that quantifies such ice pilings, although it is well known that they often occur and cause damage to minor docks and similar relatively fragile shoreline installations. Documented cases for a lake much larger than Lake Onondaga (Tsang, 1975) were associated with formation of a wide open water gap along the shoreline followed by a reversal of strong winds that then drove the solid ice sheet towards the shoreline and resulted in ice pilings that were about 2 meters high and caused significant shoreline damage. The observations of interaction with the shoreline are instructive for the Onondaga Lake concerns. When the ice impacted an embankment or rock protection, it either flexured upwards and broke, or buckled upwards and failed. When it encountered a sloping shore it slid up the shore pushing a quantity of sediment ahead of it in a shallow "bulldozing" mode. Although the depth of excavation by the "bulldozing" was not measured, the diagram of the "bulldozing" mode suggested a depth of the excavation of about ½ or less than the thickness of the ice. It was also noted that extremely high winds earlier in the winter did not cause piling and led to the conclusion that the ice piling required a precedent condition of open water along the shoreline. Additionally these ice pilings had been observed often at the study site.

Lake Otsego, located about 85 miles ESE of Onondaga Lake, is similar to Onondaga Lake, although it is somewhat deeper. It has a long term record of ice-on and ice-off (beginning and ending dates of more-or-less complete ice cover) reported by Assel and Herche (1975). Lake Otsego average ice-on date is 12 January (standard deviation of 15 days) and ice-off is 13 April (standard deviation of 12 days) based on a record longer than 100 years. In Lake Otsego "shoreline alteration and damage of artificial structures on the shore (e.g. breakwaters) due to lake ice occurs in two ways: 1. by expansion and contraction associated with temperature changes through the winter and spring before breakup and 2. by moving ice during the meteorological events responsible for breakup of ice cover." (The State of Otsego Lake, 1936 – 1996, Biological Field Station, SUNY NY at Oneonta). That report goes on to state: "Most ice damage on Otsego Lake can be attributed to the former, which heaves rip-rap and breakwaters and often pushes natural unconsolidated beach materials into large berms parallel with the water. Ice breakup is usually not accompanied by extensive catastrophic change in the eulittoral environment because the ice is not often moved by wind until it is structurally weakened by warm spring weather. Upon coming in contact with the shore or any solid object, ice 12 cm or more in thickness will typically break up easily into pencil-shaped columnar crystals, If, however, the ice starts to move before its structural integrity has been weakened, extensive damage may occur in areas exposed to the prevailing winds." This report also noted "…in 1970-71, it (ice thickness) reached a thickness of about 30 cm, the thickest recorded."

Ice freezing to the bottom

Ice freezing to the bottom is expected in shallow water at the shoreline of Onondaga Lake. In such cases it is expected that the normal thickening of the ice will encounter the bed and freezing will continue. It is possible that with the rise of the ice cover associated with inflow to the lake from spring snowmelt, and this usually occurs prior to complete melting of lake ice covers, this ice could be raised and transported a short distance during the ice decay period. The maximum thickness of the ice-and-sediment layer can easily be estimated using straightforward algorithms using daily air temperatures through the winter. Where the water depth is less than the maximum ice thickness, the combined ice-sediment frozen thickness will be somewhat greater than the maximum ice thickness since there is less water to freeze in the sediment portion. This mode of sediment interaction is limited to those areas with depths of water less than the maximum ice thickness experienced and corresponds to water depths less than about 18 inches.

CONCLUSIONS

There are a number of mechanisms that could disturb the bottom sediments of Onondaga Lake as a result of ice action. They are: thermal expansion that would push the lake ice shoreward, shoreline ice piling as a result of wind action, and ice freezing to the bottom in very shallow areas. In the first two cases, the result would be shallow disturbance to the top layers of sediment in the very near shore areas and the adjacent land. In the third case, and limited to shallow areas with depths less than the maximum thickness of the ice, it is possible for the freezing process to entrain a top layer of sediment and, if the ice is then moved, to deposit it where it melts. Processes associated with ice ridging, and with frazil and anchor ice are not expected to occur in Onondaga Lake.

Armor is being considered as a design component for a cap on the sediments. In terms of ice action, the shallow freezing entrainment mode is limited to depths less than the maximum expected ice thickness of about 18 inches.

It is also noted that the occurrence of ice piling requires some meltout prior to ice piling, so selection of 18 inches for the ice thickness is conservative. To resist ice piling action with no displacement of riprap material, one detailed model study (Sodhi, 1996) suggested the maximum rock size (D100) should be twice the ice thickness for shallow slopes (1V:3H). This would correspond to 32 inches and be considerably larger than the size presently proposed for the armoring layer. Matheson (1988) suggested, from a survey of riprap performance on Canadian hydropower reservoirs, that damage occurs to riprap with D50 less than 0.4 m (16 inches) and this corresponds to experience with ice thicknesses quite a bit greater than that experienced on Onondaga Lake. This writer believes that riprap of a size greater than 16 inches is an extreme measure and that, since the occurrences of ice piling are considered infrequent and limited to only portions of the shoreline at any event occurrence, it would be preferable to replace those limited portions of the riprap protection after annual inspection. An alternative is to provide a sacrificial layer of smaller riprap that would be replenished as needed.

REFERENCES

Assel, R. A. and L. R. Herche, 1975. Ice-on, ice-off, and ice duration for lakes and rivers with long-term records, Proceedings 14th International Symposium on Ice, Potsdam, NY 27-31 July 1998, Potsdam, NY.

----Biological Field Station in Cooperstown, 1996. The State of Otsego Lake, 1936-1996, SUNY College at Oneonta.

Matheson, D. S. 1988. Performance of riprap in northern climates. Contract report to the Canadian Electrical Association, CEA No. 625 G 571, Acres International Limited, Winnipeg, Manitoba (cited in Wuebben, J.L. 1995, Ice effects on riprap, in River, Coastal and Shoreline Protection: Erosion Control using Riprap and Armourstone, J. Wiley and Sons.)

Tsang, G. 1975. A field study on ice piling on shores and the associated hydro-meteorological parameters, Third International Symposium on Ice Problems, Hanover, NH, pp. 93-110.

Sodhi, D.S., S. L. Borland, and J. M. Stanley, 1996. Ice action on riprap: Small-scale tests, CRREL Report 96-12, U.S. Army Corps of Engineers, Cold Regions Research and Engineering Laboratory, Hanover, NH, 64 p.

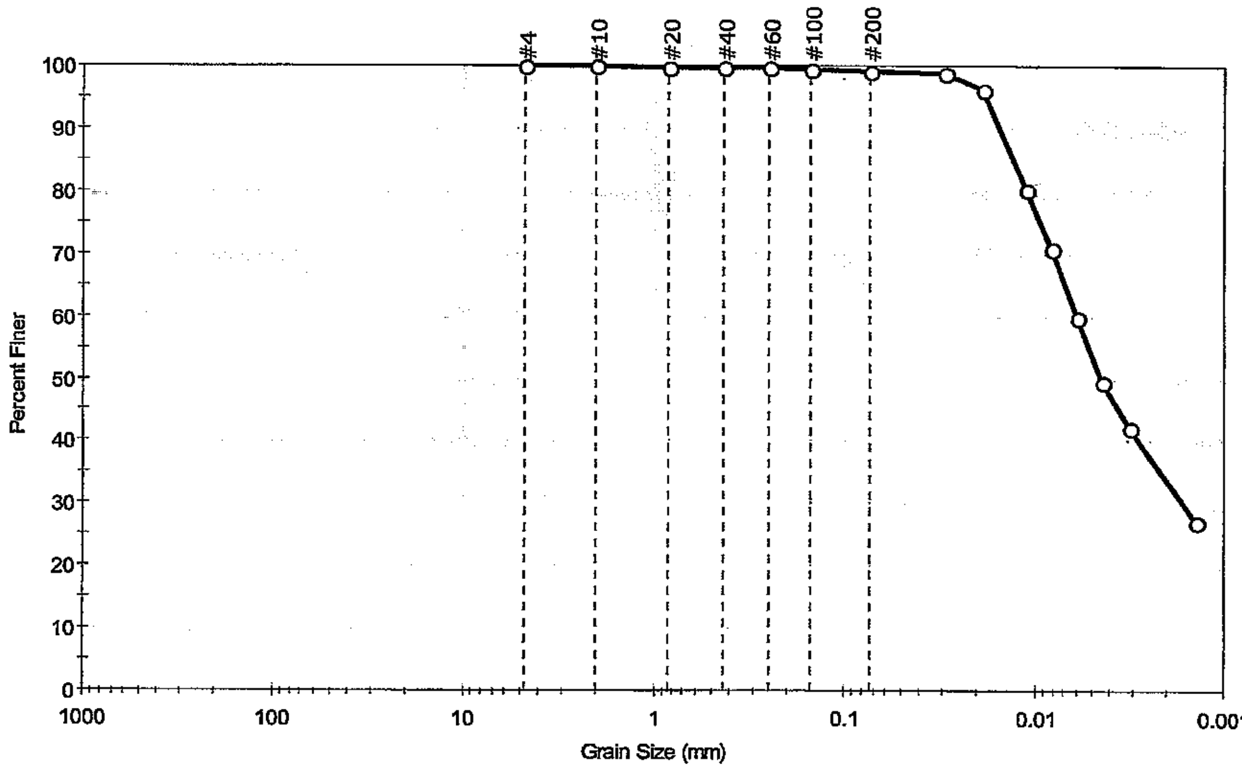
ATTACHMENT H
GRAIN SIZE ANALYSIS

GeoTesting express
a subsidiary of Geocomp Corporation

Client: Parsons Engineering Science			
Project: Onondaga			
Location: Syracuse		Project No:	GTX-7143
Boring ID: OL-VC-40016	Sample Type: jar	Tested By:	mll
Sample ID:OL-0287-02	Test Date: 02/09/07	Checked By:	jdt
Depth : 9.9-13.2 ft	Test Id: 105918		

Test Comment: ---
Sample Description: Moist, olive brown silt
Sample Comment: ---

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



% Cobble	% Gravel	% Sand	% Silt & Clay Size
—	0.0	0.8	99.2

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
#4	4.75	100		
#10	2.00	100		
#20	0.84	100		
#40	0.42	100		
#60	0.25	100		
#100	0.15	100		
#200	0.074	99		
—	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0293	99		
---	0.0190	96		
---	0.0113	80		
---	0.0082	71		
---	0.0060	60		
---	0.0044	50		
---	0.0031	42		
---	0.0014	27		

Coefficients

D_{85} =0.0132 mm D_{30} =0.0016 mm
D_{60} =0.0060 mm D_{15} =N/A
D_{50} =0.0044 mm D_{10} =N/A
C_u =N/A C_c =N/A

Classification

ASTM elastic silt (MH)

AASHTO Clayey Soils (A-7-5 (76))

Sample/Test Description

Sand/Gravel Particle Shape : ANGULAR
Sand/Gravel Hardness : HARD

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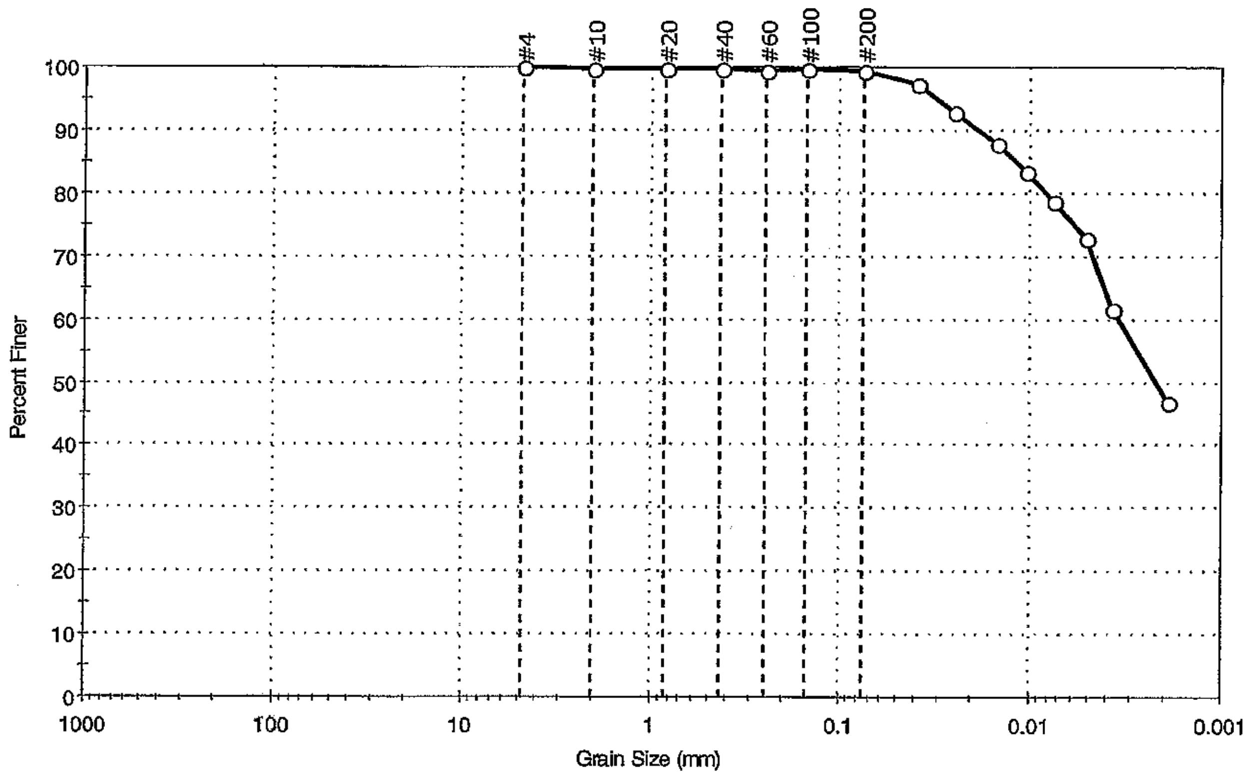
GeoTesting express
a subsidiary of Geocomp Corporation

Client:	Parsons Engineering Science				
Project:	Onondaga				
Location:	Syracuse			Project No:	GTX-7143
Boring ID:	OL-0302-06	Sample Type:	jar	Tested By:	mll
Sample ID:	OL-VC-40016	Test Date:	06/08/07	Checked By:	jdt
Depth :	13.2-16.4 ft	Test Id:	111437		
Test Comment:	---				
Sample Description:	Wet, dark gray silt				
Sample Comment:	---				

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



%Cobble	%Gravel	%Sand	%Silt & Clay Size
---	0.0	0.6	99.4

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
#4	4.75	100		
#10	2.00	100		
#20	0.84	100		
#40	0.42	100		
#60	0.25	99		
#100	0.15	100		
#200	0.075	99		
---	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0397	97		
---	0.0253	93		
---	0.0147	88		
---	0.0104	83		
---	0.0074	79		
---	0.0051	73		
---	0.0037	62		
---	0.0019	47		

Coefficients

D_{85} =0.0117 mm — D_{30} =N/A

D_{60} =0.0034 mm — D_{15} =N/A

D_{50} =0.0022 mm — D_{10} =N/A

C_u =N/A — C_c =N/A

Classification

ASTM elastic silt (MH)

AASHTO Clayey Soils (A-7-5 (64))

Sample/Test Description

Sand/Gravel Particle Shape : ROUNDED

Sand/Gravel Hardness : HARD

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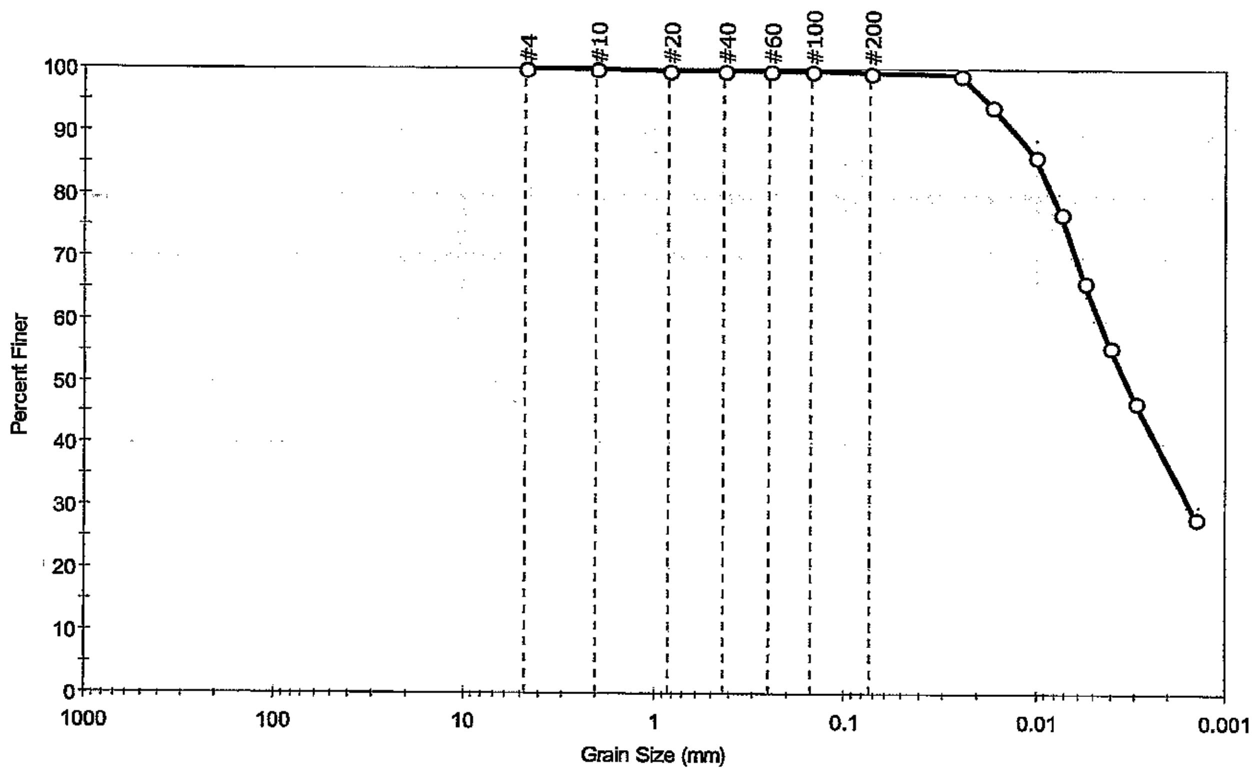
GeoTesting express
a subsidiary of Geocomp Corporation

Client: Parsons Engineering Science			
Project: Onondaga			
Location: Syracuse		Project No:	GTX-7143
Boring ID: OL-VC-40016	Sample Type: jar	Tested By:	mll
Sample ID: OL-0287-03	Test Date: 02/08/07	Checked By:	jdt
Depth : 16.5-19.8 ft	Test Id: 105919		
Test Comment: ---			
Sample Description: Moist, gray silt			
Sample Comment: ---			

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



% Cobble	% Gravel	% Sand	% Silt & Clay Size
—	0.0	0.5	99.5

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
#4	4.75	100		
#10	2.00	100		
#20	0.84	100		
#40	0.42	100		
#60	0.25	100		
#100	0.15	100		
#200	0.074	99		
---	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0253	99		
---	0.0169	94		
---	0.0102	86		
---	0.0075	77		
---	0.0055	66		
---	0.0041	56		
---	0.0030	47		
---	0.0014	28		

Coefficients

D_{85} =0.0098 mm
D_{30} =0.0015 mm
D_{60} =0.0046 mm
D_{15} =N/A
D_{50} =0.0033 mm
D_{10} =N/A
C_u =N/A
C_c =N/A

Classification

ASTM elastic silt (MH)

AASHTO Clayey Soils (A-7-5 (52))

Sample/Test Description

Sand/Gravel Particle Shape : ANGULAR

Sand/Gravel Hardness : HARD

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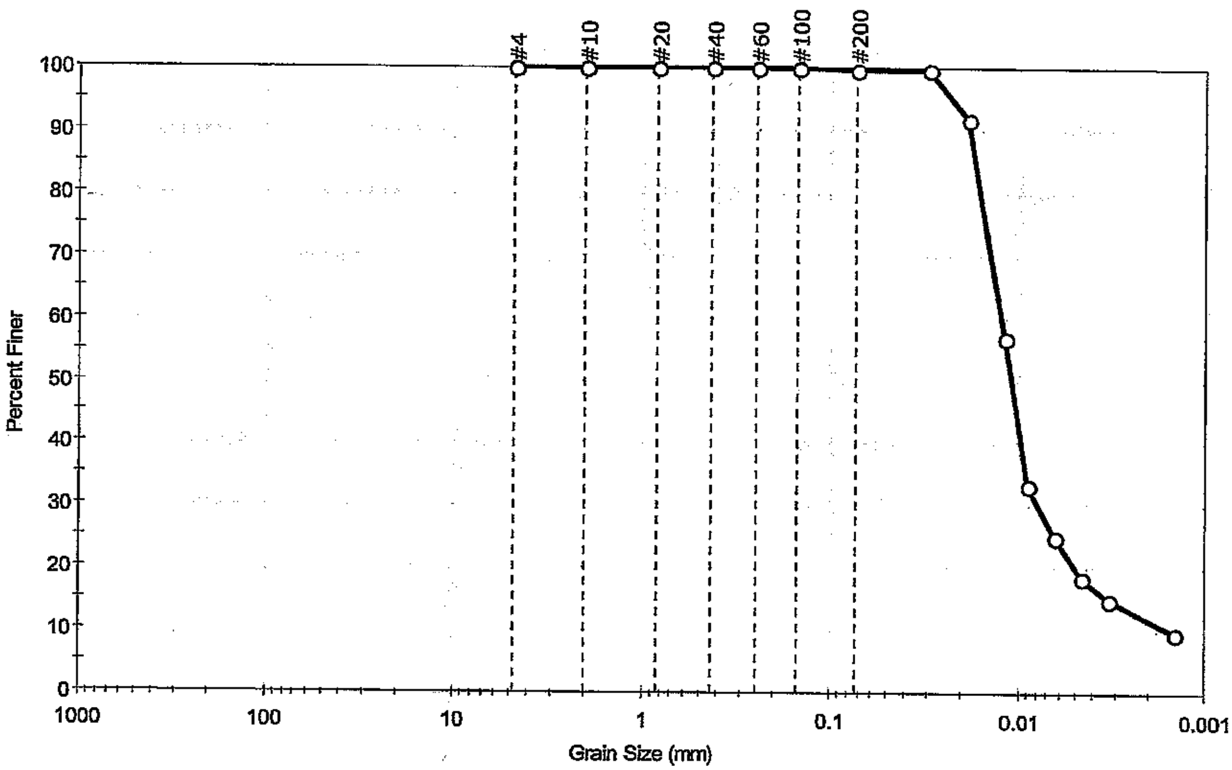
GeoTesting express
a subsidiary of Geocomp Corporation

Client: Parsons Engineering Science			
Project: Onondaga			
Location: Syracuse		Project No:	GTX-7143
Boring ID: OL-VC-40017	Sample Type: jar	Tested By:	mll
Sample ID: OL-0287-04	Test Date: 02/07/07	Checked By:	jdt
Depth : 0.5-3.3 ft	Test Id: 105920		
Test Comment: ---			
Sample Description: Wet, black silt			
Sample Comment: ---			

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



% Cobble	% Gravel	% Sand	% Silt & Clay Size
—	0.0	0.2	99.8

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
#4	4.75	100		
#10	2.00	100		
#20	0.84	100		
#40	0.42	100		
#60	0.25	100		
#100	0.15	100		
#200	0.074	100		
---	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0300	100		
---	0.0190	92		
---	0.0121	57		
---	0.0090	33		
---	0.0065	25		
---	0.0047	19		
---	0.0033	15		
---	0.0015	10		

Coefficients

D_{85} =0.0174 mm　D_{30} =0.0079 mm

D_{60} =0.0126 mm　D_{15} =0.0033 mm

D_{50} =0.0111 mm　D_{10} =0.0015 mm

C_u =N/A　C_c =N/A

Classification

ASTM　elastic silt (MH)

AASHTO　Clayey Soils (A-7-5 (24))

Sample/Test Description

Sand/Gravel Particle Shape : ANGULAR

Sand/Gravel Hardness : HARD

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GeoTesting express
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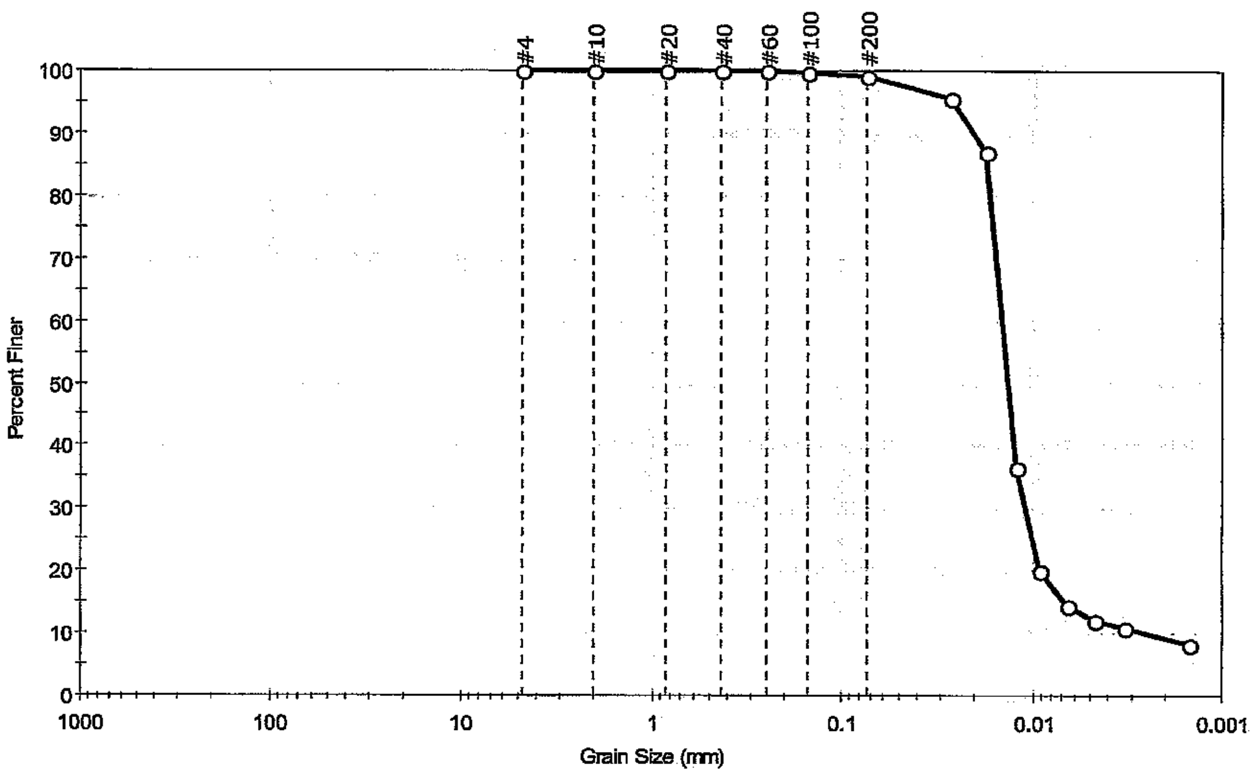
Client:	Parsons Engineering Science				
Project:	Onondaga				
Location:	Syracuse			Project No:	GTX-7143
Boring ID:	OL-VC-40017	Sample Type:	jar	Tested By:	mll
Sample ID:	OL-0287-05	Test Date:	02/08/07	Checked By:	jdt
Depth :	6.6-9.9 ft	Test Id:	105921		

Test Comment: ---
Sample Description: Wet, very dark gray silt
Sample Comment: ---

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



% Cobble	% Gravel	% Sand	% Silt & Clay Size
—	0.0	0.9	99.1

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
#4	4.75	100		
#10	2.00	100		
#20	0.84	100		
#40	0.42	100		
#60	0.25	100		
#100	0.15	100		
#200	0.074	99		
---	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0272	96		
---	0.0173	87		
---	0.0123	36		
---	0.0091	20		
---	0.0066	15		
---	0.0047	12		
---	0.0033	11		
---	0.0015	8		

Coefficients

D_{85} =0.0171 mm　D_{30} =0.0109 mm
D_{60} =0.0145 mm　D_{15} =0.0067 mm
D_{50} =0.0135 mm　D_{10} =0.0025 mm
C_u =N/A　C_c =N/A

Classification

ASTM　elastic silt (MH)

AASHTO　Clayey Soils (A-7-5 (32))

Sample/Test Description

Sand/Gravel Particle Shape : ANGULAR

Sand/Gravel Hardness : HARD

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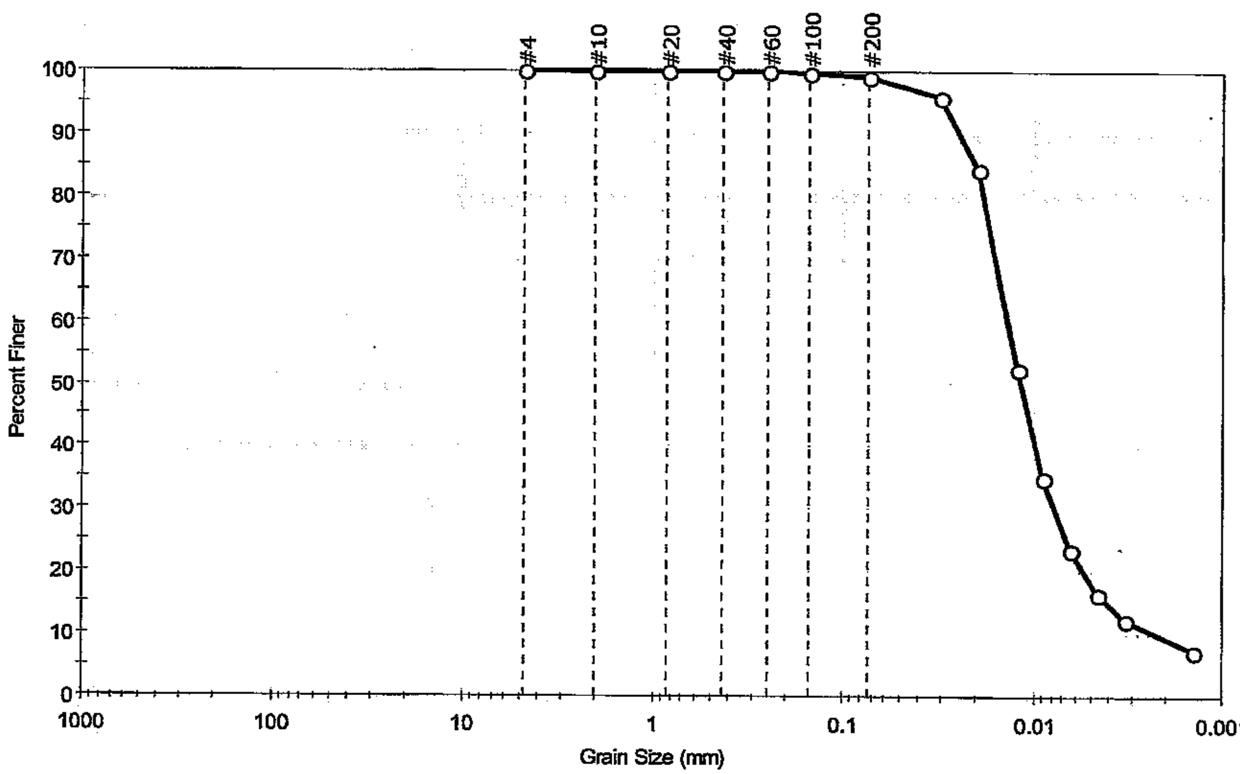
GeoTesting express
a subsidiary of Geocomp Corporation

Client:	Parsons Engineering Science				
Project:	Onondaga				
Location:	Syracuse			Project No:	GTX-7143
Boring ID:	OL-VC-40018	Sample Type:	jar	Tested By:	mll
Sample ID:	OL-0286-04	Test Date:	02/08/07	Checked By:	jdt
Depth :	0-3.3 ft	Test Id:	105899		
Test Comment:	---				
Sample Description:	Wet, dark gray silt				
Sample Comment:	---				

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



% Cobble	% Gravel	% Sand	% Silt & Clay Size
—	0.0	1.0	99.0

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
#4	4.75	100		
#10	2.00	100		
#20	0.84	100		
#40	0.42	100		
#60	0.25	100		
#100	0.15	100		
#200	0.074	99		
—	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0308	96		
---	0.0197	84		
---	0.0122	53		
---	0.0089	35		
---	0.0065	24		
---	0.0046	16		
---	0.0033	12		
---	0.0014	8		

Coefficients

D_{85} =0.0202 mm　D_{30} =0.0077 mm
D_{60} =0.0136 mm　D_{15} =0.0041 mm
D_{50} =0.0116 mm　D_{10} =0.0022 mm
C_u =N/A　C_c =N/A

Classification

ASTM　elastic silt (MH)

AASHTO　Clayey Soils (A-7-5 (18))

Sample/Test Description

Sand/Gravel Particle Shape : ANGULAR
Sand/Gravel Hardness : HARD

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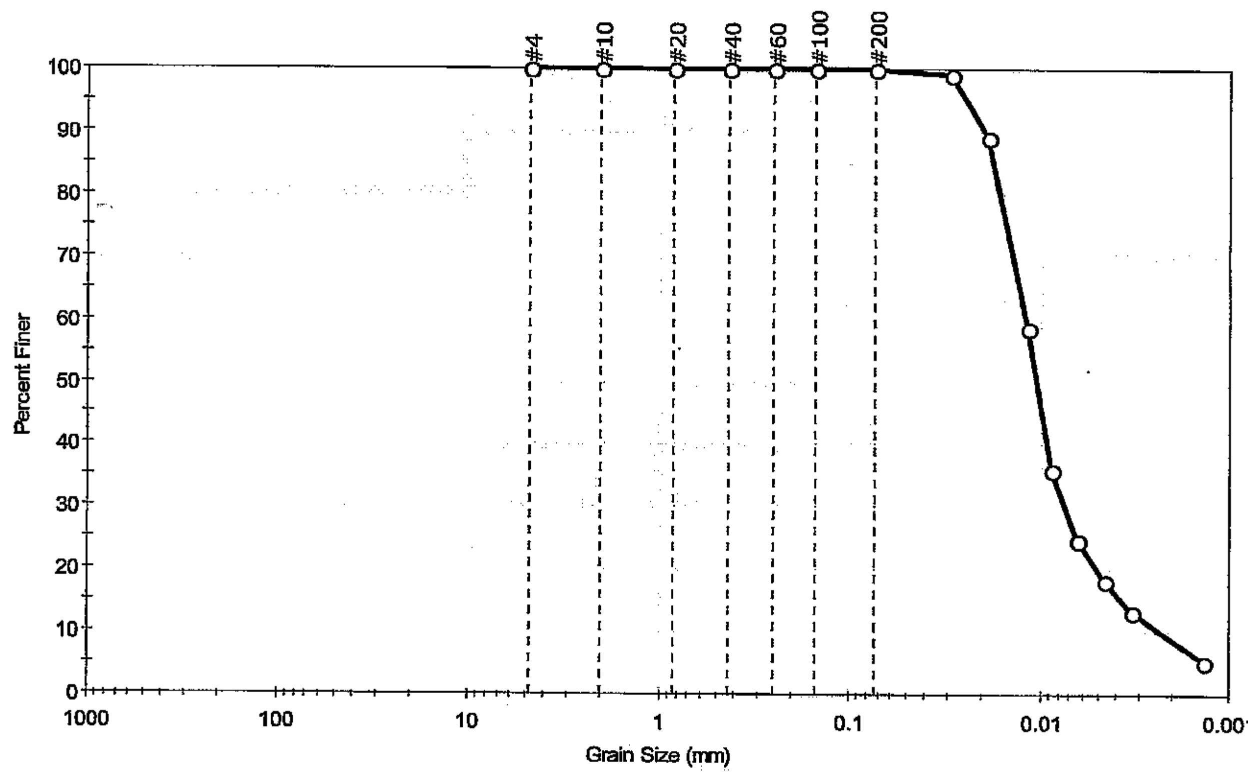
GeoTesting express
a subsidiary of Geocomp Corporation

Client:	Parsons Engineering Science		
Project:	Onondaga		
Location:	Syracuse	Project No:	GTX-7143
Boring ID: OL-VC-40018	Sample Type: jar	Tested By:	mll
Sample ID:OL-0286-05	Test Date: 02/06/07	Checked By:	jdt
Depth : 6.6-9.9 ft	Test Id: 105900		
Test Comment:	---		
Sample Description:	Wet, dark gray silt		
Sample Comment:	---		

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



% Cobble	% Gravel	% Sand	% Silt & Clay Size
—	0.0	0.1	99.9

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
#4	4.75	100		
#10	2.00	100		
#20	0.84	100		
#40	0.42	100		
#60	0.25	100		
#100	0.15	100		
#200	0.074	100		
---	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0294	99		
---	0.0187	89		
---	0.0117	59		
---	0.0088	36		
---	0.0064	25		
---	0.0046	18		
---	0.0033	13		
---	0.0014	5		

Coefficients

D_{85} =0.0176 mm	D_{30} =0.0074 mm
D_{60} =0.0120 mm	D_{15} =0.0037 mm
D_{50} =0.0105 mm	D_{10} =0.0023 mm
C_u =N/A	C_c =N/A

Classification

ASTM elastic silt (MH)

AASHTO Clayey Soils (A-7-5 (26))

Sample/Test Description

Sand/Gravel Particle Shape : ANGULAR

Sand/Gravel Hardness : HARD

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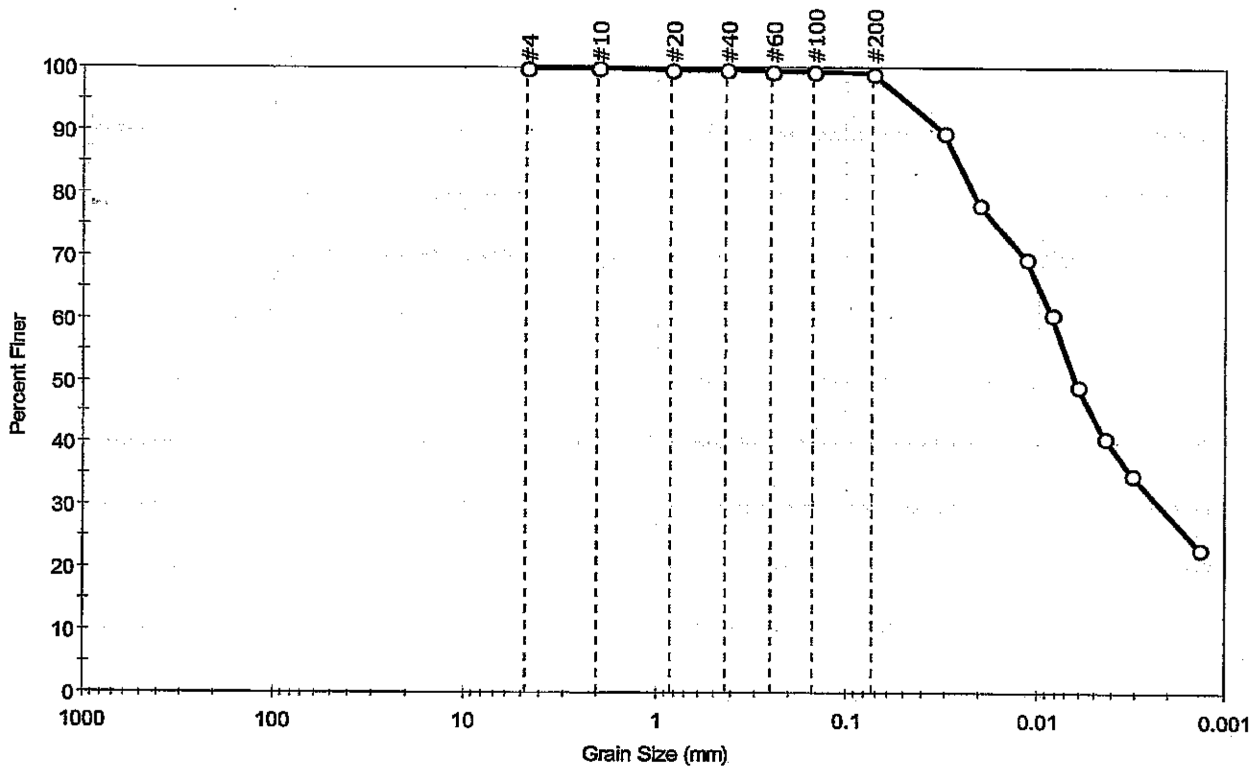
Client: Parsons Engineering Science			
Project: Onondaga			
Location: Syracuse		Project No:	GTX-7143
Boring ID: OL-VC-40018	Sample Type: jar	Tested By:	mll
Sample ID:OL-0286-06	Test Date: 02/08/07	Checked By:	jdt
Depth : 16.5-18.6 ft	Test Id: 105901		
Test Comment: ---			
Sample Description: Moist, olive brown silt			
Sample Comment: ---			

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



% Cobble	% Gravel	% Sand	% Silt & Clay Size
—	0.0	0.8	99.2

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
#4	4.75	100		
#10	2.00	100		
#20	0.84	100		
#40	0.42	100		
#60	0.25	100		
#100	0.15	99		
#200	0.074	99		
---	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0314	90		
---	0.0200	78		
---	0.0115	69		
---	0.0084	61		
---	0.0061	49		
---	0.0044	41		
---	0.0031	35		
---	0.0014	23		

Coefficients

D_{85} =0.0263 mm D_{30} =0.0022 mm
D_{60} =0.0082 mm D_{15} =N/A
D_{50} =0.0062 mm D_{10} =N/A
C_u =N/A C_c =N/A

Classification

ASTM elastic silt (MH)

AASHTO Clayey Soils (A-7-5 (80))

Sample/Test Description

Sand/Gravel Particle Shape : ANGULAR

Sand/Gravel Hardness : HARD

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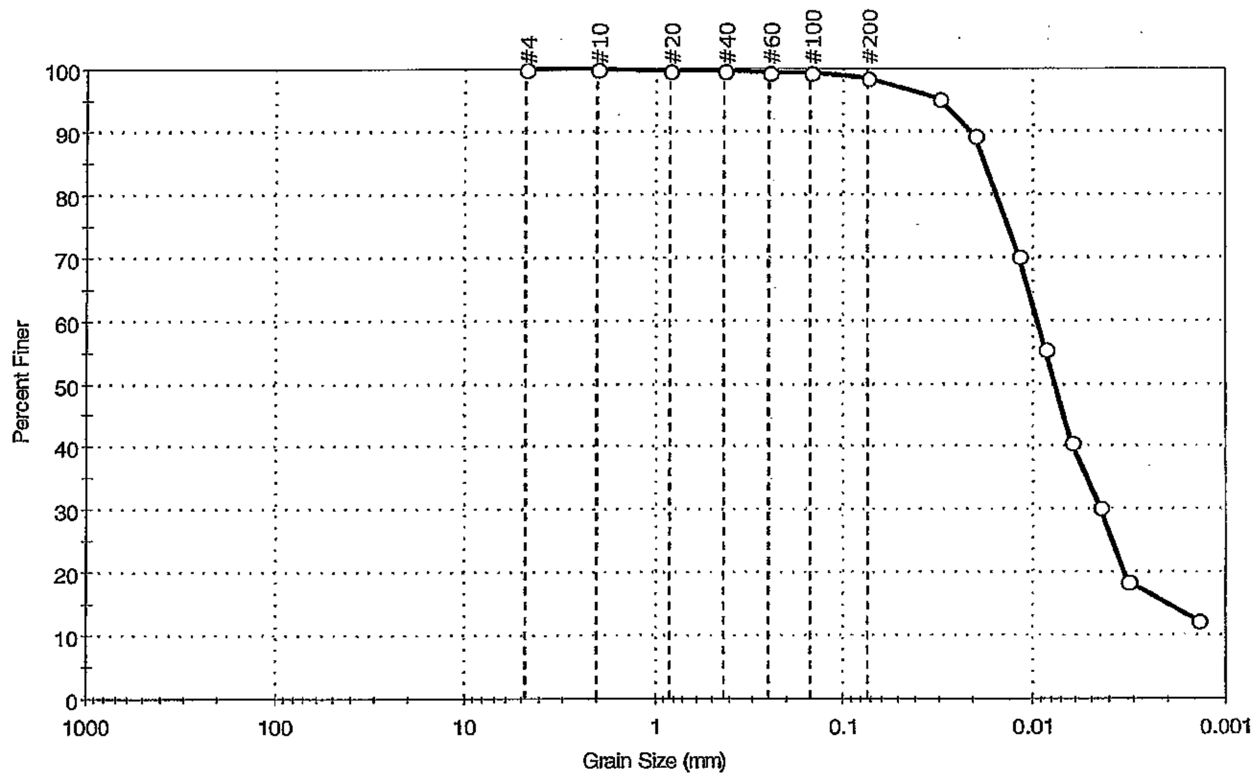
Client:	Parsons Engineering Science				
Project:	Onondaga				
Location:	Syracuse			Project No:	GTX-7143
Boring ID:	OL-VC-40019	Sample Type:	jar	Tested By:	mll
Sample ID:	OL-0288-07	Test Date:	02/09/07	Checked By:	jdt
Depth :	0.5-3.3 ft	Test Id:	106006		

Test Comment: ---
Sample Description: Wet, dark gray silt
Sample Comment: ---

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



% Cobble	% Gravel	% Sand	% Silt & Clay Size
—	0.0	1.5	98.5

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
#4	4.75	100		
#10	2.00	100		
#20	0.84	100		
#40	0.42	100		
#60	0.25	100		
#100	0.15	99		
#200	0.074	98		
---	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0306	95		
---	0.0195	89		
---	0.0117	70		
---	0.0085	55		
---	0.0062	41		
---	0.0045	30		
---	0.0033	18		
---	0.0014	12		

Coefficients

D_{85} =0.0174 mm D_{30} =0.0045 mm
D_{60} =0.0094 mm D_{15} =0.0020 mm
D_{50} =0.0076 mm D_{10} =0.0010 mm
C_u =N/A C_c =N/A

Classification

ASTM   elastic silt (MH)

AASHTO   Clayey Soils (A-7-5 (25))

Sample/Test Description

Sand/Gravel Particle Shape : ANGULAR
Sand/Gravel Hardness : HARD

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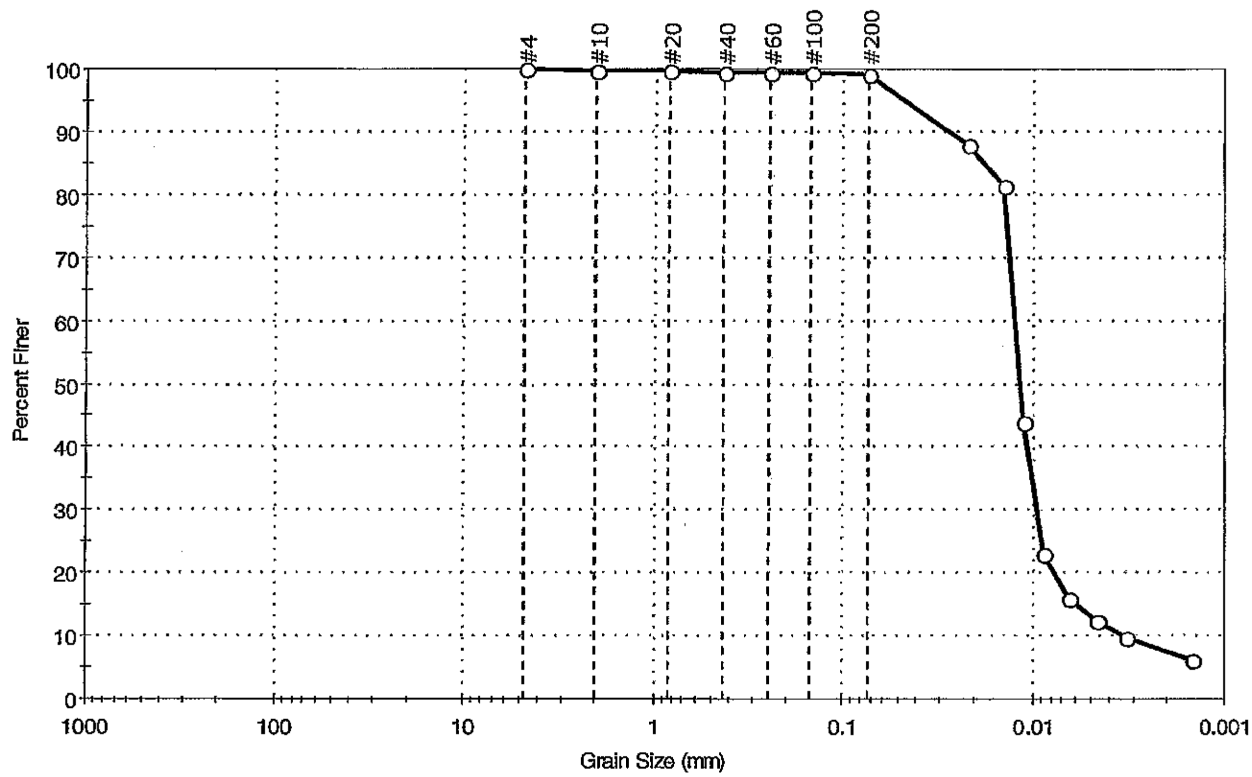
Client:	Parsons Engineering Science				
Project:	Onondaga				
Location:	Syracuse			Project No:	GTX-7143
Boring ID:	OL-VC-40019	Sample Type:	jar	Tested By:	mll
Sample ID:	OL-0288-08	Test Date:	02/09/07	Checked By:	jdt
Depth :	9.9-13.2 ft	Test Id:	106007		
Test Comment:	---				
Sample Description:	Wet, dark gray silt				
Sample Comment:	---				

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



% Cobble	% Gravel	% Sand	% Silt & Clay Size
—	0.0	1.0	99.0

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
#4	4.75	100		
#10	2.00	100		
#20	0.84	100		
#40	0.42	100		
#60	0.25	99		
#100	0.15	99		
#200	0.074	99		
---	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0215	88		
---	0.0142	81		
---	0.0111	44		
---	0.0088	23		
---	0.0064	16		
---	0.0046	12		
---	0.0033	10		
---	0.0015	6		

Coefficients

D_{85} = 0.0180 mm	D_{30} = 0.0095 mm
D_{60} = 0.0123 mm	D_{15} = 0.0059 mm
D_{50} = 0.0115 mm	D_{10} = 0.0034 mm
C_u = N/A	C_c = N/A

Classification

ASTM elastic silt (MH)

AASHTO Clayey Soils (A-7-5 (23))

Sample/Test Description

Sand/Gravel Particle Shape : ANGULAR

Sand/Gravel Hardness : HARD

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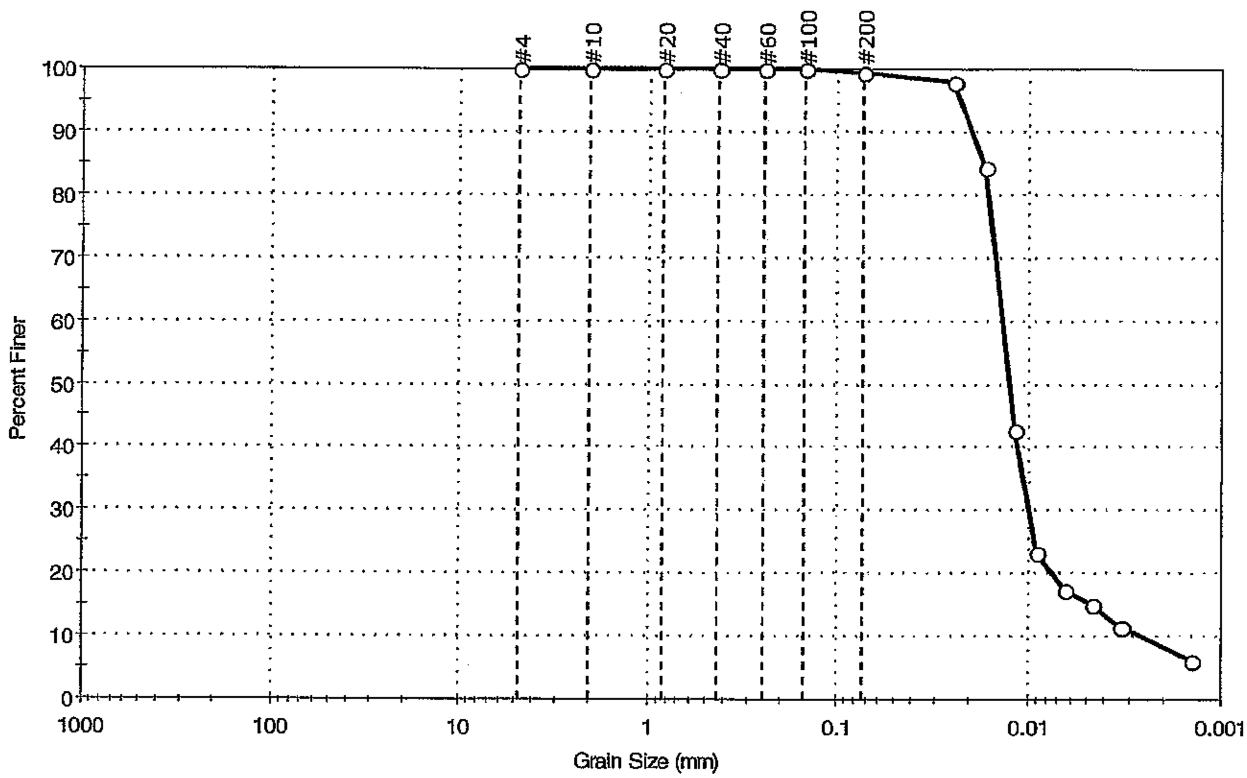
Client:	Parsons Engineering Science				
Project:	Onondaga				
Location:	Syracuse			Project No:	GTX-7143
Boring ID:	OL-VC-40019	Sample Type:	jar	Tested By:	mll
Sample ID:	OL-0288-09	Test Date:	02/09/07	Checked By:	jdt
Depth :	16.5-19.8 ft	Test Id:	106008		
Test Comment:	---				
Sample Description:	Moist, gray silt				
Sample Comment:	---				

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



% Cobble	% Gravel	% Sand	% Silt & Clay Size
---	0.0	0.6	99.4

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
#4	4.75	100		
#10	2.00	100		
#20	0.84	100		
#40	0.42	100		
#60	0.25	100		
#100	0.15	100		
#200	0.074	99		
---	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0242	98		
---	0.0166	84		
---	0.0117	43		
---	0.0090	23		
---	0.0065	17		
---	0.0046	15		
---	0.0033	12		
---	0.0014	6		

Coefficients

D_{85} =0.0170 mm	D_{30} =0.0098 mm
D_{60} =0.0136 mm	D_{15} =0.0046 mm
D_{50} =0.0125 mm	D_{10} =0.0026 mm
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 : ANGULAR

Sand/Gravel Hardness : HARD

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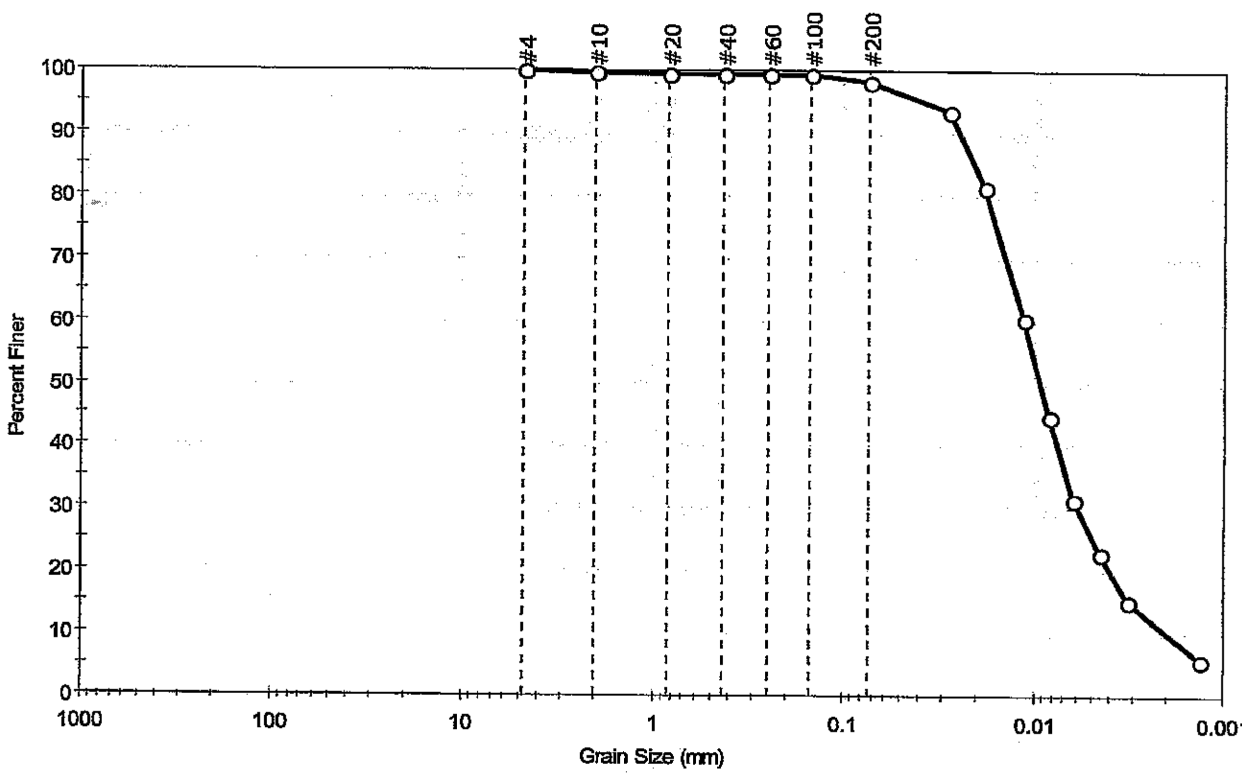
Client:	Parsons Engineering Science				
Project:	Onondaga				
Location:	Syracuse			Project No:	GTX-7143
Boring ID:	OL-VC-40021	Sample Type:	jar	Tested By:	mll
Sample ID:	OL-0286-02	Test Date:	02/07/07	Checked By:	jdt
Depth :	0.5-3.3 ft	Test Id:	105897		

Test Comment: ---
Sample Description: Wet, very dark gray silt
Sample Comment: ---

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



% Cobble	% Gravel	% Sand	% Silt & Clay Size
—	0.0	1.7	98.3

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
#4	4.75	100		
#10	2.00	100		
#20	0.84	100		
#40	0.42	100		
#60	0.25	99		
#100	0.15	99		
#200	0.074	98		
---	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0284	94		
---	0.0185	81		
---	0.0114	60		
---	0.0084	45		
---	0.0062	32		
---	0.0045	23		
---	0.0032	15		
---	0.0013	6		

Coefficients

D_{85} =0.0210 mm	D_{30} =0.0058 mm
D_{60} =0.0114 mm	D_{15} =0.0032 mm
D_{50} =0.0093 mm	D_{10} =0.0020 mm
C_u =N/A	C_c =N/A

Classification

ASTM elastic silt (MH)

AASHTO Clayey Soils (A-7-5 (29))

Sample/Test Description

Sand/Gravel Particle Shape : ANGULAR

Sand/Gravel Hardness : HARD

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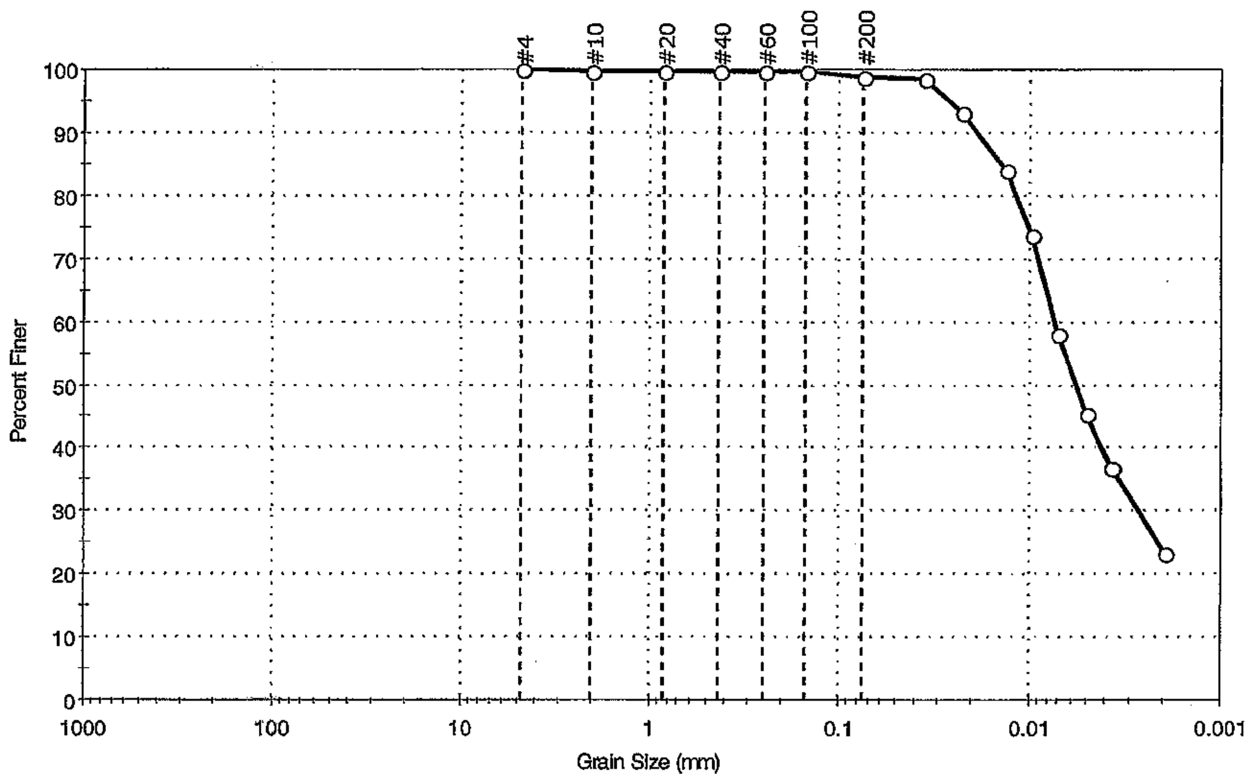
Client:	Parsons Engineering Science				
Project:	Onondaga				
Location:	Syracuse			Project No:	GTX-7143
Boring ID:	OL-0302-07	Sample Type:	jar	Tested By:	mll
Sample ID:	OL-VC-40021	Test Date:	06/08/07	Checked By:	jdt
Depth :	3.3-6.6 ft	Test Id:	111438		

Test Comment: ---
Sample Description: Wet, mottled yellowish brown and very dark gray clay
Sample Comment: ---

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



% Cobble	% Gravel	% Sand	% Silt & Clay Size
—	0.0	1.2	98.8

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
#4	4.75	100		
#10	2.00	100		
#20	0.84	100		
#40	0.42	100		
#60	0.25	100		
#100	0.15	100		
#200	0.075	99		
---	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0360	98		
---	0.0226	93		
---	0.0130	84		
---	0.0096	74		
---	0.0071	58		
---	0.0050	45		
---	0.0037	37		
---	0.0019	23		

Coefficients

D_{85} =0.0138 mm	D_{30} =0.0027 mm
D_{60} =0.0074 mm	D_{15} =N/A
D_{50} =0.0056 mm	D_{10} =N/A
C_u =N/A	C_c =N/A

Classification

ASTM fat clay (CH)

AASHTO Clayey Soils (A-7-6 (31))

Sample/Test Description

Sand/Gravel Particle Shape : ROUNDED

Sand/Gravel Hardness : HARD

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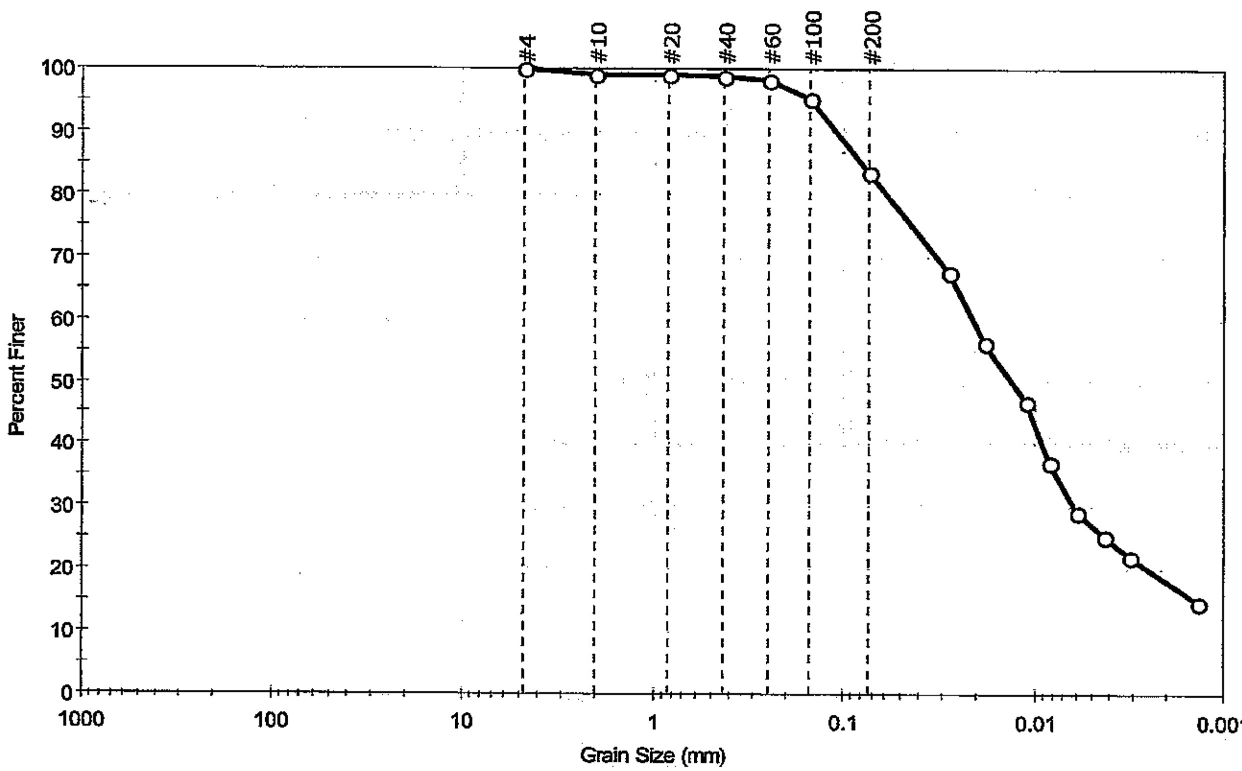
Client:	Parsons Engineering Science				
Project:	Onondaga				
Location:	Syracuse			Project No:	GTX-7143
Boring ID:	OL-VC-40021	Sample Type:	jar	Tested By:	mll
Sample ID:	OL-0286-03	Test Date:	02/08/07	Checked By:	jdt
Depth :	13.2-16.5 ft	Test Id:	105898		
Test Comment:	---				
Sample Description:	Moist, dark olive gray silt with sand				
Sample Comment:	---				

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



% Cobble	% Gravel	% Sand	% Silt & Clay Size
---	0.0	16.5	83.5

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
#4	4.75	100		
#10	2.00	99		
#20	0.84	99		
#40	0.42	99		
#60	0.25	98		
#100	0.15	95		
#200	0.074	84		
---	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0285	68		
---	0.0185	56		
---	0.0113	47		
---	0.0083	37		
---	0.0061	29		
---	0.0043	25		
---	0.0031	22		
---	0.0014	15		

Coefficients

D_{85} =0.0808 mm	D_{30} =0.0062 mm
D_{60} =0.0213 mm	D_{15} =0.0014 mm
D_{50} =0.0133 mm	D_{10} =0.0008 mm
C_u =N/A	C_c =N/A

Classification

ASTM elastic silt with sand (MH)

AASHTO Clayey Soils (A-7-5 (29))

Sample/Test Description

Sand/Gravel Particle Shape : ANGULAR

Sand/Gravel Hardness : HARD

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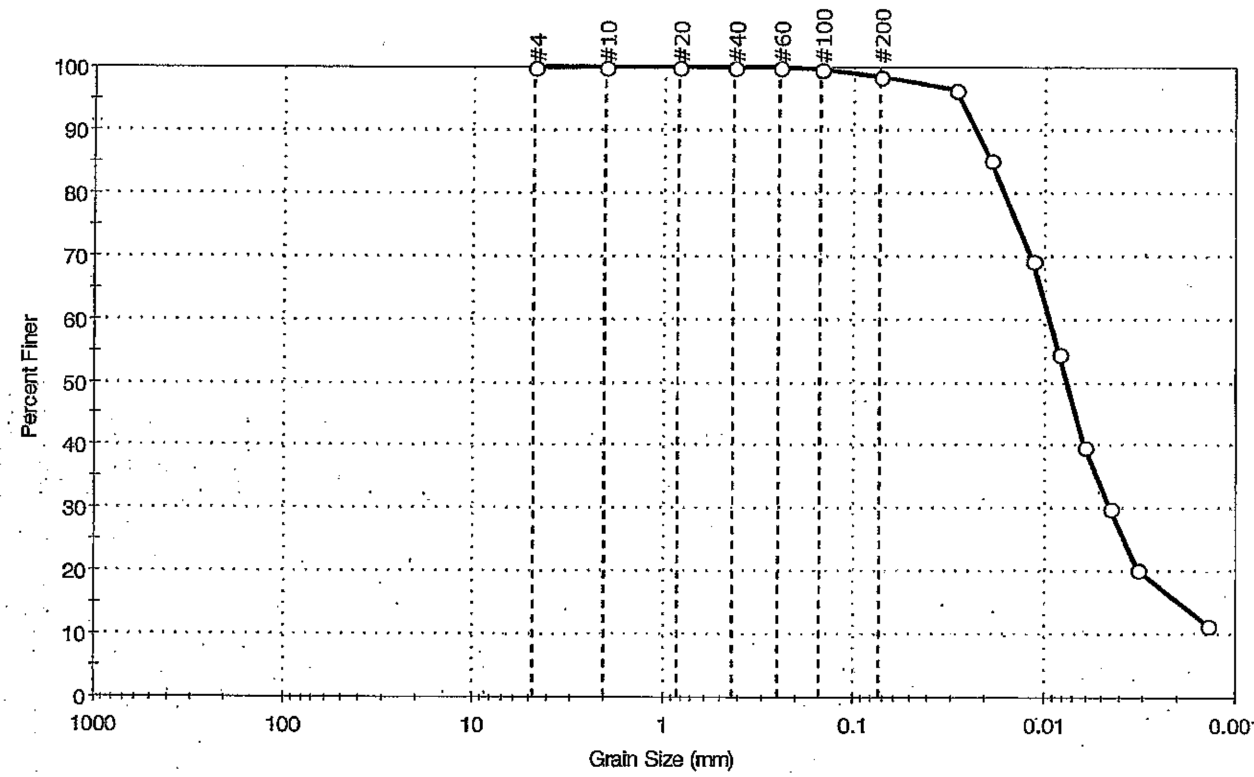
Client: Parsons Engineering Science			
Project: Onondaga			
Location: Syracuse		Project No:	GTX-7143
Boring ID: OL-VC-40022	Sample Type: jar	Tested By:	mll
Sample ID: OL-0288-05	Test Date: 02/09/07	Checked By:	jdt
Depth : 0.5-3.3 ft	Test Id: 106004		
Test Comment: ---			
Sample Description: Moist, dark gray silt			
Sample Comment: ---			

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



% Cobble	% Gravel	% Sand	% Silt & Clay Size
—	0.0	1.6	98.4

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
#4	4.75	100		
#10	2.00	100		
#20	0.84	100		
#40	0.42	100		
#60	0.25	100		
#100	0.15	100		
#200	0.074	98		
---	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0290	96		
---	0.0189	85		
---	0.0114	69		
---	0.0084	55		
---	0.0061	40		
---	0.0044	30		
---	0.0032	20		
---	0.0014	12		

Coefficients

D_{85} =0.0187 mm D_{30} =0.0044 mm
D_{60} =0.0094 mm D_{15} =0.0019 mm
D_{50} =0.0076 mm D_{10} =0.0012 mm
C_u =N/A C_c =N/A

Classification

ASTM elastic silt (MH)

AASHTO Clayey Soils (A-7-5 (28))

Sample/Test Description

Sand/Gravel Particle Shape : ANGULAR

Sand/Gravel Hardness : HARD

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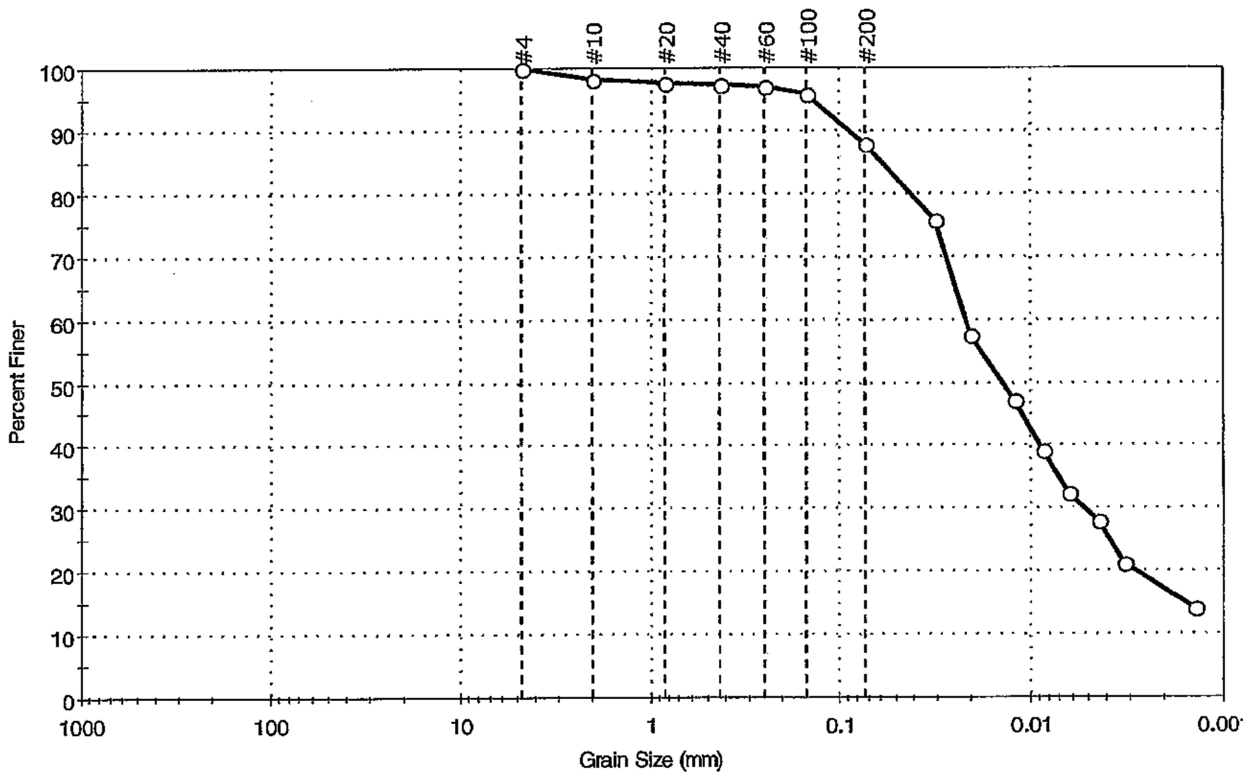
Client:	Parsons Engineering Science				
Project:	Onondaga				
Location:	Syracuse			Project No:	GTX-7143
Boring ID:	OL-VC-40022	Sample Type:	jar	Tested By:	mll
Sample ID:	OL-0288-06	Test Date:	02/09/07	Checked By:	jdt
Depth :	13.2-16.5 ft	Test Id:	106005		
Test Comment:	---				
Sample Description:	Wet, dark brown silt				
Sample Comment:	---				

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



% Cobble	% Gravel	% Sand	% Silt & Clay Size
—	0.0	12.1	87.9

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
#4	4.75	100		
#10	2.00	98		
#20	0.84	98		
#40	0.42	97		
#60	0.25	97		
#100	0.15	96		
#200	0.074	88		
---	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0308	76		
---	0.0203	58		
---	0.0119	47		
---	0.0086	39		
---	0.0062	33		
---	0.0044	28		
---	0.0032	21		
---	0.0014	14		

Coefficients

D_{85} =0.0600 mm D_{30} =0.0051 mm
D_{60} =0.0214 mm D_{15} =0.0015 mm
D_{50} =0.0137 mm D_{10} =0.0008 mm
C_u =N/A C_c =N/A

Classification

ASTM elastic silt (MH)

AASHTO Clayey Soils (A-7-5 (46))

Sample/Test Description

Sand/Gravel Particle Shape : ANGULAR

Sand/Gravel Hardness : HARD

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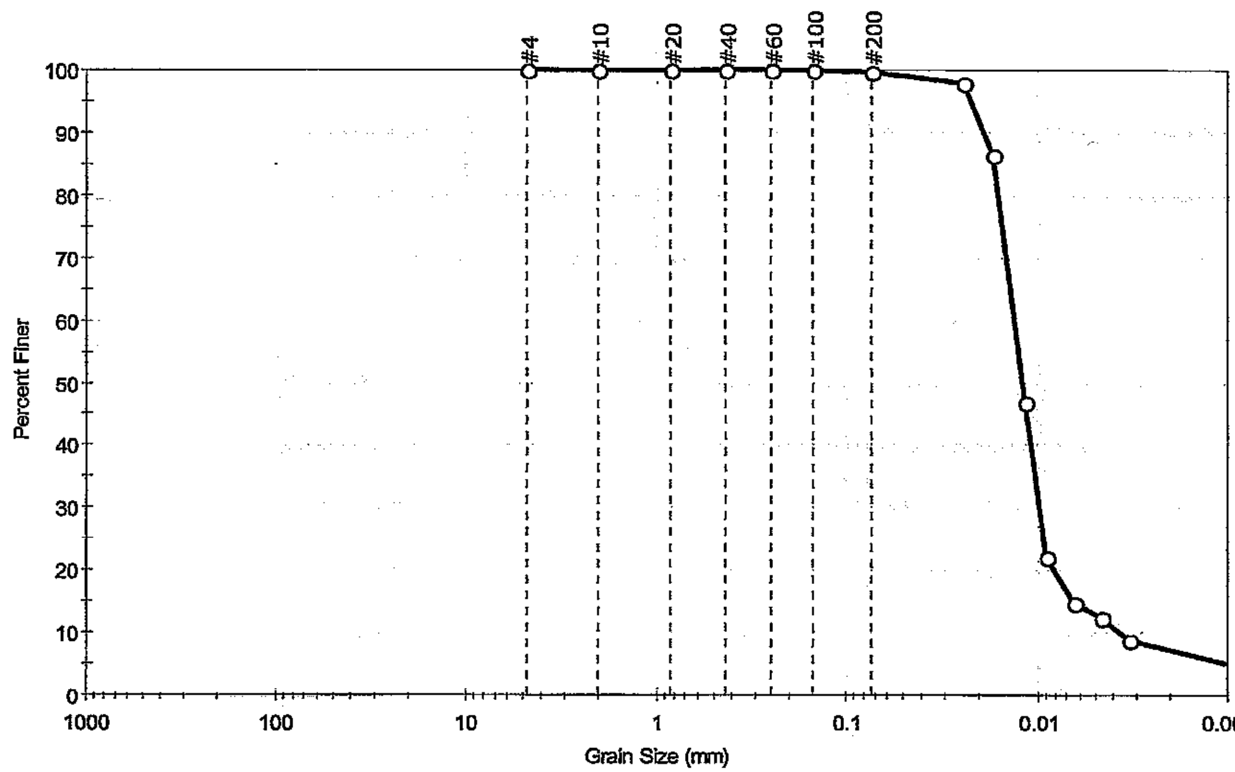
Client:	Parsons Engineering Science				
Project:	Onondaga				
Location:	Syracuse			Project No:	GTX-7143
Boring ID:	OL-VC-40023	Sample Type:	jar	Tested By:	mll
Sample ID:	OL-0285-18	Test Date:	02/05/07	Checked By:	jdt
Depth :	3.3-6.6 ft	Test Id:	105848		
Test Comment:	---				
Sample Description:	Wet, very dark gray silt				
Sample Comment:	----				

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



% Cobble	% Gravel	% Sand	% Silt & Clay Size
—	0.0	0.4	99.6

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
#4	4.75	100		
#10	2.00	100		
#20	0.84	100		
#40	0.42	100		
#60	0.25	100		
#100	0.15	100		
#200	0.074	100		
---	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0244	98		
---	0.0169	86		
---	0.0116	47		
---	0.0090	22		
---	0.0064	15		
---	0.0046	12		
---	0.0033	9		
---	0.0008	4		

Coefficients

D_{85} =0.0167 mm
D_{30} =0.0097 mm
D_{60} =0.0131 mm
D_{15} =0.0065 mm
D_{50} =0.0119 mm
D_{10} =0.0037 mm
C_u =N/A
C_c =N/A

Classification

ASTM elastic silt (MH)

AASHTO Clayey Soils (A-7-5 (39))

Sample/Test Description

Sand/Gravel Particle Shape : ANGULAR

Sand/Gravel Hardness : HARD

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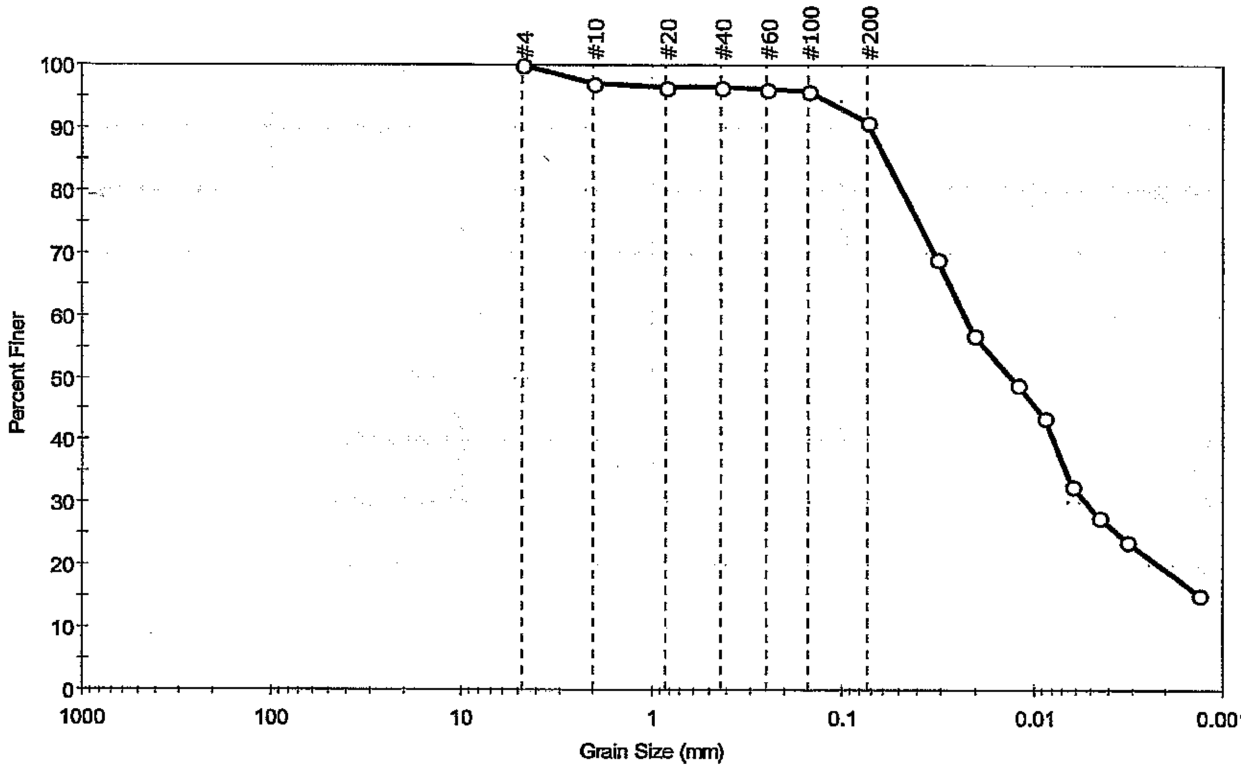
Client: Parsons Engineering Science			
Project: Onondaga			
Location: Syracuse		Project No:	GTX-7143
Boring ID: OL-VC-40023	Sample Type: jar	Tested By:	mll
Sample ID: OL-0285-19	Test Date: 02/07/07	Checked By:	jdt
Depth : 13.2-16.5 ft	Test Id: 105849		
Test Comment: ---			
Sample Description: Moist, dark brown silt			
Sample Comment: ---			

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



% Cobble	% Gravel	% Sand	% Silt & Clay Size
—	0.0	9.2	90.8

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
#4	4.75	100		
#10	2.00	97		
#20	0.84	97		
#40	0.42	96		
#60	0.25	96		
#100	0.15	96		
#200	0.074	91		
---	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0322	69		
---	0.0209	57		
---	0.0122	49		
---	0.0087	44		
---	0.0063	33		
---	0.0045	28		
---	0.0032	24		
---	0.0013	15		

Coefficients

D_{85} =0.0593 mm D_{30} =0.0052 mm
D_{60} =0.0233 mm D_{15} =N/A
D_{50} =0.0132 mm D_{10} =N/A
C_u =N/A C_c =N/A

Classification

ASTM elastic silt (MH)

AASHTO Clayey Soils (A-7-5 (57))

Sample/Test Description

Sand/Gravel Particle Shape : ANGULAR

Sand/Gravel Hardness : HARD

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Sample information for the feasibility study

Sample Number	Station ID	Date	Sample ID	Field Rep	Upper Depth (m)	Lower Depth (m)	Core Length	Data Package ID
SB0019	S344	07/27/00	SB0019	1	0.3	1	2M	K2005759
SB0020	S344	07/27/00	SB0020		1	2	2M	K2005759
SB0029	S338	08/03/00	SB0029		0.3	1.3	2M	K2005951
SB0030	S338	08/03/00	SB0030		1.3	2	2M	K2005951
SB0031	S339	08/03/00	SB0031		0.3	1	2M	K2005951
SB0032	S339	08/03/00	SB0032		1	1.68	2M	K2005951
SB0033	S340	08/03/00	SB0033		0.3	1	2M	K2005951
SB0034	S340	08/03/00	SB0034		1	2	2M	K2005951
SB0037	S342	07/27/00	SB0037		0.3	1	2M	K2005759
SB0038	S342	07/27/00	SB0038		1	2	2M	K2005759
SB0039	S343	08/04/00	SB0039	1	0.3	1	2M	K2005960
SB0040	S343	08/04/00	SB0040		1	2	2M	K2005960
SB0045	S346	08/04/00	SB0045		0.3	1.6	2M	K2005960
SB0046	S346	08/04/00	SB0046		1.6	2	2M	K2005960
SB0047	S347	08/04/00	SB0047		0.3	1	2M	K2005960
SB0048	S347	08/04/00	SB0048		1	2	2M	K2005960
SB0049	S348	08/05/00	SB0049		0.3	1.1	2M	K2006045
SB0050	S348	08/05/00	SB0050		1.1	2	2M	K2006045
SB0053	S350	08/05/00	SB0053		0.3	0.92	2M	K2006045
SB0054	S350	08/05/00	SB0054	1	0.92	2	2M	K2006045
SB0055	S351	08/05/00	SB0055		0.3	1	2M	K2006045
SB0056	S351	08/05/00	SB0056		1	2	2M	K2006045
SB0057	S352	08/10/00	SB0057		0.3	1	2M	K2006154
SB0058	S352	08/10/00	SB0058		1	2	2M	K2006154
SB0063	S341	08/04/00	SB0063		0.3	0.85	2M	K2005960
SB0064	S341	08/04/00	SB0064		0.85	1.6	2M	K2005960
SB0067	S350	08/05/00	SB0054	2	0.92	2	2M	K2006045
SB0070	S344	07/27/00	SB0019	2	0.3	1	2M	K2005759
SF0049	S302	08/14/00	SF0049		0.15	0.3	8M	K2006427
SF0062	S309	08/14/00	SF0062		0	0.15	8M	K2006427
SF0063	S309	08/14/00	SF0063		0.15	0.3	8M	K2006427
SF0064	S310	08/14/00	SF0064		0	0.15	8M	K2006427
SF0065	S310	08/14/00	SF0065		0.15	0.3	8M	K2006427
SF0068	S312	08/14/00	SF0068		0	0.15	8M	K2006427
SF0069	S312	08/14/00	SF0069		0.15	0.3	8M	K2006427
SF0072	S314	08/10/00	SF0072		0	0.15	8M	K2006154
SF0073	S314	08/10/00	SF0073		0.15	0.3	8M	K2006154
SF0075	S315	08/14/00	SF0075		0.15	0.3	8M	K2006427
SF0112	S344	07/27/00	SF0112		0.15	0.3	2M	K2005759
SF0119	S341	08/04/00	SF0119		1.6	2	2M	K2005960
SF0121	S338	08/03/00	SF0121		0	0.15	2M	K2005951
SF0123_E	S339	08/03/00	SF0123_E		1.68	2	2M	K2005951
SF0123	S340	08/15/00	SF0123	1	0	0.02	2M	K2006339
SF0123_R	S340	08/15/00	SF0123	2	0	0.02	2M	K2006412
SF0124	S339	08/03/00	SF0124		0	0.15	2M	K2005951
SF0125	S339	08/03/00	SF0125		0.15	0.3	2M	K2005951
SF0126	S340	08/03/00	SF0126		0	0.15	2M	K2005951
SF0127	S340	08/03/00	SF0127		0.15	0.3	2M	K2005951

Sample information for the feasibility study (cont.)

Sample Number	Station ID	Date	Sample ID	Field Rep	Upper Depth (m)	Lower Depth (m)	Core Length	Data Package ID
SF0128	S341	08/04/00	SF0128		0	0.15	2M	K2005960
SF0129	S341	08/04/00	SF0129		0.15	0.3	2M	K2005960
SF0130_T	S342	08/10/00	SF0130_T		0	0.15	2M	K2006154
SF0131	S342	07/27/00	SF0131		0.15	0.3	2M	K2005759
SF0132	S343	08/04/00	SF0132		0	0.15	2M	K2005960
SF0133	S343	08/04/00	SF0133		0.15	0.3	2M	K2005960
SF0138	S346	08/04/00	SF0138		0	0.15	2M	K2005960
SF0139	S346	08/04/00	SF0139		0.15	0.3	2M	K2005960
SF0140	S347	08/04/00	SF0140		0	0.15	2M	K2005960
SF0141	S347	08/04/00	SF0141		0.15	0.3	2M	K2005960
SF0142	S348	08/05/00	SF0142		0	0.15	2M	K2006045
SF0143	S348	08/05/00	SF0143		0.15	0.3	2M	K2006045
SF0146	S350	08/05/00	SF0146		0	0.15	2M	K2006045
SF0147	S350	08/05/00	SF0147		0.15	0.3	2M	K2006045
SF0149	S351	08/05/00	SF0149		0	0.15	2M	K2006045
SF0151	S352	08/10/00	SF0151		0	0.15	2M	K2006154
SF0152	S352	08/10/00	SF0152		0.15	0.3	2M	K2006154
SF0167	S343	08/04/00	SB0039	2	0.3	1	2M	K2005960
SF0173	S351	08/15/00	SF0173		0	0.02	2M	K2006339
VC0009	S302	07/22/00	VC0009		0.3	0.59	8M	K2005515
VC0010	S302	07/22/00	VC0010		0.59	1.59	8M	K2005515
VC0011	S302	07/22/00	VC0011		1.59	2.59	8M	K2005515
VC0012	S302	07/22/00	VC0012		2.59	3.59	8M	K2005515
VC0013	S302	07/22/00	VC0013		3.59	4.59	8M	K2005515
VC0014	S302	07/22/00	VC0014		4.59	5.59	8M	K2005515
VC0015	S302	07/22/00	VC0015		5.59	6.59	8M	K2005515
VC0016	S302	07/22/00	VC0016		6.59	7.61	8M	K2005515
VC0065	S309	07/20/00	VC0065		0.74	1.74	8M	K2005510
VC0066	S309	07/20/00	VC0066	1	1.74	2.74	8M	K2005510
VC0067	S309	07/20/00	VC0067		2.74	3.74	8M	K2005510
VC0068	S309	07/20/00	VC0068		3.74	4.74	8M	K2005510
VC0069	S309	07/20/00	VC0069		4.74	5.78	8M	K2005510
VC0070	S309	07/20/00	VC0070		5.78	6.27	8M	K2005510
VC0071	S309	07/20/00	VC0071		6.27	6.74	8M	K2005510
VC0072	S309	07/20/00	VC0072		6.74	6.96	8M	K2005510
VC0073	S310	07/20/00	VC0073		0.3	1	8M	K2005510
VC0074	S310	07/20/00	VC0074		1	2	8M	K2005510
VC0075	S310	07/20/00	VC0075		2	3	8M	K2005510
VC0076	S310	07/20/00	VC0076	1	3	4	8M	K2005510
VC0077	S310	07/20/00	VC0077		4	5	8M	K2005510
VC0078	S310	07/20/00	VC0078		5	6	8M	K2005510
VC0079	S310	07/20/00	VC0079		6	6.53	8M	K2005510
VC0080	S310	07/20/00	VC0080		6.53	7.24	8M	K2005510
VC0081	S311	07/20/00	VC0081		0.3	1	8M	K2005510
VC0082	S311	07/20/00	VC0082		1	2	8M	K2005510
VC0083	S311	07/20/00	VC0083		2	3	8M	K2005510
VC0084	S311	07/20/00	VC0084		3	4	8M	K2005510
VC0085	S311	07/20/00	VC0085		4	5	8M	K2005510

S302

COLUMBIA ANALYTICAL SERVICES, INC.

Analytical Report

Client: Exponent Environmental Group, Inc.
Project: OL RI/FS Phase 2A / 8600BCP.003.0801
Sample Matrix: Sediment

Service Request: K2006427
Date Collected: 8/14/00
Date Received: 8/15/00
Date Analyzed: 8/28/00

Particle Size Determination
ASTM Method D 422

Sample Name: SF0049
Lab Code: K2006427-001

Gravel and Sand
(Sieve Analysis)

Description	Sieve Size	Weight (g)	Percent Passing
Gravel	No.3/4"(19.0 mm)	0.0000	100
Gravel	No.3/8"(9.50 mm)	0.0000	100
Medium Gravel	No.4 (4.75 mm)	0.0000	100
Fine Gravel	No.10 (2.00 mm)	0.0000	100
Very Coarse Sand	No.20 (0.850 mm)	0.0134	100
Coarse Sand	No.40 (0.425 mm)	0.0375	99.9
Medium Sand	No.60 (0.250 mm)	0.0421	99.8
Fine Sand	No.140 (0.106 mm)	0.3127	99.2
Very Fine Sand	No.200 (0.0750 mm)	0.7894	97.6

Silt and Clay
(Hydrometer Analysis)

Particle Diameter	Percent Passing
0.074 mm	97.5
0.005 mm	27.2
0.001 mm	7.5

Approved By: ______________________ Date: ____________
1A/102094

		Sample Name:	**SF0049**		
		Lab Code:	**K2006427-001**		
		X	**Y**		
		arithmetic	**logarithmic**	**Convert Y**	**Value of Y**
		Percent Passing	**Particle Diameter**	**mm to nm**	**Log form**
Sieve		**(%)**	**(mm)**	**(nm)**	**(log)**
3/4"		100.0	19.0	19000000	7.279
3/8"		100.0	9.5	9500000	6.978
4		100.0	4.75	4750000	6.677
10		100.0	2.00	2000000	6.301
20		100.0	0.850	850000	5.929
40		99.9	0.425	425000	5.628
60		99.8	0.250	250000	5.398
140		99.2	0.106	106000	5.025
200		97.6	0.0750	75000	4.875
2		84.7	0.0298	29817.64788	4.474
5		74.7	0.0197	19668.92627	4.294
15		56.8	0.0122	12152.91898	4.085
30		46.8	0.0089	8891.101637	3.949
60		32.9	0.0066	6570.336525	3.818
250		18.9	0.0034	3351.87589	3.525
1440		11.0	0.0014	1445.048639	3.160
	determined hydrometer				
		mm	**mm to nm**	**log hyd x**	**% Passing**
		0.074	74000	4.87	97.5
		0.005	5000	3.70	27.2
		0.001	1000	3.00	7.5

COLUMBIA ANALYTICAL SERVICES, INC.

Analytical Report

Client: Exponent Environmental Group, Inc.
Project: OL RI/FS Phase 2A / 8600BCP.003.0801
Sample Matrix: Soil

Service Request: K2005515
Date Collected: 7/22/00
Date Received: 7/23/00
Date Analyzed: 8/1/00

Particle Size Determination
ASTM Method D 422

Sample Name: VC0009
Lab Code: K2005515-001

Gravel and Sand
(Sieve Analysis)

Description	Sieve Size	Weight (g)	Percent Passing
Gravel	No.3/4"(19.0 mm)	0.0000	100
Gravel	No.3/8"(9.50 mm)	0.0000	100
Medium Gravel	No.4 (4.75 mm)	0.0000	100
Fine Gravel	No.10 (2.00 mm)	0.0000	100
Very Coarse Sand	No.20 (0.850 mm)	0.0216	100
Coarse Sand	No.40 (0.425 mm)	0.0311	99.9
Medium Sand	No.60 (0.250 mm)	0.1538	99.6
Fine Sand	No.140 (0.106 mm)	2.0186	95.4
Very Fine Sand	No.200 (0.0750 mm)	0.4355	94.5

Silt and Clay
(Hydrometer Analysis)

Particle Diameter	Percent Passing
0.074 mm	94.4
0.005 mm	31.5
0.001 mm	0.9

Approved By: ______________________________ Date: ______________
1A/102094

		Sample Name:	VC0009		
		Lab Code:	K2005515-001		
		X	Y		
		arithmetic	logarithmic	Convert Y	Value of Y
		Percent Passing	Particle Diameter	mm to nm	Log form
Sieve		(%)	(mm)	(nm)	(log)
3/4"		100.0	19.0	19000000	7.279
3/8"		100.0	9.5	9500000	6.978
4		100.0	4.75	4750000	6.677
10		100.0	2.00	2000000	6.301
20		100.0	0.850	850000	5.929
40		99.9	0.425	425000	5.628
60		99.6	0.250	250000	5.398
140		95.4	0.106	106000	5.025
200		94.5	0.0750	75000	4.875
2		84.1	0.0299	29879.29106	4.475
5		79.9	0.0192	19215.27494	4.284
15		69.5	0.0115	11540.10016	4.062
30		57.1	0.0085	8523.259038	3.931
60		40.5	0.0064	6353.132941	3.803
250		15.6	0.0033	3260.324769	3.513
1440		5.2	0.0014	1411.435279	3.150
	determined hydrometer				
		mm	mm to nm	log hyd x	% Passing
		0.074	74000	4.87	94.4
		0.005	5000	3.70	31.5
		0.001	1000	3.00	0.9

COLUMBIA ANALYTICAL SERVICES, INC.

Analytical Report

Client: Exponent Environmental Group, Inc.
Project: OL RI/FS Phase 2A / 8600BCP.003.0801
Sample Matrix: Soil

Service Request: K2005515
Date Collected: 7/22/00
Date Received: 7/23/00
Date Analyzed: 8/1/00

Particle Size Determination
ASTM Method D 422

Sample Name: VC0010
Lab Code: K2005515-002

Gravel and Sand
(Sieve Analysis)

Description	Sieve Size	Weight (g)	Percent Passing
Gravel	No.3/4"(19.0 mm)	0.0000	100
Gravel	No.3/8"(9.50 mm)	0.0000	100
Medium Gravel	No.4 (4.75 mm)	0.0000	100
Fine Gravel	No.10 (2.00 mm)	0.0000	100
Very Coarse Sand	No.20 (0.850 mm)	0.0790	99.8
Coarse Sand	No.40 (0.425 mm)	0.0175	99.8
Medium Sand	No.60 (0.250 mm)	0.0143	99.8
Fine Sand	No.140 (0.106 mm)	0.1276	99.5
Very Fine Sand	No.200 (0.0750 mm)	0.0924	99.3

Silt and Clay
(Hydrometer Analysis)

Particle Diameter	Percent Passing
0.074 mm	99.3
0.005 mm	42.3
0.001 mm	5.7

Approved By: ______________________________ Date: ______________
1A/102094

		Sample Name:	VC0010		
		Lab Code:	K2005515-002		
		X	Y		
		arithmetic	logarithmic	Convert Y	Value of Y
		Percent Passing	Particle Diameter	mm to nm	Log form
Sieve		(%)	(mm)	(nm)	(log)
3/4"		100.0	19.0	19000000	7.279
3/8"		100.0	9.5	9500000	6.978
4		100.0	4.75	4750000	6.677
10		100.0	2.00	2000000	6.301
20		99.8	0.850	850000	5.929
40		99.8	0.425	425000	5.628
60		99.8	0.250	250000	5.398
140		99.5	0.106	106000	5.025
200		99.3	0.0750	75000	4.875
2		95.7	0.0277	27714.38682	4.443
5		93.7	0.0177	17696.05135	4.248
15		79.6	0.0109	10871.33239	4.036
30		65.5	0.0081	8123.679121	3.910
60		49.4	0.0061	6077.881238	3.784
250		25.2	0.0031	3132.614125	3.496
1440		11.1	0.0014	1372.851548	3.138
	determined hydrometer				
		mm	mm to nm	log hyd x	% Passing
		0.074	74000	4.87	99.3
		0.005	5000	3.70	42.3
		0.001	1000	3.00	5.7

COLUMBIA ANALYTICAL SERVICES, INC.

Analytical Report

Client: Exponent Environmental Group, Inc.
Project: OL RI/FS Phase 2A / 8600BCP.003.0801
Sample Matrix: Soil

Service Request: K2005515
Date Collected: 7/22/00
Date Received: 7/23/00
Date Analyzed: 8/1/00

Particle Size Determination
ASTM Method D 422

Sample Name: VC0011
Lab Code: K2005515-003

Gravel and Sand
(Sieve Analysis)

Description	Sieve Size	Weight (g)	Percent Passing
Gravel	No.3/4"(19.0 mm)	0.0000	100
Gravel	No.3/8"(9.50 mm)	0.0000	100
Medium Gravel	No.4 (4.75 mm)	0.0000	100
Fine Gravel	No.10 (2.00 mm)	0.0000	100
Very Coarse Sand	No.20 (0.850 mm)	0.1104	99.8
Coarse Sand	No.40 (0.425 mm)	0.0261	99.7
Medium Sand	No.60 (0.250 mm)	0.0240	99.7
Fine Sand	No.140 (0.106 mm)	0.3896	98.9
Very Fine Sand	No.200 (0.0750 mm)	0.1652	98.6

Silt and Clay
(Hydrometer Analysis)

Particle Diameter	Percent Passing
0.074 mm	98.5
0.005 mm	34.4
0.001 mm	9.6

Approved By: ______________________ Date: ____________
1A/102094

		Sample Name:	**VC0011**		
		Lab Code:	**K2005515-003**		
		X	**Y**		
		arithmetic	**logarithmic**	**Convert Y**	**Value of Y**
		Percent Passing	**Particle Diameter**	**mm to nm**	**Log form**
Sieve		**(%)**	**(mm)**	**(nm)**	**(log)**
3/4"		100.0	19.0	19000000	7.279
3/8"		100.0	9.5	9500000	6.978
4		100.0	4.75	4750000	6.677
10		100.0	2.00	2000000	6.301
20		99.8	0.850	850000	5.929
40		99.7	0.425	425000	5.628
60		99.7	0.250	250000	5.398
140		98.9	0.106	106000	5.025
200		98.6	0.0750	75000	4.875
2		96.0	0.0275	27547.13969	4.440
5		87.9	0.0181	18080.77989	4.257
15		71.8	0.0112	11160.46415	4.048
30		57.6	0.0083	8312.410396	3.920
60		43.5	0.0062	6160.939584	3.790
250		15.2	0.0032	3201.991671	3.505
1440		11.1	0.0014	1364.565565	3.135
	determined hydrometer				
		mm	**mm to nm**	**log hyd x**	**% Passing**
		0.074	74000	4.87	98.5
		0.005	5000	3.70	34.4
		0.001	1000	3.00	9.6

COLUMBIA ANALYTICAL SERVICES, INC.

Analytical Report

Client:	Exponent Environmental Group, Inc.	**Service Request:**	K2005515
Project:	OL RI/FS Phase 2A / 8600BCP.003.0801	**Date Collected:**	7/22/00
Sample Matrix:	Soil	**Date Received:**	7/23/00
		Date Analyzed:	8/1/00

Particle Size Determination
ASTM Method D 422

Sample Name: VC0012
Lab Code: K2005515-004

Gravel and Sand
(Sieve Analysis)

Description	Sieve Size	Weight (g)	Percent Passing
Gravel	No.3/4"(19.0 mm)	0.0000	100
Gravel	No.3/8"(9.50 mm)	0.0000	100
Medium Gravel	No.4 (4.75 mm)	0.0000	100
Fine Gravel	No.10 (2.00 mm)	0.0000	100
Very Coarse Sand	No.20 (0.850 mm)	0.0771	99.8
Coarse Sand	No.40 (0.425 mm)	0.0331	99.8
Medium Sand	No.60 (0.250 mm)	0.0220	99.7
Fine Sand	No.140 (0.106 mm)	0.1143	99.5
Very Fine Sand	No.200 (0.0750 mm)	0.2011	99.1

Silt and Clay
(Hydrometer Analysis)

Particle Diameter	Percent Passing
0.074 mm	99.0
0.005 mm	20.5
0.001 mm	5.2

Approved By: ______________________________ Date: ______________
1A/102094

		Sample Name:	**VC0012**		
		Lab Code:	**K2005515-004**		
		X	**Y**		
		arithmetic	**logarithmic**	**Convert Y**	**Value of Y**
		Percent Passing	**Particle Diameter**	**mm to nm**	**Log form**
Sieve		**(%)**	**(mm)**	**(nm)**	**(log)**
3/4"		100.0	19.0	19000000	7.279
3/8"		100.0	9.5	9500000	6.978
4		100.0	4.75	4750000	6.677
10		100.0	2.00	2000000	6.301
20		99.8	0.850	850000	5.929
40		99.8	0.425	425000	5.628
60		99.7	0.250	250000	5.398
140		99.5	0.106	106000	5.025
200		99.1	0.0750	75000	4.875
2		92.1	0.0282	28242.94479	4.451
5		88.0	0.0182	18190.55385	4.260
15		69.8	0.0113	11315.68671	4.054
30		55.7	0.0084	8421.615721	3.925
60		21.2	0.0066	6621.319264	3.821
250		19.2	0.0032	3186.204417	3.503
1440		9.1	0.0014	1380.139373	3.140
	determined hydrometer				
		mm	**mm to nm**	**log hyd x**	**% Passing**
		0.074	74000	4.87	99.0
		0.005	5000	3.70	20.5
		0.001	1000	3.00	5.2

COLUMBIA ANALYTICAL SERVICES, INC.

Analytical Report

Client: Exponent Environmental Group, Inc.
Project: OL RI/FS Phase 2A / 8600BCP.003.0801
Sample Matrix: Soil

Service Request: K2005515
Date Collected: 7/22/00
Date Received: 7/23/00
Date Analyzed: 8/1/00

Particle Size Determination
ASTM Method D 422

Sample Name: VC0013
Lab Code: K2005515-005

Gravel and Sand
(Sieve Analysis)

Description	Sieve Size	Weight (g)	Percent Passing
Gravel	No.3/4"(19.0 mm)	0.0000	100
Gravel	No.3/8"(9.50 mm)	0.0000	100
Medium Gravel	No.4 (4.75 mm)	0.0000	100
Fine Gravel	No.10 (2.00 mm)	0.0000	100
Very Coarse Sand	No.20 (0.850 mm)	0.0162	100
Coarse Sand	No.40 (0.425 mm)	0.0129	99.9
Medium Sand	No.60 (0.250 mm)	0.0152	99.9
Fine Sand	No.140 (0.106 mm)	0.3340	99.2
Very Fine Sand	No.200 (0.0750 mm)	0.3723	98.5

Silt and Clay
(Hydrometer Analysis)

Particle Diameter	Percent Passing
0.074 mm	98.4
0.005 mm	40.8
0.001 mm	4.3

Approved By: ______________________ Date: __________

1A/102094

		Sample Name:	**VC0013**		
		Lab Code:	**K2005515-005**		
		X	**Y**		
		arithmetic	**logarithmic**	**Convert Y**	**Value of Y**
		Percent Passing	**Particle Diameter**	**mm to nm**	**Log form**
Sieve		**(%)**	**(mm)**	**(nm)**	**(log)**
3/4"		100.0	19.0	19000000	7.279
3/8"		100.0	9.5	9500000	6.978
4		100.0	4.75	4750000	6.677
10		100.0	2.00	2000000	6.301
20		100.0	0.850	850000	5.929
40		99.9	0.425	425000	5.628
60		99.9	0.250	250000	5.398
140		99.2	0.106	106000	5.025
200		98.5	0.0750	75000	4.875
2		92.7	0.0286	28583.8184	4.456
5		86.6	0.0186	18573.92893	4.269
15		74.3	0.0113	11274.5254	4.052
30		62.1	0.0083	8343.647298	3.921
60		49.9	0.0062	6151.237234	3.789
250		21.4	0.0032	3206.690693	3.506
1440		9.2	0.0014	1396.799311	3.145
	determined hydrometer				
		mm	**mm to nm**	**log hyd x**	**% Passing**
		0.074	74000	4.87	98.4
		0.005	5000	3.70	40.8
		0.001	1000	3.00	4.3

COLUMBIA ANALYTICAL SERVICES, INC.

Analytical Report

Client: Exponent Environmental Group, Inc.
Project: OL RI/FS Phase 2A / 8600BCP.003.0801
Sample Matrix: Soil

Service Request: K2005515
Date Collected: 7/22/00
Date Received: 7/23/00
Date Analyzed: 8/1/00

Particle Size Determination
ASTM Method D 422

Sample Name: VC0014
Lab Code: K2005515-006

Gravel and Sand
(Sieve Analysis)

Description	Sieve Size	Weight (g)	Percent Passing
Gravel	No.3/4"(19.0 mm)	0.0000	100
Gravel	No.3/8"(9.50 mm)	0.0000	100
Medium Gravel	No.4 (4.75 mm)	0.0000	100
Fine Gravel	No.10 (2.00 mm)	0.0000	100
Very Coarse Sand	No.20 (0.850 mm)	0.0918	99.8
Coarse Sand	No.40 (0.425 mm)	0.0290	99.8
Medium Sand	No.60 (0.250 mm)	0.0272	99.7
Fine Sand	No.140 (0.106 mm)	0.2194	99.3
Very Fine Sand	No.200 (0.0750 mm)	0.3263	98.6

Silt and Clay
(Hydrometer Analysis)

Particle Diameter	Percent Passing
0.074 mm	98.4
0.005 mm	45.5
0.001 mm	12.9

Approved By: ______________________________ Date: ____________
1A/102094

		Sample Name:	VC0014		
		Lab Code:	K2005515-006		
		X	Y		
		arithmetic	logarithmic	Convert Y	Value of Y
		Percent Passing	Particle Diameter	mm to nm	Log form
Sieve		(%)	(mm)	(nm)	(log)
3/4"		100.0	19.0	19000000	7.279
3/8"		100.0	9.5	9500000	6.978
4		100.0	4.75	4750000	6.677
10		100.0	2.00	2000000	6.301
20		99.8	0.850	850000	5.929
40		99.8	0.425	425000	5.628
60		99.7	0.250	250000	5.398
140		99.3	0.106	106000	5.025
200		98.6	0.0750	75000	4.875
2		88.4	0.0288	28761.79104	4.459
5		84.3	0.0185	18512.88543	4.267
15		72.2	0.0112	11228.22276	4.050
30		66.1	0.0081	8123.679121	3.910
60		51.8	0.0060	6037.19268	3.781
250		29.5	0.0031	3096.372023	3.491
1440		17.3	0.0014	1350.752171	3.131
	determined hydrometer				
		mm	mm to nm	log hyd x	% Passing
		0.074	74000	4.87	98.4
		0.005	5000	3.70	45.5
		0.001	1000	3.00	12.9

COLUMBIA ANALYTICAL SERVICES, INC.

Analytical Report

Client: Exponent Environmental Group, Inc.
Project: OL RI/FS Phase 2A / 8600BCP.003.0801
Sample Matrix: Soil

Service Request: K2005515
Date Collected: 7/22/00
Date Received: 7/23/00
Date Analyzed: 8/1/00

Particle Size Determination
ASTM Method D 422

Sample Name: VC0015
Lab Code: K2005515-007

Gravel and Sand
(Sieve Analysis)

Description	Sieve Size	Weight (g)	Percent Passing
Gravel	No.3/4"(19.0 mm)	0.0000	100
Gravel	No.3/8"(9.50 mm)	0.0000	100
Medium Gravel	No.4 (4.75 mm)	0.0000	100
Fine Gravel	No.10 (2.00 mm)	0.0000	100
Very Coarse Sand	No.20 (0.850 mm)	0.1298	99.7
Coarse Sand	No.40 (0.425 mm)	0.0901	99.6
Medium Sand	No.60 (0.250 mm)	0.0509	99.5
Fine Sand	No.140 (0.106 mm)	0.1416	99.2
Very Fine Sand	No.200 (0.0750 mm)	0.1273	98.9

Silt and Clay
(Hydrometer Analysis)

Particle Diameter	Percent Passing
0.074 mm	98.7
0.005 mm	48.3
0.001 mm	0.0

Approved By: ______________________ Date: ____________
1A/102094

		Sample Name:	VC0015		
		Lab Code:	K2005515-007		
		X	Y		
		arithmetic	logarithmic	Convert Y	Value of Y
		Percent Passing	Particle Diameter	mm to nm	Log form
Sieve		(%)	(mm)	(nm)	(log)
3/4"		100.0	19.0	19000000	7.279
3/8"		100.0	9.5	9500000	6.978
4		100.0	4.75	4750000	6.677
10		100.0	2.00	2000000	6.301
20		99.7	0.850	850000	5.929
40		99.6	0.425	425000	5.628
60		99.5	0.250	250000	5.398
140		99.2	0.106	106000	5.025
200		98.9	0.0750	75000	4.875
2		93.7	0.0508	50848.05736	4.706
5		91.7	0.0325	32461.45364	4.511
15		81.6	0.0196	19591.03504	4.292
30		75.5	0.0142	14201.13819	4.152
60		69.5	0.0103	10282.03104	4.012
250		51.4	0.0052	5243.167685	3.720
1440		25.2	0.0024	2396.711347	3.380
	determined hydrometer				
		mm	mm to nm	log hyd x	% Passing
		0.074	74000	4.87	98.7
		0.005	5000	3.70	48.3
		0.001	1000	3.00	-4.1

COLUMBIA ANALYTICAL SERVICES, INC.

Analytical Report

Client: Exponent Environmental Group, Inc.
Project: OL RI/FS Phase 2A / 8600BCP.003.0801
Sample Matrix: Soil

Service Request: K2005515
Date Collected: 7/22/00
Date Received: 7/23/00
Date Analyzed: 8/1/00

Particle Size Determination
ASTM Method D 422

Sample Name: VC0016
Lab Code: K2005515-008

Gravel and Sand
(Sieve Analysis)

Description	Sieve Size	Weight (g)	Percent Passing
Gravel	No.3/4"(19.0 mm)	0.0000	100
Gravel	No.3/8"(9.50 mm)	0.0000	100
Medium Gravel	No.4 (4.75 mm)	0.0000	100
Fine Gravel	No.10 (2.00 mm)	0.0000	100
Very Coarse Sand	No.20 (0.850 mm)	0.3423	99.3
Coarse Sand	No.40 (0.425 mm)	0.0571	99.2
Medium Sand	No.60 (0.250 mm)	0.0419	99.1
Fine Sand	No.140 (0.106 mm)	0.1223	98.9
Very Fine Sand	No.200 (0.0750 mm)	0.2449	98.4

Silt and Clay
(Hydrometer Analysis)

Particle Diameter	Percent Passing
0.074 mm	98.2
0.005 mm	51.2
0.001 mm	19.0

Approved By: ______________________ Date: ____________
1A/102094

		Sample Name:	**VC0016**		
		Lab Code:	**K2005515-008**		
		X	**Y**		
		arithmetic	**logarithmic**	**Convert Y**	**Value of Y**
		Percent Passing	**Particle Diameter**	**mm to nm**	**Log form**
Sieve		**(%)**	**(mm)**	**(nm)**	**(log)**
3/4"		100.0	19.0	19000000	7.279
3/8"		100.0	9.5	9500000	6.978
4		100.0	4.75	4750000	6.677
10		100.0	2.00	2000000	6.301
20		99.3	0.850	850000	5.929
40		99.2	0.425	425000	5.628
60		99.1	0.250	250000	5.398
140		98.9	0.106	106000	5.025
200		98.4	0.0750	75000	4.875
2		93.8	0.0508	50848.05736	4.706
5		87.7	0.0331	33057.79739	4.519
15		79.7	0.0198	19756.53444	4.296
30		73.6	0.0143	14315.31786	4.156
60		67.6	0.0104	10360.89582	4.015
250		51.4	0.0054	5374.878469	3.730
1440		35.3	0.0023	2326.771272	3.367
	determined hydrometer				
		mm	**mm to nm**	**log hyd x**	**% Passing**
		0.074	74000	4.87	98.2
		0.005	5000	3.70	51.2
		0.001	1000	3.00	19.0

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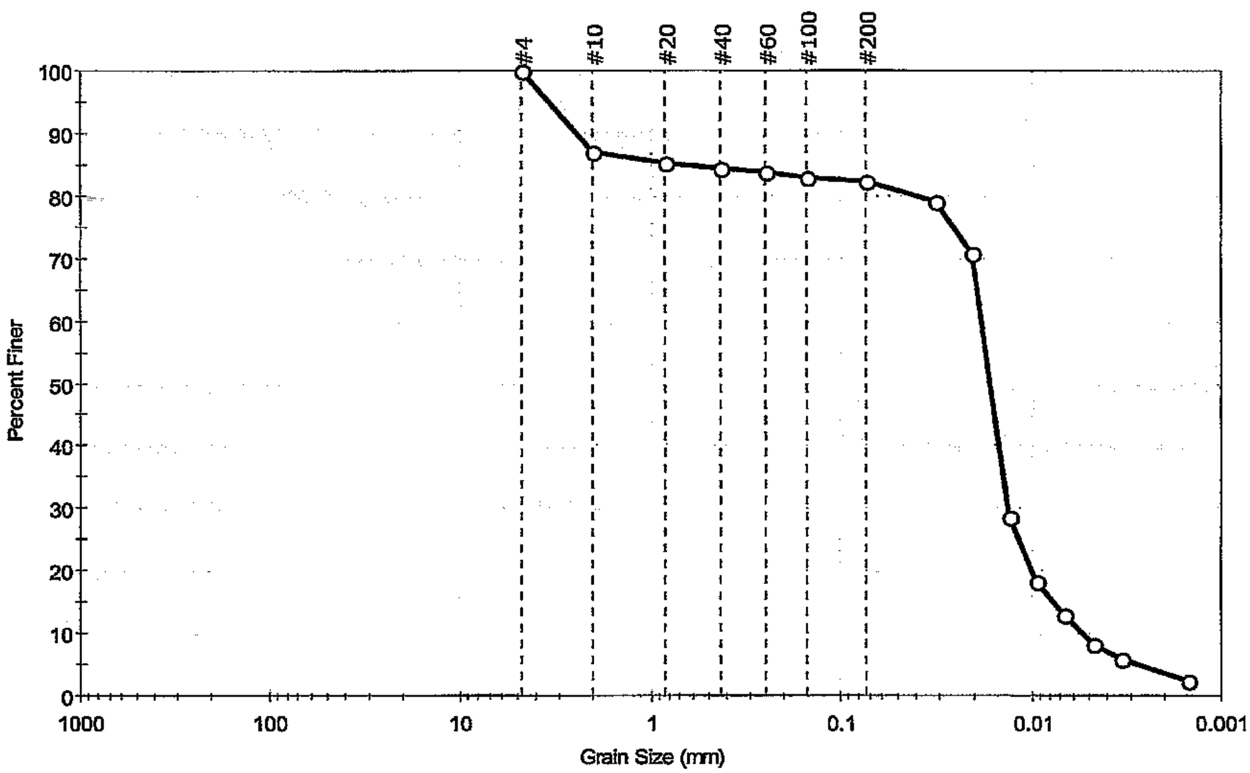
Client:	Parsons Engineering Science				
Project:	Onondaga				
Location:	Syracuse			Project No:	GTX-7143
Boring ID:	OL-VC-30034	Sample Type:	jar	Tested By:	mll
Sample ID:	OL-0285-13	Test Date:	02/06/07	Checked By:	jdt
Depth :	0.5-3.3 ft	Test Id:	105843		
Test Comment:	---				
Sample Description:	Moist, light gray silt with sand				
Sample Comment:	---				

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



% Cobble	% Gravel	% Sand	% Silt & Clay Size
—	0.0	17.8	82.2

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
#4	4.75	100		
#10	2.00	87		
#20	0.84	85		
#40	0.42	84		
#60	0.25	84		
#100	0.15	83		
#200	0.074	82		
---	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0321	79		
---	0.0209	71		
---	0.0131	29		
---	0.0094	18		
---	0.0067	13		
---	0.0048	8		
---	0.0034	6		
---	0.0015	2		

Coefficients

D_{85} =0.7678 mm D_{30} =0.0133 mm

D_{60} =0.0185 mm D_{15} =0.0077 mm

D_{50} =0.0166 mm D_{10} =0.0054 mm

C_u =N/A C_c =N/A

Classification

ASTM elastic silt with sand (MH)

AASHTO Clayey Soils (A-7-5 (59))

Sample/Test Description

Sand/Gravel Particle Shape : ANGULAR

Sand/Gravel Hardness : HARD

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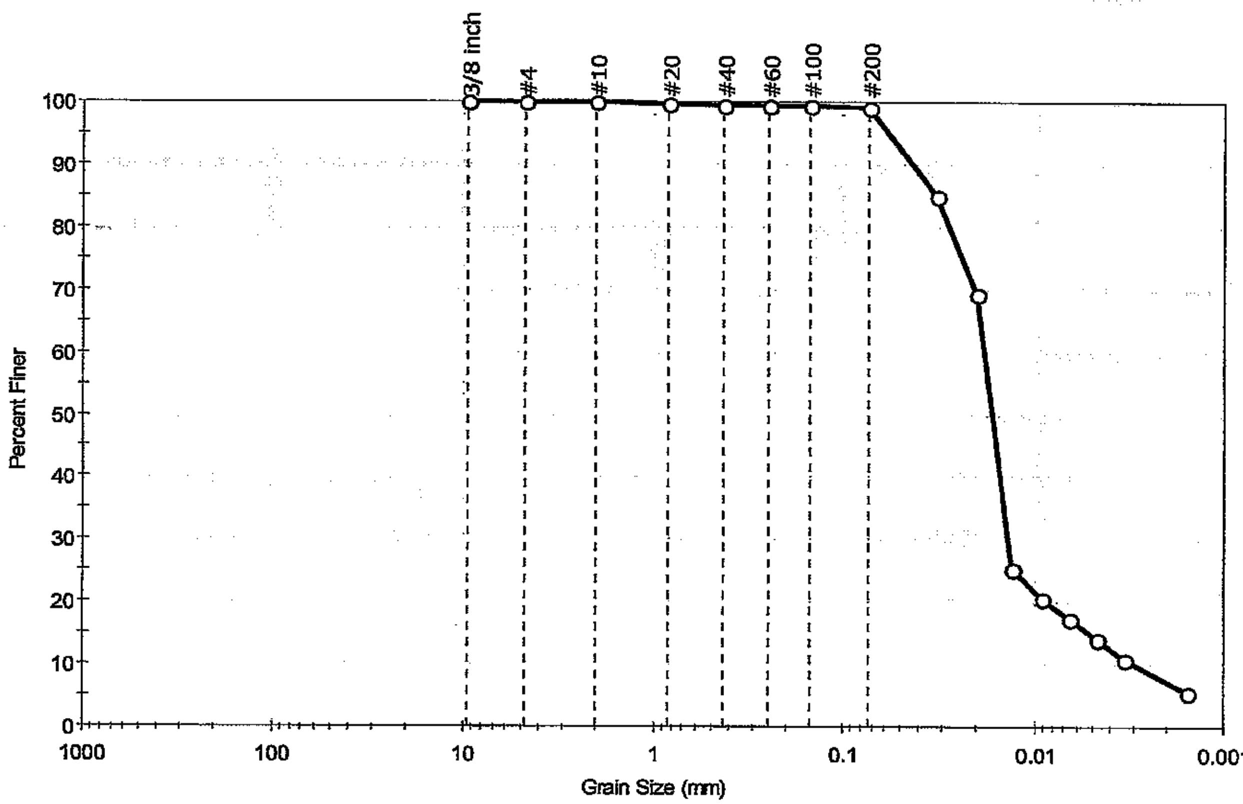
Client: Parsons Engineering Science			
Project: Onondaga			
Location: Syracuse		Project No:	GTX-7143
Boring ID: OL-VC-30034	Sample Type: jar	Tested By:	mll
Sample ID: OL-0285-14	Test Date: 02/06/07	Checked By:	jdt
Depth : 9.9-13.2 ft	Test Id: 105844		
Test Comment: ---			
Sample Description: Moist, white silt			
Sample Comment: ---			

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



% Cobble	% Gravel	% Sand	% Silt & Clay Size
—	0.0	0.9	99.1

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
3/8 inch	9.51	100		
#4	4.75	100		
#10	2.00	100		
#20	0.84	100		
#40	0.42	100		
#60	0.25	99		
#100	0.15	99		
#200	0.074	99		
---	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0326	85		
---	0.0204	69		
---	0.0131	25		
---	0.0093	21		
---	0.0066	17		
---	0.0047	14		
---	0.0033	11		
---	0.0016	6		

Coefficients

D_{85} =0.0327 mm D_{30} =0.0137 mm
D_{60} =0.0186 mm D_{15} =0.0051 mm
D_{50} =0.0168 mm D_{10} =0.0029 mm
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 : ANGULAR

Sand/Gravel Hardness : HARD

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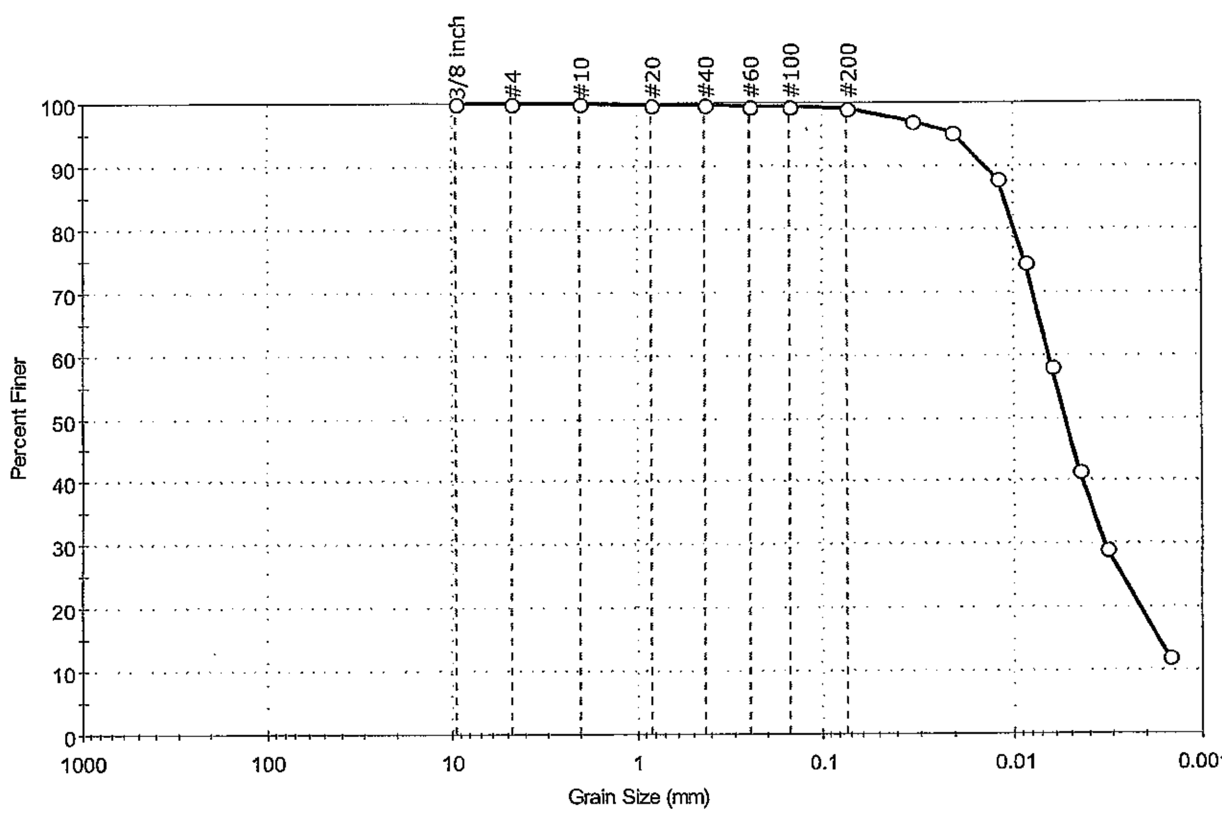
Client: Parsons Engineering Science			
Project: Onondaga			
Location: Syracuse		Project No:	GTX-7143
Boring ID: OL-VC-30035	Sample Type: jar	Tested By:	mll
Sample ID: OL-0282-18	Test Date: 01/30/07	Checked By:	jdt
Depth : 6.6-9.9 ft	Test Id: 105659		
Test Comment: ---			
Sample Description: Moist, white silt			
Sample Comment: ---			

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



% Cobble	% Gravel	% Sand	% Silt & Clay Size
—	0.0	0.9	99.1

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
3/8 inch	9.50	100		
#4	4.75	100		
#10	2.00	100		
#20	0.84	100		
#40	0.42	100		
#60	0.25	100		
#100	0.15	99		
#200	0.074	99		
---	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0334	97		
---	0.0207	95		
---	0.0120	88		
---	0.0086	75		
---	0.0063	58		
---	0.0045	42		
---	0.0032	29		
---	0.0015	12		

Coefficients

D_{85} = 0.0111 mm | D_{30} = 0.0033 mm

D_{60} = 0.0065 mm | D_{15} = 0.0017 mm

D_{50} = 0.0053 mm | D_{10} = 0.0014 mm

C_u = N/A | C_c = N/A

Classification

ASTM elastic silt (MH)

AASHTO Clayey Soils (A-7-5 (63))

Sample/Test Description

Sand/Gravel Particle Shape : ANGULAR

Sand/Gravel Hardness : HARD

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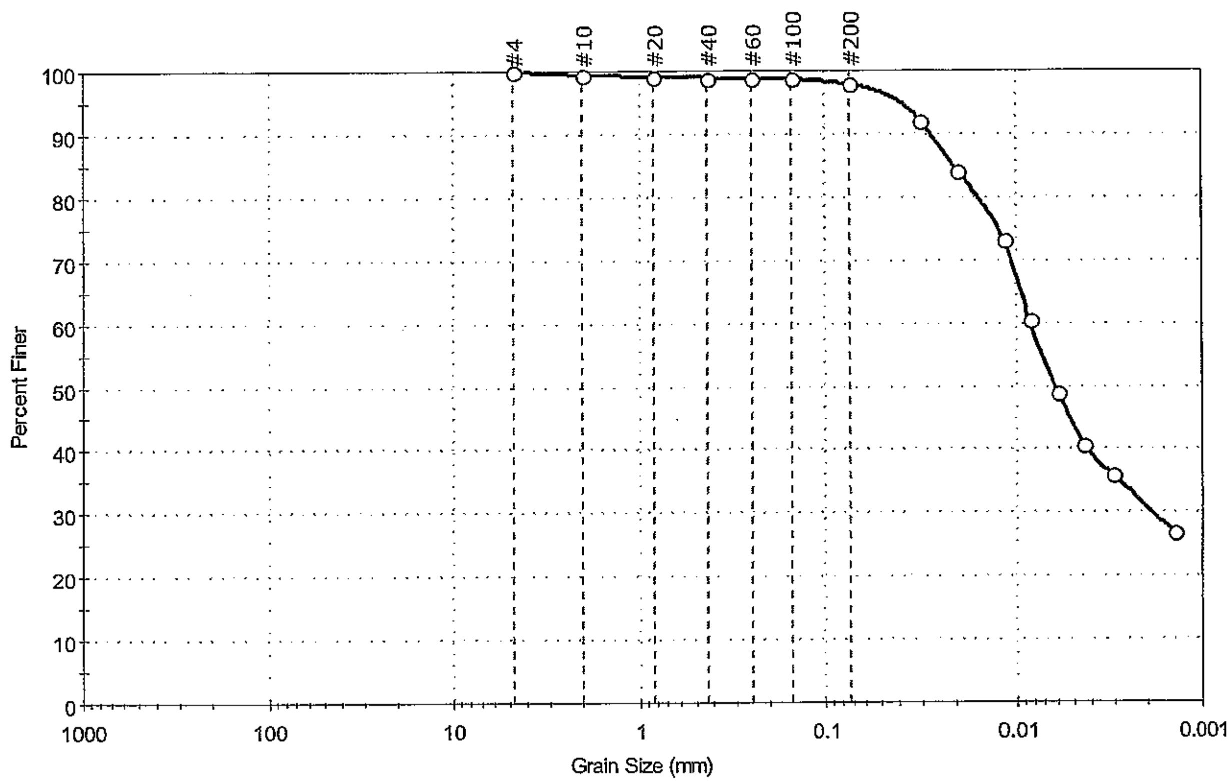
Client:	Parsons Engineering Science				
Project:	Onondaga				
Location:	Syracuse			Project No:	GTX-7143
Boring ID:	OL-VC-30035	Sample Type:	jar	Tested By:	mll
Sample ID:	OL-0282-19	Test Date:	01/30/07	Checked By:	jdt
Depth :	16.5-19.6 ft	Test Id:	105660		
Test Comment:	---				
Sample Description:	Moist, grayish 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	99		
#20	0.84	99		
#40	0.42	99		
#60	0.25	99		
#100	0.15	99		
#200	0.074	98		
---	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0307	92		
---	0.0195	84		
---	0.0115	73		
---	0.0084	60		
---	0.0059	49		
---	0.0044	41		
---	0.0031	36		
---	0.0014	27		

Coefficients

D_{85} =0.0207 mm　D_{30} =0.0019 mm

D_{60} =0.0083 mm　D_{15} =N/A

D_{50} =0.0061 mm　D_{10} =N/A

C_u =N/A　C_c =N/A

Classification

ASTM　elastic silt (MH)

AASHTO　Clayey Soils (A-7-5 (84))

Sample/Test Description

Sand/Gravel Particle Shape : ANGULAR

Sand/Gravel Hardness : HARD

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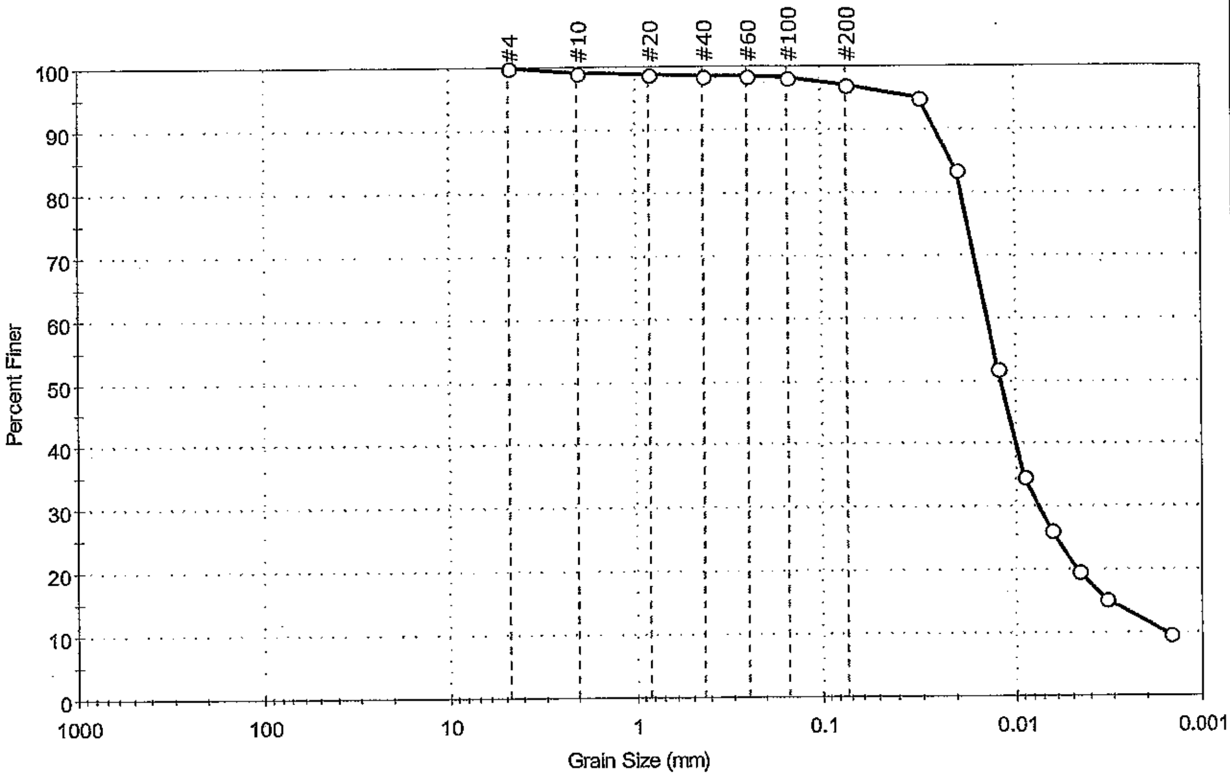
Client: Parsons Engineering Science			
Project: Onondaga			
Location: Syracuse		Project No:	GTX-7143
Boring ID: OL-VC-30036	Sample Type: jar	Tested By:	mll
Sample ID: OL-0282-20	Test Date: 01/29/07	Checked By:	jdt
Depth : 0.5-3.3 ft	Test Id: 105661		
Test Comment: ---			
Sample Description: Wet, very dark gray silt			
Sample Comment: ---			

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



%Cobble	%Gravel	%Sand	%Silt & Clay Size
—	0.0	2.9	97.1

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
#4	4.75	100		
#10	2.00	99		
#20	0.84	99		
#40	0.42	99		
#60	0.25	99		
#100	0.15	98		
#200	0.074	97		
---	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0310	95		
---	0.0198	84		
---	0.0122	52		
---	0.0090	35		
---	0.0064	26		
---	0.0046	20		
---	0.0033	15		
---	0.0015	10		

Coefficients

D_{85} =0.0209 mm | D_{30} =0.0075 mm

D_{60} =0.0138 mm | D_{15} =0.0031 mm

D_{50} =0.0118 mm | D_{10} =0.0015 mm

C_u =N/A | C_c =N/A

Classification

ASTM elastic silt (MH)

AASHTO Clayey Soils (A-7-5 (39))

Sample/Test Description

Sand/Gravel Particle Shape : ANGULAR

Sand/Gravel Hardness : HARD

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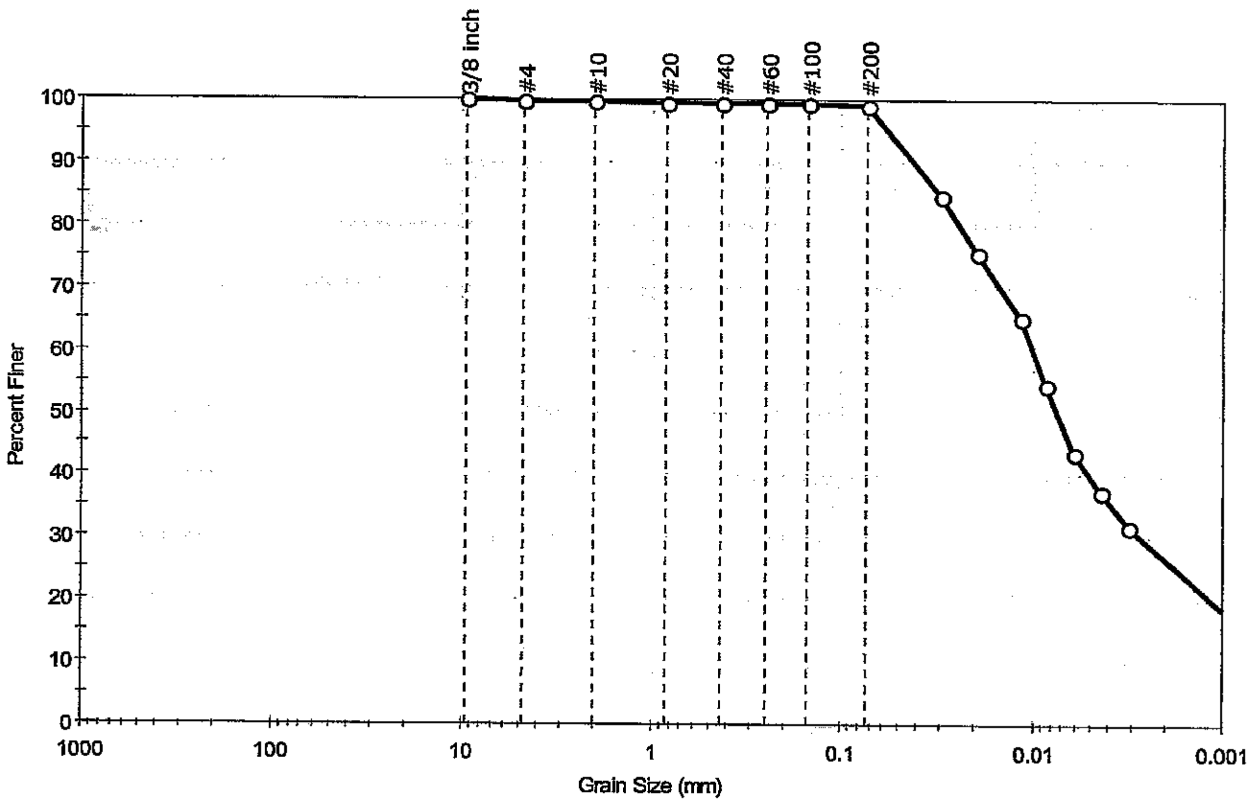
Client:	Parsons Engineering Science				
Project:	Onondaga				
Location:	Syracuse			Project No:	GTX-7143
Boring ID:	OL-VC-30036	Sample Type:	jar	Tested By:	mll
Sample ID:	OL-0285-01	Test Date:	02/05/07	Checked By:	jdt
Depth :	9.9-13.2 ft	Test Id:	105831		

Test Comment: ---
Sample Description: Moist, dark olive brown silt
Sample Comment: ---

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



% Cobble	% Gravel	% Sand	% Silt & Clay Size
—	0.3	0.6	99.1

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
3/8 inch	9.51	100		
#4	4.75	100		
#10	2.00	100		
#20	0.84	100		
#40	0.42	99		
#60	0.25	99		
#100	0.15	99		
#200	0.074	99		
---	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0300	85		
---	0.0199	75		
---	0.0117	65		
---	0.0085	55		
---	0.0061	44		
---	0.0044	38		
---	0.0031	32		
---	0.0008	16		

Coefficients

D_{85} = 0.0309 mm
D_{30} = 0.0027 mm
D_{60} = 0.0100 mm
D_{15} = N/A
D_{50} = 0.0074 mm
D_{10} = N/A
C_u = N/A
C_c = N/A

Classification

ASTM elastic silt (MH)

AASHTO Clayey Soils (A-7-5 (80))

Sample/Test Description

Sand/Gravel Particle Shape : ANGULAR

Sand/Gravel Hardness : HARD

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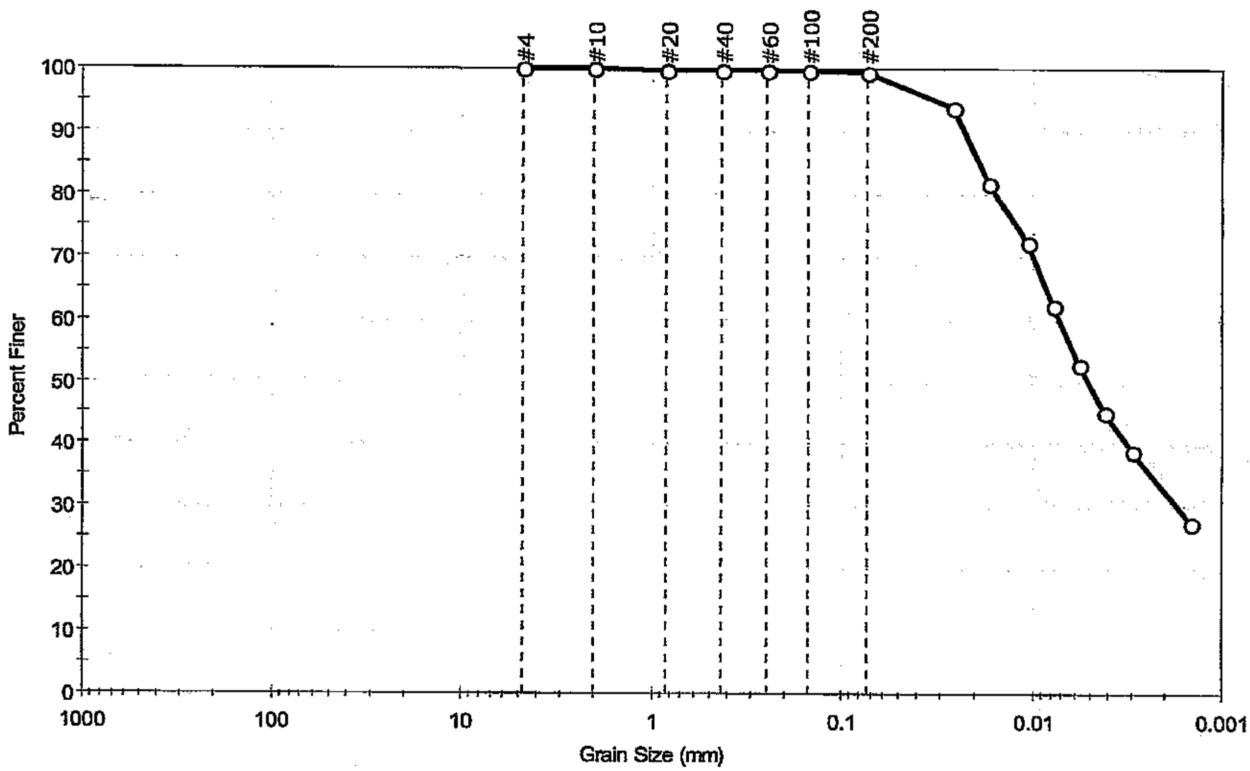
Client: Parsons Engineering Science			
Project: Onondaga			
Location: Syracuse		Project No:	GTX-7143
Boring ID: OL-VC-30036	Sample Type: jar	Tested By:	mll
Sample ID:OL-0285-02	Test Date: 02/06/07	Checked By:	jdt
Depth : 16.5-17.3 ft	Test Id: 105832		
Test Comment: ---			
Sample Description: Moist, gray silt			
Sample Comment: ---			

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



% Cobble	% Gravel	% Sand	% Silt & Clay Size
—	0.0	0.5	99.5

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
#4	4.75	100		
#10	2.00	100		
#20	0.84	100		
#40	0.42	100		
#60	0.25	100		
#100	0.15	100		
#200	0.074	100		
---	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0265	94		
---	0.0173	82		
---	0.0105	72		
---	0.0077	62		
---	0.0057	53		
---	0.0042	45		
---	0.0030	39		
---	0.0015	28		

Coefficients

D_{85} =0.0194 mm　　D_{30} =0.0017 mm

D_{60} =0.0072 mm　　D_{15} =N/A

D_{50} =0.0051 mm　　D_{10} =N/A

C_u =N/A　　C_c =N/A

Classification

ASTM　elastic silt (MH)

AASHTO　Clayey Soils (A-7-5 (36))

Sample/Test Description

Sand/Gravel Particle Shape : ANGULAR

Sand/Gravel Hardness : HARD

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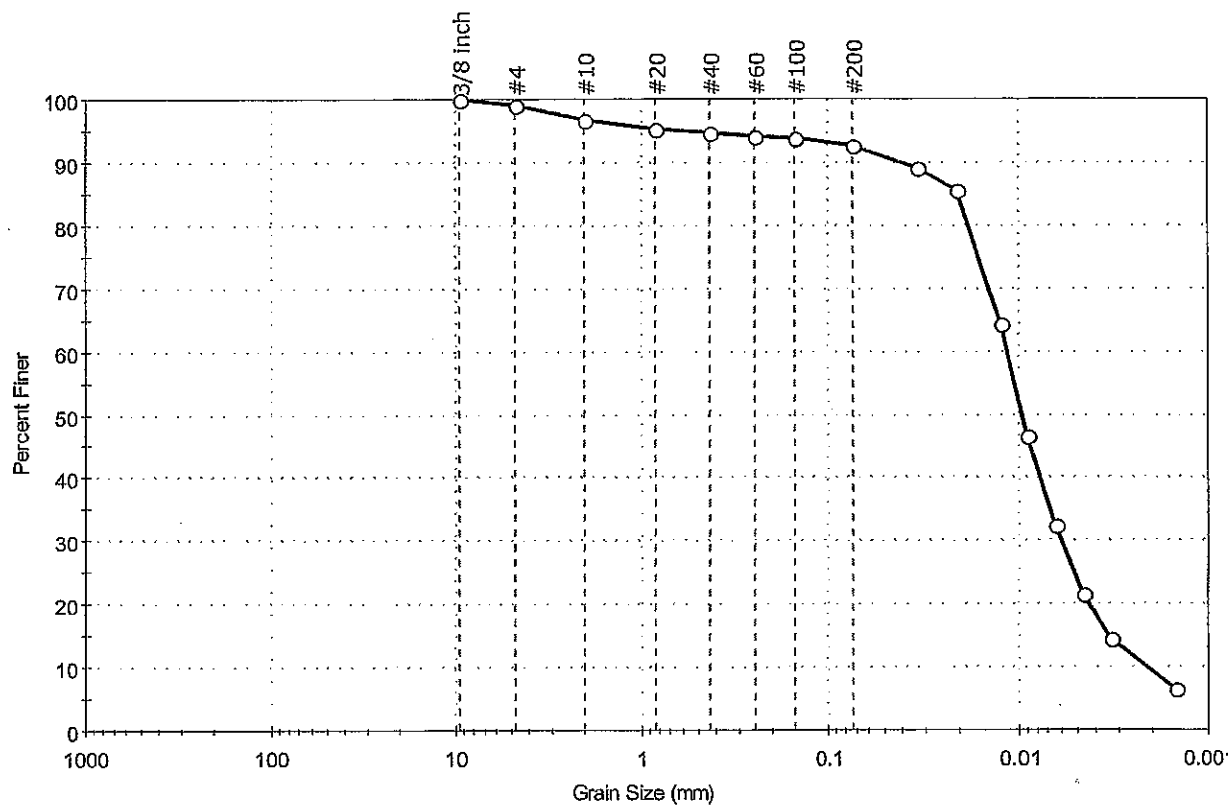
Client:	Parsons Engineering Science				
Project:	Onondaga				
Location:	Syracuse			Project No:	GTX-7143
Boring ID:	OL-VC-30037	Sample Type:	jar	Tested By:	mll
Sample ID:	OL-0282-17	Test Date:	01/29/07	Checked By:	jdt
Depth :	0.5-3.3 ft	Test Id:	105658		
Test Comment:	---				
Sample Description:	Wet, dark gray silt				
Sample Comment:	---				

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



%Cobble	%Gravel	%Sand	%Silt & Clay Size
---	1.0	6.4	92.6

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
3/8 inch	9.50	100		
#4	4.75	99		
#10	2.00	97		
#20	0.84	95		
#40	0.42	95		
#60	0.25	94		
#100	0.15	94		
#200	0.074	93		
---	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0332	89		
---	0.0205	86		
---	0.0122	64		
---	0.0089	47		
---	0.0064	32		
---	0.0046	22		
---	0.0033	15		
---	0.0015	7		

Coefficients

D_{85} =0.0202 mm D_{30} =0.0060 mm

D_{60} =0.0113 mm D_{15} =0.0033 mm

D_{50} =0.0095 mm D_{10} =0.0021 mm

C_u =N/A C_c =N/A

Classification

ASTM elastic silt (MH)

AASHTO Clayey Soils (A-7-5 (36))

Sample/Test Description

Sand/Gravel Particle Shape : ANGULAR

Sand/Gravel Hardness : HARD

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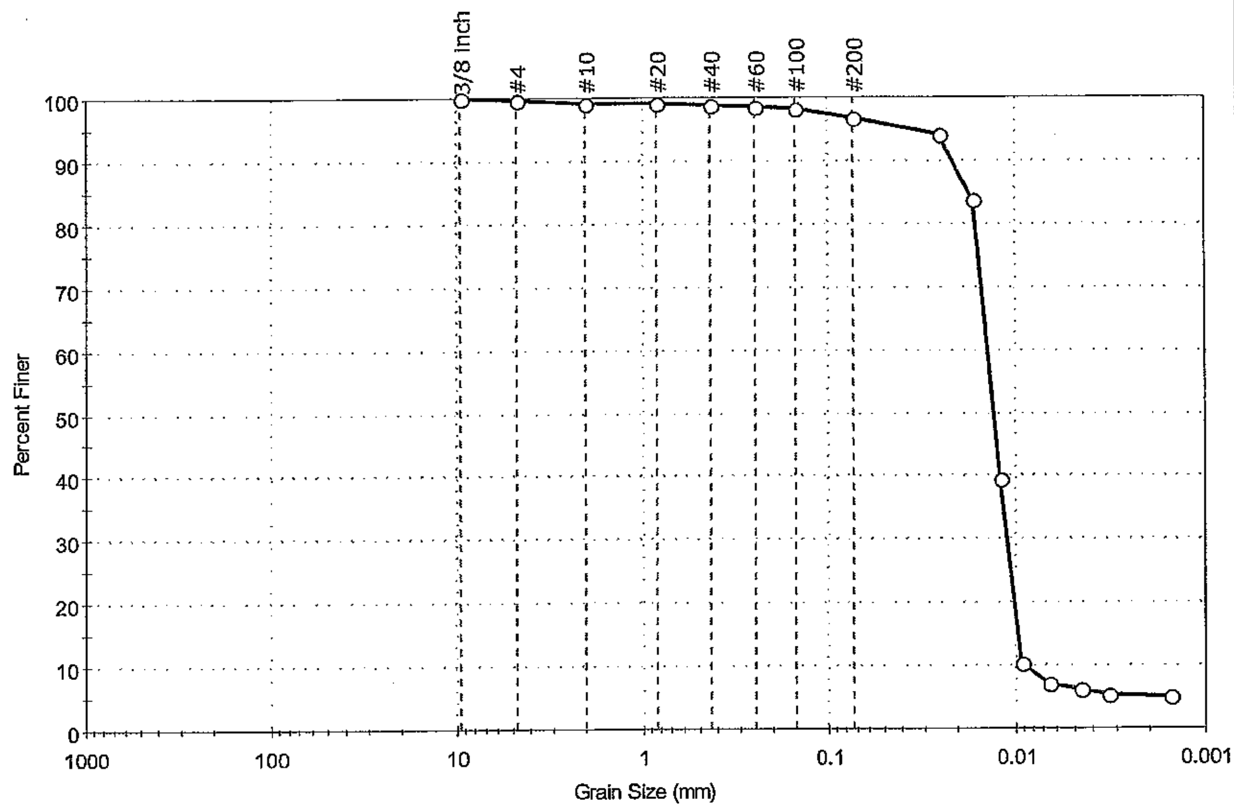
Client: Parsons Engineering Science			
Project: Onondaga			
Location: Syracuse		Project No:	GTX-7143
Boring ID: OL-VC-30037	Sample Type: jar	Tested By:	mll
Sample ID: OL-0282-15	Test Date: 01/30/07	Checked By:	jdt
Depth : 9.9-13.2 ft	Test Id: 105656		

Test Comment: ---
Sample Description: Wet, dark gray silt
Sample Comment: ---

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



% Cobble	% Gravel	% Sand	% Silt & Clay Size
—	0.4	2.7	96.9

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
3/8 inch	9.50	100		
#4	4.75	100		
#10	2.00	99		
#20	0.84	99		
#40	0.42	99		
#60	0.25	99		
#100	0.15	98		
#200	0.074	97		
---	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0251	94		
---	0.0166	84		
---	0.0118	39		
---	0.0093	10		
---	0.0066	7		
---	0.0046	6		
---	0.0033	5		
---	0.0015	5		

Coefficients

D_{85} =0.0174 mm D_{30} =0.0109 mm
D_{60} =0.0138 mm D_{15} =0.0096 mm
D_{50} =0.0128 mm D_{10} =0.0089 mm
C_u =N/A C_c =N/A

Classification

ASTM elastic silt (MH)

AASHTO Clayey Soils (A-7-5 (42))

Sample/Test Description

Sand/Gravel Particle Shape : ANGULAR

Sand/Gravel Hardness : HARD

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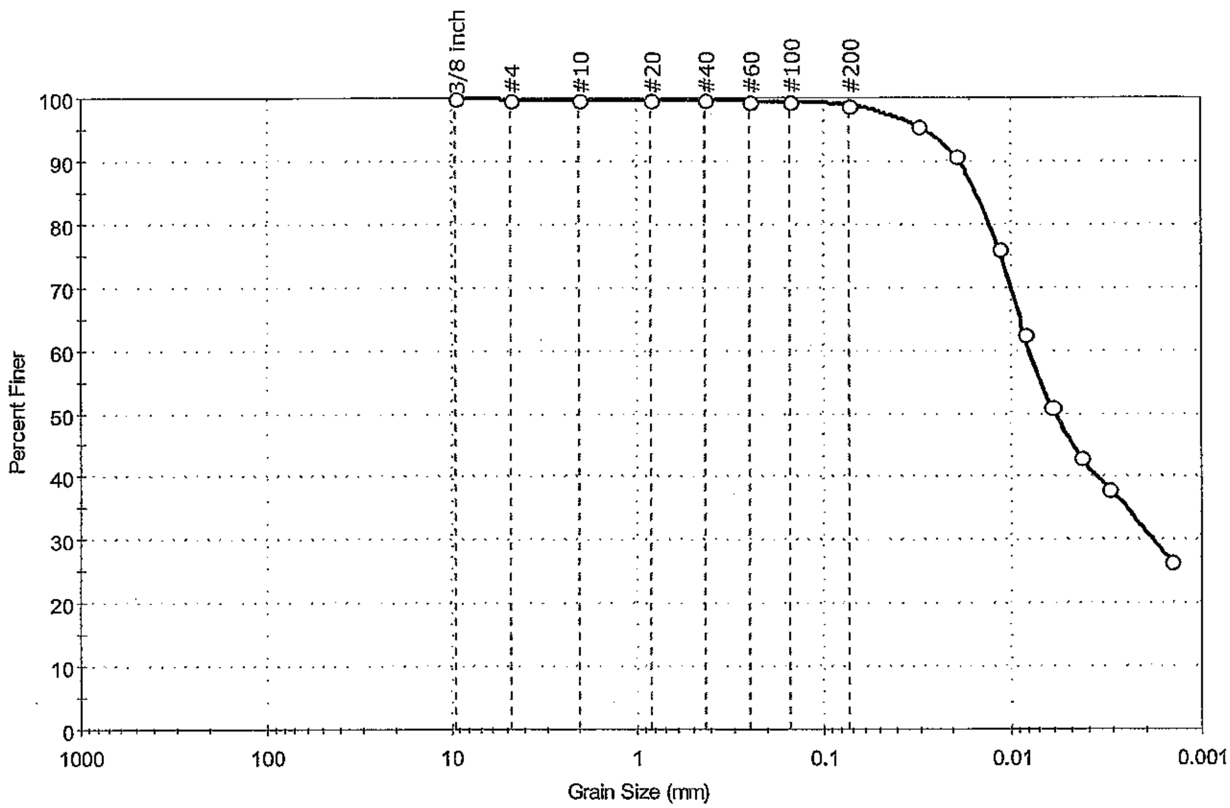
Client:	Parsons Engineering Science		
Project:	Onondaga		
Location:	Syracuse	Project No:	GTX-7143
Boring ID: OL-VC-30037	Sample Type: jar	Tested By:	mll
Sample ID: OL-0282-16	Test Date: 01/30/07	Checked By:	jdt
Depth : 13.2-16.5 ft	Test Id: 105657		
Test Comment:	---		
Sample Description:	Moist, olive brown silt		
Sample Comment:	---		

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



% Cobble	% Gravel	% Sand	% Silt & Clay Size
—	0.2	0.9	98.9

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
3/8 Inch	9.50	100		
#4	4.75	100		
#10	2.00	100		
#20	0.84	100		
#40	0.42	100		
#60	0.25	100		
#100	0.15	99		
#200	0.074	99		
---	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0310	95		
---	0.0194	91		
---	0.0115	76		
---	0.0084	63		
---	0.0061	51		
---	0.0044	43		
---	0.0031	38		
---	0.0015	27		

Coefficients

D_{85} = 0.0158 mm
D_{30} = 0.0018 mm
D_{60} = 0.0078 mm
D_{15} = N/A
D_{50} = 0.0059 mm
D_{10} = N/A
C_u = N/A
C_c = N/A

Classification

ASTM elastic silt (MH)

AASHTO Clayey Soils (A-7-5 (66))

Sample/Test Description

Sand/Gravel Particle Shape : ANGULAR

Sand/Gravel Hardness : HARD

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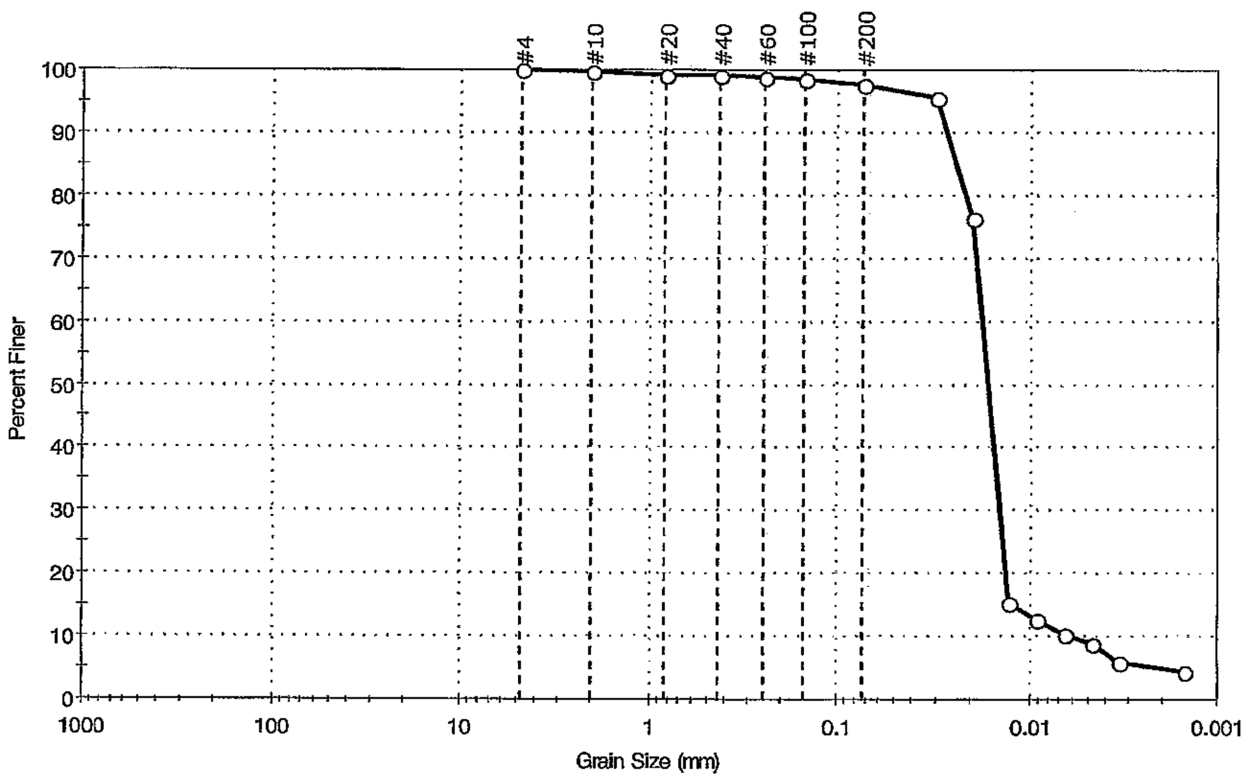
Client:	Parsons Engineering Science				
Project:	Onondaga				
Location:	Syracuse			Project No:	GTX-7143
Boring ID:	OL-VC-20067	Sample Type:	jar	Tested By:	mll
Sample ID:	OL-0289-09	Test Date:	01/25/07	Checked By:	jdt
Depth :	0-3.3 ft	Test Id:	106061		
Test Comment:	---				
Sample Description:	Wet, black silt				
Sample Comment:	---				

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



% Cobble	% Gravel	% Sand	% Silt & Clay Size
—	0.0	2.2	97.8

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
#4	4.75	100		
#10	2.00	100		
#20	0.84	99		
#40	0.42	99		
#60	0.25	99		
#100	0.15	99		
#200	0.074	98		
---	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0303	96		
---	0.0198	76		
---	0.0129	15		
---	0.0092	13		
---	0.0066	10		
---	0.0047	9		
---	0.0034	6		
---	0.0015	4		

Coefficients

D_{85} =0.0240 mm	D_{30} =0.0143 mm
D_{60} =0.0177 mm	D_{15} =0.0124 mm
D_{50} =0.0165 mm	D_{10} =0.0063 mm
C_u =N/A	C_c =N/A

Classification

ASTM elastic silt (MH)

AASHTO Clayey Soils (A-7-5 (62))

Sample/Test Description

Sand/Gravel Particle Shape : ANGULAR

Sand/Gravel Hardness : HARD

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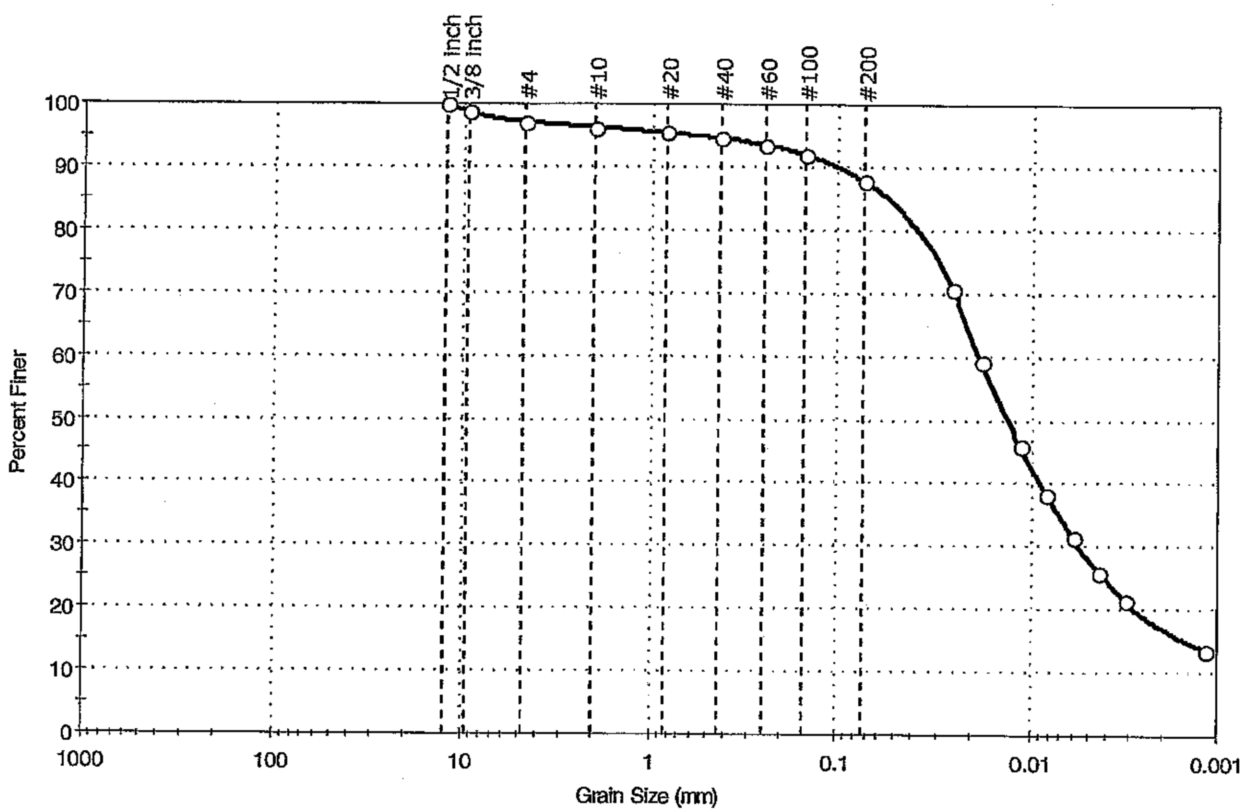
Client:	Parsons Engineering Science				
Project:	Onondaga				
Location:	Syracuse			Project No:	GTX-7143
Boring ID:	OL-VC-20067	Sample Type:	jar	Tested By:	mll
Sample ID:	OL-0289-10	Test Date:	02/13/07	Checked By:	jdt
Depth :	6.6-9.9 ft	Test Id:	106062		

Test Comment: ---
Sample Description: Moist, very dark gray silt
Sample Comment: ---

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



% Cobble	% Gravel	% Sand	% Silt & Clay Size
---	2.8	9.3	87.9

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
1/2 inch	12.50	100		
3/8 inch	9.50	99		
#4	4.75	97		
#10	2.00	96		
#20	0.84	95		
#40	0.42	95		
#60	0.25	94		
#100	0.15	92		
#200	0.074	88		
---	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0257	71		
---	0.0180	59		
---	0.0114	46		
---	0.0083	38		
---	0.0061	31		
---	0.0044	26		
---	0.0032	21		
---	0.0012	14		

Coefficients

D_{85} =0.0618 mm
D_{30} =0.0056 mm
D_{60} =0.0184 mm
D_{15} =0.0014 mm
D_{50} =0.0131 mm
D_{10} =0.0007 mm
C_u =N/A
C_c =N/A

Classification

ASTM elastic silt (MH)

AASHTO Clayey Soils (A-7-5 (19))

Sample/Test Description

Sand/Gravel Particle Shape : ANGULAR

Sand/Gravel Hardness : HARD

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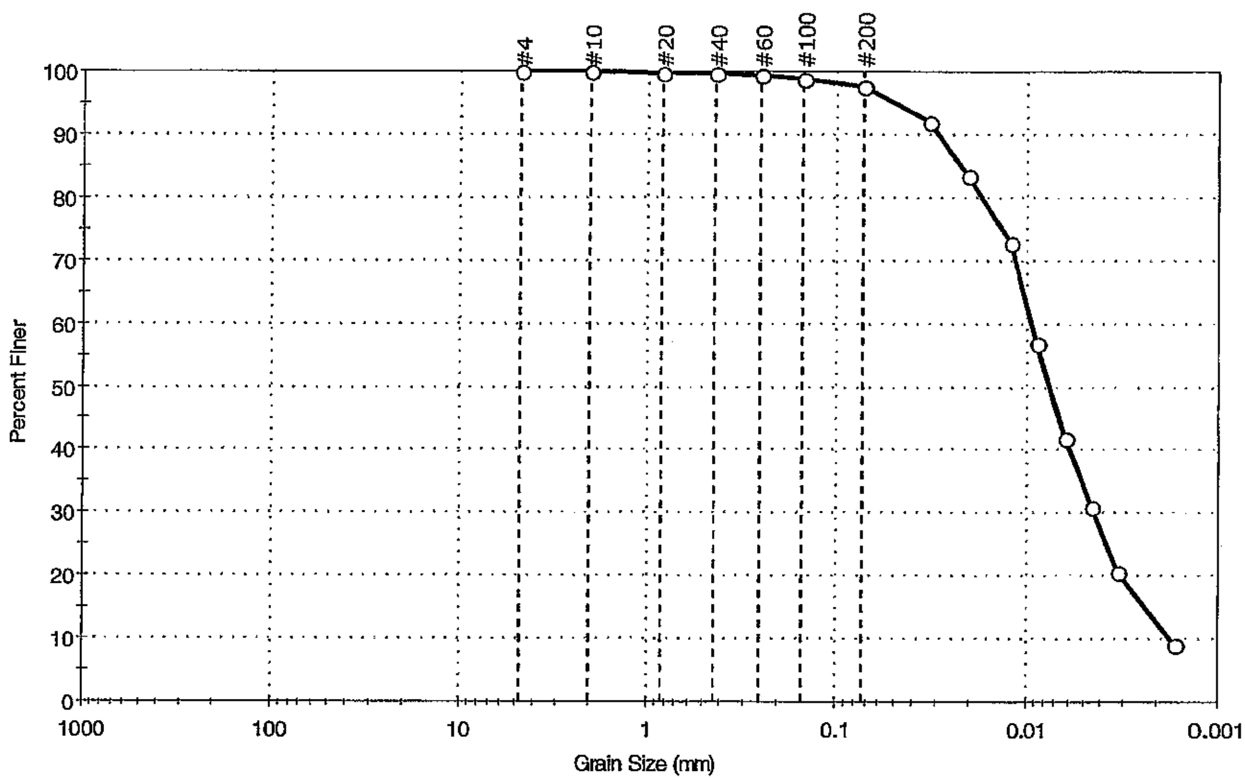
Client:	Parsons Engineering Science				
Project:	Onondaga				
Location:	Syracuse			Project No:	GTX-7143
Boring ID:	OL-VC-20073	Sample Type:	jar	Tested By:	sam
Sample ID:	OL-0232-12	Test Date:	01/04/07	Checked By:	jdt
Depth :	3.3-6.6 ft	Test Id:	103374		
Test Comment:	---				
Sample Description:	Wet, dark gray silt				
Sample Comment:	---				

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



% Cobble	% Gravel	% Sand	% Silt & Clay Size
—	0.0	2.3	97.7

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
#4	4.75	100		
#10	2.00	100		
#20	0.84	100		
#40	0.42	100		
#60	0.25	99		
#100	0.15	99		
#200	0.074	98		
---	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0333	92		
---	0.0208	83		
---	0.0122	73		
---	0.0088	57		
---	0.0063	42		
---	0.0045	31		
---	0.0033	21		
---	0.0016	9		

Coefficients

D_{85} =0.0227 mm D_{30} =0.0044 mm
D_{60} =0.0093 mm D_{15} =0.0023 mm
D_{50} =0.0075 mm D_{10} =0.0017 mm
C_u =N/A C_c =N/A

Classification

ASTM elastic silt (MH)

AASHTO Clayey Soils (A-7-5 (30))

Sample/Test Description

Sand/Gravel Particle Shape : ROUNDED

Sand/Gravel Hardness : HARD

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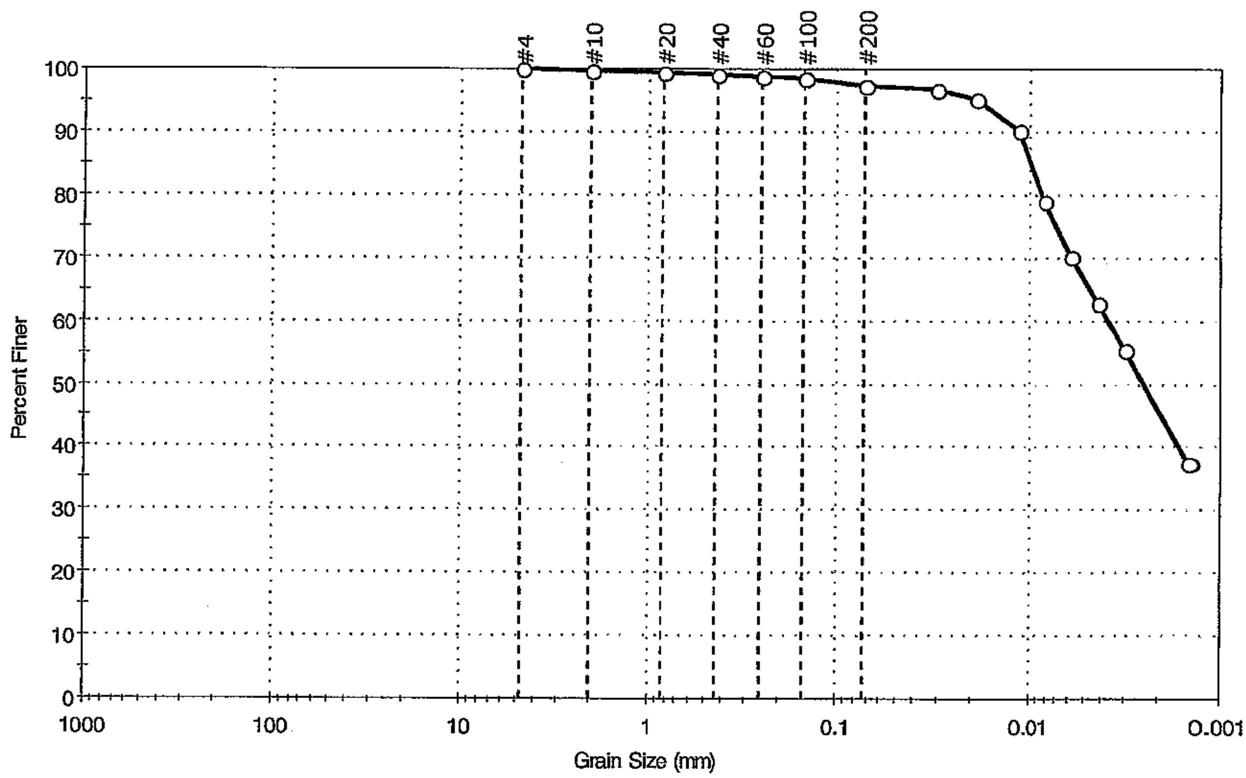
Client: Parsons Engineering Science			
Project: Onondaga			
Location: Syracuse		Project No:	GTX-7143
Boring ID: OL-VC-20073	Sample Type: jar	Tested By:	sam
Sample ID:OL-0232-13	Test Date: 01/04/07	Checked By:	jdt
Depth : 13.2-16.5 ft	Test Id: 103375		
Test Comment: ---			
Sample Description: Moist, dark gray silt			
Sample Comment: ---			

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



% Cobble	% Gravel	% Sand	% Silt & Clay Size
—	0.0	2.6	97.4

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
#4	4.75	100		
#10	2.00	100		
#20	0.84	99		
#40	0.42	99		
#60	0.25	99		
#100	0.15	98		
#200	0.074	97		
---	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0312	97		
---	0.0195	95		
---	0.0113	90		
---	0.0082	79		
---	0.0059	70		
---	0.0042	63		
---	0.0030	55		
---	0.0014	38		

Coefficients

D_{85} =0.0097 mm | D_{30} =N/A
D_{60} =0.0037 mm | D_{15} =N/A
D_{50} =0.0024 mm | D_{10} =N/A
C_u =N/A | C_c =N/A

Classification

ASTM elastic silt (MH)

AASHTO Clayey Soils (A-7-5 (50))

Sample/Test Description

Sand/Gravel Particle Shape : ANGULAR

Sand/Gravel Hardness : HARD

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GeoTesting express
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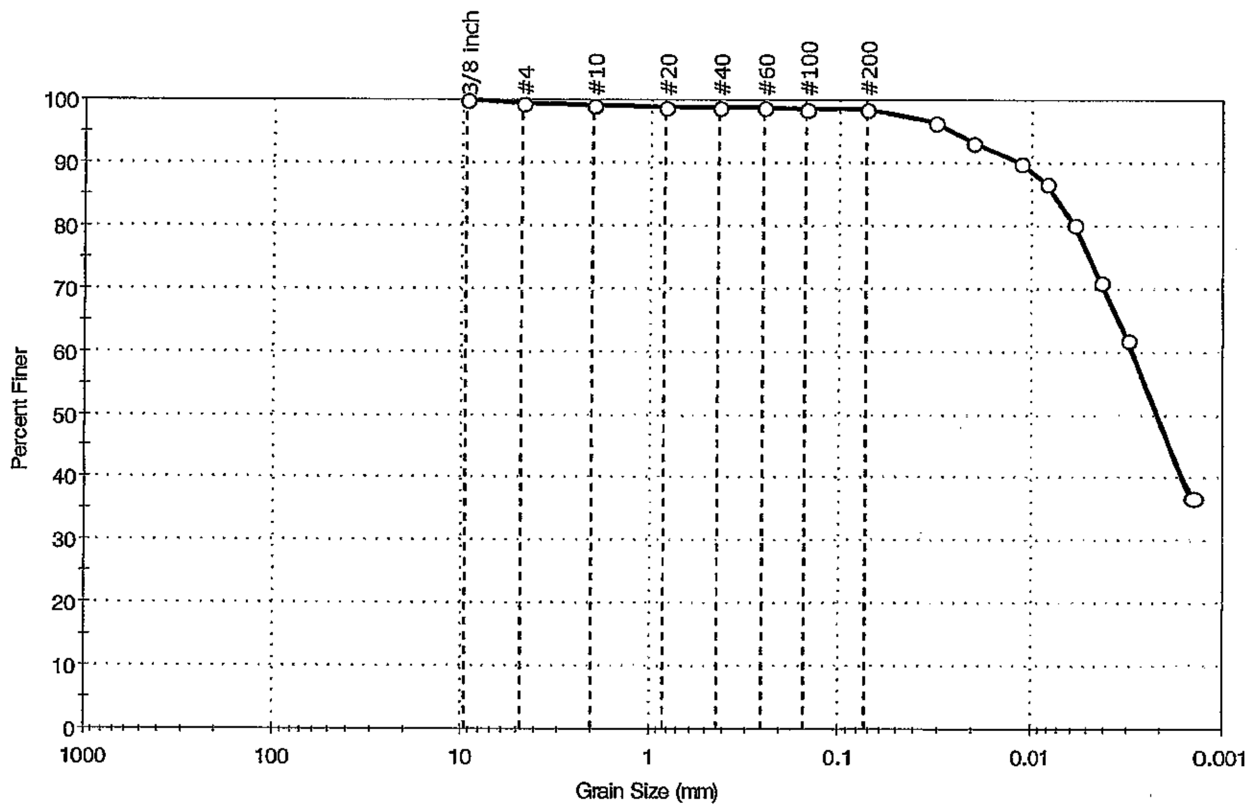
Client:	Parsons Engineering Science				
Project:	Onondaga				
Location:	Syracuse			Project No:	GTX-7143
Boring ID:	OL-VC-20073	Sample Type:	jar	Tested By:	sam
Sample ID:	OL-0232-14	Test Date:	01/05/07	Checked By:	jdt
Depth :	16.5-19.3 ft	Test Id:	103376		
Test Comment:	---				
Sample Description:	Moist, gray silt				
Sample Comment:	---				

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



% Cobble	% Gravel	% Sand	% Silt & Clay Size
---	0.7	0.8	98.5

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
3/8 inch	9.51	100		
#4	4.75	99		
#10	2.00	99		
#20	0.84	99		
#40	0.42	99		
#60	0.25	99		
#100	0.15	99		
#200	0.074	98		
---	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0318	97		
---	0.0201	93		
---	0.0115	90		
---	0.0082	87		
---	0.0059	80		
---	0.0042	71		
---	0.0030	62		
---	0.0014	37		

Coefficients

D_{85} = 0.0075 mm　D_{30} = N/A

D_{60} = 0.0028 mm　D_{15} = N/A

D_{50} = 0.0021 mm　D_{10} = N/A

C_u = N/A　C_c = N/A

Classification

ASTM　elastic silt (MH)

AASHTO　Clayey Soils (A-7-5 (36))

Sample/Test Description

Sand/Gravel Particle Shape : ANGULAR

Sand/Gravel Hardness : SOFT

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GeoTesting express
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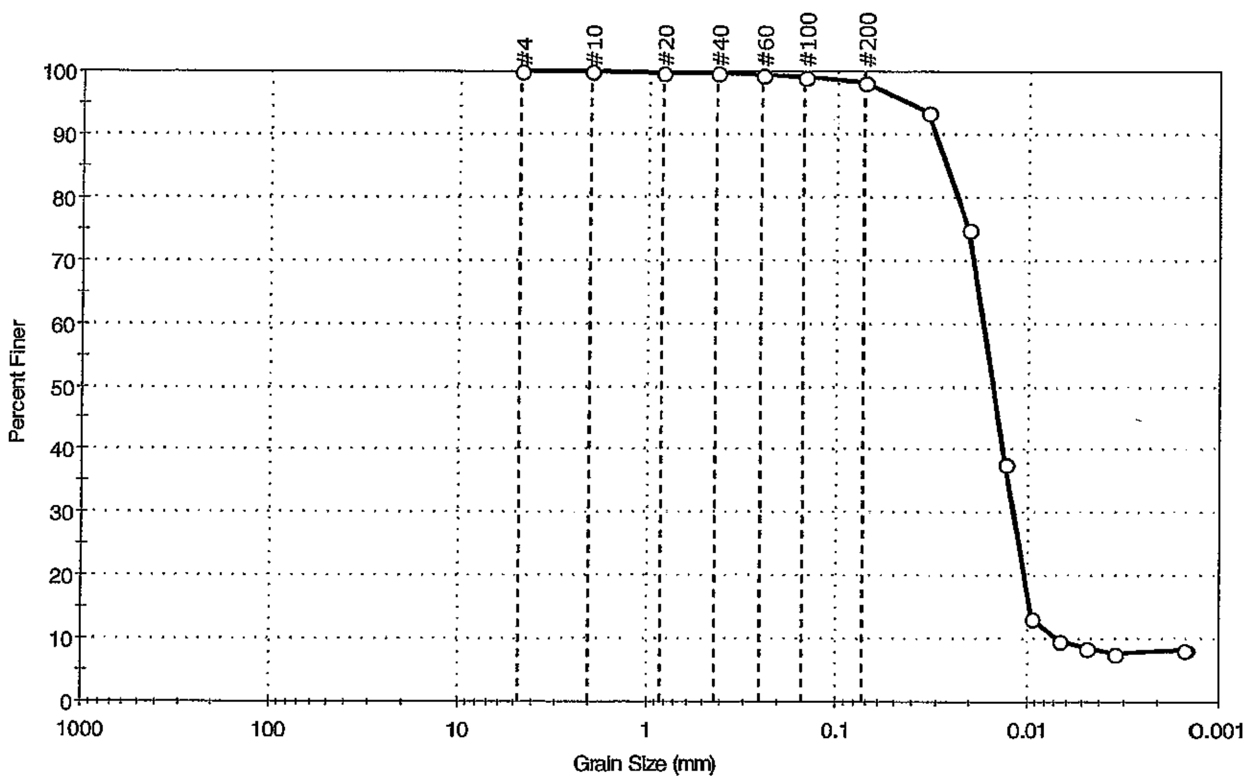
Client:	Parsons Engineering Science				
Project:	Onondaga				
Location:	Syracuse			Project No:	GTX-7143
Boring ID:	OL-VC-20074	Sample Type:	jar	Tested By:	sam
Sample ID:	OL-0232-15	Test Date:	01/12/07	Checked By:	jdt
Depth :	0-3.3 ft	Test Id:	103377		
Test Comment:	---				
Sample Description:	Wet, black silt				
Sample Comment:	---				

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



% Cobble	% Gravel	% Sand	% Silt & Clay Size
—	0.0	1.6	98.4

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
#4	4.75	100		
#10	2.00	100		
#20	0.84	100		
#40	0.42	100		
#60	0.25	99		
#100	0.15	99		
#200	0.074	98		
---	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0342	93		
---	0.0208	75		
---	0.0130	38		
---	0.0095	13		
---	0.0066	10		
---	0.0048	9		
---	0.0034	8		
---	0.0015	8		

Coefficients

D_{85} =0.0273 mm — D_{30} =0.0118 mm

D_{60} =0.0173 mm — D_{15} =0.0097 mm

D_{50} =0.0152 mm — D_{10} =0.0068 mm

C_u =N/A — C_c =N/A

Classification

ASTM elastic silt (MH)

AASHTO Clayey Soils (A-7-5 (78))

Sample/Test Description

Sand/Gravel Particle Shape : ANGULAR

Sand/Gravel Hardness : HARD

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GeoTesting express
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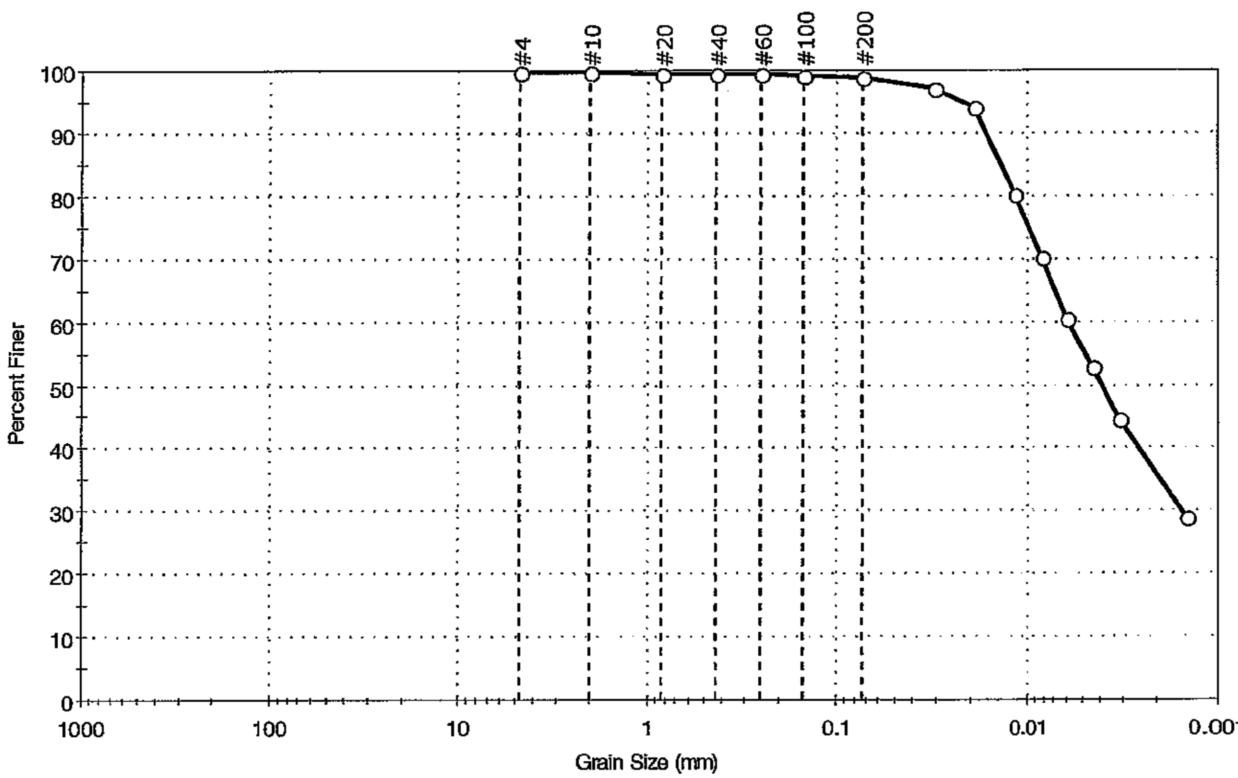
Client:	Parsons Engineering Science				
Project:	Onondaga				
Location:	Syracuse			Project No:	GTX-7143
Boring ID:	OL-VC-20074	Sample Type:	jar	Tested By:	sam
Sample ID:	OL-0232-16	Test Date:	01/10/07	Checked By:	jdt
Depth :	9.9-13.2 ft	Test Id:	103378		
Test Comment:	---				
Sample Description:	Moist, dark grayish brown clay				
Sample Comment:	---				

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



% Cobble	% Gravel	% Sand	% Silt & Clay Size
---	0.3	1.0	98.7

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
#4	4.75	100		
#10	2.00	100		
#20	0.84	100		
#40	0.42	99		
#60	0.25	99		
#100	0.15	99		
#200	0.074	99		
---	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0312	97		
---	0.0193	94		
---	0.0115	80		
---	0.0082	70		
---	0.0060	61		
---	0.0044	53		
---	0.0031	44		
---	0.0014	29		

Coefficients

D_{85} = 0.0138 mm | D_{30} = 0.0015 mm
D_{60} = 0.0059 mm | D_{15} = N/A
D_{50} = 0.0039 mm | D_{10} = N/A
C_u = N/A | C_c = N/A

Classification

ASTM fat clay (CH)

AASHTO Clayey Soils (A-7-5 (66))

Sample/Test Description

Sand/Gravel Particle Shape : ANGULAR

Sand/Gravel Hardness : HARD

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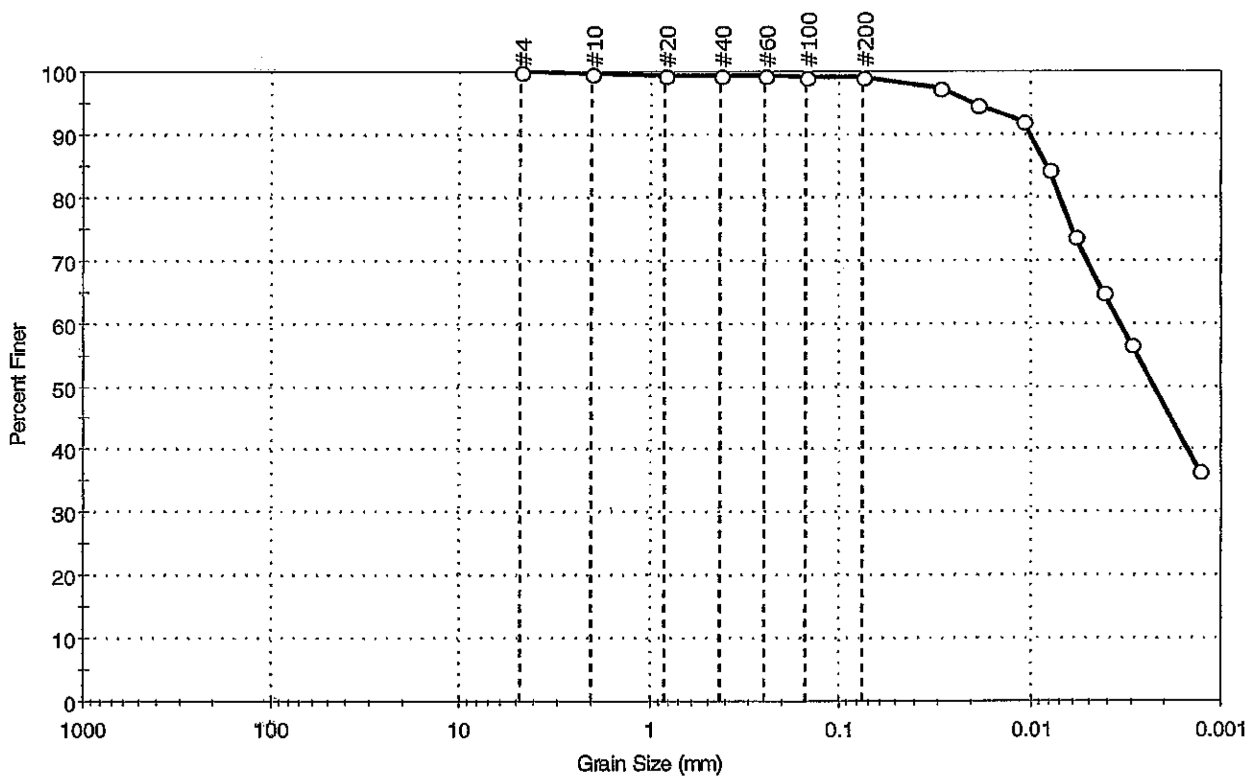
Client: Parsons Engineering Science			
Project: Onondaga			
Location: Syracuse		Project No:	GTX-7143
Boring ID: OL-0297-01	Sample Type: jar	Tested By:	mll
Sample ID:OL-VC-20074	Test Date: 06/20/07	Checked By:	jdt
Depth : 13.2-16.5 ft	Test Id: 111431		

Test Comment: ---
Sample Description: Moist, dark olive gray silt
Sample Comment: ---

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



% Cobble	% Gravel	% Sand	% Silt & Clay Size
---	0.0	1.0	99.0

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
#4	4.75	100		
#10	2.00	100		
#20	0.84	100		
#40	0.42	99		
#60	0.25	99		
#100	0.15	99		
#200	0.075	99		
---	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0295	97		
---	0.0188	95		
---	0.0109	92		
---	0.0079	84		
---	0.0058	74		
---	0.0042	65		
---	0.0030	57		
---	0.0013	37		

Coefficients

D_{85} =0.0082 mm D_{30} =N/A
D_{60} =0.0034 mm D_{15} =N/A
D_{50} =0.0023 mm D_{10} =N/A
C_u =N/A C_c =N/A

Classification

ASTM   elastic silt (MH)

AASHTO   Clayey Soils (A-7-5 (56))

Sample/Test Description

Sand/Gravel Particle Shape : ROUNDED
Sand/Gravel Hardness : HARD

printed 6/27/2007 8:20:22 AM

GeoTesting express
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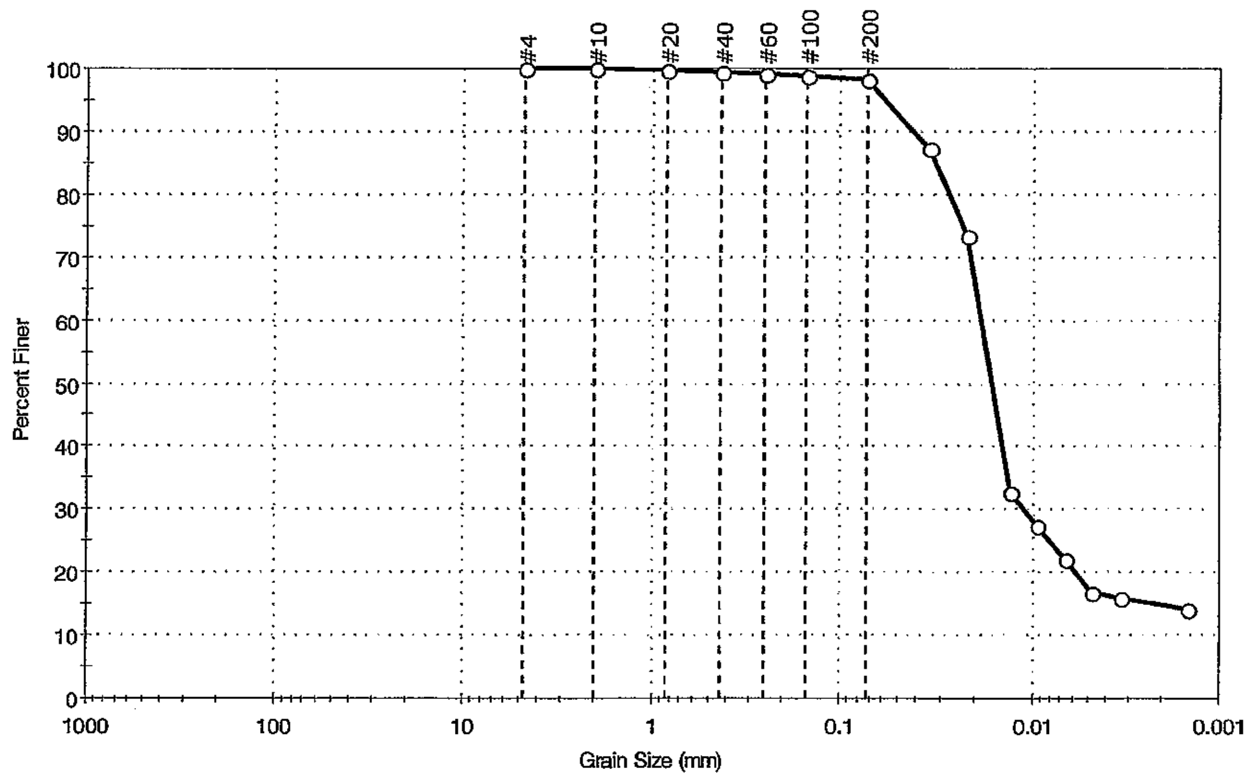
Client:	Parsons Engineering Science				
Project:	Onondaga				
Location:	Syracuse			Project No:	GTX-7143
Boring ID:	OL-VC-20076	Sample Type:	jar	Tested By:	sam
Sample ID:	OL-0232-20	Test Date:	01/04/07	Checked By:	jdt
Depth :	0-3.3 ft	Test Id:	103382		
Test Comment:	---				
Sample Description:	Wet, black silt				
Sample Comment:	---				

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



% Cobble	% Gravel	% Sand	% Silt & Clay Size
---	0.0	1.7	98.3

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
#4	4.75	100		
#10	2.00	100		
#20	0.84	100		
#40	0.42	99		
#60	0.25	99		
#100	0.15	99		
#200	0.074	98		
---	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0348	87		
---	0.0220	74		
---	0.0132	33		
---	0.0093	27		
---	0.0066	22		
---	0.0047	17		
---	0.0033	16		
---	0.0015	14		

Coefficients

D_{85} =0.0322 mm
D_{30} =0.0110 mm
D_{60} =0.0185 mm
D_{15} =0.0021 mm
D_{50} =0.0163 mm
D_{10} =0.0002 mm
C_u =N/A
C_c =N/A

Classification

ASTM elastic silt (MH)

AASHTO Clayey Soils (A-7-5 (112))

Sample/Test Description

Sand/Gravel Particle Shape : ANGULAR

Sand/Gravel Hardness : HARD

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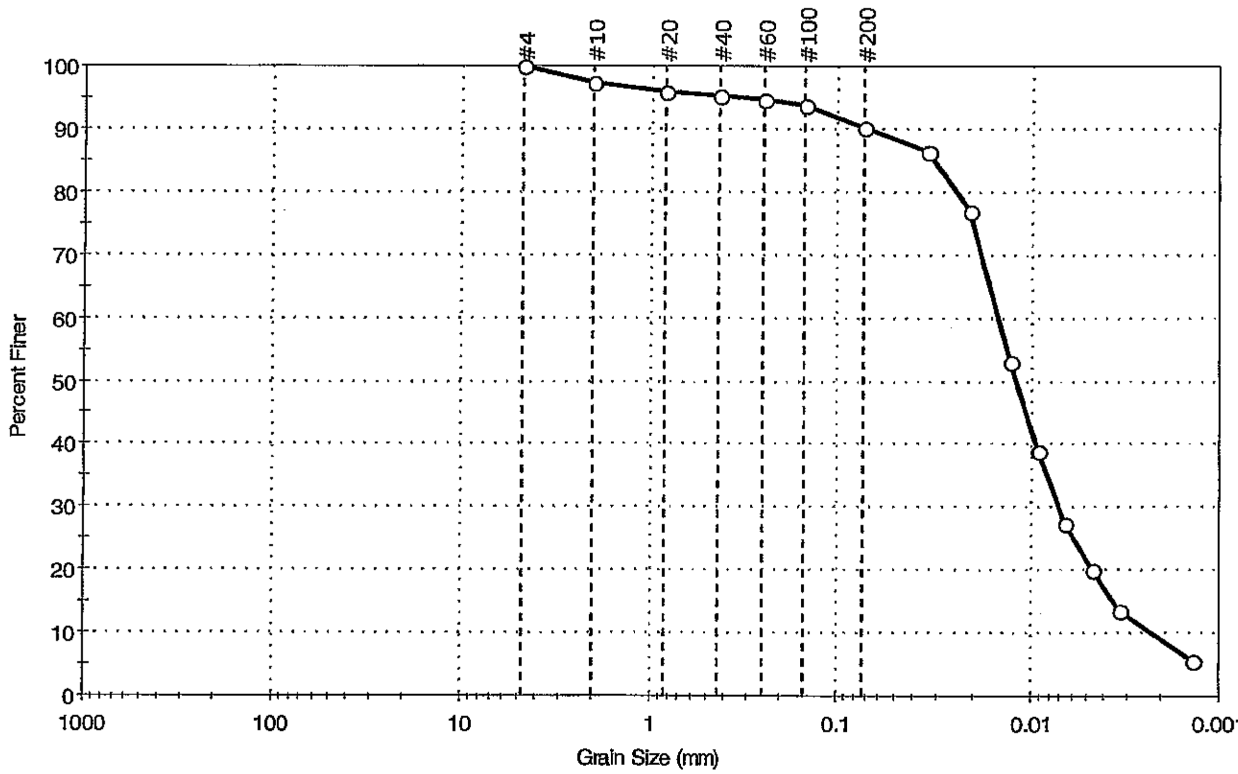
Client:	Parsons Engineering Science				
Project:	Onondaga				
Location:	Syracuse			Project No:	GTX-7143
Boring ID:	OL-VC-20076	Sample Type:	jar	Tested By:	mll
Sample ID:	OL-0233-01	Test Date:	12/12/06	Checked By:	jdt
Depth :	9.9-13.2 ft	Test Id:	103425		
Test Comment:	---				
Sample Description:	Moist, mottled pale yellow and light reddish gray silt				
Sample Comment:	---				

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



% Cobble	% Gravel	% Sand	% Silt & Clay Size
---	0.0	9.8	90.2

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
#4	4.75	100		
#10	2.00	97		
#20	0.84	96		
#40	0.42	95		
#60	0.25	95		
#100	0.15	94		
#200	0.074	90		
---	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0343	86		
---	0.0214	77		
---	0.0127	53		
---	0.0091	39		
---	0.0065	27		
---	0.0047	20		
---	0.0033	14		
---	0.0014	5		

Coefficients

D_{85} =0.0320 mm	D_{30} =0.0071 mm
D_{60} =0.0148 mm	D_{15} =0.0036 mm
D_{50} =0.0118 mm	D_{10} =0.0022 mm
C_u =N/A	C_c =N/A

Classification

ASTM elastic silt (MH)

AASHTO Clayey Soils (A-7-5 (57))

Sample/Test Description

Sand/Gravel Particle Shape : ANGULAR

Sand/Gravel Hardness : HARD

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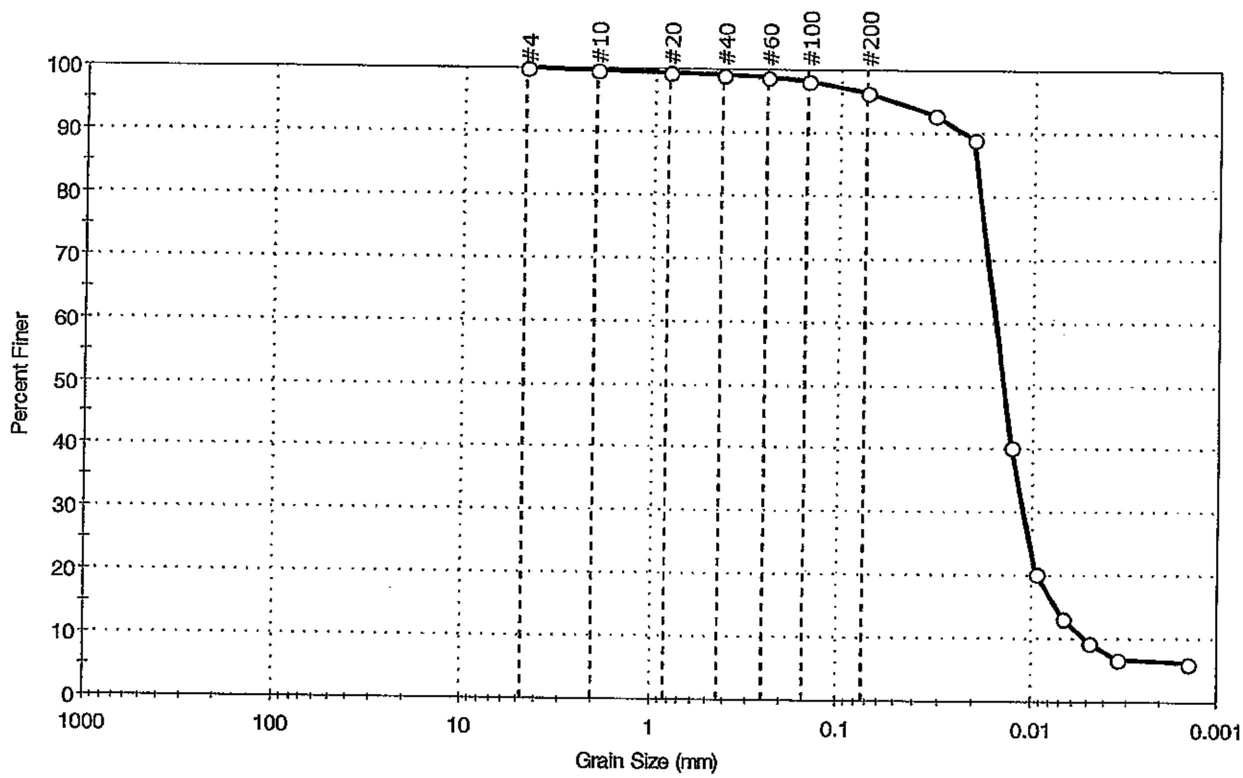
Client: Parsons Engineering Science			
Project: Onondaga			
Location: Syracuse		Project No:	GTX-7143
Boring ID: OL-VC-20077	Sample Type: jar	Tested By:	mll
Sample ID: OL-0233-02	Test Date: 01/17/07	Checked By:	jdt
Depth : 0-3.3 ft	Test Id: 103426		
Test Comment: ---			
Sample Description: Moist, black silt			
Sample Comment: ---			

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



% Cobble	% Gravel	% Sand	% Silt & Clay Size
—	0.0	3.6	96.4

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
#4	4.75	100		
#10	2.00	100		
#20	0.84	99		
#40	0.42	99		
#60	0.25	99		
#100	0.15	98		
#200	0.074	96		
---	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0334	93		
---	0.0208	89		
---	0.0130	40		
---	0.0094	20		
---	0.0067	13		
---	0.0048	10		
---	0.0034	7		
---	0.0014	6		

Coefficients

D_{85} =0.0200 mm
D_{30} =0.0110 mm
D_{60} =0.0157 mm
D_{15} =0.0073 mm
D_{50} =0.0142 mm
D_{10} =0.0050 mm
C_u =N/A
C_c =N/A

Classification

ASTM elastic silt (MH)

AASHTO Clayey Soils (A-7-5 (116))

Sample/Test Description

Sand/Gravel Particle Shape : ANGULAR

Sand/Gravel Hardness : HARD

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GeoTesting express
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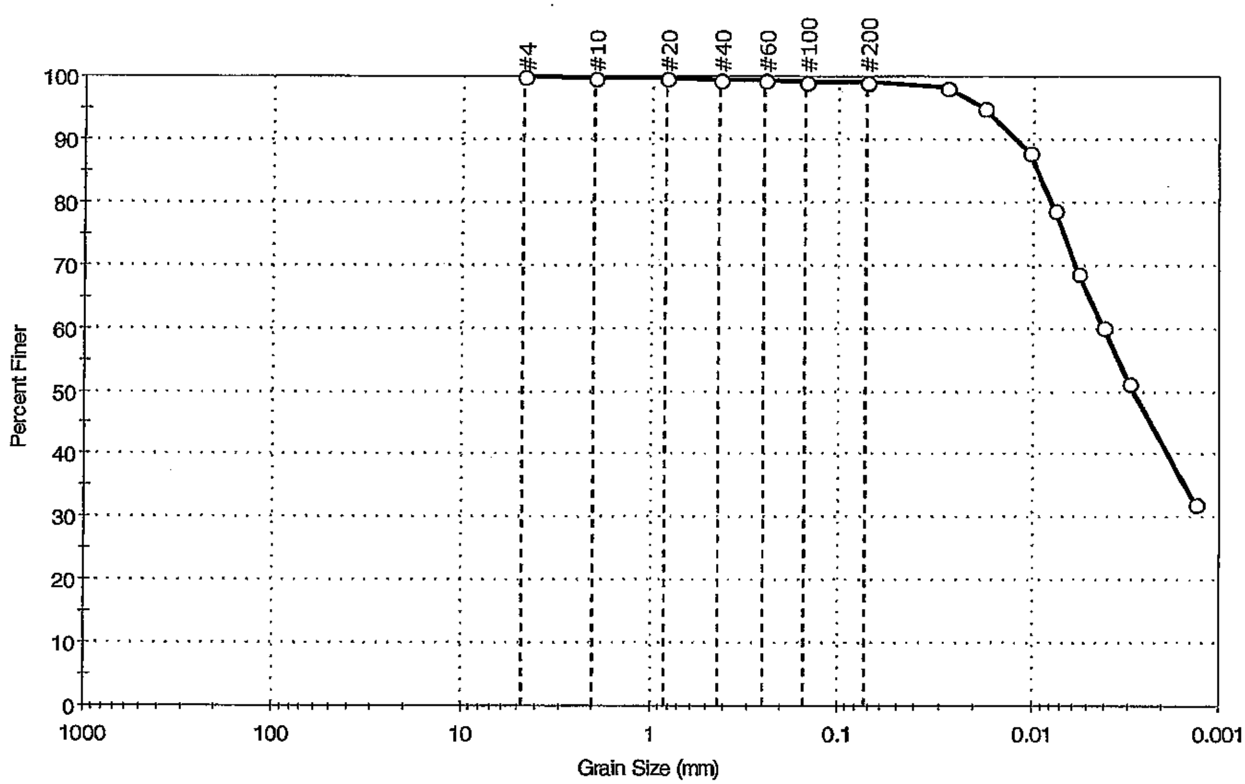
Client: Parsons Engineering Science			
Project: Onondaga			
Location: Syracuse		Project No:	GTX-7143
Boring ID: OL-VC-20077	Sample Type: jar	Tested By:	mli
Sample ID:OL-0233-03	Test Date: 01/15/07	Checked By:	jdt
Depth : 13.2-16.5 ft	Test Id: 103427		
Test Comment: ---			
Sample Description: Moist, olive brown silt			
Sample Comment: ---			

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



% Cobble	% Gravel	% Sand	% Silt & Clay Size
---	0.0	0.9	99.1

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
#4	4.75	100		
#10	2.00	100		
#20	0.84	100		
#40	0.42	100		
#60	0.25	99		
#100	0.15	99		
#200	0.074	99		
---	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0284	98		
---	0.0178	95		
---	0.0105	88		
---	0.0077	79		
---	0.0056	69		
---	0.0041	60		
---	0.0030	51		
---	0.0013	32		

Coefficients

D_{85}=0.0095 mm — D_{30}=N/A

D_{60}=0.0041 mm — D_{15}=N/A

D_{50}=0.0028 mm — D_{10}=N/A

C_u =N/A — C_c =N/A

Classification

ASTM elastic silt (MH)

AASHTO Clayey Soils (A-7-5 (50))

Sample/Test Description

Sand/Gravel Particle Shape : ANGULAR

Sand/Gravel Hardness : HARD

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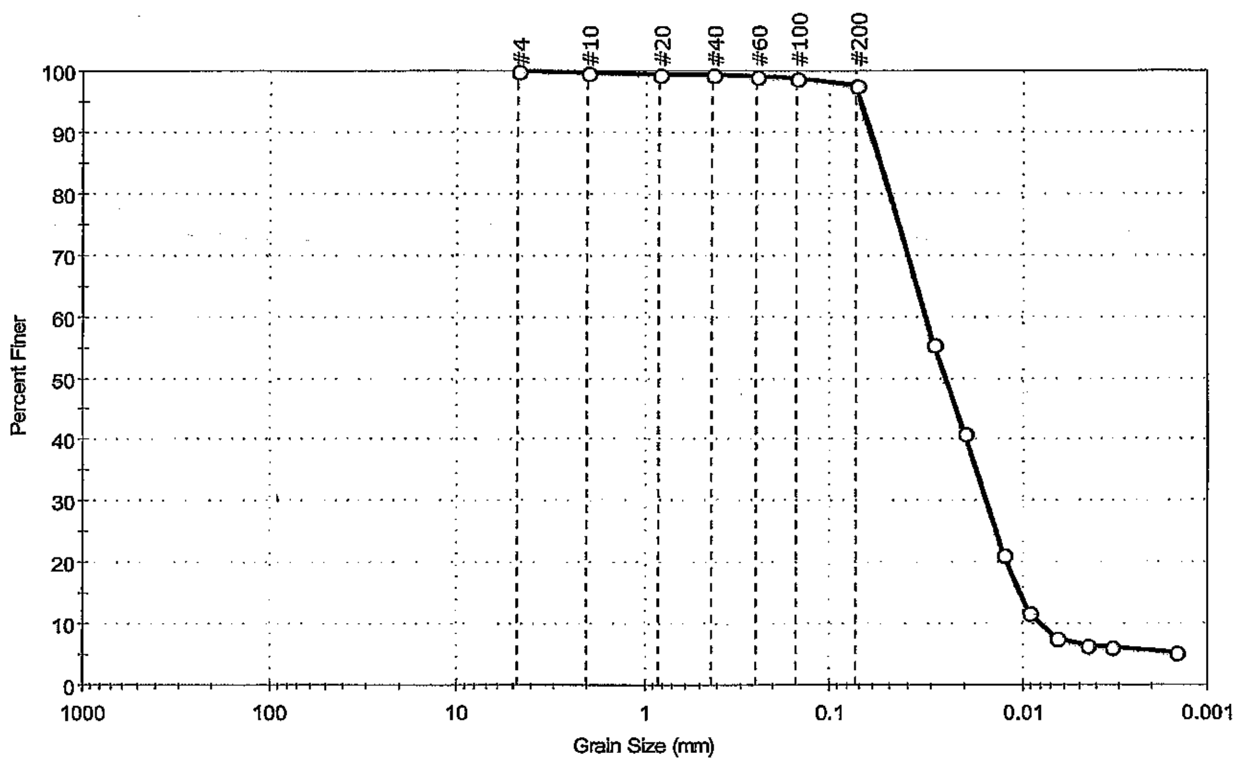
Client: Parsons Engineering Science			
Project: Onondaga			
Location: Syracuse		Project No:	GTX-7143
Boring ID: OL-VC-60054	Sample Type: jar	Tested By:	mll
Sample ID: OL-0284-20	Test Date: 01/25/07	Checked By:	jdt
Depth : 0.5-3.3 ft	Test Id: 105773		

Test Comment: ---
Sample Description: Moist, black silt
Sample Comment: ---

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



% Cobble	% Gravel	% Sand	% Silt & Clay Size
—	0.0	2.2	97.8

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
#4	4.75	100		
#10	2.00	100		
#20	0.84	99		
#40	0.42	99		
#60	0.25	99		
#100	0.15	99		
#200	0.074	98		
---	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0299	56		
---	0.0200	41		
---	0.0126	21		
---	0.0092	12		
---	0.0066	8		
---	0.0045	7		
---	0.0033	6		
---	0.0015	5		

Coefficients

D_{85} =0.0563 mm D_{30} =0.0155 mm
D_{60} =0.0329 mm D_{15} =0.0103 mm
D_{50} =0.0257 mm D_{10} =0.0080 mm
C_u =N/A C_c =N/A

Classification

ASTM elastic silt (MH)

AASHTO Clayey Soils (A-7-5 (100))

Sample/Test Description

Sand/Gravel Particle Shape : ANGULAR
Sand/Gravel Hardness : HARD

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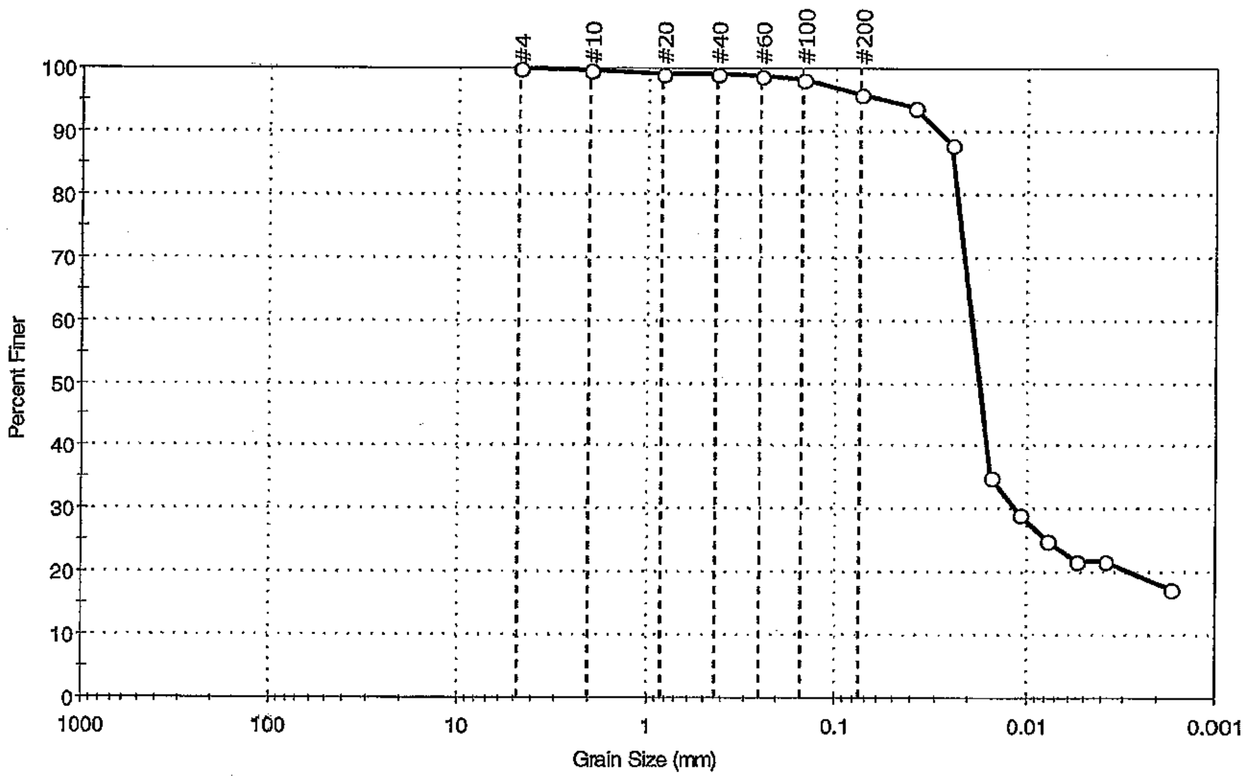
Client: Parsons Engineering Science			
Project: Onondaga			
Location: Syracuse		Project No:	GTX-7143
Boring ID: OL-0298-04	Sample Type: jar	Tested By:	mll
Sample ID: OL-VC-60054	Test Date: 06/12/07	Checked By:	jdt
Depth : 3.3-6.6 ft	Test Id: 111442		
Test Comment: ---			
Sample Description: Wet, black silt			
Sample Comment: ---			

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



% Cobble	% Gravel	% Sand	% Silt & Clay Size
—	0.0	4.2	95.8

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
#4	4.75	100		
#10	2.00	100		
#20	0.84	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
---	0.0396	94		
---	0.0248	86		
---	0.0154	35		
---	0.0109	29		
---	0.0078	25		
---	0.0054	22		
---	0.0036	22		
---	0.0017	17		

Coefficients

D_{85} =0.0241 mm — D_{30} =0.0115 mm

D_{60} =0.0193 mm — D_{15} =N/A

D_{50} =0.0176 mm — D_{10} =N/A

C_u =N/A — C_c =N/A

Classification

ASTM — elastic silt (MH)

AASHTO — Clayey Soils (A-7-5 (65))

Sample/Test Description

Sand/Gravel Particle Shape : ROUNDED

Sand/Gravel Hardness : HARD

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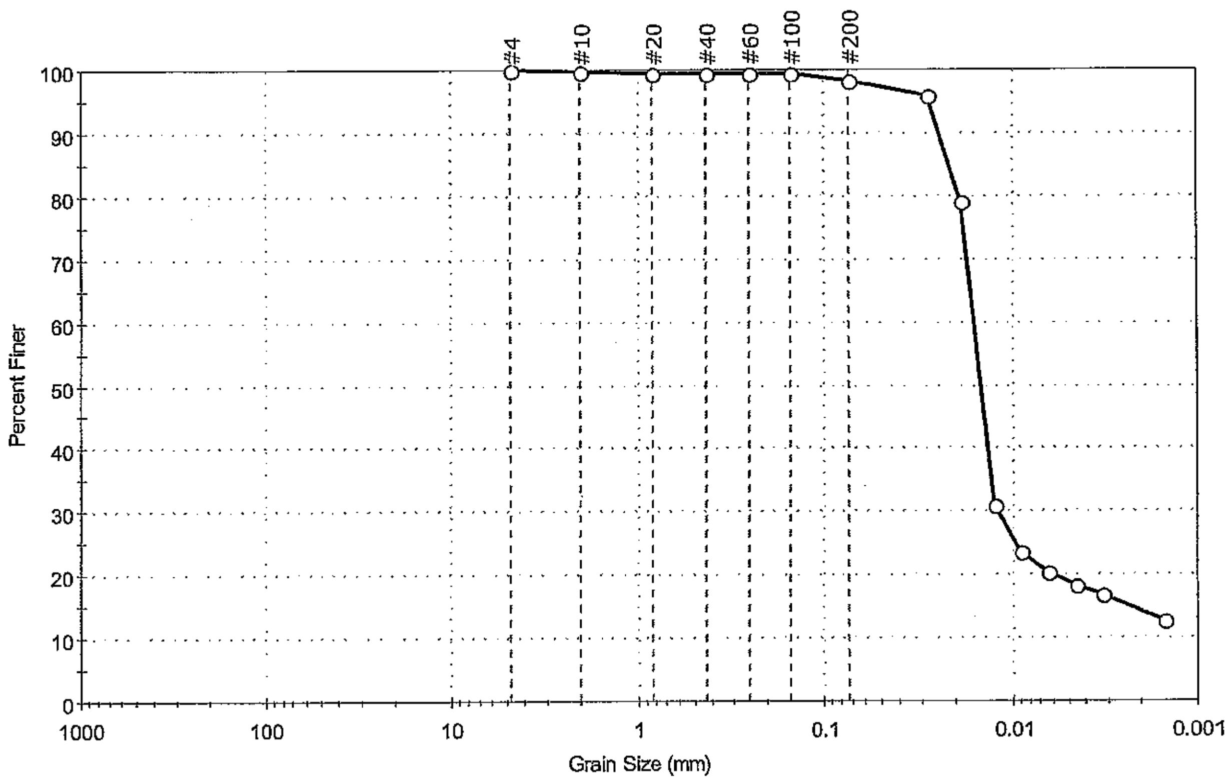
Client:	Parsons Engineering Science				
Project:	Onondaga				
Location:	Syracuse			Project No:	GTX-7143
Boring ID:	OL-VC-60054	Sample Type:	jar	Tested By:	mll
Sample ID:	OL-0282-11	Test Date:	01/30/07	Checked By:	jdt
Depth :	6.6-9.9 ft	Test Id:	105652		

Test Comment: ---
Sample Description: Moist, very dark gray silt
Sample Comment: ---

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



% Cobble	% Gravel	% Sand	% Silt & Clay Size
—	0.0	1.7	98.3

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
#4	4.75	100		
#10	2.00	100		
#20	0.84	100		
#40	0.42	99		
#60	0.25	99		
#100	0.15	99		
#200	0.074	98		
---	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0281	96		
---	0.0186	79		
---	0.0125	31		
---	0.0090	24		
---	0.0064	20		
---	0.0045	18		
---	0.0032	17		
---	0.0015	13		

Coefficients

D_{85} =0.0216 mm | D_{30} =0.0120 mm
D_{60} =0.0159 mm | D_{15} =0.0023 mm
D_{50} =0.0147 mm | D_{10} =0.0009 mm
C_u =N/A | C_c =N/A

Classification

ASTM elastic silt (MH)

AASHTO Clayey Soils (A-7-5 (53))

Sample/Test Description

Sand/Gravel Particle Shape : ANGULAR

Sand/Gravel Hardness : HARD

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GeoTesting express
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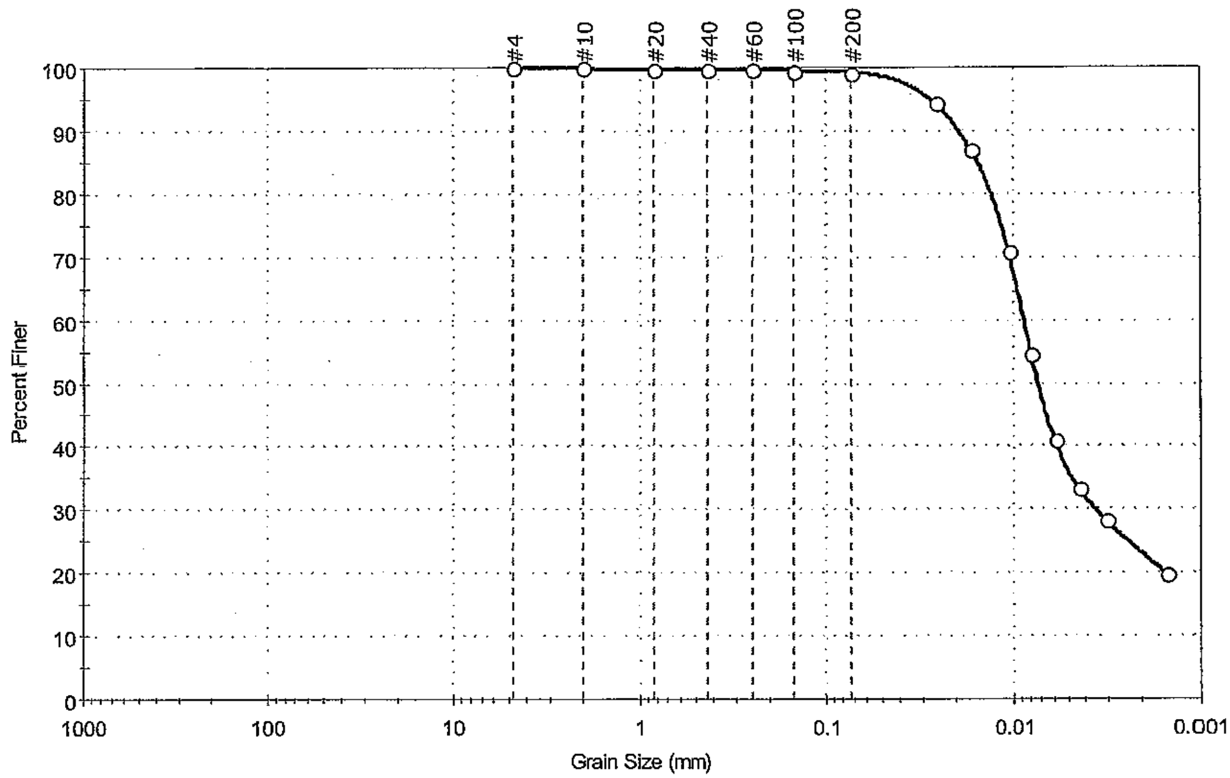
Client: Parsons Engineering Science			
Project: Onondaga			
Location: Syracuse		Project No:	GTX-7143
Boring ID: OL-VC-60054	Sample Type: jar	Tested By:	mll
Sample ID:OL-0282-12	Test Date: 01/30/07	Checked By:	jdt
Depth : 16.5-18.5 ft	Test Id: 105653		
Test Comment: ---			
Sample Description: Moist, very dark grayish brown silt			
Sample Comment: ---			

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



% Cobble	% Gravel	% Sand	% Silt & Clay Size
—	0.0	0.8	99.2

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
#4	4.75	100		
#10	2.00	100		
#20	0.84	100		
#40	0.42	100		
#60	0.25	100		
#100	0.15	100		
#200	0.074	99		
---	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0260	94		
---	0.0168	87		
---	0.0105	71		
---	0.0079	55		
---	0.0059	41		
---	0.0043	33		
---	0.0031	28		
---	0.0015	20		

Coefficients

D_{85} =0.0158 mm | D_{30} =0.0035 mm
D_{60} =0.0087 mm | D_{15} =N/A
D_{50} =0.0072 mm | D_{10} =N/A
C_u =N/A | C_c =N/A

Classification

ASTM elastic silt (MH)

AASHTO Clayey Soils (A-7-5 (65))

Sample/Test Description

Sand/Gravel Particle Shape : ANGULAR

Sand/Gravel Hardness : HARD

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