APPENDIX H: TECHNICAL EVALUATION OF *IN SITU* CAPPING AS A REMEDY COMPONENT FOR ONONDAGA LAKE

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EXECUTIVE SUMMARY

This appendix describes a technical evaluation of *in situ* subaqueous capping (ISC) as a remedy component for Onondaga Lake. The appendix discusses the general applicability of ISC as a remedial approach for Onondaga Lake, summarizes existing data as it relates to ISC, details the cap design utilizing the existing data and standard design guidance, discusses monitoring and maintenance considerations and institutional controls, and concludes with labor, equipment and material efforts likely required for ISC.

ISC is a technically feasible and efficient remedial approach for this site. ISC, in combination with pre-cap dredging, addresses concerns with lake water surface area, water depth, and lake habitat in some locations. In the remaining locations, pre-dredging is not required and the cap has been designed accordingly. Thresholds for determining partial dredging depths, areas, and volumes prior to ISC should be based on factors such as erosion potential, preservation of lake surface area, habitat enhancement, and localized presence of NAPL, hot spots, or other problem areas. These thresholds establish logical prisms for pre-cap dredging depths where required.

Cap designs described in this appendix provide physical isolation of the contaminated sediment from the aquatic environment, stabilization of contaminated sediment and prevention of resuspension and transport of contaminants to the profundal zone and other areas of the lake, reduction of the flux of dissolved and colloidally transported (i.e., facilitated transport) contaminants into surface cap materials and the overlying water column, and enhancement of aquatic habitat in the lake.

The cap design considers bioturbation depths and rates, consolidation of the cap and the sediments below the cap, and potential erosive forces due to ice scour, wind-induced waves, flood flow event currents at the mouths of tributaries, and scour from propeller wash. The geotechnical properties of the sediment being capped are evaluated to determine the likelihood of mixing during construction and means to minimize the mixing. The stability of the in-lake waste deposit (ILWD) under the weight of a cap is also specifically evaluated.

Control of groundwater flow to the lake is required for long-term effectiveness of ISC for SMUs 1, 2, and potentially 7. The proposed hydraulic containment system planned for construction at these SMUs must be considered an integral part of any capping remedy component in these areas. Capping effectiveness in SMUs 2, 3, 6, and potentially 7, can be accomplished by targeted removal of hot spots in the nearshore areas these SMUs.

The cap design includes a habitat/bioturbation layer, which is a minimum of 6 inches of sand or gravel (see Appendix M, habitat issues) placed over an armor layer. The armor layer varies by location with a minimum gradation of coarse sand required. The chemical isolation portion of the cap varies from 2 to 4.25 feet (ft) (0.6 to 1.3 meters [m] in thickness by location and includes a 6-inch (15-cm) operational allowance and a safety factor of 1.5.

A cap monitoring program should be required as part of the capping project design. The program would include monitoring during and immediately after construction followed by long-term monitoring. Short-term monitoring would focus on conformance with the cap design. The long-term monitoring would focus on cap integrity.

Since contaminated material will remain in place under the isolation cap, institutional controls will be a necessary part of an ISC remedy component. The main focus for capping is on restricting in-water activities to ensure the long-term integrity of the cap.

The ISC would be placed using a combination of hydraulic and mechanical methods. The coarser material (such as the armoring) would be placed using a clamshell bucket. The other cap materials would likely be placed as a slurry pumped out to a diffuser barge, which is moved across the capping area. Typical crew sizes and equipment for both methods are presented at the end of this appendix.

It is important to note that additional data and evaluations will be required for design of any ISC remedy component.

SECTION H.1

INTRODUCTION

H.1.1 BACKGROUND

Onondaga Lake is a 4.6-square-mile (3,000-acre) lake located just northwest of the city of Syracuse in central New York State (Figure H.1). The lake, tributaries, and adjacent upland sites have been identified as a federal Superfund site, with the New York State Department of Environmental Conservation (NYSDEC) acting as lead agency overseeing remedial investigation and feasibility study (RI/FS) activities at the site. The chemical parameters of interest (CPOIs) at the site vary by location in the lake, but include mercury, benzene, toluene, ethylbenzene, and xylene (BTEX) compounds, chlorinated benzenes, polycylic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and metals.

H.1.2 PURPOSE AND SCOPE

This appendix describes a technical evaluation of *in situ* subaqueous capping (ISC) as a remedy component for Onondaga Lake. This technical evaluation:

- Describes the general applicability of ISC as a remedial approach for the site,
- Evaluates basic design requirements for implementation of ISC in the various sediment management units (SMUs) in Onondaga Lake and evaluates the effectiveness of the basic design in these SMUs.
- Identifies other evaluations and data that would be required for design of any future ISC remedy components.

H.1.3 CAPPING AS A REMEDIAL ALTERNATIVE

H.1.3.1 Definitions

For this evaluation of capping for Onondaga Lake, the following definitions are applicable.

***In situ* Isolation Capping** is the placement of an engineered subaqueous cover, or cap, of clean material over an *in situ* deposit of contaminated sediment with the objective of isolating the contaminated sediment from benthic organisms and/or reducing contaminant flux through the cap to overlying waters. Capping of subaqueous contaminated sediments is an accepted engineering option for managing dredged materials and for *in situ* remediation of contaminated sediments (USEPA, 1994a, 2002a; NRC, 1997, 2001; Palermo, Clausner, *et al*., 1998, Palermo, Miller, *et al*., 1998). *In situ* isolation caps are generally constructed using granular material, such as clean sediment, sand, or gravel, but cap designs can include geotextiles, liners, and multiple layers. *In situ* isolation caps are also called engineered caps. Figure H.2 illustrates several example isolation cap designs. *In situ* isolation capping may be considered as a sole remedial alternative or may be used in combination with other remedial alternatives (e.g., removal and monitored natural recovery). For example, areas of higher contamination can be dredged and areas with a lower level of contamination can be capped.

***In situ* Isolation Capping with Partial Removal** involves placement of an ISC over contaminated sediments that remain in place following a partial dredging action. In this case, the remedy approach involves the removal of contaminated sediment to some depth, followed by ISC of the remaining sediment. This can be suitable where capping alone is not preferable due to habitat, hydraulic, navigation, or other restrictions on minimum water depth. *In situ* capping with partial dredging can also be used when leaving deeper contaminated sediment capped in place is desirable for preserving bank or shoreline stability or for other reasons. When ISC is used with partial dredging, the cap is designed as an engineered isolation cap, since a portion of the contaminated sediment deposit is not dredged but remains in place.

Thin Layer Capping is the placement of a thin layer of clean material over contaminated sediment to accelerate natural recovery. The acceleration can occur through several processes, including increased dilution through bioturbation of clean sediment mixed with underlying contaminated sediment. Thin layer capping is also called **enhanced natural recovery**. Thin-layer placement is different from isolation capping, because it does not provide long-term isolation of contaminants from benthic organisms. While thickness of an isolation cap can range up to several ft, the thickness of a thin layer placement could be as little as a few inches.

Residual Capping is defined as placement of a thin cap layer over a thin layer of residual sediment left behind following dredging. In this case, although the dredging operation is designed to remove the entire contaminated sediment inventory, the dredging process resuspends contaminated sediment that resettles onto the dredged surface or misses materials, forming the residual layer. Such residual layers are typically a few inches thick. Residual capping, much like thin layer capping, serves to dilute this thin layer of contaminated sediment and speed up the natural recovery process. Residual caps are not designed as isolation caps.

This appendix focuses primarily on considerations for engineered, isolation capping as a remedy component.

H.1.3.2 USEPA Sediment Guidance Principles

The U.S. Environmental Protection Agency (USEPA) has developed 11 principles for evaluating contaminated sediment sites, to include the following principle regarding evaluation of remedy options:

> EPA's policy has been and continues to be that there is no presumptive remedy for any contaminated sediment site, regardless of the contaminant or level of risk. This is consistent with the National Research Council Report on Managing PCB contaminated sediments (NRC, 2001). NRC report's states (p. 243) that "There is no presumption of a preferred or default risk-management option that is applicable to all PCB-contaminated-sediment sites." At Superfund sites, for example, the most appropriate remedy should be chosen after considering site-specific data and the NCP's nine remedy selection criteria. All remedies that may potentially meet the removal or remedial action objectives (e.g., dredging or excavation, *in situ* capping,

> *in situ* treatment, monitored natural recovery) should be evaluated prior to selecting the remedy. This evaluation should be conducted on a comparable basis, considering all components of the remedies, the temporal and spatial aspects of the sites, and the overall risk reduction potentially achieved under each option.
>
> At many sites, a combination of options will be the most effective way to manage the risk. For example, at some sites, the most appropriate remedy may be to dredge high concentrations of persistent and bioaccumulative contaminants such as PCBs or DDT, to cap areas where dredging is not practicable or cost-effective, and then to allow natural recovery processes to achieve further recovery in net depositional areas that are less contaminated. (USEPA, 2002b)

The remedial approaches of ISC or partial dredging followed by ISC described in this appendix are consistent with this principle.

H.1.3.3 Capping Guidance Documents

The U.S. Army Corps of Engineers (USACE) and USEPA have developed detailed guidance for subaqueous dredged material capping and ISC for sediment remediation. The documents *Contaminated Sediment Remediation Guidance for Hazardous Waste Sites* (USEPA, 2002a), *Guidance for Subaqueous Dredged Material Capping* (Palermo, Clausner, *et al*., 1998), and *Guidance for In situ Subaqueous Capping of Contaminated Sediments* (Palermo, Miller, *et al*., 1998), provide detailed procedures for site and sediment characterization, cap design, cap placement operations, and monitoring for subaqueous capping. These guidance documents serve as the technical basis for this appendix and should be consulted for a more detailed discussion of the various topics. Figure H.3 illustrates in flowchart format the major steps in evaluating and implementing an ISC remedy. The organization of this appendix generally follows that in the ISC chapter in USEPA *Contaminated Sediment Remediation Guidance for Hazardous Waste Sites* (USEPA, 2002a).

H.1.3.4 Advantages and Applicability of an ISC Alternative

A principle advantage of ISC is that contaminated sediments are isolated by the cap in place and do not require removal. Because the capping operation covers the contaminated sediment, the potential for contaminant resuspension and the risks associated with dispersion of contaminated materials during construction is low compared to dredging. Another major advantage is that no disposal site or *ex situ* treatment for the dredged sediment is needed. Most capping projects use conventional and locally available materials, equipment, and expertise. For this reason, in certain cases the ISC option may be implemented more quickly and may be less expensive than options involving removal and disposal or treatment. Depending on the location of the cap, the type of construction, and the availability of materials, a cap may be readily repaired, if necessary.

A well-designed cap, properly constructed and placed, and with effective long-term monitoring and maintenance, can prevent bioaccumulation by providing long-term isolation of contaminated sediments from bottom-dwelling organisms and by reducing contaminant flux into the surface water. Incorporation of habitat elements into the cap design can provide an improvement or restoration of the biological community.

The NRC provided general guidance on where conditions would be favorable, or not favorable, for the consideration of ISC (NRC, 1997). Table H.1 summarizes conditions favorable for capping with comparison to corresponding conditions for Onondaga Lake.

H.1.3.5 Disadvantages, Uncertainties, and Limitations of an ISC Alternative

A principal disadvantage of ISC is that contaminated sediment will be left in place and not removed from the lake. Since ISC leaves the contamination source in place, the sediment is not treated or detoxified. It is often necessary to rely on institutional controls, which can be limited in terms of effectiveness and reliability, to protect the cap. Although the isolation and containment associated with capping can be effective for hundreds of years or longer, contaminants may slowly migrate from the deposit over time unless offset by natural processes such as degradation, clean sediment deposition, or groundwater inflow. Even in the absence of these natural recovery processes, the rate of contaminant release to the overlying water column over long times may still be considerably reduced from current exposed sediment conditions. Long-term cap performance monitoring and maintenance is therefore required, which can offset part of the capital cost savings over removal. Capping sites within the lake may be subject to catastrophic events, such as major floods earthquakes, storms, or ice scour. These events have the potential to erode or undermine the cap, and should be factored into remedy selection, design, and monitoring and maintenance.

Erosion protection may require cap materials that are incompatible with native bottom materials and that can alter the biological community. The desire for an enhanced aquatic habitat for Onondaga Lake is an important consideration when setting design objectives for a cap at this site. However, it should be noted that the introduction of substrate to the lake bottom provides opportunities for diversifying and improving bottom conditions relative to existing conditions. It should also be noted that any active remedial activities, whether dredging or capping, have the potential to significantly change the bottom characteristics.

For sediments with high organic content, anaerobic degradation will generate significant quantities of gas. This process presents an uncertainty that is difficult to account for in modeling cap processes and effectiveness. Only degradable organic carbon will cause such gas generation. If the only source of degradable organic carbon is the carbon flux from the overlying water (e.g., leaf litter); then a cap will considerably reduce the flux of carbon to the existing sediments, eliminating gas generation over time.

Some of the most important factors when determining whether capping may be a feasible and appropriate remedy include the ability of the *in situ* contaminated sediment layer to support a man-made or naturally deposited cap, and the compatibility of a capped deposit with lake uses. In addition, institutional controls necessary to protect the cap, such as restrictions on fishing, boating, or anchoring, may not be totally reliable. The cost of routine cap maintenance and repair should therefore be included in the cost analysis. The potential for cap failure, and the subsequent need to remove portions of the cap due to unanticipated site conditions or events, should be considered in selecting areas to be capped. Also, because the history of sediment remediation is short, data on the long-term success of ISC projects is limited

Table H.2 summarizes important factors that do not favor capping as a viable alternative; it includes a comparison to corresponding conditions for Onondaga Lake. It should be emphasized, however, that all sediment management options involve tradeoffs with respect to short and long term risks.

H.1.3.6 Field Experience with Capping as a Sediment Remedy

A number of contaminated sediment sites have been remediated by ISC operations worldwide, and the experience base is growing rapidly. Numerous sediment capping projects in the U.S. have been conducted for both navigation dredging and sediment remediation projects. The contaminant movement processes are for the most part well understood, and tools are available to model the long-term behavior of contaminants under a cap. The major capping projects conducted to date are summarized in Table H.3.

H.1.4 ISC FUNCTIONS AND PERFORMANCE OBJECTIVES

ISC remedies must be considered engineered projects, designed to meet specific functions and performance objectives. The design must consider the nature of the site and all processes acting at the site that may influence the cap’s physical stability and its ability to isolate contaminants. These are discussed below.

H.1.4.1 Capping Functions and Design Criteria

The selected functions for a cap and design criteria for a specific capping project should be framed to support remedial action objectives (RAOs), preliminary remediation goals (PRGs), or selected cleanup levels. Preliminary RAOs were developed in the remedial investigation (RI) (TAMS, 2002) and are based on site-specific information, including the nature and extent of CPOIs, the transport and fate of mercury and other CPOIs, and the baseline human health and ecological risk assessments. The RAOs focus on controlling, to the extent practicable, the input of mercury and other CPOIs to the lake, as well as reducing, to the extent practicable, the magnitude of internal processes that lead to increased concentrations of mercury and other CPOIs in the hypolimnion and the surface layer of the profundal sediments. In addition, the RAOs address protection of fish and wildlife resources and attainment of surface water quality standards for CPOIs, to the extent practicable. PRGs were established to support the RAOs (See Section 2 of the feasibility study [FS]). These PRGs, presented in a narrative form, describe improved lake conditions expected to meet the RAOs, such as reducing adverse effects on fish and wildlife resources and maintaining surface water quality standard.

Based on the RAOs and PRGs, the functions for a cap for Onondaga Lake may include one or more of the following:

- Physical isolation of the contaminated sediment from the aquatic environment;

- Stabilization of contaminated sediment, preventing resuspension and transport of contaminants to the profundal area and other areas of the lake;
- Reduction of the flux of dissolved and colloidally transported (i.e., facilitated transport) contaminants into surface cap materials and the overlying water column; and
- Enhancement of aquatic habitat in the lake.

H.1.4.2 Performance Criteria for Capping in Onondaga Lake

Setting performance standards for the cap is a necessary first step in developing the design requirements and a subsequent workable design. For Onondaga Lake, the performance standards for capping should include the following:

- The cap will be designed to provide physical isolation of the contaminated sediments from benthic organisms and other receptors.
- The cap will be physically stable from scour by currents, waves, and ice. A return period for episodic events of 100 years will be considered in these evaluations. Consideration of 100-year events to assess the threshold stability for the cap will likely ensure that lower-frequency large events will not result in catastrophic failure of the cap.
- The cap will provide isolation of the contaminated sediments in the long term from flux or resuspension into the overlying surface waters. The performance criteria for chemical isolation will be a limiting upper cap layer sediment concentration for CPOIs equivalent to an SEC value in the biologically active zone of the cap or overlying habitat layers. This standard would apply as a construction standard to ensure that the isolation layer of the cap is initially placed as a clean layer, and would also apply as a long-term limit with respect to chemical isolation.

These performance standards will also apply to the outlet of each of the applicable tributaries to the lake. As noted above, the cap will be designed to withstand erosion potential including creek flow forces. In addition to these considerations, the cap will also be designed to provide a natural transition between fish and wildlife habitats in the lake and creek. If pre-design data indicate that the flow of the applicable tributary would be affected, additional dredging would be included to ensure that the impact to the flow is minimized to the extent practicable.

SECTION H.2

SITE AND SEDIMENT CHARACTERISTICS

This section provides a description of the importance of various site and sediment characteristics for cap design and the respective conditions at Onondaga Lake. More detailed descriptions of the site and the sediment characteristics are available in the RI (TAMS, 2002), and a summary of site and sediment conditions prepared to support the current FS (see Appendix B, sediment management units).

H.2.1 PHYSICAL ENVIRONMENT

Regional, climatic, and basic environmental settings for the project are important considerations as well as specific physical environmental characteristics as they may relate to cap design. Onondaga Lake is located in an urbanized area, and the lake and its environs have been influenced by development activities for over 200 years. Land around the southwest corner and southern portion of the lake is generally industrial, and the lake shoreline has been significantly modified. Land around the rest of the lake is recreational, providing hiking and biking trails, picnicking, sports, and other recreational facilities. No residential or other private properties directly adjoin the lake. The lake has several tributaries, the main ones being Onondaga Creek and Ninemile Creek. The Metropolitan Syracuse Wastewater Treatment Plant (Metro Plant) located along the southern shore of Onondaga Lake near the mouth of Onondaga Creek discharges to the lake.

Industrial activities adjacent to Onondaga Lake included production of soda ash and related products; benzene, toluene, xylene, naphthalene and tar products from the recovery of coke byproducts; chlorobenzenes and byproduct hydrochloric acid from the chlorination of benzene; and chlor-alkali products. These activities included construction of a number of containments for residuals, so-called wastebeds, in upland areas adjacent to the lake. Discharges to the lake also created a large in-lake waste deposit (ILWD) (TAMS, 2002).

The site has been divided into eight SMUs as shown in Figure H.4. The SMUs were created based on water depth, sediment type, available chemical data, sources of water entering the lake, and potential sources of CPOIs in the lake. SMUs 1 to 7 are located in the littoral zone of the lake (i.e., in water depths of 0 to 30 ft [0 to 9 m], and SMU 8 is located in the profundal zone (i.e., in water depths greater than 30 ft [9 m]). Evaluations documented in this appendix were conducted for specific SMUs as appropriate. Appendix B (sediment management units) summarizes the characteristics of each SMU to include physical characteristics and general descriptions of the sediment properties and the CPOIs present. This appendix focuses on evaluation of capping in the littoral zones delineated by SMUs 1, 2, 3, 4, 6, and 7.

H.2.1.1 Water Depth and Bathymetry

Water depths and lake level fluctuations could limit cap construction options and will affect cap design and lake uses. The potential for ice scour, erosion by waves or currents, and habitat characteristics are the most important considerations related to water depth for capping at this site.

The littoral zone (with water depths less than 30 ft [9 m]) extends from the shoreline out to distances of 700 ft. Figure H.4 shows the bathymetry within Onondaga Lake. The lake has two deep basins – a northern basin and a southern basin – that have maximum water depths of approximately 62 and 65 ft (18.8 and 19.9 m), respectively (PTI, 1992).

Most of the lake has a broad nearshore shelf in water depths of less than 12 ft (4 m). This nearshore shelf is bordered by a steeper offshore slope in water depths of 12 to 24 ft (4 to 8 m). Most of the slope area is flatter than 10 percent. The shelf and slope comprise what is termed the littoral zone (defined as extending to the 30 ft [9 m] water depth). The deeper portions of the lake are termed the profundal zone, which has maximum water depth of about 65 ft.

H.2.1.2 Hydrodynamic Conditions

Onondaga Lake is part of the New York State 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 site. Flow from the outlet is sensitive to the rate of tributary inflow, wind speed and direction, water surface elevations in the river and lake, seiche activity in the lake, and other factors (Owens and Effler, 1996). Due to the shallow depth of the outlet channel, it is likely that only water from the surface layer of the lake flows out of the lake into the river (Owens and Effler, 1996). Note that all of the littoral sediments are in “surface water,” i.e., above the stratified layer, and for roughly half of the year the entire lake is “surface water.” The annual contribution of the Seneca River to the lake via backflow has not been quantified but is believed to be less than 10 percent of the total flow to the lake. The lake elevation can also influence the characteristics of the nearshore sediments, including wetlands and parts of the littoral sediments that are subject to wave and ice disturbance.

The mean annual elevation of the lake generally is highest in early spring (due to rainfall and melting snow) and lowest during the summer dry period. From 1971 to 2000, the monthly mean elevation of the lake varied by approximately 1.5 ft (0.4 m) over the annual cycle (USGS, 2001).

Circulation of water within the lake is dominated by wind speed and direction, tributary inflows, the outflow at the northern end of the lake, shoreline configuration, and stratification. Currents at the water surface tend to move in the direction of the wind except closest to shore, where currents move water parallel to the shoreline (Owens and Effler, 1996). Winds are typically from the west and northwest, although they may occur from any direction depending on weather patterns. Current velocity is greatest when winds are situated along the major axis of the lake basin (i.e., northwest-southeast) (Owens and Effler, 1996). Under calm conditions and high tributary inflow, currents generally move toward the outlet.

H.2.1.3 Sedimentation

In a net depositional environment, the effect of new sediment deposited on the cap should be considered. Clean sediment accumulating on the cap or in voids within an armor layer can increase the isolation effectiveness of the cap over the long term. Accumulation of contaminated sediment from off-site sources can result in a contaminated surface layer over the cap. Deposition of new sediment should be considered when designing the monitoring program.

H.2.1.4 Geological Conditions

Onondaga Lake is underlain by a thick layer of unconsolidated sediments ranging from approximately 100 ft (30 m) thick near the outlet to over 300 ft (91 m) thick beneath the mouth of Onondaga Creek at the south end of the lake. The general stratigraphic sequence starting at the bedrock and proceeding upwards includes a clay or till horizon overlain by alluvium consisting of gravel, sand, and brown clay. Surficial sediments overlying the alluvium consist of clays and marls, although a thin layer of peat may be present in some areas (TAMS, 2002).

H.2.1.5 Hydrogeological Conditions and Groundwater Flow

A detailed evaluation and understanding of the site’s hydrogeology is a critical component in evaluating the effectiveness of ISC and a prerequisite to proper cap design. Upward groundwater flow at the site would require that the cap be designed to accommodate advective processes related to contaminant migration. Groundwater flow conditions are summarized in the following sections, and Appendix D (groundwater issues) presents additional detail on groundwater conditions at the site.

H.2.1.5.1 Hydrogeology and Groundwater Flow Conditions

Onondaga Lake overlies a deep, north-trending glacial trough in the Vernon Shale, the bedrock formation beneath and in the vicinity of the lake. The lake lies at the northern end of this trough, which was formed by glacial scour and glacial melt water. The trough, which averages about 300 ft (91 m) deep along the axis of the lake, is filled with primarily unconsolidated fine-grained sediments, although a relatively coarse-grained unit typically occurs at the base of the trough. The thickness of the unconsolidated sediments decreases rapidly away from the lake margins except in the valleys of the main tributaries, which are also underlain by unconsolidated sediments.

Groundwater inflow to Onondaga Lake is a very small component of the water budget of the lake. Total groundwater inflow to the lake is estimated to be less than 1,000 gallons per minute (gpm), which is about 0.4 percent of the average surface-water inflow to the lake. Most groundwater inflow to the lake occurs to the littoral zone around the entire lake, with the exception of the northern end of the lake, where there is net groundwater outflow from the lake. Groundwater inflow to the profundal zone is estimated to be negligible.

Regional groundwater flow is characterized by flow in both the bedrock and the unconsolidated sediments toward the valleys of the major tributaries and toward the lake (Winkley, 1989). The major tributaries that are groundwater discharge areas include Ninemile

Creek, Geddes Brook, Harbor Brook, Onondaga Creek, and Ley Creek. Groundwater flow towards the lake is believed to originate primarily as precipitation that infiltrates into the unconsolidated sediments bordering the lake. Since the unconsolidated sediments are restricted to a relatively narrow band on either side of the lake, the total recharge area is relatively small. As a result, recharge to and discharge from the unconsolidated sediments to the lake is relatively small.

Some bedrock groundwater, which originates from infiltration in the upland areas where the bedrock subcrops, does flow toward and discharges to the lake after moving upward through the overlying unconsolidated sediments near the lake. However, groundwater flow through the bedrock is estimated to be small because the Vernon Shale has a low permeability with most flow occurring through widely spaced fractures. Winkley noted that locally the hydraulic conductivity of the Vernon Shale approaches 4×10^{-4} cm/sec (1.1 ft/day), and that the median yield from wells in the Vernon Shale is 12 gpm (1989).

The unconsolidated deposits along the southwestern margin of the lake have been divided into five hydrostratigraphic zones that are, from shallow to deep: fill and Solvay waste, marl, silt and clay, fine sand and silt, and sand and gravel. Along the margin of the lake, the thickness of the fill and Solvay waste is as great as 50 ft thick (15 m), the marl is typically about 20 ft (6 m) thick, the silt and clay zone and the fine sand and silt zones typically have a combined thickness of 50 ft (15 m), and the sand and gravel zone is typically less than 10 ft (3 m) thick. The thicknesses of these zones decrease inland from the lake, and the zones pinch out where the bedrock subcrops.

Groundwater beneath the profundal zone of the lake is composed of sodium-chloride brines with total dissolved solids concentrations greater than 100,000 milligrams per liter (mg/L) (USGS, 2000). These brines are the result of the dissolution of halite beds in the bedrock. Some brine seeps occur along the lake shoreline, but diffuse upwelling through the sediments in the profundal zone is very small as indicated by chloride profiles in sediment porewater.

Chloride concentrations in sediment porewater in the profundal zone typically increase linearly with depth in the upper few meters of sediment. In a core from the southern basin (Station S51), chloride concentrations increased from background levels linearly to 42,000 mg/L at a depth of 16 ft (5 m) (TAMS, 2002). Similar linear profiles were observed in 36 of 42 cores collected in the profundal zone (TAMS, 2002). The linear chloride profiles indicate that the distribution of chloride in sediments is controlled by upward diffusion from natural brines beneath the lake. If the upward groundwater velocity was significant, the profile would not be linear. Based on analyses of the linear chloride profiles described in TAMS (2002), it was concluded that the upward groundwater velocity is on the order of 0.04 centimeters per year (cm/year) or less. Larger groundwater velocities are inconsistent with the observed profiles. The chloride profiles in the six cores that did not exhibit linear profiles did not exhibit the shape that would occur if upward groundwater velocity was significant; rather, the profiles suggest inhomogeneities within the sediment profile.

The presence of the brines beneath and adjacent to the lake creates, in effect, two groundwater flow systems in the vicinity of the lake. There is a relatively shallow groundwater flow system, which is primarily recharged by precipitation infiltrating into the unconsolidated sediments along the margins of the lake that discharges in the littoral zone of the lake; and there is a deep groundwater flow system consisting of brines that are relatively stagnant with very small upward movement into the profundal zone.

H.2.1.5.2 Groundwater Flux in the Littoral Zone

Groundwater flow through contaminated sediments can mobilize contaminants and result in a flux of contaminants into the lake. In developing remedial components and alternatives for the lake, it is necessary to understand the magnitude of groundwater flow (velocity) through the sediments, and to consider these groundwater flows in designing appropriate remedies for the contaminated sediments. This section describes the procedures that were used to estimate groundwater velocities in shallow sediments beneath the lake in the littoral zone. Details of these procedures are discussed in Appendix D, groundwater issues.

The littoral zone of the lake has been divided into seven SMUs for developing remedial alternatives in the FS (see Figure H.4). Groundwater flow velocities were developed for sediments within each of the SMUs. The methods used to develop the estimates of groundwater velocity varied with the existing information and analytical tools available for estimating groundwater flow.

A three-dimensional groundwater flow model has been developed for the southwestern portion of the lake and vicinity to estimate groundwater flow in those areas. This model provides a tool for selecting and designing appropriate remedial alternatives for contaminated groundwater beneath several of Honeywell’s upland sites. The model was originally developed by Blasland, Bouck & Lee (BBL, 2000) and subsequently revised by O’Brien & Gere (2002) to incorporate new information on groundwater conditions. Additional revisions were made for this FS to incorporate new information collected since 2002 and to incorporate a rigorous representation of the density effects of the brines beneath the lake.

A hydraulic containment system has been proposed for the shoreline along two of the SMUs that border the southwestern margin of the lake (SMU 1 and SMU 2 to contain contaminated groundwater as part of upland remedies. These would also minimize upward groundwater velocities in the sediment to negligible levels. In addition, cap modeling indicates that significant sediment removal or a shoreline hydraulic containment system would be required in SMU 7 to ensure cap effectiveness. For evaluation in the FS, it is assumed that a shoreline hydraulic containment system rather than sediment dredging would be implemented. The hydraulic containment system will run for a total linear distance of approximately 8,000 ft (2,438 m) along the lakeshore adjacent to SMU 1, SMU 2, and SMU 7. It will consist of a relatively impermeable wall from land surface to the top of the silt and clay zone, a drain in the fill just inland of the wall, and extraction wells in the sand and gravel zone. Water levels in the drain will be maintained at a level slightly below lake level to create an inward hydraulic gradient from the lake. Further details on the design of the SMU 7 wall, if necessary, will be identified during design.

For the FS, it is assumed that the containment system will be constructed and the design goals will be achieved during system operation. Therefore, for evaluating remedial components and alternatives in the FS, upward groundwater velocities in these SMUs were assumed to be less than 2 cm/year. This groundwater velocity is negligible and represents the approximate resolution of the analytical techniques used to estimate groundwater velocities.

For the SMUs that do not border the southwestern margin of the lake, groundwater flow and discharge to the lake were estimated from the area of unconsolidated sediments bordering the SMUs and the estimated recharge rate on these sediments. The recharge rate in the vicinity of SMUs 4 and 5 was specified as 6 inches (15 cm) per year based on Winkley (1989), and the recharge rate in the vicinity of SMUs 6 and 7 was specified as 2 inches (5 cm) per year based on discussions with the NYSDEC. The groundwater flow into each of the SMUs was then converted into groundwater velocities on the basis of a relationship that was developed between groundwater velocities and distance from shoreline. Documentation of this relationship is presented in Appendix D, groundwater issues.

The estimated groundwater velocities in each of the SMUs, as a function of distance from shore, are shown in the following tabulation (see also Appendix D, groundwater issues):

Distance from Shore (feet)	**Groundwater Darcy Flux (cm/year)**						
	SMU 1	**SMU 2**	**SMU 3**	**SMU 4**	**SMU 5**	**SMU 6**	**SMU 7***
20	<2	<2	700	300	600	70	100
60	<2	<2	90	100	300	40	60
100	<2	<2	30	70	200	20	30
140	<2	<2	20	40	90	10	20
220	<2	<2	7	20	30	3	5
300	<2	<2	4	6	10	<2	2
420	<2	<2	<2	<2	4	<2	<2
500	<2	<2	<2	<2	<2	<2	<2

* SMU 7 velocities assume no hydraulic barrier wall will be in place. If a wall is installed along SMU 7, all groundwater velocities will be <2 cm/year.

H.2.1.5.3 Potential for Nonaqueous Phase Liquids Migration

Also influencing the remedial efforts in the lake is the presence of nonaqueous phase liquids (NAPL) both within the lake sediments and in the nearshore upland area. The NAPL in the lake sediments appears to be of two basic types:

- Distributed, weathered NAPL that may have been introduced into the lake and lake sediments with the surface discharges of waste material and
- Nearshore accumulations of NAPL that may be related to subsurface NAPL plumes on shore.

An assessment of the available data was conducted to consider where and how dense NAPL (DNAPL) may have migrated in the past to try to project (by analogy) how it may migrate following implementation of the remedy (Feenstra, 2004). The following observations were made:

- There is clear evidence of monochloro- and dichlorobenzene (MCBz-DCBz) DNAPL onshore in the Willis Avenue area based on soil concentrations (hundreds to thousands of parts per million [ppm]), groundwater concentrations (tens of ppm), visual observations, and DNAPL recovery operations. Samples of recovered DNAPL have densities about 1.2 grams per cubic centimeter (g/cm3), and relatively low viscosity of about 1 centipoise (cP), as would be expected for this type of DNAPL.
- There is clear evidence of PAH-type DNAPL in the lake sediment based on sediment concentrations (hundreds to thousands of ppm total PAH) and visual observations. Almost all the visual observations of NAPL in the lake sediments have PAH concentrations that would be consistent with PAH-type DNAPL.
- There seems to be little evidence of PAH-type DNAPL onshore that may have migrated via the subsurface to the lake sediments. Some of the highest concentrations of PAHs and MCBz-DCBz are found far offshore, as far as 1,000 ft (304 m). Lateral migration of low saturations of DNAPL over these distances through relatively low permeability materials is very unlikely. Therefore, it seems most likely that the PAH-type DNAPL originated from direct discharge to the lake during the time that the Solvay wastes were discharged to the lake.
- The fluid properties of PAH -type DNAPL would be very different from MCBz-DCBz DNAPL with a lower density (1.02 to 1.08 g/cm3) and much higher viscosity (10 to 100 cP). The density of PAH-type DNAPL may not be much higher than the saline water present in the Solvay wastes.
- There is no evidence of MCBz-DCBz DNAPL in the lake sediments except in a single sample close to shore near Willis Avenue that may be related to the onshore plume. The MCBz-DCBz material elsewhere in the lake sediment appears to be more depleted chlorobenzene (ClBz) than the material onshore. This would be more consistent with direct deposition to the lake with subsequent preferential dissolution of the more soluble ClBz due to contact with large volumes of lake water, and less consistent with

subsurface migration pathways with more limited contact with groundwater and sediment porewater.

- The accumulation of PAH-type DNAPL and MCBz-DCBz DNAPL within the Solvay wastes during deposition would likely be in the form of disconnected globules, and blebs (consistent with the visual observations in sediment samples). The further migration of such residual NAPL, under any circumstances, is very unlikely because of resistance by capillary forces, and there is no evidence of significant mobility of this NAPL residual except during disturbance such as by well placement, sediment coring, and sample collection. Planned remedial efforts onshore in SMUs 1, 2 and potentially 7 would reduce current and groundwater velocities, effectively eliminating the potential for migration due to advection.

Capping of the sediments that include the distributed DNAPL will resuspend a small fraction of sediments and the associated contaminants as described in Section H.2.1.5.3. Capping over extremely soft sediments and sediments containing high concentrations of NAPL and DNAPL has been conducted elsewhere without causing significant resuspension of NAPL (e.g., Eagle Harbor, Washington and Bayou Bonfouca, Louisiana). Dredging, for example, as part of a combined dredge and cap scenario, would increase the depth of sediment subject to resuspension and loss and may expose higher-concentration NAPL to the surface. This may be especially important for more soluble components such as those associated with the MCBz-DCBz DNAPL. Soluble components at the exposed sediment surface would not require physical disturbance to move into the water column.

Subsequent to cap placement, the underlying sediments will consolidate. The hydraulic forces associated with the expression of porewater during consolidation may cause some movement of the residual NAPL. These forces can be estimated by considering the rate of consolidation. Complete consolidation of the underlying sediment would likely require several years, but a significant fraction of the total consolidation would occur within a year of cap placement. If an assumed upper bound of 39 inches (100 cm) of consolidation of underlying sediment is assumed to occur within a year, the resulting porewater flows (i.e., Darcy velocity of 100 cm/year) are of the same order as the estimated current nearshore upwelling velocities. Most of this consolidation would occur in the upper layers of the sediment column, so deeper sediments would experience significantly lower upwelling velocities than this estimate. A smaller amount of total consolidation or consolidation over a longer period of time would also reduce the resulting porewater expression rates, even in the surface sediments. Thus the expected porewater expression due to sediment consolidation is short term (i.e., approximately a year) and generally less than the estimated current nearshore upwelling velocities.

The effect of consolidation in those SMUs for which groundwater control is planned (i.e., SMUs 1 and 2) would be to cause upwelling to continue for approximately a year after cap placement. Where no groundwater control is planned, the effect of consolidation would not be a significant increase in upwelling rates relative to existing upwelling rates. In either case, this short-term effect would cause essentially no NAPL migration, since no significant NAPL migration is expected under current groundwater flow conditions.

The single sample nearshore that might be related to the onshore MCBz-DCBz plume exhibits the greatest potential for NAPL migration. This NAPL may be migrating slowly now and could continue to move, but its rate of movement would be directly proportional to the rate of groundwater flow upward into the cap material. Hydraulic controls are planned to eliminate groundwater flows and upwelling rates in the nearshore area; therefore, any upward NAPL migration would also be arrested.

H.2.1.6 Ice Scour Potential

Onondaga Lake freezes over in winter, and the potential scour effects due to ice processes were therefore evaluated. 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 the Research and Engineering Directorate at CRREL, who has over 35 years experience with ice processes (see Attachment B to this Appendix). The evaluation was based on a field site visit, reviews of published literature on ice process, observations of water temperature and ice formation at Onondaga Lake, and evaluation of data from other area lakes.

The 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. Based on the available data, the maximum ice thickness at Onondaga Lake for the 2002-2003 winter freeze was estimated to be between 12 to 16 inches (30 to 41 cm). The winter of 2002-2003 was one of the coldest winters on record and led, for example, to significant ice damming on the Grasse River in north central New York. Occasional ice pilings along the shore of Onondaga Lake have been observed, but these are of limited height (less than 5 ft [1.5 m]) and were not considered severe. Onondaga County records over a 16-year period noted only two instances of ice pilings, and these consisted of thin plates with no apparent damage observed in available photos. The shore areas of Onondaga Lake were also surveyed for evidence of ice scarring on trees and other visible signs of significant ice scour due to ice pilings. No visible tree scars or such evidence of ice erosion were found (Attachment B).

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 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 formation of frazil ice include cooling of the water to below 0º C and sufficient turbulent mixing to entrain the water and crystals to depth. In Onondaga Lake, it is very 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 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 (Attachment B).

Based on the evaluation of ice processes at Onondaga Lake, it was determined that thermal expansion of ice and winds during breakup can cause minor ice pilings on the shore. However, freezing of ice to bottom sediments at water depths less than about 16 inches (41 cm) should not occur.

H.2.2 SEDIMENT CHARACTERISTICS

The physical and chemical characteristics of the sediments vary significantly by SMU and within SMUs. A detailed description of the characteristics in each SMU was developed for this FS (See Appendix B, sediment management units).

H.2.2.1 Sediment Physical Properties

This section provides a summary of physical properties by SMU:

- **SMU 1** (the ILWD) is an accumulation of material resulting from deposition of calcium carbonate from the overflow of dikes around Wastebed B and from discharges via the East Flume. The physical nature of the ILWD is complex in that the deposit is composed of layers of soft materials and hardened “crust” layers. Seventy-seven percent of the area of this SMU has sediments with percent fines ranging from 50 to 90 percent and calcium carbonate ranging from 60 to 80 percent dry weight. Fifty-five percent of the area has total organic carbon (TOC) concentrations from 1.0 to 2.0 percent, and 40 percent of the area has TOC concentrations from 2.0 to 3.0 percent. Surficial TOC concentrations average 6.7 percent. Oncolite volume is less than 25 milliliters (mL)/0.06 square meter (m2) (grab sample) in 34 percent of the SMU area at both the depth ranges sampled (5 ft [1.5 m] and 15 ft [4.5 m]). There are basically three general geologic units observed in SMU 1:
  - **Surface Sediments** Surface sediments overlying the waste material are typically very high moisture content, low strength organic silts. Surface sediments vary in thickness from 0 to 3 ft (0 to 1 m), with thicker deposits seen offshore.
  - **Waste Material** The waste material is typically classified as very soft to soft calcareous material, with some variations observed with depth and extent. Those boreholes that penetrated the ILWD most often encountered marl beneath the Solvay waste. In certain locations, the surface is a very hard calcite layer. With depth, harder layers are also occasionally observed, but are not continuous. The thickness of these layers tends to range from 3 to 24 inches (8 to 61 cm). The known maximum thickness of this unit, based on two coring logs, is 48 ft (14.6 m) thick, although it could be greater in some areas.
  - **Native Sediments** The native sediment below the waste material is silt and clay.
- **SMU 2** This SMU is located offshore from the causeway formerly used for loading and unloading materials. Ninety-one percent of the area of this SMU has sediments with percent fines of 50 percent or less. Calcium carbonate of 60 to 80 percent dry weight occurs in 50 percent of SMU 2, but a substantial area (35 percent) of the SMU has calcium carbonate of greater than 80 percent dry weight. TOC is generally in the

1.0 to 2.0 percent category, while the average surficial TOC is 6.9 percent. Oncolite volume is low (less than 25 mL/0.06 m^2) throughout SMU 2. There are basically three general geologic units observed in SMU 2:

  - **Surface Sediments** Surface sediments overlying the waste material are typically very high moisture content, low-strength sands and silts.
  - **Debris Fill** Debris fill beneath the causeway consists of coarse sand and gravel, with wood debris, brick fragments and other debris observed in some locations up to 10 ft thick.
  - **Waste Material** Waste material was identified below the surface sediments at depths ranging from 1.6 to 10.5 ft (0.5 to 3.2 m) below the sediment surface at the eastern end of SMU 2. The matrix consists of soft-to-firm, gray, green, and white non-plastic silt.

- **SMU 3** This SMU is located offshore of Wastebeds 1 through 8. SMU 3 has 85 percent of its area with percent fines of 1 to 50 percent. Calcium carbonate of 60 to 80 percent dry weight is prevalent in SMU 3 (64 percent of the area). TOC is low (less than 1.0 percent) in almost the entire SMU (96 percent of the area), but the average surficial TOC is 3.5 percent. Oncolite volume is up to 300 mL/0.06 m^2 in 20 percent of SMU 3 along the 5-ft (1.5-m) contour, but low (less than 25 mL/0.06 m^2) throughout much of the SMU (53 percent of area). Explorations in SMU 3 only encountered a surface sediment unit. The upper 6 ft (2 m) of SMU 3 generally consists of silt. Organic debris and white, calcareous material were noted at a depth of about 9 inches (23 cm) in S365. The upper 6 inches of S363 was noted to be brown-to-gray sand.

- **SMU 4** SMU 4 includes the Ninemile Creek delta. Seventy-seven percent of SMU 4's area has sediment percent fines of 1 to 50 percent, and 18 percent of its area has percent fines of less than 1 percent. Calcium carbonate of 40 to 60 percent dry weight is found in much of the SMU sediments (54 percent of area), with the next most prevalent category being less than 40 percent (25 percent of area). Most of the area of SMU 4 has sediments with a TOC range of 1.0 to 2.0 percent (70 percent of area), with the remainder mainly less than 1 percent TOC (30 percent of area), and the average surficial TOC of 3.9 percent. Oncolite volume is less than 25 mL/0.06 m2 in 55 percent of the SMU area at the 5-ft (1.5-m) depth range. Oncolite volume is greater than 300 mL/0.06 m2 in 13 percent of the SMU area at the 5-ft (1.5-m) depth range. There are basically three general geologic units observed in SMU 2:

  - **Surface Sediments** The upper 1 ft (0.3 m) of SMU 4 consists of sand, non-plastic silt (ML), and silty sand. Below this interval, the surface sediments consist of soft black silt with zones of fine sand.
  - **Calcareous Material** At one exploration location, silty sand calcareous material (marl) was encountered at a depth of 0.6 ft (0.2 m), extending to the bottom of the boring (15 ft [4.5 m]). Shells present throughout the upper portions of this layer decreased in numbers by the 8-ft (2.4-m) interval. No shells were encountered at the 10-ft (3-m) depth.

  - **Waste Material** Waste material was identified below the surface sediments at a depth of 10 ft (3 m) in one boring. The matrix consists of silt, very fine sand, and Solvay waste. The waste was deposited through Ninemile Creek from the adjacent wastebeds during historic, high-energy discharge events.

- **SMU 6** SMU 6 extends along the eastern end of Onondaga Lake, from 700 ft (213 m) south of Onondaga Creek to the end of the Ley Creek delta. Explorations in SMU 6 only encountered a surface sediment unit. Surface sediments consist of silt and clay, with organics, wood pieces, trace sand, and occasional sand interbeds throughout the depth of the core. At one location, surface sediments were described as saturated fine-to-medium sand with trace silt, gravel, and root fibers to a depth of 19 ft (6 m). Below 19 ft, stiff sand and silt were encountered to the bottom of the exploration

- **SMU 7** SMU 7 is bordered by Harbor Brook and the southern boundary of SMU 6 (700 ft [213 m] south of Onondaga Creek). There are basically three general geologic units observed in SMU 2:

  - **Surface Sediments** Surface sediments are described as very-soft-to-loose, non-plastic, laminated silt and silty sand, with some areas of fine sand and shells. In some areas, surface sediments consist of saturated organic silt with debris and organics interspersed.

  - **Calcareous Material** Overconsolidated calcareous material (marl) was encountered from 1.5 to 10.2 ft (0.5 to 3.1 m) and extended to the bottom of both borings it was observed in (approximately 15 ft [4.5 m]). Shells are present throughout this layer, with some organics noted.

  - **Waste Material** Waste material was identified below the surface sediments in variable layers at four locations. The interbedded layers of waste in this area are a result of large-discharge events of waste material near the center of the ILWD. When large volumes of waste were discharged or overflowed to the lake, the waste flowed out towards the edge of the ILWD and was interbedded with the black organic silt/sand. The depths of the waste material varies.

H.2.2.2 Extent of Contamination

Appendix B, sediment management units, provides a detailed summary of the extent of contamination by SMU.

H.2.2.3 Shear Strength

Shear strength of contaminated sediment deposits is summarized in the attached technical memorandum on cap stability (See Attachment H). The data were measured using vane shear tests (VSTs). The data indicate that the undrained shear strength varies across the site. The softer, fine-grained sediment generally have lower shear strength. The calcium carbonate layers observed in SMU 1 have higher undrained shear strengths. The mean undrained shear strength from the VSTs is 37 pounds per square foot (lb/ft^2).

Additional data and evaluations will be required for design of any ISC remedy component. Specifically, significant additional geotechnical data will be required during final design to assess cap bearing stability and ILWD stability. Borings, cores, cone penetrometer tests (CPTs), vane shear tests, and other *in situ* tests coupled with detailed laboratory tests such as strength tests and index tests will be performed.

H.2.2.4 Gas Formation

When contaminated materials or sludges containing organic material are capped, the organic material has the potential to decompose under the influences of anaerobic and pressure-related processes. The products of such a decomposition process would consist mainly of methane and hydrogen sulfide gases. As these dissolved gases accumulate and transfer into a gaseous phase, they could begin to percolate through the capped matrix by convective or diffusive transport. This transport of gases percolating through the cap can facilitate a more rapid contaminant migration by providing avenues for contaminant release or by solubilizing the contaminants of concern and carrying them through the saturated porous media dissolved in the gaseous molecules. To an extent, the grain size and thickness of the cap can control preferential migration pathways.

With the exception of unusual conditions such as pooled NAPL, gas generation has not been documented as a problem with respect to contaminant migration through caps. Furthermore, gas formation is not expected to be a design issue for Onondaga Lake because organic contaminants at the site are not a significant source of gas. The primary source of any gas is expected to be fresh organic matter deposited with runoff, leaf litter, and sediment loads from tributaries. In addition, gas formation is highly temperature dependent, with gas generation increasing with increasing temperature. Placement of a cap will insulate the contaminated sediment surface to temperature changes (Service Engineering Group, 2004). Beneath a cap, the removal of the flux of organic matter and insulation from temperature increases should eliminate gas generation from the contaminated sediment layer within a period of months to years.

H.2.2.5 Debris and Obstructions

Debris may be present in the nearshore areas of the lake. Debris may preclude the construction of a continuous and effective cap and must be well delineated and considered in a final cap design. A side-scan sonar survey performed in 1992 indicated some debris present in limited areas of the lake (PTI, 1992), as discussed in Section 2.3.3. It should be noted that capping has been successfully placed over debris at some sites (e.g., over sunken barges at the Pine Street Canal project in Vermont) and that in general, debris poses less of a problem with capping than with removal options.

H.2.3 LAKE USES

H.2.3.1 Residence Time

In some cases, placement of a cap (without prior dredging) might reduce water depths and the retention time for a lake site. However, considering the size of the lake, and the fact that consolidation following cap placement would occur, this effect is not an issue for Onondaga Lake.

H.2.3.2 Navigation and Recreational Use

Onondaga Lake is part of the New York State Barge Canal System. The northern end of Onondaga Lake is classified as Class B waters in accordance with 6 NYCRR Part 701.7 and is appropriate for primary and secondary contact recreation and fishing. The waters in the southern end of the lake are classified as Class C waters in accordance with 6 NYCRR Part 701.8 and are best used for fishing. Class C waters should also be suitable for primary and secondary contact recreation, although other factors may limit the use for these purposes in Onondaga Lake.

The main navigational channel for boating in Onondaga Lake is a straight line between the mouth of Onondaga Creek (SMU 6) and the lake outlet (SMU 5). Water depths range from approximately 3 ft (1 m) near the barge canal and lake outlet and extend to a maximum depth of approximately 65 ft (20 m) in the southern basin. However, boating is not limited to this channel, but occurs throughout the entire lake. It should be noted that the city of Syracuse is considering developing the area at the southern end of the lake known as the Inner Harbor by transforming the barge canal terminal area (drains to SMU 6) into a harbor and marina complex.

H.2.3.3 Infrastructure and Other Physical Obstructions

Infrastructure in Onondaga Lake can be categorized as above-water structures and submersed structures. Above-water structures are limited to SMUs 2, 5, and 6. The approximate location of these structures is summarized below.

- SMU 2 - The causeway is a bridge approximately 35 ft (11 m) wide by 700 ft (213 m) long and runs along the shoreline and extends over the edge of the lake. This structure was originally constructed to support the wastebed leachate forcemain (36 inches [91 cm]) and westside pump station forcemain (12 inches [31 cm]) over the Honeywell lake water intake pipes.
- SMU 5 - Two break walls are present in this SMU, one near an 80-slip marina/boat launch at the midpoint of the lake along the eastern shore, and the other near wetland SYW-6 along the northwest shore of the lake. Two jetties located at the outlet of the lake near the Seneca River control navigation into and out of the lake.
- SMUs 5 and 6 - There is future potential for a bikeway trail (similar to a causeway) to be constructed through portions of SMU 5 and 6. Specifically, the trail would extend from the railroad tracks along the Onondaga Lake shore to approximately 300 ft (91 m) off the lakeshore, beginning at the east side of Onondaga Creek and ending at a point north of the Montreal Secondary railroad bridge. This project is currently in the feasibility stage.

Submersed structures were located using side-scan sonar data collected during the 1992 geophysical investigation on Onondaga Lake. This study identified four outfall pipes, one target characteristic of a sunken vessel (barge), three targets characteristic of a discrete cultural artifact, two large mounds of unknown material (possibly sedimentary), and some debris (PTI, 1992).

No submersed structures were identified for SMU 3 or 7 in the geophysical investigation, but visual observations have noted an extensive amount of tires and other small debris in SMU 7.

Locations where targets characteristic of cultural artifacts were identified should be further investigated prior to remedial action in those areas. Federal and state laws mandate the identification of significant cultural resources and mitigation of adverse impacts to those resources in compliance with the National Historic Preservation Act and Executive Order 11593, Protection and Enhancement of the Cultural Environment. A significant cultural resource is defined as any material remains of human activity that are eligible for inclusion on the National Register of Historic Places.

A typical dredge or capping operation can impact a wide area on the bottom and therefore must be preceded by a remote sensing archaeological survey of the impacted area. The remote sensing survey detects irregularities in the sediments (blips). Each blip could be a culturally significant artifact. Dredging would have to be conducted around the blip, or divers would be used to identify the source of the irregularity.

The approximate locations of the submersed structures are summarized below.

- SMU 1 - One target characteristic of a cultural artifact was located approximately 4,200 ft (1,280 m) from the eastern shoreline and 1,000 ft (305 m) from the southern shoreline. A long narrow linear feature, characteristic of a pipe or outfall was identified approximately 500 ft (152 m) east of the cultural artifact above.
- SMU 2 - A 500-ft (152 m) radius mound of unknown material was identified adjacent to the shoreline approximately 6,600 ft (2,010 m) from the eastern end of the lake. Some debris was also identified in and around this mound.
- SMU 4 - One target characteristic of a sunken barge was located approximately 2,000 ft (610 m) northeast of Ninemile Creek, along the boundary with SMU 3.
- SMU 5 - A long narrow linear feature, characteristic of a pipe or outfall, was identified in close proximity to the marina/boat launch located near the midpoint of the lake's northern shoreline in SMU 5. One target characteristic of a cultural artifact was located approximately 4,500 ft (1,372 m) west of this pipe.
- SMU 6 - Two long narrow linear features, characteristic of pipes or outfalls, were identified; one immediately adjacent to Ley Creek, and the other approximately 1,000 ft (305 m) south of Onondaga Creek (likely the Metro Plant outfall). Both of these pipes or outfalls are approximately 1,000 ft (305 m) from the eastern shoreline.
- SMU 8 - One target characteristic of a cultural artifact was located in alignment with Onondaga Creek, 5,000 ft (1,524 m) from the eastern shore. A 900 by 300 ft (274 by 91 m) mound of unknown material was located approximately 1,200 ft (366 m) south of Onondaga Creek and 2,500 ft (762 m) off the eastern shore in 26 to 46 ft (8 to 14 m) of water.

H.2.3.4 Habitat Considerations

Habitat enhancement is a design objective for ISC for this site. An evaluation of desirable lake habitat and associated characteristics with respect to water depth and substrate grain sizes was developed in Appendix M, habitat issues. The results of that effort are summarized in Table H.4. In general, habitat enhancement will require the addition of a habitat layer as an integral component of the overall cap design for the shallow water portions of areas to be remediated. The details of the habitat layer, such as the total organic carbon content, will be determined as part of remedial design.

H.2.4 PRE-CAP DREDGING AND IDENTIFICATION OF CAPPING AREAS

H.2.4.1 Partial Dredging Followed by Capping as a Remedial Approach

ISC implemented as the sole remedial approach is evaluated in this FS, but may result in loss of lake surface area and water depths. Therefore dredging followed by capping is also evaluated in the FS as a remedial approach.

There are two different approaches for partial dredging followed by capping. First, the total inventory of CPOIs could be removed in selected hot spots; eliminating the need for an isolation cap in those selected areas (these areas may still need a residual cap to control post-dredging residuals). The second approach is to partially dredge to a selected sediment depth within a SMU or portion of a SMU and cap the remaining inventory with an isolation cap.

The concentration of CPOIs as a function of sediment depth is a major factor in evaluating the approach for partial dredging to a selected depth. Contamination extends to significant sediment depth across most of the surface area of the SMUs; in such areas, dredging to increasingly greater incremental depth would result in no incremental risk reduction with incremental partial removal, unless the total inventory of CPOIs were removed. Further, because concentrations of CPOIs remain high in deep sediments, there is no incremental benefit with incremental depth of removal with respect to isolation cap design requirements for subsequent contaminant isolation.

Based on these considerations, thresholds for determining partial dredging depths, areas, and volumes prior to ISC were developed considering factors such as erosion potential, future uses, habitat enhancement, and dredging limitations. These thresholds establish logical prisms for pre-cap dredging depths.

Specific considerations in establishing thresholds for the partial dredging depths, areas, and volumes may include:

- Preserve present water surface area;
- Optimize aquatic habitat;
- Preserve recreational use of littoral areas;
- Minimize cap armor layer requirements;

- Avoid ice erosion;
- Remove to desired sediment concentrations for subset of CPOIs;
- Improve slope stability of ILWD; and
- Improve overall geotechnical conditions for cap placement.

The resulting thresholds are summarized in Table H.4. These thresholds should serve as the basis for developing partial dredging/capping options for each SMU and subsequent lake-wide alternatives for inclusion in the FS.

Areas within each SMU to be capped will be determined based on the following considerations:

- An engineered isolation cap would be placed over all surface areas within the SMU with remaining inventory (i.e., sediments exceeding cleanup criteria) following any pre-cap dredging, extending down to a water depth of 30 ft (9 m), although a thin-layer cap would be evaluated in remedial design and may be selected if appropriate;
- A thin-layer cap is assumed for all surface areas within the SMU greater than 30 ft (9 m);
- No capping will be done in navigation channels (with an appropriate buffer to allow future slope dredging) nor over other infrastructure that might be damaged or impaired by the cap;
- Capping over areas with infrastructure such as pipelines, utility easements, bridge piers, trail bridges, or levees will require evaluation on a case-by-case basis where such capping may damage or interfere with the function of the infrastructure.

SECTION H.3

IN SITU CAP DESIGN AND CONSTRUCTION

To meet remedial goals and objectives, an ISC project must be treated as an engineering project, with careful consideration of design, construction, and monitoring. Site-specific constraints must be considered when selecting construction methods and capping materials. Construction should conform to project specifications. Cap improvements may be necessary to address field constraints and other requirements. Short-term risks can increase on or off site during and immediately following remediation due to construction-related disturbance and potential for contaminant transport. Therefore, designs must include plans to mitigate and monitor impacts during and after construction.

The composition, dimensions, and thickness of the components of a cap can be referred to as the cap design. This design should address the intended functions and design or performance standards of the cap. The general steps for ISC design are shown in the flowchart on Figure H.5, and include the following:

- Identify candidate capping materials and compatibility with contaminated sediment at the site;
- Assess the bioturbation potential of bottom-dwelling organisms that would likely populate a cap or habitat layers on top of an isolation layer, and design a cap component to physically isolate sediment contaminants from them;
- Evaluate the potential erosion at the capping site due to currents, waves, ice scour, and propeller wash, and design a cap component to stabilize the contaminated sediment and other cap components;
- Evaluate the potential flux of sediment contaminants, and design a cap component to reduce the flux of dissolved contaminants into the water column and to reduce the surficial sediment concentrations at the top of the cap or habitat layer;
- Evaluate the potential interactions and compatibility among cap components, including mixing and consolidation of compressible materials;
- Evaluate the operational considerations and determine restrictions or additional protective measures (e.g., institutional controls) needed to ensure cap integrity; and
- Evaluate the need for long-term monitoring of cap effectiveness and develop a plan for implementation.

This section develops preliminary designs for ISC for each SMU at Onondaga Lake for evaluating effectiveness and implementability of ISC as a remedy and for cost estimating. The information is not developed in sufficient detail to constitute a “final” design.

H.3.1 IDENTIFICATION AND SELECTION OF CAPPING MATERIALS

Caps are generally composed of clean granular materials, such as sediment or soil; however, more complex cap designs could be required to meet site-specific RAOs. The design should consider the need for effective short- and long-term chemical isolation of contaminants, bioturbation, consolidation, erosion, and other related processes. For example, if the potential for erosion of the cap is significant, the cap thickness could be increased using a material with larger grain size, or an armor layer could be incorporated into the design.

Porous geotextiles do not contribute to contaminant isolation, but serve to reduce the potential for mixing and displacement of the underlying sediment with the cap material. Geotextiles can also add structural support during cap placement. However, there may be problems with geotextiles, such as difficulties in subaqueous placement, clogging, and difficulties in uniform cap placement over the relatively smooth surface of the geotextile. A cap composed of naturally occurring sand is generally preferred over quarry run sand, because the associated fine fraction and organic carbon content found in natural sands are more effective in providing chemical isolation by sequestering contaminants as they pass through the cap.

Also, specialized materials may be considered for caps to enhance the chemical isolation capacity. Examples include engineered clay aggregate materials (e.g., AquaBlok™ or geosynthetic clay liners). These approaches are recent developments and are collectively referred to as “reactive caps.” However, the potential for gas generation may inhibit or prohibit use of impermeable components such as AquaBlok™ or membranes.

The capping materials considered in this evaluation are granular sands and gravels, which may be obtained from nearby sources. However, use of geotextiles or reactive capping materials could be later incorporated into ISC designs for Onondaga Lake as conditions warrant.

Quarries near Onondaga Lake are potential sources of granular cap materials. These include the Route 49 pit located in West Monroe, New York, approximately 25 miles north of the lake and the Hanson Aggregates rock quarry located in Jamesville, New York, approximately 15 miles southeast of the lake. Materials from these sources will have to be trucked to the site and then either loaded onto barges via conveyors for offshore placement or pumped as a slurry from an on-shore stockpile to the capping areas.

Another possible source of cap material is dredged material from the Canal Authority. The Canal Authority has about 300,000 cubic yards (CY) of material adjacent to Oneida Lake, which is a one-day barge trip to Onondaga Lake. That material may be available for a low price, and the barging cost would be less than $1/ton, cost-competitive with trucking from the local quarries. This dredged material is only a potential source at this point, and, as part of final design, samples will be taken and evaluated for cap material suitability.

For this appendix and the modeling of cap effectiveness, the cap is assumed to be composed of sand with a 0.1 percent TOC, but the TOC could be specified as higher if required for localized problem areas. Higher TOC caps can be constructed in a number of ways. Dredged material or upland materials can be identified with naturally higher TOC. Activated carbon could be mixed with cap material. Activated carbon use may require special handling such as using higher specific gravity agents, releasing the material closer to the bed being capped, or incorporating into a geotextile composite. This will be evaluated as part of remedial design.

H.3.2 CAP COMPONENTS AND THICKNESSES

For a Superfund site such as Onondaga Lake, an appropriate level of conservatism should be considered in approaching the cap design. The total thickness of a cap and the composition of the cap components should be based on an evaluation of all the pertinent processes for the site and the ability of the design to achieve the intended functions of the cap. Pertinent processes include physical isolation of benthic organisms, bioturbation, cap consolidation, erosion, operational factors, and chemical isolation. Some of the processes for design of cap components can be evaluated rigorously with models, but others require engineering judgment. Cap design is evolving as more experience is gained across the range of project conditions.

For cap design with a granular material, a conservative “layer approach” is recommended. As shown on Figure H.5, each component is considered, and the necessary cap thickness is conservatively assumed as the sum of the layers for each component. Because diffusion is controlled by porosity, which is largely independent of sediment grain or particle size, the armoring layer also contributes to the isolation layer as long as a habitat/bioturbation zone separates the armoring layer from the convective motions in the overlying water. Monitoring of the habitat/bioturbation zone will evaluate the effectiveness of this zone to resist the potential erosion forces associated with convective motions. The following sections discuss considerations for Onondaga Lake, following the design flowchart on Figure H.5 for evaluating and selecting the design of each of the cap components.

H.3.2.1 Determine Cap Design Objective

Cap design criteria were discussed in Section H.1.4.

H.3.2.2 Bioturbation Component

Aquatic organisms that live in or on bottom sediment can greatly increase the migration of sediment contaminants through bioturbation. The depth to which species will burrow depends on the species’ behavior and the characteristics of the substrate (e.g., grain size, compaction, and organic content). In general, the depth of bioturbation by marine organisms is greater than that of freshwater organisms, although more than 80 percent of the time the depths that are actively mixed are less than 4 inches (10 cm) regardless of freshwater or marine conditions. The types of organisms likely to colonize a capped site and the normal behavior of these organisms are generally well known. The USACE technical note, *Subaqueous Cap Design: Selection of Bioturbation Profiles, Depths and Process Rates* (Clarke and Palermo, 2001), in addition to providing information on designing ISCs, also provides many useful references on bioturbation. A summary of some 280 sites and bioturbation depths is also available in the WEF report referenced in the NRC report (Thoms, *et al*., 1995).

To provide long-term protection, an isolation cap should be sufficiently thick to prevent direct contact of burrowing organisms with the underlying contaminated sediment or with potentially contaminated subsurface layers of the cap. To design a cap component for this function, the bioturbation potential of local bottom-dwelling organisms should be evaluated. Onondaga Lake is a freshwater system, and the potential depths of bioturbation are limited to the upper few centimeters. The NYSDEC has specified 0 to 6 inches (0 to 15 cm) as the biologically active zone.

For this site, a habitat enhancement layer is anticipated as the surface layer for any cap. This layer would serve as the bioturbation layer for the cap. Also, an armor layer is anticipated beneath the habitat layer in nearshore areas, and armor materials would serve as a barrier to deep bioturbation. The armor layer component of the cap can therefore be considered the component for both physical and bioturbation isolation (see additional discussion below). It also can provide chemical isolation, although that is not normally included in assessing a protective thickness of a capping layer.

H.3.2.3 Consolidation Component

Fine-grained granular capping materials could undergo consolidation due to self weight. Even if the cap material is not compressible, most contaminated sediment is highly compressible, and will almost always undergo consolidation due to the added weight of capping material or armor stone. Therefore, consolidation must be considered when designing the cap.

The thickness of any compressible granular cap material should have an allowance for consolidation so that the minimum required cap thickness is maintained following consolidation. Caps constructed using sand and gravel/stone are subject to minimal, short-term internal consolidation, so evaluation of consolidation of the cap layer is not necessary. Monitoring of cap thickness during construction typically takes this consolidation into account, allowing internal consolidation of granular caps following cap placement to occur before confirming cap thickness.

The analysis of consolidation of the underlying contaminated sediments must be conducted as a part of the evaluation of the chemical isolation cap component (see discussion below). Consolidation of the underlying contaminated sediment will be a factor for Onondaga Lake. The degree of consolidation of the underlying contaminated sediment will provide an indication of the volume of water expelled by the contaminated layer and capping layer due to consolidation. This can be used to estimate the movement of a front of porewater upward into the cap. Such an estimate of the consolidation-driven advection of porewater should be considered in the evaluation of contaminant flux. Methods used to define and quantify consolidation characteristics of sediment and capping materials, such as standard laboratory tests and computerized models, are available (Palermo, Clausner, *et al*., 1998; Palermo, Miller, *et al*., 1998).

An evaluation of consolidation was conducted for this site using available data on sediment physical properties within each SMU and available consolidation data for sediment samples (Attachment C).

Consolidation was calculated for applied cap thicknesses of 1 to 5 ft (0.3 to 1.5 m), considering both existing geotechnical profiles and post-partial-dredging profiles. The evaluations assumed that the cap was composed of loose fine sand. Boring data from the RI were used to define a sediment profile for SMUs 1 through 7, and the calculations were based on 5–ft (1.5-m) sublayers within the profiles. The post-partial-dredging conditions were based on assumed removal thicknesses of 0 to 6 ft (2 m). SMUs 1, 6, and 7 exhibited higher potential settlements, with the ultimate settlements roughly corresponding to the applied cap thickness. A plot of the magnitude of consolidation versus applied cap thickness for various pre-cap dredging depths is presented in Figure H.6.

Consolidation analysis indicates that settlements should be taken into account in defining depths for partial dredging cuts, especially if the goal of the partial removal is to avoid net fill of the lake. Consolidation underneath a cap reduces the removal depth required to achieve a desired final sediment surface elevation.

Note that during remedial design, additional field data will be collected to further evaluate cap-induced consolidation. Specifically, significant additional geotechnical data will be required during final design to assess cap settlement. Borings, cores, CPTs, and/or other *in situ* tests coupled with detailed laboratory tests such as consolidation analysis and index tests will be performed. Detailed modeling will be used with the data to predict consolidation of sediments under the weight of caps. Based on these remedial design evaluations, additional removal beyond that contained in the FS may be required to maintain an acceptable water depth.

H.3.2.4 Stabilization/Erosion Protection Component

The cap component for stabilization/erosion protection has a dual function to stabilize the contaminated sediment being capped, and to prevent the sediment from being resuspended and transported off site.

The potential for erosion of a cap depends on the erosive processes that are likely to occur at the site and the materials composing the cap layers. Erosive processes may include stream flow or tidal velocity forces, ice scour, turbulence around structures, wave-induced currents, and ship/vessel propeller wash. Potential for episodic events such as floods, lake storms, ice, ship groundings, etc. should be evaluated. The particle size and sediment cohesion properties of the cap material should be selected to resist the erosive forces likely to occur.

For Onondaga Lake, the site conditions across the SMUs vary, and different erosive processes may control the armor design for different SMUs. There are four processes that would potentially cause erosion of a constructed cap at this site. These include:

- Scour due to ice forces;
- Wind-induced waves due to episodic storm events;
- Currents resulting from flood flows in tributaries; and
- Scour due to propeller wash from vessels.

The resulting water depth following any partial dredging and cap construction is a major consideration in determining the erosive force resulting from an episodic event such as a flood or storm. As discussed in Section H.2.3.4, habitat constraints should also be a major factor in selecting the post-capping water depths and material properties for the cap components. USEPA design guidance for caps calls for consideration of the 100-year return interval event in design for armor layers (USEPA, 2002a).

Each of the above erosive processes was evaluated independently to determine design requirements for a cap-armoring component. The results of these evaluations should be integrated into appropriate designs for cap-armoring components across the SMUs for various alternatives developed for the FS.

H.3.2.4.1 Ice Scour

The processes resulting in potential ice scour were described in Section H.2.1.6. The depth of potential freezing and adhesion to sediments was determined to be approximately 16 inches (41 cm). Ice piling would be limited to a few feet near the shoreline. To resist ice piling action with no displacement of an armor riprap material, the armor size should be twice the ice thickness for shallow slopes (Attachment B). This would correspond to an armor size of 32 inches (81 cm). To avoid the need for a cap armor component with this stone size, contaminated material in the shallow nearshore areas could be partially removed to allow cap placement below the depth of potential ice scour, or smaller stone sizes could be used and replaced as necessary following any severe ice scour event.

H.3.2.4.2 Wind-Wave Analysis

A wind-wave analysis was performed to determine stable sediment sizes as a function of water depth for the various SMUs (see Attachment D). The 100-year return interval wind-generated wave conditions were calculated for this analysis, based on 39 years of wind records. The predominant wind direction and the direction of the strongest winds are from west-southwest to west-northwest. Average wind speed is about 10 miles/hour, while the strongest recorded wind speed was 51 miles/hour. USACE's Automated Coastal Engineering System (ACES) program was used to model wave growth and propagation for each SMU based on available bathymetry for the lake. The design 100-year wave for each SMU was determined using the probability analysis techniques in the ACES program to include the elevation and bottom orbital velocities at different depths, as well as breaking height and depth. The results from this evaluation indicated that the maximum wave height for the lake would be approximately 4 ft (1.2 m), with wave breaking occurring at a water depth of about 5 ft (1.5 m).

The stable sediment size under a progressive wave before it reaches the breaking zone (surf zone) was estimated at various water depths, and the maximum sediment grain sizes that were predicted were used as the stable sediment size for purposes of armor material design. Figure H.7 summarizes the results of this evaluation. The required armor sizes range from coarse gravel to fine gravel at water depths of 5 to 10 ft (1.5 to 3 m) and fine gravel to medium sand at water depths of 10 to 20 ft (3 to 6 m). The stable stone size for waves in the surf zone is 9- to 16-inch (23- to 41-cm) rock.

H.3.2.4.3 Flood Flow Analysis

The currents resulting from flow from tributaries into Onondaga Lake was also evaluated as a mechanism for cap erosion. Seven different creeks are tributary to Onondaga Lake (see Figure 1 of Attachment E):

- Tributary 5A in SMU 2,
- Ninemile Creek in SMU 4,
- Sawmill Creek in SMU 5,
- Bloody Brook in SMU 5,
- Ley Creek in SMU 6,
- Onondaga Creek in SMU 6, and
- Harbor Brook in SMUs 1 and 7.

For this evaluation, the erosive potential for Onondaga Creek was evaluated and applied to the other tributaries (see Attachment E). This approach is acceptable for this appendix because the main tributary flows to the lake are from Onondaga Creek and Ninemile Creek, which have similar flow characteristics. The erosive potential for Ninemile Creek was evaluated to confirm this assumption (see Attachment J). Specific evaluations of erosive potential for the other tributaries will be done in the final design.

The velocity field generated by a 100-year flow coming out of Onondaga Creek was modeled using a simple two-dimensional model of Onondaga Creek and the USACE hydraulic model RMA-2 to evaluate current distribution due to the creek inflow. The 100-year flow was 5,100 cubic feet (145 cm) per second. The results indicate maximum bottom velocities of about 5 ft per second at a distance of 50 ft (15 m) offshore, with velocities decreasing with increasing distance offshore.

The sediment stable grain sizes corresponding to these velocities were determined as the highest value based on three different methods (see Attachment E). The stable grain sizes varied from a fine gravel of 0.5 inch (12 millimeters [mm]) at the shoreline to medium sand offshore. Figure H.8 presents the stable sediment size required versus distance from the creek inflow. The required stable sizes for the flood flow were smaller than those required to resist wind-generated waves (see discussion above).

H.3.2.4.4 Propeller Wash Analysis

As part of the evaluation of the erosion cap component, an analysis of the prop wash potential was conducted (see Attachment F).

The analysis was conducted using the spreadsheet model PROPWASH based on the equations developed by Blaauw and van de Kaa (1978) and Verhey (1983), as generally recommended in the EPA guidance document *Guidance for In situ Capping of Contaminated Sediments* (Palermo, Miller, *et al*., 1998). This model considers vessel characteristics (e.g., propeller diameter, depth of shaft, and shaft horsepower) and determines bottom velocities at various distances behind the propeller at specific water depths.

A variety of vessels operate in Onondaga Lake, including tugs, a passenger vessel, and a variety of private recreational vessels. The characteristics of the various vessels were considered, and representative commercial and recreational design vessels were selected for the analysis. For commercial vessels (tugs and the *City of Syracuse*), the model was run assuming that the operators were using 25 percent of their horsepower and were operating in 30 ft of water. For recreational vessels, characteristics of a "high-end" family recreational vessel were selected, assuming the boat was equipped with one or two 250 HP engines, operating in 10 to 30-ft water depths at 25 to 100 percent power.

The model predicts the grain size required to resist the long-term, steady-state prop wash from vessels. This is conservative since, in reality, the propeller wash force is transient in nature, only impacting the cap for a short time. The results of the analysis indicated that, for typical operating characteristics of the vessels on the lake, coarse sand to fine gravel is required to resist a long-term steady state propwash from these design vessels. These grain sizes are consistent with those required for resisting erosion due to wind-generated waves.

H.3.2.5 Chemical Isolation Component

The primary objective of a cap is physical and chemical containment of the contaminants in the underlying sediments. The chemical isolation component of the cap should therefore control the movement of contaminants by advection and diffusion. Diffusion is a very slow process in which ionic and molecular species in water are transported by random molecular motion across a concentration gradient. Advection refers to the flow of sediment porewater or underlying groundwater resulting from consolidation of the contaminated sediment layer due to cap placement or upward flow of groundwater. Advection transports dissolved contaminants and colloidally bound fractions (e.g., ligand-sorbed colloids) (USEPA, 1994). This section summarizes evaluations of the required chemical isolation component. More details on these evaluations are found in Attachment G.

H.3.2.5.1 Modeling Approaches

A model of chemical fate and transport, such as that described in Appendix B of the standard guidance for *in situ* subaqueous capping, is typically used to evaluate the long-term effectiveness of a cap as defined by its ability to provide chemical isolation in a sub-aqueous environment (Palermo, Miller, *et al.*, 1998). For this evaluation, an analytical version of this model using conservative assumptions was applied. The model is based on the following principles:

- The cap is physically stable (armored if required) such that erosion of the cap does not influence the rate of contaminant migration,
- The biologically active zone in which contaminants are transported by organism reworking is confined to a small layer above the chemical isolation layer,

- The primary means of contaminant transport are the physico-chemical processes of advection and diffusion in the porewater of the capping layer,
- The concentration in the underlying sediment is assumed constant, without degradation or reduction due to chemical migration out of the sediments,
- The model results are calculated for steady state conditions, which are conservative since the contaminant flux is a maximum at steady state,
- Degradation of appropriate compounds is considered, and
- The model results are described in terms of predicted sediment concentrations in the biologically active zone at steady state for purposes of comparison to probable effect concentration (PEC) and sediment screening criteria (SSC) values.

Details regarding the algorithms of the model and model assumptions are described in Attachment G.

H.3.2.5.2 Cap Modeling Application

Input was derived from Onondaga Lake RI results, subsequent field data that has been submitted to NYSDEC (Parsons, 2003), and literature values if site-specific information was not available.

CPOIs that exceeded a PEC quotient of one were modeled for SMUs 1, 2, 3, 4, 6, and 7. Benzene, toluene, and phenol were not correlated with acute benthic toxicity on a lake-wide basis. However, because these compounds were among the predominant volatile organic compounds (VOCs) detected in the porewater during the upwelling investigation, the potential impacts of benzene, toluene, and phenol were evaluated based on predicted exceedances of the SSC for these compounds in biologically active layers of the cap. To model the effectiveness in containing the heavy PAHs, (i.e., all the PAHs except naphthalene and fluorene), representative three-ring (phenanthrene), four-ring (pyrene), and five-ring (benzo(a)pyrene) PAHs were selected for evaluation.

The groundwater model for the site was used to estimate upwelling Darcy velocities in each SMU. If this velocity resulted in exceedances of the cap performance criteria, the model was run to find an acceptable velocity that would not result in an exceedance of the performance criteria for the CPOIs evaluated in that SMU. Results of the groundwater model are presented in Appendix D.

Effective diffusion coefficients were estimated based on the Millington and Quirk model as described in Palermo, Clausner, *et al.* (1998). Diffusion coefficients for inorganic compounds were obtained from various literature sources. Values for dispersivity were estimated based on an assumed grain size diameter of the cap material (Palermo, Clausner, *et al.*, 1998).

The chemical isolation layer of the cap was assumed to contain 0.1 percent organic carbon. The overlying biologically active layer was evaluated assuming 1 percent and 5 percent organic carbon. Recommendations regarding required cap thickness were conservatively made based on the worst-case results, assuming either a 1 percent or a 5 percent organic carbon content in the biologically active layer.

Typically, porewater analyses are used to develop initial concentrations for input into cap modeling calculations. Results from Parsons 2002/2003 porewater sampling were used (where available, generally in SMUs 1, 4, and 7) to estimate the maximum underlying porewater concentrations for non-volatile compounds (Parsons, 2003). If porewater data was not available for non-volatile compounds, initial concentrations were calculated from the maximum sediment concentration in each SMU.

The results of the porewater analysis for volatile organic compounds produced lower concentrations than anticipated. Therefore, to avoid the possibility of underestimating the initial porewater concentrations, the porewater data were not used as the initial concentration model input for the volatiles analysis. Instead, initial porewater concentrations for volatile compounds were calculated from maximum sediment concentrations in each SMU using literature-based partitioning coefficients.

For non-volatile compounds, the sediment and porewater concentrations measured during the porewater sampling effort were used to estimate site-specific partition coefficients for calculating porewater concentration in SMUs where field measurements of porewater concentrations were not available. For volatile compounds, and for non-volatiles where porewater data was insufficient, partitioning coefficients developed from literature were employed to calculate initial porewater concentrations for input to the model.

Partitioning coefficients based on values reported in literature were used to estimate sorption to the cap material, as no site-specific data exists to define this phenomenon. Literature values were also used to predict contaminant half-lives for applicable compounds. Contaminant half-lives were selected at the high end of ranges provided in literature as a conservative estimate.

Cap effectiveness was based on the following criteria:

1. Steady-state predicted concentration in biologically active layer less than sediment criteria
    a. $W_{bio} < \text{PEC}$
    b. $W_{bio\ (benzene,\ toluene,\ phenol)} < \text{SSC}$
2. If these criteria are exceeded at steady state, the time required to achieve steady state was evaluated. If the time to achieve steady state was >> 1,000 years the contaminant concentration was predicted at the top of the chemical isolation layer after 1,000 years to ensure that concentrations remained below the PEC or SSC for at least 1,000 years. The cap was considered effective if more than 1,000 years was required to achieve steady state conditions, and concentrations using the transient model in the chemical isolation layer were below PEC or SSC values.

These relationships were employed to estimate the fluxes through the cap and the concentrations at the bottom of the bioturbation layer. The appropriate thicknesses required to isolate each of the CPOIs in the SMUs around the lake were evaluated by requiring that the sediment concentration in the bioturbation layer exceed neither the PEC values (for all CPOIs except benzene, toluene and phenol) nor the SSC values (only for benzene, toluene and phenol).

H.3.2.5.3 Modeling Results and Isolation Component Requirements by SMU

The results of the cap modeling and the required isolation component thicknesses are summarized here by SMU. Note that the capping model will be rerun as part of remedial design, incorporating any new data, and the cap design will be modified as appropriate. Attachment G provides detailed modeling results.

SMU	Recommended Action
SMU 1	Install hydraulic containment system. Cap with a 2.5-ft chemical isolation layer.
SMU 2	Install hydraulic containment system. Cap with a 2.5-ft chemical isolation layer.
SMU 3	Delineate locations of high contaminant levels. Remove high concentrations near shore where velocity is greater than 5 cm/yr. Cap with a 1-ft isolation layer.
SMU 4	Cap with a 1-ft chemical isolation layer.
SMU 6	Delineate locations of high contaminant levels. Remove high concentrations near shore where velocity is greater than 3 cm/yr. Cap with a 1-ft isolation layer.
SMU 7	Install hydraulic containment system. Cap with a 2.5-ft isolation layer.

H.3.2.6 Operational Component

Even though cap placement methods are available that minimize sediment resuspension and the mixing of cap material and softer contaminated sediments being capped, all placement methods will result in some degree of mixing. The degree of mixing will depend on the physical nature of the materials and the methods of placement. Penetration into soft, unconsolidated sediments of the initially applied sand cap was observed at the Soda Lake site in Wyoming. Up to 4 inches (1.6 cm) of the applied sand was found to have mixed with the softer, contaminated sediments before a solid foundation layer was formed that could bear the additional cap material. This was probably the softest material capped to date and so represents a likely upper bound.

This is consistent with the modeled findings of Zeman, *et al*., (1992) for the Hamilton Harbor site, who also cited work at the Hiroshima Bay, Japan, ISC site, where between 2 and 4 inches (5 and 10 cm) had mixed with the underlying contaminated sediments. Attachment H presents further discussion on cap/sediment mixing during placement. Increasing the overall cap design thickness can offset mixing.

Another operational concern is the ability to place a relatively thin cap layer as a uniform layer. Various placement techniques have proven successful in placing layers about 0.5- to 0.75-feet (15- to 20-cm) thick with reasonable assurance (though at increased cost due to increased operational controls). The placement process will likely result in some unevenness of the cap thickness.

An additional thickness of sand cap to account for operational considerations such as mixing and uniformity should be considered in calculation of the volume of capping material required. For this appendix, an operational thickness component of 6 inches (15 cm) is recommended. Attachment H discusses cap placement techniques used successfully on other projects.

H.3.2.7 Component Interactions and Overall Cap Thickness

The most conservative design approach for an ISC is to consider components necessary for the basic cap functions independently as described above. Using this approach, components are additive (see Figure H.9). This approach is most appropriate for caps designed with a single type of granular material, where the total thickness of cap material is the sum of the thicknesses for physical isolation, chemical isolation, and stabilization/erosion protection. Additional amounts of granular material might be added to account for consolidation (discussed below) or for other construction or operational considerations.

The cap components for physical isolation and erosion protection would seem to have the greatest potential for dual function. In the case of an armored layer placed on top of a sand cap and designed to be stable under all but very extreme events, the ability of such a layer to deter bioturbation might be considered in addition to its erosion protection function. This is especially the case for Onondaga Lake, because both an armor layer and habitat enhancement layer will be incorporated into the cap design. At some water depths, a single layer of given characteristics may fulfill both functions.

For Onondaga Lake, the cap design would require components for habitat enhancement and bioturbation, physical isolation and stability (erosion layer), chemical isolation, and operational considerations. Considering the present lack of detailed information on site conditions and sediment characteristics, cap designs for Onondaga Lake should incorporate an appropriate safety factor applied to the cap thickness deemed necessary for chemical isolation to account for uncertainty in site conditions, sediment properties, and migration processes. For this appendix and the FS, a factor of 1.5 (applied to the isolation thickness component only) is considered appropriate.

H.3.2.8 Overall Cap Design Requirements by SMU

Based on the evaluations described in this section, design requirements for an ISC were determined for each SMU, as summarized in Table H.4. The design requirements generally include the following:

- Pre-cap dredging over most littoral areas, resulting in a level cut extending from shoreline at a selected depth, providing room for armor and cap, and resulting in the optimum combination of habitat enhancement, no loss of water surface area, and armor surface below the wave-break depth. As stated before, the FS considers capping alternatives that do not include pre-dredging, which is technically feasible.
- Cap placed over the entire post-dredging surface area of the SMUs except localized areas around infrastructure, navigational channels, etc.
- Cap layers from top will include:
  - Habitat/bioturbation layer – minimum of 6 inches of gravel or sand as addressed in the habitat appendix (Appendix M, habitat issues),
  - Backfill layer – fill as needed in immediate nearshore zones to bring habitat layer up into shallow water,
  - Armor layer – consisting of gravel or coarse sand with a minimum thickness of 6 inches (15 cm), and
  - Isolation/operational component – sand with 0.1 percent TOC at thickness of 2 to 4.25 ft (0.6 to 1.3 m) (the 4.25-ft [1.3-m] isolation layer needed in SMUs 1, 2, and 7 includes a 6-inch [15 cm] operational allowance and a safety factor of 1.5 applied to the isolation thickness).

Figures H.9 and H.10 show a typical cap cross section reflecting these design requirements. These design requirements should be considered in developing alternatives for the FS. The design evaluations and cap design requirements presented here are based on the available data. Additional data and evaluations will be required for any ISC remedy components for final design.

H.3.3 GEOTECHNICAL CONSIDERATIONS

Geotechnical considerations important to cap design include shear strength of the contaminated sediments (which determine their ability to support a cap) and liquefaction issues for seismically active areas.

At Onondaga Lake, the following geotechnical considerations are important for cap design:

- Bearing capacity of the sediments (the ability to support a cap without displacement failures),
- Stability of caps placed on slopes (the ability to place the cap on a given slope and the stability of the edges of the cap), and

- Stability of the overall sediment deposits with cap placement (the slope stability of the deposit with cap, considering the loading of the cap).

Shear strength data is a key consideration in evaluating geotechnical considerations.

H.3.3.1 Bearing Capacity

Usually, contaminated fine-grained sediment is predominately saturated and therefore has low shear strengths. These materials are generally compressible. Unless appropriate controls are implemented, contaminated sediments can be easily displaced or resuspended during cap placement. Additional geotechnical issues following placement include cap stability and settlement due to consolidation.

As with any geotechnical problem of this nature, the shear strength of the underlying sediment will influence its resistance to localized bearing capacity or sliding failures, which could cause localized mixing of capping and contaminated materials. Cap stability immediately after placement is critical, before any excess porewater pressure due to the weight of the cap has dissipated. Usually, gradual placement of capping materials over a large area will reduce the potential for localized failures.

Field monitoring data have shown successful sand cap covering of contaminated sediment with low strength. However, data on the behavior of soft deposits during placement of capping materials is limited. That is, when sediment fails due to the weight of the cap, the failure mechanisms are not well understood. Therefore, geotechnical engineers use a conservative approach for determining cap bearing capacity: a model that equates a cap on sediment to an isolated footing bearing on the sediment is used. Conventional geotechnical design approaches should therefore be applied with caution. These design approaches could be conservative for conditions normally encountered in cap design. For example, a cap should be built up gradually over the entire area to be capped. This would reduce the potential for mixing with and overturning of the contaminated sediment. Similarly, caps with flat transition slopes at the edges should not be subject to a sliding failure normally evaluated by conventional slope stability analysis.

The capping material should be applied slowly and uniformly to avoid problems with bearing capacity or slope failures if the contaminated sediment deposit is soft. Uncontrolled release of a large amount of material or the buildup of a localized mound could cause a bearing capacity failure. If this occurs, cap material will penetrate into the contaminated deposit and could cause contaminated material to resuspend and disperse into the water column.

The sediments across the SMUs are variable. Many of the sediments are soft and compressible, but no more so than other sediments that have been successfully capped. Methods for cap placement should be considered that gradually build up the sand cap thickness to minimize sediment and cap mixing. Once the sand cap component is in place in a given working area, the placement of armor layers can proceed using conventional placement methods.

An analysis of the bearing capacity of the sediments was conducted to determine the maximum difference in cap material thickness that could be tolerated by the sediments during cap placement (see Attachment H). This analysis was conducted using deterministic methods, probabilistic methods, and by comparison to past similar capping projects. Deterministic methods, based on traditional soil mechanics relationships, indicated an 18-inch (46-cm) differential thickness would be stable against bearing failure. The probabilistic evaluation indicated a 95 percent probability of placement without bearing failures for a differential thickness of 6 inches (15 cm). A review of other capping projects indicated that sediments with sediment moisture contents and shear strengths similar to those at Onondaga Lake were successfully capped without bearing failures when the caps were constructed by incremental placement of thin capping layers to gradually build up the required cap thickness. Table 2 of Attachment H to this appendix present a detailed summary of other successful capping projects (undrained shear strengths, moisture content, and Atterberg limit data are presented in the table for each project). Many of these projects had comparable or significantly lower undrained shear strengths compared to the data available on Onondaga Lake. Specifically, the KPC Ward Cove capping project, Los Angeles Corps Aquatic capping pilot project, Matsushima Bay Japan, PPG Barberton, Hiroshima Bay Sediments Japan, and Lake Biwa Japan projects all had comparable strength sediments.

Based on these evaluations, if the cap height differential is kept below 6 inches (15 cm), bearing failure of the cap material into the underlying sediment should not occur. Past cap construction projects also conclude that keeping the cap height differential low during lift placement is key to successfully placing a cap on soft sediments. To maintain a low differential thickness during cap construction, a hydraulic capping approach would likely be used. For this approach, the capping material would be slurried and pumped to a diffuser barge over the capping area. The diffuser barge would be moved back and forth, allowing the capping material to gently fall through the water column. Thin lifts would be placed with each pass. Any armor material would likely need to be placed using a clamshell bucket after the full sand cap thickness is in place. Following buildup of initial cap thickness of 1 ft or more, the applied layer thickness may be increased. Armor material would also be placed in lifts on top of the base cap layer.

Additional data and evaluations will be required for design of any ISC remedy component. Specifically, significant additional geotechnical data will be required during final design to assess cap bearing and cap height differential. Cores, vane shear tests, and other *in situ* tests coupled with detailed laboratory tests such as strength tests and index tests will be performed.

H.3.3.2 Stability of the Overall Sediment Deposits

Slumps were reported in the surface of the ILWD in the geophysical survey report prepared by Exponent in 1992 (PTI, 1992). In 1943, a section of the dike on one of the on-land waste deposits failed, and the waste material flowed onto adjacent roads and property. Therefore, slope stability of the overall deposit with cap in place is of special concern in the ILWD.

Several factors can be considered in evaluating the current potential of a slope failure in the ILWD as compared to 1943. The 1943 event was a failure of an upland confining berm followed by flow of waste that had been confined. In contrast, the ILWD was deposited approximately 50 to 100 years ago and has been subject to constant immersion in the lake waters and to the upwelling of groundwater entering the lake from the bedrock aquifer. The consolidation and strength properties of the ILWD and on-land waste will differ because of these differences. Shear strength data for the on-land waste (Kulhawy, *et al*., 1977) indicates an internal friction angle of 32º ±6º with no cohesion (results from consolidated/undrained triaxial shear tests). Results reported on samples taken by Parsons in the fall of 2002 as a part of the groundwater upwelling investigation were friction angle 0º and average cohesion 300 lb/ft^2 (results from unconsolidated/undrained triaxial tests). Kulhawy's work and measurements made on the in-lake waste agree that a total unit weight of approximately 78 pounds per cubic foot (lb/ft^3) is applicable to the waste material.

Since the in-lake waste does not have a containment berm and has long ago reached equilibrium (obtained a stable slope), the ILWD should not flow suddenly from adding the small uniform load of a sand cap. Any partial dredging of the ILWD and the subsequent placement of a cap would present an even more stable condition.

An evaluation was conducted to address slope stability issues associated with capping the ILWD (see Attachment I).

The geotechnical parameters for the lacustrine soils lying under the in-lake waste are unknown. Because they have supported the in-lake waste for many years and have consolidated under that load, an analysis that assumes they are stronger than the in-lake waste is appropriate for an assessment of the slope stability of the in-lake waste. The only place where this may be an invalid assumption is near the toe of the ILWD slope, where recently deposited organic silts are likely to have a lower strength than the in-lake waste.

The analysis was performed on the ILWD using the STABL 5M software program produced by Purdue University. Two slope profiles in the southeast corner of Onondaga Lake were analyzed, one selected based on the slump profile in a hydrographic survey completed by Exponent in 1992 and the second location selected corresponding to the steepest slope in the ILWD. The slope stability analysis was run using the existing static conditions and dynamic conditions under a pseudo-static earthquake loading of 0.03 gravity (g). Analysis were run with both the existing slopes and with a 5-ft (1.5-meter) sand cap installed.

For static stability of the existing slope, the factors of safety against a slope failure were 10.1 for the slump profile and 5.1 for the steepest profile. For dynamic conditions, the factors of safety were 2.8 and 1.7, respectively. For static stability of the capped slope, the factors of safety against a slope failure were 7.7 for the slump profile and 4.1 for the steepest profile. For dynamic conditions for the capped slope, the factors of safety were 2.4 and 1.5, respectively. The factors of safety for all conditions were well above the value of 1.3 commonly used as a design criterion by the USACE. Partial dredging of any of the SMUs would result in increased stability, and placement of the cap would also induce consolidation, which would increase the shear strength of the sediments. Considering that the slope analysis was conducted for a pre-dredging cross-section, the factor of safety should be even greater.

Note that during remedial design, additional field data will be collected to support further stability evaluations. Specifically, significant additional geotechnical data will be required during final design to assess ILWD stability. Borings, cores, CPTs, vane shear tests, and/or other *in situ* tests coupled with detailed laboratory tests such as strength tests, consolidation analysis, and index tests will be performed. Detailed modeling will be used with the data to determine slope stability of the ILWD. Based on these remedial design evaluations, additional engineered controls, possibly including additional removal, may need to be implemented for a cap to be stable under static and seismic conditions.

H.3.4 CAP CONSTRUCTION

H.3.4.1 Cap Construction and Placement Methods

Placement of Base (Sand) Cap Material. The base chemical isolation layer of the cap (sandy material) will need to be placed slowly and evenly to minimize mixing of cap material with the soft sediments (see Section 3.3 and Attachment H). A common method of placing a cap slowly and evenly is to place the cap hydraulically in thin lifts (Figure H.11). Coarser armor material that is too large to be placed hydraulically would likely be placed by clamshell bucket (Figure H.12). Each method is described and the anticipated production rates are presented below.

The cap material will be brought to the site either via truck or barge. Based on a preliminary search of cap material sources, it appears that the cap material will likely be brought to the site by truck. Once on site, the material would be stockpiled. The stockpiled cap material would then be slurried and pumped to a diffuser barge for placement. This approach has been used on two recent capping projects: Soda Lake capping project in Wyoming (Houck, *et al.*, 2001) and the Hudson Run Reservoir (HRR) capping project in Barberton, Ohio (Verduin, 2004).

The HRR capping project used an end loader to load capping material into a hopper, which fed another hopper at the intake of an 8-inch dredge. The second hopper had intake slots to allow water to flow into the pump with the cap material to form the cap slurry. The dredge pumped the cap slurry to a diffuser barge located in the HRR. The contractor used three sets of winches and cable lines to move the barge back and forth across the HRR. The contractor met the target lift thickness of 3 inches (8cm) by making six passes of the diffuser over the capping area. Very minimal mixing of soft sediment and cap material was observed (less than a few inches on average) (Verduin, 2004).

The contractor for the Barberton, Ohio project placed an average of 250 to 350 CY of capping material in a 10-hour day using this approach. The area capped was 7 acres. Because the cap area on Onondaga Lake is significantly larger, the contractor would most likely use a larger pumping system. We would anticipate that a contractor capping Onondaga Lake would use a 10- to 12-inch (25- to 30-cm) diameter pump and pipe to place the cap material. A 12-inch (30-cm) pump/pipe capping system could place 80 to 120 CY per hour (CY/hr) (this is a net production rate, assuming efficiencies observed at the Barberton, Ohio project).

Placement of Coarse Cap Material (Armor Layer). Capping materials generally larger than 2 to 4 inches (5 to 10 cm) in diameter would need to be placed mechanically (Figure H.12). The placement operation would consist of a derrick-mounted barge with a haul barge containing the cap material nearby. The material would most likely be placed mechanically with a 3- to 5-CY bucket or a skip box. The derrick would cast the material into the water. On slopes, the cap would be placed from the toe upward to control potential slumping. This capping approach was used successfully on a number of projects (Verduin, *et al*., 1998; Verduin, *et al.*, 2001; Verduin, *et al.*, 2002). Again, the contractor would be required to place the cap in lifts. The estimated production rate for this type of placement approach is 70 to 120 CY/hr (coarser armor material would generally be placed at the slower rate).

H.3.4.2 Availability of Materials and Equipment

Section H.3.1 describes considerations for selecting cap materials and potential sources of cap materials at local quarries. The final selection of cap material would be part of the design, but availability of cap materials has been confirmed. The necessary equipment and materials for cap placement operations can be obtained from local sources or be custom-fabricated as needed.

H.3.4.3 Contaminant Releases During Construction

During cap placement, resuspension, volatilization, or other movement of chemical contaminants can occur. The potential short-term risk to the community, workers, or environment during cap placement should therefore be evaluated. Also, the potential for resuspended sediment to be transported and deposited in the profundal zone is of concern for this site.

Even though there are no standardized methods to predict the degree of contaminated sediment resuspension resulting from cap placement, field data provide some insights. USEPA has conducted monitoring of capping-induced resuspension for projects at Eagle Harbor and Boston Harbor (Magar, *et al*., 2002). Capping resuspension was low for both sites and decreased as capping operations continued. Similar results were also found for capping resuspension monitored for a large-scale capping field pilot study at the Palos Verdes site near Los Angeles (Palermo, *et al*., 2001; McDowell, *et al*., 2001), where contaminant concentrations quickly returned to background levels. Extensive water quality monitoring of capping-induced resuspension conducted for the Soda Lake project (ThermoRetec, 2001) detected no site-related petroleum hydrocarbons. Recent observations at the Anacostia River Cap Demonstration Project indicated no observable sediment resuspension due to cap placement with a clamshell operating within a silt curtain enclosure (Reible, 2004).

These studies indicate that levels of sediment resuspension due to well-managed capping operations were acceptable, and rates of release were low compared to that for environmental dredging. It should be noted that not only are rates of release from capping low as compared to dredging activities, but also the mass of sediment release per unit area remediated from capping activities would be much less than that for dredging, since the sediment thickness exposed to the resuspension process during cap placement would be limited to a thin surface layer, on the order of inches, as compared to the full thickness of a production dredging cut.

For this appendix, the total mass of sediments resuspended by cap placement is conservatively assumed to be 0.5 percent of the mass of sediment in the upper 6 inches (15 cm) over the total area capped. The sediment mass resuspended is assumed to be composed of half capping material and half contaminated sediment. A sediment thickness of 6 inches is deemed an appropriate thickness of sediment exposed to resuspension processes, since the initial capping material placed will tend to attenuate and shield the sediments from further resuspension as capping progresses.

Measures to reduce the potential for resuspension, volatilization, or other contaminant movement should include selection of cap materials, placement equipment, and methods designed to spread the capping material over the site gradually. For the Eagle Harbor project, cap material was hydraulically washed off a barge. A manifold arrangement for placement of cap material slurry was used at a capping project at Hamilton Harbor in Canada. At the Simpson Tacoma project and at Soda Lake, a horizontal auger dredge was used to place cap-material. These and other projects illustrate the range of possible approaches successfully used to place caps in a gradual manner to minimize potential for resuspension and displacement of contaminated sediments.

The potential short-term risk to the community, workers, or environment during cap placement should be evaluated. Measures to reduce the potential for resuspension, volatilization, or other contaminant movement should include selection of cap materials, placement equipment, and methods designed to spread the capping material over the site gradually. Selection of the proper construction techniques will allow the cap to be gradually built up without the potential for geotechnical instability (bearing or slope failure) or excessive disturbance. In addition, use of silt curtains and other barriers may be considered to prevent or minimize contaminant migration. In extremely contaminated areas or at shallow sites, use of sheet pile cofferdams may be considered to prevent contaminant migration from the construction site.

H.3.5 THIN LAYER CAPPING

Since a thin layer cap is not intended to be an isolation cap, a rigorous technical evaluation is not required. The effectiveness of thin layer capping is discussed in Appendix N, monitored natural recovery. The thickness of the placed thin cap will determine the degree of enhanced natural recovery achieved by mixing with the underlying contaminated sediments. It is assumed for purposes of this appendix that an isolation cap would be placed over sediments between the 20 and 30 ft (6 and 9 m) depth contours. However, it is anticipated that the appropriate remedial approach for this area would be determined as part of the pre-design investigation and design process. This thickness can be used in the FS for costing purposes.

SECTION H.4

MONITORING AND MAINTENANCE CONSIDERATIONS

H.4.1 MONITORING

A monitoring program should be required as a part of any capping project design. The main objectives of monitoring for ISC would normally be to ensure that the cap is placed as intended and that the cap is performing the basic functions (physical isolation, sediment stabilization, and chemical isolation) as required to meet the remedial objectives. Specific items or processes that may be monitored include cap integrity, thickness, and consolidation; the need for cap nourishment (subsequent filling or capping); benthic recolonization; and chemical migration potential.

Frequent monitoring is necessary at capping sites during and immediately after construction, followed by long-term monitoring at less frequent intervals. In all cases, the objectives of the monitoring effort and any management or additional remedial actions to be considered as a result of the monitoring should be clearly defined as a part of the overall project design. The cost and effort involved in long-term monitoring and potential management actions should be evaluated as part of the initial FS.

Monitoring programs for Simpson, Eagle Harbor, Soda Lake, Barberton and other projects have included components for resuspension and cap integrity during construction as well as components for long-term cap effectiveness. Plume monitoring with instruments as well as discrete samples for contaminant concentrations are the usual approaches for resuspension monitoring. Pre- and post-bathymetric surveys, along with consolidation measurements, help evaluate whether cap thickness design objectives are achieved. Cores taken through the cap are the most frequent tools used to determine cap integrity during and immediately following construction as well as at longer time intervals to evaluate long-term effectiveness. Samples from the cores are analyzed for physical parameters as well as sediment and/or porewater chemistry.

For Onondaga Lake, it is especially important that the performance standard in the upper layers of the cap, specifically in the bioactive zones be confirmed by monitoring. Any construction monitoring to determine if this standard is met needs to occur *prior* to placement of any stone armor layer. For long-term monitoring for effectiveness, sediment samples should be taken in the lower portions of the cap profile in addition to the upper biologically active zone. This will determine if any contamination in the cap is due to cap performance issues (migration from below) or recontamination from above.

H.4.2 CAP MAINTENANCE

Routine cap maintenance should be considered in developing costs for any capping remedy component. In most cases, maintenance would be limited to small repairs of the cap armor layers. For Onondaga Lake, the cap armor stone in the immediate vicinity of the shoreline may be subject to ice scour events, and large stone sizes are required for complete protection. One option for ice scour protection is the placement of the smaller stone size consistent with design requirements for wave erosion, with periodic maintenance following ice scour events as needed. For costing, such periodic maintenance should be assumed to occur every five years, consisting of replacement of 1 ft of armor stone, 1 ft of gravel, and 0.5 ft of sand over an area of 10 acres.

H.4.3 CAP REPAIR FOR EXTREME EVENTS

The NYSDEC has commented that the cost estimates for capping should account for possible “failure” scenarios. There are three types of relevant events that could be considered.

First, a cap could be physically damaged by an extreme episodic event, one exceeding the magnitude of the design events for which the cap armor layer is designed. An example of such an event would be a wind-driven wave event that exceeds the 100-year return interval for which the armor material sizes have been selected. Another example may be the occurrence of an ice cover of thicker dimension than the anticipated maximum of 16 inches (41 cm) and the subsequent breakup and piling of the ice on shore with greater-than-expected ice scour impacts to the nearshore armor stone. However, catastrophic failure of large areas of the cap would not occur during either of these examples.

In the case of a wave event, the exposure of the cap to an extreme event is of limited duration. Some armor material may be moved by the extreme wave energy, but the armor material would not “disappear,” and energy would be attenuated by the resulting windrows formed by the armor material. In the case of an ice scour event, any damage would be limited to areas at the immediate nearshore boundary of the capped area. Damage to the cap could be repaired in both examples described above. In accounting for such damage repair, it should be assumed that no more than 10 percent of the total area capped in any SMU would require repair, and that such repairs would be made to similar specifications and using similar materials as the original construction. Such a major repair should be considered in addition to normal cap maintenance and should be limited to a one-time occurrence for cost estimating purposes.

A second type of failure scenario is a possible slope failure in the ILWD resulting from a seismic event that exceeds the return interval considered in the design. This failure scenario would apply only to SMU 1. Considering the overall factors of safety against sliding calculated for the FS, such a failure would occur only in the areas of steepest slope in the ILWD. Damage to the cap resulting from a slump could be repaired by some material removal at the head of the slump and subsequent replacement of the cap. It should be assumed that no more than 10 percent of the total area capped in SMU 1 would require repair, and that such repairs would be made to similar specifications and using similar materials as the original construction. For cost estimates, such a major repair should be limited to a one-time occurrence.

The third type of event that may be considered is a failure of the chemical isolation effectiveness of the cap. The cap designs for chemical isolation are based on well-accepted scientific principles governing the chemical migration of contaminants due to diffusive and advective transport processes and appropriately conservative engineering principles. Therefore, the only cause for such an effectiveness failure would be the mischaracterization of the physical and/or chemical properties of the sediment during design. Since any design of a capping remedy would be based on a refined sediment characterization effort, such a mischaracterization would be limited to a missed hotspot of high sediment contaminant concentrations or pooled NAPL. The area subject to any such mischaracterization should be assumed limited to no more than 5 percent of the total area capped in any SMU.

Since the mischaracterization would essentially be in the form of isolated hotspot(s), two repair approaches are possible. The first approach would entail removal of the hotspot. In this case, the cost estimate of repair would be based on an isolation of the area using sheet piles, removal of the cap and contaminated material by dredging, disposal of the removed material at either the SCA or at an off-site landfill, and replacement of the cap. A second approach would involve the replacement or supplement of the existing cap with a new reactive cap. The cost of such a repair (or construction upgrade) would be based on the isolation of the hotspot with sheet piles, removal of the existing cap, and subsequent placement of the reactive layer followed by conventional sand isolation layers and armor layer. Removal of the existing cap would be necessary if the hotspot is in shallow water, but in deeper water the reactive cap could be placed over the exiting cap. Such a major reconstruction should be limited to a one-time occurrence.

SECTION H.5

INSTITUTIONAL CONTROLS

Since contaminated material will remain in place under the isolation cap, institutional controls (IC) will be a necessary part of an ISC remedy component. The main focus for capping is on restricting in-water activities to ensure the long-term integrity of the cap. Because caps would be constructed in the littoral areas of Onondaga Lake, IC would logically include restrictions on nearshore developments (such as pier construction or dredging activities) and restrictions on certain types of navigation or anchoring activities.

Existing infrastructure would be considered in defining pre-cap dredging and capping requirements in the design stage. Future shoreline development plans could also be considered in final design of an ISC remedy component. Long-term plans for development around the lake could be integrated into the final pre-cap dredging design. Even with a cap in place, later developments would not be precluded. However, such development would require careful consideration with respect to potential effects on the cap. With sufficient design and controls, nearshore construction, to include limited dredging, could be accomplished, with the cap reconstructed in areas as appropriate.

Navigation and anchorage restrictions would differ for smaller recreational vessels as compared to larger commercial vessels. The partial dredging scenarios described in this appendix leave a level, shallow-water “bench” out to distances of 700 ft from the shoreline. The water depths would restrict movement of large, deeper-draft vessels in this benched area, but recreational vessels would be free to navigate there. The cap design accounts for the effects of prop wash from vessels able to navigate over the benched area. Anchorage by recreational vessels would not affect the integrity of the cap, since the depth of penetration of recreational anchors is limited, and the isolation cap is protected by a habitat layer and armor layer. However, the isolation cap does extend beyond the bench, following the lake slopes to depths of 30 ft (9 m). Some anchorage restrictions for larger vessels would be appropriate in these areas.

SECTION H.6

CONSTRUCTION REQUIREMENTS FOR COST ESTIMATES

Costing of capping operations is very specific to characteristics of cap material and physical conditions of the site. The labor and equipment required for typical hydraulic and mechanical cap placement equipment in Onondaga Lake have been estimated. These efforts would be modified during final design, when specific conditions are better known.

Daily costs can be estimated by multiplying labor and equipment by appropriate rates. Capping unit costs can be estimated by dividing the daily dredging costs presented below by the production rates.

Hydraulic capping equipment would be used predominantly to place the base cap in the soft sediment areas. The coarser-grain material required for armoring would be placed by mechanical methods.

H.6.1 HYDRAULIC CAPPING APPROACH

Mobilization and demobilization includes the following tasks:

- Deliver pump and set up feeder;
- Haul and prepare (fuse) pipe;
- Prepare, deliver, and assemble diffuser barge;
- Deliver tug; and
- Supervise for one month.

Daily operational costs include labor as well as rental, operation, and supply of the various pieces of equipment. Labor costs should assume that two eight-hour shifts would work 14 hours per day (extended work hours are possible and would shorten the overall timeline for implementation). The other two hours would be spent in preparation and close-down each day.

As discussed in previous sections, the delivery of the capping material could be either by truck (upland) or barge (offshore). The labor breakdown presented below assumes that the material is brought to the site by barge and that the material is offloaded with a derrick and placed into a hopper to slurry the material.

The following labor would be required for a hydraulic operation (this is total number of person-shifts each day):

On offloading facility

- 1 captain

- 2 operators (loading)
- 2 deck hands
- 2 pump operators

On support vessels

- 2 deck hands

At diffuser barge

- 1 laborer
- 1 supervisor

Daily equipment costs would cover the rental, operation, and supply of the following:

- Pump
- Loader derrick
- Tug
- Diffuser barge
- Pipeline

H.6.2 MECHANICAL CAPPING APPROACH

Mechanical capping equipment would be used to place the base cap in select locations or to place the armor material. Mobilization and demobilization includes the following tasks:

- Prepare and deliver clamshell derrick and tug,
- Set up, and
- Supervise for two weeks.

Daily operational costs include labor costs as well as rental, operation, and supply of the various pieces of equipment. Labor costs assume that two 8-hour shifts would work 14 hours per day. The other two hours would go toward preparation and close-down each day.

The following labor would be required for a rehandling bucket capping operation (this is total number of person-shifts each day):

- 2 clam operators
- 2 deck hands
- 2 mates
- 2 deck hands
- 1 supervisor

Daily equipment costs would cover the rental, operation, and supply of the following:

- Dredge (derrick barge)
- Tug

SECTION H.7

CONCLUSIONS

Based on the evaluations conducted, the following general conclusions are made regarding applicability of subaqueous *in situ* capping as a remedy component for Onondaga Lake:

- *In situ* capping is a technically feasible and efficient remedial approach for this site. *In situ* capping in combination with pre-cap dredging addresses concerns with lake water surface area, water depth, and lake habitat in some locations. In other locations, pre-dredging is not required and the cap has been designed accordingly.
- The degree of pre-cap dredging and the cap design should be determined for each SMU or for sub-areas within SMUs. Thresholds for determining partial dredging depths, areas, and volumes prior to *in situ* capping should be based on factors such as erosion potential, preservation of lake surface area, habitat enhancement, and localized presence of NAPL, hot spots, or other problem areas. These thresholds establish logical prisms for pre-cap dredging depths based on technical considerations.
- Cap designs described in this appendix provide physical isolation of the contaminated sediment from the aquatic environment, stabilize contaminated sediment, prevent resuspension and transport of contaminants to the profundal area and other areas of the lake, reduce the flux of dissolved and colloidally transported (i.e., facilitated transport) contaminants into surface cap materials and the overlying water column, and enhance aquatic habitat in the lake.
- Control of groundwater flow to the lake is required for long-term effectiveness of ISC for SMUs 1, 2, and potentially 7. The proposed hydraulic containment system planned for construction at these SMUs must be considered an integral part of any capping remedy component in these areas. Capping effectiveness in SMU 3, SMU 6, and potentially SMU 7, can be accomplished by targeted removal of hot spots in the nearshore areas in these SMUs.
- Additional data and evaluations will be required for design of any ISC remedy component. Specifically, significant additional geotechnical data will be required during final design to assess cap settlement and ILWD stability. Borings, cores, CPTs, vane shear tests, and/or other *in situ* tests coupled with detailed laboratory tests such as strength tests, consolidation analysis, and index tests will be performed. Detailed modeling will be used with the data to determine slope stability of the ILWD and to predict consolidation of sediments under the weight of caps.

APPENDIX H

TABLES

TABLE H.1
SITE CONDITIONS THAT FAVOR *IN-SITU* CAPPING AND THE CORRESPONDING CONDITIONS FOR ONONDAGA LAKE

Conditions Favorable for ISC (NRC, 1997)	Corresponding Conditions for Onondaga Lake
Contaminant sources have been sufficiently abated to prevent re-contamination of the cap.	The overall remedial plans for the site call for upland units to be remediated prior to remedial activities for the lake. Slurry walls to reduce upwelling and actions for major tributaries will be an integral part of the lake remedy.
MNR is too slow to meet RAOs in a reasonable time frame.	MNR is appropriate for SMU 8 but is generally considered non-protective for littoral SMUs.
Cost and/or environmental effects of removal are very high.	Implementation costs of complete removal of all CPOIs to levels below PECs are very high. The potential impacts of complete removal are significant.
Suitable types and quantities of cap materials are available.	Capping materials are available within the general area.
Hydrologic conditions will not compromise the cap.	Onondaga Lake is a controlled site, and tributaries only have potential for erosion near the inflow points to the Lake. Wind generated waves are the chief forcing function for erosion, but fetch distances are limited. Ice processes are of concern for water depths shallower than 16 inches. Armor layers will be a required cap component.
Weight of the cap can be supported by the original bed.	Capping has been successful at sites with physical sediment properties similar to conditions in Onondaga Lake.
Cap is compatible with current and/or future waterway uses.	Loss of lake surface area and water depth should be avoided for capping remedies in certain locations. Capping would be applied as a remedy component in combination with removal in some locations. Enhancement of aquatic habitat is a cap design objective.
Site conditions are not favorable for complete removal of contaminated sediment.	Site conditions may limit the applicability of a removal alternative due to the excessive depth of contamination.

TABLE H.2
SITE CONDITIONS THAT DO NOT FAVOR CAPPING AND THE CORRESPONDING CONDITIONS FOR ONONDAGA LAKE

Conditions Unfavorable to ISC (NRC, 1997)	Corresponding Conditions for Onondaga Lake
Contaminant sources have not been sufficiently abated to prevent re-contamination of the cap.	The overall remedial plans for the site call for upland units to be remediated prior to remedial activities for the lake. Slurry walls to reduce upwelling and actions for major tributaries will be an integral part of the Lake remedy.
Unacceptable risk of catastrophic failure due to wave events, flood events, ice scour, slope failure, or seismic events.	Placement of an armor layer will be required for scour protection; cap layer will either be placed at elevations below and not susceptible to ice scour or armored accordingly. Sediments will be dredged and graded as necessary in order to obtain appropriate safety factors required for statically and seismically stable slopes
Contaminant mobility and transport conditions cannot be effectively controlled by a designed cap (e.g., some combination of high contaminant concentrations, presence of non-aqueous phase liquids (NAPL), and advective groundwater flow conditions).	Control of groundwater upwelling, especially for SMUs 1, and 2, will be critical for long-term effectiveness of a capping remedy.
Public use of groundwater, if surface water recharges a shallow aquifer underneath the contaminated sediment.	Groundwater is saline in aquifers underlying the lake, so uses of groundwater are limited.
Unacceptable short-term risk posed by placement of the cap.	Short-term risk of cap placement is likely to be equivalent to or less than that associated with environmental removal. Resuspension by cap placement must be considered in selecting the methods and equipment.
Presence of infrastructure, such as piers, bridges, or pipelines, incompatible with a permanent cap.	Available data indicates debris present in only limited areas. Some pipeline outfalls would require special consideration in design.
Cap is incompatible with water body uses, such as navigation, flood control, or recreation.	Caps will not be placed in navigation channel areas. Pre-cap dredging would accommodate continued use of the lake for recreational boating.

TABLE H.3
SUMMARY OF CONTAMINATED SEDIMENT CAPPING PROJECTS

Sediment Project	Chemicals of Concern	Site Conditions	Design Thickness (feet)	Cap Material	Year Constructed	Performance Results	Comments
Great Lakes Region							
Sheboygan River/Harbor Wisconsin	PCBs		Composite of geotextile on fabric, 6 inches aggregate, geotextile, 6 inches cobble, with the perimeter anchored with gabions	Armored stone composite	1989–1990	• Undetermined cap effectiveness • Some erosion of fine-grained material • WDNR/EPA order cap removal in ROD	Demonstration bench-scale project. Composite armored cap required as sediments were located in high-energy river environment. Gabions placed around the corners for anchoring. Additional course material placed into voids/gaps.
Wausau Steel Site Wisconsin	Lead, zinc, mercury	Oxbow on the Big Rib River, nearshore cap	2	Composite: sand over geotextile	1997	• Chemical isolation failed • Cap not physically stable	Methane gas trapped under the geotextile forced cap to rise in the center, pulling away geotextile from the edge. Sand erosion also occurred in the nearshore areas
Manistique Capping Project Michigan (pilot)	PCBs		40-mil (0.1 feet)	HDPE	1993	• Physical inspection of the temporary cap approximately one year after installation showed cap was physically intact and most anchors still in place, but was methane-filled	A 240 feet by 100 feet HDPE temporary cap was anchored by 38 2-ton concrete blocks placed around the perimeter of the cap. This temporary cap was installed to prevent erosion of contaminated sediments within a river hotspot with elevated surface concentrations.

TABLE H.3
SUMMARY OF CONTAMINATED SEDIMENT CAPPING PROJECTS

Sediment Project	Chemicals of Concern	Site Conditions	Design Thickness (feet)	Cap Material	Year Constructed	Performance Results	Comments
Hamilton Harbor Ontario, Canada	PAHs		1.6	Sand (2.5 acres) (*in situ*)	1995	• Chemical isolation effective • No erosion of cap	Cap monitoring in porewater ongoing.
Puget Sound							
Duwamish Waterway Seattle, Washington	Heavy metals, PCBs		1–3	Sand (4,000 cy)	1984	• Chemical isolation effective • No erosion of cap	Monitoring as recent as 1996 showed cap remains effective and stable. Split-hull dump barge placed sand over relocated sediments (CAD site) in 70' water.
One Tree Island Olympia, Washington	Heavy metals, PAHs		4	Sand	1987	• Chemical isolation effective • No erosion of cap	Last monitoring occurred in 1989, showed that sediment contaminants were contained.
St. Paul Waterway Tacoma, Washington	Phenols, PAHs, dioxins		2–12	Coarse sand	1988	• Chemical isolation effective • Cap within specifications	Some redistribution of cap materials has occurred, but overall remains >1.5 m (4.9 feet). *C. californieus* found in sediments, but never >1 m (3.3 feet).
Pier 51 Ferry Terminal Seattle, Washington	Mercury, PAHs, PCBs		1.5	Coarse sand (4 acres) (*in situ*)	1989	• Chemical isolation effective • Cap within specifications • Recolonization observed	As recent as 1994, cap thickness remained within design specifications. While benthic infauna have recolonized the cap, there is no indication of cap breach due to bioturbation.
Denny Way CSO Seattle, Washington	Heavy metals, PAHs, PCBs	Water depth 18’–50’	2–3	Sand (3 acres)	1990	• Chemical isolation effective • Cap within specifications • Recolonization observed	Cores taken in 1996 show that while cap surface chemistry shows signs of recontamination, there is no migration of isolated chemicals through the cap.
Piers 53–55 CSO Seattle, Washington	Heavy metals, PAHs		1.3–2.6	Sand (4.5 acres) (*in situ*)	1992	• Chemical isolation effective • Cap stable, and increased by 15 cm (6") of new deposition	Pre-cap infaunal communities were destroyed in the rapid burial associated with cap construction, but had recovered by 1996. The initial community established in the sand over time shifted as fine-grained material was redeposited on the cap.
Pier 64 Seattle, Washington	Heavy metals, PAHs, phthalates, dibenzofuran		0.5–1.5	Sand	1994	• Some loss of cap thickness • Reduction in surface chemical concentrations	Thin-layer capping was used to enhance natural recovery and to reduce resuspension of contaminants during pile driving.

TABLE H.3
SUMMARY OF CONTAMINATED SEDIMENT CAPPING PROJECTS

Sediment Project	Chemicals of Concern	Site Conditions	Design Thickness (feet)	Cap Material	Year Constructed	Performance Results	Comments
GP Lagoon Bellingham, Washington (*in situ*)	Mercury	Shallow intertidal lagoon	3	Sand	2001	• Chemical isolation effective at 3-months • Cap successfully placed	Ongoing monitoring.
East Eagle Harbor/Wyckoff Bainbridge Island, Washington	Mercury, PAHs		1–3	Sand (275,000 cy)	1994	• Chemical isolation effective • Cap erosion in ferry lanes • Some recontamination observed due to off-site sources	Cap erosion measured within first year of monitoring only in area proximal to heavily-used Washington ferry lane. Chemicals also observed in sediment traps. Ongoing monitoring.
West Eagle Harbor/Wyckoff Bainbridge Island, Washington (*in situ*)	Mercury, PAHs	500-acre site	Thin cap 0.5 feet over 6 acres and thick cap 3 feet over 0.6 acre	Sand (22,600 tons for thin cap and 7,400 tons for thick cap)	Partial dredge and cap 1997	• Chemical isolation effective	To date, post-verification surface sediment samples have met the cleanup criteria established for the project. Ongoing monitoring.
California and Oregon							
PSWH Los Angeles, California	Heavy metals, PAHs		15	Sand	1995	• No data to date	Overall effective cap was >15 feet. This was not a function of design, but rather a function of the low contaminated-to-clean sediment volume.
Convair Lagoon San Diego, California	PCBs	5.7-acre cap in 10-acre site; water depth 10 feet–18 feet	2 feet of sand over 1 feet rock	Sand over crushed rock	1998	• Chemical isolation effective • Cap was successfully placed • Some chemicals observed in cap	Ongoing monitoring for 20 to 50 years, including diver inspection, cap coring, biological monitoring.
McCormick and Baxter Portland, Oregon	Heavy metals, PAHs	15 acres of nearshore sediments and soils	NA	Sand	Planned, but not constructed	• No data to date	Long-term monitoring, Operations and Monitoring and Maintenance Plan, and institutional controls were also specified.

TABLE H.3
SUMMARY OF CONTAMINATED SEDIMENT CAPPING PROJECTS

Sediment Project	Chemicals of Concern	Site Conditions	Design Thickness (feet)	Cap Material	Year Constructed	Performance Results	Comments
New England/New York							
Stamford-New Haven-N New Haven, Connecticut	Metals, PAHs		1.6	Sand	1978	• Chemical isolation effective	Cores collected in 1990.
Stamford-New Haven-S New Haven, Connecticut	Metals, PAHs		1.6	Silt	1978	• Chemical isolation effective	Cores collected in 1990.
New York Mud Dump Disposal Site New York	Metals (from multiple harbor sources)		Unknown	Sand (12 million cy)	1980	• Chemical isolation effective	Cores taken in 1993 (3.5 years later) showed cap integrity over relocated sediments in 80 feet of water.
Mill-Quinniapiac River Connecticut	Metals, PAHs		1.6	Silt	1981	• Required additional cap	Cores collected in 1991.
Norwalk, Connecticut	Metals, PAHs		1.6	Silt	1981	• No problems	Routine monitoring.
Central Long Island Sound Disposal Site (CLIS) New York	Multiple harbor sources		Unknown	Sand	1979–1983	• Some cores uniform structure with low-level chemicals • Some cores chemical isolation effective • Some slumping	Extensive coring study at multiple mounds showed cap stable at many locations. Poor recolonization in many areas.
Cap Site 1 Connecticut	Metals, PAHs		1.6	Silt	1983	• Chemical isolation effective	Cores collected in 1990.
Cap Site 2 Connecticut	Metals, PAHs		1.6	Sand	1983	• Required additional cap	Cores collected in 1990.
Experimental Mud Dam New York	Metals, PAHs		3.3	Sand	1983	• Chemical isolation effective	Cores collected in 1990.
New Haven Harbor New Haven, Connecticut	Metals, PAHs		1.6	Silt	1993	• Chemical isolation effective	Extensive coring study.

TABLE H.3
SUMMARY OF CONTAMINATED SEDIMENT CAPPING PROJECTS

Sediment Project	Chemicals of Concern	Site Conditions	Design Thickness (feet)	Cap Material	Year Constructed	Performance Results	Comments
Port Newark/Elizabeth New York	Metals, PAHs		5.3	Sand	1993	• Chemical isolation effective	Extensive coring study.
52 Smaller Projects New England	Metals, PAHs		1.6	Silt	1980–1995	• Chemical isolation effective	Routine monitoring.
Other North American Projects							
Soda Lake, Wyoming	Oil refinery residuals	Soft, unconsolidated sediments	3	Sand	2000	• Chemical isolation effective	Demonstration project that showed successful placement over soft sediments and isolation of PAHs and metals in refinery residuals.
International Projects							
Rotterdam Harbor Netherlands	Oils	Water depth 5 to 12 m	2–3	Silt/clay sediments	1984	• No available monitoring data	As pollution of groundwater was a potential concern, the site was lined with clay prior to sediment disposal and capping.
Hiroshima Bay Japan		Water depth 21 m	5.3	Sand	1983	• No available data	

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TABLE H.4

SUMMARY OF CAP DESIGN REQUIREMENTS BY SEDIMENT MANAGEMENT UNIT FOR ONONDAGA LAKE

			WIND-WAVE ANALYSIS (100-yr STORM)						FLOOD FLOW ANALYSIS	HABITAT ANALYSIS (3)							
				Armor Grain Size Requirements						Primary Habitat			Secondary Habitat			Features	
SMU	Chemical Isolation Thickness (ft) (1)	Critical Ice Depth (ft) (2)	Water Depth (ft) for Wave Breaking	d50 in Break Zone (SZ)	SZ to 5 ft Water Depth	5 to 10 ft Water Depth	10 to 15 ft Water Depth	15 to 20 ft Water Depth	Armor Grain Size Requirements	Type	Water Depth (ft)	Substrate	Type	Water Depth (ft)	Substrate	Type	Water Depth (ft)
1	4.25	1.5	5.1	14 inch rock	NA	Fine gravel	Fine gravel	Coarse sand	NA	FSS	6 to 15	6 inches fine gravel	SM	2 to 6	6 inches sand	EW or RO	0.5 to 2
2	4.25	1.5	4.6	14 inch rock	NA	Fine gravel	Fine gravel	Coarse sand	Fine gravel at mouth of Trib 5A	FSS	6 to 15	6 inches fine gravel	SM	2 to 6	6 inches sand	LWD	5 to 10
3	2	1.5	3.5	10 inch rock	Coarse gravel	Fine gravel	Coarse sand	Medium sand	NA	FSS; LWD	6 to 15	6 inches fine gravel	SM	2 to 6	6 inches sand	EW and/or FW	New
4	2	1.5	3.2	9 inch rock	Fine gravel	Fine gravel	Coarse sand	Medium sand	Fine gravel at mouth of Ninemile Creek	FSS; LWD	6 to 15	Fine gravel or existing substrates	SM	2 to 6	Sand or existing substrate (c)	EW	0.5 to 2
6	2	1.5	6.1	16 inch rock	NA	Coarse gravel	Fine gravel	Coarse sand	Fine gravel at mouth of Onondaga Creek	SM	2 to 6	6 inches sand	FSS; LWD	6 to 15	6 inches fine gravel	NA	NA
7	4.25	1.5	6.1	16 inch rock	NA	Coarse gravel	Fine gravel	Coarse sand	Fine gravel at mouth of Harbor Brook	SM	2 to 6	6 inches sand	FSS; LWD	6 to 15	6 inches fine gravel	EW	0.5 to 2

Notes:

(1) This thickness includes the isolation thickness determined from the cap model multiplied by 1.5 (safety factor) plus 6 inches of for operational allowance.

(2) To resist scour by ice, rip rap 32 inches in diameter is likely required. Alternatively, contaminated sediments can be removed below a depth of 16 inches (depth of potential ice scour), or smaller stone sizes could be used and replaced as necessary following any severe ice scour event. See Attachment B for more details.

(3) Please refer to *Appendix M -- Integrating Habitat Considerations in the Remedial Alternatives for Onondaga Lake* for more details.

d50 = median grain size
BMI = benthic macroinvertebrate substrate
EW = emergent wetland
FSS = fish spawning substrate
FW = forested wetland
LWD = large woody debris
NA = not applicable
RO = riparian overhang
SM = submerged macrophyte
SZ = surf zone. Water depth at which the 100 year wave begins to break and armor needs to resist turbulent flow.

APPENDIX H

FIGURES

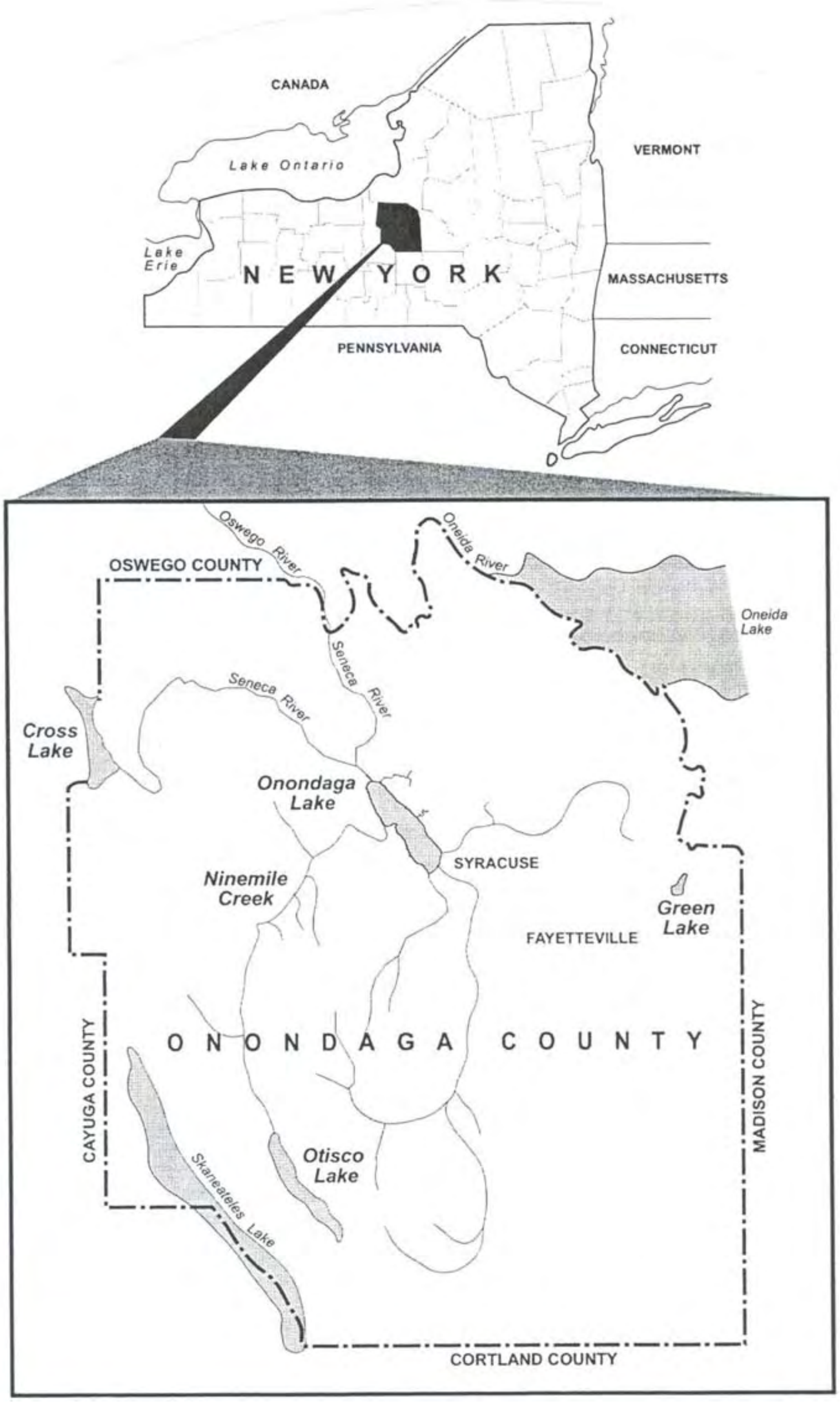

FIGURE H.1

ONONDAGA LAKE

SYRACUSE, NEW YORK

GENERAL SITE MAP OF
ONONDAGA LAKE

Source: Exponent, 2001c

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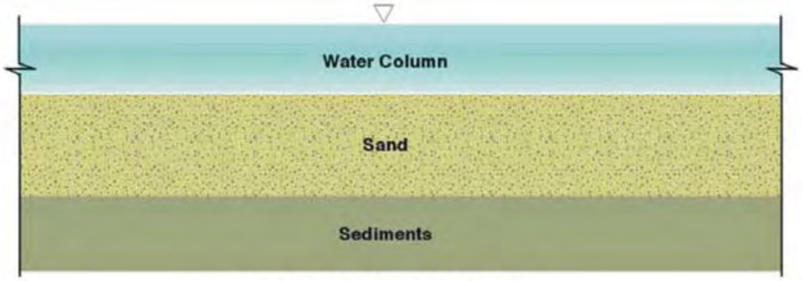
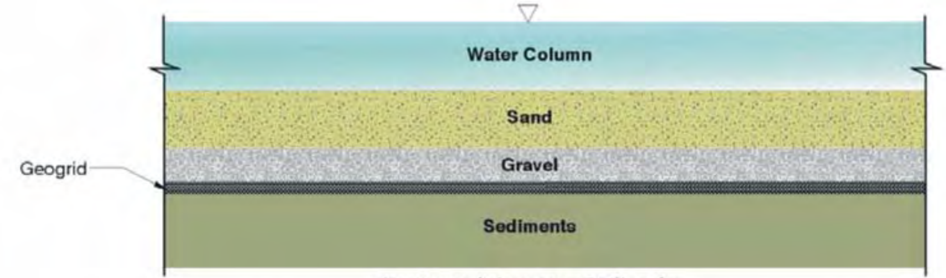
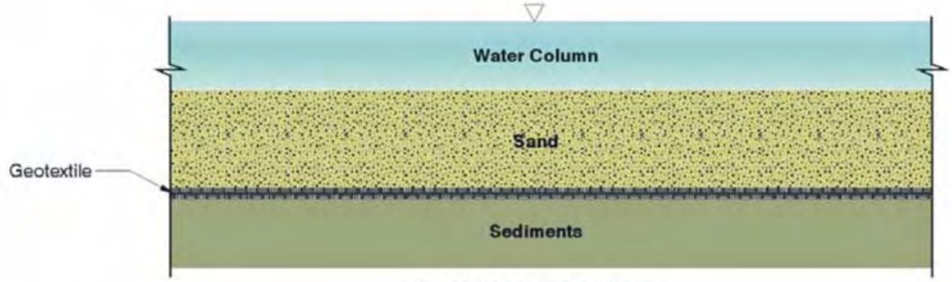


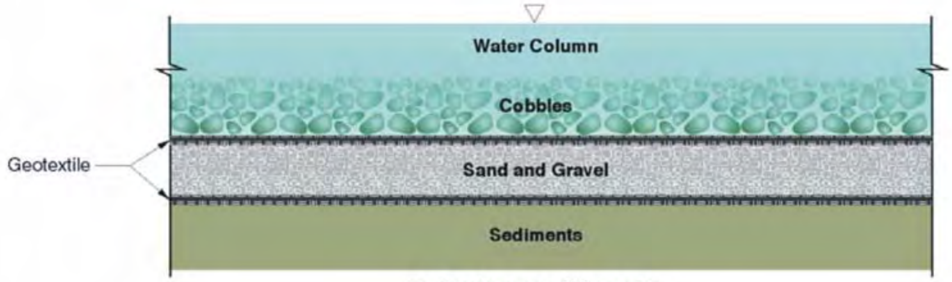
A. Eagle Harbor, Washington
(EPA/USACE 1995)



B. Convair Lagoon, California
(Mehr and Sanders, 1996)



C. Mocks Pond, Indiana
(RETEC, 2001)



D. Sheboygan, Wisconsin
(Palermo et al, 1998)

Source: Palermo, Thompson, & Swed. White Paper No. 6B_IN-SITU Capping as a Remedy Component for the Lower Fox River. Dec. 2002

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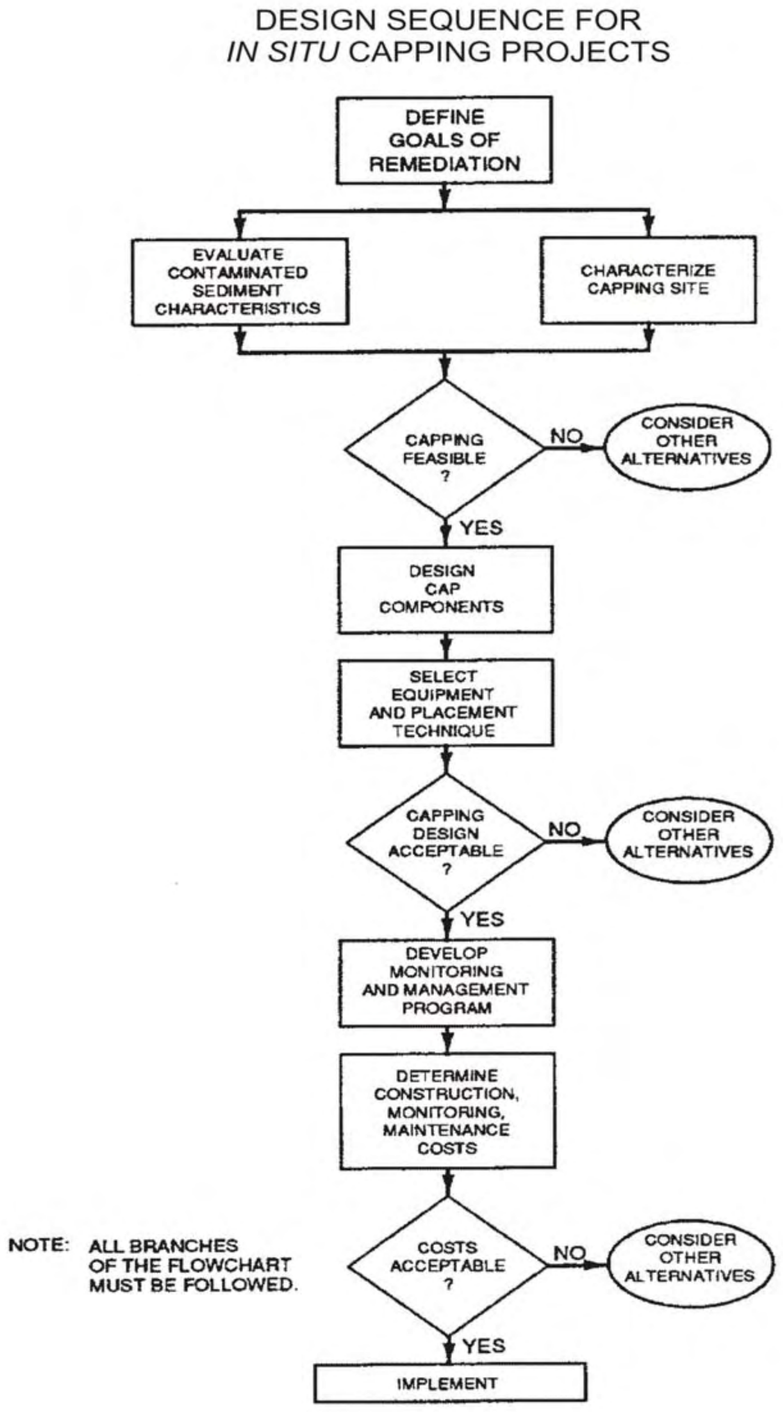
FIGURE H.2

ONONDAGA LAKE

SYRACUSE, NEW YORK

EXAMPLES OF CAP DESIGNS



NOTE: ALL BRANCHES OF THE FLOWCHART MUST BE FOLLOWED.

FIGURE H.3

ONONDAGA LAKE

SYRACUSE, NEW YORK

FLOWCHART SHOWING SEQUENCE OF STEPS INVOLVED WITH THE DESIGN OF AN *IN SITU* CAPPING PROJECT

Source: Palermo M., S. Maynord, J. Miller, and D. Reible, 1998. “Guidance for In-Situ Subaqueous Capping of Contaminated Sediments,” EPA 905-B96-004. Great Lakes National Program Office, Chi. Ill.

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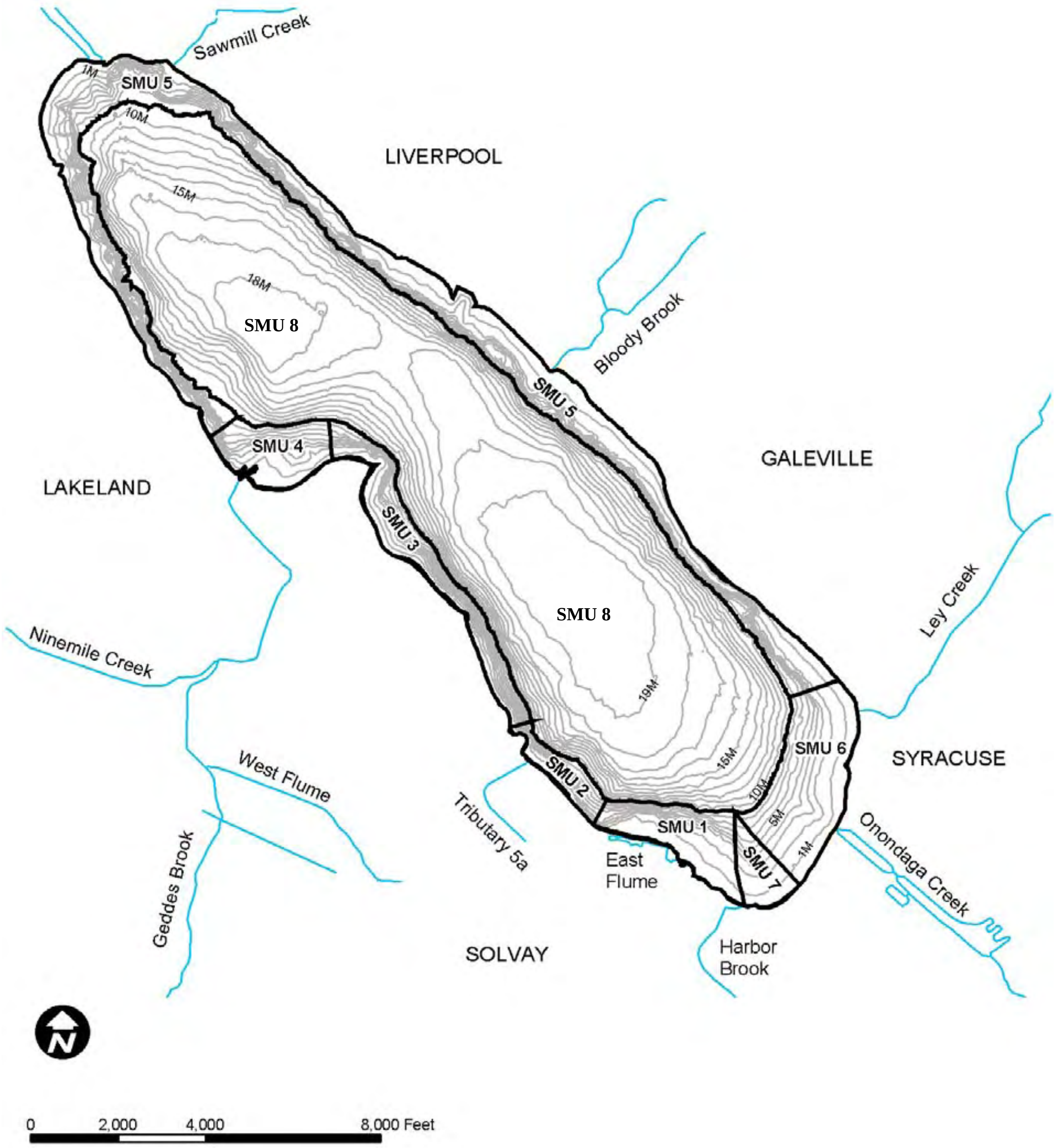

Note: Water Surface Elevation is: 363.39 feet (110.76 meters) above Mean Sea Level.
SMU: Sediment Management Unit

Source: Modified from TAMS, 2002

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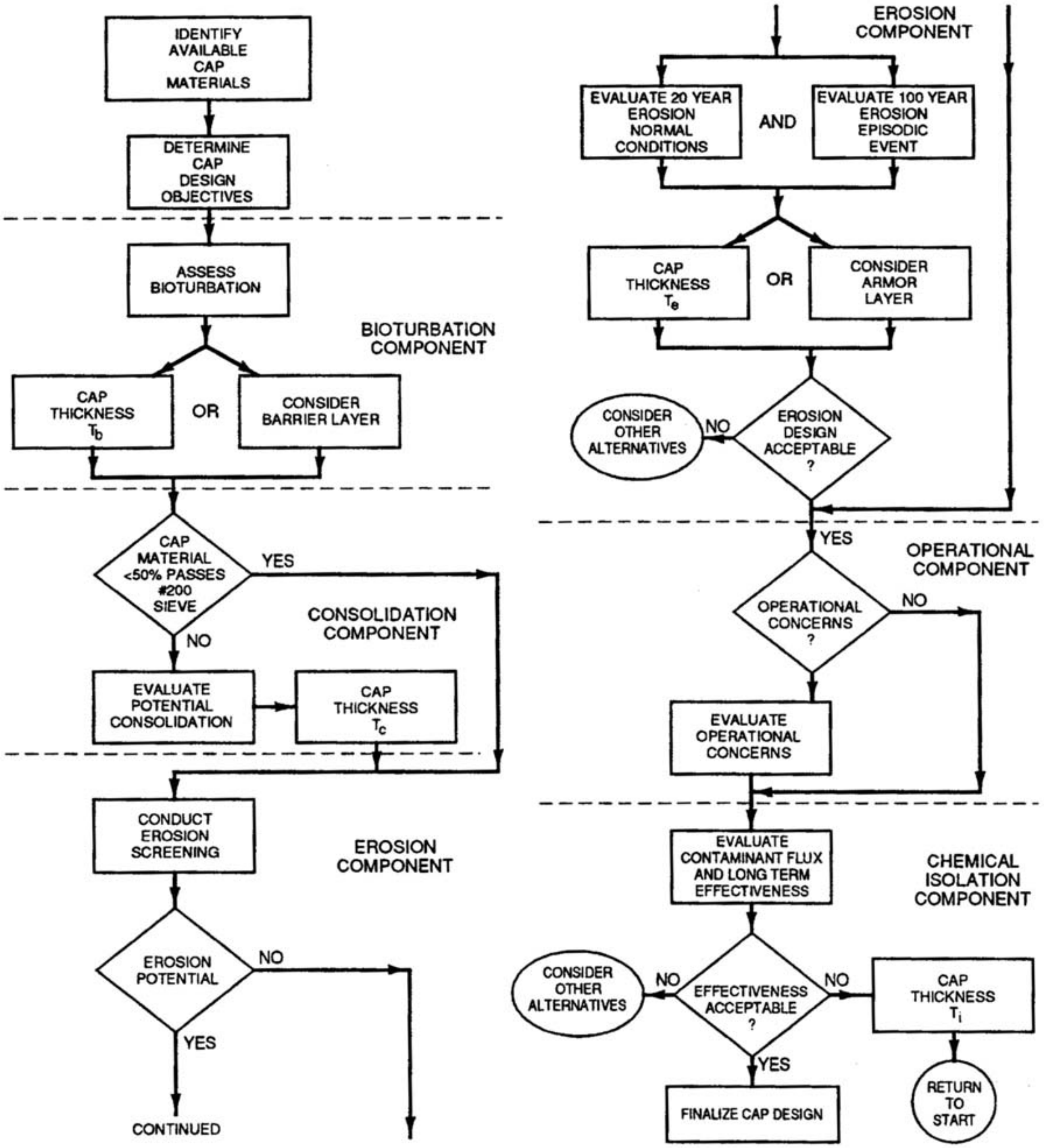
FIGURE H.4

ONONDAGA LAKE

SYRACUSE, NEW YORK

SITE BATHYMETRY AND
SMU LOCATIONS

IN SITU
CAP DESIGN FLOW CHART



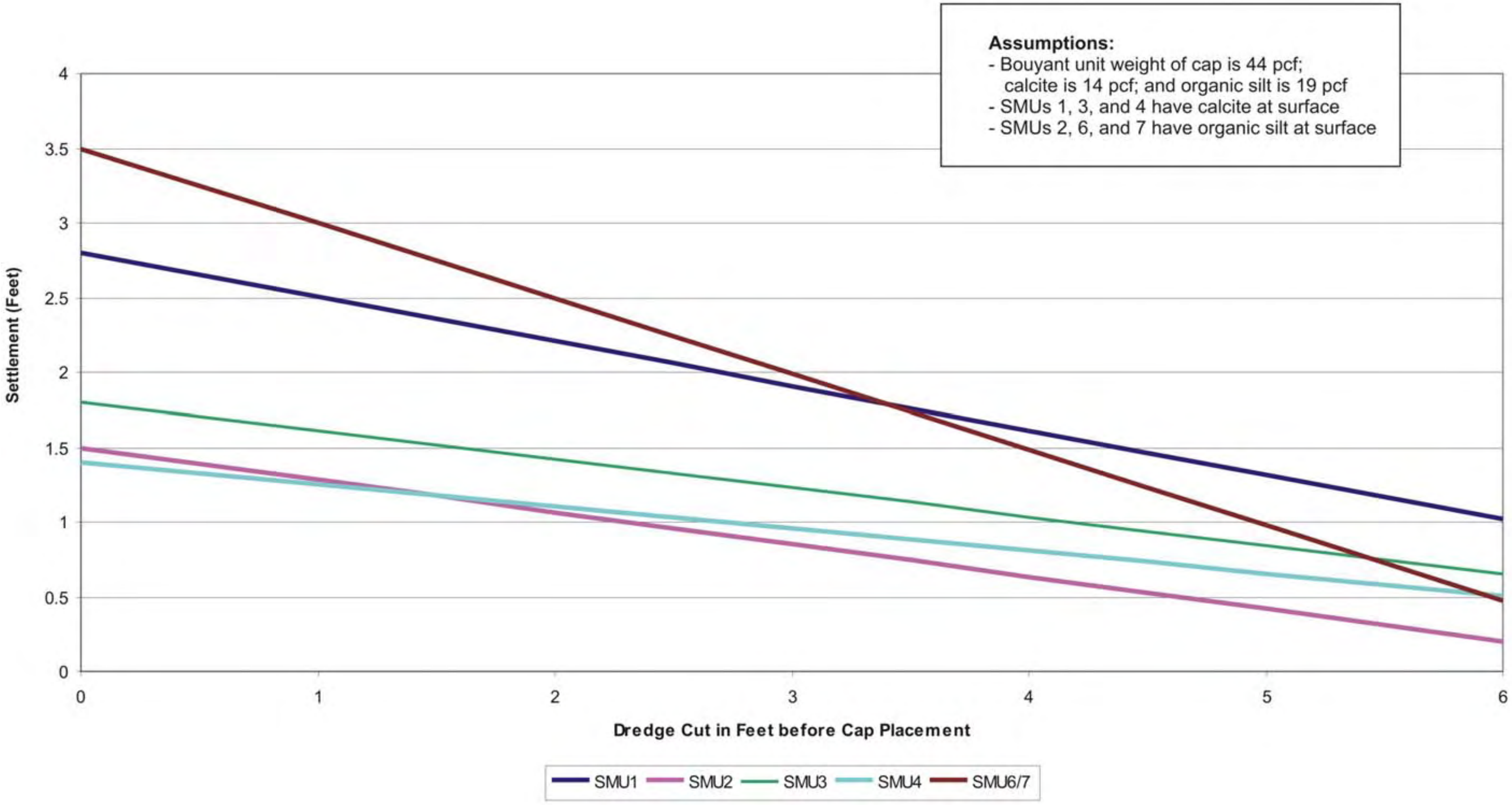
Source: Palermo M., S. Maynord, J. Miller, and D. Reible, 1998. "Guidance for In-Situ Subaqueous Capping of Contaminated Sediments," EPA 905-B96-004. Great Lakes National Program Office, Chi. Ill.

FIGURE H.5

ONONDAGA LAKE

SYRACUSE, NEW YORK

FLOWCHART SHOWING STEPS INVOLVED IN DESIGN EVALUATION OF VARIOUS *IN SITU* CAP COMPONENTS



Assumptions:
- Bouyant unit weight of cap is 44 pcf; calcite is 14 pcf; and organic silt is 19 pcf
- SMUs 1, 3, and 4 have calcite at surface
- SMUs 2, 6, and 7 have organic silt at surface

FIGURE H.6

Onondaga Lake
Syracuse, New York

PREDICTED SETTLEMENT VERSUS DREDGE CUT BY SMU FOR A 3-FOOT CAP

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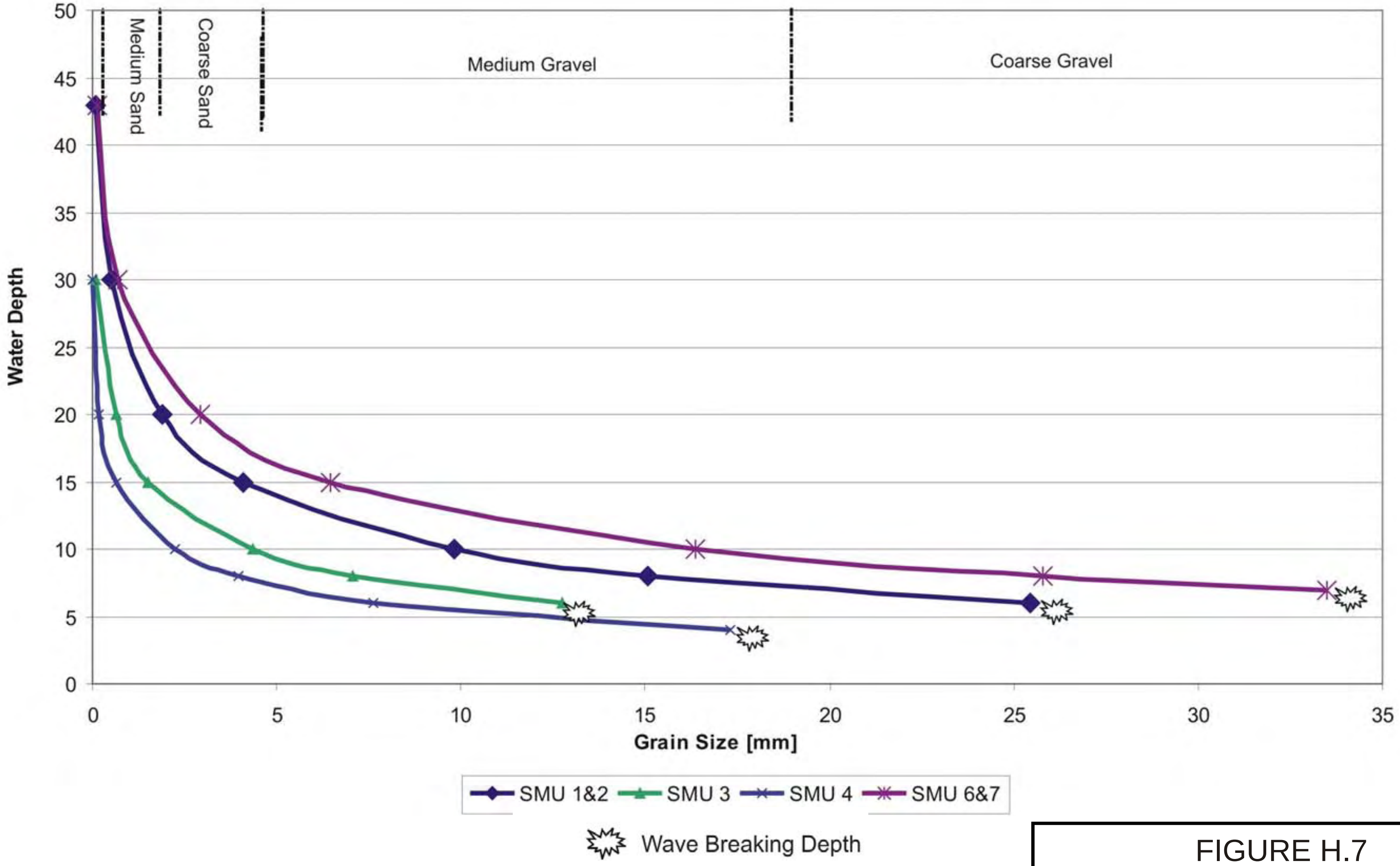

FIGURE H.7

Onondaga Lake
Syracuse, New York

CAP SEDIMENT SIZE VARIATION AS A FUNCTION OF DEPTH FOR DIFFERENT SMUs

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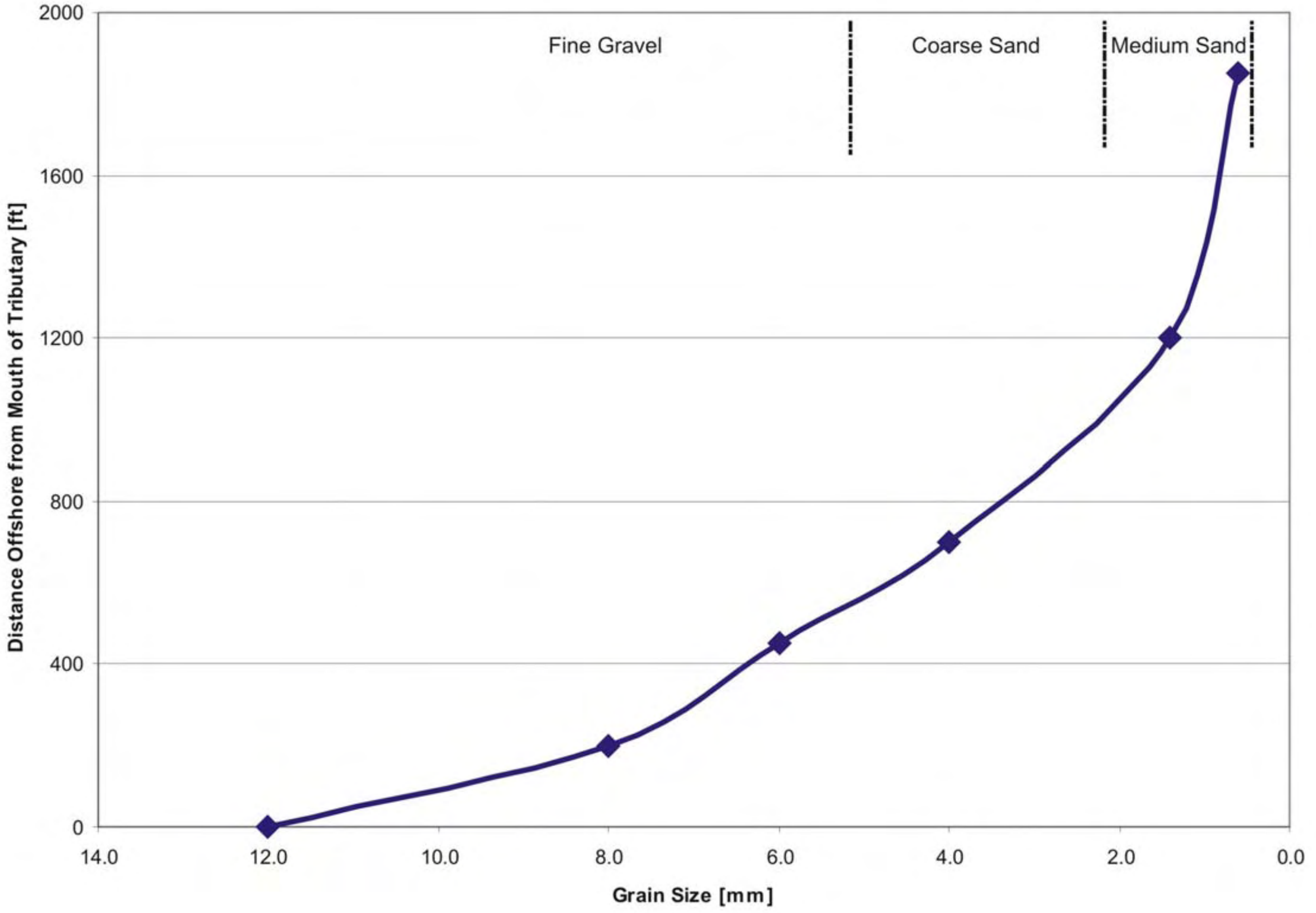
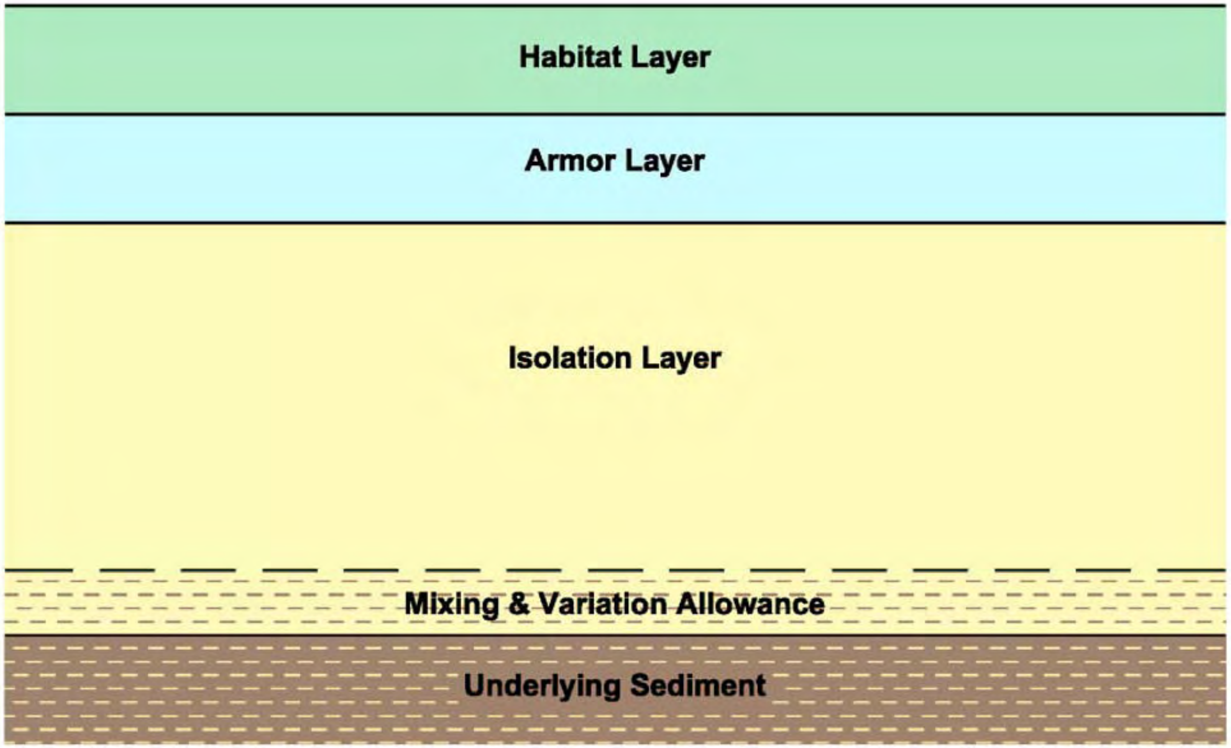


FIGURE H.8

Onondaga Lake
Syracuse, New York

CAP SEDIMENT SIZE VARIATION AS A FUNCTION OF DISTANCE OFFSHORE FROM MOUTH OF TRIBUTARY



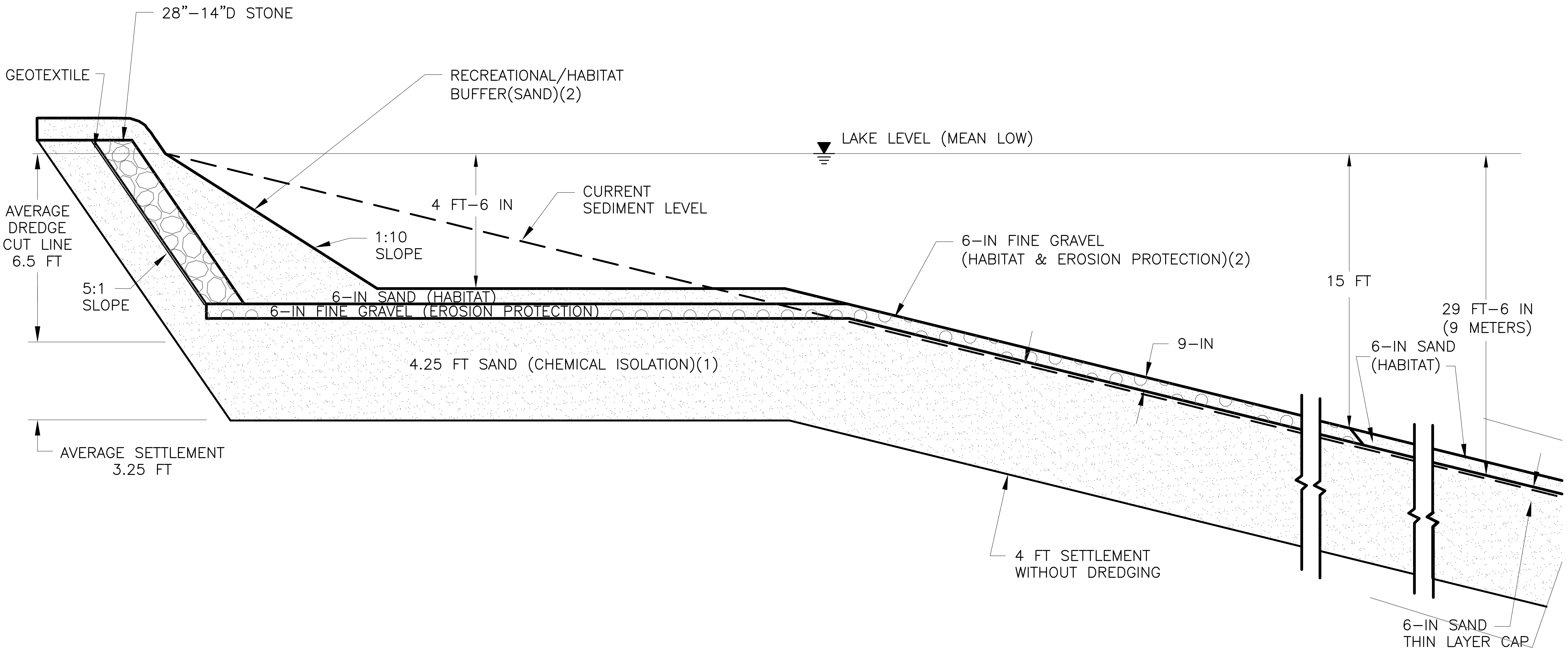
Not to Scale

FIGURE H.9

Onondaga Lake
Syracuse, New York

CONCEPTUAL CAP
CROSS SECTION

ANCHOR
ENVIRONMENTAL, L.L.C.



NOTES:

1. ASSUME 4.25 FT PLACEMENT TO RESULT IN MINIMUM 3.75 FT EFFECTIVENESS THROUGHOUT THE AREA.

2. ASSUME 9–12" OF MATERIAL WILL BE PLACED FOR THESE LAYERS TO ACHIEVE A MINIMUM 6" LAYER.

NOT TO SCALE

FIGURE H.10

ONONDAGA LAKE
SYRACUSE, NEW YORK

TYPICAL CROSS–SECTION FOR PARTIAL DREDGING AND CAPPING SCENARIO

P:\HONEYWELL–SYR\741627\CAD\SMU CROSS SECTIONS\SMU 1 HABITAT CAPPING (FIG H10), 11/15/04; CLW


Diffuser Barge - Tacoma, WA


Spraying Cap - Casper, WY


Diffuser Box - Tacoma, WA


Spraying Cap - Casper, WY

FIGURE H.11

Onondaga Lake
Syracuse, New York

PHOTOS OF HYDRAULIC CAPPING APPROACH

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Derrick and Scow Barge - Georgia Pacific Log Pond


Rehandling Bucket - Eagle Harbor West Harbor Operable Unit (WHOU)


Rehandling Bucket - Eagle Harbor WHOU

FIGURE H.12

ONONDAGA LAKE

SYRACUSE, NEW YORK

PHOTOS OF MECHANICAL
CAPPING APPROACH

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APPENDIX H
ATTACHMENT A

REFERENCES

ATTACHMENT A

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APPENDIX H
ATTACHMENT B

ICE STUDY

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.

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APPENDIX H
ATTACHMENT C

CONSOLIDATION ANALYSIS

Anchor Environmental, L.L.C.
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Memorandum

Written for the Onondaga Lake Feasibility Study

From: John R. Verduin, III, PE, Anchor Environmental, L.L.C.

Date: April 13, 2004

Re: Cap-Induced Consolidation in Different SMUs
Onondaga Lake Feasibility Study

This memorandum presents the estimated settlement induced by the weight of caps placed in the different sediment management units (SMUs) of Onondaga Lake. The settlement predictions consider the weight of the cap, the reduced effective stress associated with pre-dredging, and the estimated consolidation properties of the capped material. This memorandum builds upon the work completed by Harrington Engineering & Construction, Inc. (see attached).

Harrington presents a detailed discussion of sediment profiles and geotechnical characteristics of each SMU. He also details the analysis methods he used to predict primary and secondary consolidation. His analysis did not consider the effect of pre-dredging on primary consolidation, however. Pre-dredging reduces the effective stress on the capped sediment thus reducing the total load when a cap is eventually placed. This effect will reduce the amount of consolidation. Anchor, in this memorandum, considers the effect of pre-dredging on total primary settlement.

Anchor used the geotechnical and physical properties presented by Harrington to determine the effect of pre-dredging on consolidation. The buoyant unit weight of the surficial materials to be dredged in each SMU was compared against the buoyant unit weight of the cap material. With this comparison, the different pre-dredge cuts and cap thickness combinations were equated to different equivalent cap thicknesses. Table 1 presents these equivalent cap thicknesses.

The equivalent cap thicknesses were then compared against Harrington's settlement calculations to estimate settlement for the different pre-dredge and cap scenarios. Table 1 summarizes the results and Figures 1, 2, 3, and 4 graphically illustrate the primary settlement of a 3-, 4-, 5- and 6-foot cap, respectively, after pre-dredging cuts from 0 to 6 feet in depth.

As part of final design for the selected remedy, additional physical and geotechnical data will need to be collected to better characterize cap-induced consolidation in the different SMUs.

Attachments

Table 1 – Primary Consolidation Summary
Figure 1 – Settlement vs. Dredge Cut by SMU for a 3-foot Cap
Figure 2 – Settlement vs. Dredge Cut by SMU for a 4-foot Cap
Figure 3 – Settlement vs. Dredge Cut by SMU for a 5-foot Cap
Figure 4 – Settlement vs. Dredge Cut by SMU for a 6-foot Cap
Harrington Engineering & Construction, Inc. December 2, 2003 Memorandum on Settling and Time Rate of Consolidation Estimates: Sub-Aqueous Cap

HE&C
Harrington Engineering & Construction, Inc.

Memorandum

TO: John Verduin — December 2, 2003

FROM: Tim Harrington — 01-011-04

SUBJECT: Onondaga Lake Feasibility Study

Settling and Time Rate of Consolidation Estimates
Sub-Aqueous Cap

Onondaga Lake is divided into eight (8) sediment management units (SMU's) for the purpose of assessing potential remedial actions for the Lake. A sub-aqueous cap installed either directly on the sediment of a SMU or installed after completion of some partial sediment removal is one alternate being assessed for the Feasibility of restoring Onondaga Lake. For purposes of this analysis the sub-aqueous cap is considered to be a loose fine sand cap placed by hydraulic methods and having a thickness of 1, 2 or 3-feet.

For the settlement analysis the fine sand is assumed placed at a minimum relative density of 85 lbs/ft^3, a porosity of 40%, and will have a solids specific gravity of 2.65. At this placed density the sand will have water content of 25% (assuming 100% saturation of the sand by water). The total unit weight of the placed cap is 106 lbs/ft^3 and the buoyant unit weight that will increase the effective pressure in the sediment underlying the cap will be approximately 44 lbs/ft^3.

Sediment Profiles

SMU numbers 5, 8 and 9 are not considered candidates for application of a sub-aqueous cap and are not analyzed in this report. The sediment profiles for the other SMU's are established based on available information from the Remedial Investigation Report for Onondaga Lake, and from other sources as listed below.

1. **SMU 1 – (0-50 feet calcite and 50-120 feet lacustrine sediment)** -- Two soil borings, B76-1 & B76-2, installed by Empire in 1976 provide an accurate soil profile for this SMU. The soil borings indicate 50 feet of calcite waste underlain by lacustrine sediments to a till surface at approximately 120 feet. A thin layer of organic silt or fine sand is ignored for this analysis. Vibracore samples S309, S310, and S311 from the RI collaborate the first 25-feet of the deeper borings and show that there is approximately 2-feet of organic silt over the calcite waste at S309 and S310 near the outer edge of SMU 1 and no organic sediment over

the calcite waste at S311 near the center of SMU 1.

2. **SMU 2 – (0-10 feet organic silt)** -- Vibracore sample S308 from the RI shows organic silt over brown silt and clay at approximately 10-foot depth into the sediment profile. Work from the Willis Avenue site just shoreward of SMU 2 indicates that the till surface has only a 10-foot thick cover of lacustrine deposits. The available data indicates that the very loose sediments are thin in SMU 2.
3. **SMU 3 -- (0-10 feet calcite waste, 10-50 feet lacustrine sediment)** -- Only the 2-meter vibracore sample S324 is available for this SMU. The results show calcite waste to the bottom of the sample. Borings taken just to the west of SMU 3 for the Ninemile Creek RI show that glacial till is at elevation 310 feet (50-feet below the normal water level of Onondaga Lake). The profile uses calcite waste to 10-feet and then assumes that lacustrine sediment is present to the till interface at 50-feet.
4. **SMU 4 – (0-20 feet calcite waste, greater than 20-feet silt and sand outwash)** -- The profile is based on the vibracore samples S304 and S305 that show a mixture of calcite waste, fine sand, and organic silt in the first 20-feet underlain by denser sand and silt. This is the delta deposit from Ninemile Creek and has been assumed to have the properties of calcite waste in the upper twenty feet. This is also the only profile that has a drainage layer below the sediment that will be consolidated by the cap and is assigned double drained conditions when assessing the time rate of consolidation.
5. **SMU 6 (0-25 feet organic silt, 25-120 feet lacustrine sediment)** -- Vibracore samples S316, S317, S318 & S319 show that this area is fine organic sand in 10-feet of water and organic silt in 20-feet of water. Since no information is available below 25-feet, it is assumed that the lacustrine sediments extend to 120-feet since we are in the south end of the lake.
6. **SMU 7 (0-25 feet organic silt, 25-120 feet lacustrine sediment)** -- Vibracore samples S313, S314 & S315 show that this area contains at least 25-feet of organic silt. Since no other information is available, the profile for SMU 7 will be treated equal to SMU 6.

Sediment Properties

The buoyant "submerged" unit weights of the sediments are taken from average values reported in the RI for calcite waste and organic silt. These values compare favorably to typical very loose organic sediments with total in place unit weights of 1.0-1.1 ton per cubic yard. For the lacustrine sediments that will have a lower organic content and are generally deeper in the profile the submerged unit weight is increased to 25 lbs/ft^3 (1.18 ton per cubic yard in place weight).

The average coefficient of compression for the calcite waste measured in one-dimensional consolidation tests is 1.0 (Appendix E1 of the RI Report). This is less than the range of 2.1 – 3.4 reported in Kulhawy[1], but is likely influence by the long

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[1] Kulhawy Fred H., Dwight Sangrey and C. Sherman Grove, Jr., "Geotechnical Behavior

depositional time underwater that changed the chemical composition of the calcite waste. The RI values for calcite will be used in the estimate for settlement. The coefficient of compression for the organic silt is based on the water content range of 150-200% reported in the RI. Landva[2] provides a relationship between water content and coefficient of compressibility for highly organic soils that indicates a coefficient of compressibility of 2.0 should be applicable for the water content range measured in the Onondaga Lake sediments. The coefficient of compressibility for lacustrine soils is a typical value of 1.0 as reported for mineral grained silt and clayey silt as presented on Figure 22.1 of Lambe[3].

The coefficient of secondary compression that is used to estimate the impacts of time effects not related to increases in loading is estimated using the average value of 0.004 as reported from the RI testing on calcite waste. The values for organic silt and lacustrine soil are 0.01 and 0.007, respectively as estimated from Mesri[4]. The organic sediment was assumed to have water content of approximately 150% and the lacustrine soil water content of 80%.

The relationship between initial void ratio and the effective stress and the relationship between permeability and the initial void ratio were assumed to follow the power law relationship as used for estimating settlement and the time rate of settlement for high void ratio sediments that show large strain when compressing under the effects of small load additions. The power laws take the form of:

$$e = A\sigma'^{-B} \quad (1)$$
$$k = Ce^{D} \quad (2)$$

where: e = void ratio
σ' = effective stress (Kpa)
k = permeability (cm/sec)
A & C = constants (with C having units of cm/sec)
B & D = power law factors

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of Solvay Process Waste", Specialty Conference on Geotechnical Properties of Waste Materials, ASCE June 1977.

[2] Landva A. O. and P. La Rochelle, "Compressibility and Shear Characteristics of Radforth Peats", ASTM STP 820, June 1982.

[3] Lambe T. William and Robert V Whitman, "Soil Mechanics", John Wiley Press, 1969.

[4] Mesri G., "Coefficient of Secondary Compression" Journal of Soil Mechanics and Foundations Division, ASCE Vol. 99, No. SM1, 122-137.

[5] 5. Results should be considered as a lower bound estimate of settlement. Smaller increments indicate that settlement may increase by a factor of 2 (see the piecewise linear results for SMU 2).

[6] Fox, Patrick and James Berles, "CS-2: A Piecewise Linear Model for Large Strain Consolidation", International Journal for Numerical and Analytical Methods in Geomechanics, Vol. 21, pg 453-475, 1997.

The constants and power law factors for calcite waste were determined by curve fitting the e vs log p and the c_v versus log p relationship reported for sample CT0004 in Appendix E1 of the RI (This test had a coefficient of compressibility of 1.15). The values for the organic silt and the lacustrine sediment were developed from a review of data collected by Harrington Engineering and Anchor Environmental from four different sites. The materials generally classified as organic silt and ranged with 10-20% fine sand and 10-25% clay in the sediment by weight. These results were used to bracket the likely range of characteristics. The final values for A and B were then varied within this range to produce a coefficient of compression in the range of effective stress of interest that were close to the values selected as described above. In a similar manner, the final values of C and D were varied within the likely range to produce permeability in the range of void ratio likely in the area of interest that placed the organic silt in the 10^{-5} to 10^{-6} cm/sec range and the lacustrine sediment in the 10^{-6} to 10^{-7} cm/sec range. The constants and power law factors used in the analysis are:

Sediment	A	B	C (cm/sec)	D
Calcite waste	5.25	-0.16	$2E10^{-10}$	8.96
Organic silt	7.0	-0.3	$2E10^{-6}$	1.1
Lacustrine	6.0	-0.15	$4E10^{-8}$	5.0

Settlement Analysis

The settlement analysis was performed using 5-foot thick sub-layers for each SMU profile. The initial void ratio for each layer was based on the effective stress in each layer caused by the weight of the overlying material and using the power law relationship between effective stress and void ratio assigned to the material of the layer. A final void ratio and settlement for the layer after adding a one-foot, two-foot and three-foot thick sand cap was determined by:

$$e_f = e_o - C_c * \log ((\sigma' + t * \Delta \sigma')/ \sigma')$$

$$\Delta H = H*(e_f - e_o)/(1+e_o)$$

where: e_o= initial void ratio
e_f= final void ratio
C_c= coefficient of compression
σ'= initial effective stress
$\Delta \sigma'$= change in effective stress from one foot of sand cap
t = thickness of sand cap
ΔH = settlement of individual layer
H = thickness of individual layer

The sub-layers are then summed to provide the total primary consolidation settlement due to the change in effective stress produced by the addition of the cap.

The secondary consolidation was estimated by multiplying the logarithm of ½ year divided by 30 years times the coefficient of secondary compression for the material of the sub-layer times 5-feet. The sub-layers are then summed to provide an estimate of the probable secondary compression that would occur for 30-years after installation of the cap (The estimate does not account for compression that will occur from the continued deposition of fresh sediment on top of the cap).

The results for the analysis of total settlement are presented in the separate attached spreadsheet showing the detailed results for each SMU. The total primary and secondary settlement results are:

Total Settlement Results[5]

SMU #	One-Foot Cap (feet)	Two-Foot Cap (feet)	Three-Foot Cap (feet)	Secondary Compression (feet)
1	1.1	2.0	2.8	1.2
2	0.7	1.1	1.5	0.2
3	0.8	1.3	1.8	0.6
4	0.6	1.1	1.4	0.1
6 & 7	1.4	2.5	3.5	1.6

The time rate of consolidation was estimated using the power law relationships presented above and a one-dimensional piecewise-linear finite difference approximation as presented by Fox[6]. The model was formulated to apply to a bed of uniform homogeneous material and does not presently have the capability to handle different layers of sediment in a profile. Each profile was assigned the properties of the uppermost layer unless the layer was very thin and underlain by a thicker layer of different sediment, as is the case for SMU 3. The predominant sediment in the model profile and also the sediment that experiences the largest settlement control the time rate of primary consolidation using this assumption.

The results from the analysis indicate the time to 95% of primary consolidation shown in the following table. The results also show the points at which most of the consolidation is completed. Because of the relatively high permeability of the very loose sediment in Onondaga Lake, most of the porewater from consolidation of the sediment will be expelled during the time of placing the cap and will intermix with the cap material.

Time to Completion of Settlement			
	Time to 95% Consolidation, Years		
SMU #	One-Foot Cap	Two-Foot Cap	Three-Foot Cap
1	9.6	11.5	12.8
2	0.76	0.59	0.49
3	0.41	0.45	0.51
4	0.10	0.12	0.13
6 & 7	9.9	10.6	10.8

Time to Complete 2/3 of Total Settlement			
	Time to 67% Consolidation, Years		
SMU #	One-Foot Cap	Two-Foot Cap	Three-Foot Cap
1	0.2	0.4	0.6
2	0.17	0.14	0.13
3	0.04	0.07	0.08
4	0.01	0.02	0.03
6 & 7	1.1	1.3	1.4

Tables showing the time rate of consolidation for each of the five profiles analyzed are also attached for use in determining the percent completion at times other than shown above. The results for SMU 4 are based on a double drained condition (porewater is allowed to leave from both the top and bottom of the sediment profile). The other SMU’s are based on single drainage from the top surface of the sediment profile only (through the sand cap).

ATTACHMENT C
Table 1
Primary Consolidation Summary
Onondaga Lake Feasibility Study

Material	Bouyant unit weight in pcf	Ratio to Cap
Cap	44	100%
Calcite	14	32%
Organic silt	19	43%
Lacustrine	25	57%

Thickness of Cap in Feet Equivalent to Weight of Material Dredged

SMU	Surface Material	Height of Dredge Cut in Feet					
		1	2	3	4	5	6
1	Calcite	0.3	0.6	1.0	1.3	1.6	1.9
2	Organic silt	0.4	0.9	1.3	1.7	2.2	2.6
3	Calcite	0.3	0.6	1.0	1.3	1.6	1.9
4	Calcite	0.3	0.6	1.0	1.3	1.6	1.9
6	Organic silt	0.4	0.9	1.3	1.7	2.2	2.6
7	Organic silt	0.4	0.9	1.3	1.7	2.2	2.6

Primary Settlement in Feet with No Dredging

SMU	Cap Thickness in	2	3	4	5	6
1	1.1	2	2.8	3.5	4.2	5.0
2	0.7	1.1	1.5	1.7	2.0	2.4
3	0.8	1.3	1.8	2.2	2.6	-
4	0.6	1.1	1.4	1.5	1.7	-
6	1.4	2.5	3.5	5.0	6.6	-
7	1.4	2.5	3.5	5.0	6.6	-

Estimated from other settlement numbers

Primary Settlement in Feet Under 3 foot Cap with Different Dredging Depths

SMU	Height of Dredge Cut in Feet						
	0	1	2	3	4	5	6
SMU1	2.8	2.5	2.2	1.9	1.6	1.3	1.0
SMU2	1.5	1.3	1.1	0.9	0.6	0.4	0.2
SMU3	1.8	1.6	1.4	1.2	1.0	0.8	0.7
SMU4	1.4	1.3	1.1	1.0	0.8	0.7	0.5
SMU6/7	3.5	3.0	2.5	2.0	1.5	1.0	0.5

Primary Settlement in Feet Under 4 foot Cap with Different Dredging Depths

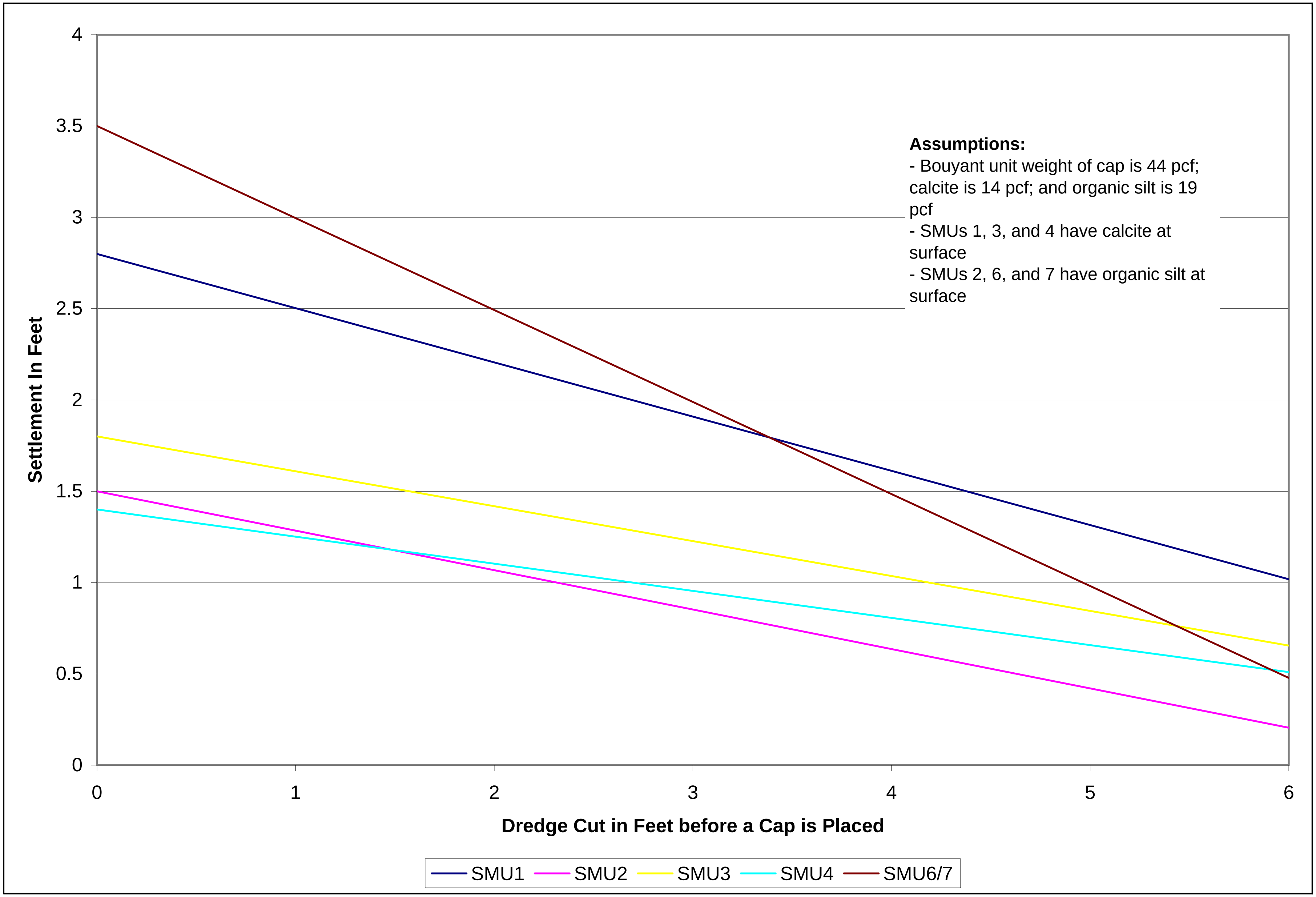
SMU	Height of Dredge Cut in Feet						
	0	1	2	3	4	5	6
SMU1	3.5	3.2	2.9	2.6	2.4	2.1	1.8
SMU2	1.7	1.6	1.4	1.2	1.0	0.8	0.6
SMU3	2.2	2.0	1.8	1.7	1.5	1.3	1.1
SMU4	1.5	1.4	1.3	1.2	1.0	0.9	0.8
SMU6/7	5.0	4.5	3.9	3.4	2.9	2.3	1.8

Primary Settlement in Feet Under 5 foot Cap with Different Dredging Depths

SMU	Height of Dredge Cut in Feet						
	0	1	2	3	4	5	6
SMU1	4.2	3.9	3.6	3.4	3.1	2.8	2.6
SMU2	2.0	1.8	1.6	1.5	1.3	1.1	1.0
SMU3	2.6	2.5	2.3	2.1	2.0	1.8	1.6
SMU4	1.7	1.6	1.5	1.4	1.2	1.1	1.0
SMU6/7	6.6	6.0	5.4	4.9	4.3	3.7	3.2

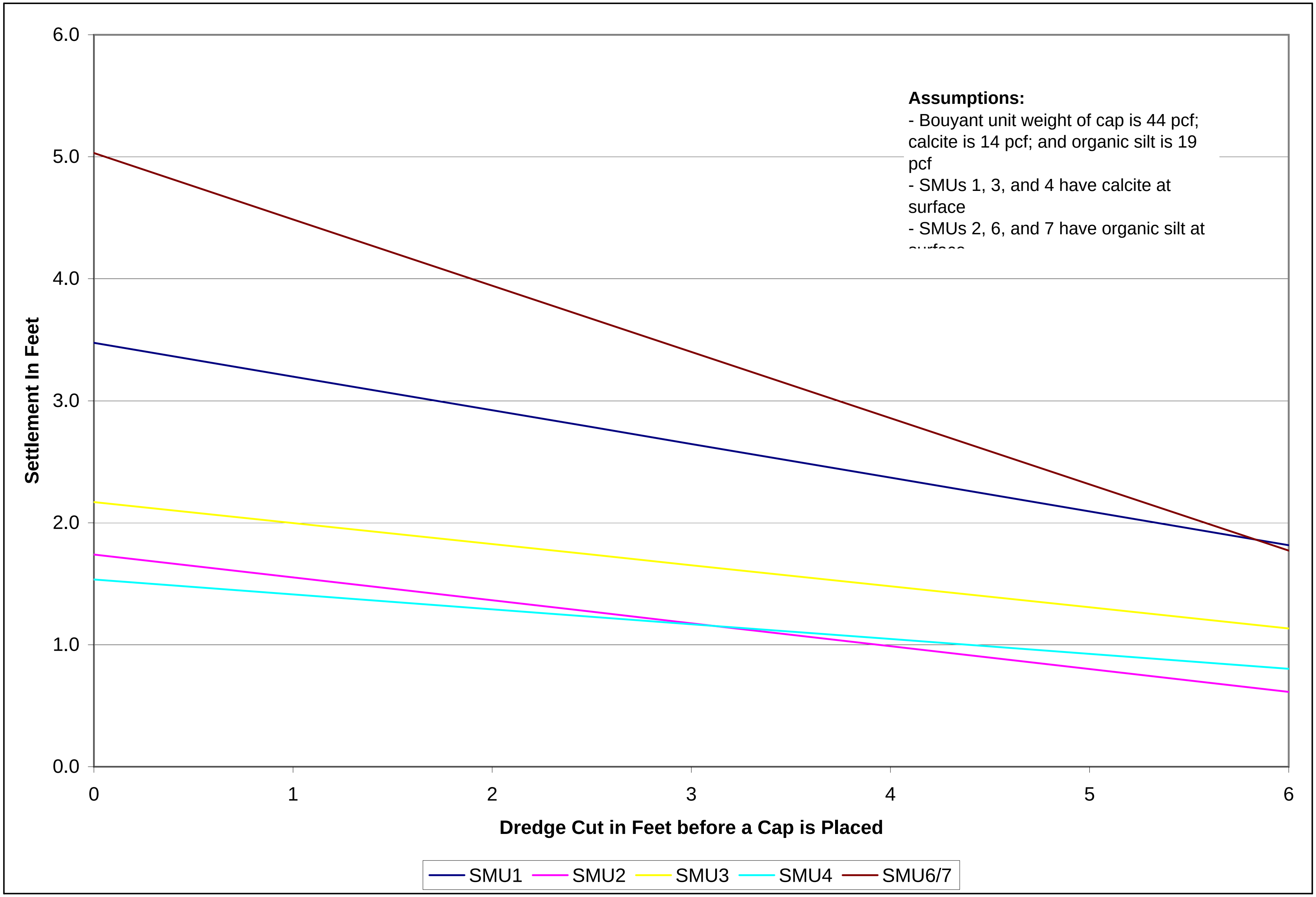
Primary Settlement in Feet Under 6 foot Cap with Different Dredging Depths

SMU	Height of Dredge Cut in Feet						
	0	1	2	3	4	5	6
SMU1	5.0	4.7	4.5	4.2	3.9	3.7	3.4
SMU2	2.4	2.2	2.1	1.9	1.7	1.5	1.4

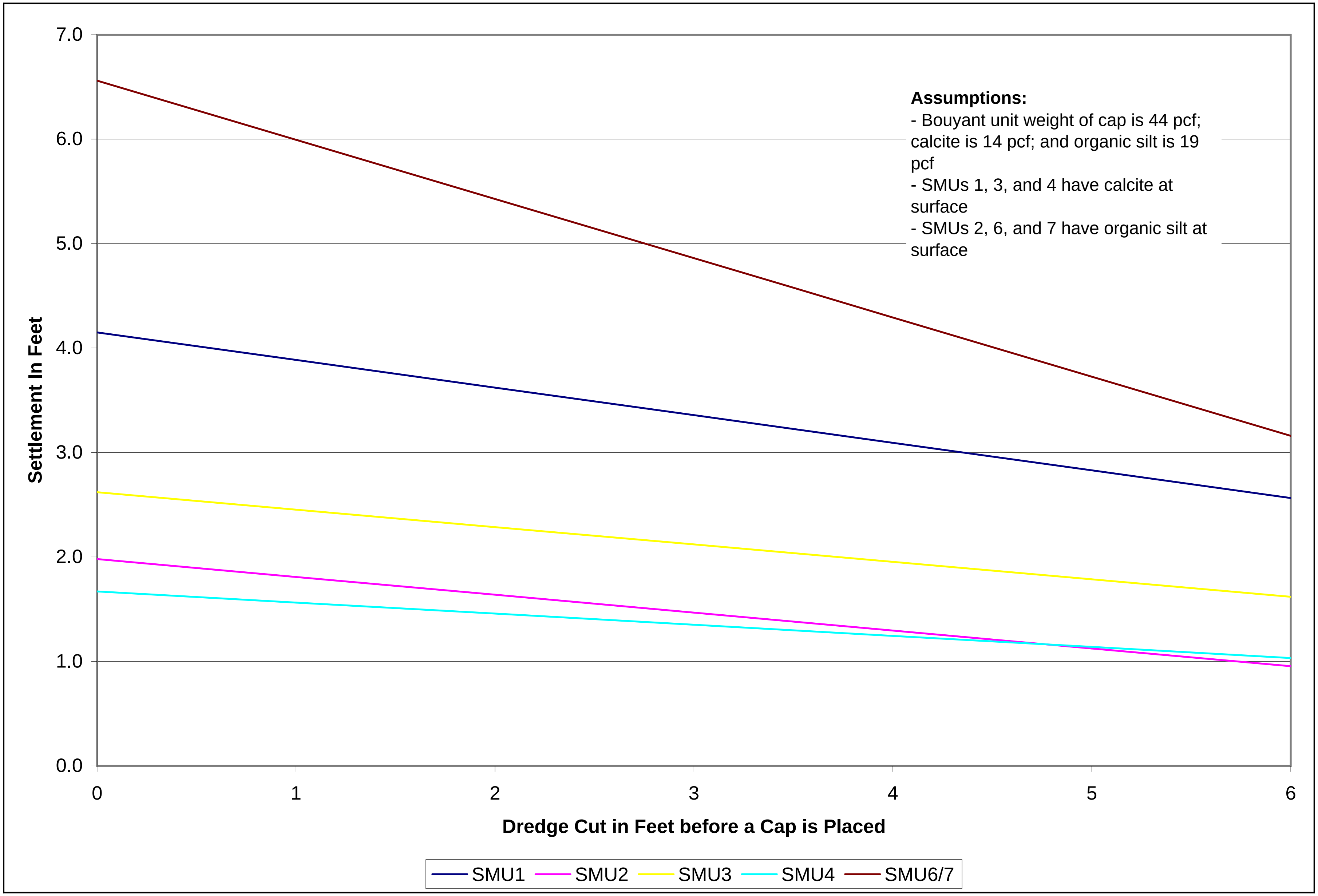


Assumptions:
- Bouyant unit weight of cap is 44 pcf; calcite is 14 pcf; and organic silt is 19 pcf
- SMUs 1, 3, and 4 have calcite at surface
- SMUs 2, 6, and 7 have organic silt at surface

Attachment C: Figure 1
Settlement vs. Dredge Cut
by SMU for a 3-foot Cap



Attachment C: Figure 2
Settlement vs. Dredge Cut
by SMU for a 4-foot Cap



Assumptions:
- Bouyant unit weight of cap is 44 pcf; calcite is 14 pcf; and organic silt is 19 pcf
- SMUs 1, 3, and 4 have calcite at surface
- SMUs 2, 6, and 7 have organic silt at surface

Attachment C: Figure 3
Settlement vs. Dredge Cut
by SMU for a 5-foot Cap

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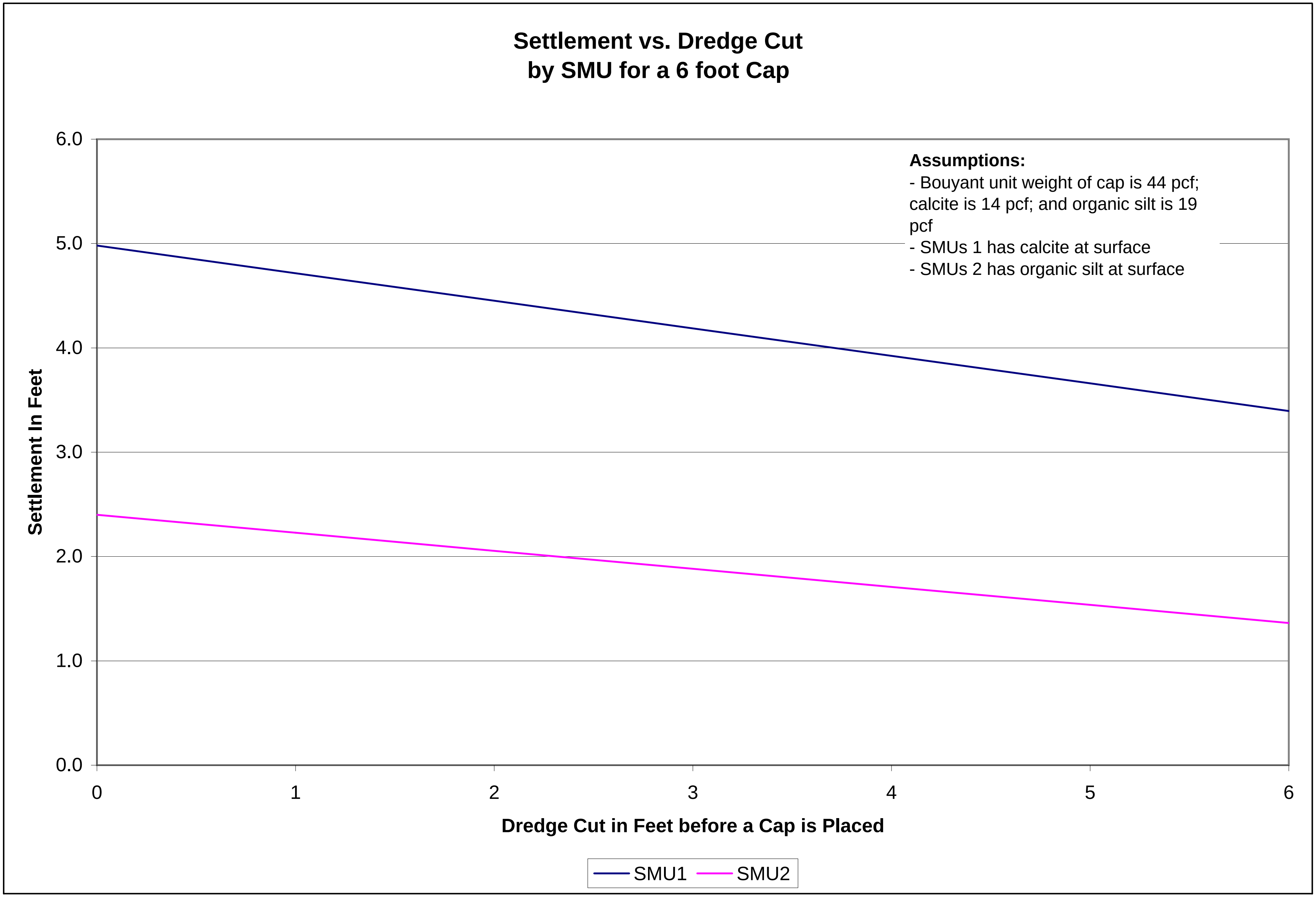

Assumptions:
- Bouyant unit weight of cap is 44 pcf; calcite is 14 pcf; and organic silt is 19 pcf
- SMUs 1 has calcite at surface
- SMUs 2 has organic silt at surface

Attachment C: Figure 4
Settlement vs. Dredge Cut
by SMU for a 6-foot Cap

APPENDIX H
ATTACHMENT D

WIND-WAVE ANALYSIS

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Technical Memorandum

Written for the Onondaga Lake Feasibility Study

From: Greg Guannel and John Verduin, P.E., Anchor Environmental

Date: April 21, 2004

Re: Onondaga Lake Wind-Wave Analysis

This memorandum summarizes the findings of the wind-wave analysis that was performed to determine stable sediment sizes in each of Onondaga Lake's Sediment Management Units (SMU). The 100-year wave that can be formed in the Lake and reach each SMU was calculated, and the results of this analysis were compiled to evaluate, at various depths, the sediment size that can resist wave erosive forces. This analysis was necessary to develop a preliminary understanding of the types of armoring required in the Lake.

1 BACKGROUND

It is necessary to determine stable sediment size at various depths in Onondaga Lake in order to evaluate armor requirements at various SMUs (Figure 1). To simplify the analysis, and considering the site configuration, SMUs 1 and 2 were combined, as well as SMUs 6 and 7.

In general, an erosion analysis requires establishing a cap design life and evaluating significant erosive forces at a site, which are typically due to wind-waves, currents, vessel propeller wash, and ice. Once these forces are identified, it is possible to compute the stable sediment size that can resist each, or a combination of, these forces.

A wind-wave analysis was performed to determine wave induced forces on a cap. It is likely that currents generated by the runoff of streams and rivers can increase the forces that could erode sediments when combined with the waves. These forces are expected to be the strongest near the mouth of these tributaries, and dissipate further away. Current-induced erosive forces will be evaluated in a separate technical memorandum.

2 WIND-WAVE ANALYSIS

2.1 Wind Environment

2.1.1 Data Description

A wind-wave hindcast analysis was performed for each SMU in Onondaga Lake, based on 39 years of wind records from January 1961 to December 1990, and from January 1993 to November 2002. These records were obtained from the meteorological station at Hancock International Airport, in Syracuse (National Climatic Data Center station number 14771), which is approximately two miles southeast of the Lake. The station gives, at each hour, wind direction (in compass degrees) and wind speed (in miles per hour [mph]). Winds were measured 21 feet above the ground.

2.1.2 Wind Environment

A wind rose chart was developed, with the WRPLOT software, with wind data from 1961 to 1990. It appears that most of the winds, as well as the strongest winds, blow from the west-southwest/west-northwest quadrant (Figure 2). The average wind speed, over land, is approximately 10 mph (8.6 knots), which corresponds to approximately 16 mph over water (13 knots). The highest wind speed recorded overland during the 1961-2002 period was 51 mph (44 knots) in 1967.

2.2 Wind-Wave Computation Methodology

2.2.1 Bathymetry

A bathymetric chart of the site was obtained from Parsons (Figure 1). Information from this chart was used to determine wave heights and bottom orbital velocities at various depths and nearshore slopes.

2.2.2 Wind-Wave Generation

The U.S. Army Corps of Engineers (USACE) Automated Coastal Engineering System (ACES) program was used to model wave growth and propagation due to winds (CERC 1992). This software package was developed in 1992 by the USACE and is an accepted worldwide reference for modeling water wave mechanics and properties.

Figures 3A to 3D illustrate the fetch radials and distances that were used in the ACES model for SMUs 1/2, 3, 4, and 6/7. Given the water body geometry, the restricted fetch approach was applied. The restricted fetch methodology allows for wave growth and development in off-wind directions while considering the shape of the basin (CERC 1992). To be conservative, it was assumed that the waves would form in the Lake just before it freezes, which means that the air-water temperature difference would 4°C. At this stage, the water is still in its liquid form and has a slightly higher density than at warmer temperatures. This allows for the formation of higher waves.

For each SMU, a wind direction and speed data set corresponding to the SMU location and fetch radials was prepared, and wave parameters were hindcast using ACES simulations. A set of wave information and associated period was then prepared in order to determine the 100-year wave.

2.2.3 Extremal Wave Height Analysis

Once a sufficient amount of wave data (longer than the wave record period) had been obtained, ACES' Extremal Significant Wave Height Analysis module was used to estimate the 100-year wave that can reach each SMU. This module provides significant wave height estimates for various returns periods (Table A-1).

The approach developed by Goda (1988) is used to fit five candidate probability distributions to an input of array of extreme significant wave heights. Candidate distribution functions are Fisher-Tippett Type I and Weibull, with a range of exponents k varying from 0.75 to 2.0 (CERC 1992). Design values for the 100-year wave were obtained from the distribution that best fit the data (highest correlation).

2.2.4 Wave Transformation

For each SMU, the 100-year wave was transformed, using ACES, to determine its elevation and bottom orbital velocities at different depths, as well as its breaking height and depth. To perform such an operation, a wave period had to be associated to the wave height. Usually, at a given depth, the bottom orbital velocity and the shear stress that is exerted on the sediments increases with wave height and wave period.

2.3 Cap Sediment Size Determination

2.3.1 Before Waves Break

Stable sediment size under a progressive wave before it reaches the breaking zone (surf zone) was estimated at various water depths using four different methods (Appendix C). The first one was developed by Komar and Miller (1975) and the second one was presented by Van Rijn (1989). The third one was developed based on experiments in rivers made by Shields (1936) (Vanoni 1975), and the fourth one was an adaptation of the Shields diagram for oscillatory flow (Dean and Dalrymple 2001) instead of unidirectional flows, as found in rivers. For this last method, a friction coefficient of 0.03 was assumed. The maximum sediment grain sizes that were predicted from these different methods were used as the stable sediment size for the design cap.

2.3.2 In the Surf Zone

As will be discussed in Section 3, the majority of the highest waves that can be formed in Onondaga Lake break in a plunging or surging fashion. Because of the amount of turbulence generated by such waves, as opposed to waves that break in a spilling fashion, the cap armor layer was designed as a rubble mound berm in the surf zone. This design is conservative, but it will ensure the cap's stability in the surf zone.

ACES' Rubble Mound Revetment Design module was used to determine the armor gradation. It was assumed that the berm would be composed of a rock layer (equivalent to the armor layer) on top of a filter layer (cap) that would serve as an interface between the berm core (sediment to be capped) and the rock surface (armor layer). In order to minimize wave reflection, the structure was designed to be permeable.

2.4 Summary

In summary, cap sediment sizes that can resist wave forces in each SMU were computed based on the 100-year wave height. Design wave heights were obtained from 39 years of wind records. Bottom orbital velocities due to the progression of the 100-year wave were modeled at different water depths before the wave breaks. Stable cap sediment sizes were computed based on different equations before the design wave breaks. For water depths shallower than the breaking depth, the cap surface was designed as a rubble mound structure.

3 CAP SEDIMENT SIZE DETERMINATION PER SMU

3.1 SMU 1/2

3.1.1 Wind-Wave Generation

Based on site configuration, SMUs 1 and 2 have been combined, and wind fetches from SMU 1 were used to conduct the wind-wave analysis for this section of the Lake. Because of the SMU location, winds blowing from 320 to 30 degrees were considered in this analysis. The ten highest waves obtained from ACES are presented in Table 1. The complete list of wave heights that were used to compute the 100-year wave height is presented in Appendix B to this attachment. The data best fit a Weibull distribution (k=1), and the design wave was estimated to be 3.96 feet high (Table A-1).

Table 1
Ten Highest Wind Waves That Could Reach SMU 1/2

Year	Wind Direction [degrees]	Wind Speed [mph]	Wave Height [feet]	Wave Period [seconds]
1963	320	49	3.89	3.61
1963	320	44	3.5	3.44
1963	320	37	2.94	3.19
1967	360	41	2.88	3.15
1966	300	40	2.85	3.14
1993	340	35	2.77	3.10
1967	320	34	2.7	3.07
1962	320	34	2.7	3.07
1967	300	37	2.64	3.03
1969	310	34	2.6	3.02

3.1.2 Wave Transformation and Stable Cap Sediment Size Determination

ACES was run to estimate design wave heights and bottom orbital velocities as the wave moves into shallower water. Based on the wind-wave analysis results, a conservative design wave period of four seconds was assumed. This wave period is longer than the period of most of the highest waves that can reach the site (Table 1).

Given the SMU configuration and offshore slope, the 100-year wave is 3.96 feet in deep water, increasing to a maximum height of 4.45 feet as the water depth gets shallower, until it breaks in 5.11 feet of water depth, in a plunging fashion (Van Rijn 1993). Wave heights and bottom orbital velocities at various depths before breaking are presented in Table 2. Based on this information, stable sediment sizes before the surf zone were predicted and are also presented in Table 2. A more complete table that presents results obtained from the various methods is presented in Table A-3.

Upon breaking, stable cap sediment size was computed using ACES’ Rubble Mound Berm design function. Model results indicate that a 2.54-foot-thick armor layer, with a medium rock size of approximately 1.16 feet would be necessary to maintain cap stability in this region (Table A-4).

Table 2
Design Wave Heights and Bottom Orbital Velocities at Various Depths Before Breaking for SMU 1/2

Depth [feet]	Wave Height [feet]	Maximum Orbital Velocity [feet/second]	Design D50 [mm]	Sediment Type
43	3.96	0.23	0.10	Fine Sand
30	3.81	0.58	0.50	Fine Sand
20	3.6	1.12	1.89	Medium Sand
15	3.48	1.56	4.09	Coarse Sand
10	3.41	2.27	9.79	Fine Gravel
8	3.43	2.73	15.05	Fine Gravel
6	3.5	3.42	25.43	Fine Gravel

3.2 SMU 3

3.2.1 Wind-Wave Generation

Based on the SMU location, winds blowing from 330 to 130 degrees were considered in this analysis. The ten highest waves obtained from ACES are presented in Table 3. The complete list of wave heights that were used to compute the 100-year wave height is presented in Appendix B. The data best fit a Weibull distribution (k=1), and the design wave was estimated to be 2.95 feet high (Table A-1).

Table 3
Ten Highest Wind Waves That Could Reach SMU 3

Year	Wind Direction [degrees]	Wind Speed [mph]	Wave Height [feet]	Wave Period [seconds]
1963	320	49	2.86	3.15
1963	320	44	2.56	3.00
1967	360	41	2.29	2.85
1963	320	37	2.14	2.77
1993	340	35	2.11	2.75
1962	90	37	2.05	2.71
1962	110	34	2.02	2.7
1964	320	34	1.96	2.67
1962	320	34	1.96	2.67
1967	350	33	1.94	2.65

3.2.2 Wave Transformation and Stable Cap Sediment Size Determination

ACES was run to estimate design wave heights and bottom orbital velocities as the wave moves into shallower water. Based on the wind-wave analysis results, a conservative design wave period of 3.5 seconds was assumed. This wave period is longer than the period of most of the highest waves that can reach the site (see Table 3).

Given the SMU configuration and offshore slope, the 100-year wave is 2.95 feet in deep water, increasing to a maximum height of 3.39 feet as the water depth gets shallower, until it breaks in 3.54 feet of water depth, in a surging fashion (Van Rijn 1993). Wave heights and bottom orbital velocities at various depths before breaking are presented in Table 4. Based on this information, stable sediment sizes before the surf zone were predicted and are also presented in Table 4. A more complete table that presents results obtained from the various methods is presented in Table A-3.

Upon breaking, stable cap sediment size was computed using ACES' Rubble Mound Berm design function. Model results indicate that a 1.74-foot-thick armor layer, with a medium rock size of approximately 0.87 feet would be necessary to maintain cap stability in this region (Table A-4).

Table 4
Design Wave Heights and Bottom Orbital Velocities at Various Depths Before Breaking for SMU 3

Depth [feet]	Wave Height [feet]	Maximum Orbital Velocity [feet/second]	Design D_{50} [mm]	Sediment Type
43	2.95	0.07	—	—
30	2.92	0.26	0.10	Fine Sand
20	2.82	0.65	0.63	Medium Sand
15	2.74	1.01	1.52	Medium Sand
10	2.69	1.60	4.34	Coarse Sand
8	2.70	1.97	7.04	Coarse Sand
6	2.75	2.54	12.72	Fine Gravel
4	2.89	3.54	27.55	Coarse Gravel

3.3 SMU 4

3.3.1 Wind-wave Generation

Based on the SMU location, winds blowing from 330 to 100 degrees were considered in this analysis. The ten highest waves obtained from ACES are presented in Table 5. The complete list of wave heights that were used to compute the 100-year wave height is presented in Appendix B. The data best fit a Weibull distribution (k=2), and the design wave was estimated to be 2.67 feet high (Table A-1).

Table 5
Ten Highest Wind Waves That Could Reach SMU 4

Year	Wind Direction [degrees]	Wind Speed [mph]	Wave Height [feet]	Wave Period [seconds]
1963	320	49	2.67	3.03
1963	320	44	2.39	2.88
1967	360	41	2.30	2.83
1962	90	37	2.12	2.74
1963	320	37	2.00	2.67
1993	340	35	1.97	2.65
1962	90	34	1.94	2.63
1967	350	33	1.85	2.58
1964	320	34	1.83	2.57
1962	320	34	1.83	2.57

3.3.2 Wave Transformation and Stable Cap Sediment Size Determination

ACES was run to estimate design wave heights and bottom orbital velocities as the wave moves into shallower water. Based on the wind-wave analysis results, a conservative design wave period of 3.5 seconds was assumed. This wave period is longer than the period of most of the highest waves that can reach the site (see Table 5).

Given the SMU configuration and offshore slope, the 100-year wave is 2.67 feet in deep water, increasing to a maximum height of 2.91 feet as the water depth gets shallower, until it breaks in 3.19 feet of water depth, in a surging fashion (Van Rijn 1993). Wave heights and bottom orbital velocities at various depths before breaking are presented in Table 6. Based on this information, stable sediment sizes before the surf zone were predicted and are also presented in Table 6. A more complete table that presents results obtained from the various methods is presented in Table A-3.

Upon breaking, stable cap sediment size was computed using ACES' Rubble Mound Berm design function. Model results indicate that a 1.49 foot thick armor layer, with a medium rock size of approximately 0.75 feet would be necessary to maintain cap stability in this region (Table A-4).

Table 6
Design Wave Heights and Bottom Orbital Velocities at Various Depths Before Breaking for SMU 4

Depth [feet]	Wave Height [feet]	Maximum Orbital Velocity [feet/second]	Design D_{50} [mm]	Sediment Type
43	2.67	0.06	—	—
30	2.64	0.23	0.08	Fine Sand
20	2.55	0.59	0.52	Fine Sand
15	2.47	0.91	1.24	Medium Sand
10	2.42	1.44	3.40	Coarse Sand
8	2.43	1.78	5.56	Fine Gravel
6	2.47	2.28	9.89	Fine Gravel
4	2.59	3.18	21.46	Coarse Gravel

3.4 SMU 6/7

3.4.1 Wind-wave Generation

Based on site configuration, SMUs 6 and 7 have been combined, and wind fetches from SMU 6 were used to conduct the wind-wave analysis for this section of the Lake. Based the SMU location, winds blowing from 280 to 340 degrees were considered in this analysis. The ten highest waves obtained from ACES are presented in Table 7. The complete list of wave heights that were used to compute the 100-year wave height is presented in Appendix B. The data best fit a Weibull distribution (k=1), and the design wave was estimated to be 4.65 feet high (Table A-1).

Table 7
Ten Highest Wind Waves That Could Reach SMU 6/7

Year	Wind Direction [degrees]	Wind Speed [mph]	Wave Height [feet]	Wave Period [seconds]
1963	320	49	4.29	3.80
1963	290	51	4.10	3.72
1965	280	55	4.04	3.70
1963	320	44	3.85	3.63
1967	280	51	3.74	3.58
1963	290	43	3.45	3.45
1966	300	40	3.41	3.43
1963	320	37	3.24	3.36
1967	300	37	3.15	3.32
1969	310	34	2.98	3.24

3.4.2 Wave Transformation and Stable Cap Sediment Size Determination

ACES was run to estimate design wave heights and bottom orbital velocities as the wave moves into shallower water. Based on the wind-wave analysis results, a conservative design wave period of four seconds was assumed. This wave period is longer than the period of most of the highest waves that can reach the site (see Table 7).

Given the SMU configuration and offshore slope, the 100-year wave is 4.65 feet in deep water, increasing to a maximum height of 4.86 feet as the water depth gets shallower, until it breaks in 6.14 feet of water depth, in a plunging fashion (Van Rijn 1993). Wave heights and bottom orbital velocities at various depths before breaking are presented in Table 8. Based on this information, stable sediment sizes before the surf zone were predicted and are also presented in Table 8. A more complete table that presents results obtained from the various methods is presented in Table A-3.

Upon breaking, stable cap sediment size was computed using ACES' Rubble Mound Berm design function. Model results indicate that a 3.16 foot thick armor layer, with a medium rock size of approximately 1.31 feet would be necessary to maintain cap stability in this region.

Table 8
Design Wave Heights and Bottom Orbital Velocities at Various Depths Before Breaking for SMU 6/7

Depth [feet]	Wave Height [feet]	Maximum Orbital Velocity [feet/second]	Design D_{50} [mm]	Sediment Type
43	4.65	0.27	0.11	Fine Sand
30	4.50	0.68	0.69	Medium Sand
20	4.32	1.35	2.92	Coarse Sand
15	4.24	1.90	6.47	Fine Gravel
10	4.26	2.83	16.36	Fine Gravel
8	4.33	3.44	25.77	Coarse Gravel
7	4.39	3.85	33.49	Coarse Gravel

4 CONCLUSIONS

A wind-wave analysis was conducted to determine stable sediment sizes at various depths in SMUs 1/2, 3, 4, and 6/7. Given the SMUs' locations in the Lake, possible fetch radials were computed and a 100-year wave height determined for each one of them. It was found that SMU 6/7 was likely to be impacted by the highest waves (design wave height is 4.65 feet), and SMU 4 by the lowest waves (design wave height of 2.67 feet). It is also likely that most of the highest waves will break in water depth varying from 3 to 6 feet.

Stable sediment size was computed for various water depths prior to the wave breaking. In general, cap sediment grain size should increase as water depth decreases. Figure 4 presents cap sediment gradation variation for each different SMU. In the area where the wave breaks, cap sediment size was computed assuming that the cap armor layer would be treated as a rubble mound berm. Medium rock size varied from 1.31 feet (SMU 6/7) to 0.75 feet (SMU 4).

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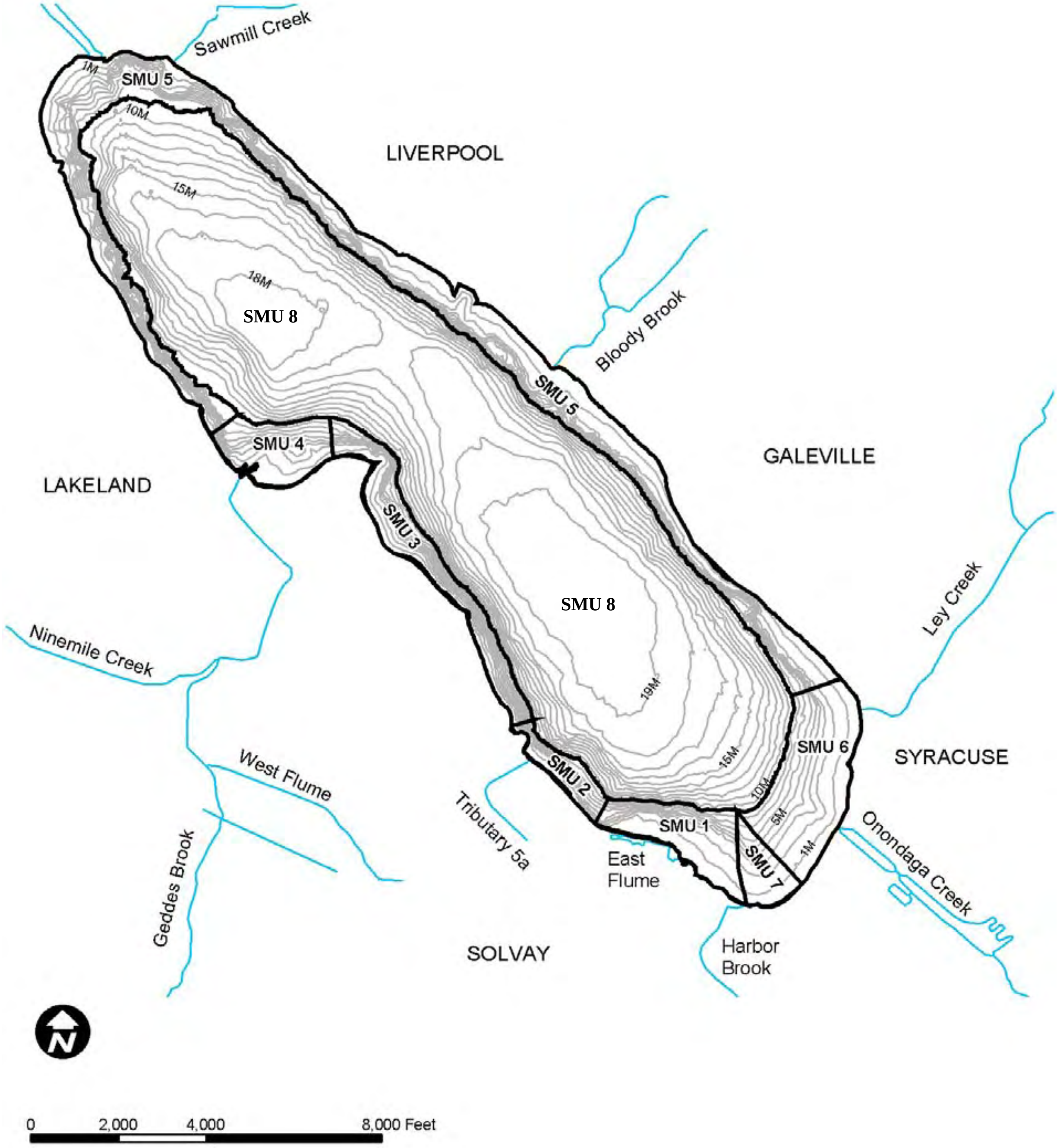
List of Tables (included in text)

Table 7 Ten Highest Wind Waves that Could Reach SMU 6/7
Table 8 Design Wave Heights and Bottom Orbital Velocities at Various Depths before Breaking for SMU 6/7

Attachments

Figure 1 Site Bathymetry and Sediment Management Unit Location
Figure 2 Wind Rose
Figure 3A Fetch Radials for SMU 1/2
Figure 3B Fetch Radials for SMU 3
Figure 3C Fetch Radials for SMU 4
Figure 3D Fetch Radials for SMU 5/6
Figure 4 Cap Sediment Size Variation as a Function of Depth for Different SMUs

Appendix A: Design Wave and Cap Sediment Size Calculation Summary
Appendix B: Wind Wave Analysis Results, per SMU
Appendix C: Methods Used to Compare Stable Sediment Size



Note: Water Surface Elevation is: 363.39 feet (110.76 meters) above Mean Sea Level.
SMU: Sediment Management Unit

Source: Modified from TAMS, 2002c

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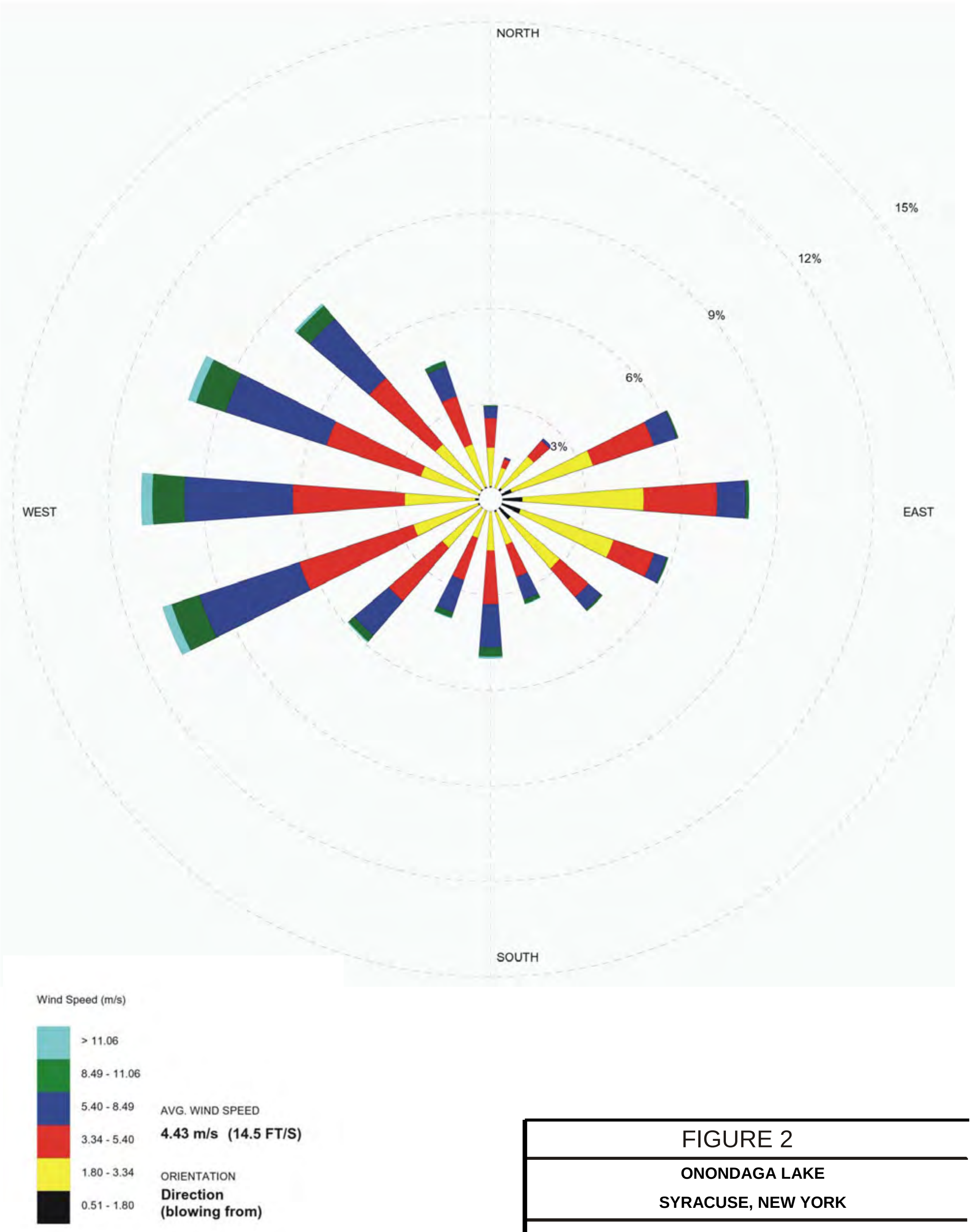
FIGURE 1

ONONDAGA LAKE

SYRACUSE, NEW YORK

SITE BATHYMETRY AND SMU LOCATIONS



AVG. WIND SPEED

4.43 m/s (14.5 FT/S)

ORIENTATION

Direction (blowing from)

ANCHOR
ENVIRONMENTAL, L.L.C.

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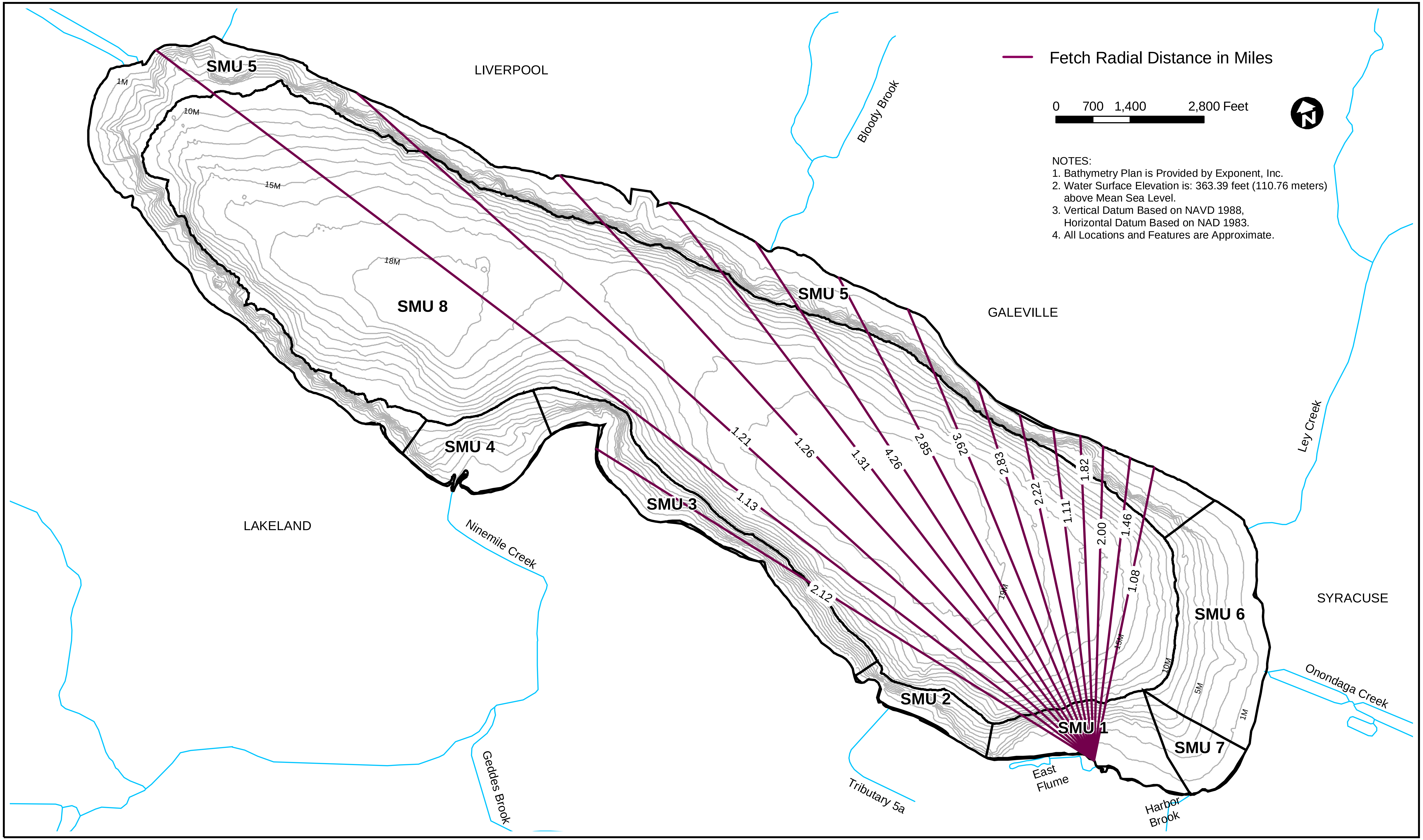
FIGURE 2

ONONDAGA LAKE

SYRACUSE, NEW YORK

WIND ROSE
ONONDAGA LAKE
SYRACUSE, NEW YORK



NOTES:
1. Bathymetry Plan is Provided by Exponent, Inc.
2. Water Surface Elevation is: 363.39 feet (110.76 meters) above Mean Sea Level.
3. Vertical Datum Based on NAVD 1988, Horizontal Datum Based on NAD 1983.
4. All Locations and Features are Approximate.

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ANCHOR
ENVIRONMENTAL, L.L.C.

FIGURE 3A

Fetch Radials for SMU 1/2
Onondaga Lake, Syracuse, New York

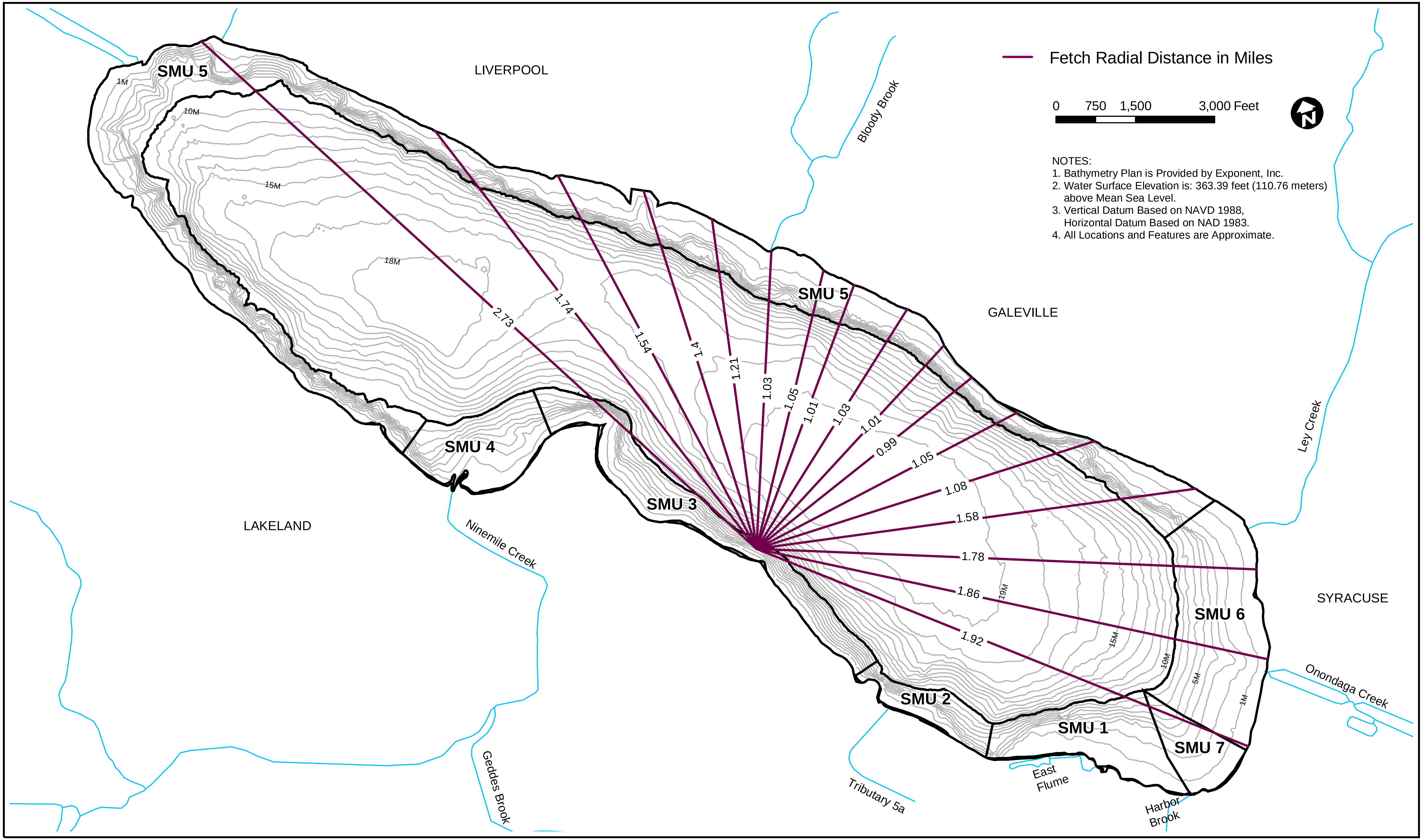

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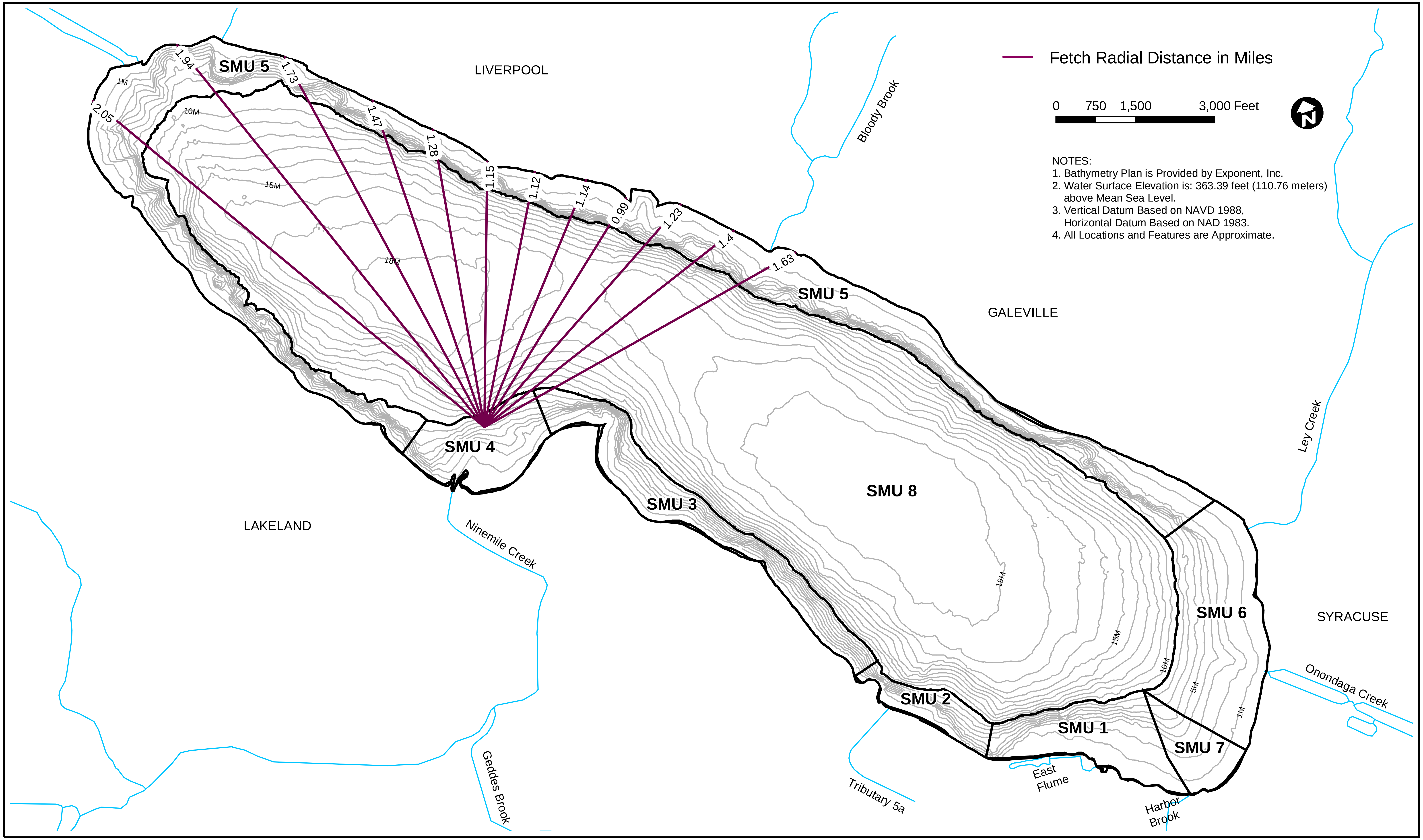
FIGURE 3B

Fetch Radials for SMU 3
Onondaga Lake, Syracuse, New York



NOTES:
1. Bathymetry Plan is Provided by Exponent, Inc.
2. Water Surface Elevation is: 363.39 feet (110.76 meters) above Mean Sea Level.
3. Vertical Datum Based on NAVD 1988, Horizontal Datum Based on NAD 1983.
4. All Locations and Features are Approximate.

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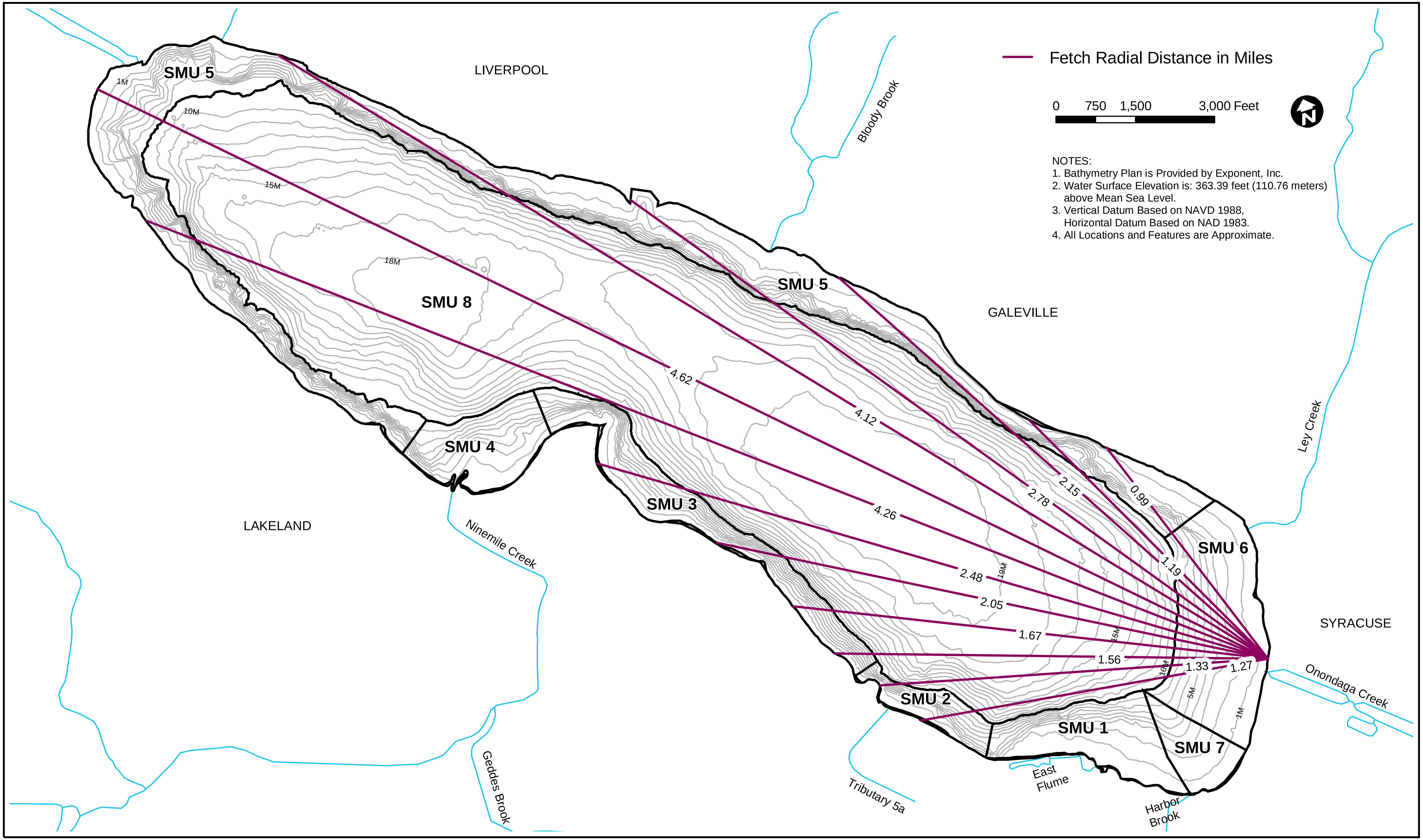
FIGURE 3C

Fetch Radials for SMU 4
Onondaga Lake, Syracuse, New York



NOTES:
1. Bathymetry Plan is Provided by Exponent, Inc.
2. Water Surface Elevation is: 363.39 feet (110.76 meters) above Mean Sea Level.
3. Vertical Datum Based on NAVD 1988, Horizontal Datum Based on NAD 1983.
4. All Locations and Features are Approximate.

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FIGURE 3D

Fetch Radials for SMU 6/7
Onondaga Lake, Syracuse, New York

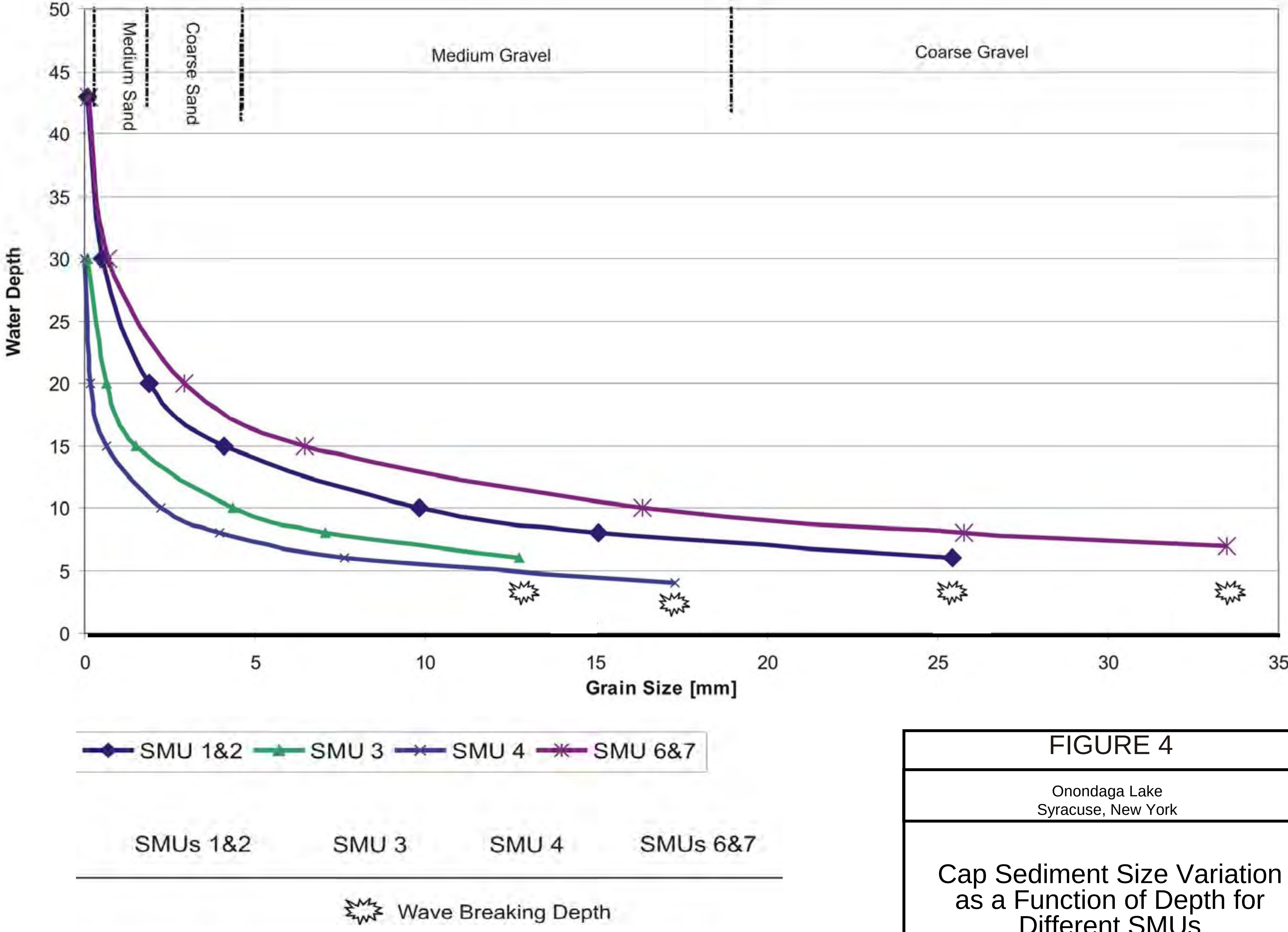

FIGURE 4

Onondaga Lake
Syracuse, New York

Cap Sediment Size Variation as a Function of Depth for Different SMUs

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ATTACHMENT D
APPENDIX A
Design Wave and Cap Sediment Size Calcluation Summary

Table A-1 – Extremal Wave Analysis Results

Return Period [Year]	Wave Height [feet]			
	SMU 1/2	**SMU 3**	**SMU 4**	**SMU 6/7**
2	2.23	1.67	1.62	2.8
5	2.63	1.97	1.91	3.23
10	2.94	2.2	2.1	3.56
25	3.34	2.5	2.34	3.99
50	3.65	2.73	2.51	4.32
100	3.96	2.95	2.67	4.65

Table A-2 – Design Wave Info

	Wave Height [feet]	Wave Period [seconds]	Breaker Height [feet]	Breaker Depth [feet]	Breaker Index c
SMU 1/2	3.96	4	4.45	5.11	0.87
SMU 3	2.95	3.5	3.39	3.54	0.92
SMU 4	2.67	3	2.91	3.19	0.91
SMU 6/7	4.65	4	4.86	6.14	0.79

Note: Breaker index indicates type of breaking:
c ≤ 0.4: no breaker
c = 0.4 to 0.6: spilling breaker
c = 0.6 to 0.9: plunging breaker
c = 0.9 to 1.2 surging breaker

ATTACHMENT D
APPENDIX A
Design Wave and Cap Sediment Size Calcluation Summary

Table A-3 – Cap Sediment Size Calculation Summary

SMU 1 & 2

Depth [feet]	Max. Orb. Vel [feet/second]	D_{50} (Komar)* [mm]	D_{50} (Van Rijn)* [mm]	D_{50} (Shields)* [mm]	D_{50} (Shields2)* [mm]	Design D_{50}** [mm]	Sediment Type
43	0.23	0.026	0.100		0.08	0.10	Fine Sand
30	0.58	0.41	0.20	0.40	0.50	0.50	Fine Sand
20	1.12	1.89	1.50	1.50	1.87	1.89	Medium Sand
15	1.56	4.09	3.20	2.60	3.63	4.09	Coarse Sand
10	2.27	9.79		7.20	7.70	9.79	Fine Gravel
8	2.73	15.05		8.00	11.13	15.05	Fine Gravel
6	3.42	25.4		15.00	17.47	25.43	Fine Gravel

SMU 3

Depth [feet]	Max. Orb. Vel [feet/second]	D_{50} (Komar)* [mm]	D_{50} (Van Rijn)* [mm]	D_{50} (Shields)* [mm]	D_{50} (Shields2)* [mm]	Design D_{50}** [mm]	Sediment Type
43	0.07	--			--	--	--
30	0.26	0.037	0.00	0.00	0.10	0.10	Fine Sand
20	0.65	0.53	0.28	0.45	0.63	0.63	Medium Sand
15	1.01	1.49	1.02	1.25	1.52	1.52	Medium Sand
10	1.60	4.34		3.00	3.82	4.34	Coarse Sand
8	1.97	7.04		5.00	5.80	7.04	Coarse Sand
6	2.54	12.72		7.50	9.63	12.72	Fine Gravel
4	3.54	27.55		16.00	18.71	27.55	Coarse Gravel

SMU 4

Depth [feet]	Max. Orb. Vel [feet/second]	D_{50} (Komar)* [mm]	D_{50} (Van Rijn)* [mm]	D_{50} (Shields)* [mm]	D_{50} (Shields2)* [mm]	Design D_{50}** [mm]	Sediment Type
43	0.02				--	--	
30	0.09	0.002			0.01	0.01	Fine Sand
20	0.35	0.09	0.12	0.15	0.18	0.18	Fine Sand
15	0.66	0.55	0.30	0.53	0.65	0.65	Medium Sand
10	1.20	2.22	2.10	1.90	2.15	2.22	Coarse Sand
8	1.54	3.97	2.80	2.55	3.54	3.97	Coarse Sand
6	2.04	7.64		5.00	6.21	7.64	Fine Gravel
4	2.90	17.32		10.00	12.56	17.32	Fine Gravel

Table A-3 (Continued)– Cap Sediment Size Calculation Summary

SMU 6 and 7

Depth [feet]	Max. Orb. Vel [feet/second]	D_{50} (Komar)* [mm]	D_{50} (Van Rijn)* [mm]	D_{50} (Shields)* [mm]	D_{50} (Shields2)* [mm]	Design D_{50}** [mm]	Sediment Type
43	0.27	0.04	0.11		0.11	0.11	Fine Sand
30	0.68	0.66	0.31	0.43	0.69	0.69	Medium Sand
20	1.35	2.92	2.30	2.00	2.72	2.92	Coarse Sand
15	1.90	6.47		4.50	5.39	6.47	Fine Gravel
10	2.83	16.36		8.00	11.96	16.36	Fine Gravel
8	3.44	25.77		17.00	17.67	25.77	Coarse Gravel
7	3.85	33.49		18.00	22.14	33.49	Coarse Gravel

Notes:
* See Appendix A
** Design sediment size is maximum of all sediment sizes.

Table A-4 – Cap Armor Gradation in the Surf Zone*

Percent Less Than, by	Dimension [ft]			
	SMU 1 and 2	SMU 3	SMU 4	SMU 6 and 7
0 [min]	0.58	0.43	0.37	0.65
15	0.85	0.64	0.55	0.96
50	1.16	0.87	0.75	1.31
85	1.45	1.09	0.93	1.64
100 [max]	1.84	1.38	1.18	2.07

Note:
*Armor gradation based on ACES' rubble mound berm design module. Armor thickness approximately twice the size of the 50 percent passing rock..

ATTACHMENT D
APPENDIX B
Wind Wave Analysis Results, per SMU

SMU 1/2

Year	Month	Day	Wind Direction [degrees]	Wind Speed [mph]	Wave Height [feet]	Wave Period [seconds]
1963	4	4	320	49	3.89	3.61
1963	4	4	320	44	3.5	3.44
1963	3	18	320	37	2.94	3.19
1967	10	6	360	41	2.88	3.15
1966	1	31	300	40	2.85	3.14
1993	3	14	340	35	2.77	3.10
1964	8	30	320	34	2.7	3.07
1962	12	31	320	34	2.7	3.07
1967	4	10	300	37	2.64	3.03
1969	4	16	310	34	2.6	3.02
1990	11	12	330	32	2.58	3
1965	11	17	320	32	2.55	2.99
1967	3	12	350	33	2.5	2.96
1963	2	3	340	31	2.46	2.94
1962	12	30	340	31	2.46	2.94
1965	11	4	300	34	2.42	2.92
1997	3	12	310	31	2.37	2.9
1961	12	24	340	29	2.3	2.86
2001	11	19	300	32	2.28	2.84
1964	2	16	330	28	2.26	2.83
1997	9	20	330	28	2.26	2.83
1961	1	18	320	28	2.23	2.82
1965	12	25	340	28	2.22	2.81
2002	5	3	300	31	2.21	2.8
1996	1	19	310	28	2.14	2.77
1990	2	19	300	30	2.14	2.76
1975	3	20	310	28	2.14	2.77
1999	10	14	330	26	2.08	2.73
1998	11	23	300	29	2.07	2.72
1995	4	5	300	29	2.07	2.72
1985	3	15	300	29	2.07	2.72
1982	8	9	300	29	2.07	2.72
1970	4	3	300	29	2.07	2.72
2000	1	16	320	26	2.05	2.72
1962	12	30	360	29	2.04	2.71
1989	11	21	330	25	2	2.69
1999	12	11	300	28	2	2.68
1984	3	16	320	25	1.98	2.67
1990	3	26	340	25	1.97	2.67
1968	1	15	340	25	1.97	2.67
1966	7	6	330	24	1.92	2.64
1988	11	2	310	24	1.82	2.58
1993	4	23	300	25	1.77	2.54
1973	1	6	300	25	1.77	2.54
1986	4	23	330	22	1.76	2.54
1987	3	16	330	22	1.76	2.54

ATTACHMENT D
APPENDIX B
Wind Wave Analysis Results, per SMU

SMU 3

Year	Month	Day	Wind Direction [degrees]	Wind Speed [mph]	Wave Height [feet]	Wave Period [seconds]
1963	4	4	320	49	2.86	3.15
1963	4	4	320	44	2.56	3.00
1967	10	6	360	41	2.29	2.85
1963	3	18	320	37	2.14	2.77
1993	3	14	340	35	2.11	2.75
1962	11	10	90	37	2.05	2.71
1962	11	10	110	34	2.02	2.70
1964	8	30	320	34	1.96	2.67
1962	12	31	320	34	1.96	2.67
1967	3	12	350	33	1.94	2.65
1990	11	12	330	32	1.92	2.64
1962	11	10	90	34	1.88	2.60
1965	11	17	320	32	1.85	2.59
1989	6	24	140	31	1.79	2.56
1999	11	2	140	30	1.74	2.53
1961	12	24	340	29	1.74	2.53
1993	1	31	330	29	1.73	2.52
1965	2	25	100	30	1.73	2.52
1965	2	25	110	29	1.72	2.51
1996	1	27	140	29	1.68	2.49
1982	10	20	140	29	1.68	2.49
1965	12	25	340	28	1.68	2.49
1997	9	20	330	28	1.67	2.48
1964	2	16	330	28	1.67	2.48
1981	2	10	110	28	1.66	2.47
1961	4	16	110	28	1.66	2.47
1985	2	12	80	30	1.56	2.39
1970	3	26	120	26	1.56	2.41
1999	10	14	330	26	1.54	2.40
1994	11	21	130	25	1.49	2.36
1968	1	15	340	25	1.49	2.36
2000	1	16	320	26	1.48	2.36
1974	3	13	330	25	1.48	2.35
1998	2	18	80	28	1.45	2.32
1985	2	12	80	28	1.45	2.32
1973	10	29	80	28	1.45	2.32
1995	11	11	140	25	1.43	2.32
1988	11	5	140	25	1.43	2.32
1984	3	16	320	25	1.43	2.32
1981	4	1	140	25	1.43	2.32
1971	3	4	320	25	1.43	2.32
1971	11	30	330	24	1.42	2.31
1966	2	13	90	26	1.42	2.30
1966	7	6	330	24	1.42	2.31
1987	3	30	120	23	1.37	2.28
1986	1	25	140	24	1.37	2.28
1982	1	23	90	25	1.37	2.26
1975	1	11	130	23	1.37	2.27
1972	4	13	120	23	1.37	2.28
1970	3	26	120	23	1.37	2.28
1968	4	24	120	23	1.37	2.28
1969	2	9	330	23	1.36	2.27
1988	11	5	110	23	1.35	2.26
2001	2	25	140	23	1.32	2.24
1973	3	7	140	23	1.32	2.24
1969	11	19	140	23	1.32	2.24
2002	2	11	340	22	1.31	2.23

ATTACHMENT D
APPENDIX B
Wind Wave Analysis Results, per SMU

SMU 4

Year	Month	Day	Wind Direction [degrees]	Wind Speed [mph]	Wave Height [feet]	Wave Period [seconds]
1963	4	4	320	49	2.67	3.03
1963	4	4	320	44	2.39	2.88
1967	10	6	360	41	2.3	2.83
1962	11	10	90	37	2.12	2.74
1963	3	18	320	37	2	2.67
1993	3	14	340	35	1.97	2.65
1962	11	10	90	34	1.94	2.63
1967	3	12	350	33	1.85	2.58
1964	8	30	320	34	1.83	2.57
1962	12	31	320	34	1.83	2.57
1990	11	12	330	32	1.79	2.54
1963	2	3	340	31	1.74	2.51
1962	12	30	340	31	1.74	2.51
1965	11	17	320	32	1.72	2.5
1965	2	25	100	30	1.7	2.48
1985	2	12	80	30	1.68	2.47
1993	3	4	90	29	1.65	2.45
1961	12	24	340	29	1.63	2.44
1996	3	19	80	29	1.62	2.43
1993	1	31	330	29	1.62	2.43
1990	10	19	320	30	1.62	2.43
1965	12	25	340	28	1.57	2.4
1998	2	18	80	28	1.56	2.39
1997	9	20	330	28	1.56	2.39
1985	2	12	80	28	1.56	2.39
1973	10	29	80	28	1.56	2.39
1964	2	16	330	28	1.56	2.39
1961	1	18	320	28	1.51	2.35
1966	2	13	90	26	1.47	2.33
1989	11	21	340	26	1.45	2.31
1999	10	14	330	26	1.44	2.31
1996	3	19	90	25	1.41	2.29
1982	1	23	90	25	1.41	2.29
1967	1	27	90	25	1.41	2.29
2000	1	16	320	26	1.39	2.27
1968	1	15	340	25	1.39	2.27
1989	11	21	330	25	1.38	2.27
1974	3	13	330	25	1.38	2.27
1998	2	18	90	24	1.35	2.25
1968	5	29	90	24	1.35	2.25
1966	11	28	100	24	1.34	2.24
1984	3	16	320	25	1.33	2.23
1971	3	4	320	25	1.33	2.23
1987	4	4	100	23	1.29	2.2
1988	12	4	350	23	1.28	2.19
1981	3	16	340	23	1.28	2.19
1983	12	12	80	23	1.27	2.18
1969	2	9	330	23	1.27	2.18
2002	2	11	340	22	1.22	2.15
1986	4	23	330	22	1.22	2.14
1995	10	5	80	22	1.21	2.14
1994	2	23	80	22	1.21	2.14
1972	12	15	90	21	1.18	2.12
2001	4	17	330	21	1.16	2.1
1975	2	13	330	21	1.16	2.1
1975	4	3	70	21	1.11	2.06
1970	12	16	70	21	1.11	2.06

ATTACHMENT D
APPENDIX B
Wind Wave Analysis Results, per SMU

SMU 6/7

Year	Month	Day	Wind Direction [degrees]	Wind Speed [mph]	Wave Height [feet]	Wave Period [seconds]
1963	4	4	320	49	4.29	3.8
1963	4	4	290	51	4.1	3.72
1965	10	31	280	55	4.04	3.7
1963	4	4	320	44	3.85	3.63
1967	2	16	280	51	3.74	3.58
1963	4	4	290	43	3.45	3.45
1966	1	31	300	40	3.41	3.43
1963	3	18	320	37	3.24	3.36
1967	4	10	300	37	3.15	3.32
1969	4	16	310	34	2.98	3.24
1964	8	30	320	34	2.98	3.24
1962	12	31	320	34	2.98	3.24
1966	1	31	270	46	2.96	3.2
1965	11	4	300	34	2.9	3.19
1967	2	16	270	44	2.83	3.16
1993	3	14	340	35	2.82	3.15
1965	11	17	320	32	2.81	3.15
1990	11	25	280	38	2.79	3.14
2001	11	19	300	32	2.73	3.11
1990	11	12	330	32	2.73	3.11
1989	11	16	290	34	2.73	3.11
1997	3	12	310	31	2.72	3.11
1970	4	3	290	33	2.65	3.07
1968	3	24	290	33	2.65	3.07
1961	5	3	290	33	2.65	3.07
2002	5	3	300	31	2.64	3.07
2001	2	10	270	41	2.63	3.06
1997	2	27	270	41	2.63	3.06
2002	2	1	270	40	2.57	3.02
1972	10	8	290	32	2.57	3.03
1962	10	23	270	40	2.57	3.02
1990	2	19	300	30	2.56	3.02
1990	10	19	320	30	2.56	3.02
1989	12	26	300	30	2.56	3.02
1964	4	15	310	29	2.55	3.02
1963	1	21	270	39	2.5	2.99
1963	2	3	340	31	2.5	2.99
1962	12	30	340	31	2.5	2.99
1971	3	5	290	31	2.49	2.99
1998	11	23	300	29	2.48	2.98
1995	4	5	300	29	2.48	2.98
1993	1	31	330	29	2.48	2.98
1985	3	15	300	29	2.48	2.98
1982	8	9	300	29	2.48	2.98
1970	4	3	300	29	2.48	2.98
1996	1	19	310	28	2.46	2.97
1975	3	20	310	28	2.46	2.97
1961	1	18	320	28	2.46	2.97
1967	3	12	350	33	2.43	2.95
1994	11	6	280	33	2.42	2.95
1999	12	11	300	28	2.39	2.93
1997	9	20	330	28	2.39	2.93
1987	4	30	300	28	2.39	2.93
1986	1	5	300	28	2.39	2.93
1984	5	1	270	28	2.39	2.93
1964	2	16	330	28	2.39	2.93
1996	2	28	270	37	2.37	2.92
1995	4	4	280	32	2.35	2.91

ATTACHMENT D
APPENDIX B
Wind Wave Analysis Results, per SMU

SMU 6/7 continued

Year	Month	Day	Wind Direction [degrees]	Wind Speed [mph]	Wave Height [feet]	Wave Period [seconds]
1961	12	24	340	29	2.34	2.9
1993	11	20	270	36	2.31	2.89
2000	1	16	320	26	2.27	2.86
1999	12	10	280	31	2.27	2.87
1974	1	31	280	31	2.27	2.87
1986	11	9	290	28	2.25	2.86
1983	10	28	290	28	2.25	2.86
1999	10	14	330	26	2.21	2.83
1974	3	10	300	26	2.2	2.83
1972	12	16	300	26	2.2	2.83
1972	12	17	300	26	2.2	2.83
1985	4	6	270	34	2.18	2.81
1984	3	11	270	34	2.18	2.81
1984	3	16	320	25	2.18	2.81
1971	3	4	320	25	2.18	2.81
1981	4	14	280	29	2.13	2.78
1973	1	6	300	25	2.12	2.78
1967	2	11	270	33	2.12	2.78

Attachment D: Appendix C

Methods Used to Compute Stable Sediment Size

1. Komar and Miller (1975)

Komar and Miller showed that stable sediment size under oscillatory flow could be determined with the following equations (Van Rijn, 1993):

$$\frac{U^2}{(s-1)gd_{50}} = 0.21\left(\frac{2A}{d_{50}}\right)^{0.5} \quad \text{for } d_{50} < 0.5\text{ mm}$$

$$\frac{U^2}{(s-1)gd_{50}} = 1.45\left(\frac{2A}{d_{50}}\right)^{0.25} \quad \text{for } d_{50} \geq 0.5\text{ mm}$$

where:

U = Critical peak value of orbital velocity near the bed
s = Ratio of sediment density over water density
A = Critical peak value of orbital excursion near the bed
d_{50} = Stable sediment size

2. Van Rijn (1989)

Figure C-1 presents the graph developed by Van Rijn (1989) to determine stable sediment size under oscillatory flow.

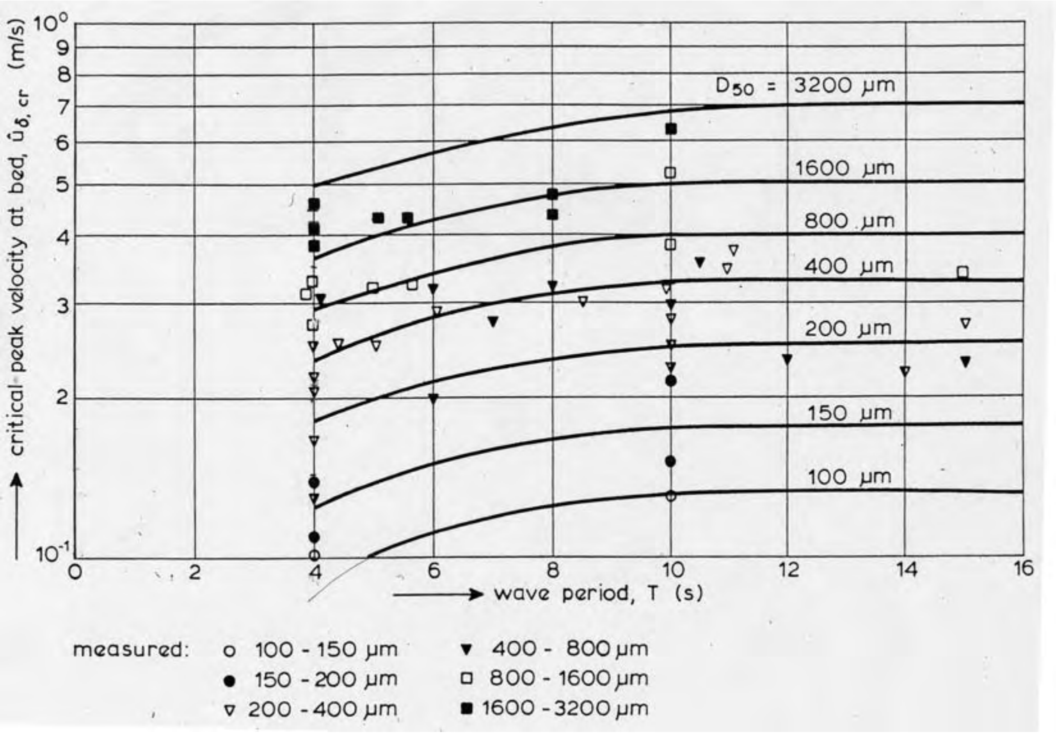

Figure C-1: Initiation of motion for waves over a plane bed based on critical velocity.

3. Shields

Figure C-2 presents the graph developed by Vanoni (1975) to determine stable sediment sizes under different flow velocities. This graph presents the Shields curves that provide sediment size for a certain value of flow velocity.

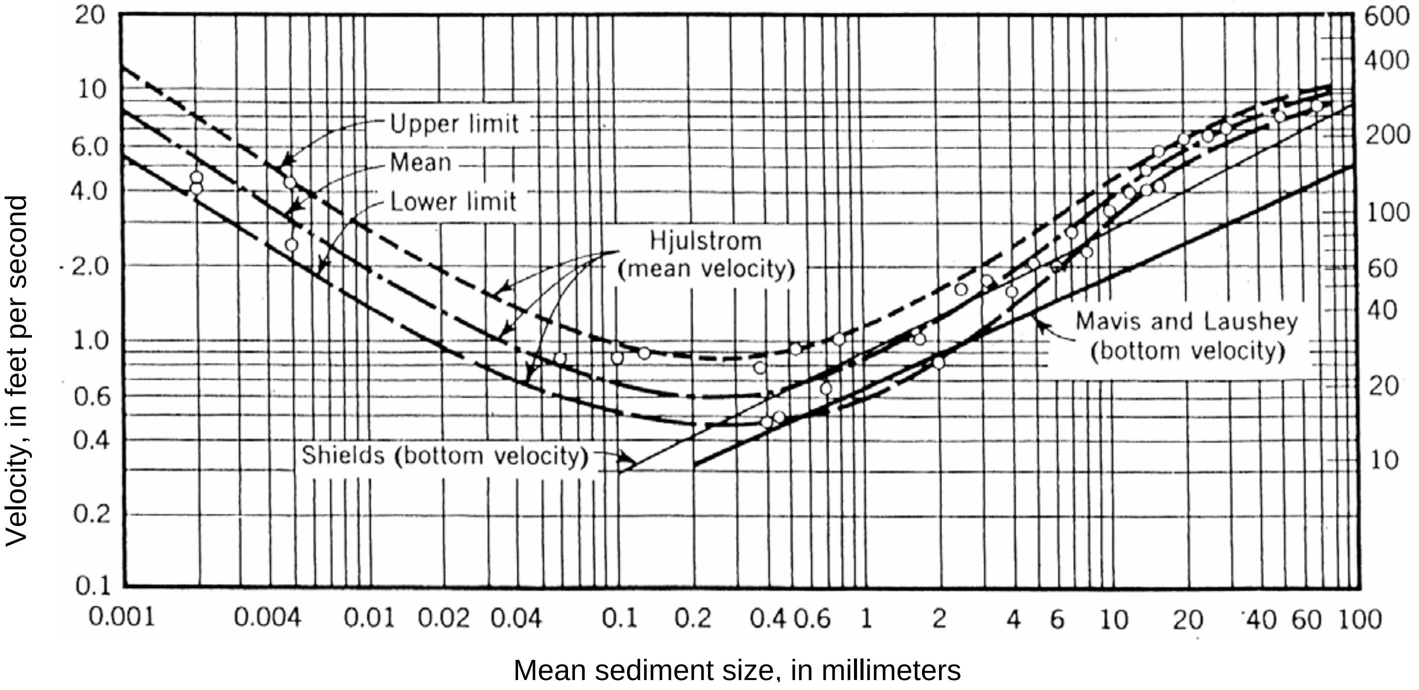

Figure C-2: Shields diagram for initiation of cap material movement.

4. Shields diagram

The fourth method used to compute stable sediment size was based on the modified Shields diagram (Figure C-3) for oscillatory flow. Critical shear stress (τ_*)was computed assuming a friction coefficient of 0.03.

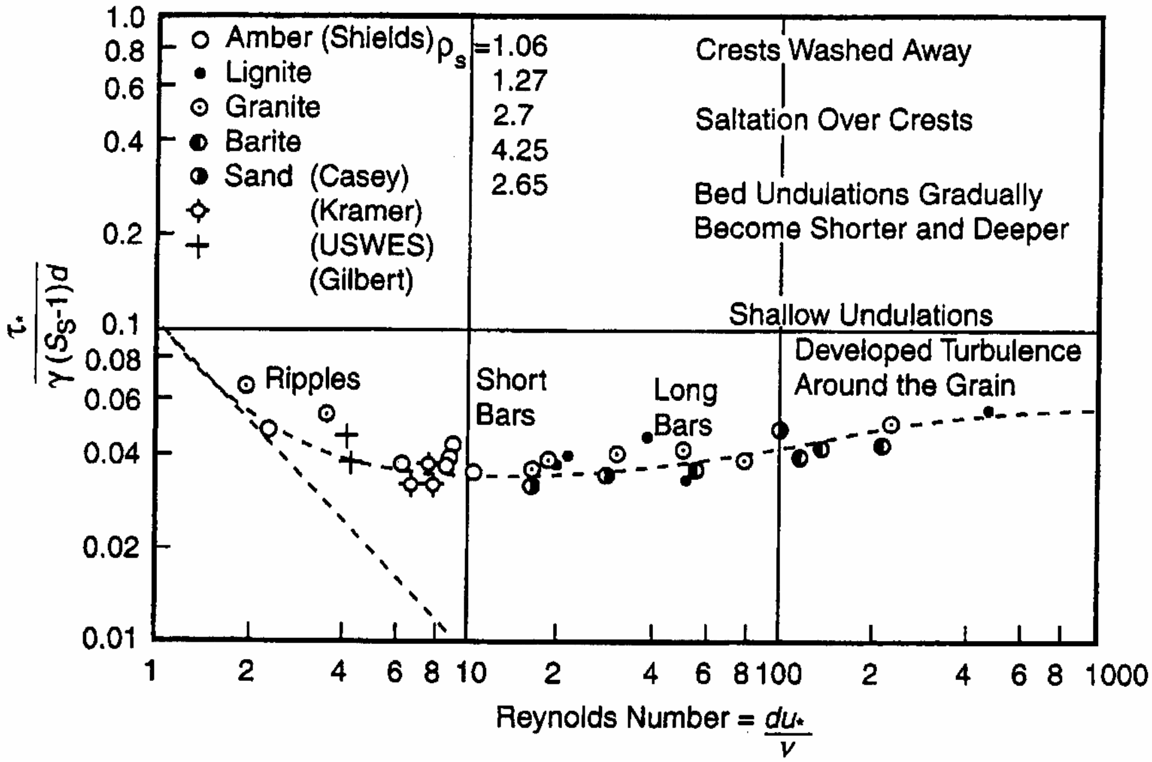

Figure C-3: Critical water velocities for quartz sediment as function of mean grain.

APPENDIX H
ATTACHMENT E

FLOOD FLOW ANALYSIS – ONONDAGA CREEK

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Memorandum

Written for the Onondaga Lake Feasibility Study

From: Greg Guannel and John Verduin, P.E., Anchor Environmental, L.L.C.

Date: April 21, 2004

Re: Onondaga Lake Feasibility Study - Creek Erosion Analysis

This memorandum summarizes the findings of creek-induced current analyses performed to determine which sediment size resists forces generated by the creeks flowing into Onondaga Lake. Results of this analysis will later be used with other erosion analysis results to summarize stable sediment sizes required at various water depths that can resist wave, current, and propwash forces. The interaction between currents and waves in the tributaries' area of influence will be evaluated as part of the final design.

1 CREEK-INDUCED CURRENT EROSION ANALYSIS

1.1 Background

There are seven different creeks that are tributaries to Onondaga Lake (Figure 1):

- Trib 5A in SMU 2
- Ninemile Creek in SMU 4
- Sawmill Creek in SMU 5
- Bloody Brook in SMU 5
- Ley Creek in SMU 6
- Onondaga Creek in SMU 6
- Harbor Brook in SMU 7

We focused our study on Onondaga Creek and in the feasibility study we will apply the results from Onondaga Creek to the other creeks. We applied the analysis results of Onondaga Creek to all of the creeks for the following reasons:

- The main contributors to the total freshwater input flow into Onondaga Lake are Onondaga Creek (34 percent) and Ninemile Creek (33 percent) (Exponent 2002). A comparison of flows in Ninemile Creek (Limno-Tech 2003) and Onondaga Creek (based on USGS stations 423900 and 4240010) indicate that the flows are similar (Walton 2003, personal communication).

- Harbor Brook contributes only 2.1 percent of the total flow (Exponent 2002) and is wider than Onondaga and Ninemile Creek, therefore experiencing smaller flows. It is reasonable to assume that currents at the mouth of Harbor Brook will be smaller than those generated by Onondaga Creek, and will dissipate quite rapidly (Walton 2003 personal communication).
- No information could be obtained concerning Trib 5A, Ley Creek, Bloody Brook, and Sawmill Creek.

Therefore, we will apply the results of the Onondaga Creek analysis to Ninemile Creek and Harbor Brook. As part of final design a more detailed analysis will be completed to include results for Trib 5A, Ley Creek, Bloody Brook, and Sawmill Creek.

1.2 Onondaga Creek Modeling

To determine stable cap sediment size in Onondaga Lake, it is necessary to understand the velocity field generated by each creek that is a tributary to the Lake. For the purpose of this Feasibility Study, the velocity field generated by a 100-year flow coming out of Onondaga Creek was modeled.

Because no flow information and distribution of current velocity in the Lake due to the creek inflow was available, Dr. Ray Walton of WEST Consultants developed a simple 2-D model of Onondaga Creek flowing into the Lake and used the hydraulic model RMA-2 to evaluate current distribution caused by creek inflow (Appendix A). Based on aerial photos, site bathymetry and configuration, and information presented in Effler (1996), Dr. Walton's main assumptions are:

- The 100-year flow was modeled at 5,140 cubic feet per seconds (cfs).
- The discharge of Onondaga Creek to the lake is approximately 150 feet wide and 6 feet deep at the mouth.
- The discharge is essentially perpendicular to the shoreline.
- The lake slopes uniformly downward with a slope of 1.9 percent from the mouth.

Results of his analysis are presented in Appendix A and summarized in Table 1 and Figure 2.

Table 1
Current Velocity along Discharge Centerline

Distance Offshore [ft]	Water Depth [ft]	Centerline Current Velocity [ft/s]
50	7	5
100	8	4.5
150	9	4.3
200	10	4.05
300	12	3.7
400	14	3.3
500	16	2.9
750	21	2.3
1000	26	1.8
1500	36	1.2
2000	46	0.9

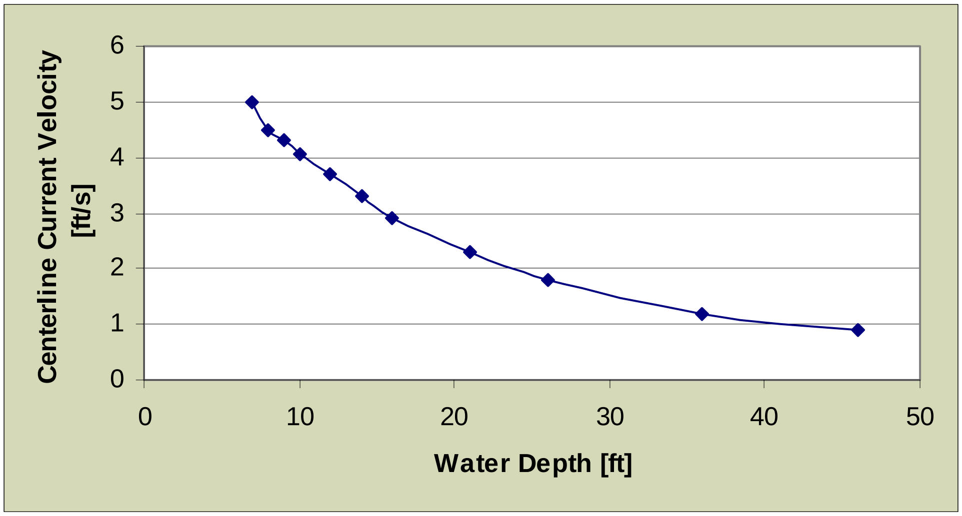

Figure 2
Velocity Field in the Lake due to Onondaga Creek Inflow

1.3 Stable Sediment Size to Resist Creek Current Velocities

Based on results of Dr. Walton's analysis (Appendix A to this attachment), stable sediment sizes that resist creek flow velocity in the Lake at various water depths are presented in Table 2.

Table 2
Stable Sediment Size that can Resist Velocities from Onondaga Creek for a 100-Year Storm

Distance Offshore [ft]	Depth [ft]	Velocity [ft/s]	Sediment Size [mm]	Sediment Type
0	6	5.0	12.0	Fine Gravel
200	10	4.1	8.0	Fine Gravel
450	15	3.2	6.0	Fine Gravel
700	20	2.4	4.0	Fine Gravel
1200	30	1.5	1.4	Medium Sand
1850	43	1.0	0.6	Medium Sand

In Table 2, sediment size represents the highest value of stable sediment sizes that were determined based on three different methods (Appendix B to this attachment):

- Ackers and White, as presented in Gailani (1999)
- Hjustom curve (Vanoni 1975)
- Shields' diagram for initiation of bed material movement

For the last method, a conservative Shields coefficient of 0.03 was used. Current shear-stress was computed using the following formula:

$$\tau_c = \frac{1}{2}\rho f_c V^2$$

where τ_c represents shear stress due to current

ρ represents water density

f_c represents the friction coefficient due to the current; f_c was computed based on the method developed by Christoffersen and Jonsson (1985).

V represents the current velocity

The different sediment sizes presented in Table 2 are expected to be stable in a 150-foot-wide channel centered on the mouth of Onondaga Creek and Ninemile Creek. This sediment size is also expected to be stable in the area of influence of Harbor Brook.

2 REFERENCES

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Effler, S.W., 1996. "*Limnological and Engineering Analysis of a Polluted Urban Lake*", Springer-Verlag New York, Inc., 832 pp.

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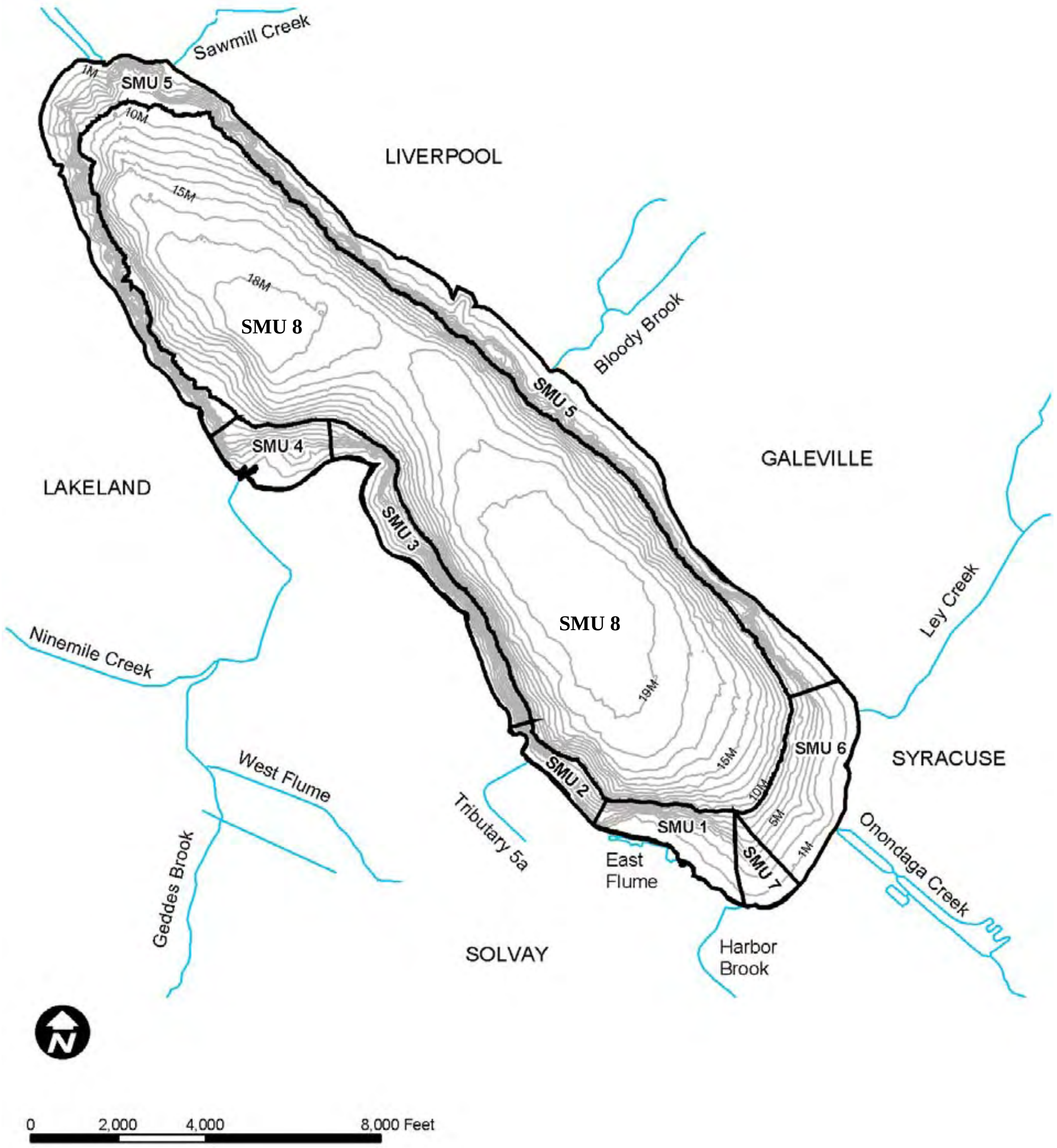
Limno-Tech, Inc., October 2003. "Baseline and Capping Alternative HEC-RAS Simulation Results for Ninemile Creek and Geddes Brrok", Memorandum from Scott Hinz and Kristen Chaffin to David Johnson and David Babcock, Parsons Engineering and Science.

Vanoni, V.A., 1975. "Sedimentation Engineering", ASCE Manuals and Reports on Engineering Practice – No. 54, ASCE, 745 pp.

Walton, R., 2003. Personal communication between Dr. Walton, from WEST Consultants, and Greg Guannel, from Anchor Environmental.



Note: Water Surface Elevation is: 363.39 feet
(110.76 meters) above Mean Sea Level.
SMU: Sediment Management Unit

FIGURE 1

ONONDAGA LAKE

SYRACUSE, NEW YORK

LAKE MAP AND TRIBUTARY CREEKS

Source: Modified from TAMS, 2002c

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ATTACHMENT E
APPENDIX A

ESTIMATION OF VELOCITIES

ONONDAGA LAKE SEDIMENT REMEDIATION

MEMORANDUM

To: Greg Guannel, Anchor Environmental

From: Ray Walton

Date: December 5, 2003

Subject: ESTIMATION OF VELOCITIES

WEST
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Introduction and Approach

Anchor Environmental is evaluating sediment remediation alternatives for Onondaga Lake in Syracuse, New York State. One alternative is to dredge and cap contaminated sediments. To size bed materials, they need to know potential velocities in the lake under design conditions, particularly in the vicinity of creek inflows.

The largest flow to Onondaga Lake comes from Onondaga Creek at the east end of the lake (Figure 1 shows sediment plume from Onondaga Creek). After evaluating a number of analytical methods, including surface jet dynamics and studies of sudden expansions downstream of bridges over rivers, we decided that the most suitable approach was to develop a schematic two-dimensional model of the discharge region of Onondaga Creek. The model selected was the Corps of Engineers' Engineer Research and Development Center (ERDC) model, RMA-2, running in the graphical pre- and post-processor, SMS.

Figure 1 Aerial View of Onondaga Lake

Model Development and Results

Figure 2 shows the bathymetry of Onondaga Lake. As we were asked to develop an expedited estimate of the velocities in the vicinity of the creek discharges to the lake, rather than develop a detailed bathymetric model of the lake, instead we developed a conceptual model of the lake making the following assumptions:

- The 100-year flow was modeled.
- The discharge of Onondaga Creek to the lake is approximately 150 feet wide and 6 feet deep.
- The discharge is essentially perpendicular to the shoreline.
- The lake slopes uniformly downward with a slope of 1.9 percent (estimated from Figure 2)

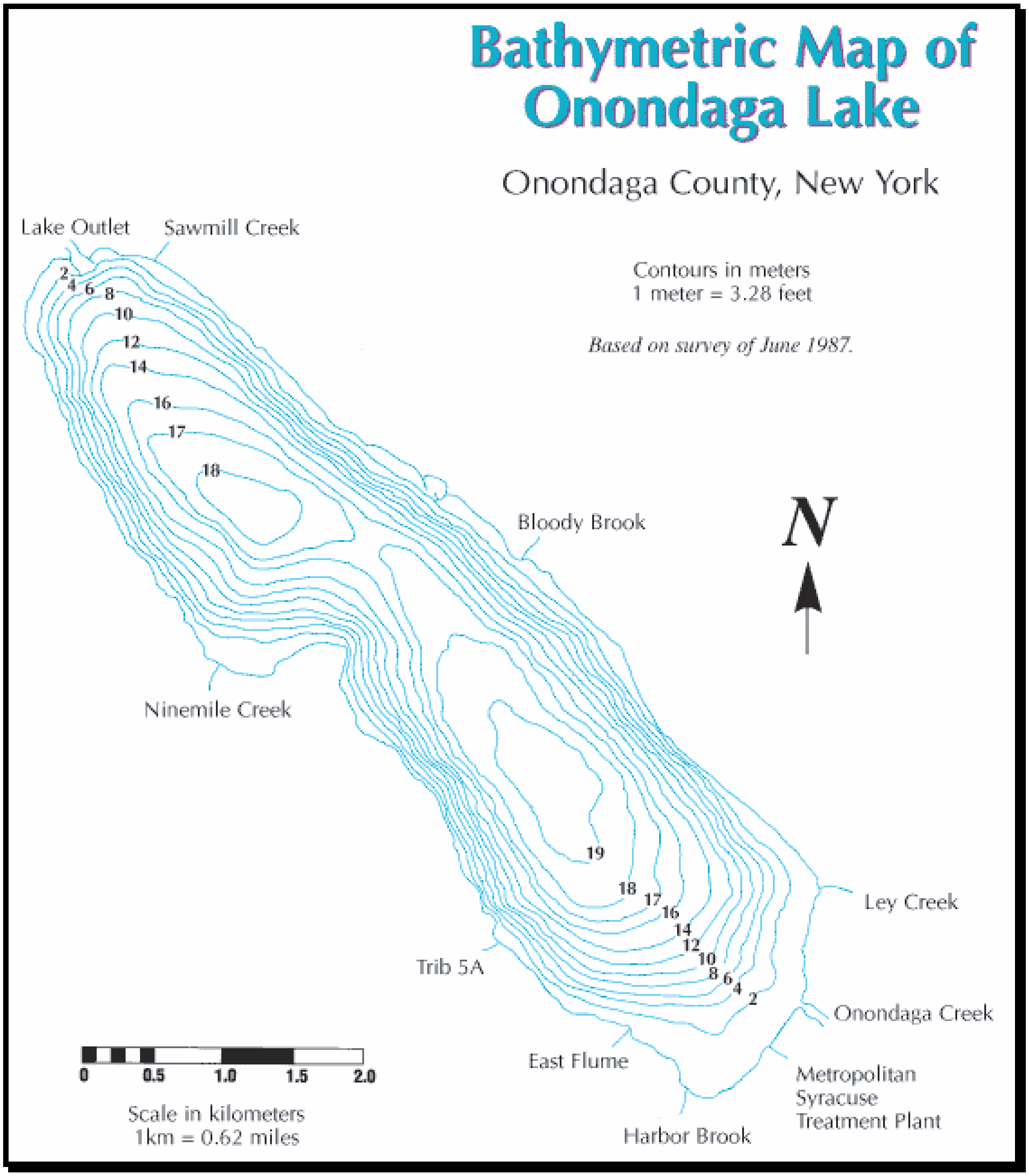

Figure 2 Bathymetry of Onondaga Lake

There is a U.S. Geological Survey gauge 04240010 (Onondaga Creek at Spenser Street, Syracuse) with 32 years of streamflow data. The flows from this gauge were analyzed using the Corps' Flood Frequency Analysis (FFA) program to determine the "expected probability" flows (Table 1). The flows on Ninemile Creek are similar but slightly smaller.

Table 1 Streamflows at USGS Gauge 04240010 on Onondaga Creek

Return Interval (years)	Flow (cfs)
10	3140
20	3700
50	4490
100	5140
500	6940

Assuming symmetry along the discharge axis, a two-dimensional, finite-element grid was developed 2,000 feet out into the lake, and 800 feet along the shore, with elements roughly 25 feet square. The grid sloped from a depth of 6 feet at the discharge to 44 feet at 2,000 feet offshore (a bottom slope of 1.9 percent). One half of the 100-year flow of 5,140 cfs was introduced over three shoreline elements.

The model was run for three values of eddy viscosity, E=10, 20 and 50 lb-sec/ft^2.

Table 2 shows the centerline current speeds (or “velocity magnitudes”) for each case. Figure 3 shows the distribution of current speeds for the “default” value of E=20 lb-sec/ft^2.

Table 2 Current Speeds Along Discharge Centerline

Distance Offshore (feet)	Centerline Current Speed (feet/second)		
	E=10 lb-sec/ft^2	E=20 lb-sec/ft^2	E=50 lb-sec/ft^2
50	5.0	5.0	5.0
100	4.5	4.5	4.5
150	4.3	4.3	4.1
200	4.1	4.05	3.7
300	3.9	3.7	3.1
400	3.6	3.3	2.65
500	3.4	2.9	2.3
750	2.7	2.3	1.7
1000	2.3	1.8	1.3
1500	1.6	1.2	0.7
2000	1.3	0.9	0.4

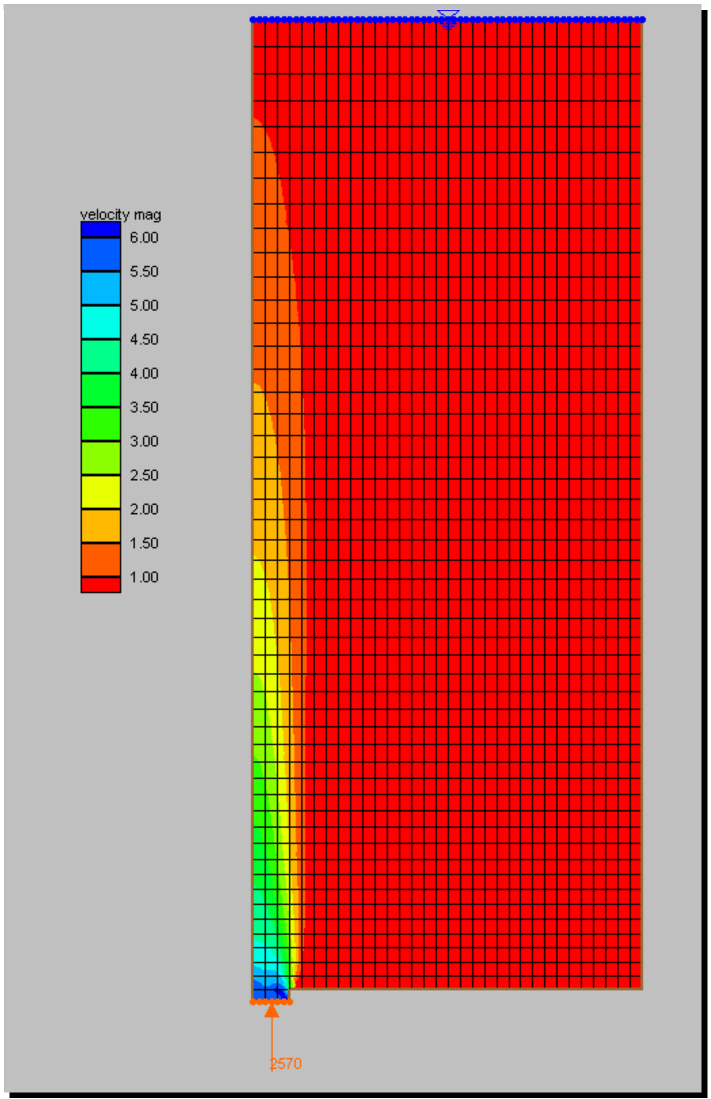

Figure 3 Velocity Magnitude for E=20 lb-sec/ft^2

Summary

I recommend that the values of current speeds (in Table 2) representing the “default” value of E=20 lb-sec/ft^2 be used. This should provide a “conservatively high” estimate of speeds to assess the stability of proposed capping materials

ATTACHMENT E
APPENDIX B

TABLE SEDIMENT SIZE TO RESIST CURRENT FORCES

Appendix B
Table 1
Stable Sediment Size at Various Depths

Distance Offshore [ft]	Depth [ft]	Velocity [ft/s]	Sediment Size [mm]				Design Size [mm]	Sediment Type
			Hjulstrom*	Shear Stress*	Ackers and White*	Vanoni*		
0	6	5.0	12.0	11.0	NA	NA	12.0	Fine Gravel
200	10	4.1	8.0	6.3	4	NA	8.0	Fine Gravel
450	15	3.2	6.0	3.2	3.9	NA	6.0	Fine Gravel
700	20	2.4	4.0	1.9	1.8	2.10	4.0	Fine Gravel
1200	30	1.5	1.4	0.9	0.6	0.30	1.4	Medium Sand
1850	43	1.0	0.6	0.4	0.2	0.10	0.6	Medium Sand

* Methods used to compute sediments size are presented in the memo, Section 1.

APPENDIX H
ATTACHMENT F

PROPELLER WASH ANALYSIS

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Memorandum

Written for the Onondaga Lake Feasibility Study

From: Greg Guannel and John Verduin, P.E., Anchor Environmental, L.L.C.

Date: January 23, 2004

Re: Onondaga Lake Propwash Analysis

LAKE USE

Onondaga Lake was closed to swimming and fishing in 1940 and 1970 respectively (Onondaga Lake Partners website), but commercial and recreational uses of the Lake still exist. Discussions with New York State Canal Corporation representatives (NYS Canal Corporation personal communication 2003) and with barge operators (Pellegrino Marine personal communication 2003) indicate that Pellegrino Marine operates two tugs in the Lake, the *Sean* and the *Maverick H*, and that Mid-Lake Navigation Corporation also operates a passenger vessel, the *City of Syracuse*. Private vessels, such as motorized family boats or race boats, are often present on the Lake.

DESIGN VESSELS

Discussions with tug operators and the *City of Syracuse* representatives indicate that their vessels navigate in the deeper portion of the Lake and use an average of approximately 25 percent of their horsepower (HP). It was more difficult to gather data on private vessels, but it appears that most family boats have one or two engines, and private users sometimes use a significant amount of available horsepower, especially when they operate race boats.

Characteristics of the different vessels considered in this analysis are presented in Table 1. We assumed that an average high-end family boat would be equipped with one or two 250 HP Yamaha engines. Also, because no institutional controls were established for use of the site, we assumed that they would navigate in shallow water as well as in deeper water, and would use 25 to 100 percent of their horsepower, depending on water depth. We could not gather information on average engine characteristics for the race boats.

Table 1
Design Vessels Characteristics

Vessel Name	Ducted Propeller [Y/N]	Prop Diameter [ft]	Prop. Shaft Depth [ft]	HP
SEAN	N	2.2	3	600
MAVERICK	Y	4.0	3	800
City of Syracuse	N	2.5	3	125
Private (Yamaha)	N	1.4	2	250

PROPWASH MODELING

Theory

Propeller wash produces an underwater jet of water from the rotation of the vessel's propeller. The bottom water velocities caused by propellers were predicted using a spreadsheet model PROPWASH, based on the equations developed by Blaauw and van de Kaa (1978) and Verhey (1983). For a defined water depth, bottom velocities at various distances behind the propeller were computed.

This approach is also recommended in Appendix A of the U.S. Environmental Protection Agency's (EPA) guidance document *Guidance for In-Situ Capping of Contaminated Sediments* (Palermo et al. 1998). This model requires specific input regarding vessel characteristics (e.g., propeller diameter, depth of shaft, and shaft horsepower) and has been used for several cap designs approved by state and federal agencies (e.g., Elliott Bay, Washington [Ecology 1995]; Georgia-Pacific Log Pond in Bellingham, Washington [Anchor 2000]; and Lockheed Shipyard in Seattle Washington, [Hart Crowser 1999]).

The model predicts the grain size required to resist the long-term, steady state propeller wash from vessels, given a cap's depth and distance behind the propeller. In reality, the propeller wash force is transient in nature, only impacting force on the cap for a short time.

Commercial Vessels

For the tugs and the *City of Syracuse*, the model was run assuming that the operators were using 25 percent of their horsepower, and were operating in 30 feet of water. This is a conservative value considering that most of the Lake is deeper than 30 feet. Results are presented in Table 2. Medium sand to fine gravel would be necessary to resist erosion of a cap due to commercial vessels' propeller wash; this grain size is only required in areas where these vessels navigate. The PROPWASH spreadsheet results are presented in Appendix A.

Table 2
Stable Sediment Size that Can Resist Propwash

Vessel Name	Stable Sediment Size [mm]	Sediment Type
Sean	1.8	Medium Sand
Maverick H	7.4	Fine Gravel
City of Syracuse	0.7	Medium Sand

Private Vessels

For private vessels, the analysis was conducted for boats with one or two 250 HP Yamaha engines. The same equations used earlier were applied to that engine and, for boats with two engines, design velocities were obtained by multiplying velocities for one engine by $\sqrt{2}$ (Schokking 2002). Because private vessels navigate in all possible depths, the analysis was conducted in 10, 20, and 30 feet of water, for 25, 50, and 100 HP. Figures 1 and 2 present stable sediment size in 10, 20, and 30 feet of water. It appears that a medium to coarse sand is required in deeper waters, and coarse gravel to cobble would be stable in shallower waters when full power is used. However, it is unlikely that vessels will operate with greater than 25 percent horsepower in water shallower than 5 to 10 feet due to safety issues.

CONCLUSION

By reviewing Table 2 and Figures 1 and 2, and understanding typical operating characteristics of the vessels on the Lake, this analysis indicates that coarse sand to fine gravel is required to resist a long-term steady state propwash from these design vessels.

List of Attachments

Figure 1—Propwash Results for Boats with One Engine
Figure 2—Propwash Results for Boats with Two Engines
Appendix A--PROPWASH Spreadsheets

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ATTACHMENT F
APPENDIX A

PROPWASH SPREADSHEETS

Pellegrino Marine - *Sean*

INPUT		
Propeller Type	non-ducted	[ducted/non-ducted]
Prop Diameter (D_p)	2.2	[ft]
Prop Shaft Depth	3	[ft]
HP	600	
Frequency of Attack	infrequent	[frequent/infrequent]
C_1	0.22	[-]
C_2	9.72	[-]
C_3	0.70	[-]

VARIABLES	
Max Applied Power [%]	**25%**
P_d [HP]	150
Water Depth [ft]	**30**
Dist. From Prop z [ft]	27.0
OUTPUT	
D_o [ft]	1.56
H_p [ft]	27.00
U_0 [ft/sec]	30.5
Horiz. dist. bhd prop. x [ft]	100
V_x [ft/sec]	0.4
D_{50} [mm]	1.77

Pellegrino Marine - *Maverick*

INPUT		
Propeller Type	ducted	[ducted/non-ducted]
Prop Diameter (D_p)	4.0	[ft]
Prop Shaft Depth	3	[ft]
HP	800	
Frequency of Attack	infrequent	[frequent/infrequent]
C_1	0.30	[-]
C_2	7.68	[-]
C_3	0.70	[-]

VARIABLES	
Max Applied Power [%]	**25%**
P_d [HP]	200
Water Depth [ft]	**30**
Dist. From Prop z [ft]	27.0
OUTPUT	
D_o [ft]	4.00
H_p [ft]	27.00
U_0 [ft/sec]	17.8
Horiz. dist. bhd prop. x [ft]	100
V_x [ft/sec]	0.8
D_{50} [mm]	7.37

Mid-Lakes Navigation Co. - *City of Syracuse*

INPUT		
Propeller Type	non-ducted	[ducted/non-ducted]
Prop Diameter (D_p)	2.5	[ft]
Prop Shaft Depth	3	[ft]
HP	125	
Frequency of Attack	infrequent	[frequent/infrequent]
C_1	0.22	[-]
C_2	9.72	[-]
C_3	0.70	[-]

VARIABLES	
Max Applied Power [%]	**25%**
P_d [HP]	31
Water Depth [ft]	**30**
Dist. From Prop z [ft]	27.0
OUTPUT	
D_o [ft]	1.78
H_p [ft]	27.00
U_0 [ft/sec]	16.6
Horiz. dist. bhd prop. x [ft]	100
V_x [ft/sec]	0.2
D_{50} [mm]	0.68

Private Boat 1 Engine

INPUT	
Propeller Type	non-ducted
Prop Diameter (D_p)	1.4
Prop Shaft Depth	2
HP	250
Frequency of Attack	infrequent
C_1	0.22
C_2	9.72
C_3	0.70

VARIABLES			
Max Applied Power [%]	**25%**	**25%**	**25%**
Water Depth [ft]	**10**	**20**	**30**
Dist. From Prop z [ft]	8.0	18.0	28.0
OUTPUT			
D_o [ft]	0.99	0.99	0.99
H_p [ft]	8.00	18.00	28.00
U_0 [ft/sec]	30.8	30.8	30.8
Horiz. dist. bhd prop. x [ft]			
V_x [ft/sec]	1.2	0.5	0.3
D_{50} [mm]	16.55	3.27	

VARIABLES			
Max Applied Power [%]	**50%**	**50%**	**50%**
Water Depth [ft]	**10**	**20**	**30**
Dist. From Prop z [ft]	8.0	18.0	28.0
OUTPUT			
D_o [ft]	0.99	0.99	0.99
H_p [ft]	8.00	18.00	28.00
U_0 [ft/sec]	38.8	38.8	38.8
Horiz. dist. bhd prop. x [ft]			
V_x [ft/sec]	1.5	0.7	0.4
D_{50} [mm]	26.27	5.19	2.14

VARIABLES			
Max Applied Power [%]	**100%**	**100%**	**100%**
Water Depth [ft]	**10**	**20**	**30**
Dist. From Prop z [ft]	8.0	18.0	28.0
OUTPUT			
D_o [ft]	0.99	0.99	0.99
H_p [ft]	8.00	18.00	28.00
U_0 [ft/sec]	48.9	48.9	48.9
Horiz. dist. bhd prop. x [ft]			
V_x [ft/sec]	1.9	0.8	0.5
D_{50} [mm]	41.69	8.24	3.40

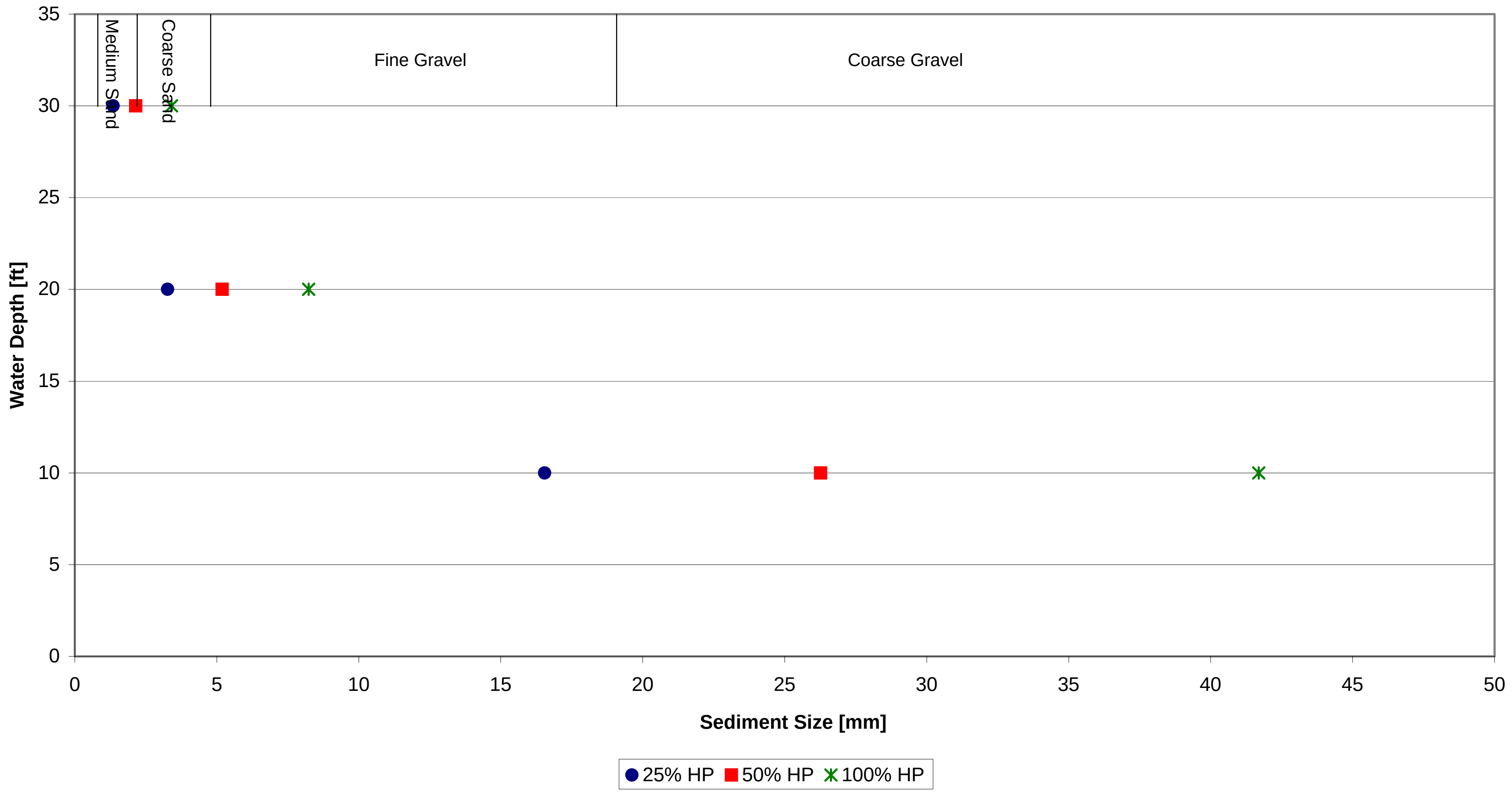
Private Boat 2 Engines

INPUT	
Propeller Type	non-ducted
Prop Diameter (D_p)	1.4
Prop Shaft Depth	2
HP	250
Frequency of Attack	infrequent
C_1	0.22
C_2	9.72
C_3	0.70

VARIABLES			
Max Applied Power [%]	**25%**	**25%**	**25%**
Water Depth [ft]	**10**	**20**	**30**
Dist. From Prop z [ft]	8.0	18.0	28.0
OUTPUT			
D_o [ft]	0.99	0.99	0.99
H_p [ft]	8.00	18.00	28.00
U_0 [ft/sec]	30.8	30.8	30.8
Horiz. dist. bhd prop. x [ft]	40	100	150
V_x [ft/sec]	1.7	0.7	0.5
D_{50} [mm]	33.09	6.54	

VARIABLES			
Max Applied Power [%]	**50%**	**50%**	**50%**
Water Depth [ft]	**10**	**20**	**30**
Dist. From Prop z [ft]	8.0	18.0	28.0
OUTPUT			
D_o [ft]	0.99	0.99	0.99
H_p [ft]	8.00	18.00	28.00
U_0 [ft/sec]	38.8	38.8	38.8
Horiz. dist. bhd prop. x [ft]			
V_x [ft/sec]	2.1	0.9	0.6
D_{50} [mm]	52.53	10.38	4.29

VARIABLES			
Max Applied Power [%]	**100%**	**100%**	**100%**
Water Depth [ft]	**10**	**20**	**30**
Dist. From Prop z [ft]	8.0	18.0	28.0
OUTPUT			
D_o [ft]	0.99	0.99	0.99
H_p [ft]	8.00	18.00	28.00
U_0 [ft/sec]	48.9	48.9	48.9
Horiz. dist. bhd prop. x [ft]			
V_x [ft/sec]	2.7	1.2	0.8
D_{50} [mm]	83.39	16.47	6.81



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Attachment F: Figure 1
Propwash Results for Boats with One Engine
Onondaga Lake Propwash Analysis

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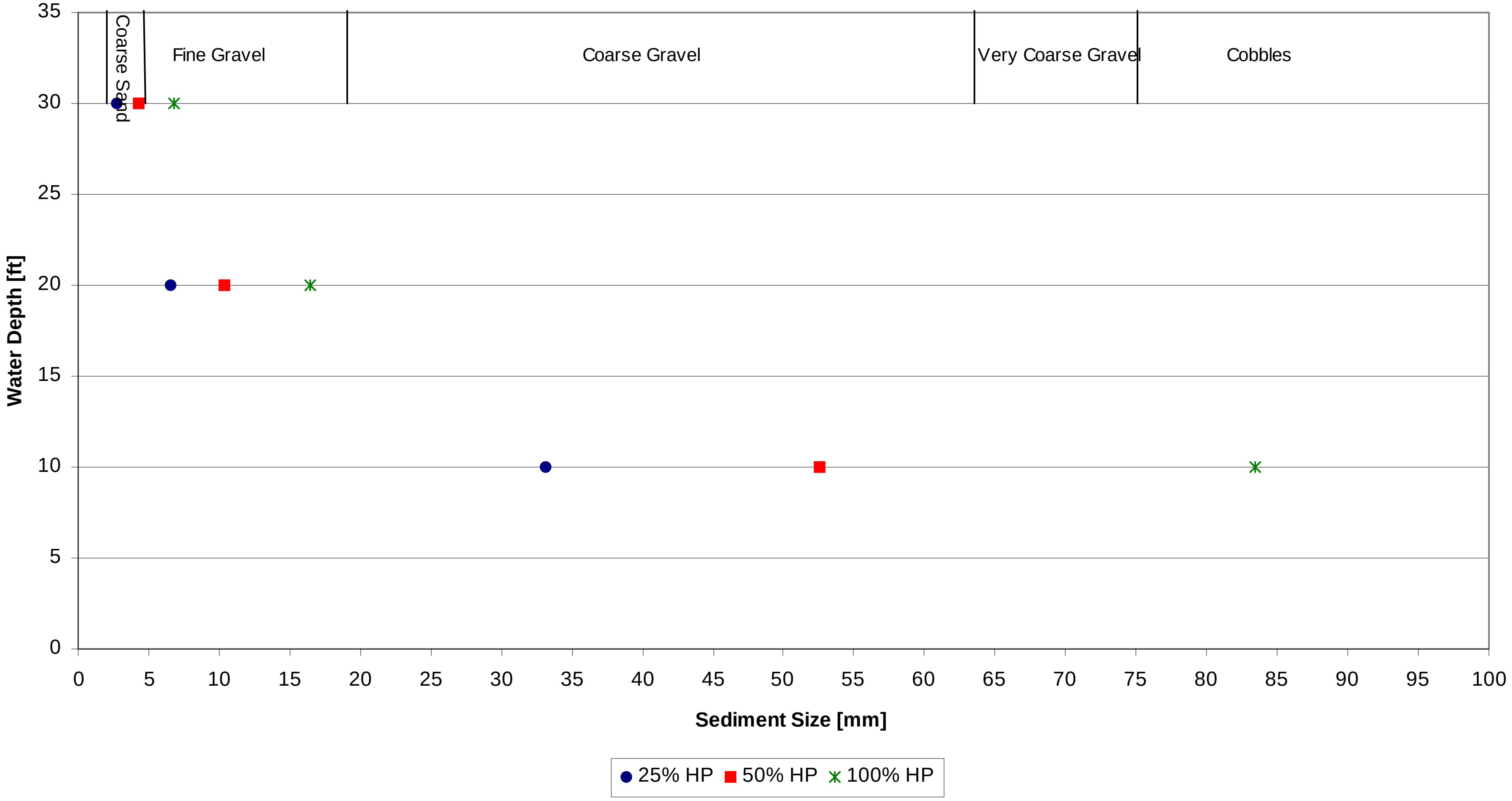


Attachment F: Figure 2
Propwash Results for Boats with Two Engines
Onondaga Lake Propwash Analysis

APPENDIX H
ATTACHMENT G

CAP MODELING ANALYSIS

ATTACHMENT G
CAP MODELING ANALYSIS
CHEMICAL ISOLATION COMPONENT

A model of chemical fate and transport, such as that described in Appendix B of the standard guidance for *in situ* sub aqueous capping, is typically used to evaluate the long term effectiveness of a cap as defined by its ability to provide chemical isolation in a sub aqueous environment (Palermo *et al*., 1998).

These models assume that the cap is armored such that erosion of the cap does not provide the primary means of contaminant migration. In addition, the biologically active zone in which contaminants are transported by organism reworking is assumed to be confined to a small layer above the chemical isolation layer. The primary means of contaminant transport within the chemical isolation layer are the physico-chemical processes of advection and diffusion in the porewater.

The driving force for chemical transport is a combination of the contaminant concentration within the porewater of the underlying sediment and the groundwater advection. As a conservative estimate of the chemical flux through a capping layer, it is normally assumed that the contaminant concentration in the overlying water is effectively zero, which maximizes the driving force for chemical diffusion. In addition, the concentration in the underlying sediment is assumed constant, without degradation or reduction due to chemical migration out of the sediments.

One method of estimating chemical migration in a cap is via a transient advection-diffusion model as described in Palermo *et al*., (1998). This model is applied to the chemical isolation layer of a cap which is the cap thickness after removing components for porewater expression via consolidation of underlying sediment, consolidation of the cap, and bioturbation of the upper cap layers. Normally, an analytical solution to the mass conservation equation, assuming that the cap is semi-infinite, is employed in such an analysis. Such a model is, in general, not applicable after the conditions at the top of the cap (such as benthic activity or changing organic content) influence contaminant behavior. When the upper boundary of the cap begins to influence contaminant migration, a numerical model is normally required to describe transient behavior. An alternative approach is to consider only steady-state conditions, in which it is possible to consider the complexities of the upper boundary and still employ analytical solutions to the chemical transport equations. The estimation of flux through a cap at steady state is conservative as the contaminant flux is a maximum at steady state. This flux can then be used to estimate concentrations in the biologically active layer. Chemical reactivity can be incorporated for appropriate compounds by employing either measured rates of degradation or by considering conservative estimates from the literature.

If a feasible cap is not deemed sufficiently protective by such an analysis, the assumptions can be relaxed and a more sophisticated analysis, such as a numerical model incorporating transient processes, employed to estimate the true effectiveness of the cap. One key aspect of the method defined above is the assumption that the concentration beneath a cap remains constant for all time, reduced by neither chemical reactions nor by the flux into and through the cap. This assumption may be overly conservative. A simple indication of the appropriateness of assuming constant underlying conditions can be made by evaluating the time required to achieve steady state or the time required before the contaminant migrates through the entire capping layer. Due to sorption onto the capping materials for many sediment contaminants, this time may be very long, and the mass accumulated in a cap under steady state conditions may be large compared to the total mass of contaminants in the underlying sediment. Thus, the calculated steady state may never be achieved if there are fate or dilution processes influencing the contaminant in the underlying sediment. Contaminants that reach steady state conditions relatively rapidly are reasonably well described by the model, but the model would likely over-predict concentrations and fluxes for contaminants requiring very long times to achieve steady state.

MODEL

Concentration and Partitioning

The concentration of contaminant in the porewater of the underlying sediments can be measured via porewater sample collection or estimated from sediment data through the development of a site and contaminant-specific partitioning coefficient. The site-specific partition coefficient between solid and water matrices, K_d^{obs}, can be estimated through use of the relationship

$$K_d^{obs} = \left(\frac{W_s}{C_{pw}} \right)_{known} \tag{1a}$$

where W_s and C_{pw} are known values of total sediment concentration (e.g. in mg/kg) and porewater concentration (e.g., in mg/L), respectively. This partitioning coefficient can then be used to estimate porewater concentrations in locations where porewater data are not available. C_0, the contaminant concentration in the porewater in the sediment underlying a cap, is given by

$$C_0 = \frac{W_s}{K_d^{obs}} \tag{1b}$$

Sorption related partitioning of organic contaminants is normally predicted more accurately than desorption related partitioning. For organic contaminants, the contaminant partition coefficient for sorption in the cap can be estimated by

$$K_d^{cap} = K_{oc} f_{oc} \tag{2}$$

where K_{oc} is the organic carbon based partition coefficient, a tabulated compound specific measure of hydrophobicity, and f_{oc} is the fraction organic carbon in the cap materials which tends to be the dominant location for contaminant sorption. For sand, the organic carbon fraction tends to be small, on the order of 0.1 percent. At these low organic carbon contents, mineral sorption of even organic contaminants tends to become important so the assumption of 0.1 percent organic carbon is likely a lower bound to the effective sorption of organic contaminants on cap materials.

Effective Cap Thickness

The various layers in a cap are shown in Figure 1. The effective cap thickness, h_{cap}, is given by

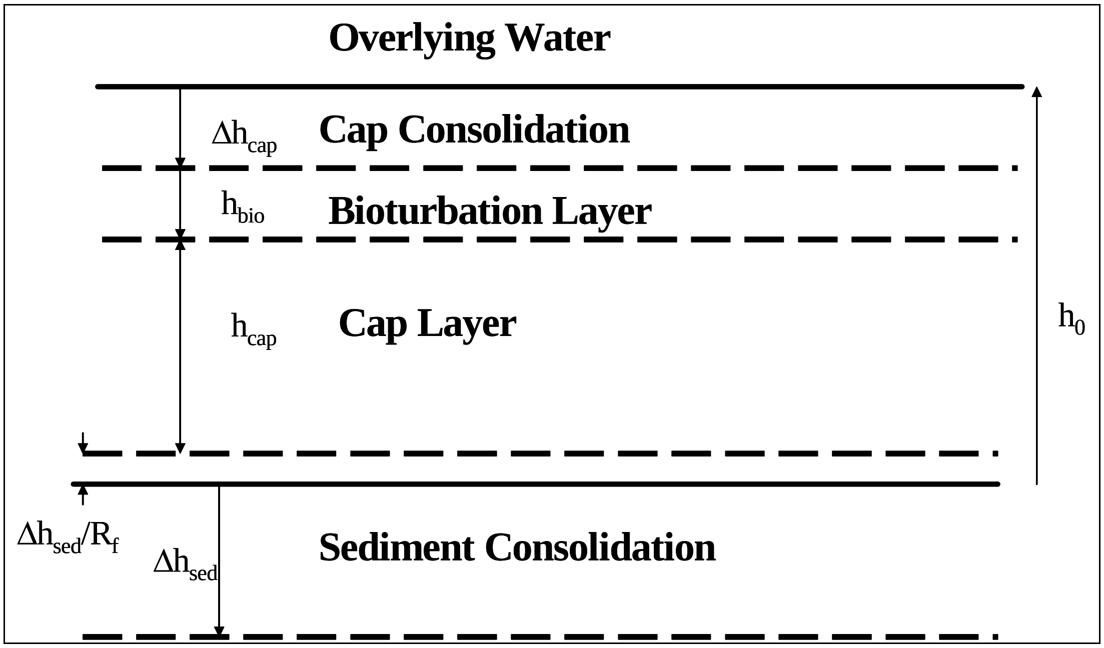
$$h_{cap} = h_0 - \frac{\Delta h_{sed}}{\varepsilon\, R_f} - \Delta h_{cap} - h_{bio} \qquad (3)$$

where h_0 is the initially placed cap thickness, Δh_{sed} is the consolidation distance in the underlying sediment, Δh_{cap} is the consolidation thickness of the capping material itself, and h_{bio} is the layer influenced by bioturbation by benthic organisms. The product εR_f, or porosity times the retardation factor, is the ratio of the total contaminant in an elementary volume of the cap material to the contaminant in the mobile phase (the porewater volume). Its role in Equation (3) is to emphasize that the mass of contaminant expressed by sediment consolidation is both sorbed onto the cap material as well as mobile in the porewater. The net effect is to reduce the contaminant migration into the cap relative to the porewater volume expressed. This same effect slows the rate of chemical migration through the cap after consolidation. The retardation factor is estimated by the relationship:

$$R_f = 1 + \frac{\rho_b K_d^{cap}}{\varepsilon} \qquad (4)$$

Here ε is the porosity of the cap layer (typically about 40 percent for unconsolidated sand), ρ_b is the bulk (dry) density of the cap layer (typically about 1.3–1.5 g/cm^3 for sand) and K_d^{cap} is the contaminant partition coefficient in the capping materials.

FIGURE 1
CONTAMINANT MIGRATION PROCESSES WITHIN A CAP



Consolidation occurs relatively quickly (over a period of months to years), essentially instantaneously compared to the design lifetime of a cap. The modeling conducted here assumes that any porewater expression of contaminants leads to an instantaneous reduction of effective cap thickness, as indicated by Equation (3). While appropriate for the evaluation of the dynamics of contaminant migration, this phenomenon results only in transient effects on cap performance. Any short-term chemical migration due to consolidation of the underlying sediment will be overcome by the long-term chemical migration characteristics of a cap. Thus, for steady state migration through a cap, the effective cap thickness in Equation (3) is replaced with:

$$h_{cap} = h_0 - \Delta h_{cap} - h_{bio} \tag{5}$$

Although consolidation of the cap is accounted for in Equation (5), it is minimal with most capping materials such as sand and is omitted hereafter.

Advection-Diffusion Model of Transport in a Cap

Within the effective chemical isolation thickness of a cap, as defined by Equation (3) under transient conditions or (5) under steady state conditions, the chemical migration processes are limited to advection and diffusion. The dynamics of the chemical migration behavior within this layer can be estimated by the advection-diffusion equation. For simplicity, the cap is often approximated as semi-infinite, with a constant underlying sediment contaminant concentration. The transient behavior can be estimated using an analytical solution of the advection-diffusion equation (Palermo *et al.*, 1988). The approach can be extended to reactive contaminants using the solution of van Genuchten (1981), also for a semi-infinite layer with constant underlying sediment concentration.

Governing Equation:

$$R_f \frac{\partial C}{\partial t} = -v \frac{\partial C}{\partial z} + D' \frac{\partial^2 C}{\partial z^2} - \lambda C$$

Boundary Conditions:

$$C(z=0,t) = C_o$$

$$\frac{\partial C}{\partial z}(\infty, t) = 0$$

Solution (van Genuchten, 1981)

$$C = C_i \exp\left(-\frac{\lambda t}{R_f}\right)\left\{1 - \frac{1}{2}\operatorname{erfc}\left[\frac{R_f z - vt}{2\sqrt{D' R_f t}}\right] - \frac{1}{2}\exp\left(\frac{vz}{D'}\right)\operatorname{erfc}\left[\frac{R_f z + vt}{2\sqrt{D' R_f t}}\right]\right\}$$

$$+ C_0\left\{\frac{1}{2}\exp\left[\frac{(v-u)z}{2D'}\right]\operatorname{erfc}\left[\frac{R_f z - ut}{2\sqrt{D' R_f t}}\right] + \frac{1}{2}\exp\left[\frac{(v+u)z}{2D'}\right]\operatorname{erfc}\left[\frac{R_f z + ut}{2\sqrt{D' R_f t}}\right]\right\} \qquad (6)$$

where:

C_i= initial contaminant concentration in the cap (assumed to be zero)

C_o= contaminant concentration in the underlying porewater (e.g., mg/L)

λ = reaction term or biodegration rate (e.g., /yr)

z = vertical distance in the cap (chemical isolation layer thickness, h_{cap}) (e.g., cm)

v = porewater velocity (e.g., cm/yr)

t = time (e.g., yr)

D' = effective diffusion/dispersion through porous media (e.g., cm^2/yr)

u = $\sqrt{v^2 + 4\lambda D'}$

and:

$$D' = av + \frac{D_w}{\varepsilon^{-1/3}}$$

where:

a = dispersivity (e.g., cm)

D_w = molecular diffusion of chemical species in water (e.g., cm^2/yr)

$\varepsilon^{-1/3}$ = hindrance parameter (H_p)

The solutions in Palermo *et al.*, (1998) or van Genuchten (1981), however, assume a semi-infinite cap layer and cannot account for changes in conditions in the near surface cap layer, for example, due to changes in organic carbon content in the surface layer or changes in rate of migration due to bioturbation or other processes. They can be used to estimate concentrations within the cap during the transient period.

The semi-infinite models are accurate predictions of contaminant migration and resulting concentrations only until near-steady-state conditions are reached and the influence of the conditions at the upper boundary can no longer be ignored. The time required to achieve steady state can be estimated from the relationships below. A separate relationship is provided for advectively dominated transport and diffusion dominated transport.

$$\tau_{ss,adv} = \frac{R_f \; h_{cap}}{v} \qquad (7)$$
$$\tau_{ss,diff} = 3.69\frac{h_{cap}^2 R_f}{\pi^2 D'}$$

For times approaching or exceeding these times under either advectively-dominated or diffusion dominated conditions, a more complete model that includes the transport processes at the upper boundary is necessary, to accurately predict fluxes and contaminant concentrations. Typically, a numerical solution is necessary but it is also possible to take a conservative approach and develop an analytical solution for the case of steady state behavior. This model is discussed in more detail below.

Analytical Steady State Model of Transport in a Cap

Advection and diffusion in the cap materials are subject to retardation by transient sorption, as is contaminant migration in ground water. Under steady conditions, sorption does not influence the flux of contaminants through the cap materials. Thus, the steady state fluxes (rates per unit area) of diffusion and advection in the cap are given simply by

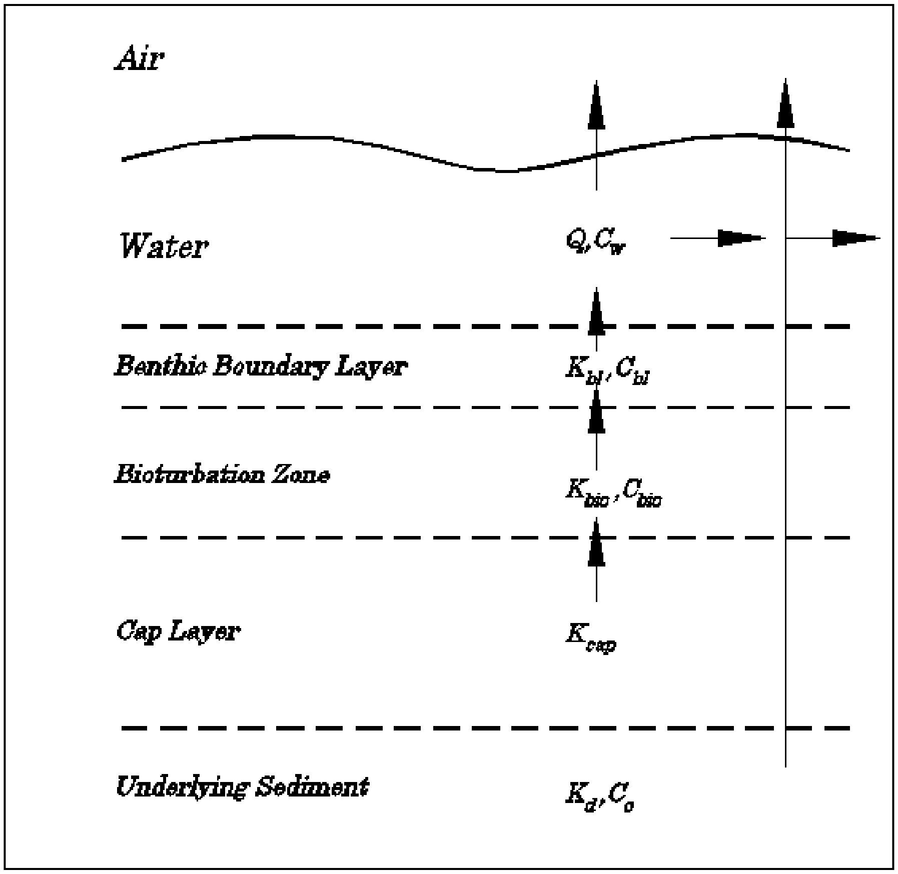
$$Flux_{adv} = UC_0 \qquad Flux_{diff} = \frac{D}{h_{cap}}\left(C_0 - C_{bio}\right) \qquad (8)$$

Here, *U* represents the superficial or Darcy velocity of the groundwater flow through the cap ($U=\varepsilon v$), *D* represents the effective diffusion [i.e., *D'* includes dispersion but not *D* per earlier convention] coefficient in the cap and C_{bio} represents the porewater concentration within the bioturbation layer (C_{bio}, as well as other location specific parameters discussed in the following sections are depicted on Figure 2). For diffusion dominated processes, *D* is the molecular diffusivity in water of the contaminant of interest multiplied by the porosity and divided by the tortuosity (or hindrance factor, H_p) of the sediment ($D=D_w\varepsilon/H_p$). The Millington and Quirk model (as referenced in Palermo *et al.*, 1998) suggests $H_p \sim \varepsilon^{-1/3}$, which for a cap with 40 percent porosity, is about 1.4. The molecular diffusion coefficient in water is a function of temperature and can be estimated by the methods defined in Lyman *et al.,* (1990). In the presence of advection *D* increases due to mechanical dispersion in the medium (typically modeled as some dispersivity, α, multiplied by the interstitial velocity, *v*). The dispersivity is an empirical parameter but is related to the mean particle size in nearly uniform sand beds.

$$D = \frac{D_w \varepsilon}{H_p} \qquad D' = \frac{D}{\varepsilon} + \alpha v \qquad (9)$$

Note that where D includes advection-related dispersion and is normalized by porosity, it is denoted as D' consistent with the notation for the van Genuchten (1981) equation above.

FIGURE 2
CAP LAYERS AND RELATED PARAMETERS



Bioturbation in the upper layers of a cap can lead to rapid chemical migration. The normal feeding and burrowing activities of benthic organisms results in the rapid movement of particles and the contaminants with which they are associated, as well as the movement of porewater. The layer that is effectively mixed by organisms, h_{bio}, is relatively small. More than 90 percent of the 240 observations of bioturbation mixing depths in fresh and salt water reported by Thoms *et al.*, (1995) were 6 inches (15 cm) or less, and more than 80 percent were 4 inches (10 cm) or less. In freshwater systems, most measurements of mixing depth are of the order of 1.2 to 2 inches (3 to 5 cm). Most of these measurements were based upon particle-associated radionuclides and the observed effective particle diffusion coefficients, D_{bio}^{p}. The observed effective particle diffusion coefficients fell within the range of 0.3 to 30 cm^2 /yr more than two-thirds of the time. Thibodeaux also reported a range of particle diffusion coefficients that ranged from 1.4 cm^2/yr to more than 470 cm^2/yr in all but the deep ocean where effective bioturbation diffusion coefficients were less (1966). As these particles are mixed and transported by the benthic organisms, sediment contaminants are also transported at an equivalent rate. The flux of contaminants associated with particles in the bioturbation layer can be estimated by

$$Flux_{bio}^{p} = \frac{D_{bio}^{p}}{h_{bio}} \varepsilon \, R_f \left(C_{bio} - C_{bl} \right) \qquad (10)$$

where C_{bl} is the concentration at the cap-water interface at the bottom of the benthic boundary layer of the lake. The factor εR_f is the ratio of the total concentration in an elementary sediment volume to that in the porewater. The product of this quantity and the porewater concentration represents the total quantity of contaminants per unit volume of sediments.

The ratio of D_{bio}^{p} / h_{bio} represents an effective mass transfer coefficient, k_{bio}^{p}. Thoms *et al.*, (1995) report 38 measurements in freshwater systems for which this ratio can be calculated ranging from 0.02 cm/yr to 4604 cm/yr. The average value is 130 cm/yr; about 60 percent of the measurements exceed 1 cm/yr and 90 percent exceed 0.1 cm/yr. In shallow waters such as would be observed nearshore, Boudreaux (1997) provided correlations between bioturbation and depth that suggest a 2.54 and 29.5 cm/yr effective particle mass transfer coefficient. One (1) cm/yr appears to be a reasonably conservative estimate of the effective particle bioturbation mass transfer coefficient in a clean shallow system such as the top of a nearshore sediment cap. A coefficient of the order of 1 cm/yr or more has also been observed by Thibodeaux *et al.*, 2002.

In addition to particle mixing, organisms also irrigate the surficial sediments through direct porewater exchange with the overlying water. Filter feeders process water for food, while other organisms cause water exchange through simple movement or respiration processes. Thibodeaux (1996) and Boudreaux (1997) reported porewater mixing coefficients associated with the exchange of porewater by benthic organisms. The porewater mixing rate tends to be much higher numerically than particle effective diffusion coefficients, 1000 to 6000 cm^2/yr, but is generally of less importance than particle reworking due to the strongly sorbing nature of most sediment contaminants. However, in Onondaga Lake there are a number of relatively soluble contaminants such as chlorobenzene where porewater irrigation may be more important.

$$Flux_{bio}^{pw} = \frac{D_{bio}^{pw}}{h_{bio}} \left(C_{bio} - C_{bl} \right) \tag{11}$$

The mass transfer coefficient associated with this process is termed the bioirrigation coefficient and can be defined $D_{bio}^{pw} / h_{bio} = k_{bio}^{pw}$. There are fewer direct measurements of bioirrigation mass transfer coefficients, and its estimation is thus subject to greater uncertainty. A reasonably conservative value of this coefficient is 100 cm/yr.

C_{bl} in Equations (10) and (11) is the concentration at the cap-water interface and this can be related to the flux via a similar equation.

$$Flux_{bl} = k_{bl} \left(C_{bl} - C_{w} \right) \tag{12}$$

Here, k_{bl} is the benthic boundary layer mass transfer coefficient and C_w is the concentration of contaminant in the overlying water. The benthic boundary layer mass transfer coefficient is a function of the turbulence and speed of water flow over the surface. A reasonable order of magnitude estimate is 1 cm/hr. As indicated previously, the maximum flux will be estimated when $C_w=0$.

Under steady conditions, the fluxes through the chemical isolation layer of the cap, the bioturbation layer, and the benthic boundary layer are all equal. This provides a basis for estimating the steady state concentrations in each layer as described below.

The flux through the chemical isolation layer of the cap tends to be dominated by either advection or diffusion, as indicated by the Peclet number

$$N_{Pe} = \frac{vh_{cap}}{D'} \quad (13)$$

Here $N_{Pe} > 1$ means that transport in the chemical isolation layer is dominated by advection, while $N_{Pe} < 1$ implies that transport is dominated by diffusion. Advection and diffusion in either the cap isolation layer or bioturbation layer are not independent because advection tends to reduce diffusion gradients and diffusion tends to reduce the advective flux. In the cap isolation layer, a reasonable approximation is to assume that the flux is well estimated by the dominant flux (either advection or diffusion).

The total flux through the bioturbation layer is the sum of the flux via porewater and particle processes because they act independently. The particle processes are solely the result of bioturbation (characterized by k_{bio}^{p}) in the absence of erosion. Of the potential porewater processes in the bioturbation layer, diffusion tends to be very small compared to bioturbation and will be neglected. In an advection dominated system, however, it is possible that advection remains important relative to porewater irrigation. The porewater processes include those driven by bioturbation (characterized by k_{bio}^{pw}) and advection (driven by hydraulic gradients and characterized by the seepage velocity U), which also act independently of each other, i.e. organisms do not significantly influence advection nor does advection at the rates of a few hundred cm/yr (<1 cm/day) significantly influence the organisms. Thus the total flux through the bioturbation layer is the sum of all three processes (particle and porewater irrigation by bioturbation and advection).

Similarly, the advective flux at the cap-water interface (vertical seepage into the overlying water) is largely independent of the benthic boundary layer mass transfer coefficient (driven by horizontal velocity shear and turbulence above the surficial sediments). The total flux through this surficial sediment layer is thus the sum of the two processes. As noted above, a reasonable order of magnitude estimate for the benthic boundary layer mass transfer coefficient is 1 cm/hr. This rarely controls the overall contaminant release from the sediments and thus the benthic boundary layer concentration tends to be small (if the overlying water concentration is small or assumed zero as here to estimate the maximum flux to the overlying water).

Setting the fluxes in the chemical isolation layer, the bioturbation layer and the overlying benthic boundary layer equal at steady state, the fluxes through the various layers are related by

$$Flux = Max\left\langle Flux_{adv}, Flux_{diff} \right\rangle = Flux_{bio}^{p} + Flux_{bio}^{pw} + Flux_{adv} = Flux_{bl} + Flux_{adv} \quad (14)$$

From these relationships and by analogy to Equations (19) through (22) in Appendix B of Palermo *et al.*, (1998), the concentration in the bioturbation layer can be estimated. In that appendix, however, only diffusion and bioturbation by particles were considered. Here the more complicated case is necessary because of the additional operative processes. Rewriting Equation (14), defining the steady state flux as the maximum of the diffusive or advective flux in the chemical isolation layer, results in the equation.

$$Flux = \left(k_{bio}^{p} \varepsilon \, R_f + k_{bio}^{pw} + U\left[\frac{C_{bio}}{C_{bio} - C_{bl}} \right] \right)(C_{bio} - C_{bl}) = \left(k_{bl} + U\left[\frac{C_{bl}}{C_{bl} - C_w} \right] \right)(C_{bl} - C_w) \qquad (14a)$$

The concentration in the overlying water, C_w, is assumed to be zero to estimate a maximum flux. Similarly, we will estimate a maximum concentration in the bioturbation layer (subject to zero overlying water concentration) by assuming that $C_{bio} >> C_{bl} >> C_w$. Then we can write

$$C_{bio} - C_{bl} = \frac{Flux}{k_{bio}^{p} \varepsilon \, R_f + k_{bio}^{pw} + U} \qquad C_{bl} - C_w = \frac{Flux}{k_{bl} + U} \qquad (14b)$$

$$C_{bio} - C_w = \frac{Flux}{k_{bio}^{p} \varepsilon \, R_f + k_{bio}^{pw} + U} + \frac{Flux}{k_{bl} + U} \qquad (14c)$$

Since C_w is approximately 0, the predicted concentration in the bioturbation layer is given by

$$C_{bio} = Flux\left[\frac{1}{k_{bio}^{p} \varepsilon \, R_f + k_{bio}^{pw} + U} + \frac{1}{k_{bl} + U} \right] \qquad (15)$$

The solid concentration in the bioturbation layer, which can then be compared to sediment quality standards such as the probable effects concentration (PEC) or the NYSDEC sediment screening criteria (SSC), is given by

$$W_{bio} = K_d C_{bio} \qquad (16)$$

where K_d is an effective partition coefficient appropriate for the bioturbation layer. If the top layer of the cap constitutes the bioturbation layer, then this may be the effective partition coefficient in the cap. It may be appropriate to have a surficial sediment layer that contains additional organic carbon or has other characteristics different than the cap. For purposes of this evaluation, it was assumed that the bioturbation layer contains additional organic carbon. Initially the surface layer would have the same organic carbon content as the bulk of the cap, i.e. 0.1 percent. Over time, the deposition of fresh organic material may increase the surficial cap layer to the order of 1 percent organic carbon. For those areas where additional organic matter may be added or encouraged to enhance habitat, 5 percent organic carbon content was also considered. With 1 percent organic carbon, the effective partition coefficient, K_d, for organic compounds is $0.01*K_{oc}$.

Steady State Model for Reactive Contaminants

For degrading contaminants, the flux through the cap and to the bioturbation layer is reduced. The degradation rate of a contaminant is related to its half-life in the environment

$$\lambda = \frac{\ln(2)}{\tau_{1/2}} \tag{17}$$

Half-lives that are reported for most compounds represent reactivity in the media of concern. Half-lives reported in soils or sediments represent the time required for the soil or sediment concentration to be halved. For this model it is assumed that the half-lives apply to the porewater concentrations of the contaminant and local equilibrium between solid and porewater is assumed. This assumption neglects any additional reaction that occurs in the solid phase or slow desorption into the porewater that may slow the overall degradation rate.

Advectively-dominated conditions

Under advectively dominated conditions, the contaminant degrades according to its residence time in the cap, h_{cap}/v, where v is the interstitial velocity in the cap (U/ε). The concentration at the top of the isolation layer (but not necessarily the bottom of the bioturbation layer) is given by

$$C = C_0 e^{-\frac{\lambda h_{cap}}{v}} \tag{18}$$

The flux through the cap is then

$$Flux_{adv} = UC = UC_0 e^{-\frac{\lambda h_{cap}}{v}} \tag{19}$$

and Equations (13) and (14) may still be used to estimate the porewater and solid concentration, respectively, at the bottom of the bioturbation layer.

Diffusively-dominated conditions

Under diffusively dominated conditions, the problem is more complicated. Degradation of the contaminant decreases both concentrations and flux in the cap, but the decrease in flux is partially offset by increased concentration gradients (i.e. increasing the driving force for diffusion). A simple model of this process can be derived by assuming that the concentration at the top of the cap is small compared to the concentration in the underlying sediment, C_0. The model equations and boundary conditions can be written as

$$D\frac{\partial^2 C}{\partial z^2} = \lambda\varepsilon\, C \quad \left\langle \begin{array}{l} C(z=h_{cap})<<C_0 \\ C(z=0)=C_0 \end{array} \right. \tag{20}$$

The solution to Equation (18) written in terms of flux at the top of the cap is

$$Flux_{diff} = DC_0\left(\frac{\lambda\ \varepsilon}{D}\right)^{1/2}\left(\sinh\left(\left(\frac{\lambda\ \varepsilon}{D}\right)^{1/2} h_{cap}\right) - \frac{\cosh\left(\left(\frac{\lambda\varepsilon}{D}\right)^{1/2} h_{cap}\right)}{\tanh\left(\left(\frac{\lambda\ \varepsilon}{D}\right)^{1/2} h_{cap}\right)}\right) \tag{21}$$

This flux with Equations (13) and (14) may be used to estimate the porewater and solid concentration at the bottom of the bioturbation layer for a reacting, diffusion dominated system.

All models presented presume steady state conditions, in which the flux and bioturbation layer concentration values are at their highest levels. Note that the models assume that the underlying sediment concentration remains constant throughout the transient period leading up to steady state. Thus, the calculated steady state may never be achieved if there are fate or dilution processes influencing the contaminant in the underlying sediment. Contaminants that reach steady state conditions relatively rapidly are reasonably well described by the model, but the model would likely over-predict concentrations and fluxes for contaminants requiring very long times to achieve steady state.

Equations 14, 15, and 16 were employed to estimate the flux and contaminant concentrations in the biological active (bioturbation) layer for a non-reactive contaminant. For a reacting contaminant, Equations 19 and 21 were used to estimate the flux through the capping layer, and Equations 15 and 16 were employed to estimate the contaminant concentrations in the biologically active layer. If the predicted concentrations were of concern, Equation 7 was used to estimate the time required to achieve steady state conditions. Equations 6 and 16 could then be used to estimate the concentrations in the chemical isolation layer during the transient period. If an exceedance was observed and the time to reach steady state was very large (>> 1,000 yrs), Equations 6 and 16 were used to evaluate the concentration at the top of the chemical isolation layer after 1,000 yrs. Due to the change in conditions in the bioturbation layer, including the potential for different chemical migration rates and different sediment characteristics (e.g. organic carbon fraction), the transient model, Equation (6) could not be used to predict concentrations in the bioturbation layer.

Using the above procedure, cap effectiveness was based on the following criteria:

1. Steady-state predicted concentration in biologically active layer less than sediment criteria
    a. $W_{bio} < \text{PEC}$
    b. $W_{bio\ (benzene,\ toluene,\ phenol)} < \text{SSC}$
2. If these criteria are exceeded at steady state, the time required to achieve steady state (Equation 7) was evaluated. If the time to achieve steady state was >> 1,000 years Equations 6 and 16 were used to evaluate the contaminant concentration at the top of the chemical isolation layer after 1,000 yrs to ensure that concentrations remained below the PEC or SSC for at least 1,000 years. The cap was considered effective if more than 1,000 years was required to achieve steady state conditions and concentrations using the transient model in the chemical isolation layer were below PEC or SSC values.

These relationships were employed to estimate the fluxes through the cap and the concentrations at the bottom of the bioturbation layer. The appropriate thicknesses required to isolate each of the chemical parameters of interest (CPOIs) in the sediment management units

(SMUs) around the lake were valuated by requiring that the sediment concentration in the bioturbation layer did not exceed PEC values, or SSC values for benzene, toluene and phenol (as discussed below). The CPOIs evaluated in each SMU are provided in Table 1 of Addendum 1.

MODEL INPUT

Addendum 1 includes the primary input used in the cap modeling analysis. In general, baseline values, as shown in the model input table included in Table 2 of Addendum 1, were used in the model runs. Other input parameter ranges were evaluated through a sensitivity analysis. Input was derived from Onondaga Lake remedial investigation (RI) results, subsequent field data which has been submitted to NYSDEC (Parsons, 2003), and from literature values if site-specific information was not available.

CPOIs that exceeded a PEC quotient of one were modeled for SMUs 1, 2, 3, 4, 6 and 7. PEC quotients were calculated using all available data from the 0- to 6- inch (15-cm) interval in these SMUs, with non-detects excluded from the calculation. In SMU 5, PEC exceedances were hit and miss, with no clear trends. In general, where there were PEC exceedances, concentrations did not significantly exceed the PEC. The hit-or-miss pattern of relatively low level exceedances makes it difficult to model cap effectiveness in SMU 5. Therefore, based on the relatively low concentrations, no modeling was completed, and it was assumed that a 1-ft (0.3-m) thick chemical isolation layer would be effective in SMU 5.

Benzene, toluene, and phenol were not correlated with acute benthic toxicity on a lake-wide basis. However, because these compounds were among the predominant VOCs detected in the porewater during the upwelling investigation the potential impacts of benzene, toluene, and phenol were evaluated. Because benzene, toluene, and phenol were not correlated with acute benthic toxicity in the lake, cleanup goals or performance standards for these compounds were not developed in the FS. Slight exceedances of the PEC by these compounds would not necessarily be expected to result in toxicity. In addition, phenol concentrations were not present in porewater from the upwelling investigation at concentrations that would be expected to result in toxicity. Nevertheless, to facilitate evaluation of the effectiveness of the cap, benzene, toluene, and phenol were evaluated based on predicted exceedances of the sediment screening criteria (SSC) for these compounds in biologically active layers of the cap. For benzene and toluene, the SSCs used for the cap performance criteria are based on benthic aquatic life chronic toxicity.

Phenol was detected in porewater samples at concentrations ranging from 1.5 to 5,200 µg/L. Phenol is an unusual compound in that the NYSDEC surface water quality standards, and thus the SSCs that are based on these standards, are based on organoleptic (i.e., odor and taste) effects rather than on toxicity. The 2002 USEPA National Recommended Water Quality Criteria include only one toxicity-based criterion for phenol (21,000 µg/L), which is protective of bioaccumulation via water and organism for human health. The USEPA organoleptic effect criterion for phenol is 300 µg/L. Review of USEPA's EcoTox database for toxic effects of environmental contaminants confirms that phenol generally has low toxicity with LC50s in the thousands of µg/L. This is consistent with the findings for Onondaga Lake, which indicate that phenol is not correlated with sediment toxicity on a lake-wide basis. Although the observed values in porewater exceed the NYSDEC standards, they are not elevated with respect to concentrations found to produce toxic effects. Therefore, consideration of phenol in the cap isolation model was completed by comparing predicted phenol concentrations in the bioturbation layer to 50X the SSC for phenol. A factor of 50 was used because this is the common factor used in the SSCs for chronic versus acute benthic aquatic toxicity.

To model the effectiveness in containing the heavy polycyclic aromatic hydrocarbons (PAHs), (i.e., all the PAHs except naphthalene and fluorene), representative 3-ring (phenanthrene), 4-ring (pyrene), and 5-ring (benzo(a)pyrene) PAHs were selected for evaluation. These PAHs were selected based on consideration of their physical properties, such as toxicity and partitioning coefficient, as well as their relative concentrations and PEC quotients, to represent worst case conditions.

Hexachlorobenzene is elevated in SMUs 1 and 4. Hexachlorobenzene was not correlated with acute benthic toxicity. However, other potential risks associated with hexachlorobenzene were identified in the RI. Therefore, hexachlorobenzene was also modeled for these SMUs for use in evaluating post-remediation residual risks. However, it was not compared to its PEC, which is a toxicity-based criterion.

The groundwater model for the site was used to estimate upwelling Darcy velocities in each SMU. In SMUs 1 and 2 a velocity of 2 cm/yr was employed in recognition of the hydraulic containment systems expected as part of the Willis/Semet and Wastebed B IRMs. Groundwater modeling results indicate that these hydraulic containment systems are expected to reduce current seepage velocities to below 2 cm/yr. In SMUs where hydraulic containment systems are not planned, Darcy velocities were estimated by the groundwater model based on regional surficial and groundwater flow predictions. The maximum velocity predicted by the groundwater model was evaluated in each of these SMUs (3, 4, and 6). If this velocity resulted in exceedances of the cap performance criteria, the model was run to find an acceptable velocity that would result in no exceedance of the performance criteria for all of the CPOIs evaluated in that SMU. Results of the groundwater model are presented in Appendix D.

Effective diffusion coefficients were estimated based upon the Millington and Quirk model as described in Palermo *et al.*, (1998). Diffusion coefficients for inorganic compounds were obtained from various literature sources. Values for dispersivity were estimated based upon an assumed grain size diameter of the cap material (Palermo, *et al*., 1998).

The chemical isolation layer of the cap was assumed to contain 0.1 percent organic carbon. The overlying biologically active layer was evaluated assuming 1 percent, and 5 percent organic carbon. This allowed for an evaluation of contaminant accumulation in the biologically active layer containing different sorption characteristics than the chemical isolation layer. Immediately after placement, the cap surface may contain as little as 0.1 percent organic carbon, but over time this will increase to levels consistent with or below pre-cap conditions (approximately 5 percent), as siltation of organic material and fine grained sediments will occur. Recommendations regarding required cap thickness were conservatively made based on the worst case results assuming either a 1 percent or a 5 percent organic carbon content in the biologically active layer.

Typically porewater analyses are used to develop initial concentrations for input into cap modeling calculations. Results from Parsons 2002/2003 porewater sampling were used (where available, generally in SMUs 1, 4, and 7) to estimate the maximum underlying porewater concentrations (Parsons 2003) for non-volatile compounds. If porewater data was not available for non-volatile compounds initial concentrations were calculated from the maximum sediment concentration in each SMU.

The results of the porewater analysis for volatile organic compounds produced lower concentrations than anticipated. Therefore, to avoid the possibility of underestimating the initial porewater concentrations, the porewater data were not used as the initial concentration model input for the volatile analysis. Initial porewater concentrations for volatile compounds were instead calculated from maximum sediment concentrations in each SMU using literature-based partitioning coefficients.

For non-volatile compounds, the sediment and porewater concentrations measured during the porewater sampling effort were used to estimate site-specific partition coefficients for use in calculating porewater concentrations in SMUs where field measurements of porewater concentrations were not available (Equation 1a). The geometric mean of the calculated site-specific partitioning coefficients were applied to the maximum sediment concentrations (TAMS, 2002) to calculate porewater concentrations from sediment data in SMUs where porewater data was not available, generally SMUs 2, 3, and 6. For volatile compounds, and for non-volatiles where porewater data was insufficient, partitioning coefficients were developed from literature, and employed to calculate initial porewater concentrations for input to the model. A summary table of both site-specific partitioning coefficients and those provided in literature is provided in Addendum 1, Table 5.

Partitioning coefficients based on values reported in literature were used to estimate sorption to the cap material as no site-specific data exists to define this phenomenon. Literature values were also used to predict contaminant half-lives for applicable compounds. Contaminant half-lives were selected at the high end of ranges provided in literature as a conservative estimate. A detailed summary of model input parameters with references are included in the model input table in Addendum 1, Table 2.

MODEL RESULTS AND ISOLATION COMPONENT REQUIREMENTS BY SMU

The results of the cap modeling and the recommended isolation layer thicknesses are summarized below by SMU. Detailed modeling results are provided in Addendum 2. The modeled scenarios presented in Addendum 2 were run for different Darcy velocities, 1% and 5% organic carbon contents in the biologically active layer, and for maximum initial concentrations. To be conservative, recommended cap thicknesses provided below are based on the worst-case assumptions for each these three variables. Cap effectiveness and recommended chemical isolation layer thickness recommendations were developed using the PEC concentration as the performance criteria, with the exception of benzene, toluene, and phenol which were compared to SSCs.

If an exceedance of the cap performance criteria (PEC or SSC) was predicted at the maximum concentration and maximum velocity, the model was used iteratively to calculate an acceptable groundwater upwelling velocity at which the performance criteria would no longer be exceeded. Within model results presented in Addendum 2 the first row for each CPOI predicts concentrations in the biologically active layer of the cap assuming the maximum velocity anticipated in that SMU. If that velocity results in an exceedance of the performance criteria, the second line for each CPOI presents the velocity at which there were no cap performance criteria exceedances for any of the CPOIs evaluated in that SMU. This value is referred to as the "acceptable velocity". Acceptable upwelling velocities were calculated for use in the FS for evaluating potential targeted dredging areas that may be considered to enhance cap effectiveness.

In SMU 7 the acceptable velocity resulted in a very extensive targeted dredging area. Based on these results, a shoreline hydraulic barrier wall and groundwater containment system would be more cost effective. Therefore, in SMU 7 a third velocity is evaluated, which represents the maximum velocity anticipated after a hydraulic containment system is in place. However, consistent with the text of the FS, it is anticipated that either targeted dredging or hydraulic control in conjunction with capping would be effective, and that the determination regarding the most cost-effective approach would be made as part of the pre-design investigation and design process.

The chemical isolation thickness in each SMU, was selected such that the performance criteria were not exceeded for each CPOI. Addendum 2 presents the most feasible combination of acceptable velocities and layer thicknesses. The cap design presented in Appendix H applies a 1.5X safety factor to the recommended chemical isolation layer thicknesses. Assuming this additional amount of cap material the calculated concentration in the bioturbation layer is shown in the far right hand column of Addendum 2.

SMU 1

To control groundwater upwelling and contaminant migration from onshore plumes, the onshore remedial plans include a hydraulic containment system at the lake shoreline (Wastebed B). Modeling efforts demonstrate that hydraulic containment efforts would reduce upwelling within SMU 1 to a Darcy velocity less than 2 cm/yr.

Predicted concentrations in the biologically active layer at steady state were compared against the performance criteria. In SMU 1 assuming a one-foot cap, at the maximum velocity and maximum concentration, performance criteria exceedances were predicted for xylene, chlorobenzene, dichlorobenzene, naphthalene, and benzo(a)pyrene. For benzo(a)pyrene, the predicted concentration at the top of the chemical isolation layer (calculated using Equation 6) is less than the cap performance criteria for over 1,000 years. However, for chlorobenzene, xylene, naphthalene, and dichlorbenzene, the chemical isolation layer thickness must be increased to prevent performance criteria exceedances.

A 2.5-ft (0.3-m) cap would effectively contain the contaminants in SMU 1 assuming that a hydraulic containment system is in place.

SMU 2

As in SMU 1, to control groundwater upwelling and contaminant migration from onshore plumes, the onshore remedial plans include a hydraulic containment system at the lake shoreline (Wastebed B). Modeling efforts demonstrate that hydraulic containment efforts would reduce upwelling within SMU 2 to a Darcy velocity less than 2 cm/yr.

Due to predicted exceedances for benzene, xylene, chlorobenzene, dichlorobenzene and napthlene assuming a 1-ft (0.3-m) chemical isolation layer, increasing isolation layer thicknesses were considered. The model showed that a chemical isolation layer 2.5-ft (0.6-m) thick would effectively contain the contaminants in SMU 2 assuming that a hydraulic containment system is in place.

As stated in the model input section, insufficient porewater data exists in SMU 2 (only one sampling location); therefore, sediment concentrations and partitioning coefficients were used to estimate initial porewater concentrations for use in the model. However, the one porewater sample taken in SMU 2 detected high concentrations of organics. Porewater concentrations for chlorobenzene and dichlorobenzene slightly exceeded the porewater concentrations calculated using the maximum sediment concentration and the literature partitioning coefficient. The slightly higher concentrations measured during the porewater investigation do not affect the ability of a 2.5-foot chemical isolation layer to effectively contain the contaminants in SMU 2.

SMU 3

A hydraulic containment system is not envisioned for SMU 3. Seepage velocities estimated by the ground water model range from less than 2 cm/yr (greater than 420 feet from shore) up to 700 cm/yr in nearshore areas. Assuming a one-foot cap in SMU 3, benzene, toluene, xylene, and naphthalene cause exceedances of the cap performance criteria at the maximum concentration, maximum velocity, and with a 5% organic carbon content in the biologically active layer. At these high velocities, differences in chemical isolation thicknesses are negligible, and a 2- or 3-ft (0.6- to 1-m) chemical isolation layer would not result in significant containment advantages over a 1-ft (0.3-m) thick layer.

Further delineation of contaminant concentrations are recommended in the nearshore areas of this SMU. Based on the modeling effort and current data, it appears that upwelling velocities greater than 5 cm/yr would cause some performance criteria exceedances with a one-foot chemical isolation layer in place. Therefore, it is recommended that removal take place in locations where the velocity is anticipated to be greater that 5 cm/yr, followed by a 1-ft (0.3-m) chemical isolation layer across the SMU.

SMU 4

A hydraulic containment system is not planned for SMU 4; therefore, as with SMU 3, the groundwater model was used to predict a velocity profile. Seepage velocities predicted by the ground water model range from less than 2 cm/yr (greater than 300 ft (91 m) from shore) up to 300 cm/yr in nearshore areas. The CPOIs modeled in SMU 4 were benzene, toluene, mercury and hexachlorobenzene. However, hexachlorobenzene has not been correlated with toxicity; therefore, the hexachlorobenzene results were only used in estimating post remediation residual effects.

Based on the model results in SMU 4, a 1-ft (0.3-m) cap would be sufficient for containing CPOIs below the cap performance criteria at steady state.

SMU 6

In SMU 6, the upwelling velocities predicted by the groundwater model range from less than 2 cm/yr up to 70 cm/yr in nearshore areas.

The model predicts that xylene, dichlorobenzene, naphthalene, fluorene, phenanthrene, pyrene, benzo(a)pyrene, and PCBs would exceed the cap performance criteria using a 1-ft (0.3-m) isolation cap component, and assuming the maximum concentrations, and a maximum velocity of 70 cm/yr. At the high velocities anticipated nearshore, differences in chemical isolation thicknesses are negligible and a 2- or 3-ft (0.6- to 1-m) chemical isolation layer would not result in significant containment advantages over a 1-ft (0.3-m) thick layer.

Further delineation of contaminant concentrations are recommended in the nearshore areas of this SMU. Based on the modeling effort and current data, it appears that upwelling velocities greater than 3 cm/yr would cause some performance criteria exceedances with a one-foot chemical isolation layer in place. Therefore, it is recommended that removal take place in locations where the velocity is anticipated to be greater that 3 cm/yr, followed by a 1-ft (0.3-m) chemical isolation layer across the SMU.

SMU 7

Originally, a hydraulic containment system was not envisioned for SMU 7. Seepage velocities predicted by the ground water model range from less than 2 cm/yr (greater than 420 ft (128 m) from shore) up to 100 cm/yr in nearshore areas.

The compounds, assuming maximum concentrations and a maximum velocity of 100 cm/yr, that exceed their performance criteria using a 1-ft (0.3-m) isolation cap component include benzene, toluene, xylene, chlorobenzene, dichlorobenzene, napthalene, fluorene, phenatharene, pyrene, benzo(a)pyrene, and PCBs. At the high velocities anticipated nearshore, differences in chemical isolation thicknesses are negligible; however, as discussed below, the acceptable velocity in SMU 7 is low enough that chemical isolation layer thickness does become a factor.

Further delineation of contaminant concentrations are recommended in the nearshore areas of this SMU. Based on the modeling effort and current data, it appears that upwelling velocities greater than 3 cm/yr would cause some exceedances of cap performance criteria with a 2.5-foot chemical isolation layer in place. With no barrier wall in place, the recommended action would be removal in locations where the velocity is anticipated to be greater than 3 cm/yr, followed by a 2.5-ft (0.8-m) chemical isolation layer across the SMU. This acceptable velocity results in an extensive removal volume. As discussed above, a hydraulic containment system would be more cost effective based on this evaluation. If the velocity is reduced to 2 cm/yr through a hydraulic containment system, a 2.5-ft chemical isolation layer is required to effectively contain the contaminants in SMU 7.

SUMMARY

A summary of the recommended isolation cap component thickness and other actions are tabulated as follows:

SMU	Recommended Action
SMU 1	Install hydraulic containment system. Cap with a 2.5-ft chemical isolation layer
SMU 2	Install hydraulic containment system. Cap with a 2.5-ft chemical isolation layer
SMU 3	Delineate locations of high contaminant levels. Remove high concentrations near shore where velocity is greater than 5 cm/yr. Cap with a 1-ft isolation layer.
SMU 4	Cap with a 1-ft chemical isolation layer
SMU 6	Delineate locations of high contaminant levels. Remove high concentrations nearshore where velocity is greater than 3 cm/yr. Cap with a 1-ft isolation layer.
SMU 7	Install hydraulic containment system. Cap with a 2.5-ft isolation layer.

SENSITVITY ANALYSIS

The approach to quantifying the sensitivity of the model output (sediment concentration in the bioturbation layer) involved varying one input parameter value at a time, over an appropriate range, and calculating the sensitivity ratio (SR) for each realization of the model. The sensitivity ratio is equal to the percentage change in output divided by the percentage change in input for a specific input variable, as shown in the following equation (USEPA 2001):

$$SR = \frac{(Y_2 - Y_1)/Y_1 \ * 100\%}{(X_2 - X_1)/X_1 * 100\%}$$

where

Y_1 = the baseline value of the sediment concentration using baseline values of input variables

Y_2 = the value of the sediment concentration after changing the value of one input variable

X_1 = the baseline point estimate for an input variable

X_2 = the value of the input variable after changing X1.

The model is considered most sensitive to input variables that yield the highest absolute value for SR. A SR near zero indicates no sensitivity to that input variable, a SR of 1 indicates a linear relationship between the input variable and output.

Since metals and organics have significantly different distribution coefficients, and only organics biodegrade, those sets of compounds are analyzed separately. Additionally, there is a tremendous difference in upwelling velocities between SMUs with barriers and those without. Therefore, SR values were calculated for four scenarios: metals-high-velocity, metals-low-velocity, organics high-velocity, organics low-velocity.

For many of the compounds the calculated SR varies depending upon the percentage change in the input variable. This indicates that different parameters become more (or less) important over the input variables' range. To enable a comparison of the model's sensitivity to different parameters, local SRs are calculated and compared. A local SR is based on a small change in the input value, ± 5 percent. The following table summarizes the local SRs.

ONONDAGA LAKE CAP MODEL

LOCAL SENSITIVITY RATIO RESULTS

	Metal – Mercury		Organic – Naphthalene	
Parameter	**Low velocity**	**High velocity**	**Low velocity**	**High velocity**
$k_{bio(p)}$	-0.69	-0.64	-0.63	-0.36
$k_{bio(pw)}$	-0.02	-0.02	-0.34	-0.19
k_{bl}	-0.29	-0.30	-0.03	-0.05
Porosity (ε)	0.46	0.43	2.11	0.17
C_o	1.00	1.00	1.00	1.00
Darcy velocity (U)	1.00	0.96	-0.01	0.68
dispersivity (alpha)	0.00	0.00	0.00	0.00
Diffusion coeff. (D_w)	0.00	0.00	2.06	0.00
K_d/K_{oc}	0.31	0.36	0.38	0.64
Cap thickness (z)	0.00	0.00	-2.92	-0.07
Half-life ($t^{½}$)	NA	NA	1.08	0.07
f_{oc} (C.I layer)	NA	NA	0.00	0.00
f_{oc} (bio layer)	NA	NA	0.40	0.65
Rank				
High sensitivity	C_o, U	C_o, U	z, ε, D_w, $t^{½}$, C_o	C_o
Moderate sensitivity	$k_{bio(p)}$, ε, K_d	$k_{bio(p)}$, ε, K_d	$k_{bio(p)}$, f_{oc}(bio), K_{oc}, $k_{bio(pw)}$	U, f_{oc}(bio), K_{oc}, $k_{bio(p)}$
Low sensitivity	k_{bl}, $k_{bio(pw)}$	k_{bl}, $k_{bio(pw)}$	k_{bl}, U	$k_{bio(pw)}$, ε, z, t½, k_{bl}
No sensitivity	z, D_w, alpha	z, D_w, alpha	f_{oc}(C.I. layer), alpha	f_{oc}(C.I. layer), D_w, alpha

DISCUSSION

It should be noted that the baseline values used in the model are conservative values, and the sensitivity analysis might change if range midpoint values were used instead. Also, there is significant interplay among the various parameters, while this analysis is based on varying one input parameter at a time.

Mass Transfer Coefficients

The local sensitivity ratios indicate that k_{biop} (particle bioturbation mass transfer coefficient) is an important parameter for metals, somewhat less so for some organics. This is due to the higher distribution coefficients for some metals, which increase the product ($R_f * \varepsilon$), increasing the effect of k_{biop} in the denominator of the C_{bio} equation.

Particle mixing is the most important mass transfer process in the upper layers for each of the four scenarios. For metals, the high distribution coefficients overwhelm the effect of bioturbation pore water mixing and create an effect on the scale of benthic layer (k_{bl}) mixing, which then becomes the secondary process. For organics, particle mixing is still the primary mass transfer process, but in many cases, the lower distribution coefficients do not raise it to the range where benthic layer mixing could have an impact. Therefore, bioturbation layer pore water mixing (k_{biopw}) becomes the secondary process for organics. As Darcy velocity increases from 2 cm/yr (low) to 200 cm/yr (high) and therefore exceeds k_{biopw}, it becomes significant in terms of organic mass transfer and reduces model sensitivity to both k_{biop} and k_{biopw}. (Note that the distribution coefficient for organics used in assessing bioturbation mass transfer is based on the organic content of the bioturbation layer, not the chemical isolation layer.)

Chemical Half-Life

Biodegradation is modeled as a first-order decay process. The local SRs indicate that it is a very important parameter for the low-velocity setting, and not important for the high-velocity setting. The sensitivity analysis is based on a baseline scenario involving naphthalene and a 1-ft (0.3-m) cap. At the high-velocity range there is not enough time for biodegradation to have an effect. In the low-velocity range, biodegradation can be critical.

Porosity

Porosity is moderately important for metals. The effect is felt through its role in bioturbation mass transfer, which becomes increasingly important at higher distribution coefficients. (Note that even though the product ($R_f * \varepsilon$) equals ($\varepsilon + \rho_b K_d$), and therefore ε appears insignificant, dry bulk density depends on porosity).

Porosity has less effect on bioturbation mass transfer for organics due to the lower distribution coefficients. However it plays an important role in diffusion, which is the dominant flux process in the low-velocity setting, especially when combined with biodegradation.

Initial Concentration

There is a linear relationship between the contaminant concentration in the underlying sediment and the steady-state contaminant concentration in the bioturbation layer.

Darcy Velocity

For metals, there is a near-linear relationship between the contaminant concentration in the underlying sediment and the steady-state contaminant concentration in the bioturbation layer.

For organics, the sensitivity depends on the velocity setting. As has been noted, the dominant flux for degradable organics in the low-velocity setting is diffusive flux. Therefore, the Darcy velocity has only a slight effect (through the dispersivity term in the effective diffusion coefficient formulation). In high-velocity settings, advective flux dominates and the reactive flux changes almost linearly with Darcy velocity. However, the bioturbation processes control C_{bio}, and bioturbation pore water mixing (of which Darcy velocity is a component) exerts only about 60 percent control over C_{bio}. Therefore, the sensitivity to Darcy velocity is reduced from 1 to 0.68.

Dispersivity

No effect.

Diffusion Coefficient

The only situation in which diffusive flux exceeds advective flux is for degradable organics in the low-velocity setting. In this scenario, the diffusion coefficient is very important.

K_d/K_{oc}

For metals, the distribution coefficient is moderately important. Particle mixing is the most important mass transfer process for compounds such as metals with high distribution coefficients. The sensitivity to K_d is less than that to K_{biop} (another critical component in particle mixing) because K_d appears in both the denominator (C_{bio}) and numerator (C_{sed}) of the equations used to calculate the concentration in the bioturbation layer sediment. That is, an increasing K_d will serve to lower C_{bio} by placing more mass in the particle phase, but will increase the sediment concentration occasioned by C_{bio} by placing more mass in the sorbed phase of the sediment, canceling part of its effect.

The sensitivity is the same for organics in the low-velocity setting. In this scenario, a low-distribution coefficient and low-velocity, particle mixing is the most important bioturbation layer process, and the effect of the distribution coefficient is muted by its presence in the C_{sed} equation. Alternately, in the high-velocity setting, pore water mixing is more important (by virtue of the increased Darcy velocity) and there is less of a canceling effect. Therefore, K_d can have more of an impact, and C_{sed} becomes more sensitive to it. In this scenario K_d (i.e., $K_{oc} * f_{oc}(bio)$), becomes an important parameter.

Cap Thickness

There is no effect on metals, as the modeling approach is based on steady-state conditions. Therefore, there is no adsorption or degradation to attenuate concentrations, no matter the length of the flow path. Of course, the amount of adsorption and the length of the flow path do affect the time to steady-state, which is one of the determinants of whether the cap is effective.

Since organics are to one degree or another biodegradable, the length of the flow path (cap thickness) can have an impact. In the high-velocity setting, travel times are too short for biodegradation to have an effect. However, in the low-velocity setting the sensitivity of the output to cap thickness is greater than any other parameter. Diffusion is the dominant flux process for the reactive compound in this setting. The sediment concentration for naphthalene is reduced by 20 fold by increasing the cap thickness from 1 ft to 2 ft.

Organic Content of Chemical Isolation Layer

As constituted the model shows no sensitivity to this parameter, as contaminant degradation is based solely on the interstitial velocity, not the retarded velocity (i.e., affected by adsorption). This is a very conservative approach.

Organic Content of the Bioturbation Layer

There is moderate sensitivity to this parameter in the low-velocity setting, where particle mixing is the most important mass transfer process. As noted above, there is some canceling of the effect of bioturbation layer organic content in this scenario. As particle mixing becomes relatively less important, as in the high-velocity setting, there is less of a canceling effect and the output becomes more sensitive to this parameter.

Additional Sensitivity Discussion

To account for the difficulties inherent to a more complex sensitivity analysis, in addition to the local sensitivity analysis discussed above, model results were evaluated (as discussed above in the results sections and as presented in Addendum 2) under different scenarios. Three different Darcy velocity values, which spanned the range of the groundwater model predicted velocities, were evaluated against maximum and average concentrations in each SMU. This resulted in six scenarios evaluated for each CPOI in each SMU. These scenarios were then evaluated over a range of organic carbon contents in the biologically active zone, representing conditions following cap placement through organic carbon conditions anticipated after a significant amount of time. Organizing the model output in this way incorporates a sensitivity analysis within the actual modeled results. Given the variety of compounds, the variability of SMU specific conditions, and the limitations of the model, Darcy velocity, initial concentration, and organic carbon content are believed to be the most influential input parameters, and were modeled accordingly.

ATTACHMENT G
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ATTACHMENT G
ADDENDA

Addendum 1
Model Input Parameters and Supporting Data

CPOIs by SMU

Summary of Model Input Parameters

Porewater Sampling Data

Sediment Sampling Data – Maximum Concentrations

K_{oc}/K4 Calculations and Literature Values Summary Sheet

Average Fraction of Organic Carbon Data

Addendum 2
Results

1 percent f_{oc} in Bioturbation Layer

1 percent f_{oc} in Bioturbation Layer – Benzene, Toluene, and Phenol

5 percent f_{oc} in Bioturbation Layer

5 percent f_{oc} in Bioturbation Layer – Benzene, Toluene, and Phenol

ADDENDUM 1

MODEL INPUT PARAMETERS AND SUPPORTING DATA

- Table 1 CPOIs by SMU
- Table 2 Summary of Model Input Parameters
- Table 3 Porewater Sampling Data
- Table 4 Sediment Sampling Data – Maximum Concentrations
- Table 5 K_{oc}/K_d Calculations and Literature Values Summary Sheet
- Table 6 Average Fraction of Organic Carbon Data

ADDENDUM 2

RESULTS

- 1 percent f_{oc} in Bioturbation Layer
- 1 percent f_{oc} in Bioturbation Layer – Benzene, Toluene, and Phenol
- 5 percent f_{oc} in Bioturbation Layer
- 5 percent foc in Bioturbation Layer – Benzene, Toluene, and Phenol

TABLE 1
CPOIs MODELED IN EACH SMU

SMU 1	SMU 2	SMU 3	SMU 4	SMU 6	SMU 7
Mercury	Mercury		Mercury	Mercury	Mercury
Ethylbenzene	Ethylbenzene	Ethylbenzene			Ethylbenzene
Xylene	Xylene	Xylene		Xylene	Xylene
Chlorobenzene	Chlorobenzene				Chlorobenzene
Dichlorobenzenes	Dichlorobenzenes			Dichlorobenzenes	Dichlorobenzenes
Naphthalene	Naphthalene	Naphthalene		Naphthalene	Naphthalene
Fluorene	Fluorene			Fluorene	Fluorene
Phenanthrene	Phenanthrene			Phenanthrene	Phenanthrene
Pyrene	Pyrene			Pyrene	Pyrene
Benzo(a)pyrene	Benzo(a)pyrene			Benzo(a)pyrene	Benzo(a)pyrene
Hexachlorobenzene			Hexachlorobenzene		
PCBs	PCBs			PCBs	PCBs
Benzene	Benzene	Benzene	Benzene	Benzene	Benzene
Toluene	Toluene	Toluene	Toluene	Toluene	Toluene
Phenol	Phenol			Phenol	Phenol

TABLE 2
MODEL INPUT

Parameter	Range	Baseline	Units	Reference/Source
Darcy Velocity	Varies Depending on SMU		cm/yr	See Velocity from Groundwater Model Table in this Attachment
Fraction of Organic Carbon in Cap Material	0.1%			Conservative value based on the assumption of a typical sand cap; actual foc will be determined during design phase depending on cap material selected and origin
Porosity	0.25 - 4.75	0.4		Theoretical maximum porosity for uniform spherical particles is 0.4765 (cubic packing); if the particles are rhombohedrally packed, then the uniform maximum porosity is 0.2595. Baseline value based on a typical value for loosely packed, medium-grain sand.
Solid Density	2.65			Reference 1
Retardation Factor	Dependant on contaminant, bulk density and porosity			$R_f = 1 + \frac{\rho_b K_d}{n}$
Hindrance Parameter	Dependant on porosity			$n^{-1/3}$
Dispersivity	0.0125-6	0.0125	cm	Range based on typical dispersivity values and up to 1/10 the domain length, a typical groundwater modeling assumption. The Baseline assumption is based on recommendations in Reference 13.
$k_{bio(particle)}$	0.01-100	1	cm/yr	Reference 21
$k_{bio(water)}$	10-1000	100	cm/yr	Reference 15, 22
k_{bl}	0.025-4	1	cm/hr	Reference 22
Mercury				
Mercury Partition Coefficient	60 - 990,000	2,200	mL/g	Range and Baseline developed based on Reference 8.
Mercury Concentration in SMU 1	2.92E-3 - 7.48E-1	7.48E-01	mg/L	Based on Reference 10.
Maximum Mercury Concentration in sediment in SMU 2	NA	23	mg/kg	Baseline Value developed from Reference 19
Maximum Calculated Mercury Porewater Concentration in SMU 2	NA	3.30E-03	mg/L	Calculated as Cpw=Ws/Kd, Kd developed based on Reference 16; the Kd measured for mercury was 6,961
Mercury Concentration in SMU 4	6.5E-6 - 4.12E-5	4.12E-05	mg/L	Based on Reference 10.
Maximum Mercury Concentration in sediment in SMU 6	NA	17.2	mg/kg	Baseline Value developed from Reference 19
Maximum Calculated Mercury Porewater Concentration in SMU 6	NA	2.47E-03	mg/L	Calculated as Cpw=Ws/Kd, Kd developed based on Reference 16; the Kd measured for mercury was 6,961
Mercury Concentration in SMU 7	0.01E-3 - 0.03E-3	3.00E-05	mg/L	Based on Reference 10
Diffusion Coefficient for Mercury	1.96E-06	1.96E-06	cm^2/sec	Range developed based on Reference 9
Mercury PEC	2.2		mg/kg	Based on Reference 9
Ethylbenzene				
Organic Carbon Partition Coefficient for Ethylbenzene	165 - 588	588	mL/g	Range developed based on Reference 7, Baseline Value typically developed based on Reference 11. However value (1413 mL/g) was higher than range presented in Reference 7; thus, the high end of the range from Reference 7 was selected as the baseline.
Maximum Ethylbenzene Concentration in sediment in SMU 1 at all depths	NA	29	mg/kg	Baseline Value developed from Reference 19
Maximum Calculated Ethylbenzene Porewater Concentration in SMU 1 at all depths	NA	7.36E-01	mg/L	Calculated as Cpw=Ws/Kd, Kd developed based on Reference 7, and the measured foc in SMU 1 was 0.067.
Maximum Ethylbenzene Concentration in sediment in SMU 2 at all depths	NA	71	mg/kg	Baseline Value developed from Reference 19
Maximum Calculated Ethylbenzene Porewater Concentration in SMU 2 at all depths	NA	1.75E+00	mg/L	Calculated as Cpw=Ws/Kd, Kd developed based on Reference 7, and the measured foc in SMU 2 was 0.069.
Maximum Ethylbenzene Concentration in sediment in SMU 3 at all depths	NA	1.1	mg/kg	Baseline Value developed from Reference 19
Maximum Calculated Ethylbenzene Porewater Concentration in SMU 3 at all depths	NA	5.34E-02	mg/L	Calculated as Cpw=Ws/Kd, Kd developed based on Reference 7, and the measured foc in SMU 3 was 0.035.
Maximum Ethylbenzene Concentration in sediment in SMU 7 at all depths	NA	7.1	mg/kg	Baseline Value developed from Reference 19

TABLE 2
MODEL INPUT

Parameter	Range	Baseline	Units	Reference/Source
Maximum Calculated Ethylbenzene Porewater Concentration in SMU 7 at all depths	NA	1.75E-01	mg/L	Calculated as Cpw=Ws/Kd, Kd developed based on Reference 7, and the measured foc in SMU 7 was 0.069.
Diffusion Coefficient for Ethylbenzene[13]	0.81E-5 @ 20C - 0.90E-5 @ 25C	4.80E-6 @ 45F	cm^2/sec	Range developed based on Reference 7, Baseline Value based on Reference 20.
Ethylbenzene Half Life	6 - 228	228	days	Range developed based on Reference 3, Baseline Value conservatively based on maximum value of range
Ethylbenzene PEC	1.76E-01		mg/kg	Based on Reference 9
Xylene				
Organic Carbon Partition Coefficient for Xylene	48-2,000	1413	mL/g	Range developed based on Reference 7, Baseline Value developed based on Reference 11
Maximum Xylene Total Concentration in sediment in SMU 1 at all depths	NA	430	mg/kg	Baseline Value developed from Reference 19
Maximum Calculated Xylene Total Porewater Concentration in SMU 1 at all depths	NA	4.54E+00	mg/L	Calculated as Cpw=Ws/Kd, Kd developed based on Reference 11, and the measured foc in SMU 1 was 0.067.
Maximum Xylene Total Concentration in sediment in SMU 2 at all depths	NA	330	mg/kg	Baseline Value developed from Reference 19
Maximum Calculated Xylene Total Porewater Concentration in SMU 2 at all depths	NA	3.38E+00	mg/L	Calculated as Cpw=Ws/Kd, Kd developed based on Reference 11, and the measured foc in SMU 2 was 0.069.
Maximum Xylene Total Concentration in sediment in SMU 3 at all depths	NA	28.85	mg/kg	Baseline Value developed from Reference 19
Maximum Calculated Xylene Total Porewater Concentration in SMU 3 at all depths	NA	5.83E-01	mg/L	Calculated as Cpw=Ws/Kd, Kd developed based on Reference 11, and the measured foc in SMU 3 was 0.035.
Maximum Xylene Total Concentration in sediment in SMU 6 at all depths	NA	65	mg/kg	Baseline Value developed from Reference 19
Maximum Calculated Xylene Total Porewater Concentration in SMU 6 at all depths	NA	1.48E+00	mg/L	Calculated as Cpw=Ws/Kd, Kd developed based on Reference 11, and the measured foc in SMU 6 was 0.031.
Maximum Xylene Total Concentration in sediment in SMU 7 at all depths	NA	120	mg/kg	Baseline Value developed from Reference 19
Maximum Calculated Xylene Total Porewater Concentration in SMU 7 at all depths	NA	1.23E+00	mg/L	Calculated as Cpw=Ws/Kd, Kd developed based on Reference 11, and the measured foc in SMU 7 was 0.069.
Diffusion Coefficient for Xylene	0.79E-5 @ 20C	4.80E-6 @ 45F	cm^2/sec	Range developed based on Reference 7, Baseline Value based on Reference 20.
Xylene Half Life	2-767	767	days	Range developed based on Reference 3, Baseline Value conservatively based on maximum value of range
Xylene PEC	5.61E-01		mg/kg	Based on Reference 9
Chlorobenzene				
Organic Carbon Partition Coefficient for Chlorobenzene	81 - 500	500	mL/g	Range developed based on Reference 7, Baseline Value typically developed based on Reference 11; however, value (500 mL/g) was higher than range presented in Reference 7; thus, the high end of the range from Reference 7 was selected as the baseline.
Maximum Chlorobenzene Total Concentration in sediment in SMU 1 at all depths	NA	1000	mg/kg	Baseline Value developed from Reference 19
Maximum Calculated Chlorobenzene Total Porewater Concentration in SMU 1 at all depths	NA	2.99E+01	mg/L	Calculated as Cpw=Ws/Kd, Kd developed based on Reference 7, and the measured foc in SMU 1 was 0.067.
Maximum Chlorobenzene Concentration in sediment in SMU 2 at all depths	NA	640	mg/kg	Baseline Value developed from Reference 19
Maximum Calculated Chlorobenzene Porewater Concentration in SMU 2 at all depths	NA	1.86E+01	mg/L	Calculated as Cpw=Ws/Kd, Kd developed based on Reference 7, and the measured foc in SMU 2 was 0.069.

TABLE 2
MODEL INPUT

Parameter	Range	Baseline	Units	Reference/Source
Maximum Chlorobenzene Concentration in sediment in SMU 7 at all depths	NA	150	mg/kg	Baseline Value developed from Reference 19
Maximum Calculated Chlorobenzene Porewater Concentration in SMU 7 at all depths	NA	4.35E+00	mg/L	Calculated as Cpw=Ws/Kd, Kd developed based on Reference 7, and the measured foc in SMU 7 was 0.069.
Diffusion Coefficient for Chlorobenzene	0.98E-5 - 1.04 E-5 @ 25C	5.35E-6 @ 45F	cm^2/sec	Range developed based on Reference 7, Baseline Value based on Reference 20.
Chlorobenzene Half Life	2.1 - 600	600	days	Range developed based on Reference 3, Baseline Value conservatively based on maximum value of range
Chlorobenzene PEC	4.28E-01		mg/kg	Based on Reference 9
Dichlorobenzene				
Organic Carbon Partition Coefficient for Dichlorobenzene	180 - 3,235	2,399	mL/g	Range developed based on Reference 7, Baseline Value developed based on Reference 11
Maximum Dichlorobenzene Total Concentration in sediment in SMU 1 at all depths	NA	1050	mg/kg	Baseline Value developed from Reference 19
Maximum Calculated Dichlorobenzene Total Porewater Concentration in SMU 1 at all depths	NA	6.53E+00	mg/L	Calculated as Cpw=Ws/Kd, Kd developed based on Reference 11, and the measured foc in SMU 1 was 0.067.
Maximum Dichlorobenzene Total Concentration in sediment in SMU 2 at all depths	NA	155	mg/kg	Baseline Value developed from Reference 19
Maximum Calculated Dichlorobenzene Total Porewater Concentration in SMU 2 at all depths	NA	9.36E-01	mg/L	Calculated as Cpw=Ws/Kd, Kd developed based on Reference 11, and the measured foc in SMU 2 was 0.069.
Maximum Dichlorobenzene Total Concentration in sediment in SMU 6 at all depths	NA	5.4	mg/kg	Baseline Value developed from Reference 19
Maximum Calculated Dichlorobenzene Total Porewater Concentration in SMU 6 at all depths	NA	7.26E-02	mg/L	Calculated as Cpw=Ws/Kd, Kd developed based on Reference 11, and the measured foc in SMU 6 was 0.031.
Maximum Dichlorobenzene Concentration in sediment in SMU 7 at all depths	NA	661	mg/kg	Baseline Value developed from Reference 19
Maximum Calculated Dichlorobenzene Porewater Concentration in SMU 7 at all depths	NA	3.99E+00	mg/L	Calculated as Cpw=Ws/Kd, Kd developed based on Reference 11, and the measured foc in SMU 7 was 0.069.
Diffusion Coefficient for 1,2 Dichlorobenzene[13]	8.7E-6 - 9.4E-6 @25C	4.85E-6 @ 45F	cm^2/sec	Range developed based on Reference 7, Baseline Value based on Reference 20.
Dichlorobenzene Half Life	6 - 720	720	days	Range developed based on Reference 3, Baseline Value conservatively based on maximum value of range.
Dichlorobenzene PEC	2.39E-01		mg/kg	Based on Reference 9
Naphthalene				
Organic Carbon Partition Coefficient for Naphthalene	415 - 100,000	2,344	mL/g	Range developed based on Reference 7, Baseline Value developed based on Reference 11
Maximum Napthlene Total Concentration in sediment in SMU 1 at all depths	NA	1300	mg/kg	Baseline Value developed from Reference 19
Maximum Calculated Napthlene Total Porewater Concentration in SMU 1 at all depths	NA	8.28E+00	mg/L	Calculated as Cpw=Ws/Kd, Kd developed based on Reference 11, and the measured foc in SMU 1 was 0.067.
Maximum Naphthalene Concentration in sediment in SMU 2 at all depths	NA	26000	mg/kg	Baseline Value developed from Reference 19
Maximum Calculated Naphthalene Porewater Concentration in SMU 2 at all depths	NA	1.61E+02	mg/L	Calculated as Cpw=Ws/Kd, Kd developed based on Reference 11, and the measured foc in SMU 2 was 0.069.
Maximum Naphthalene Concentration in sediment in SMU 3 at all depths	NA	14	mg/kg	Baseline Value developed from Reference 19

TABLE 2
MODEL INPUT

Parameter	Range	Baseline	Units	Reference/Source
Maximum Calculated Naphthalene Porewater Concentration in SMU 3 at all depths	NA	1.71E-01	mg/L	Calculated as Cpw=Ws/Kd, Kd developed based on Reference 11, and the measured foc in SMU 3 was 0.035.
Maximum Naphthalene Concentration in sediment in SMU 6 at all depths	NA	120	mg/kg	Baseline Value developed from Reference 19
Maximum Calculated Naphthalene Porewater Concentration in SMU 6 at all depths	NA	1.65E+00	mg/L	Calculated as Cpw=Ws/Kd, Kd developed based on Reference 11, and the measured foc in SMU 6 was 0.031.
Maximum Napthlene Concentration in sediment in SMU 7 at all depths	NA	500	mg/kg	Baseline Value developed from Reference 19
Maximum Calculated Napthlene Porewater Concentration in SMU 7 at all depths	NA	3.09E+00	mg/L	Calculated as Cpw=Ws/Kd, Kd developed based on Reference 11, and the measured foc in SMU 7 was 0.069.
Diffusion Coefficient for Naphthalene[13]	0.7E-5 @ 20C	4.66E-6 @ 45F	cm^2/sec	Range developed based on Reference 7, Baseline Value based on Reference 20.
Naphthalene Half Life	0.2 - 225	219	days	Range developed through references - 2,3,4 (219 days selected by DEC)
Naphthalene PEC	9.17E-01		mg/kg	Based on Reference 9
Fluorene				
Organic Carbon Partition Coefficient for Fluorene	3,980 - 213,800	15,136	mL/g	Range developed based on Reference 7, Baseline Value developed based on Reference 11
Fluorene Concentration in SMU 1	35.598E-3 - 95E-3	9.50E-02	mg/L	Based on Reference 10.
Maximum Fluorene Concentration in sediment in SMU 2 at all depths	NA	42	mg/kg	Baseline Value developed from Reference 16
Maximum Calculated Fluorene Porewater Concentration in SMU 2 at all depths	NA	4.02E-02	mg/L	Calculated as Cpw=Ws/Kd, Kd developed based on Reference 16; literature value used for Koc due to lack of porewater data (lit value of 15,136) the measured foc in SMU 2 was 0.069.
Maximum Fluorene Concentration in sediment in SMU 6 at all depths	NA	35	mg/kg	Baseline Value developed from Reference 16
Maximum Calculated Fluorene Porewater Concentration in SMU 6 at all depths	NA	7.46E-02	mg/L	Calculated as Cpw=Ws/Kd, Kd developed based on Reference 16; literature value used for Koc due to lack of porewater data (lit value of 15,136) the measured foc in SMU 6 was 0.031.
Fluorene Concentration in SMU 7	4.67E-3 - 7.10E-3	7.10E-03	mg/L	Based on Reference 10.
Diffusion Coefficient for Fluorene[13]	0.61E-5@20C	4.04E-6 @ 45F	cm^2/sec	Range developed based on Reference 7, Baseline Value based on Reference 20.
Fluorene Half Life	32-240	240	days	Range developed based on Reference 3, Baseline Value conservatively based on maximum value of range.
Fluorene PEC	2.64E-01		mg/kg	Based on Reference 9
Phenanthrene				
Organic Carbon Partition Coefficient for Phenanthrene	1,400-1,318,000	28,184	mL/g	Range developed based on Reference 7, Baseline Value developed based on Reference 11
Phenanthrene Concentration in SMU 1	33.40E-3 - 95.00E-3	9.50E-02	mg/L	Based on Reference 10.
Maximum Phenanthrene Concentration in sediment in SMU 2 at all depths	NA	630	mg/kg	Baseline Value developed from Reference 19
Maximum Calculated Phenanthrene Porewater Concentration in SMU 2 at all depths	NA	2.66E-02	mg/L	Calculated as Cpw=Ws/Kd, Kd developed based on Reference 16; the measured Koc for pheneanthrene was 342,748 and the measured foc in SMU 2 was 0.069.
Maximum Phenanthrene Concentration in sediment in SMU 6 at all depths	NA	130	mg/kg	Developed from Reference 19
Maximum Calculated Phenanthrene Concentration in porewater in SMU 6 at all depths	NA	1.22E-02	mg/L	Calculated as Cpw=Ws/Kd, Kd developed based on Reference 16; the measured Koc for pheneanthrene was 342,748 and the measured foc in SMU 6 was 0.031.
Maximum Phenanthrene Concentration in sediment in SMU 7 at all depths	NA	380	mg/kg	Developed from Reference 19
Maximum Calculated Phenanthrene Concentration in porewater in SMU 7 at all depths	NA	1.61E-02	mg/L	Calculated as Cpw=Ws/Kd, Kd developed based on Reference 16; the measured Koc for pheneanthrene was 342,748 and the measured foc in SMU 7 was 0.069.
Diffusion Coefficient for Phenanthrene[13]	0.59E-5@20C	3.94E-6 @ 45F	cm^2/sec	Range developed based on Reference 7, Baseline Value based on Reference 20.

TABLE 2
MODEL INPUT

Parameter	Range	Baseline	Units	Reference/Source
Phenanthrene Half Life	3 - 800	800	days	Range developed based on Reference 3, Baseline Value conservatively based on maximum value of range.
Phenanthrene PEC	5.43E-01		mg/kg	Based on Reference 9
Pyrene				
Organic Carbon Partition Coefficient for Pyrene	43,650 - 3,981,000	208,930	mL/g	Range developed based on Reference 7, Baseline Value developed based on Reference 11
Pyrene Concentration in SMU 1	39.63E-3 - 95E-3	9.50E-02	mg/L	Based on Reference 10.
Maximum Pyrene Concentration in sediment in SMU 2 at all depths	NA	49	mg/kg	Baseline Value developed from Reference 16
Maximum Calculated Pyrene Porewater Concentration in SMU 2 at all depths	NA	3.40E-03	mg/L	Calculated as Cpw=Ws/Kd, Kd developed based on Reference 16; literature value used for Koc due to lack of porewater data (lit value of 208,930) the measured foc in SMU 2 was 0.069.
Maximum Pyrene Concentration in sediment in SMU 6 at all depths	NA	51	mg/kg	Developed from Reference 19
Maximum Pyrene Concentration in SMU 6 at all depths	NA	7.87E-03	mg/L	Calculated as Cpw=Ws/Kd, Kd developed based on Reference 16; literature value used for Koc due to lack of porewater data (lit value of 208,930) measured foc in SMU 6 was 0.031.
Maximum Pyrene Concentration in sediment in SMU 7 at all depths	NA	150	mg/kg	Developed from Reference 19
Maximum Pyrene Concentration in SMU 7 at all depths	NA	1.04E-02	mg/L	Calculated as Cpw=Ws/Kd, Kd developed based on Reference 16; literature value used for Koc due to lack of porewater data (lit value of 208,930) measured foc in SMU 7 was 0.069.
Diffusion Coefficient for Pyrene[13]	0.56E-5@20C	3.75E-6@45F	cm^2/sec	Range developed based on Reference 7, Baseline Value based on Reference 20.
Pyrene Half Life	840 - 8,000	8,000	days	Range developed based on Reference 3, Baseline Value conservatively based on maximum value of range.
Pyrene PEC	3.44E-01		mg/kg	Based on Reference 9
Benzo(a)pyrene				
Organic Carbon Partition Coefficient for Benzo(a)pyrene	891,000 - 25,119,900	1,096,478	mL/g	Range developed based on Reference 7, Baseline Value developed based on Reference 11
Benzo(a)pyrene Concentration in SMU 1	39.63E-3 - 95E-3	9.50E-02	mg/L	Based on Reference 10
Maximum Benzo(a)pyrene Concentration in SMU 2 at all depths	NA	31.00	mg/kg	Developed from Reference 19
Maximum Calculated Benzo(a)pyrene Concentration in porewater in SMU 2 at all depths	NA	4.10E-04	mg/L	Calculated as Cpw=Ws/Kd, Kd developed based on Reference 16; due to lack of porewater data a literature value was used for Koc (lit value of 1,096,478), the measured foc in SMU 2 was 0.069.
Maximum Benzo(a)pyrene Concentration in SMU 6 at all depths	NA	33.0	mg/kg	Developed from Reference 19
Maximum Calculated Benzo(a)pyrene Concentration in porewater in SMU 6 at all depths	NA	9.71E-04	mg/L	Calculated as Cpw=Ws/Kd, Kd developed based on Reference 16; due to lack of porewater data a literature value was used for Koc (lit value of 1,096,478), the measured foc in SMU 6 was 0.031.
Benzo(a)pyrene Concentration in SMU 7	4.99E-3 - 6.00E-3	6.00E-03	mg/L	Based on Reference 10
Average Diffusion Coefficient for Benzo(a)pyrene[13]	0.5E-5@20C	3.30E-6 @ 45 F	cm^2/sec	Range developed based on Reference 7, Baseline Value based on Reference 20.
Benzo(a)pyrene Half Life	57-2120	2120	days	Range developed based on Reference 3, Baseline Value conservatively based on maximum value of range.
Benzo(a)pyrene PEC	1.46E-01		mg/kg	Based on Reference 9
Hexachlorobenzene				
Hexachlorobenzene Partition Coefficient	501-2,511,886	1,513,561	mL/g	Range developed based on Reference 7, Baseline Value developed based on Reference 11
Maximum Hexachlorobenzene Concentration in sediment in SMU 1 at all depths	NA	1.2	mg/kg	Developed from Reference 19

TABLE 2
MODEL INPUT

Parameter	Range	Baseline	Units	Reference/Source
Maximum Calculated Hexachlorobenzene Porewater Concentration in SMU 1 at all depths	NA	1.18E-05	mg/L	Calculated as Cpw=Ws/Kd, Kd developed based on Reference 16; due to lack of porewater data a literature value was used for Koc (lit value of 1,513,561), the measured foc in SMU 1 was 0.067.
Maximum Hexachlorobenzene Concentration in sediment in SMU 4 at all depths	NA	1.38	mg/kg	Baseline Value developed from Reference 19
Maximum Calculated Hexachlorobenzene Porewater Concentration in SMU 4 at all depths	NA	2.34E-05	mg/L	Calculated as Cpw=Ws/Kd, Kd developed based on Reference 16; due to lack of porewater data a literature value was used for Koc (lit value of 1,513,561), the measured foc in SMU 4 was 0.039.
Average Diffusion Coefficient for Hexachlorobenzene	0.5E-5@20C	3.67E-6 @ 45 F	cm2/sec	Range developed based on Reference 7, Baseline Value based on Reference 20.
Hexachlorobenzene Half Life	986-8364	8364	days	Range developed based on Reference 3, Baseline Value conservatively based on maximum value of range.
Hexachlorobenzene PEC	1.64E-02		mg/kg	Based on Reference 9
PCBs				
General Organic Carbon Partition Coefficient for PCBs	275 - 162,181,000	1,380,384	mL/g	Range developed based on Reference 7, Baseline Value developed based on Reference 11
Maximum PCB Concentration in SMU 1	NA	22.5	mg/kg	Developed from Reference 19
Maximum Calculated PCB Concentration in porewater in SMU 1 at all depths	NA	2.43E-04	mg/L	Calculated as Cpw=Ws/Kd, Kd developed based on Reference 16; due to lack of porewater data a literature value was used for Koc (lit value of 1,380,384), the measured foc in SMU 1 was 0.067.
Maximum PCB Concentration in SMU 2	NA	3.8	mg/kg	Developed from Reference 19
Maximum Calculated PCB Concentration in porewater in SMU 2 at all depths	NA	3.99E-05	mg/L	Calculated as Cpw=Ws/Kd, Kd developed based on Reference 16; due to lack of porewater data a literature value was used for Koc (lit value of 1,380,384), the measured foc in SMU 2 was 0.069.
Maximum PCB Concentration in SMU 6 at all depths	NA	6.39E+00	mg/kg	Developed from Reference 19
Maximum Calculated PCB Concentration in porewater in SMU 6 at all depths	NA	1.49E-04	mg/L	Calculated as Cpw=Ws/Kd, Kd developed based on Reference 16; due to lack of porewater data a literature value was used for Koc (lit value of 1,380,384), the measured foc in SMU 6 was 0.031.
Maximum PCB Concentration in SMU 7 at all depths	NA	1.27E+01	mg/kg	Developed from Reference 19
Maximum Calculated PCB Concentration in porewater in SMU 7 at all depths	NA	1.33E-04	mg/L	Calculated as Cpw=Ws/Kd, Kd developed based on Reference 16; due to lack of porewater data a literature value was used for Koc (lit value of 1,380,384), the measured foc in SMU 7 was 0.069.
General Diffusion Coefficient for PCBs[13]	0.53E-5@20C	3.42E-6 @ 45 F	cm^2/sec	Range developed based on Reference 7, Baseline Value based on Reference 20.
PCB Half Life	NA	NA	days	
PCBs PEC	2.95E-01		mg/kg	Based on Reference 9
Benzene				
Organic Carbon Partition Coefficient for Benzene	25 - 1023	100	mL/g	Range developed based on Reference 7, Baseline Value developed based on Reference 11
Maximum Benzene Concentration in SMU 1 at all depths	NA	72.0	mg/kg	Developed from Reference 19
Maximum Calculated Benzene Concentration in porewater in SMU 1 at all depths	NA	1.07E+01	mg/L	Calculated as Cpw=Ws/Kd, Kd developed based on Reference 11; the measured foc in SMU 1 was 0.067.
Maximum Benzene Concentration in SMU 2 at all depths	NA	270.0	mg/kg	Developed from Reference 19
Maximum Calculated Benzene Concentration in porewater in SMU 2 at all depths	NA	3.91E+01	mg/L	Calculated as Cpw=Ws/Kd, Kd developed based on Reference 11; the measured foc in SMU 2 was 0.069.

TABLE 2
MODEL INPUT

Parameter	Range	Baseline	Units	Reference/Source
Maximum Benzene Concentration in SMU 3 at all depths	NA	8.40E+00	mg/kg	Developed from Reference 19
Maximum Calculated Benzene Concentration in porewater in SMU 3 at all depths	NA	2.40E+00	mg/L	Calculated as Cpw=Ws/Kd, Kd developed based on Reference 11; the measured foc in SMU 3 was 0.035.
Maximum Benzene Concentration in SMU 4 at all depths	NA	5.50E-02	mg/kg	Developed from Reference 19
Maximum Calculated Benzene Concentration in porewater in SMU 4 at all depths	NA	1.41E-02	mg/L	Calculated as Cpw=Ws/Kd, Kd developed based on Reference 11; the measured foc in SMU 4 was 0.039.
Maximum Benzene Concentration in SMU 6 at all depths	NA	1.90E-01	mg/kg	Developed from Reference 19
Maximum Calculated Benzene Concentration in porewater in SMU 6 at all depths	NA	6.13E-02	mg/L	Calculated as Cpw=Ws/Kd, Kd developed based on Reference 11; the measured foc in SMU 6 was 0.031.
Maximum Benzene Concentration in SMU 7 at all depths	NA	1.70E+01	mg/kg	Developed from Reference 19
Maximum Calculated Benzene Concentration in porewater in SMU 7 at all depths	NA	2.46E+00	mg/L	Calculated as Cpw=Ws/Kd, Kd developed based on Reference 11; the measured foc in SMU 7 was 0.069.
Diffusion Coefficient for Benzene	1.06E-5 - 1.13E-5 @25C	6.01E-6 @ 45F	cm^2/sec	Range developed based on Reference 7, Baseline Value based on Reference 20.
Benzene Half Life	5 - 720	720	days	Range developed based on Reference 3, Baseline Value developed based on Reference 2
Benzene SSC (foc=5%)	1.40E+00		mg/kg	Based on Reference 11
Benzene SSC (foc=1%)	2.80E-01		mg/kg	Based on Reference 11
Toluene				
Organic Carbon Partition Coefficient for Toluene	37 - 10,964	490	mL/g	Range developed based on Reference 7, Baseline Value developed based on Reference 11
Maximum Toluene Concentration in SMU 1 at all depths	NA	230.0	mg/kg	Developed from Reference 19
Maximum Calculated Toluene Concentration in porewater in SMU 1 at all depths	NA	7.01E+00	mg/L	Calculated as Cpw=Ws/Kd, Kd developed based on Reference 11; the measured foc in SMU 1 was 0.067.
Maximum Toluene Concentration in SMU 2 at all depths	NA	78.0	mg/kg	Developed from Reference 19
Maximum Calculated Toluene Concentration in porewater in SMU 2 at all depths	NA	2.31E+00	mg/L	Calculated as Cpw=Ws/Kd, Kd developed based on Reference 11; the measured foc in SMU 2 was 0.069.
Maximum Toluene Concentration in SMU 3 at all depths	NA	8.00E+00	mg/kg	Developed from Reference 19
Maximum Calculated Toluene Concentration in porewater in SMU 3 at all depths	NA	4.66E-01	mg/L	Calculated as Cpw=Ws/Kd, Kd developed based on Reference 11; the measured foc in SMU 3 was 0.035.
Maximum Toluene Concentration in SMU 4 at all depths	NA	4.00E-02	mg/kg	Developed from Reference 19
Maximum Calculated Toluene Concentration in porewater in SMU 4 at all depths	NA	2.09E-03	mg/L	Calculated as Cpw=Ws/Kd, Kd developed based on Reference 11; the measured foc in SMU 4 was 0.039.
Maximum Toluene Concentration in SMU 6 at all depths	NA	1.10E+00	mg/kg	Developed from Reference 19
Maximum Calculated Toluene Concentration in porewater in SMU 6 at all depths	NA	7.24E-02	mg/L	Calculated as Cpw=Ws/Kd, Kd developed based on Reference 11; the measured foc in SMU 6 was 0.031.
Maximum Toluene Concentration in SMU 7 at all depths	NA	3.20E+01	mg/kg	Developed from Reference 19
Maximum Calculated Toluene Concentration in porewater in SMU 7 at all depths	NA	9.46E-01	mg/L	Calculated as Cpw=Ws/Kd, Kd developed based on Reference 11; the measured foc in SMU 7 was 0.069.

TABLE 2
MODEL INPUT

Parameter	Range	Baseline	Units	Reference/Source
Diffusion Coefficient for Toluene[13]	0.93 E-5 - 0.95 E-5@ 25C	5.31E-6 @ 45F	cm^2/sec	Range developed based on Reference 7, Baseline Value based on Reference 20.
Toluene Half Life	8 - 365	365	days	Range developed based on Reference 3, Baseline Value developed based on Reference 2
Toluene SSC (foc=5%)	2.45E+00		mg/kg	Based on Reference 11
Toluene SSC (foc=1%)	4.90E-01		mg/kg	Based on Reference 11
Phenol				
Organic Carbon Partition Coefficient for Phenol	16-3090	100	mL/g	Range developed based on Reference 7, Baseline Value developed based on Reference 11
Maximum Phenol Concentration in porewater in SMU 1 at all depths	NA	5.30E+00	mg/L	Based on Reference 10
Maximum Phenol Concentration in SMU 2 at all depths	NA	1.9	mg/kg	Developed from Reference 19
Maximum Calculated Phenol Concentration in porewater in SMU 2 at all depths	NA	2.75E-01	mg/L	Calculated as Cpw=Ws/Kd, Kd developed based on Reference 11; the measured foc in SMU 2 was 0.069.
Maximum Phenol Concentration in SMU 6 at all depths	NA	8.50E-02	mg/kg	Developed from Reference 19
Maximum Calculated Phenol Concentration in porewater in SMU 6 at all depths	NA	2.74E-02	mg/L	Calculated as Cpw=Ws/Kd, Kd developed based on Reference 11; the measured foc in SMU 6 was 0.031.
Maximum Phenol Concentration in SMU 7 at all depths	NA	2.50E-01	mg/kg	Developed from Reference 19
Maximum Calculated Phenol Concentration in porewater in SMU 7 at all depths	NA	3.62E-02	mg/L	Calculated as Cpw=Ws/Kd, Kd developed based on Reference 11; the measured foc in SMU 7 was 0.069.
Diffusion Coefficient for Phenol	0.87e-5 @ 20C	5.75E-06	cm^2/sec	Range developed based on Reference 7, Baseline Value based on Reference 20.
Phenol Half Life	0.5 - 28	28	days	Range developed based on Reference 3, Baseline Value conservatively based on maximum value of range.
Phenol SSC (foc=5%)	1.25E+00		mg/kg	Based on Reference 11
Phenol SSC (foc=1%)	2.50E-01		mg/kg	Based on Reference 11

References:

NA - Not available
NC - Not calculated because of an insufficient number of deleted observations or data points

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TABLE 2
MODEL INPUT

Parameter	Range	Baseline	Units	Reference/Source

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16. Sediment concentrations were multiplied by the partitioning coefficient, Kd, (=Kocxfoc for organics) developed from the Parsons/Honeywell 2002/2003 porewater sampling effort to obtain porewater concentrations. If sufficient Kd data was not available from the porewater sampling effort, literature values (Reference 11) were used.

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TABLE 3
POREWATER CONCENTRATIONS SMU 1

Fluorene

Sample Locations	Porewater Concentrations ROUND 1 (µg/l)		Porewater Concentrations ROUND 2 (µg/l)	
SD-UW-TR05-A	50	ND	50	ND
SD-UW-TR05-B	55	ND	50	ND
SD-UW-TR02-B	5.5	ND	47	ND
SD-UW-TR02-C	48.5	ND	50	ND
SD-UW-TR03-A	95	ND	3.8	J
SD-UW-TR03-B	5.5	ND	75	ND
SD-UW-TR03-C	55	ND	24	ND
SD-UW-TR03-D	4.85	ND	80	ND
SD-UW-TR04-A	55	ND	47.5	ND
SD-UW-TR04-B	55	ND	48.5	ND
SD-UW-TR04-C	55	ND	50	ND
SD-UW-TR04-D	55	ND	49.5	ND

Fluorene	
C_O MAX=	95.00
C_O AVG=	46.44
C_O GEOMEAN=	35.60

Chlorobenzene

Sample Locations	Porewater Concentrations ROUND 1 (µg/l)		Porewater Concentrations ROUND 2 (µg/l)	
SD-UW-TR05-A	1.6		2.5	ND
SD-UW-TR05-B	38		12.5	ND
SD-UW-TR02-B	12.5	ND	5.2	
SD-UW-TR02-C	12.5	ND	5	ND
SD-UW-TR03-A	9		11	
SD-UW-TR03-B	380		380	
SD-UW-TR03-C	6.2		98	
SD-UW-TR03-D	2.5	ND	140	
SD-UW-TR04-A	5.1		2.5	ND
SD-UW-TR04-B	12.5	ND	12.5	ND
SD-UW-TR04-C	12.5	ND	12.5	ND
SD-UW-TR04-D	10		12.5	ND

Chlorobenzene	
C_O MAX=	380.00
C_O AVG=	49.86
C_O GEOMEAN=	13.28

Benzo (a) Pyrene

Sample Locations	Porewater Concentrations ROUND 1 (µg/l)		Porewater Concentrations ROUND 2 (µg/l)	
SD-UW-TR05-A	50	ND	50	ND
SD-UW-TR05-B	55	ND	50	ND
SD-UW-TR02-B	5.5	ND	47	ND
SD-UW-TR02-C	48.5	ND	50	ND
SD-UW-TR03-A	95	ND	5	ND
SD-UW-TR03-B	5.5	ND	75	ND
SD-UW-TR03-C	55	ND	24	ND
SD-UW-TR03-D	48.5	ND	80	ND
SD-UW-TR04-A	55	ND	47.5	ND
SD-UW-TR04-B	55	ND	48.5	ND
SD-UW-TR04-C	55	ND	50	ND
SD-UW-TR04-D	55	ND	49.5	ND

Benzo (a) Pyrene	
C_O MAX=	95.00
C_O AVG=	48.31
C_O GEOMEAN=	39.63

Xylene

Sample Locations	Porewater Concentrations ROUND 1 (µg/l)		Porewater Concentrations ROUND 2 (µg/l)	
SD-UW-TR05-A	33		12.8	
SD-UW-TR05-B	22.4		12.5	ND
SD-UW-TR02-B	12.5	ND	5	ND
SD-UW-TR02-C	12.5	ND	5	ND
SD-UW-TR03-A	186		332	
SD-UW-TR03-B	670		640	
SD-UW-TR03-C	4.9		142	
SD-UW-TR03-D	2.5	ND	214	
SD-UW-TR04-A	32		22.4	
SD-UW-TR04-B	12.5	ND	12.5	ND
SD-UW-TR04-C	12.5	ND	12.5	ND
SD-UW-TR04-D	6.6		12.5	ND

Xylene	
C_O MAX=	670.00
C_O AVG=	101.28
C_O GEOMEAN=	25.65

Mercury

Sample Locations	Porewater Concentrations ROUND 1 (µg/l)		Porewater Concentrations ROUND 2 (µg/l)	
SD-UW-TR05-A	0.0015		0.002	
SD-UW-TR05-B	632		748	
SD-UW-TR02-B	8.77		20.3	
SD-UW-TR02-C	0.167		0.0618	
SD-UW-TR03-A	9.43		12.1	
SD-UW-TR03-B	1.7		7.02	
SD-UW-TR03-C	50.4		87.6	
SD-UW-TR03-D	0.952		3.94	
SD-UW-TR04-A	0.0792		0.0904	
SD-UW-TR04-B	2.04		8.93	
SD-UW-TR04-C	7		6.88	
SD-UW-TR04-D	23.3		16.6	

Mercury	
C_O MAX=	748.00
C_O AVG=	68.64
C_O GEOMEAN=	2.92

Phenanthrene

Sample Locations	Porewater Concentrations ROUND 1 (µg/l)		Porewater Concentrations ROUND 2 (µg/l)	
SD-UW-TR05-A	50	ND	15	J
SD-UW-TR05-B	55	ND	50	ND
SD-UW-TR02-B	5.5	ND	47	ND
SD-UW-TR02-C	48.5	ND	50	ND
SD-UW-TR03-A	95	ND	2.8	J
SD-UW-TR03-B	5.5	ND	75	ND
SD-UW-TR03-C	55	ND	24	ND
SD-UW-TR03-D	4.85	ND	80	ND
SD-UW-TR04-A	55	ND	47.5	ND
SD-UW-TR04-B	55	ND	48.5	ND
SD-UW-TR04-C	55	ND	50	ND
SD-UW-TR04-D	55	ND	48.5	ND

Phenanthrene	
C_O MAX=	95.00
C_O AVG=	44.90
C_O GEOMEAN=	33.40

1,4 - Dichlorobenzene

Sample Locations	Porewater Concentrations ROUND 1 (µg/l)		Porewater Concentrations ROUND 2 (µg/l)	
SD-UW-TR05-A	50	ND	50	ND
SD-UW-TR05-B	55	ND	50	ND
SD-UW-TR02-B	5.5	ND	47	ND
SD-UW-TR02-C	48.5	ND	50	ND
SD-UW-TR03-A	95	ND	7.3	
SD-UW-TR03-B	14		75	ND
SD-UW-TR03-C	55	ND	13	
SD-UW-TR03-D	4.85	ND	80	ND
SD-UW-TR04-A	17		22	
SD-UW-TR04-B	55	ND	48.5	ND
SD-UW-TR04-C	55	ND	50	ND
SD-UW-TR04-D	55	ND	49.5	ND

1,4 - Dichlorobenzene	
C_O MAX=	95.00
C_O AVG=	43.84
C_O GEOMEAN=	34.19

1,3 - Dichlorobenzene

Sample Locations	Porewater Concentrations ROUND 1 (µg/l)		Porewater Concentrations ROUND 2 (µg/l)	
SD-UW-TR05-A	50	ND	50	ND
SD-UW-TR05-B	55	ND	50	ND
SD-UW-TR02-B	5.5	ND	47	ND
SD-UW-TR02-C	48.5	ND	50	ND
SD-UW-TR03-A	95	ND	5	ND
SD-UW-TR03-B	5.5	ND	75	ND
SD-UW-TR03-C	55	ND	24	ND
SD-UW-TR03-D	4.85	ND	80	ND
SD-UW-TR04-A	55	ND	47.5	ND
SD-UW-TR04-B	55	ND	48.5	ND
SD-UW-TR04-C	55	ND	50	ND
SD-UW-TR04-D	55	ND	48.5	ND

1,3 - Dichlorobenzene	
C_O MAX=	95.00
C_O AVG=	46.45
C_O GEOMEAN=	35.98

TABLE 3
POREWATER CONCENTRATIONS SMU 1

Sample Locations	Napthalene Porewater Concentrations ROUND 1 (µg/l)		Napthalene Porewater Concentrations ROUND 2 (µg/l)		Ethylbenzene Porewater Concentrations ROUND 1 (µg/l)		Ethylbenzene Porewater Concentrations ROUND 2 (µg/l)		o-Xylene Porewater Concentrations ROUND 1 (µg/l)		o-Xylene Porewater Concentrations ROUND 2 (µg/l)	
SD-UW-TR05-A	940		400		4.8	J	2.1	J	13		5.6	
SD-UW-TR05-B	55	ND	50	ND	5.4	J	12.5	ND	8.4	J	25	
SD-UW-TR02-B	1.1		47	ND	12.5	ND	5	ND	12.5	ND	5	ND
SD-UW-TR02-C	48.5	ND	50	ND	12.5	ND	5	ND	12.5	ND	5	ND
SD-UW-TR03-A	1600		860		8	J	14	J	46		82	
SD-UW-TR03-B	340		220		28		28		230		220	
SD-UW-TR03-C	55	ND	150		2.5	ND	5.6		1.9	J	49	
SD-UW-TR03-D	4.86	ND	80	ND	2.5	ND	8.7	J	2.5	ND	74	
SD-UW-TR04-A	920		1400		1.6	J	1.1	J	11		8.4	
SD-UW-TR04-B	55	ND	48.5	ND	12.5	ND	12.5	ND	12.5	ND	12.5	ND
SD-UW-TR04-C	55	ND	50	ND	12.5	ND	12.5	ND	12.5	ND	12.5	ND
SD-UW-TR04-D	55	ND	48.5	ND	12.5	ND	12.5	ND	12.5	ND	12.5	ND

Napthalene	
C_O MAX=	1600.00
C_O AVG=	313.89
C_O GEOMEAN=	100.32

Ethylbenzene	
C_O MAX=	28.00
C_O AVG=	9.78
C_O GEOMEAN=	7.27

o-Xylene	
C_O MAX=	230.00
C_O AVG=	36.95
C_O GEOMEAN=	15.91

Sample Locations	1,2 - Dichlorobenzene Porewater Concentrations ROUND 1 (µg/l)		1,2 - Dichlorobenzene Porewater Concentrations ROUND 2 (µg/l)		m+p-Xylene Porewater Concentrations ROUND 1 (µg/l)		m+p-Xylene Porewater Concentrations ROUND 2 (µg/l)		Pyrene Porewater Concentrations ROUND 1 (µg/l)		Pyrene Porewater Concentrations ROUND 2 (µg/l)		Phenol Porewater Concentrations ROUND 1 (µg/l)		Phenol Porewater Concentrations ROUND 2 (µg/l)	
SD-UW-TR05-A	55	ND	50	ND	20		7.2		50	ND	50	ND	300		130	ND
SD-UW-TR05-B	55	ND	50	ND	14	J	12.5	ND	55	ND	50	ND	3800		3700	
SD-UW-TR02-B	5.5	ND	47	ND	12.5	ND	5	ND	5.5	ND	47	ND	1200	J	1095	
SD-UW-TR02-C	48.5	ND	50	ND	9.2	J	10	ND	48.5	ND	50	ND	5300	J	3400	
SD-UW-TR03-A	95	ND	5.9		140		250		95	ND	5	ND	1500		870	
SD-UW-TR03-B	15		75	ND	440		420		5.5	ND	75	ND	1800	J	2200	
SD-UW-TR03-C	55	ND	13		3	J	93		55	ND	24	ND	190	J	250	
SD-UW-TR03-D	4.85	ND	80	ND	2.5	ND	140		48.5	ND	80	ND	120		2300	
SD-UW-TR04-A	21		28		21		14		55	ND	47.5	ND	680		570	
SD-UW-TR04-B	55	ND	48.5	ND	12.5	ND	12.5	ND	55	ND	48.5	ND	670		620	
SD-UW-TR04-C	55	ND	50	ND	12.5	ND	12.5	ND	55	ND	50	ND	790		2700	
SD-UW-TR04-D	55	ND	49.5	ND	6.6	J	12.5	ND	55	ND	49.5	ND	2500		2100	

1,2 - Dichlorobenzene	
C_O MAX=	95.00
C_O AVG=	44.45
C_O GEOMEAN=	34.77

m+p-Xylene	
C_O MAX=	440.00
C_O AVG=	70.13
C_O GEOMEAN=	21.00

Pyrene	
C_O MAX=	95.00
C_O AVG=	48.31
C_O GEOMEAN=	39.63

Phenol	
C_O MAX=	5300.00
C_O AVG=	1616.04
C_O GEOMEAN=	1019.40

TABLE 3 (Continued)
POREWATER CONCENTRATIONS SMU 4

Mercury

Sample Locations	Porewater Concentrations ROUND 1 (µg/l)		Porewater Concentrations ROUND 2 (µg/l)	
SD-UW-TR01-A	0.0412		0.0102	
SD-UW-TR01-B	0.0048		0.0005	ND
SD-UW-TR01-C	0.007		0.0105	

Mercury	
C_O MAX=	0.0412
C_O AVG=	0.0124
C_O GEOMEAN=	0.0065

TABLE 3, CONTINUED
POREWATER CONCENTRATIONS SMU 7

Chlorobenzene

Sample Locations	Porewater Concentrations ROUND 1 (µg/l)		Porewater Concentrations ROUND 2 (µg/l)	
SD-UW-TR05-C	39		25	ND
SD-UW-TR05-D	12.5	ND	12.5	ND
SD-UW-TR06-A	2.5	ND	4.7	
SD-UW-TR06-B	5	ND	5	ND
SD-UW-TR06-C	25	ND	25	ND

Chlorobenzene	
C_O MAX=	39.00
C_O AVG=	15.62
C_O GEOMEAN=	11.08

Xylene

Sample Locations	Porewater Concentrations ROUND 1 (µg/l)		Porewater Concentrations ROUND 2 (µg/l)	
SD-UW-TR05-C	25	ND	25	ND
SD-UW-TR05-D	12.5	ND	12.5	ND
SD-UW-TR06-A	2.5	ND	3.4	
SD-UW-TR06-B	5	ND	5	ND
SD-UW-TR06-C	25	ND	25	ND

Xylene	
C_O MAX=	25.00
C_O AVG=	14.09
C_O GEOMEAN=	10.26

Fluorene

Sample Locations	Porewater Concentrations ROUND 1 (µg/l)		0.0 (µg/l)	
SD-UW-TR05-C				
SD-UW-TR05-D				
SD-UW-TR06-A	2.3	J	7.1	J
SD-UW-TR06-B	5.0	ND	5.5	ND
SD-UW-TR06-C	4.8	ND	4.9	ND

Fluorene	
C_O MAX=	7.10
C_O AVG=	4.92
C_O GEOMEAN=	4.67

Phenanthrene

Sample Locations	Porewater Concentrations ROUND 1 (µg/l)		Porewater Concentrations ROUND 2 (µg/l)	
SD-UW-TR05-C	5.5	ND	5.5	ND
SD-UW-TR05-D	6	ND	5	ND
SD-UW-TR06-A	4.2	J	15	
SD-UW-TR06-B	5	ND	5.5	ND
SD-UW-TR06-C	4.75	ND	4.85	ND

Phenanthrene	
C_O MAX=	15.00
C_O AVG=	6.13
C_O GEOMEAN=	5.70

Pyrene

Sample Locations	Porewater Concentrations ROUND 1 (µg/l)		Porewater Concentrations ROUND 2 (µg/l)	
SD-UW-TR05-C	5.5	ND	5.5	ND
SD-UW-TR05-D	6	ND	5	ND
SD-UW-TR06-A	2.2	J	9.1	J
SD-UW-TR06-B	5	ND	5.5	ND
SD-UW-TR06-C	4.75	ND	4.85	ND

Pyrene	
C_O MAX=	9.10
C_O AVG=	5.34
C_O GEOMEAN=	5.08

Benzo (a) pyrene

Sample Locations	Porewater Concentrations ROUND 1 (µg/l)		Porewater Concentrations ROUND 2 (µg/l)	
SD-UW-TR05-C	5.5	ND	5.5	ND
SD-UW-TR05-D	6	ND	5	ND
SD-UW-TR06-A	6	ND	2.8	J
SD-UW-TR06-B	5	ND	5.5	ND
SD-UW-TR06-C	4.75	ND	4.85	ND

Benzo (a) pyrene	
C_O MAX=	6.00
C_O AVG=	5.09
C_O GEOMEAN=	4.99

TABLE 3, CONTINUED
POREWATER CONCENTRATIONS SMU 7

Napthalene

Sample Locations	Porewater Concentrations ROUND 1 (µg/l)		Porewater Concentrations ROUND 2 (µg/l)	
SD-UW-TR05-C	5.5	ND	5.5	ND
SD-UW-TR05-D	1.9		5	ND
SD-UW-TR06-A	120		73	
SD-UW-TR06-B	5	ND	5.5	ND
SD-UW-TR06-C	4.75	ND	4.95	ND

Napthalene
C_O MAX= 120.00
C_O AVG= 23.11
C_O GEOMEAN= 8.34

1,2 - Dichlorobenzene

Sample Locations	Porewater Concentrations ROUND 1 (µg/l)		Porewater Concentrations ROUND 2 (µg/l)	
SD-UW-TR05-C	5.5	ND	5.5	ND
SD-UW-TR05-D	6	ND	5	ND
SD-UW-TR06-A	6	ND	5	ND
SD-UW-TR06-B	5	ND	5.5	ND
SD-UW-TR06-C	4.75	ND	4.85	ND

1,2 - Dichlorobenzene
C_O MAX= 6.00
C_O AVG= 5.31
C_O GEOMEAN= 5.29

1,4 - Dichlorobenzene

Sample Locations	Porewater Concentrations ROUND 1 (µg/l)		Porewater Concentrations ROUND 2 (µg/l)	
SD-UW-TR05-C	1.6		5.5	ND
SD-UW-TR05-D	2.5		5	ND
SD-UW-TR06-A	4		4.3	
SD-UW-TR06-B	5	ND	5.5	ND
SD-UW-TR06-C	4.75	ND	4.85	ND

1,4 - Dichlorobenzene
C_O MAX= 5.50
C_O AVG= 4.30
C_O GEOMEAN= 4.05

o-Xylene

Sample Locations	Porewater Concentrations ROUND 1 (µg/l)		Porewater Concentrations ROUND 2 (µg/l)	
SD-UW-TR05-C	25	ND	50	
SD-UW-TR05-D	12.5	ND	25	
SD-UW-TR06-A	2.5	ND	1.1	J
SD-UW-TR06-B	5	ND	5	ND
SD-UW-TR06-C	25	ND	25	ND

o-Xylene
C_O MAX= 50.00
C_O AVG= 17.61
C_O GEOMEAN= 10.53

1,3 - Dichlorobenzene

Sample Locations	Porewater Concentrations ROUND 1 (µg/l)		Porewater Concentrations ROUND 2 (µg/l)	
SD-UW-TR05-C	5.5	ND	5.5	ND
SD-UW-TR05-D	6	ND	5	ND
SD-UW-TR06-A	6	ND	5	ND
SD-UW-TR06-B	5	ND	5.5	ND
SD-UW-TR06-C	4.75	ND	4.85	ND

1,3 - Dichlorobenzene
C_O MAX= 6.00
C_O AVG= 5.31
C_O GEOMEAN= 5.29

Mercury

Sample Locations	Porewater Concentrations ROUND 1 (µg/l)		Porewater Concentrations ROUND 2 (µg/l)	
SD-UW-TR05-C	0.0323		0.022	
SD-UW-TR05-D	0.016		0.0187	
SD-UW-TR06-A	0.0245		0.0158	
SD-UW-TR06-B	0.007		0.0056	
SD-UW-TR06-C	0.0176		0.005	

Mercury
C_O MAX= 0.03
C_O AVG= 0.02
C_O GEOMEAN= 0.01

Ethylbenzene

Sample Locations	Porewater Concentrations ROUND 1 (µg/l)		Porewater Concentrations ROUND 2 (µg/l)	
SD-UW-TR05-C	25	ND	25	ND
SD-UW-TR05-D	12.5	ND	12.5	ND
SD-UW-TR06-A	2.5	ND	2.5	ND
SD-UW-TR06-B	5	ND	5	ND
SD-UW-TR06-C	25	ND	25	ND

Ethylbenzene
C_O MAX= 25.00
C_O AVG= 14.00
C_O GEOMEAN= 9.95

m+p-Xylene

Sample Locations	Porewater Concentrations ROUND 1 (µg/l)		Porewater Concentrations ROUND 2 (µg/l)	
SD-UW-TR05-C	25	ND	25	ND
SD-UW-TR05-D	12.5	ND	12.5	ND
SD-UW-TR06-A	2.5	ND	2.3	J
SD-UW-TR06-B	5	ND	5	ND
SD-UW-TR06-C	25	ND	25	ND

m+p-Xylene
C_O MAX= 25.00
C_O AVG= 13.98
C_O GEOMEAN= 9.87

TABLE 4
MAXIMUM SEDIMENT CONCENTRATIONS (ug/kg)

Chemical	**SMU1**	**SMU2**	**SMU3**	**SMU4**	**SMU6**	**SMU7**
Mercury	77,700	23,000	-	125,000	17,200	71,000
Ethylbenzene	29,000	71,000	1,100	-	-	7,100
Total Xylene [1]	430,000	330,000	28,850	-	65,000	120,000
Chlorobenzene	1,000,000	640,000	-	-	-	150,000
Dichlorobenzenes (Sum)	1,052,000	155,000	-	-	5,400	661,000
Naphthalene	1,300,000	26,000,000	14,000	-	120,000	500,000
Fluorene	97,000	42,000	-	-	35,000	140,000
Phenanthrene	180,000	630,000	-	-	130,000	380,000
Pyrene	220,000	49,000	-	-	51,000	150,000
Benzo(a)pyrene	18,000	31,000	-	-	33,000	65,000
Hexachlorobenzene	1,190	-	-	1,380	-	-
PCBs	22,500	3,800	-	-	6,390	12,700
Benzene	72,000	270,000	8,400	55	190	17,000
Toluene	230,000	78,000	8,000	40	1,100	32,000
Phenol	16,000	1,900	-	-	85	250

Notes:

[1] The data for total xylene include the lab analyzed total or the sum of the isomers, whichever data were available.

Field duplicates are averaged.

- Indicates compund was not a CPOI in that SMU.

TABLE 5
Kd/Koc SUMMARY TABLE

CPOI	Site-Specific Koc[1]	Range of Koc[2,4] from Literature	Literature Koc[3,4] used for Chemical Isolation Layer and Volatile Compounds Initial Concentration Development
	mL/g	mL/g	mL/g
Mercury	6,961 (kd value)	60 - 990,000	2,200
Benzene	1,262	25 - 1023	100
Toluene	6,899	37 - 10,964	490
Phenol	96	16-3090	100
Ethylbenzene	22,280	165 - 588	588
Xylene	21,175	40-2,000	1,413
Chlorobenzene	4,172	81 - 500	500
Dichlorobenzene	21,322	169-39,810	2,399
Napthalene	24,244	415 - 100,000	2,344
Fluorene	NA	3,980 - 213,800	15,136
Phenanthrene	342,748	1,400-1,318,000	28,184
Pyrene	NA	43,650 - 3,981,000	208,930
Benzo(a)pyrene	NA	891,000 - 25,119,900	1,096,478
Hexachlorobenzene	NA	501-2,511,886	1,513,561
PCBs	NA	275 - 162,181,000	1,380,384

NA - Not available; CPOI was not analyzed in 2002/2003 pore water sampling or the data that was collected returned a majority of non detects.

1. Geometeric mean of K_{oc} for Onondaga Lake Sediment. Values as determined from Parsons/Honeywell Upwelling Investigation and Porewater Sampling in 2002/2003, through the relationship $K_d=W_s/C_{pw}$ and $K_d=K_{oc}f_{oc.}$ Certain compounds had insufficient porewater data to calculated a site-specific Koc; therfore, a value was used from literature (Pyrene, Fluorene, BAP, HCB and PCBs)

2. As referenced in chemical isolation layer model input table.

3. K_{oc} values used to determine partitioning in the chemical isolation layer model (from porewater onto cap material) differ from those values measured in the field due to the chemical characteristics and sorption phenomena within an aged sediment. K_{oc} values used in the cap model were extracted from the NYSDEC's Technical Sediment Screening Guidance (1999), which provides a table of K_{ow} (where the guidance suggests K_{ow} is approximatly equal to Koc) values for various contaminants; if the value provided in this guidance was greater than the range provided in literature the Koc for the cap model was conservativly selected from literature (applied to Ethylbenzene, chlorobenzene). These values were also used to calculate initial porewater concentrations from sediment data for volatile compounds where porewater data was insufficient or unavailable.

4. Values shown for mercury is partitioning coefficients (K_d) not organic carbon partitioning coefficients (K_{oc}). $K_d=W_s/C_{pw}$.

TABLE 6
SURFICIAL T_{oc} DATA

SMU	Average T_{oc}	f_{oc}
1	6.68	0.067
2	6.86	0.069
3	3.46	0.035
4	3.93	0.039
5	3.12	0.031
6	3.09	0.031
7	6.88	0.069
8	3.4	0.034

1 PERCENT f_{oc} IN BIOTURBATION LAYER

SMU 1

foc	z	kbio(particle) cm/yr	1	kbl cm/hr	1
0.10%	76.25	kbio(water) cm/yr	100	foc (bio layer)	0.01

Variable	ρ_b	ε or (n)	v	U	C_o	a	Vb	Dw	Hp	D'	foc	Koc	K_d	z	R_f	t_{50}	λ	u	SS Rxn	Approximate Time to Steady Conditions	Maximum of Diffusive or Advective Flux	Reactive Flux	Sediment Concentration (W_{bio})	*PEC*	PEC Exceedence?	Sediment Concentration (W_{bio}) Assuming 1.5X Safety Factor Applied to Thickness (z)
	Bulk density of cap material (1-ε)*ρs	Porosity	Pore water Velocity (U/ε)	Darcy Velocity (or v*ε)	Initial pore water concentration	Dispersivity	Organic Compd LeBas Molar Volume	Molecular diffusion coefficient (at 45 F)	Hindrance Parameter ($\varepsilon^{-1/3}$)	Diffusion/dispersion coefficient	Fraction of organic carbon in cap material	Organic carbon partition coeff for organics	Observed partition coefficient for CB (organics=foc*Koc, metals=literature value))	Chemical Isolation Layer Thickness	Retardation Factor	Half Life	Reaction Term (=ln2/t_{50})	$\sqrt{v^2+4\lambda D'}$								
	g/cm^3		cm/yr	cm/yr	mg/L		cm3/mol	cm^2/sec		cm^2/yr		mL/g	L/kg	cm		day	yr^{-1}		/cm	years	mg/cm2/yr	mg/cm2/yr	mg/kg	mg/kg		mg/kg
Mercury	1.59	0.4	5.0	2	7.48E-01	0.0125		1.96E-06	1.4	46	0.1%	NA	2,200	76.25	8746	0	0.0	5	0	133376.5	1.50E-03	NC	1.29E+00	2.20E+00	does not exceed	1.29E+00
Ethylbenzene	1.59	0.4	5.0	2	7.36E-01	0.0125	140.4	4.80E-06	1.4	112	0.1%	588	0.59	76.25	3	228	1.1	23	0.09966	50.9	1.47E-03	3.28E-06	1.75E-04	1.76E-01	does not exceed	3.92E-06
Xylene	1.59	0.4	5.0	2	4.54E+00	0.0125	140.4	4.80E-06	1.4	112	0.1%	1,413	1.41	76.25	7	767	0.3	13	0.05434	100.9	9.08E-03	3.50E-04	4.02E-02	5.61E-01	does not exceed	5.06E-03
Chlorobenzene	1.59	0.4	5.0	2	2.99E+01	0.0125	116.9	5.35E-06	1.4	124	0.1%	500	0.50	76.25	3	600	0.4	15	0.05821	45.6	5.98E-02	2.05E-03	9.39E-02	4.28E-01	does not exceed	1.02E-02
Dichlorobenzene	1.59	0.4	5.0	2	6.53E+00	0.0125	137.8	4.85E-06	1.4	113	0.1%	2,399	2.40	76.25	11	720	0.4	14	0.05577	160.7	1.31E-02	4.68E-04	8.12E-02	2.39E-01	does not exceed	9.68E-03
Naphthalene	1.59	0.4	5.0	2	8.28E+00	0.0125	147.6	4.66E-06	1.4	108	0.1%	2,344	2.34	76.25	10	219	1.2	23	0.1032	157.3	1.66E-02	2.84E-05	4.84E-03	9.17E-01	does not exceed	9.46E-05
Fluorene	1.59	0.4	5.0	2	9.50E-02	0.0125	187.9	4.04E-06	1.4	94	0.1%	15,136	15.14	76.25	61	240	1.1	21	0.10584	932.8	1.90E-04	2.37E-07	1.09E-04	2.64E-01	does not exceed	1.92E-06
Phenanthrene	1.59	0.4	5.0	2	9.50E-02	0.0125	196.7	3.94E-06	1.4	92	0.1%	28,184	28.18	76.25	113	800	0.3	12	0.05875	1723.7	1.90E-04	4.64E-06	2.52E-03	5.43E-01	does not exceed	2.68E-04
Pyrene	1.59	0.4	5.0	2	9.50E-02	0.0125	213.8	3.75E-06	1.4	87	0.1%	208,930	208.93	76.25	831	8000	0.0	6	0.01904	12680.3	1.90E-04	1.17E-04	9.95E-02	3.44E-01	does not exceed	7.82E-02
Benzo(a)pyrene	1.59	0.4	5.0	2	9.50E-02	0.0125	265.4	3.30E-06	1.4	77	0.1%	1,096,478	1,096	76.25	4360	2120	0.1	8	0.03942	66482.4	1.90E-04	3.08E-05	5.78E-02	1.46E-01	does not exceed	2.33E-02
Hexachlorobenzene	1.59	0.4	5.0	2	1.18E-05	0.0125	221.4	3.67E-06	1.4	85	0.1%	1,513,561	1,514	76.25	6017	8364	0.0	6	0.01881	91765.4	2.36E-08	1.49E-08	3.50E-05		NA	2.78E-05
							Est.																			
PCB's	1.59	0.4	5.0	2	2.43E-04	0.0125	250.0	3.42E-06	1.4	80	0.1%	1,380,384	1,380	76.25	5488	0	0.0	5	0	83692.4	4.87E-07	NC	3.69E-03	2.95E-01	does not exceed	3.69E-03

Notes:

Not a CPOI in this SMU

NA - Not applicable (See Attachment G)

NC - Not calculated

1 PERCENT f_{oc} IN BIOTURBATION LAYER

SMU 2

foc	z	kbio(particle) cm/yr		kbl cm/hr	
0.10%	76.25	kbio(water) cm/yr	1 100	foc (bio layer)	1 0.01

Variable	ρ_b	ε or (n)	v	U	C_o	a	Vb	Dw	Hp	D'	foc	Koc	K_d	z	R_f	t_{50}	λ	u	SS Rxn	Approximate Time to Steady Conditions	Maximum of Diffusive or Advective Flux	Reactive Flux	Sediment Concentration (W_{bio})	*PEC*	PEC Exceedence?	Sediment Concentration (W_{bio}) Assuming 1.5X Safety Factor Applied to Thickness (z)
	Bulk density of cap material (1-ε)*ps	Porosity	Pore water Velocity (U/ε)	Darcy Velocity (or v*ε)	Initial pore water concentration	Dispersivity	Organic Compd LeBas Molar Volume	Molecular diffusion coefficient (at 45 F)	Hindrance Parameter ($\varepsilon^{-1/3}$)	Diffusion/dispersion coefficient	Fraction of organic carbon in cap material	Organic carbon partition coeff for organics	Observed partition coefficient for CB (organics=foc*Koc, metals=literature value))	Chemical Isolation Layer Thickness	Retardation Factor	Half Life	Reaction Term (=ln2/t_{50})	$\sqrt{v^2+4\lambda D'}$								
	g/cm^3		cm/yr	cm/yr	mg/L		cm3/mol	cm^2/sec		cm^2/yr		mL/g	L/kg	cm		day	yr^{-1}		/cm	years	mg/cm2/yr	mg/cm2/yr	mg/kg	mg/kg		mg/kg
Mercury	1.59	0.4	5.0	2	3.30E-03	0.0125		1.96E-06	1.4	46	0.1%	NA	2,200	76.25	8746	0	0.0	5	0	133376.5	6.61E-06	NC	5.70E-03	2.20E+00	does not exceed	5.70E-03
Ethylbenzene	1.59	0.4	5.0	2	1.75E+00	0.0125	140.4	4.80E-06	1.4	112	0.1%	588	0.59	76.25	3	228	1.1	23	0.09966	50.9	3.50E-03	7.81E-06	4.16E-04	1.76E-01	does not exceed	9.31E-06
Xylene	1.59	0.4	5.0	2	3.38E+00	0.0125	140.4	4.80E-06	1.4	112	0.1%	1,413	1.41	76.25	7	767	0.3	13	0.05434	100.9	6.76E-03	2.61E-04	2.99E-02	5.61E-01	does not exceed	3.77E-03
Chlorobenzene	1.59	0.4	5.0	2	1.86E+01	0.0125	116.9	5.35E-06	1.4	124	0.1%	500	0.50	76.25	3	600	0.4	15	0.05821	45.6	3.72E-02	1.27E-03	5.84E-02	4.28E-01	does not exceed	6.35E-03
Dichlorobenzenes	1.59	0.4	5.0	2	9.36E-01	0.0125	137.8	4.85E-06	1.4	113	0.1%	2,399	2.40	76.25	11	720	0.4	14	0.05577	160.7	1.87E-03	6.71E-05	1.16E-02	2.39E-01	does not exceed	1.39E-03
Naphthalene	1.59	0.4	5.0	2	1.61E+02	0.0125	147.6	4.66E-06	1.4	108	0.1%	2,344	2.34	76.25	10	219	1.2	23	0.1032	157.3	3.22E-01	5.51E-04	9.40E-02	9.17E-01	does not exceed	1.84E-03
Fluorene	1.59	0.4	5.0	2	4.02E-02	0.0125	187.9	4.04E-06	1.4	94	0.1%	15,136	15.14	76.25	61	240	1.1	21	0.10584	932.8	8.04E-05	1.00E-07	4.59E-05	2.64E-01	does not exceed	8.13E-07
Phenanthrene	1.59	0.4	5.0	2	2.66E-02	0.0125	196.7	3.94E-06	1.4	92	0.1%	28,184	28.18	76.25	113	800	0.3	12	0.05875	1723.7	5.32E-05	1.30E-06	7.06E-04	5.43E-01	does not exceed	7.52E-05
Pyrene	1.59	0.4	5.0	2	3.40E-03	0.0125	213.8	3.75E-06	1.4	87	0.1%	208,930	208.93	76.25	831	8000	0.0	6	0.01904	12680.3	6.80E-06	4.20E-06	3.56E-03	3.44E-01	does not exceed	2.80E-03
Benzo(a)pyrene	1.59	0.4	5.0	2	4.10E-04	0.0125	265.4	3.30E-06	1.4	77	0.1%	1,096,478	1,096	76.25	4360	2120	0.1	8	0.03942	66482.4	8.19E-07	1.33E-07	2.49E-04	1.46E-01	does not exceed	1.00E-04
Hexachlorobenzene	1.59	0.4	5.0	2	0.00E+00	0.0125	221.4	3.67E-06	1.4	85	0.1%	1,513,561	1,514	76.25	6017	8364	0.0	6	0.01881	91765.4	0.00E+00	0.00E+00	0.00E+00		NA	0.00E+00
							Est.																			
PCB's	1.59	0.4	5.0	2	3.99E-05	0.0125	250.0	3.42E-06	1.4	80	0.1%	1,380,384	1,380	76.25	5488	0	0.0	5	0	83692.4	7.98E-08	NC	6.05E-04	2.95E-01	does not exceed	6.05E-04

Notes:

Not a CPOI in this SMU

NA - Not applicable (See Attachment G)

NC - Not calculated

1 PERCENT f_{oc} IN BIOTURBATION LAYER

SMU 3

z 30.5

foc 0.10%

kbio(particle) cm/yr 1 kbl cm/hr 1

kbio(water) cm/yr 100 foc (bio layer) 0.01

Variable	ρ_b	ε or (n)	v	U	C_o	a	Vb	Dw	Hp	D'	foc	Koc	K_d	z	R_f	t_{50}	λ	u	SS Rxn	Approximate Time to Steady Conditions	Maximum of Diffusive or Advective Flux	Reactive Flux	Sediment Concentration (W_{bio})	*PEC*	PEC Exceedence?	Sediment Concentration (W_{bio}) Assuming 1.5X Safety Factor Applied to Thickness (z)
	Bulk density of cap material (1-ε)*ps	Porosity	Pore water Velocity (U/ε)	Darcy Velocity (or v*ε)	Initial pore water concentration	Dispersivity	Organic Compd LeBas Molar Volume	Molecular diffusion coefficient (at 45 F)	Hindrance Parameter ($\varepsilon^{-1/3}$)	Diffusion/dispersion coefficient	Fraction of organic carbon in cap material	Organic carbon partition coeff for organics	Observed partition coefficient for CB (organics=foc*Koc, metals=literature value))	Chemical Isolation Layer Thickness	Retardation Factor	Half Life	Reaction Term (=ln2/t_{50})	$\sqrt{v^2+4\lambda D'}$								
	g/cm^3		cm/yr	cm/yr	mg/L		cm3/mol	cm^2/sec		cm^2/yr		mL/g	L/kg	cm		day	yr^{-1}		/cm	years	mg/cm2/yr	mg/cm2/yr	mg/kg	mg/kg		mg/kg
Mercury	1.59	0.4	1750.0	700	0.00E+00	0.0125		1.96E-06	1.4	67	0.1%	NA	2,200	30.5	8746	0	0.0	1750	0	152.4	0.00E+00	NC	0.00E+00	2.20E+00	does not exceed	0.00E+00
	1.59	0.4	12.5	5	0.00E+00	0.0125		1.96E-06	1.4	46	0.1%	NA	2,200	30.5	8746	0	0.0	13	0	21340.2	0.00E+00	NC	0.00E+00	2.20E+00	does not exceed	0.00E+00
Ethylbenzene	1.59	0.4	1750.0	700	5.34E-02	0.0125	140.4	4.80E-06	1.4	134	0.1%	588	0.59	30.5	3	228	1.1	1750	0.09116	0.1	3.74E-02	3.67E-02	2.89E-01	1.76E-01	does not exceed	2.86E-01
	1.59	0.4	12.5	5	5.34E-02	0.0125	140.4	4.80E-06	1.4	112	0.1%	588	0.59	30.5	3	228	1.1	26	0.09962	8.1	2.67E-04	2.28E-05	1.19E-03	1.76E-01	does not exceed	2.59E-04
Xylene	1.59	0.4	1750.0	700	5.83E-01	0.0125	140.4	4.80E-06	1.4	134	0.1%	1,413	1.41	30.5	7	767	0.3	1750	0.0497	0.1	4.08E-01	4.06E-01	7.57E+00	5.61E-01	Exceeds PEC	7.55E+00
	1.59	0.4	12.5	5	5.83E-01	0.0125	140.4	4.80E-06	1.4	112	0.1%	1,413	1.41	30.5	7	767	0.3	17	0.05431	16.1	2.92E-03	1.30E-03	1.46E-01		does not exceed	9.77E-02
Chlorobenzene	1.59	0.4	1750.0	700	0.00E+00	0.0125	116.9	5.35E-06	1.4	146	0.1%	500	1	30.5	3	600	0.4	1750	0.05369	0.1	0.00E+00	0.00E+00	0.00E+00	4.28E-01	does not exceed	0.00E+00
	1.59	0.4	12.5	5	0.00E+00	0.0125	116.9	5.35E-06	1.4	125	0.1%	500	1	30.5	3	600	0.4	19	0.05819	7.3	0.00E+00	0.00E+00	0.00E+00	4.28E-01	does not exceed	0.00E+00
Dichlorobenzene	1.59	0.4	1750.0	700	0.00E+00	0.0125	137.8	4.85E-06	1.4	135	0.1%	2,399	2	30.5	11	720	0.4	1750	0.05106	0.2	0.00E+00	0.00E+00	0.00E+00		does not exceed	0.00E+00
	1.59	0.4	12.5	5	0.00E+00	0.0125	137.8	4.85E-06	1.4	113	0.1%	2,399	2	30.5	11	720	0.4	18	0.05575	25.7	0.00E+00	0.00E+00	0.00E+00		does not exceed	0.00E+00
Naphthalene	1.59	0.4	1750.0	700	1.71E-01	0.0125	147.6	4.66E-06	1.4	130	0.1%	2,344	2.34	30.5	10	219	1.2	1750	0.09416	0.2	1.20E-01	1.17E-01	3.57E+00	9.17E-01	Exceeds PEC	3.54E+00
	1.59	0.4	12.5	5	1.71E-01	0.0125	147.6	4.66E-06	1.4	109	0.1%	2,344	2.34	30.5	10	219	1.2	26	0.10315	25.2	8.55E-04	6.60E-05	1.10E-02	9.17E-01	does not exceed	2.28E-03
Fluorene	1.59	0.4	1750.0	700	0.00E+00	0.0125	187.9	4.04E-06	1.4	116	0.1%	15,136	15	30.5	61	240	1.1	1750	0.09536	1.1	0.00E+00	0.00E+00	0.00E+00	2.64E-01	does not exceed	0.00E+00
	1.59	0.4	12.5	5	0.00E+00	0.0125	187.9	4.04E-06	1.4	94	0.1%	15,136	15	30.5	61	240	1.1	24	0.10578	149.2	0.00E+00	0.00E+00	0.00E+00	2.64E-01	does not exceed	0.00E+00
Phenanthrene	1.59	0.4	1750.0	700	0.00E+00	0.0125	196.7	3.94E-06	1.4	113	0.1%	28,184	28	30.5	113	800	0.3	1750	0.0528	2.0	0.00E+00	0.00E+00	0.00E+00	5.43E-01	does not exceed	0.00E+00
	1.59	0.4	12.5	5	0.00E+00	0.0125	196.7	3.94E-06	1.4	92	0.1%	28,184	28	30.5	113	800	0.3	16	0.05872	275.8	0.00E+00	0.00E+00	0.00E+00	5.43E-01	does not exceed	0.00E+00
Pyrene	1.59	0.4	1750.0	700	0.00E+00	0.0125	213.8	3.75E-06	1.4	109	0.1%	208,930	209	30.5	831	8000	0.0	1750	0.01703	14.5	0.00E+00	0.00E+00	0.00E+00	3.44E-01	does not exceed	0.00E+00
	1.59	0.4	12.5	5	0.00E+00	0.0125	213.8	3.75E-06	1.4	87	0.1%	208,930	209	30.5	831	8000	0.0	13	0.01903	2028.9	0.00E+00	0.00E+00	0.00E+00	3.44E-01	does not exceed	0.00E+00
Benzo(a)pyrene	1.59	0.4	1750.0	700	0.00E+00	0.0125	265.4	3.30E-06	1.4	99	0.1%	1,096,478	1,096	30.5	4360	2120	0.1	1750	0.03479	76.0	0.00E+00	0.00E+00	0.00E+00	1.46E-01	does not exceed	0.00E+00
	1.59	0.4	12.5	5	0.00E+00	0.0125	265.4	3.30E-06	1.4	77	0.1%	1,096,478	1,096	30.5	4360	2120	0.1	14	0.0394	10637.2	0.00E+00	0.00E+00	0.00E+00	1.46E-01	does not exceed	0.00E+00
Hexachlorobenzene	1.59	0.4	1750.0	700	0.00E+00	0.0125	221.4	3.67E-06	1.4	107	0.1%	1,513,561	1,514	30.5	6017	8364	0.0	1750	0.01679	104.9	0.00E+00	0.00E+00	0.00E+00			0.00E+00
	1.59	0.4	12.5	5	0.00E+00	0.0125	221.4	3.67E-06	1.4	86	0.1%	1,513,561	1,514	30.5	6017	8364	0.0	13	0.0188	14682.5	0.00E+00	0.00E+00	0.00E+00			0.00E+00
							Est.																			
PCB's	1.59	0.4	1750.0	700	0.00E+00	0.0125	250.0	3.42E-06	1.4	101	0.1%	1,380,384	1,380	30.5	5488	0	0.0	1750	0	95.6	0.00E+00	NC	0.00E+00	2.95E-01	does not exceed	0.00E+00
	1.59	0.4	12.5	5	0.00E+00	0.0125	250.0	3.42E-06	1.4	80	0.1%	1,380,384	1,380	30.5	5488	0	0.0	13	0	13390.8	0.00E+00	NC	0.00E+00	2.95E-01	does not exceed	0.00E+00

Notes:

Not a CPOI in this SMU

NA - Not applicable (See Attachment G)

NC - Not calculated

1 PERCENT f_{oc} IN BIOTURBATION LAYER

SMU 4

z 30.5

foc 0.10%

kbio(particle) cm/yr 1 kbl cm/hr 1

kbio(water) cm/yr 100 foc (bio layer) 0.01

Variable	ρ_b	ε or (n)	v	U	C_o	a	Vb	Dw	Hp	D'	foc	Koc	K_d	z	R_f	t_{50}	λ	u	SS Rxn	Approximate Time to Steady Conditions	Maximum of Diffusive or Advective Flux	Reactive Flux	Sediment Concentration (W_{bio})	*PEC*	PEC Exceedence?	Sediment Concentration (W_{bio}) Assuming 1.5X Safety Factor Applied to Thickness (z)
	Bulk density of cap material (1-ε)*ρs	Porosity	Pore water Velocity (U/ε)	Darcy Velocity (or v*ε)	Initial pore water concentration	Dispersivity	Organic Compd LeBas Molar Volume	Molecular diffusion coefficient (at 45 F)	Hindrance Parameter ($\varepsilon^{-1/3}$)	Diffusion/dispersion coefficient	Fraction of organic carbon in cap material	Organic carbon partition coeff for organics	Observed partition coefficient for CB (organics=foc*Koc, metals=literature value))	Chemical Isolation Layer Thickness	Retardation Factor	Half Life	Reaction Term (=ln2/t_{50})	$\sqrt{v^2+4\lambda D'}$								
	g/cm^3		cm/yr	cm/yr	mg/L		cm3/mol	cm^2/sec		cm^2/yr		mL/g	L/kg	cm		day	yr^{-1}		/cm	years	mg/cm2/yr	mg/cm2/yr	mg/kg	mg/kg		mg/kg
Mercury	1.59	0.4	750.0	300	4.12E-05	0.0125		1.96E-06	1.4	55	0.1%	NA	2,200	30.5	8746	0	0.0	750	0	355.7	1.24E-05	NC	9.98E-03	2.20E+00	does not exceed	9.98E-03
Ethylbenzene	1.59	0.4	750.0	300	0.00E+00	0.0125	140.4	4.80E-06	1.4	121	0.1%	588	0.59	30.5	3	228	1.1	750	0.09575	0.1	0.00E+00	0.00E+00	0.00E+00	1.76E-01	does not exceed	0.00E+00
Xylene	1.59	0.4	750.0	300	0.00E+00	0.0125	140.4	4.80E-06	1.4	121	0.1%	1,413	1.41	30.5	7	767	0.3	750	0.0522	0.3	0.00E+00	0.00E+00	0.00E+00		does not exceed	0.00E+00
Chlorobenzene	1.59	0.4	750.0	300	0.00E+00	0.0125	116.9	5.35E-06	1.4	134	0.1%	500	0.50	30.5	3	600	0.4	750	0.05615	0.1	0.00E+00	0.00E+00	0.00E+00	4.28E-01	does not exceed	0.00E+00
Dichlorobenzene	1.59	0.4	750.0	300	0.00E+00	0.0125	137.8	4.85E-06	1.4	122	0.1%	2,399	2.40	30.5	11	720	0.4	750	0.05361	0.4	0.00E+00	0.00E+00	0.00E+00		does not exceed	0.00E+00
Naphthalene	1.59	0.4	750.0	300	0.00E+00	0.0125	147.6	4.66E-06	1.4	118	0.1%	2,344	2.34	30.5	10	219	1.2	750	0.09903	0.4	0.00E+00	0.00E+00	0.00E+00	9.17E-01	does not exceed	0.00E+00
Fluorene	1.59	0.4	750.0	300	0.00E+00	0.0125	187.9	4.04E-06	1.4	103	0.1%	15,136	15.14	30.5	61	240	1.1	750	0.10096	2.5	0.00E+00	0.00E+00	0.00E+00	2.64E-01	does not exceed	0.00E+00
Phenanthrene	1.59	0.4	750.0	300	0.00E+00	0.0125	196.7	3.94E-06	1.4	101	0.1%	28,184	28.18	30.5	113	800	0.3	750	0.05598	4.6	0.00E+00	0.00E+00	0.00E+00	5.43E-01	does not exceed	0.00E+00
Pyrene	1.59	0.4	750.0	300	0.00E+00	0.0125	213.8	3.75E-06	1.4	97	0.1%	208,930	208.93	30.5	831	8000	0.0	750	0.0181	33.8	0.00E+00	0.00E+00	0.00E+00	3.44E-01	does not exceed	0.00E+00
Benzo(a)pyrene	1.59	0.4	750.0	300	0.00E+00	0.0125	265.4	3.30E-06	1.4	86	0.1%	1,096,478	1096.48	30.5	4360	2120	0.1	750	0.03723	177.3	0.00E+00	0.00E+00	0.00E+00	1.46E-01	does not exceed	0.00E+00
Hexachlorobenzene	1.59	0.4	750.0	300	2.34E-05	0.0125	221.4	3.67E-06	1.4	95	0.1%	1,513,561	1,514	30.5	6017	8364	0.0	750	0.01787	244.7	7.01E-06	7.00E-06	1.60E-02	NA		1.60E-02
							Est.																			
PCB's	1.59	0.4	750.0	300	0.00E+00	0.0125	250.0	3.42E-06	1.4	89	0.1%	1,380,384	1380.38	30.5	5488	0	0.0	750	0	223.2	0.00E+00	NC	0.00E+00	2.95E-01	does not exceed	0.00E+00

Notes:

Not a CPOI in this SMU

NA - Not applicable (See Attachment G)

NC - Not calculated

1 PERCENT f_{oc} IN BIOTURBATION LAYER

SMU 6

z 30.5

foc 0.10%

kbio(particle) cm/yr 1 kbl cm/hr 1

kbio(water) cm/yr 100 foc (bio layer) 0.01

Variable	ρ_b	ε or (n)	v	U	C_o	a	Vb	Dw	Hp	D'	foc	Koc	K_d	z	Rf	t_{50}	λ	u	SS Rxn	Approximate Time to Steady Conditions	Maximum of Diffusive or Advective Flux	Reactive Flux	Sediment Concentration (W_{bio})	*PEC*	PEC Exceedence?	Sediment Concentration (W_{bio}) Assuming 1.5X Safety Factor Applied to Thickness (z)
	Bulk density of cap material (1-ε)*ρs	Porosity	Pore water Velocity (U/ε)	Darcy Velocity (or v*ε)	Initial pore water concentration	Dispersivity	Organic Compd LeBas Molar Volume	Molecular diffusion coefficient (at 45 F)	Hindrance Parameter ($\varepsilon^{-1/3}$)	Diffusion/dispersion coefficient	Fraction of organic carbon in cap material	Organic carbon partition coeff for organics	Observed partition coefficient for CB (organics=foc*Koc, metals=literature value))	Chemical Isolation Layer Thickness	Retardation Factor	Half Life	Reaction Term (=ln2/t_{50})	$\sqrt{v^2+4\lambda D'}$								
	g/cm^3		cm/yr	cm/yr	mg/L		cm3/mol	cm^2/sec		cm^2/yr		mL/g	L/kg	cm		day	yr^{-1}		/cm	years	mg/cm2/yr	mg/cm2/yr	mg/kg	mg/kg		mg/kg
Mercury	1.59	0.4	175.0	70	2.47E-03	0.0125		1.96E-06	1.4	48	0.1%	NA	2,200	30.5	8746	0	0.0	175.0	0	1524.3	1.73E-04	NC	1.47E-01	2.20E+00	does not exceed	1.47E-01
	1.59	0.4	7.5	3	2.47E-03	0.0125		1.96E-06	1.4	46	0.1%	NA	2,200	30.5	8746	0	0.0	7.5	0	35567.1	7.41E-06	NC	6.39E-03	2.20E+00	does not exceed	6.39E-03
Ethylbenzene	1.59	0.4	175.0	70	0.0000	0.0125	140.4	4.80E-06	1.4	114	0.1%	588	0.59	30.5	3	228	1.1	176.4	0.09873	0.6	0.00E+00	0.00E+00	0.00E+00	1.76E-01	does not exceed	0.00E+00
	1.59	0.4	7.5	3	0.0000	0.0125	140.4	4.80E-06	1.4	112	0.1%	588	0.59	30.5	3	228	1.1	23.5	0.09965	13.6	0.00E+00	0.00E+00	0.00E+00	1.76E-01	does not exceed	0.00E+00
Xylene	1.59	0.4	175.0	70	1.48E+00	0.0125	140.4	4.80E-06	1.4	114	0.1%	1,413	1.41	30.5	7	767	0.3	175.4	0.05383	1.2	1.04E-01	9.78E-02	7.32E+00	5.61E-01	Exceeds PEC	7.12E+00
	1.59	0.4	7.5	3	1.48E+00	0.0125	140.4	4.80E-06	1.4	112	0.1%	1,413	1.41	30.5	7	767	0.3	14.3	0.05433	26.9	4.44E-03	1.42E-03	1.62E-01		does not exceed	6.86E-02
Chlorobenzene	1.59	0.4	175.0	70	0.0000	0.0125	116.9	5.35E-06	1.4	127	0.1%	500	0.50	30.5	3	600	0.4	175.6	0.05772	0.5	0.00E+00	0.00E+00	0.00E+00	4.28E-01	does not exceed	0.00E+00
	1.59	0.4	7.5	3	0.0000	0.0125	116.9	5.35E-06	1.4	124	0.1%	500	0.50	30.5	3	600	0.4	16.3	0.0582	12.1	0.00E+00	0.00E+00	0.00E+00	4.28E-01	does not exceed	0.00E+00
Dichlorobenzenes	1.59	0.4	175.0	70	7.26E-02	0.0125	137.8	4.85E-06	1.4	115	0.1%	2,399	2.40	30.5	11	720	0.4	175.5	0.05526	1.8	5.08E-03	4.78E-03	5.63E-01	2.39E-01	Exceeds PEC	5.46E-01
	1.59	0.4	7.5	3	7.26E-02	0.0125	137.8	4.85E-06	1.4	113	0.1%	2,399	2.40	30.5	11	720	0.4	14.7	0.05577	42.8	2.18E-04	6.91E-05	1.19E-02		does not exceed	4.94E-03
Naphthalene	1.59	0.4	175.0	70	1.65E+00	0.0125	147.6	4.66E-06	1.4	111	0.1%	2,344	2.34	30.5	10	219	1.2	176.5	0.1022	1.8	1.16E-01	9.44E-02	1.09E+01	9.17E-01	Exceeds PEC	9.87E+00
	1.59	0.4	7.5	3	1.65E+00	0.0125	147.6	4.66E-06	1.4	108	0.1%	2,344	2.34	30.5	10	219	1.2	23.6	0.10318	42.0	4.95E-03	6.36E-04	1.08E-01	9.17E-01	does not exceed	1.08E-01
Fluorene	1.59	0.4	175.0	70	7.46E-02	0.1250	187.9	4.04E-06	1.4	116	0.1%	15,136	15.14	30.5	61	240	1.1	176.4	0.09536	10.7	5.22E-03	4.35E-03	1.67E+00	2.64E-01	Exceeds PEC	1.53E+00
	1.59	0.4	7.5	3	7.46E-02	0.1250	187.9	4.04E-06	1.4	95	0.1%	15,136	15.14	30.5	61	240	1.1	21.4	0.10535	248.7	2.24E-04	2.41E-05	1.10E-02	2.64E-01	does not exceed	2.20E-03
Phenanthrene	1.59	0.4	175.0	70	1.22E-02	0.0125	196.7	3.94E-06	1.4	94	0.1%	28,184	28.18	30.5	113	800	0.3	175.3	0.05808	19.7	8.56E-04	8.11E-04	3.95E-01	5.43E-01	does not exceed	3.84E-01
	1.59	0.4	7.5	3	1.22E-02	0.0125	196.7	3.94E-06	1.4	92	0.1%	28,184	28.18	30.5	113	800	0.3	13.1	0.05874	459.7	3.67E-05	1.01E-05	5.51E-03	5.43E-01	does not exceed	2.90E-03
Pyrene	1.59	0.4	175.0	70	7.87E-03	0.0125	213.8	3.75E-06	1.4	89	0.1%	208,930	208.93	30.5	831	8000	0.0	175.0	0.01881	144.9	5.51E-04	5.48E-04	4.57E-01	3.44E-01	Exceeds PEC	4.56E-01
	1.59	0.4	7.5	3	7.87E-03	0.0125	213.8	3.75E-06	1.4	87	0.1%	208,930	208.93	30.5	831	8000	0.0	8.2	0.01904	3381.4	2.36E-05	2.08E-05	1.76E-02	3.44E-01	does not exceed	1.65E-02
Benzo(a)pyrene	1.59	0.4	175.0	70	9.71E-04	0.0125	265.4	3.30E-06	1.4	79	0.1%	1,096,478	1,096	30.5	4360	2120	0.1	175.1	0.03888	759.8	6.80E-05	6.66E-05	1.24E-01	1.46E-01	does not exceed	1.23E-01
	1.59	0.4	7.5	3	9.71E-04	0.0125	265.4	3.30E-06	1.4	77	0.1%	1,096,478	1,096	30.5	4360	2120	0.1	9.6	0.03941	17728.6	2.91E-06	1.79E-06	3.36E-03	1.46E-01	does not exceed	2.64E-03
Hexachlorobenzene	1.59	0.4	175.0	70	0.0000	0.0125	221.4	3.67E-06	1.4	88	0.1%	1,513,561	1513.56	30.5	6017	8364	0.0	175.0	0.01859	1048.7	0.00E+00	0.00E+00	0.00E+00			0.00E+00
	1.59	0.4	7.5	3	0.0000	0.0125	221.4	3.67E-06	1.4	85	0.1%	1,513,561	1513.56	30.5	6017	8364	0.0	8.2	0.01881	24470.8	0.00E+00	0.00E+00	0.00E+00			0.00E+00
							Est.																			
PCB's	1.59	0.4	175.0	70	1.49E-04	0.0125	250.0	3.42E-06	1.4	82	0.1%	1,380,384	1,380	30.5	5488	0	0.0	175.0	0	956.5	1.04E-05	NC	7.72E-02	2.95E-01	does not exceed	7.72E-02
	1.59	0.4	7.5	3	1.49E-04	0.0125	250.0	3.42E-06	1.4	80	0.1%	1,380,384	1,380	30.5	5488	0	0.0	7.5	0	22318.0	4.47E-07	NC	3.39E-03	2.95E-01	does not exceed	3.39E-03

Notes:

Not a CPOI in this SMU

NA - Not applicable (See Attachment G)

NC - Not calculated

1 PERCENT f_{oc} IN BIOTURBATION LAYER

SMU 7

foc	z	kbio(particle) cm/yr	1	kbl cm/hr	1
0.10%	76.25	kbio(water) cm/yr	100	foc (bio layer)	0.01

Variable	ρ_b	ε or (n)	v	U	C_o	a	Vb	Dw	Hp	D'	foc	Koc	K_d	z	R_f	t_{50}	λ	u	SS Rxn	Approximate Time to Steady Conditions	Maximum of Diffusive or Advective Flux	Reactive Flux	Sediment Concentration (W_{bio})	*PEC*	PEC Exceedence?	Sediment Concentration (W_{bio}) Assuming 1.5X Safety Factor Applied to Thickness (z)
	Bulk density of cap material (1-ε)*ρs	Porosity	Pore water Velocity (U/ε)	Darcy Velocity (or v*ε)	Initial pore water concentration	Dispersivity	Organic Compd LeBas Molar Volume	Molecular diffusion coefficient (at 45 F)	Hindrance Parameter ($\varepsilon^{-1/3}$)	Diffusion/dispersion coefficient	Fraction of organic carbon in cap material	Organic carbon partition coeff for organics	Observed partition coefficient for CB (organics=foc*Koc, metals=literature value))	Chemical Isolation Layer Thickness	Retardation Factor	Half Life	Reaction Term (=ln2/t_{50})	$\sqrt{v^2+4\lambda D'}$								
	g/cm^3		cm/yr	cm/yr	mg/L		cm3/mol	cm^2/sec		cm^2/yr		mL/g	L/kg	cm		day	yr^{-1}		/cm	years	mg/cm2/yr	mg/cm2/yr	mg/kg	mg/kg		mg/kg
Mercury	1.59	0.4	250.0	100	3.00E-05	0.0125		1.96E-06	1.4	49	0.1%	NA	2,200	76.25	8746	0	0.0	250	0	2667.5	3.00E-06	NC	2.53E-03	2.20E+00	does not exceed	2.53E-03
	1.59	0.4	7.5	3	3.00E-05	0.0125		1.96E-06	1.4	46	0.1%	NA	2,200	76.25	8746	0	0.0	8	0	88917.7	9.00E-08	NC	7.76E-05	2.20E+00	does not exceed	7.76E-05
	1.59	0.4	5.0	2	3.00E-05	0.0125		1.96E-06	1.4	46	0.1%	NA	2,200	76.25	8746	0	0.0	5	0	133376.5	6.00E-08	NC	5.17E-05	2.20E+00	does not exceed	5.17E-05
Ethylbenzene	1.59	0.4	250.0	100	1.75E-01	0.0125	140.4	4.80E-06	1.4	115	0.1%	588	0.59	76.25	3	228	1.1	251	0.09832	1.0	1.75E-02	1.25E-02	3.58E-01	1.76E-01	does not exceed	3.02E-01
	1.59	0.4	7.5	3	1.75E-01	0.0125	140.4	4.80E-06	1.4	112	0.1%	588	0.59	76.25	3	228	1.1	23	0.09965	33.9	5.25E-04	7.82E-07	4.13E-05	1.76E-01	does not exceed	9.24E-07
	1.59	0.4	5.0	2	1.75E-01	0.0125	140.4	4.80E-06	1.4	112	0.1%	588	0.59	76.25	3	228	1.1	23	0.09966	50.9	3.50E-04	7.81E-07	4.16E-05	1.76E-01	does not exceed	9.31E-07
Xylene	1.59	0.4	250.0	100	1.23E+00	0.0125	140.4	4.80E-06	1.4	115	0.1%	1,413	1.41	76.25	7	767	0.3	250	0.05361	2.0	1.23E-01	1.11E-01	7.23E+00	5.61E-01	Exceeds PEC	6.87E+00
	1.59	0.4	7.5	3	1.23E+00	0.0125	140.4	4.80E-06	1.4	112	0.1%	1,413	1.41	76.25	7	767	0.3	14	0.05433	67.3	3.69E-03	1.29E-04	1.47E-02		does not exceed	2.75E-03
	1.59	0.4	5.0	2	1.23E+00	0.0125	140.4	4.80E-06	1.4	112	0.1%	1,413	1.41	76.25	7	767	0.3	13	0.05434	100.9	2.46E-03	9.48E-05	1.09E-02		does not exceed	1.37E-03
Chlorobenzene	1.59	0.4	250.0	100	4.35E+00	0.0125	116.9	5.35E-06	1.4	127	0.1%	500	0.50	76.25	3	600	0.4	250	0.05751	0.9	4.35E-01	3.83E-01	9.40E+00	4.28E-01	Exceeds PEC	8.81E+00
	1.59	0.4	7.5	3	4.35E+00	0.0125	116.9	5.35E-06	1.4	124	0.1%	500	0.50	76.25	3	600	0.4	16	0.0582	30.4	1.31E-02	2.98E-04	1.36E-02	4.28E-01	does not exceed	1.47E-03
	1.59	0.4	5.0	2	4.35E+00	0.0125	116.9	5.35E-06	1.4	124	0.1%	500	0.50	76.25	3	600	0.4	15	0.05821	45.6	8.70E-03	2.98E-04	1.37E-02	4.28E-01	does not exceed	1.48E-03
Dichlorobenzene	1.59	0.4	250.0	100	3.99E+00	0.0125	137.8	4.85E-06	1.4	116	0.1%	2,399	2.40	76.25	11	720	0.4	250	0.05503	3.2	3.99E-01	3.58E-01	3.70E+01	2.39E-01	Exceeds PEC	3.51E+01
	1.59	0.4	7.5	3	3.99E+00	0.0125	137.8	4.85E-06	1.4	113	0.1%	2,399	2.40	76.25	11	720	0.4	15	0.05577	107.1	1.20E-02	3.36E-04	5.79E-02		does not exceed	9.72E-03
	1.59	0.4	5.0	2	3.99E+00	0.0125	137.8	4.85E-06	1.4	113	0.1%	2,399	2.40	76.25	11	720	0.4	14	0.05577	160.7	7.98E-03	2.86E-04	4.96E-02		does not exceed	5.92E-03
Naphthalene	1.59	0.4	250.0	100	3.09E+00	0.0125	147.6	4.66E-06	1.4	112	0.1%	2,344	2.34	76.25	10	219	1.2	251	0.10177	3.1	3.09E-01	2.17E-01	2.20E+01	9.17E-01	Exceeds PEC	1.84E+01
	1.59	0.4	7.5	3	3.09E+00	0.0125	147.6	4.66E-06	1.4	108	0.1%	2,344	2.34	76.25	10	219	1.2	24	0.10318	104.9	9.27E-03	1.06E-05	1.79E-03	9.17E-01	does not exceed	3.51E-05
	1.59	0.4	5.0	2	3.09E+00	0.0125	147.6	4.66E-06	1.4	108	0.1%	2,344	2.34	76.25	10	219	1.2	23	0.1032	157.3	6.18E-03	1.06E-05	1.80E-03	9.17E-01	does not exceed	3.53E-05
Fluorene	1.59	0.4	250.0	100	7.10E-03	0.0125	187.9	4.04E-06	1.4	97	0.1%	15,136	15.14	76.25	61	240	1.1	251	0.10415	18.7	7.10E-04	5.15E-04	1.85E-01	2.64E-01	does not exceed	1.58E-01
	1.59	0.4	7.5	3	7.10E-03	0.0125	187.9	4.04E-06	1.4	94	0.1%	15,136	15.14	76.25	61	240	1.1	21	0.10582	621.9	2.13E-05	1.77E-08	8.10E-06	2.64E-01	does not exceed	1.43E-07
	1.59	0.4	5.0	2	7.10E-03	0.0125	187.9	4.04E-06	1.4	94	0.1%	15,136	15.14	76.25	61	240	1.1	21	0.10584	932.8	1.42E-05	1.77E-08	8.11E-06	2.64E-01	does not exceed	1.43E-07
Phenanthrene	1.59	0.4	250.0	100	1.61E-02	0.0125	196.7	3.94E-06	1.4	95	0.1%	28,184	28.18	76.25	113	800	0.3	250	0.0578	34.5	1.61E-03	1.46E-03	6.82E-01	5.43E-01	Exceeds PEC	6.50E-01
	1.59	0.4	7.5	3	1.61E-02	0.0125	196.7	3.94E-06	1.4	92	0.1%	28,184	28.18	76.25	113	800	0.3	13	0.05874	1149.2	4.83E-05	1.94E-06	1.05E-03	5.43E-01	does not exceed	2.11E-04
	1.59	0.4	5.0	2	1.61E-02	0.0125	196.7	3.94E-06	1.4	92	0.1%	28,184	28.18	76.25	113	800	0.3	12	0.05875	1723.7	3.22E-05	7.86E-07	4.27E-04	5.43E-01	does not exceed	4.55E-05
Pyrene	1.59	0.4	250.0	100	1.04E-02	0.0125	213.8	3.75E-06	1.4	90	0.1%	208,930	208.93	76.25	831	8000	0.0	250	0.01872	253.6	1.04E-03	1.03E-03	8.54E-01	3.44E-01	Exceeds PEC	8.50E-01
	1.59	0.4	7.5	3	1.04E-02	0.0125	213.8	3.75E-06	1.4	87	0.1%	208,930	208.93	76.25	831	8000	0.0	8	0.01904	8453.6	3.12E-05	2.26E-05	1.92E-02	3.44E-01	does not exceed	1.63E-02
	1.59	0.4	5.0	2	1.04E-02	0.0125	213.8	3.75E-06	1.4	87	0.1%	208,930	208.93	76.25	831	8000	0.0	6	0.01904	12680.3	2.08E-05	1.28E-05	1.09E-02	3.44E-01	does not exceed	8.56E-03
Benzo(a)pyrene	1.59	0.4	250.0	100	6.00E-03	0.0125	265.4	3.30E-06	1.4	80	0.1%	1,096,478	1,096	76.25	4360	2120	0.1	250	0.03866	1329.6	6.00E-04	5.79E-04	1.08E+00	1.46E-01	Exceeds PEC	1.06E+00
	1.59	0.4	7.5	3	6.00E-03	0.0125	265.4	3.30E-06	1.4	77	0.1%	1,096,478	1,096	76.25	4360	2120	0.1	10	0.03941	44321.6	1.80E-05	5.35E-06	1.00E-02	1.46E-01	does not exceed	5.48E-03
	1.59	0.4	5.0	2	6.00E-03	0.0125	265.4	3.30E-06	1.4	77	0.1%	1,096,478	1,096	76.25	4360	2120	0.1	8	0.03942	66482.4	1.20E-05	1.95E-06	3.65E-03	1.46E-01	does not exceed	1.47E-03
Hexachlorobenzene	1.59	0.4	250.0	100	0.00E+00	0.0125	221.4	3.67E-06	1.4	88	0.1%	1,513,561	1,514	76.25	6017	8364	0.0	250	0.01849	1835.3	0.00E+00	0.00E+00	0.00E+00	NA		0.00E+00
	1.59	0.4	7.5	3	0.00E+00	0.0125	221.4	3.67E-06	1.4	85	0.1%	1,513,561	1,514	76.25	6017	8364	0.0	8	0.01881	61177.0	0.00E+00	0.00E+00	0.00E+00			0.00E+00
	1.59	0.4	5.0	2	0.00E+00	0.0125	221.4	3.67E-06	1.4	85	0.1%	1,513,561	1,514	76.25	6017	8364	0.0	6	0.01881	91765.4	0.00E+00	0.00E+00	0.00E+00			0.00E+00
							Est.																			
PCB's	1.59	0.4	250.0	100	1.33E-04	0.0125	250.0	3.42E-06	1.4	83	0.1%	1,380,384	1,380	76.25	5488	0	0.0	250	0	1673.8	1.33E-05	NC	9.76E-02	2.95E-01	does not exceed	9.76E-02
	1.59	0.4	7.5	3	1.33E-04	0.0125	250.0	3.42E-06	1.4	80	0.1%	1,380,384	1,380	76.25	5488	0	0.0	8	0	55794.9	4.00E-07	NC	3.03E-03	2.95E-01	does not exceed	3.03E-03
	1.59	0.4	5.0	2	1.33E-04	0.0125	250.0	3.42E-06	1.4	80	0.1%	1,380,384	1,380	76.25	5488	0	0.0	5	0	83692.4	2.67E-07	NC	2.02E-03	2.95E-01	does not exceed	2.02E-03

Notes:

Not a CPOI in this SMU
NA - Not applicable (See Attachment G)
NC - Not calculated

5 PERCENT f_{oc} IN BIOTURBATION LAYER

SMU 1

foc	z	kbio(particle) cm/yr	1	kbl cm/hr	1
0.10%	76.25	kbio(water) cm/yr	100	foc (bio layer)	0.05

Variable	ρ_b	ε or (n)	v	U	C_o	a	Vb	Dw	Hp	D'	foc	Koc	K_d	z	R_f	t_{50}	λ	u	SS Rxn	Approximate Time to Steady Conditions	Maximum of Diffusive or Advective Flux	Reactive Flux	Sediment Concentration (W_{bio})	*PEC*	PEC Exceedence?	Sediment Concentration (W_{bio}) Assuming 1.5X Safety Factor Applied to Thickness (z)
	Bulk density of cap material (1-ε)*ρs	Porosity	Pore water Velocity (U/ε)	Darcy Velocity (or v*ε)	Initial pore water concentration	Dispersivity	Organic Compd LeBas Molar Volume	Molecular diffusion coefficient (at 45 F)	Hindrance Parameter ($\varepsilon^{-1/3}$)	Diffusion/dispersion coefficient	Fraction of organic carbon in cap material	Organic carbon partition coeff for organics	Observed partition coefficient for CB (organics=foc*Koc, metals=literature value))	Chemical Isolation Layer Thickness	Retardation Factor	Half Life	Reaction Term (=ln2/t_{50})	$\sqrt{v^2+4\lambda D'}$								
	g/cm^3		cm/yr	cm/yr	mg/L		cm3/mol	cm^2/sec		cm^2/yr		mL/g	L/kg	cm		day	yr^{-1}		/cm	years	mg/cm2/yr	mg/cm2/yr	mg/kg	mg/kg		mg/kg
Mercury	1.59	0.4	5.0	2	7.48E-01	0.0125		1.96E-06	1.4	46	0.1%	NA	2,200	76.25	8746	0	0.0	5	0	133376.5	1.50E-03	NC	1.29E+00	2.20E+00	does not exceed	1.29E+00
Ethylbenzene	1.59	0.4	5.0	2	7.36E-01	0.0125	140.4	4.80E-06	1.4	112	0.1%	588	0.59	76.25	3	228	1.1	23	0.09966	50.9	1.47E-03	3.28E-06	6.58E-04	1.76E-01	does not exceed	1.47E-05
Xylene	1.59	0.4	5.0	2	4.54E+00	0.0125	140.4	4.80E-06	1.4	112	0.1%	1,413	1.41	76.25	7	767	0.3	13	0.05434	100.9	9.08E-03	3.50E-04	1.18E-01	5.61E-01	does not exceed	1.49E-02
Chlorobenzene	1.59	0.4	5.0	2	2.99E+01	0.0125	116.9	5.35E-06	1.4	124	0.1%	500	0.50	76.25	3	600	0.4	15	0.05821	45.6	5.98E-02	2.05E-03	3.66E-01	4.28E-01	does not exceed	3.98E-02
Dichlorobenzene	1.59	0.4	5.0	2	6.53E+00	0.0125	137.8	4.85E-06	1.4	113	0.1%	2,399	2.40	76.25	11	720	0.4	14	0.05577	160.7	1.31E-02	4.68E-04	1.98E-01	2.39E-01	does not exceed	2.36E-02
Naphthalene	1.59	0.4	5.0	2	8.28E+00	0.0125	147.6	4.66E-06	1.4	108	0.1%	2,344	2.34	76.25	10	219	1.2	23	0.1032	157.3	1.66E-02	2.84E-05	1.19E-02	9.17E-01	does not exceed	2.33E-04
Fluorene	1.59	0.4	5.0	2	9.50E-02	0.0125	187.9	4.04E-06	1.4	94	0.1%	15,136	15.14	76.25	61	240	1.1	21	0.10584	932.8	1.90E-04	2.37E-07	1.58E-04	2.64E-01	does not exceed	2.79E-06
Phenanthrene	1.59	0.4	5.0	2	9.50E-02	0.0125	196.7	3.94E-06	1.4	92	0.1%	28,184	28.18	76.25	113	800	0.3	12	0.05875	1723.7	1.90E-04	4.64E-06	3.53E-03	5.43E-01	does not exceed	3.76E-04
Pyrene	1.59	0.4	5.0	2	9.50E-02	0.0125	213.8	3.75E-06	1.4	87	0.1%	208,930	208.93	76.25	831	8000	0.0	6	0.01904	12680.3	1.90E-04	1.17E-04	2.13E-01	3.44E-01	does not exceed	1.68E-01
Benzo(a)pyrene	1.59	0.4	5.0	2	9.50E-02	0.0125	265.4	3.30E-06	1.4	77	0.1%	1,096,478	1,096	76.25	4360	2120	0.1	8	0.03942	66482.4	1.90E-04	3.08E-05	2.12E-01	1.46E-01	Exceeds PEC*	8.54E-02
Hexachlorobenzene	1.59	0.4	5.0	2	1.18E-05	0.0125	221.4	3.67E-06	1.4	85	0.1%	1,513,561	1,514	76.25	6017	8364	0.0	6	0.01881	91765.4	2.36E-08	1.49E-08	1.38E-04		NA	1.09E-04
							Est.																			
PCB's	1.59	0.4	5.0	2	2.43E-04	0.0125	250.0	3.42E-06	1.4	80	0.1%	1,380,384	1,380	76.25	5488	0	0.0	5	0	83692.4	4.87E-07	NC	1.85E-02	2.95E-01	does not exceed	1.85E-02

Notes:

Not a CPOI in this SMU

NA - Not applicable (See Attachment G)

NC - Not calculated

* Time to steady state is >> 1,000 years (approx 66,000), the concentration at the top of the chemical isolation layer at 1,000 is less than the PEC.

5 PERCENT f_{oc} IN BIOTURBATION LAYER

SMU 2

foc 0.10%

z 76.25

kbio(particle) cm/yr 1 kbl cm/hr 1

kbio(water) cm/yr 100 foc (bio layer) 0.05

Variable	ρ_b	ε or (n)	v	U	C_o	a	Vb	Dw	Hp	D'	foc	Koc	K_d	z	R_f	t_{50}	λ	u	SS Rxn	Approximate Time to Steady Conditions	Maximum of Diffusive or Advective Flux	Reactive Flux	Sediment Concentration (W_{bio})	*PEC*	PEC Exceedence?	Sediment Concentration (W_{bio}) Assuming 1.5X Safety Factor Applied to Thickness (z)
	Bulk density of cap material (1-ε)*ps	Porosity	Pore water Velocity (U/ε)	Darcy Velocity (or v*ε)	Initial pore water concentration	Dispersivity	Organic Compd LeBas Molar Volume	Molecular diffusion coefficient (at 45 F)	Hindrance Parameter ($\varepsilon^{-1/3}$)	Diffusion/dispersion coefficient	Fraction of organic carbon in cap material	Organic carbon partition coeff for organics	Observed partition coefficient for CB (organics=foc*Koc, metals=literature value))	Chemical Isolation Layer Thickness	Retardation Factor	Half Life	Reaction Term (=ln2/t_{50})	$\sqrt{v^2+4\lambda D'}$								
	g/cm^3		cm/yr	cm/yr	mg/L		cm3/mol	cm^2/sec		cm^2/yr		mL/g	L/kg	cm		day	yr^{-1}		/cm	years	mg/cm2/yr	mg/cm2/yr	mg/kg	mg/kg		mg/kg
Mercury	1.59	0.4	5.0	2	3.30E-03	0.0125		1.96E-06	1.4	46	0.1%	NA	2,200	76.25	8746	0	0.0	5	0	133376.5	6.61E-06	NC	5.70E-03	2.20E+00	does not exceed	5.70E-03
Ethylbenzene	1.59	0.4	5.0	2	1.75E+00	0.0125	140.4	4.80E-06	1.4	112	0.1%	588	0.59	76.25	3	228	1.1	23	0.09966	50.9	3.50E-03	7.81E-06	1.56E-03	1.76E-01	does not exceed	3.50E-05
Xylene	1.59	0.4	5.0	2	3.38E+00	0.0125	140.4	4.80E-06	1.4	112	0.1%	1,413	1.41	76.25	7	767	0.3	13	0.05434	100.9	6.76E-03	2.61E-04	8.78E-02	5.61E-01	does not exceed	1.11E-02
Chlorobenzene	1.59	0.4	5.0	2	1.86E+01	0.0125	116.9	5.35E-06	1.4	124	0.1%	500	0.50	76.25	3	600	0.4	15	0.05821	45.6	3.72E-02	1.27E-03	2.28E-01	4.28E-01	does not exceed	2.47E-02
Dichlorobenzenes	1.59	0.4	5.0	2	9.36E-01	0.0125	137.8	4.85E-06	1.4	113	0.1%	2,399	2.40	76.25	11	720	0.4	14	0.05577	160.7	1.87E-03	6.71E-05	2.84E-02	2.39E-01	does not exceed	3.38E-03
Naphthalene	1.59	0.4	5.0	2	1.61E+02	0.0125	147.6	4.66E-06	1.4	108	0.1%	2,344	2.34	76.25	10	219	1.2	23	0.1032	157.3	3.22E-01	5.51E-04	2.31E-01	9.17E-01	does not exceed	4.52E-03
Fluorene	1.59	0.4	5.0	2	4.02E-02	0.0125	187.9	4.04E-06	1.4	94	0.1%	15,136	15.14	76.25	61	240	1.1	21	0.10584	932.8	8.04E-05	1.00E-07	6.67E-05	2.64E-01	does not exceed	1.18E-06
Phenanthrene	1.59	0.4	5.0	2	2.66E-02	0.0125	196.7	3.94E-06	1.4	92	0.1%	28,184	28.18	76.25	113	800	0.3	12	0.05875	1723.7	5.32E-05	1.30E-06	9.89E-04	5.43E-01	does not exceed	1.05E-04
Pyrene	1.59	0.4	5.0	2	3.40E-03	0.0125	213.8	3.75E-06	1.4	87	0.1%	208,930	208.93	76.25	831	8000	0.0	6	0.01904	12680.3	6.80E-06	4.20E-06	7.63E-03	3.44E-01	does not exceed	5.99E-03
Benzo(a)pyrene	1.59	0.4	5.0	2	4.10E-04	0.0125	265.4	3.30E-06	1.4	77	0.1%	1,096,478	1,096	76.25	4360	2120	0.1	8	0.03942	66482.4	8.19E-07	1.33E-07	9.15E-04	1.46E-01	does not exceed	3.68E-04
Hexachlorobenzene	1.59	0.4	5.0	2	0.00E+00	0.0125	221.4	3.67E-06	1.4	85	0.1%	1,513,561	1,514	76.25	6017	8364	0.0	6	0.01881	91765.4	0.00E+00	0.00E+00	0.00E+00		NA	0.00E+00
							Est.																			
PCB's	1.59	0.4	5.0	2	3.99E-05	0.0125	250.0	3.42E-06	1.4	80	0.1%	1,380,384	1,380	76.25	5488	0	0.0	5	0	83692.4	7.98E-08	NC	3.03E-03	2.95E-01	does not exceed	3.03E-03

Notes:

Not a CPOI in this SMU

NA - Not applicable (See Attachment G)

NC - Not calculated

5 PERCENT f_{oc} IN BIOTURBATION LAYER

SMU 3

z 30.5

foc 0.10%

kbio(particle) cm/yr 1 kbl cm/hr 1

kbio(water) cm/yr 100 foc (bio layer) 0.05

Variable	ρ_b	ε or (n)	v	U	C_o	a	Vb	Dw	Hp	D'	foc	Koc	K_d	z	R_f	t_{50}	λ	u	SS Rxn	Approximate Time to Steady Conditions	Maximum of Diffusive or Advective Flux	Reactive Flux	Sediment Concentration (W_{bio})	*PEC*	PEC Exceedence?	Sediment Concentration (W_{bio}) Assuming 1.5X Safety Factor Applied to Thickness (z)
	Bulk density of cap material (1-ε)*ρs	Porosity	Pore water Velocity (U/ε)	Darcy Velocity (or v*ε)	Initial pore water concentration	Dispersivity	Organic Compd LeBas Molar Volume	Molecular diffusion coefficient (at 45 F)	Hindrance Parameter ($\varepsilon^{-1/3}$)	Diffusion/dispersion coefficient	Fraction of organic carbon in cap material	Organic carbon partition coeff for organics	Observed partition coefficient for CB (organics=foc*Koc, metals=literature value))	Chemical Isolation Layer Thickness	Retardation Factor	Half Life	Reaction Term (=ln2/t_{50})	$\sqrt{v^2+4\lambda D'}$								
	g/cm^3		cm/yr	cm/yr	mg/L		cm3/mol	cm^2/sec		cm^2/yr		mL/g	L/kg	cm		day	yr^{-1}		/cm	years	mg/cm2/yr	mg/cm2/yr	mg/kg	mg/kg		mg/kg
Mercury	1.59	0.4	1750.0	700	0.00E+00	0.0125		1.96E-06	1.4	67	0.1%	NA	2,200	30.5	8746	0	0.0	1750	0	152.4	0.00E+00	NC	0.00E+00	2.20E+00	does not exceed	0.00E+00
	1.59	0.4	12.5	5	0.00E+00	0.0125		1.96E-06	1.4	46	0.1%	NA	2,200	30.5	8746	0	0.0	13	0	21340.2	0.00E+00	NC	0.00E+00	2.20E+00	does not exceed	0.00E+00
Ethylbenzene	1.59	0.4	1750.0	700	5.34E-02	0.0125	140.4	4.80E-06	1.4	134	0.1%	588	0.59	30.5	3	228	1.1	1750	0.09116	0.1	3.74E-02	3.67E-02	1.39E+00	1.76E-01	does not exceed	1.37E+00
	1.59	0.4	12.5	5	5.34E-02	0.0125	140.4	4.80E-06	1.4	112	0.1%	588	0.59	30.5	3	228	1.1	26	0.09962	8.1	2.67E-04	2.28E-05	4.49E-03	1.76E-01	does not exceed	9.81E-04
Xylene	1.59	0.4	1750.0	700	5.83E-01	0.0125	140.4	4.80E-06	1.4	134	0.1%	1,413	1.41	30.5	7	767	0.3	1750	0.0497	0.1	4.08E-01	4.06E-01	3.44E+01	5.61E-01	Exceeds PEC	3.43E+01
	1.59	0.4	12.5	5	5.83E-01	0.0125	140.4	4.80E-06	1.4	112	0.1%	1,413	1.41	30.5	7	767	0.3	17	0.05431	16.1	2.92E-03	1.30E-03	4.34E-01		does not exceed	2.90E-01
Chlorobenzene	1.59	0.4	1750.0	700	0.00E+00	0.0125	116.9	5.35E-06	1.4	146	0.1%	500	1	30.5	3	600	0.4	1750	0.05369	0.1	0.00E+00	0.00E+00	0.00E+00	4.28E-01	does not exceed	0.00E+00
	1.59	0.4	12.5	5	0.00E+00	0.0125	116.9	5.35E-06	1.4	125	0.1%	500	1	30.5	3	600	0.4	19	0.05819	7.3	0.00E+00	0.00E+00	0.00E+00	4.28E-01	does not exceed	0.00E+00
Dichlorobenzene	1.59	0.4	1750.0	700	0.00E+00	0.0125	137.8	4.85E-06	1.4	135	0.1%	2,399	2	30.5	11	720	0.4	1750	0.05106	0.2	0.00E+00	0.00E+00	0.00E+00		does not exceed	0.00E+00
	1.59	0.4	12.5	5	0.00E+00	0.0125	137.8	4.85E-06	1.4	113	0.1%	2,399	2	30.5	11	720	0.4	18	0.05575	25.7	0.00E+00	0.00E+00	0.00E+00		does not exceed	0.00E+00
Naphthalene	1.59	0.4	1750.0	700	1.71E-01	0.0125	147.6	4.66E-06	1.4	130	0.1%	2,344	2.34	30.5	10	219	1.2	1750	0.09416	0.2	1.20E-01	1.17E-01	1.54E+01	9.17E-01	Exceeds PEC	1.52E+01
	1.59	0.4	12.5	5	1.71E-01	0.0125	147.6	4.66E-06	1.4	109	0.1%	2,344	2.34	30.5	10	219	1.2	26	0.10315	25.2	8.55E-04	6.60E-05	2.74E-02	9.17E-01	does not exceed	5.67E-03
Fluorene	1.59	0.4	1750.0	700	0.00E+00	0.0125	187.9	4.04E-06	1.4	116	0.1%	15,136	15	30.5	61	240	1.1	1750	0.09536	1.1	0.00E+00	0.00E+00	0.00E+00	2.64E-01	does not exceed	0.00E+00
	1.59	0.4	12.5	5	0.00E+00	0.0125	187.9	4.04E-06	1.4	94	0.1%	15,136	15	30.5	61	240	1.1	24	0.10578	149.2	0.00E+00	0.00E+00	0.00E+00	2.64E-01	does not exceed	0.00E+00
Phenanthrene	1.59	0.4	1750.0	700	0.00E+00	0.0125	196.7	3.94E-06	1.4	113	0.1%	28,184	28	30.5	113	800	0.3	1750	0.0528	2.0	0.00E+00	0.00E+00	0.00E+00	5.43E-01	does not exceed	0.00E+00
	1.59	0.4	12.5	5	0.00E+00	0.0125	196.7	3.94E-06	1.4	92	0.1%	28,184	28	30.5	113	800	0.3	16	0.05872	275.8	0.00E+00	0.00E+00	0.00E+00	5.43E-01	does not exceed	0.00E+00
Pyrene	1.59	0.4	1750.0	700	0.00E+00	0.0125	213.8	3.75E-06	1.4	109	0.1%	208,930	209	30.5	831	8000	0.0	1750	0.01703	14.5	0.00E+00	0.00E+00	0.00E+00	3.44E-01	does not exceed	0.00E+00
	1.59	0.4	12.5	5	0.00E+00	0.0125	213.8	3.75E-06	1.4	87	0.1%	208,930	209	30.5	831	8000	0.0	13	0.01903	2028.9	0.00E+00	0.00E+00	0.00E+00	3.44E-01	does not exceed	0.00E+00
Benzo(a)pyrene	1.59	0.4	1750.0	700	0.00E+00	0.0125	265.4	3.30E-06	1.4	99	0.1%	1,096,478	1,096	30.5	4360	2120	0.1	1750	0.03479	76.0	0.00E+00	0.00E+00	0.00E+00	1.46E-01	does not exceed	0.00E+00
	1.59	0.4	12.5	5	0.00E+00	0.0125	265.4	3.30E-06	1.4	77	0.1%	1,096,478	1,096	30.5	4360	2120	0.1	14	0.0394	10637.2	0.00E+00	0.00E+00	0.00E+00	1.46E-01	does not exceed	0.00E+00
Hexachlorobenzene	1.59	0.4	1750.0	700	0.00E+00	0.0125	221.4	3.67E-06	1.4	107	0.1%	1,513,561	1,514	30.5	6017	8364	0.0	1750	0.01679	104.9	0.00E+00	0.00E+00	0.00E+00			0.00E+00
	1.59	0.4	12.5	5	0.00E+00	0.0125	221.4	3.67E-06	1.4	86	0.1%	1,513,561	1,514	30.5	6017	8364	0.0	13	0.0188	14682.5	0.00E+00	0.00E+00	0.00E+00			0.00E+00
							Est.																			
PCB's	1.59	0.4	1750.0	700	0.00E+00	0.0125	250.0	3.42E-06	1.4	101	0.1%	1,380,384	1,380	30.5	5488	0	0.0	1750	0	95.6	0.00E+00	NC	0.00E+00	2.95E-01	does not exceed	0.00E+00
	1.59	0.4	12.5	5	0.00E+00	0.0125	250.0	3.42E-06	1.4	80	0.1%	1,380,384	1,380	30.5	5488	0	0.0	13	0	13390.8	0.00E+00	NC	0.00E+00	2.95E-01	does not exceed	0.00E+00

Notes:

Not a CPOI in this SMU

NA - Not applicable (See Attachment G)

NC - Not calculated

5 PERCENT f_{oc} IN BIOTURBATION LAYER

SMU 4

z 30.5

foc 0.10%

kbio(particle) cm/yr 1 kbl cm/hr 1

kbio(water) cm/yr 100 foc (bio layer) 0.05 0.05

Variable	ρ_b	ε or (n)	v	U	C_o	a	Vb	Dw	Hp	D'	foc	Koc	K_d	z	R_f	t_{50}	λ	u	SS Rxn	Approximate Time to Steady Conditions	Maximum of Diffusive or Advective Flux	Reactive Flux	Sediment Concentration (W_{bio})	*PEC*	PEC Exceedence?	Sediment Concentration (W_{bio}) Assuming 1.5X Safety Factor Applied to Thickness (z)
	Bulk density of cap material (1-ε)*ρs	Porosity	Pore water Velocity (U/ε)	Darcy Velocity (or v*ε)	Initial pore water concentration	Dispersivity	Organic Compd LeBas Molar Volume	Molecular diffusion coefficient (at 45 F)	Hindrance Parameter ($\varepsilon^{-1/3}$)	Diffusion/dispersion coefficient	Fraction of organic carbon in cap material	Organic carbon partition coeff for organics	Observed partition coefficient for CB (organics=foc*Koc, metals=literature value))	Chemical Isolation Layer Thickness	Retardation Factor	Half Life	Reaction Term (=ln2/t_{50})	$\sqrt{v^2+4\lambda D'}$								
	g/cm^3		cm/yr	cm/yr	mg/L		cm3/mol	cm^2/sec		cm^2/yr		mL/g	L/kg	cm		day	yr^{-1}		/cm	years	mg/cm2/yr	mg/cm2/yr	mg/kg	mg/kg		mg/kg
Mercury	1.59	0.4	750.0	300	4.12E-05	0.0125		1.96E-06	1.4	55	0.1%	NA	2,200	30.5	8746	0	0.0	750	0	355.7	1.24E-05	NC	9.98E-03	2.20E+00	does not exceed	9.98E-03
Ethylbenzene	1.59	0.4	750.0	300	0.00E+00	0.0125	140.4	4.80E-06	1.4	121	0.1%	588	0.59	30.5	3	228	1.1	750	0.09575	0.1	0.00E+00	0.00E+00	0.00E+00	1.76E-01	does not exceed	0.00E+00
Xylene	1.59	0.4	750.0	300	0.00E+00	0.0125	140.4	4.80E-06	1.4	121	0.1%	1,413	1.41	30.5	7	767	0.3	750	0.0522	0.3	0.00E+00	0.00E+00	0.00E+00		does not exceed	0.00E+00
Chlorobenzene	1.59	0.4	750.0	300	0.00E+00	0.0125	116.9	5.35E-06	1.4	134	0.1%	500	0.50	30.5	3	600	0.4	750	0.05615	0.1	0.00E+00	0.00E+00	0.00E+00	4.28E-01	does not exceed	0.00E+00
Dichlorobenzene	1.59	0.4	750.0	300	0.00E+00	0.0125	137.8	4.85E-06	1.4	122	0.1%	2,399	2.40	30.5	11	720	0.4	750	0.05361	0.4	0.00E+00	0.00E+00	0.00E+00		does not exceed	0.00E+00
Naphthalene	1.59	0.4	750.0	300	0.00E+00	0.0125	147.6	4.66E-06	1.4	118	0.1%	2,344	2.34	30.5	10	219	1.2	750	0.09903	0.4	0.00E+00	0.00E+00	0.00E+00	9.17E-01	does not exceed	0.00E+00
Fluorene	1.59	0.4	750.0	300	0.00E+00	0.0125	187.9	4.04E-06	1.4	103	0.1%	15,136	15.14	30.5	61	240	1.1	750	0.10096	2.5	0.00E+00	0.00E+00	0.00E+00	2.64E-01	does not exceed	0.00E+00
Phenanthrene	1.59	0.4	750.0	300	0.00E+00	0.0125	196.7	3.94E-06	1.4	101	0.1%	28,184	28.18	30.5	113	800	0.3	750	0.05598	4.6	0.00E+00	0.00E+00	0.00E+00	5.43E-01	does not exceed	0.00E+00
Pyrene	1.59	0.4	750.0	300	0.00E+00	0.0125	213.8	3.75E-06	1.4	97	0.1%	208,930	208.93	30.5	831	8000	0.0	750	0.0181	33.8	0.00E+00	0.00E+00	0.00E+00	3.44E-01	does not exceed	0.00E+00
Benzo(a)pyrene	1.59	0.4	750.0	300	0.00E+00	0.0125	265.4	3.30E-06	1.4	86	0.1%	1,096,478	1096.48	30.5	4360	2120	0.1	750	0.03723	177.3	0.00E+00	0.00E+00	0.00E+00	1.46E-01	does not exceed	0.00E+00
Hexachlorobenzene	1.59	0.4	750.0	300	2.34E-05	0.0125	221.4	3.67E-06	1.4	95	0.1%	1,513,561	1,514	30.5	6017	8364	0.0	750	0.01787	244.7	7.01E-06	7.00E-06	6.29E-02	NA		6.29E-02
							Est.																			
PCB's	1.59	0.4	750.0	300	0.00E+00	0.0125	250.0	3.42E-06	1.4	89	0.1%	1,380,384	1380.38	30.5	5488	0	0.0	750	0	223.2	0.00E+00	NC	0.00E+00	2.95E-01	does not exceed	0.00E+00

Notes:

Not a CPOI in this SMU

NA - Not applicable (See Attachment G)

NC - Not calculated

5 PERCENT f_{oc} IN BIOTURBATION LAYER

SMU 6

z 30.5

foc 0.10%

kbio(particle) cm/yr 1 kbl cm/hr 1

kbio(water) cm/yr 100 foc (bio layer) 0.05

Variable	ρ_b	ε or (n)	v	U	C_o	a	Vb	Dw	Hp	D'	foc	Koc	K_d	z	Rf	t_{50}	λ	u	SS Rxn	Approximate Time to Steady Conditions	Maximum of Diffusive or Advective Flux	Reactive Flux	Sediment Concentration (W_{bio})	*PEC*	PEC Exceedence?	Sediment Concentration (W_{bio}) Assuming 1.5X Safety Factor Applied to Thickness (z)
	Bulk density of cap material (1-ε)*ρs	Porosity	Pore water Velocity (U/ε)	Darcy Velocity (or v*ε)	Initial pore water concentration	Dispersivity	Organic Compd LeBas Molar Volume	Molecular diffusion coefficient (at 45 F)	Hindrance Parameter $(\varepsilon^{-1/3})$	Diffusion/dispersion coefficient	Fraction of organic carbon in cap material	Organic carbon partition coeff for organics	Observed partition coefficient for CB (organics=foc*Koc, metals=literature value))	Chemical Isolation Layer Thickness	Retardation Factor	Half Life	Reaction Term (=ln2/t_{50})	$\sqrt{v^2+4\lambda D'}$								
	g/cm^3		cm/yr	cm/yr	mg/L		cm3/mol	cm^2/sec		cm^2/yr		mL/g	L/kg	cm		day	yr^{-1}		/cm	years	mg/cm2/yr	mg/cm2/yr	mg/kg	mg/kg		mg/kg
Mercury	1.59	0.4	175.0	70	2.47E-03	0.0125		1.96E-06	1.4	48	0.1%	NA	2,200	30.5	8746	0	0.0	175.0	0	1524.3	1.73E-04	NC	1.47E-01	2.20E+00	does not exceed	1.47E-01
	1.59	0.4	7.5	3	2.47E-03	0.0125		1.96E-06	1.4	46	0.1%	NA	2,200	30.5	8746	0	0.0	7.5	0	35567.1	7.41E-06	NC	6.39E-03	2.20E+00	does not exceed	6.39E-03
Ethylbenzene	1.59	0.4	175.0	70	0.00E+00	0.0125	140.4	4.80E-06	1.4	114	0.1%	588	0.59	30.5	3	228	1.1	176.4	0.09873	0.6	0.00E+00	0.00E+00	0.00E+00	1.76E-01	does not exceed	0.00E+00
	1.59	0.4	7.5	3	0.00E+00	0.0125	140.4	4.80E-06	1.4	112	0.1%	588	0.59	30.5	3	228	1.1	23.5	0.09965	13.6	0.00E+00	0.00E+00	0.00E+00	1.76E-01	does not exceed	0.00E+00
Xylene	1.59	0.4	175.0	70	1.48E+00	0.0125	140.4	4.80E-06	1.4	114	0.1%	1,413	1.41	30.5	7	767	0.3	175.4	0.05383	1.2	1.04E-01	9.78E-02	2.52E+01	5.61E-01	Exceeds PEC	2.45E+01
	1.59	0.4	7.5	3	1.48E+00	0.0125	140.4	4.80E-06	1.4	112	0.1%	1,413	1.41	30.5	7	767	0.3	14.3	0.05433	26.9	4.44E-03	1.42E-03	4.77E-01		does not exceed	2.02E-01
Chlorobenzene	1.59	0.4	175.0	70	0.00E+00	0.0125	116.9	5.35E-06	1.4	127	0.1%	500	0.50	30.5	3	600	0.4	175.6	0.05772	0.5	0.00E+00	0.00E+00	0.00E+00	4.28E-01	does not exceed	0.00E+00
	1.59	0.4	7.5	3	0.00E+00	0.0125	116.9	5.35E-06	1.4	124	0.1%	500	0.50	30.5	3	600	0.4	16.3	0.0582	12.1	0.00E+00	0.00E+00	0.00E+00	4.28E-01	does not exceed	0.00E+00
Dichlorobenzenes	1.59	0.4	175.0	70	7.26E-02	0.0125	137.8	4.85E-06	1.4	115	0.1%	2,399	2.40	30.5	11	720	0.4	175.5	0.05526	1.8	5.08E-03	4.78E-03	1.65E+00	2.39E-01	Exceeds PEC	1.60E+00
	1.59	0.4	7.5	3	7.26E-02	0.0125	137.8	4.85E-06	1.4	113	0.1%	2,399	2.40	30.5	11	720	0.4	14.7	0.05577	42.8	2.18E-04	6.91E-05	2.91E-02		does not exceed	1.21E-02
Naphthalene	1.59	0.4	175.0	70	1.65E+00	0.0125	147.6	4.66E-06	1.4	111	0.1%	2,344	2.34	30.5	10	219	1.2	176.5	0.1022	1.8	1.16E-01	9.44E-02	3.23E+01	9.17E-01	Exceeds PEC	2.92E+01
	1.59	0.4	7.5	3	1.65E+00	0.0125	147.6	4.66E-06	1.4	108	0.1%	2,344	2.34	30.5	10	219	1.2	23.6	0.10318	42.0	4.95E-03	6.36E-04	2.66E-01	9.17E-01	does not exceed	2.66E-01
Fluorene	1.59	0.4	175.0	70	7.46E-02	0.1250	187.9	4.04E-06	1.4	116	0.1%	15,136	15.14	30.5	61	240	1.1	176.4	0.09536	10.7	5.22E-03	4.35E-03	2.77E+00	2.64E-01	Exceeds PEC	2.52E+00
	1.59	0.4	7.5	3	7.46E-02	0.1250	187.9	4.04E-06	1.4	95	0.1%	15,136	15.14	30.5	61	240	1.1	21.4	0.10535	248.7	2.24E-04	2.41E-05	1.60E-02	2.64E-01	does not exceed	3.21E-03
Phenanthrene	1.59	0.4	175.0	70	1.22E-02	0.0125	196.7	3.94E-06	1.4	94	0.1%	28,184	28.18	30.5	113	800	0.3	175.3	0.05808	19.7	8.56E-04	8.11E-04	6.03E-01	5.43E-01	Exceeds PEC	5.87E-01
	1.59	0.4	7.5	3	1.22E-02	0.0125	196.7	3.94E-06	1.4	92	0.1%	28,184	28.18	30.5	113	800	0.3	13.1	0.05874	459.7	3.67E-05	1.01E-05	7.73E-03	5.43E-01	does not exceed	4.06E-03
Pyrene	1.59	0.4	175.0	70	7.87E-03	0.0125	213.8	3.75E-06	1.4	89	0.1%	208,930	208.93	30.5	831	8000	0.0	175.0	0.01881	144.9	5.51E-04	5.48E-04	9.89E-01	3.44E-01	Exceeds PEC	9.87E-01
	1.59	0.4	7.5	3	7.87E-03	0.0125	213.8	3.75E-06	1.4	87	0.1%	208,930	208.93	30.5	831	8000	0.0	8.2	0.01904	3381.4	2.36E-05	2.08E-05	3.77E-02	3.44E-01	does not exceed	3.54E-02
Benzo(a)pyrene	1.59	0.4	175.0	70	9.71E-04	0.0125	265.4	3.30E-06	1.4	79	0.1%	1,096,478	1,096	30.5	4360	2120	0.1	175.1	0.03888	759.8	6.80E-05	6.66E-05	4.55E-01	1.46E-01	Exceeds PEC	4.50E-01
	1.59	0.4	7.5	3	9.71E-04	0.0125	265.4	3.30E-06	1.4	77	0.1%	1,096,478	1,096	30.5	4360	2120	0.1	9.6	0.03941	17728.6	2.91E-06	1.79E-06	1.23E-02	1.46E-01	does not exceed	9.68E-03
Hexachlorobenzene	1.59	0.4	175.0	70	0.00E+00	0.0125	221.4	3.67E-06	1.4	88	0.1%	1,513,561	1,514	30.5	6017	8364	0.0	175	0.01859	1048.7	0.00E+00	0.00E+00	0.00E+00	NA		0.00E+00
	1.59	0.4	7.5	3	0.00E+00	0.0125	221.4	3.67E-06	1.4	85	0.1%	1,513,561	1,514	30.5	6017	8364	0.0	8	0.01881	24470.8	0.00E+00	0.00E+00	0.00E+00			0.00E+00
							Est.																			
PCB's	1.59	0.4	175.0	70	1.49E-04	0.0125	250.0	3.42E-06	1.4	82	0.1%	1,380,384	1,380	30.5	5488	0	0.0	175.0	0	956.5	1.04E-05	NC	3.86E-01	2.95E-01	Exceeds PEC	3.86E-01
	1.59	0.4	7.5	3	1.49E-04	0.0125	250.0	3.42E-06	1.4	80	0.1%	1,380,384	1,380	30.5	5488	0	0.0	7.5	0	22318.0	4.47E-07	NC	1.69E-02	2.95E-01	does not exceed	1.69E-02

Notes:

Not a CPOI in this SMU

NA - Not applicable (See Attachment G)

NC - Not calculated

5 PERCENT f_{oc} IN BIOTURBATION LAYER

SMU 7

foc	z	kbio(particle) cm/yr			
		kbio(particle) cm/yr	1	kbl cm/hr	1
0.10%	76.25	kbio(water) cm/yr	100	foc (bio layer)	0.05

Variable	ρ_b	ε or (n)	v	U	C_o	a	Vb	Dw	Hp	D'	foc	Koc	K_d	z	R_f	t_{50}	λ	u	SS Rxn	Approximate Time to Steady Conditions	Maximum of Diffusive or Advective Flux	Reactive Flux	Sediment Concentration (W_{bio})	*PEC*	PEC Exceedence?	Sediment Concentration (W_{bio}) Assuming 1.5X Safety Factor Applied to Thickness (z)
	Bulk density of cap material (1-ε)*ρs	Porosity	Pore water Velocity (U/ε)	Darcy Velocity (or v*ε)	Initial pore water concentration	Dispersivity	Organic Compd LeBas Molar Volume	Molecular diffusion coefficient (at 45 F)	Hindrance Parameter ($\varepsilon^{-1/3}$)	Diffusion/dispersion coefficient	Fraction of organic carbon in cap material	Organic carbon partition coeff for organics	Observed partition coefficient for CB (organics=foc*Koc, metals=literature value))	Chemical Isolation Layer Thickness	Retardation Factor	Half Life	Reaction Term (=ln2/t_{50})	$\sqrt{v^2+4\lambda D'}$								
	g/cm^3		cm/yr	cm/yr	mg/L		cm3/mol	cm^2/sec		cm^2/yr		mL/g	L/kg	cm		day	yr^{-1}		/cm	years	mg/cm2/yr	mg/cm2/yr	mg/kg	mg/kg		mg/kg
Mercury	1.59	0.4	250.0	100	3.00E-05	0.0125		1.96E-06	1.4	49	0.1%	NA	2,200	76.25	8746	0	0.0	250	0	2667.5	3.00E-06	NC	2.53E-03	2.20E+00	does not exceed	2.53E-03
	1.59	0.4	7.5	3	3.00E-05	0.0125		1.96E-06	1.4	46	0.1%	NA	2,200	76.25	8746	0	0.0	8	0	88917.7	9.00E-08	NC	7.76E-05	2.20E+00	does not exceed	7.76E-05
	1.59	0.4	5.0	2	3.00E-05	0.0125		1.96E-06	1.4	46	0.1%	NA	2,200	76.25	8746	0	0.0	5	0	133376.5	6.00E-08	NC	5.17E-05	2.20E+00	does not exceed	5.17E-05
Ethylbenzene	1.59	0.4	250.0	100	1.75E-01	0.0125	140.4	4.80E-06	1.4	115	0.1%	588	0.59	76.25	3	228	1.1	251	0.09832	1.0	1.75E-02	1.25E-02	1.53E+00	1.76E-01	does not exceed	1.29E+00
	1.59	0.4	7.5	3	1.75E-01	0.0125	140.4	4.80E-06	1.4	112	0.1%	588	0.59	76.25	3	228	1.1	23	0.09965	33.9	5.25E-04	7.82E-07	1.56E-04	1.76E-01	does not exceed	3.49E-06
	1.59	0.4	5.0	2	1.75E-01	0.0125	140.4	4.80E-06	1.4	112	0.1%	588	0.59	76.25	3	228	1.1	23	0.09966	50.9	3.50E-04	7.81E-07	1.56E-04	1.76E-01	does not exceed	3.50E-06
Xylene	1.59	0.4	250.0	100	1.23E+00	0.0125	140.4	4.80E-06	1.4	115	0.1%	1,413	1.41	76.25	7	767	0.3	250	0.05361	2.0	1.23E-01	1.11E-01	2.60E+01	5.61E-01	Exceeds PEC	2.47E+01
	1.59	0.4	7.5	3	1.23E+00	0.0125	140.4	4.80E-06	1.4	112	0.1%	1,413	1.41	76.25	7	767	0.3	14	0.05433	67.3	3.69E-03	1.29E-04	4.33E-02		does not exceed	8.10E-03
	1.59	0.4	5.0	2	1.23E+00	0.0125	140.4	4.80E-06	1.4	112	0.1%	1,413	1.41	76.25	7	767	0.3	13	0.05434	100.9	2.46E-03	9.48E-05	3.20E-02		does not exceed	4.03E-03
Chlorobenzene	1.59	0.4	250.0	100	4.35E+00	0.0125	116.9	5.35E-06	1.4	127	0.1%	500	0.50	76.25	3	600	0.4	250	0.05751	0.9	4.35E-01	3.83E-01	4.09E+01	4.28E-01	Exceeds PEC	3.84E+01
	1.59	0.4	7.5	3	4.35E+00	0.0125	116.9	5.35E-06	1.4	124	0.1%	500	0.50	76.25	3	600	0.4	16	0.0582	30.4	1.31E-02	2.98E-04	5.29E-02	4.28E-01	does not exceed	5.75E-03
	1.59	0.4	5.0	2	4.35E+00	0.0125	116.9	5.35E-06	1.4	124	0.1%	500	0.50	76.25	3	600	0.4	15	0.05821	45.6	8.70E-03	2.98E-04	5.32E-02	4.28E-01	does not exceed	5.78E-03
Dichlorobenzene	1.59	0.4	250.0	100	3.99E+00	0.0125	137.8	4.85E-06	1.4	116	0.1%	2,399	2.40	76.25	11	720	0.4	250	0.05503	3.2	3.99E-01	3.58E-01	1.15E+02	2.39E-01	Exceeds PEC	1.09E+02
	1.59	0.4	7.5	3	3.99E+00	0.0125	137.8	4.85E-06	1.4	113	0.1%	2,399	2.40	76.25	11	720	0.4	15	0.05577	107.1	1.20E-02	3.36E-04	1.42E-01		does not exceed	2.38E-02
	1.59	0.4	5.0	2	3.99E+00	0.0125	137.8	4.85E-06	1.4	113	0.1%	2,399	2.40	76.25	11	720	0.4	14	0.05577	160.7	7.98E-03	2.86E-04	1.21E-01		does not exceed	1.44E-02
Naphthalene	1.59	0.4	250.0	100	3.09E+00	0.0125	147.6	4.66E-06	1.4	112	0.1%	2,344	2.34	76.25	10	219	1.2	251	0.10177	3.1	3.09E-01	2.17E-01	6.87E+01	9.17E-01	Exceeds PEC	5.76E+01
	1.59	0.4	7.5	3	3.09E+00	0.0125	147.6	4.66E-06	1.4	108	0.1%	2,344	2.34	76.25	10	219	1.2	24	0.10318	104.9	9.27E-03	1.06E-05	4.43E-03	9.17E-01	does not exceed	8.67E-05
	1.59	0.4	5.0	2	3.09E+00	0.0125	147.6	4.66E-06	1.4	108	0.1%	2,344	2.34	76.25	10	219	1.2	23	0.1032	157.3	6.18E-03	1.06E-05	4.44E-03	9.17E-01	does not exceed	8.68E-05
Fluorene	1.59	0.4	250.0	100	7.10E-03	0.0125	187.9	4.04E-06	1.4	97	0.1%	15,136	15.14	76.25	61	240	1.1	251	0.10415	18.7	7.10E-04	5.15E-04	3.22E-01	2.64E-01	Exceeds PEC	2.74E-01
	1.59	0.4	7.5	3	7.10E-03	0.0125	187.9	4.04E-06	1.4	94	0.1%	15,136	15.14	76.25	61	240	1.1	21	0.10582	621.9	2.13E-05	1.77E-08	1.18E-05	2.64E-01	does not exceed	2.09E-07
	1.59	0.4	5.0	2	7.10E-03	0.0125	187.9	4.04E-06	1.4	94	0.1%	15,136	15.14	76.25	61	240	1.1	21	0.10584	932.8	1.42E-05	1.77E-08	1.18E-05	2.64E-01	does not exceed	2.08E-07
Phenanthrene	1.59	0.4	250.0	100	1.61E-02	0.0125	196.7	3.94E-06	1.4	95	0.1%	28,184	28.18	76.25	113	800	0.3	250	0.0578	34.5	1.61E-03	1.46E-03	1.08E+00	5.43E-01	Exceeds PEC	1.03E+00
	1.59	0.4	7.5	3	1.61E-02	0.0125	196.7	3.94E-06	1.4	92	0.1%	28,184	28.18	76.25	113	800	0.3	13	0.05874	1149.2	4.83E-05	1.94E-06	1.48E-03	5.43E-01	does not exceed	2.96E-04
	1.59	0.4	5.0	2	1.61E-02	0.0125	196.7	3.94E-06	1.4	92	0.1%	28,184	28.18	76.25	113	800	0.3	12	0.05875	1723.7	3.22E-05	7.86E-07	5.99E-04	5.43E-01	does not exceed	6.37E-05
Pyrene	1.59	0.4	250.0	100	1.04E-02	0.0125	213.8	3.75E-06	1.4	90	0.1%	208,930	208.93	76.25	831	8000	0.0	250	0.01872	253.6	1.04E-03	1.03E-03	1.85E+00	3.44E-01	Exceeds PEC	1.85E+00
	1.59	0.4	7.5	3	1.04E-02	0.0125	213.8	3.75E-06	1.4	87	0.1%	208,930	208.93	76.25	831	8000	0.0	8	0.01904	8453.6	3.12E-05	2.26E-05	4.11E-02	3.44E-01	does not exceed	3.50E-02
	1.59	0.4	5.0	2	1.04E-02	0.0125	213.8	3.75E-06	1.4	87	0.1%	208,930	208.93	76.25	831	8000	0.0	6	0.01904	12680.3	2.08E-05	1.28E-05	2.33E-02	3.44E-01	does not exceed	1.83E-02
Benzo(a)pyrene	1.59	0.4	250.0	100	6.00E-03	0.0125	265.4	3.30E-06	1.4	80	0.1%	1,096,478	1,096	76.25	4360	2120	0.1	250	0.03866	1329.6	6.00E-04	5.79E-04	3.94E+00	1.46E-01	Exceeds PEC	3.87E+00
	1.59	0.4	7.5	3	6.00E-03	0.0125	265.4	3.30E-06	1.4	77	0.1%	1,096,478	1,096	76.25	4360	2120	0.1	10	0.03941	44321.6	1.80E-05	5.35E-06	3.68E-02	1.46E-01	does not exceed	2.01E-02
	1.59	0.4	5.0	2	6.00E-03	0.0125	265.4	3.30E-06	1.4	77	0.1%	1,096,478	1,096	76.25	4360	2120	0.1	8	0.03942	66482.4	1.20E-05	1.95E-06	1.34E-02	1.46E-01	does not exceed	5.39E-03
Hexachlorobenzene	1.59	0.4	250.0	100	0.00E+00	0.0125	221.4	3.67E-06	1.4	88	0.1%	1,513,561	1,514	76.25	6017	8364	0.0	250	0.01849	1835.3	0.00E+00	0.00E+00	0.00E+00	NA		0.00E+00
	1.59	0.4	7.5	3	0.00E+00	0.0125	221.4	3.67E-06	1.4	85	0.1%	1,513,561	1,514	76.25	6017	8364	0.0	8	0.01881	61177.0	0.00E+00	0.00E+00	0.00E+00			0.00E+00
	1.59	0.4	5.0	2	0.00E+00	0.0125	221.4	3.67E-06	1.4	85	0.1%	1,513,561	1,514	76.25	6017	8364	0.0	6	0.01881	91765.4	0.00E+00	0.00E+00	0.00E+00			0.00E+00
							Est.																			
PCB's	1.59	0.4	250.0	100	1.33E-04	0.0125	250.0	3.42E-06	1.4	83	0.1%	1,380,384	1,380	76.25	5488	0	0.0	250	0	1673.8	1.33E-05	NC	4.88E-01	2.95E-01	Exceeds PEC	4.88E-01
	1.59	0.4	7.5	3	1.33E-04	0.0125	250.0	3.42E-06	1.4	80	0.1%	1,380,384	1,380	76.25	5488	0	0.0	8	0	55794.9	4.00E-07	NC	1.52E-02	2.95E-01	does not exceed	1.52E-02
	1.59	0.4	5.0	2	1.33E-04	0.0125	250.0	3.42E-06	1.4	80	0.1%	1,380,384	1,380	76.25	5488	0	0.0	5	0	83692.4	2.67E-07	NC	1.01E-02	2.95E-01	does not exceed	1.01E-02

Notes:

Not a CPOI in this SMU

NA - Not applicable (See Attachment G)

NC - Not calculated

1 PERCENT f_{oc} IN BIOTURBATION LAYER - BENZENE, TOLUENE AND PHENOL

SMU 1

foc	z	kbio(particle) cm/yr	1	kbl cm/hr	1
0.10%	76.25	kbio(water) cm/yr	100	foc (bio layer)	0.01

Variable	ρ_b	ε or (n)	v	U	C_o	a	Vb	Dw	Hp	D'	foc	Koc	K_d	z	R_f	t_{50}	λ	u	SS Rxn	Approximate Time to Steady Conditions	Maximum of Diffusive or Advective Flux	Reactive Flux	Sediment Concentration (W_{bio})	*SSC*	SSC Sediment Concentration Exceedence?
	Bulk density of cap material (1-ε)*ρs	Porosity	Pore water Velocity (U/ε)	Darcy Velocity (or v*ε)	Initial pore water concentration	Dispersivity	Organic Compd LeBas Molar Volume	Molecular diffusion coefficient (at 45 F)	Hindrance Parameter ($\varepsilon^{-1/3}$)	Diffusion/dispersion coefficient	Fraction of organic carbon in cap material	Organic carbon partition coeff for organics	Observed partition coefficient for CB (organics=foc*Koc, metals=literature value))	Chemical Isolation Layer Thickness	Retardation Factor	Half Life	Reaction Term (=ln2/t_{50})	$\sqrt{v^2+4\lambda D'}$							
	g/cm^3		cm/yr	cm/yr	mg/L		cm3/mol	cm^2/sec		cm^2/yr		mL/g	L/kg	cm		day	yr^{-1}		/cm	years	mg/cm2/yr	mg/cm2/yr	mg/kg	mg/kg	
Benzene	1.59	0.4	5.0	2	1.07E+01	0.0125	96.0	6.01E-06	1.4	140	0.1%	100	0.10	76.25	1	720	0.4	15	0.05015	21.3	2.14E-02	1.31E-03	1.28E-02	2.80E-01	does not exceed
Toluene	1.59	0.4	5.0	2	7.01E+00	0.0125	118.2	5.31E-06	1.4	124	0.1%	490	0.49	76.25	3	365	0.7	19	0.07488	45.0	1.40E-02	1.72E-04	7.75E-03	4.90E-01	does not exceed
Phenol	1.59	0.4	5.0	2	5.30E+00	0.0125	103.4	5.75E-06	1.4	134	0.1%	100	0.10	76.25	1	28	9.0	70	0.2599	21.3	1.06E-02	1.57E-62	1.52E-61	2.50E-01	does not exceed

Sediment Concentration (W_{bio}) Assuming 1.5X Safety Factor Applied to Thickness (z)
mg/kg
1.88E-03
4.46E-04
1.85E-91

1 PERCENT f_{oc} IN BIOTURBATION LAYER - BENZENE, TOLUENE AND PHENOL

SMU 2

foc	z	kbio(particle) cm/yr	1	kbl cm/hr	1
0.10%	76.25	kbio(water) cm/yr	100	foc (bio layer)	0.01

Variable	ρ_b	ε or (n)	v	U	C_o	a	Vb	Dw	Hp	D'	foc	Koc	K_d	z	R_f	t_{50}	λ	u	SS Rxn	Approximate Time to Steady Conditions	Maximum of Diffusive or Advective Flux	Reactive Flux	Sediment Concentration (W_{bio})	*SSC*	SSC Sediment Concentration Exceedence?
	Bulk density of cap material (1-ε)*ρs	Porosity	Pore water Velocity (U/ε)	Darcy Velocity (or v*ε)	Initial pore water concentration	Dispersivity	Organic Compd LeBas Molar Volume	Molecular diffusion coefficient (at 45 F)	Hindrance Parameter ($\varepsilon^{-1/3}$)	Diffusion/dispersion coefficient	Fraction of organic carbon in cap material	Organic carbon partition coeff for organics	Observed partition coefficient for CB (organics=foc*Koc, metals=literature value))	Chemical Isolation Layer Thickness	Retardation Factor	Half Life	Reaction Term (=ln2/t_{50})	$\sqrt{v^2+4\lambda D'}$							
	g/cm^3		cm/yr	cm/yr	mg/L		cm3/mol	cm^2/sec		cm^2/yr		mL/g	L/kg	cm		day	yr^{-1}		/cm	years	mg/cm2/yr	mg/cm2/yr	mg/kg	mg/kg	
Benzene	1.59	0.4	5.0	2	3.91E+01	0.0125	96.0	6.01E-06	1.4	140	0.1%	100	0.10	76.25	1	720	0.4	15	0.05015	21.3	7.83E-02	4.79E-03	4.67E-02	2.80E-01	does not exceed
Toluene	1.59	0.4	5.0	2	2.31E+00	0.0125	118.2	5.31E-06	1.4	124	0.1%	490	0.49	76.25	3	365	0.7	19	0.07488	45.0	4.61E-03	5.66E-05	2.55E-03	4.90E-01	does not exceed
Phenol	1.59	0.4	5.0	2	2.75E-01	0.0125	103.4	5.75E-06	1.4	134	0.1%	100	0.10	76.25	1	28	9.0	70	0.2599	21.3	5.51E-04	8.14E-64	7.92E-63	2.50E-01	does not exceed

Variable	Sediment Concentration (W_{bio}) Assuming 1.5X Safety Factor Applied to Thickness (z)
	mg/kg
Benzene	6.89E-03
Toluene	1.47E-04
Phenol	9.63E-93

1 PERCENT f_{oc} IN BIOTURBATION LAYER - BENZENE, TOLUENE AND PHENOL

SMU 3

z 30.5

foc 0.10%

kbio(particle) cm/yr 1 kbl cm/hr 1

kbio(water) cm/yr 100 foc (bio layer) 0.01

Variable	ρ_b	ε or (n)	v	U	C_o	a	Vb	Dw	Hp	D'	foc	Koc	K_d	z	R_f	t_{50}	λ	u	SS Rxn	Approximate Time to Steady Conditions	Maximum of Diffusive or Advective Flux	Reactive Flux	Sediment Concentration (W_{bio})	SSC	SSC Sediment Concentration Exceedence?	Sediment Concentration (W_{bio}) Assuming 1.5X Safety Factor Applied to Thickness (z)
	Bulk density of cap material (1-ε)*ρs	Porosity	Pore water Velocity (U/ε)	Darcy Velocity (or v*ε)	Initial pore water concentration	Dispersivity	Organic Compd LeBas Molar Volume	Molecular diffusion coefficient (at 45 F)	Hindrance Parameter ($\varepsilon^{-1/3}$)	Diffusion/dispersion coefficient	Fraction of organic carbon in cap material	Organic carbon partition coeff for organics	Observed partition coefficient for CB (organics=foc*Koc, metals=literature value))	Chemical Isolation Layer Thickness	Retardation Factor	Half Life	Reaction Term (=ln2/t_{50})	$\sqrt{v^2+4\lambda D'}$								
	g/cm^3		cm/yr	cm/yr	mg/L		cm3/mol	cm^2/sec		cm^2/yr		mL/g	L/kg	cm		day	yr^{-1}		/cm	years	mg/cm2/yr	mg/cm2/yr	mg/kg	mg/kg		mg/kg
Benzene	1.59	0.4	1750.0	700	2.40E+00	0.0125	96.0	6.01E-06	1.4	162	0.1%	100	0.10	30.5	1	720	0.4	1750	0.04664	0.0	1.68E+00	1.67E+00	2.26E+00	2.80E-01	Exceeds SSC	2.25E+00
	1.59	0.4	12.5	5	2.40E+00	0.0125	96.0	6.01E-06	1.4	140	0.1%	100	0.10	30.5	1	720	0.4	19	0.05013	3.4	1.20E-02	5.09E-03	4.82E-02	2.80E-01	does not exceed	3.14E-02
Toluene	1.59	0.4	1750.0	700	4.66E-01	0.0125	118.2	5.31E-06	1.4	145	0.1%	490	0.49	30.5	3	365	0.7	1750	0.06903	0.1	3.26E-01	3.22E-01	2.12E+00	4.90E-01	Exceeds SSC	2.11E+00
	1.59	0.4	12.5	5	4.66E-01	0.0125	118.2	5.31E-06	1.4	124	0.1%	490	0.49	30.5	3	365	0.7	22	0.07485	7.2	2.33E-03	4.30E-04	1.88E-02	4.90E-01	does not exceed	8.09E-03
Phenol	1.59	0.4	1750.0	700	0.00E+00	0.0125	103.4	5.75E-06	1.4	156	0.1%	100	0.10	30.5	1	28	9.0	1752	0.24099	0.0	0.00E+00	0.00E+00	0.00E+00	2.50E-01	does not exceed	0.00E+00
	1.59	0.4	12.5	5	0.00E+00	0.0125	103.4	5.75E-06	1.4	134	0.1%	100	0.10	30.5	1	28	9.0	71	0.25981	3.4	0.00E+00	0.00E+00	0.00E+00	2.50E-01	does not exceed	0.00E+00

Not a CPOI in this SMU

1 PERCENT f_{oc} IN BIOTURBATION LAYER - BENZENE, TOLUENE AND PHENOL

SMU 4

z 30.5

foc 0.10%

kbio(particle) cm/yr 1

kbl cm/hr 1

kbio(water) cm/yr 100

foc (bio layer) 0.01

Variable	ρ_b	ε or (n)	v	U	C_o	a	Vb	Dw	Hp	D'	foc	Koc	K_d	z	R_f	t_{50}	λ	u	SS Rxn	Approximate Time to Steady Conditions	Maximum of Diffusive or Advective Flux	Reactive Flux	Sediment Concentration (W_{bio})	*SSC*	SSC Sediment Concentration Exceedence?	Sediment Concentration (W_{bio}) Assuming 1.5X Safety Factor Applied to Thickness (z)
	Bulk density of cap material (1-ε)*ρs	Porosity	Pore water Velocity (U/ε)	Darcy Velocity (or v*ε)	Initial pore water concentration	Dispersivity	Organic Compd LeBas Molar Volume	Molecular diffusion coefficient (at 45 F)	Hindrance Parameter ($\varepsilon^{-1/3}$)	Diffusion/dispersion coefficient	Fraction of organic carbon in cap material	Organic carbon partition coeff for organics	Observed partition coefficient for CB (organics=foc*Koc, metals=literature value))	Chemical Isolation Layer Thickness	Retardation Factor	Half Life	Reaction Term (=ln2/t_{50})	$\sqrt{v^2+4\lambda D'}$								
	g/cm^3		cm/yr	cm/yr	mg/L		cm3/mol	cm^2/sec		cm^2/yr		mL/g	L/kg	cm		day	yr^{-1}		/cm	years	mg/cm2/yr	mg/cm2/yr	mg/kg	mg/kg		mg/kg
Benzene	1.59	0.4	750.0	300	1.41E-02	0.0125	96.0	6.01E-06	1.4	149	0.1%	100	0.10	30.5	1	720	0.4	750	0.04855	0.1	4.23E-03	4.17E-03	1.08E-02	2.80E-01	does not exceed	1.08E-02
Toluene	1.59	0.4	750.0	300	2.09E-03	0.0125	118.2	5.31E-06	1.4	133	0.1%	490	0.49	30.5	3	365	0.7	750	0.07221	0.1	6.28E-04	6.10E-04	7.66E-03	4.90E-01	does not exceed	7.55E-03
Phenol	1.59	0.4	750.0	300	0.00E+00	0.0125	103.4	5.75E-06	1.4	143	0.1%	100	0.10	30.5	1	28	9.0	753	0.2513	0.1	0.00E+00	0.00E+00	0.00E+00	2.50E-01	does not exceed	0.00E+00

1 PERCENT f_{oc} IN BIOTURBATION LAYER - BENZENE, TOLUENE AND PHENOL

SMU 6

z	foc	kbio(particle) cm/yr	1	kbl cm/hr	1
30.5	0.10%	kbio(water) cm/yr	100	foc (bio layer)	0.01

Variable	ρ_b	ε or (n)	v	U	C_o	a	Vb	Dw	Hp	D'	foc	Koc	K_d	z	Rf	t_{50}	λ	u	SS Rxn	Approximate Time to Steady Conditions	Maximum of Diffusive or Advective Flux	Reactive Flux	Sediment Concentration (W_{bio})	*SSC*	SSC Sediment Concentration Exceedence?	Sediment Concentration (W_{bio}) Assuming 1.5X Safety Factor Applied to Thickness (z)
	Bulk density of cap material (1-ε)*ps	Porosity	Pore water Velocity (U/ε)	Darcy Velocity (or v*ε)	Initial pore water concentration	Dispersivity	Organic Compd LeBas Molar Volume	Molecular diffusion coefficient (at 45 F)	Hindrance Parameter ($\epsilon^{-1/3}$)	Diffusion/dispersion coefficient	Fraction of organic carbon in cap material	Organic carbon partition coeff for organics	Observed partition coefficient for CB (organics=foc*Koc, metals=literature value))	Chemical Isolation Layer Thickness	Retardation Factor	Half Life	Reaction Term (=ln2/t_{50})	$\sqrt{v^2+4\lambda D'}$								
	g/cm^3		cm/yr	cm/yr	mg/L		cm3/mol	cm^2/sec		cm^2/yr		mL/g	L/kg	cm		day	yr^{-1}		/cm	years	mg/cm2/yr	mg/cm2/yr	mg/kg	mg/kg		mg/kg
Benzene	1.59	0.4	175.0	70	6.13E-02	0.0125	96.0	6.01E-06	1.4	142	0.1%	100	0.10	30.5	1	720	0.4	175.6	0.04977	0.2	4.29E-03	4.04E-03	2.39E-02	2.80E-01	does not exceed	2.32E-02
	1.59	0.4	7.5	3	6.13E-02	0.0125	96.0	6.01E-06	1.4	140	0.1%	100	0.10	30.5	1	720	0.4	15.9	0.05014	5.7	1.84E-04	7.81E-05	7.53E-04	2.80E-01	does not exceed	3.38E-04
Toluene	1.59	0.4	175.0	70	7.24E-02	0.0125	118.2	5.31E-06	1.4	126	0.1%	490	0.49	30.5	3	365	0.7	176.0	0.07424	0.5	5.07E-03	4.49E-03	1.26E-01	4.90E-01	does not exceed	1.19E-01
	1.59	0.4	7.5	3	7.24E-02	0.0125	118.2	5.31E-06	1.4	124	0.1%	490	0.49	30.5	3	365	0.7	20.0	0.07487	12.0	2.17E-04	5.52E-05	2.46E-03	4.90E-01	does not exceed	7.80E-04
Phenol	1.59	0.4	175.0	70	2.74E-02	0.0125	103.4	5.75E-06	1.4	136	0.1%	100	0.10	30.5	1	28	9.0	188.5	0.25786	0.2	1.92E-03	3.98E-04	2.36E-03	2.50E-01	does not exceed	1.07E-03
	1.59	0.4	7.5	3	2.74E-02	0.0125	103.4	5.75E-06	1.4	134	0.1%	100	0.10	30.5	1	28	9.0	69.9	0.25987	5.7	8.23E-05	2.75E-07	2.65E-06	2.50E-01	does not exceed	5.05E-08

1 PERCENT f_{oc} IN BIOTURBATION LAYER - BENZENE, TOLUENE AND PHENOL

SMU 7

foc 0.10%

z 76.25

kbio(particle) cm/yr 1 kbl cm/hr 1

kbio(water) cm/yr 100 foc (bio layer) 0.01

Variable	ρ_b	ε or (n)	v	U	C_o	a	Vb	Dw	Hp	D'	foc	Koc	K_d	z	R_f	t_{50}	λ	u	SS Rxn	Approximate Time to Steady Conditions	Maximum of Diffusive or Advective Flux	Reactive Flux	Sediment Concentration (W_{bio})	*SSC*	SSC Sediment Concentration Exceedence?	Sediment Concentration (W_{bio}) Assuming 1.5X Safety Factor Applied to Thickness (z)
	Bulk density of cap material (1-ε)*ρs	Porosity	Pore water Velocity (U/ε)	Darcy Velocity (or v*ε)	Initial pore water concentration	Dispersivity	Organic Compd LeBas Molar Volume	Molecular diffusion coefficient (at 45 F)	Hindrance Parameter ($\varepsilon^{-1/3}$)	Diffusion/dispersion coefficient	Fraction of organic carbon in cap material	Organic carbon partition coeff for organics	Observed partition coefficient for CB (organics=foc*Koc, metals=literature value))	Chemical Isolation Layer Thickness	Retardation Factor	Half Life	Reaction Term (=ln2/t_{50})	$\sqrt{v^2+4\lambda D'}$								
	g/cm^3		cm/yr	cm/yr	mg/L		cm3/mol	cm^2/sec		cm^2/yr		mL/g	L/kg	cm		day	yr^{-1}		/cm	years	mg/cm2/yr	mg/cm2/yr	mg/kg	mg/kg		mg/kg
Benzene	1.59	0.4	250.0	100	2.46E+00	0.0125	96.0	6.01E-06	1.4	143	0.1%	100	0.10	76.25	1	720	0.4	250	0.0496	0.4	2.46E-01	2.21E-01	1.12E+00	2.80E-01	Exceeds SSC	1.06E+00
	1.59	0.4	7.5	3	2.46E+00	0.0125	96.0	6.01E-06	1.4	140	0.1%	100	0.10	76.25	1	720	0.4	16	0.05014	14.2	7.39E-03	3.02E-04	2.91E-03	2.80E-01	does not exceed	4.30E-04
	1.59	0.4	5.0	2	2.46E+00	0.0125	96.0	6.01E-06	1.4	140	0.1%	100	0.10	76.25	1	720	0.4	15	0.05015	21.3	4.93E-03	3.02E-04	2.94E-03	2.80E-01	does not exceed	4.34E-04
Toluene	1.59	0.4	250.0	100	9.46E-01	0.0125	118.2	5.31E-06	1.4	127	0.1%	490	0.49	76.25	3	365	0.7	251	0.07397	0.9	9.46E-02	7.66E-02	1.85E+00	4.90E-01	Exceeds SSC	1.66E+00
	1.59	0.4	7.5	3	9.46E-01	0.0125	118.2	5.31E-06	1.4	124	0.1%	490	0.49	76.25	3	365	0.7	20	0.07487	30.0	2.84E-03	2.33E-05	1.04E-03	4.90E-01	does not exceed	5.98E-05
	1.59	0.4	5.0	2	9.46E-01	0.0125	118.2	5.31E-06	1.4	124	0.1%	490	0.49	76.25	3	365	0.7	19	0.07488	45.0	1.89E-03	2.32E-05	1.05E-03	4.90E-01	does not exceed	6.02E-05
Phenol	1.59	0.4	250.0	100	3.62E-02	0.0125	103.4	5.75E-06	1.4	137	0.1%	100	0.10	76.25	1	28	9.0	260	0.25698	0.4	3.62E-03	2.30E-04	1.17E-03	2.50E-01	does not exceed	2.94E-04
	1.59	0.4	7.5	3	3.62E-02	0.0125	103.4	5.75E-06	1.4	134	0.1%	100	0.10	76.25	1	28	9.0	70	0.25987	14.2	1.09E-04	1.41E-44	1.36E-43	2.50E-01	does not exceed	1.55E-63
	1.59	0.4	5.0	2	3.62E-02	0.0125	103.4	5.75E-06	1.4	134	0.1%	100	0.10	76.25	1	28	9.0	70	0.2599	21.3	7.25E-05	1.07E-64	1.04E-63	2.50E-01	does not exceed	1.27E-93

5 PERCENT f_{oc} IN BIOTURBATION LAYER - BENZENE, TOLUENE AND PHENOL

SMU 1

foc	z	kbio(particle) cm/yr	1	kbl cm/hr	1
0.10%	76.25	kbio(water) cm/yr	100	foc (bio layer)	0.05

Variable	ρ_b	ε or (n)	v	U	C_o	a	Vb	Dw	Hp	D'	foc	Koc	K_d	z	R_f	t_{50}	λ	u	SS Rxn	Approximate Time to Steady Conditions	Maximum of Diffusive or Advective Flux	Reactive Flux	Sediment Concentration (W_{bio})	*SSC*	SSC Sediment Concentration Exceedence?	Sediment Concentration (W_{bio}) Assuming 1.5X Safety Factor Applied to Thickness (z)
	Bulk density of cap material (1-ε)*ρs	Porosity	Pore water Velocity (U/ε)	Darcy Velocity (or v*ε)	Initial pore water concentration	Dispersivity	Organic Compd LeBas Molar Volume	Molecular diffusion coefficient (at 45 F)	Hindrance Parameter ($\varepsilon^{-1/3}$)	Diffusion/dispersion coefficient	Fraction of organic carbon in cap material	Organic carbon partition coeff for organics	Observed partition coefficient for CB (organics=foc*Koc, metals=literature value))	Chemical Isolation Layer Thickness	Retardation Factor	Half Life	Reaction Term (=ln2/t_{50})	$\sqrt{v^2+4\lambda D'}$								
	g/cm^3		cm/yr	cm/yr	mg/L		cm3/mol	cm^2/sec		cm^2/yr		mL/g	L/kg	cm		day	yr^{-1}		/cm	years	mg/cm2/yr	mg/cm2/yr	mg/kg	mg/kg		mg/kg
Benzene	1.59	0.4	5.0	2	1.07E+01	0.0125	96.0	6.01E-06	1.4	140	0.1%	100	0.10	76.25	1	720	0.4	15	0.05015	21.3	2.14E-02	1.31E-03	6.01E-02	1.40E+00	does not exceed	8.89E-03
Toluene	1.59	0.4	5.0	2	7.01E+00	0.0125	118.2	5.31E-06	1.4	124	0.1%	490	0.49	76.25	3	365	0.7	19	0.07488	45.0	1.40E-02	1.72E-04	3.03E-02	2.45E+00	does not exceed	1.74E-03
Phenol	1.59	0.4	5.0	2	5.30E+00	0.0125	103.4	5.75E-06	1.4	134	0.1%	100	0.10	76.25	1	28	9.0	70	0.2599	21.3	1.06E-02	1.57E-62	7.19E-61	1.25E+00	does not exceed	8.74E-91

5 PERCENT f_{oc} IN BIOTURBATION LAYER - BENZENE, TOLUENE AND PHENOL

SMU 2

foc 0.10%

z 76.25

kbio(particle) cm/yr 1

kbl cm/hr 1

kbio(water) cm/yr 100

foc (bio layer) 0.05

Variable	ρ_b	ε or (n)	v	U	C_o	a	Vb	Dw	Hp	D'	foc	Koc	K_d	z	R_f	t_{50}	λ	u	SS Rxn	Approximate Time to Steady Conditions	Maximum of Diffusive or Advective Flux	Reactive Flux	Sediment Concentration (W_{bio})	*SSC*	SSC Sediment Concentration Exceedence?	Sediment Concentration (W_{bio}) Assuming 1.5X Safety Factor Applied to Thickness (z)
	Bulk density of cap material (1-ε)*ρs	Porosity	Pore water Velocity (U/ε)	Darcy Velocity (or v*ε)	Initial pore water concentration	Dispersivity	Organic Compd LeBas Molar Volume	Molecular diffusion coefficient (at 45 F)	Hindrance Parameter ($\varepsilon^{-1/3}$)	Diffusion/dispersion coefficient	Fraction of organic carbon in cap material	Organic carbon partition coeff for organics	Observed partition coefficient for CB (organics=foc*Koc, metals=literature value))	Chemical Isolation Layer Thickness	Retardation Factor	Half Life	Reaction Term (=ln2/t_{50})	$\sqrt{v^2+4\lambda D'}$								
	g/cm^3		cm/yr	cm/yr	mg/L		cm3/mol	cm^2/sec		cm^2/yr		mL/g	L/kg	cm		day	yr^{-1}		/cm	years	mg/cm2/yr	mg/cm2/yr	mg/kg	mg/kg		mg/kg
Benzene	1.59	0.4	5.0	2	3.91E+01	0.0125	96.0	6.01E-06	1.4	140	0.1%	100	0.10	76.25	1	720	0.4	15	0.05015	21.3	7.83E-02	4.79E-03	2.20E-01	1.40E+00	does not exceed	3.25E-02
Toluene	1.59	0.4	5.0	2	2.31E+00	0.0125	118.2	5.31E-06	1.4	124	0.1%	490	0.49	76.25	3	365	0.7	19	0.07488	45.0	4.61E-03	5.66E-05	9.97E-03	2.45E+00	does not exceed	5.74E-04
Phenol	1.59	0.4	5.0	2	2.75E-01	0.0125	103.4	5.75E-06	1.4	134	0.1%	100	0.10	76.25	1	28	9.0	70	0.2599	21.3	5.51E-04	8.14E-64	3.73E-62	1.25E+00	does not exceed	4.54E-92

5 PERCENT f_{oc} IN BIOTURBATION LAYER - BENZENE, TOLUENE AND PHENOL

SMU 3

z 30.5

foc 0.10%

kbio(particle) cm/yr 1 kbl cm/hr 1

kbio(water) cm/yr 100 foc (bio layer) 0.05

Variable	ρ_b	ε or (n)	v	U	C_o	a	Vb	Dw	Hp	D'	foc	Koc	K_d	z	R_f	t_{50}	λ	u	SS Rxn	Approximate Time to Steady Conditions	Maximum of Diffusive or Advective Flux	Reactive Flux	Sediment Concentration (W_{bio})	*SSC*	SSC Sediment Concentration Exceedence?	Sediment Concentration (W_{bio}) Assuming 1.5X Safety Factor Applied to Thickness (z)
	Bulk density of cap material (1-ε)*ρs	Porosity	Pore water Velocity (U/ε)	Darcy Velocity (or v*ε)	Initial pore water concentration	Dispersivity	Organic Compd LeBas Molar Volume	Molecular diffusion coefficient (at 45 F)	Hindrance Parameter ($\varepsilon^{-1/3}$)	Diffusion/dispersion coefficient	Fraction of organic carbon in cap material	Organic carbon partition coeff for organics	Observed partition coefficient for CB (organics=foc*Koc, metals=literature value))	Chemical Isolation Layer Thickness	Retardation Factor	Half Life	Reaction Term (=ln2/t_{50})	$\sqrt{v^2+4\lambda D'}$								
	g/cm^3		cm/yr	cm/yr	mg/L		cm3/mol	cm^2/sec		cm^2/yr		mL/g	L/kg	cm		day	yr^{-1}		/cm	years	mg/cm2/yr	mg/cm2/yr	mg/kg	mg/kg		mg/kg
Benzene	1.59	0.4	1750.0	700	2.40E+00	0.0125	96.0	6.01E-06	1.4	162	0.1%	100	0.10	30.5	1	720	0.4	1750	0.04664	0.0	1.68E+00	1.67E+00	1.12E+01	1.40E+00	Exceeds SSC	1.12E+01
	1.59	0.4	12.5	5	2.40E+00	0.0125	96.0	6.01E-06	1.4	140	0.1%	100	0.10	30.5	1	720	0.4	19	0.05013	3.4	1.20E-02	5.09E-03	2.28E-01	1.40E+00	does not exceed	1.48E-01
Toluene	1.59	0.4	1750.0	700	4.66E-01	0.0125	118.2	5.31E-06	1.4	145	0.1%	490	0.49	30.5	3	365	0.7	1750	0.06903	0.1	3.26E-01	3.22E-01	1.02E+01	2.45E+00	Exceeds SSC	1.02E+01
	1.59	0.4	12.5	5	4.66E-01	0.0125	118.2	5.31E-06	1.4	124	0.1%	490	0.49	30.5	3	365	0.7	22	0.07485	7.2	2.33E-03	4.30E-04	7.41E-02	2.45E+00	does not exceed	3.18E-02
Phenol	1.59	0.4	1750.0	700	0.00E+00	0.0125	103.4	5.75E-06	1.4	156	0.1%	100	0.10	30.5	1	28	9.0	1752	0.24099	0.0	0.00E+00	0.00E+00	0.00E+00	1.25E+00	does not exceed	0.00E+00
	1.59	0.4	12.5	5	0.00E+00	0.0125	103.4	5.75E-06	1.4	134	0.1%	100	0.10	30.5	1	28	9.0	71	0.25981	3.4	0.00E+00	0.00E+00	0.00E+00	1.25E+00	does not exceed	0.00E+00

Not a CPOI in this SMU

5 PERCENT f_{oc} IN BIOTURBATION LAYER - BENZENE, TOLUENE AND PHENOL

SMU 4

z 30.5

foc 0.10%

kbio(particle) cm/yr 1 kbl cm/hr 1

kbio(water) cm/yr 100 foc (bio layer) 0.05 0.05

Variable	ρ_b	ε or (n)	v	U	C_o	a	Vb	Dw	Hp	D'	foc	Koc	K_d	z	R_f	t_{50}	λ	u	SS Rxn	Approximate Time to Steady Conditions	Maximum of Diffusive or Advective Flux	Reactive Flux	Sediment Concentration (W_{bio})	*SSC*	SSC Sediment Concentration Exceedence?	Sediment Concentration (W_{bio}) Assuming 1.5X Safety Factor Applied to Thickness (z)
	Bulk density of cap material (1-ε)*ρs	Porosity	Pore water Velocity (U/ε)	Darcy Velocity (or v*ε)	Initial pore water concentration	Dispersivity	Organic Compd LeBas Molar Volume	Molecular diffusion coefficient (at 45 F)	Hindrance Parameter ($\varepsilon^{-1/3}$)	Diffusion/dispersion coefficient	Fraction of organic carbon in cap material	Organic carbon partition coeff for organics	Observed partition coefficient for CB (organics=foc*Koc, metals=literature value))	Chemical Isolation Layer Thickness	Retardation Factor	Half Life	Reaction Term (=ln2/t_{50})	$\sqrt{v^2+4\lambda D'}$								
	g/cm^3		cm/yr	cm/yr	mg/L		cm3/mol	cm^2/sec		cm^2/yr		mL/g	L/kg	cm		day	yr^{-1}		/cm	years	mg/cm2/yr	mg/cm2/yr	mg/kg	mg/kg		mg/kg
Benzene	1.59	0.4	750.0	300	1.41E-02	0.0125	96.0	6.01E-06	1.4	149	0.1%	100	0.10	30.5	1	720	0.4	750	0.04855	0.1	4.23E-03	4.17E-03	5.34E-02	1.40E+00	does not exceed	5.30E-02
Toluene	1.59	0.4	750.0	300	2.09E-03	0.0125	118.2	5.31E-06	1.4	133	0.1%	490	0.49	30.5	3	365	0.7	750	0.07221	0.1	6.28E-04	6.10E-04	3.57E-02	2.45E+00	does not exceed	3.52E-02
Phenol	1.59	0.4	750.0	300	0.00E+00	0.0125	103.4	5.75E-06	1.4	143	0.1%	100	0.10	30.5	1	28	9.0	753	0.2513	0.1	0.00E+00	0.00E+00	0.00E+00	1.25E+00	does not exceed	0.00E+00

5 PERCENT f_{oc} IN BIOTURBATION LAYER - BENZENE, TOLUENE AND PHENOL

SMU 6

z	foc	kbio(particle) cm/yr	1	kbl cm/hr	1
30.5	0.10%	kbio(water) cm/yr	100	foc (bio layer)	0.05

Variable	ρ_b	ε or (n)	v	U	C_o	a	Vb	Dw	Hp	D'	foc	Koc	K_d	z	Rf	t_{50}	λ	u	SS Rxn	Approximate Time to Steady Conditions	Maximum of Diffusive or Advective Flux	Reactive Flux	Sediment Concentration (W_{bio})	SSC	SSC Sediment Concentration Exceedence?	Sediment Concentration (W_{bio}) Assuming 1.5X Safety Factor Applied to Thickness (z)
	Bulk density of cap material (1-ε)*ρs	Porosity	Pore water Velocity (U/ε)	Darcy Velocity (or v*ε)	Initial pore water concentration	Dispersivity	Organic Compd LeBas Molar Volume	Molecular diffusion coefficient (at 45 F)	Hindrance Parameter ($\varepsilon^{-1/3}$)	Diffusion/dispersion coefficient	Fraction of organic carbon in cap material	Organic carbon partition coeff for organics	Observed partition coefficient for CB (organics=foc*Koc, metals=literature value))	Chemical Isolation Layer Thickness	Retardation Factor	Half Life	Reaction Term (=ln2/t_{50})	$\sqrt{v^2+4\lambda D'}$								
	g/cm^3		cm/yr	cm/yr	mg/L		cm3/mol	cm^2/sec		cm^2/yr		mL/g	L/kg	cm		day	yr^{-1}		/cm	years	mg/cm2/yr	mg/cm2/yr	mg/kg	mg/kg		mg/kg
Benzene	1.59	0.4	175.0	70	6.13E-02	0.0125	96.0	6.01E-06	1.4	142	0.1%	100	0.10	30.5	1	720	0.4	175.6	0.04977	0.2	4.29E-03	4.04E-03	1.15E-01	1.40E+00	does not exceed	1.12E-01
	1.59	0.4	7.5	3	6.13E-02	0.0125	96.0	6.01E-06	1.4	140	0.1%	100	0.10	30.5	1	720	0.4	15.9	0.05014	5.7	1.84E-04	7.81E-05	3.55E-03	1.40E+00	does not exceed	1.59E-03
Toluene	1.59	0.4	175.0	70	7.24E-02	0.0125	118.2	5.31E-06	1.4	126	0.1%	490	0.49	30.5	3	365	0.7	176.0	0.07424	0.5	5.07E-03	4.49E-03	5.38E-01	2.45E+00	does not exceed	5.07E-01
	1.59	0.4	7.5	3	7.24E-02	0.0125	118.2	5.31E-06	1.4	124	0.1%	490	0.49	30.5	3	365	0.7	20.0	0.07487	12.0	2.17E-04	5.52E-05	9.66E-03	2.45E+00	does not exceed	3.05E-03
Phenol	1.59	0.4	175.0	70	2.74E-02	0.0125	103.4	5.75E-06	1.4	136	0.1%	100	0.10	30.5	1	28	9.0	188.5	0.25786	0.2	1.92E-03	3.98E-04	1.14E-02	1.25E+00	does not exceed	5.17E-03
	1.59	0.4	7.5	3	2.74E-02	0.0125	103.4	5.75E-06	1.4	134	0.1%	100	0.10	30.5	1	28	9.0	69.9	0.25987	5.7	8.23E-05	2.75E-07	1.25E-05	1.25E+00	does not exceed	2.38E-07

5 PERCENT f_{oc} IN BIOTURBATION LAYER - BENZENE, TOLUENE AND PHENOL

SMU 7

foc	z	kbio(particle) cm/yr	1	kbl cm/hr	1
0.10%	76.25	kbio(water) cm/yr	100	foc (bio layer)	0.05

Variable	ρ_b	ε or (n)	v	U	C_o	a	Vb	Dw	Hp	D'	foc	Koc	K_d	z	R_f	t_{50}	λ	u	SS Rxn	Approximate Time to Steady Conditions	Maximum of Diffusive or Advective Flux	Reactive Flux	Sediment Concentration (W_{bio})	*SSC*	SSC Sediment Concentration Exceedence?	Sediment Concentration (W_{bio}) Assuming 1.5X Safety Factor Applied to Thickness (z)
	Bulk density of cap material (1-ε)*ps	Porosity	Pore water Velocity (U/ε)	Darcy Velocity (or v*ε)	Initial pore water concentration	Dispersivity	Organic Compd LeBas Molar Volume	Molecular diffusion coefficient (at 45 F)	Hindrance Parameter ($\varepsilon^{-1/3}$)	Diffusion/dispersion coefficient	Fraction of organic carbon in cap material	Organic carbon partition coeff for organics	Observed partition coefficient for CB (organics=foc*Koc, metals=literature value))	Chemical Isolation Layer Thickness	Retardation Factor	Half Life	Reaction Term (=ln2/t_{50})	$\sqrt{v^2+4\lambda D'}$								
	g/cm^3		cm/yr	cm/yr	mg/L		cm3/mol	cm^2/sec		cm^2/yr		mL/g	L/kg	cm		day	yr^{-1}		/cm	years	mg/cm2/yr	mg/cm2/yr	mg/kg	mg/kg		mg/kg
Benzene	1.59	0.4	250.0	100	2.46E+00	0.0125	96.0	6.01E-06	1.4	143	0.1%	100	0.10	76.25	1	720	0.4	250	0.0496	0.4	2.46E-01	2.21E-01	5.44E+00	1.40E+00	Exceeds SSC	5.15E+00
	1.59	0.4	7.5	3	2.46E+00	0.0125	96.0	6.01E-06	1.4	140	0.1%	100	0.10	76.25	1	720	0.4	16	0.05014	14.2	7.39E-03	3.02E-04	1.37E-02	1.40E+00	does not exceed	2.03E-03
	1.59	0.4	5.0	2	2.46E+00	0.0125	96.0	6.01E-06	1.4	140	0.1%	100	0.10	76.25	1	720	0.4	15	0.05015	21.3	4.93E-03	3.02E-04	1.38E-02	1.40E+00	does not exceed	2.05E-03
Toluene	1.59	0.4	250.0	100	9.46E-01	0.0125	118.2	5.31E-06	1.4	127	0.1%	490	0.49	76.25	3	365	0.7	251	0.07397	0.9	9.46E-02	7.66E-02	8.05E+00	2.45E+00	Exceeds SSC	7.25E+00
	1.59	0.4	7.5	3	9.46E-01	0.0125	118.2	5.31E-06	1.4	124	0.1%	490	0.49	76.25	3	365	0.7	20	0.07487	30.0	2.84E-03	2.33E-05	4.07E-03	2.45E+00	does not exceed	2.34E-04
	1.59	0.4	5.0	2	9.46E-01	0.0125	118.2	5.31E-06	1.4	124	0.1%	490	0.49	76.25	3	365	0.7	19	0.07488	45.0	1.89E-03	2.32E-05	4.09E-03	2.45E+00	does not exceed	2.35E-04
Phenol	1.59	0.4	250.0	100	3.62E-02	0.0125	103.4	5.75E-06	1.4	137	0.1%	100	0.10	76.25	1	28	9.0	260	0.25698	0.4	3.62E-03	2.30E-04	5.66E-03	1.25E+00	does not exceed	1.43E-03
	1.59	0.4	7.5	3	3.62E-02	0.0125	103.4	5.75E-06	1.4	134	0.1%	100	0.10	76.25	1	28	9.0	70	0.25987	14.2	1.09E-04	1.41E-44	6.41E-43	1.25E+00	does not exceed	7.30E-63
	1.59	0.4	5.0	2	3.62E-02	0.0125	103.4	5.75E-06	1.4	134	0.1%	100	0.10	76.25	1	28	9.0	70	0.2599	21.3	7.25E-05	1.07E-64	4.91E-63	1.25E+00	does not exceed	5.97E-93

APPENDIX H
ATTACHMENT H

CAP STABILITY-CONSTRUCTABILITY ANALYSIS

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Memorandum

Written for the Onondaga Lake Feasibility Study

From: John R. Verduin, III, PE, Anchor Environmental, L.L.C.

Date: December 18, 2003

Re: Cap Stability/Constructability
Onondaga Lake Feasibility Study

This memorandum presents a geotechnical analysis on capping the Onondaga Lake sediment. Existing strength data on Onondaga Lake sediment was used to complete the analysis. Based on the analysis, recommendations are made concerning how the sediment should be capped. As part of final design, more site specific data will be collected and the analysis will be refined.

ISSUES OF CONCERN

As cap material is placed on the surface of soft sediment, it results in an unbalanced load wherever there are variations in cap thickness. The unbalanced load is usually most prominent along the edge of the cap lift where the difference is equal to the height of the lift. However, an imbalance can also occur in the interior of a cap if a variation in lift thickness occurs during placement. Figure 1 illustrates the concepts of uneven cap load.

Theoretically, there is a critical cap height difference (h) that will induce a differential load sufficient to cause failure of the subgrade. When this occurs, the cap material can become intermixed with contaminated sediment. The intent of this analysis is to determine the critical height difference and to evaluate if this critical height is reasonable given typical cap construction techniques.

STRENGTH PROPERTIES

Table 1 summarizes the available undrained shear strength data in the surface sediment of Onondaga Lake. The data was measured using vane shear tests (VST). The feasibility study provides more data on the geotechnical engineering properties of the surface sediment. With depth, the undrained shear strength should increase. Therefore, this approach of using the surface strengths is somewhat conservative. As reflected in Table 1, the undrained shear strength varies across the site. The softer, fine grained sediment generally have lower shear strength. The calcium carbonate layers observed in SMU 1 had higher undrained shear strengths. Figure 2 presents the cumulative distribution of the undrained shear strength measured from the VST results presented in Table 1. The mean undrained shear strength from the VSTs is 37 pounds per square foot (psf).

METHODS OF ANALYSIS

Appendix C of the Assessment and Remediation of Contaminated (ARCS) Program cap design guidance manual "*Guidance for In-Situ Subaqueous Capping of Contaminated Sediments*" (Palermo et al. 1998) describes a method of assessing stability of a cap placed on soft sediment. The method is based on the bearing capacity theory applied to a shallow foundation on a subgrade. Cap stability for this site was analyzed in accordance with this method (referenced as the deterministic approach herein).

The ARCS guidance manual states that a safety factor of 3 is typical for a bearing capacity analysis. Traditionally with foundation design this safety factor is appropriate because it limits potentially damaging settlement that could impact a structure. However, during cap placement with incremental layer placement, a lower safety factor would be acceptable. To better address foundation stability, we completed a probabilistic analysis of cap bearing failure that incorporates the uncertainty of the sediment strength and cap weight. We used the traditional foundation bearing capacity analysis, but instead of using a rigid safety factor we predicted the probability of no failure. This approach is also useful when the shear strength properties vary significantly and the average value varies from the highest and lowest values.

Finally, as an additional check, we assessed case histories for previously completed capping projects as a "reality check" on this concept of potential cap failure.

The critical cap height differential was evaluated using three different methods, which are detailed below:

- Deterministic evaluation
- Probabilistic evaluation
- Comparison to past similar capping projects

Deterministic Evaluation. As discussed above, the deterministic approach treats the sand cap as equivalent to a footing bearing on a subgrade, in this case, the sediment being capped. The approach recommends a safety factor of 3 be used for the analysis. Using this approach we determined that the critical cap height differential (see Figure 1) is 20 inches for a factor of safety of 2.5, and 18 inches for a factor of safety of 3.

Probabilistic Evaluation. We used the same deterministic formula described above, but accounted for the uncertainty of the cap weight and the sediment strength. This method accounts for the lower observed shear strengths that the deterministic approach does not consider. The approach used a Monte Carlo simulation considering the different input uncertainties. The cumulative distribution of undrained strength data depicted on Figure 2 was used, for example, in assigning a statistical uncertainty to this parameter. The potential variability of the cap buoyant unit weight was also accounted for by assuming a mean value of 43 pounds per cubic foot (pcf), a normal distribution and a coefficient of variation of 4 percent (Harr 1987; Table 1.8.1).

The probabilistic approach determined that a 6-inch cap differential corresponds to a 95 percent probability of success. This means that if the cap differential ("h" in Figure 1) were 6 inches, 95 percent of the time the cap would not cause a bearing capacity failure into the underlying sediment.

Comparison to Past Similar Capping Projects ("Reality Check"). As a final "reality check" on these two different theoretical calculations, we evaluated past capping projects to determine if any conclusions could be drawn from the results. We limited the evaluation to projects where significant information was available on the physical properties of the material being capped.

In all but one case, the undrained shear strength of the sediment has been measured. Another project screening criterion was that results of the capping have been evaluated either by completing cores through the placed cap or other means. As a final project screening criterion, information on the construction approach was required.

Table 2 summarizes the projects we identified. All of the projects identified, with the exception of one, demonstrate that capping of soft sediment is feasible. In one project, for the Los Angeles District Corps, a modified construction technique was necessary to successfully install a cap without sediment intermixing or mud waves. Initially, the Contractor placed the material on the soft sediment by bottom dumping from a stationary barge. The energy of the cap material as it struck the subgrade, combined with the cap height differential, resulted in cap loads that were greater than the bearing strength of the underlying material. Subsequently, the Contractor was required to move the barge during placement and to place the material more slowly. This helped to reduce the differential cap lift thickness. The cap placement techniques used for the Los Angeles District Corps capping project are not being considered for Onondaga Lake because of site constraints.

Two projects in Table 2 that are particularly similar to Onondaga Lake are the Barberton, Ohio capping project and the Soda Lake capping project in Casper, Wyoming. All three projects have similar moisture contents and undrained shear strengths. The water depths at both sites are comparable to the shallow capping areas in Onondaga Lake. The required cap thickness will likely be between the 1 foot required for the Barberton, Ohio cap and the 3 feet required for the Soda Lake cap. Both caps were placed hydraulically with a diffuser barge in 3- to 6-inch lifts. Post cap cores showed a clear boundary between the cap material and underlying sediment indicating successful cap placement for both projects (Houck et al 2001; Verduin 2003). Therefore, utilizing a similar approach for Onondaga Lake capping should be successful.

CONCLUSIONS ON CAP PLACEMENT

Our various theoretical analyses indicate that, given the sediment strength in Onondaga Lake, as long as the cap height differential (see “h” in Figure 1) is kept below 6 inches, bearing failure of the cap material into the underlying sediment should not occur. Past cap construction projects also conclude that keeping the cap height differential low during lift placement is key to successfully placing a cap on soft sediment.

In order to obtain this target “h” thickness, a hydraulic capping approach would likely be used. For this approach, the capping material would be slurried and pumped to a diffuser barge over the capping area. The diffuser barge would be moved back and forth allowing the capping material to gently fall through the water column. Thin lifts would be placed with each pass.

The Contractor for the Barberton, Ohio project placed an average of 250 to 350 cubic yards of capping material in a 10 hour day using this approach. The Contractor used an 8-inch dredge to pump the slurry to the diffuser barge. The Contractor was able to meet the target lift thickness of 3 inches by making six passes of the diffuser over the capping area. Very minimal mixing of soft sediment and cap material was observed (less than a few centimeters on average) (Verduin 2003).

Any armor material would likely be placed using a clamshell bucket. Armor material would also be placed in lifts on top of the base cap layer.

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List of Tables

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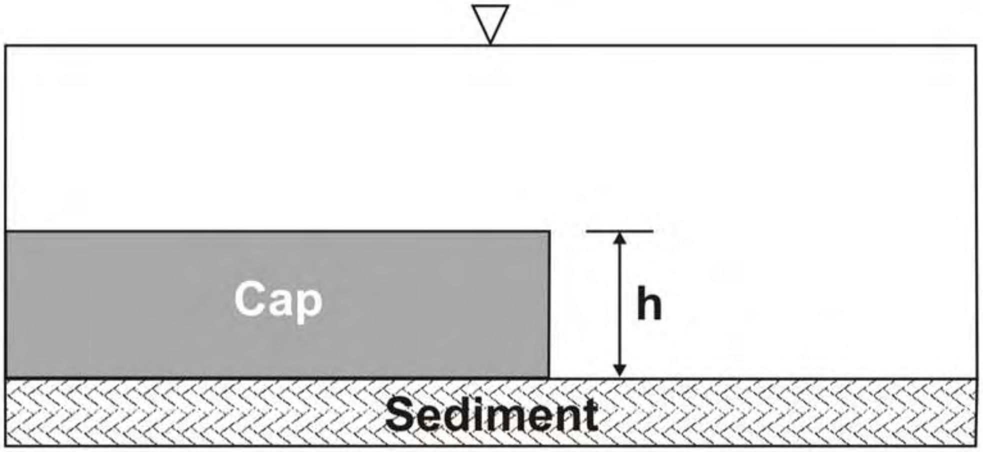
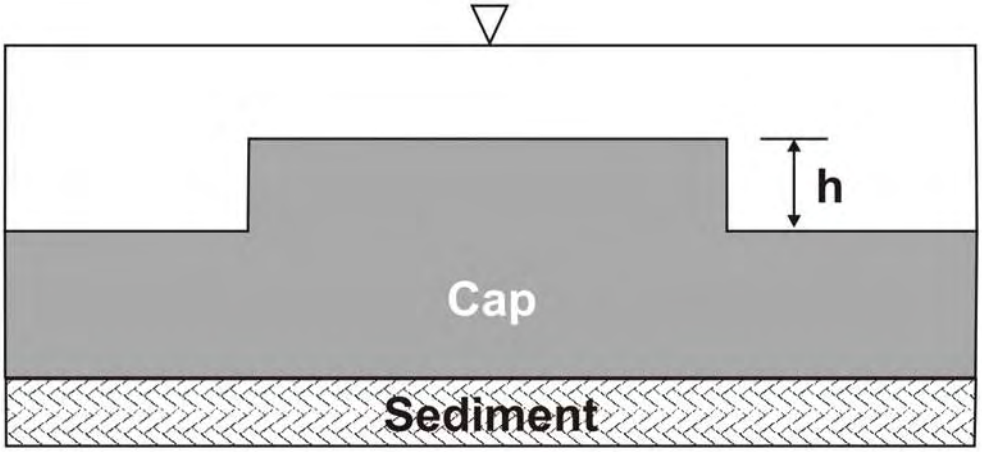


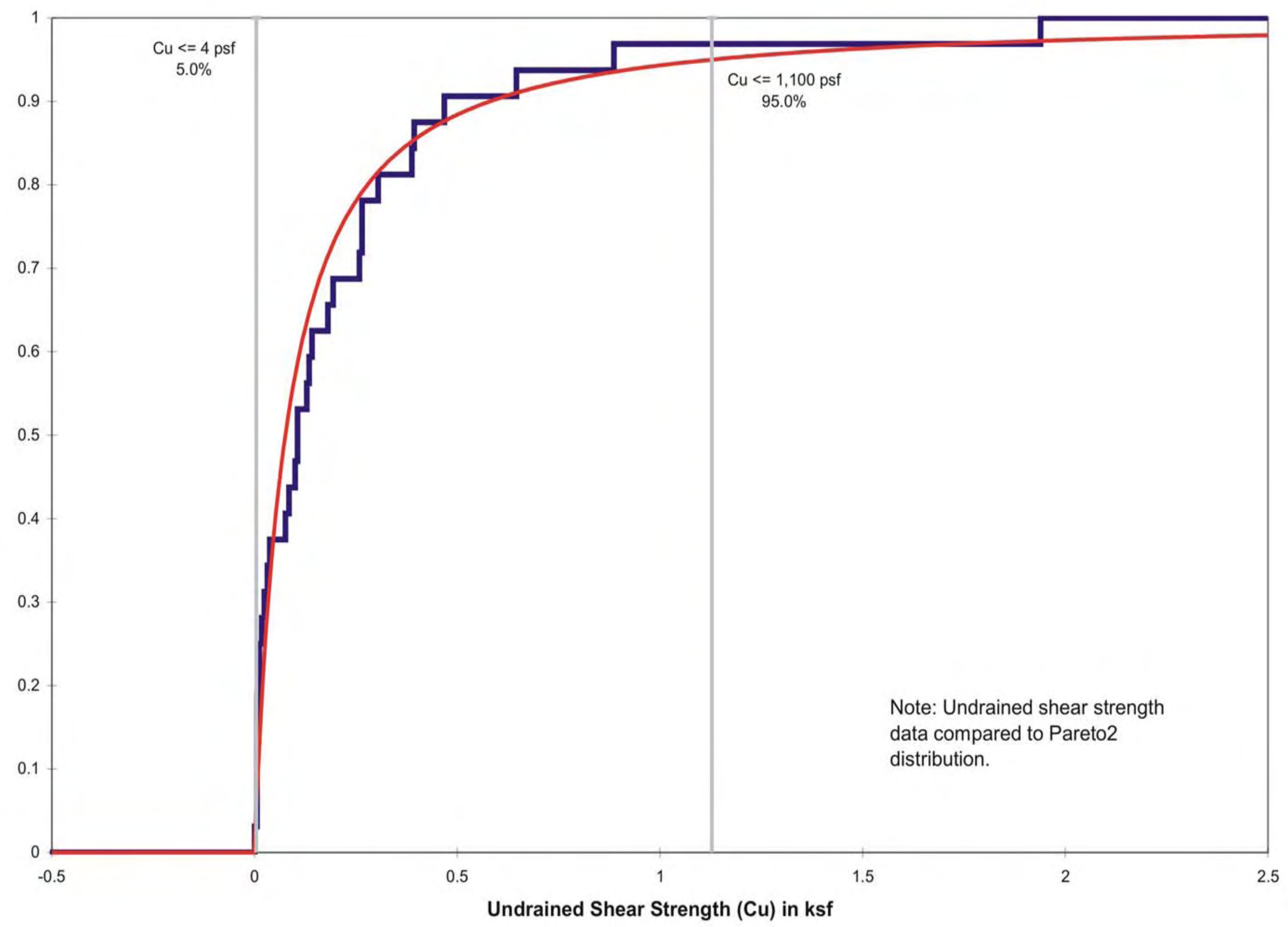
A. Cap thickness variation at edge of cap (initial lift)



B. Cap thickness variation (subsequent lifts)

4/16/04 cvd CAD\Jobs\010139-ONODAGA_LAKE\01013902\FIG 1-FS.cdr

Figure 1
Conceptual Schematic of Cap Height
Onondaga Lake Feasibility Study



Note: Undrained shear strength data compared to Pareto2 distribution.

ANCHOR ENVIRONMENTAL, L.L.C.

Figure 2
Distribution of Undrained Shear Strengths
Onondaga Lake Feasibility Study

ATTACHMENT H
TABLE 1
Onondaga Lake RI/FS Vane Shear Field Test Results
Undrained Shear Strength in Upper 2 Feet

Core ID	Depth	Undrained Shear Strength in psf
S302	0.3	2.8
S309	0.3	8.7
S310	0.3	0
S311	0.3	36.4
S312	0.3	20.8
S314	0.3	8.7
S315	0.3	1.7
S338	0.3	0.1
S339A	0.3	0
S340	0.3	468.1
S341A	0.3	304.7
S342A	0.3	76.2
S343	0.3	886.4
S344	0.3	0.1
S346VS	0.3	142
S348	0.3	193.9
S350	0.3	84.8
S351A	0.3	13.8
S352VS	0.3	31.5
TR01-B	1-1.8'	259
TR01-C	1-1.8'	388
TR02-B	1-1.8'	646
TR02-C	1-1.8'	<129.3
TR03-D	1-1.8'	129
TR04-C	1-1.8'	388
TR04-D	1-1.8'	<129.3
TR05-A	1-1.8'	181
TR05-B	1-1.8'	259
TR05-D	1-1.8'	129
TR06-A	1-1.8'	259
TR06-B	1-1.8'	<129.3

ATTACHMENT H

TABLE 2

SUMMARY OF PREVIOUSLY COMPLETED CAPPING PROJECTS

Project	Moisture Content	Percent Solids	Atterberg Limits		Undrained Shear Strength in psf	Water depth in feet	Cap Design	Method of Placement	Observations
			LL	PI					
KPC Ward Cove Sediment Remediation Ketchikan, AK (1)	Avg 415%	Avg 19%			3 to 100	40 to 120	6" to 12" of clean, fine to medium sand	Rehandling with bucket	Clear cap/sediment boundary
LA Corps Aquatic Capping Project Dredge Material Placement Los Angeles Harbor, CA (2)	140 to 183% Avg 161%	35 to 41% Avg 38%	53 to 76 Avg 66	22 to 41 Avg 33	7.5 to 13 Avg 11	60	Placed 2.5 to 3.0 feet of LARE material	Stagnant bottom dump barge.	Mudwaves created in some locations. Other areas performed as anticipated.
LA Corps Aquatic Capping Project Cap Material Placement Los Angeles Harbor, CA (2)	98 to 134% Avg 111%	43 to 51% Avg 47%	38 to 51 Avg 44	7 to 20 Avg 13	5 to 22 Avg 11	52	5 feet of fine to medium sand	Bottom dump barge moving and rehandling with bucket	Post dredge cores indicate little mixing of the cap and underlying contaminated sediment.
Matsushima Bay Japan (3)	200 to 375% Avg 275%	21 to 33% Avg 27%	160 to 175 Avg 170	115 to 130 Avg 125	5 to 35	10	12" fine sand cap	Unknown	Successful
Soda Lake Capping Casper, WY (4)	161 to 455% Avg 200%	18 to 38% Avg 33%	91 to 155	>50	Less than 280	0.5 to 12	3' cap of medium clean sand	Hydraulic with surface diffuser barge	Clear cap/sediment boundary
PPG Barberton Project Barberton, OH (5)	7 to 287% Avg 199%	26 to 94% Avg 37%	35 to 93 Avg 76	16 to 55 Avg 38	9 to 76 Avg 21	4 to 6	1 foot of clean sand	Hydraulic with surface diffuser barge	Clear cap/sediment boundary
Hiroshima Bay Sediments Japan (3)	80 to 100% Avg 88%	50 to 56% Avg 53%	60 to 75 Avg 68	22 to 38 Avg 31	20 to 85	65 to 70	12" to 20" sand cap	Unknown	Successful
Lake Biwa Japan (3)	95 to 150% Avg 125%	40 to 51% Avg 44%	70 to 135 Avg 105	40 to 70 Avg 55	20 to 190	5	8" medium sand cap	Unknown	Successful
G-P Log Pond Bellingham, WA (6)	97 to 175% Avg 142%	36 to 51% Avg 41%	65 to 175 Avg 105	36 to 79 Avg 61	65 to 277 Avg 144	3 to 15	6" to 8' fine to medium sand cap	Rehandling with bucket	Clear cap/sediment boundary
West Waterway CAD Seattle, WA (7)	Avg 91%	Avg 52%	Avg 73	Avg 39	Not measured	55 to 65	2' uniformly-graded sand cap	Bottom dump barge	Clear cap/sediment boundary

Notes:

LL = liquid limit

PL = plasticity index (LL minus the plastic limit)

References:

(1) Hartman Consulting (2000)

(2) Verduin et al (2002)

(3) Palermo et al (1998b)

(4) Houck et al (2001)

(5) Anchor (2003)

(6) Verduin et al (2001)

(7) Sumeri (1996)

APPENDIX H
ATTACHMENT I

SLOPE STABILITY ANALYSIS

HE&C
Harrington Engineering & Construction, Inc.

Memorandum

TO: John Verduin — April 19, 2004

FROM: Tim Harrington — 01-011-2
Kevin Brissette

SUBJECT: Slope Stability of In-Lake Waste Deposit

Harrington Engineering & Construction, Inc. (HE&C) understands that the New York Department of Environmental Conservation (NYSDEC) questioned the stability of the in-lake waste deposit with a cap installed on the deposit as proposed in the draft FS. The NYSDEC referenced a possible submarine slump in the surface of the in-lake waste deposit reported in the Geophysical Survey Report prepared by Exponent in 1992 as the cause for their concern. The NYSDEC asked a series of questions:

1. In 1943 a section of the dike on one of the on-land waste deposits failed and the material flowed onto the adjacent highway, railroad, and the New York State Fairgrounds property. Could something similar happen in the in-lake waste deposit?
2. What are the geotechnical properties of the in-lake waste materials and the underlying peat, marl, and clay sediments?
3. Is the in-lake waste deposit stable?
4. Will the in-lake waste deposit remain stable?
5. What is the slope stability safety factor?
6. Will the in-lake waste deposit be adversely impacted by construction of the proposed sediment cap?

Kulhawy[1] obtained samples from the on-land waste cells and performed geotechnical testing to measure the consolidation and strength properties of the waste. The on-land waste cells and the in-lake waste deposit have been subject to different conditions after deposition of the waste. The in-lake waste was deposited approximately 100 years ago and has since that time been subject to constant immersion in the waters of Onondaga Lake and to the seepage of ground water entering the lake from the bedrock aquifer. We should not expect the consolidation and strength properties of the in-lake and on-land waste to be the same because of the differences in exposure (the chemistry of the waste that is basically a leachable salt is likely different for the two exposure conditions).

1943 Failure of On-land Waste Deposit

The initiating sequence for the 1943 failure was failure of the confining berm followed by the flow of contained on-land waste. A flow from the failure of a containment berm for hydraulically placed sediment or waste is a common concern for the geotechnical engineering design of a containment berm. When a containment berm fails, the flowing sediment eventually reaches a stable condition and stops flowing. Since the in-lake waste was never contained by a berm structure, the in-lake waste reached a stable condition shortly after it flowed into place. In addition, field investigations have shown that the in-lake waste contains cemented layers that increase the strength of the waste deposit above and beyond the strength developed from long-term consolidation.

Geotechnical Parameters

The on-land waste was reported by Kulhawy to have an internal friction angle of 32º±6º with no cohesion (results from consolidated/undrained triaxial shear tests). Results reported on in-lake waste samples taken by Parsons in the fall of 2002 as part of the groundwater upwelling investigation showed a friction angle of 0º and an average cohesion of 300 lb/ft^2 (results from unconsolidated/undrained triaxial tests, samples from transects 2, 3, and 4). The fall of 2002 triaxial test results do not measure the increased strength caused by the cemented layers or increasing depth in the in-lake waste deposit, however, the results show a deviator stress versus strain response that indicates the in-lake waste does not soften during shear. Both Kulhawy's work and measurements made on the in-lake waste agree that a total unit weight of approximately 78 lb/ft^3 is applicable for the waste material.

The geotechnical parameters for the lacustrine soils lying under the in-lake waste are unknown. Because they have supported the in-lake waste for many years and have consolidated under the load of the in-lake waste, an analysis that assumes they are stronger than the in-lake waste is appropriate for a preliminary assessment of the slope stability of the in-lake waste (during final design, the strength properties of the lacustrine soils beneath the in-lake waste should be measured to determine if the assumption of strength exceeding the overlying waste is valid).

Slope Stability Analysis

A slope stability analysis was performed on the submerged in-lake waste for two slope profiles in the southeast corner of Onondaga Lake. The locations of the two slopes are shown on Figure 1. The first location (A-A') was selected because it was identified in the hydrographic survey completed by Exponent[2] as the area of a possible submarine slump. The second location (B-B') was selected because it is currently the area with the steepest slope in the in-lake waste deposit in the southeast corner of the lake (maximum slope of approximately 8%).

Figure 2 shows a cross section based on two deep borings drilled in the in-lake waste deposit in 1976. Boring B-76-1 extends to a depth of 153 feet below the water surface and B-76-2 extends to a depth of 133 feet. Both of these borings fully penetrate the in-lake waste, the lacustrine sediments, and extend into the underlying glacial soil. The B-76-1 boring log indicates that the in-lake waste near shore (under 3.3 feet of water) is 44 feet thick. The B-76-2 boring log indicates that the in-lake waste approximately 950 feet offshore (under 15 feet of water) is 36 feet thick. The borings are aligned perpendicular with the shore in the area between the two slope profiles. The approximate boring locations are shown on Figure 1.

The slope stability analysis conservatively assumes that the in-lake waste is a minimum of 50 feet thick at the toe of slope and thicker farther up the slope. All of the failure surfaces analyzed were conservatively assumed to be in the in-lake waste even though consolidated lacustrine soils are likely within the analyzed depth range. The analysis also conservatively ignores strength gain with depth that is common in lacustrine deposits. The available unconfined/undrained strength tests were all performed on relatively shallow samples taken from less than three feet below the lake bottom.

The slope stability analysis was run using:

1. The existing static conditions,

2. A pseudo-static earthquake loading, and
3. Static and earthquake loading with a five-foot sand cap installed.

A pseudo-static earthquake value of 0.03g was used for the earthquake loading and is based on:

1. A maximum bedrock acceleration of 0.03g with a 10% probability of exceedence in 50-years at Syracuse, New York (also equivalent to a return period of once in 475 years) as produced from the USGS 1997 National Seismic Hazard Maps, Frankel et al[3].
2. An amplification of the maximum bedrock acceleration to 0.06g by the approximately 100-feet of soft sediment laying over till in the bottom of the lake (Idriss)[4].
3. Reducing the product of step 2 by 50% per standard practice, Hynes and Franklin[5].
4. Using a vertical acceleration that is $^2/_3$ of the horizontal acceleration as recommended by Newmark and Hall[6].

The American Society of Civil Engineers[9] (ASCE) provides guidance for seismic design of waterfront structures. ASCE recommends a severe contingency level earthquake corresponding to a 10% probability of being exceeded in 50 years. The ASCE reasons that the damage under this level of earthquake will be controlled, economically repairable, and not threaten life. A seismic return period based on the ASCE recommendation was selected for the analysis of the in-lake waste deposit at the Eagle Harbor sediment site[7] and at the Bellingham Bay sediment site[8] to assess both in-place cap and containment dike stability.

A pseudo-static analysis approach is valid for soil that does not show substantial loss of strength due to shearing. The available shear test data for the in-lake waste indicates that the pseudo-static assumption is valid. (Hynes and Franklin[5], Makdisi and Seed[10])

The sand cap will be constructed by placing five feet of clean sand on the submerged in-lake waste deposit. The sand was assumed to have a total unit weight of 110 pounds per cubic foot and an internal angle of friction of 30^0.

The slope stability calculations were performed using the simplified Bishop method option in the STABL 5m software program produced by Purdue University (See Appendix A for STABL input files). As discussed above, the slope stability was performed on two cross sections in the southeast corner of the Lake and analyzed for both static (existing) and dynamic (with a horizontal pseudo-static earthquake load of 0.03g) conditions. The plots of the 10 most critical failure surfaces and the input files for the runs from the flatter slope (A-A') and the steeper slope (B-B') are presented in Appendices B and C, respectively. The lowest factor of safety from each run is summarized below:

Factors of Safety Against Slope Failure for Various Conditions

	Flatter Slope		Steeper Slope	
Condition	Existing	Capped	Existing	Capped
Static	10.1	7.7	5.1	4.1
Pseudo-static	2.8	2.4	1.7	1.5

The results indicate that the factor of safety against a failure of the existing slope is equal to or greater than 1.5 for both static and pseudo-static analysis indicating that the slopes are stable under both static and seismic conditions. An artifact of the low unit weight of the submerged in-lake waste (78pcf - 62.4pcf = 16pcf) is that the design earthquake of 0.03g causes a larger reduction in the calculated factor of safety than would normally be calculated for an equivalent unsaturated soil.

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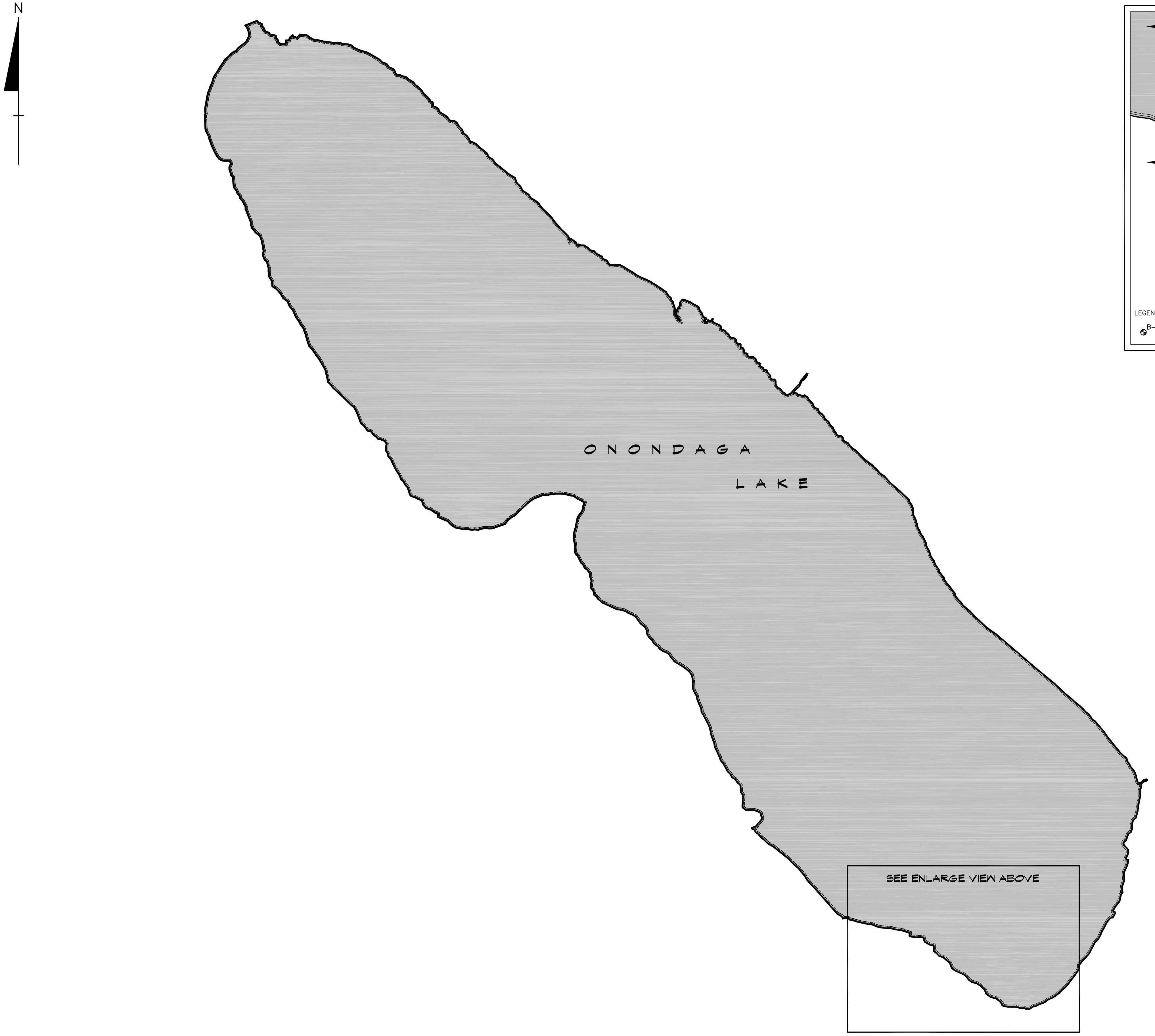

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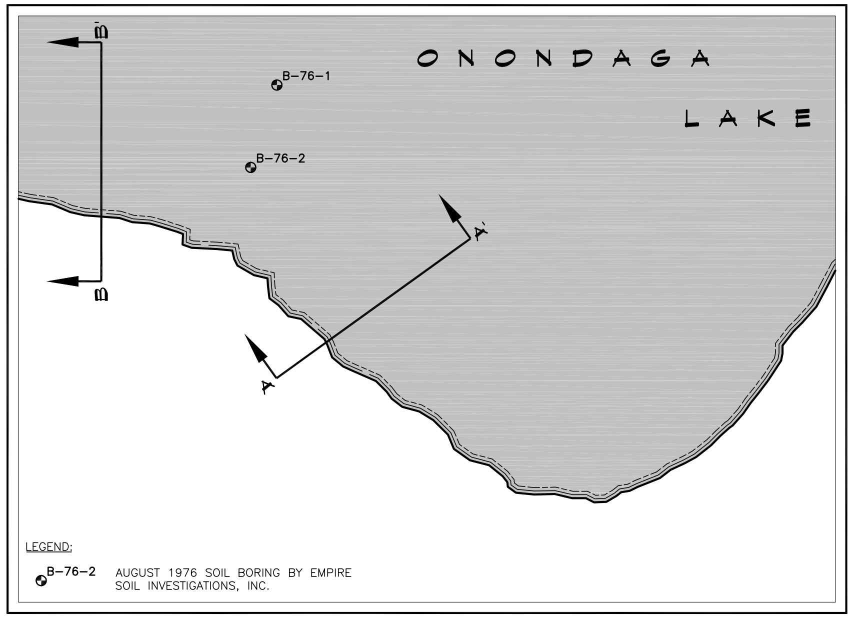

LEGEND:

B–76–2 AUGUST 1976 SOIL BORING BY EMPIRE SOIL INVESTIGATIONS, INC.

ENLARGED VIEW

APPROXIMATE SCALE
500 0 500 1,000 FEET

NOTES:

1. SECTION A–A' IS THE LOCATION OF THE SLUMPED SLOPE REPORTED IN ONONDAGA LAKE RI/FS GEOPHYSICAL SIRVEY, AUGUST, 1992.

2. SECTION B–B' IS THE LOCATION OF THE STEEPEST SLOPE SHOWN ON THE BATHYMETRIC SURVEY OF ONONDAGA LAKE.

CROSS SECTION LOCATION PLAN
SLOPE STABILITY ANALYSIS
SYRACUSE, NEW YORK
PREPARED FOR
PARSONS
ENGINEERING SCIENCE, INC.

HE&C
1050 Broadway, Suite 7
Chesterton, Indiana 46304
Phone: (219) 926–5508 · Fax: (219) 926–8446
Harrington Engineering & Construction, Inc.

DATE:	01–27–04	FIGURE 1	DRAWING NUMBER 01–011–E1	3
SCALE:	AS SHOWN			

No.	DATE	ISSUE / REVISION	DWN. BY	CK'D BY	AP'D BY
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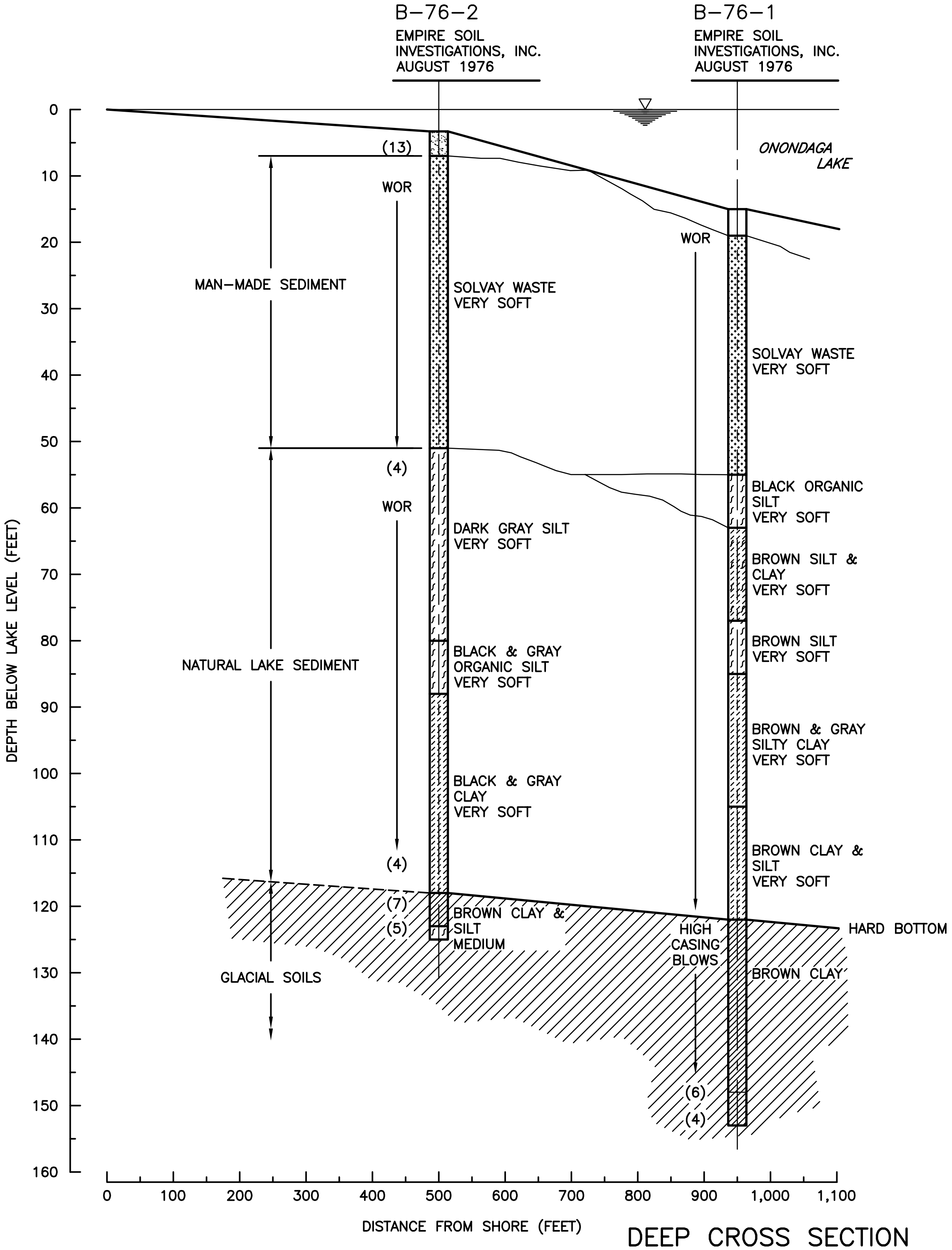
SOURCE: WWW.TERRASERVER.COM, AERIAL PHOTOGRAPH: 27 MAR 1995

DRAWING NUMBER 01-011-A2



WOR = WEIGHT OF ROD
(13) = SAMPLER BLOW COUNT

DEEP CROSS SECTION
ONONDAGA LAKE
SYRACUSE, NEW YORK

PREPARED FOR

PARSONS
ENGINEERING SCIENCE, INC.

HEC
1050 Broadway, Suite 7
Chesterton, Indiana 46304
Phone: (219) 926-5508 · Fax: (219) 926-8446
Harrington Engineering & Construction, Inc.

△1	03-26-04	ISSUED FOR REVIEW	M_A_M	TCW	TJH
No.	DATE	ISSUE / REVISION	DWN. BY	CK'D BY	AP'D BY

DATE: 03-24-04
SCALE: AS SHOWN

FIGURE 2

DRAWING NUMBER
01-011-A2

ATTACHMENT I
APPENDIX A

STABL 5M Input Files

Onondaga Lake STABL5M Input files

Ref: \\Kmb\C\stabl5m\STED

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145. 58.3 200. 61.6 1
200. 61.6 255. 64.8 1
255. 64.8 300. 68.1 1
300. 68.1 355. 71.4 1
355. 71.4 422. 74.7 1
422. 74.7 500. 78. 1
500. 78. 656. 81.2 1
656. 81.2 889. 84.5 1
889. 84.5 1211. 87.8 1
0. 50. 145. 53.3 2
145. 53.3 200. 56.6 2
200. 56.6 255. 59.8 2
255. 59.8 300. 63.1 2
300. 63.1 355. 66.4 2
355. 66.4 422. 69.7 2
422. 69.7 500. 73. 2
500. 73. 656. 76.2 2
656. 76.2 889. 79.5 2
889. 79.5 1211. 82.8 2
SOIL  Sand    Solvay
2
110. 110. 0. 30. 0. 0. 1
78. 78. 300. 0. 0. 0. 1
WATER
1 62.4
2
0. 82.8
1211. 82.8
EQUAKE
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CIRCL2-Bishop circular, search
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0. 200. 300. 500. 0. 9. 0. 0.
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1011FACS

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145. 58.3 200. 61.6 1
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200. 61.6 255. 64.8 1
255. 64.8 300. 68.1 1
300. 68.1 355. 71.4 1
355. 71.4 422. 74.7 1
422. 74.7 500. 78. 1
500. 78. 656. 81.2 1
656. 81.2 889. 84.5 1
889. 84.5 1211. 87.8 1
0. 50. 145. 53.3 2
145. 53.3 200. 56.6 2
200. 56.6 255. 59.8 2
255. 59.8 300. 63.1 2
300. 63.1 355. 66.4 2
355. 66.4 422. 69.7 2
422. 69.7 500. 73. 2
500. 73. 656. 76.2 2
656. 76.2 889. 79.5 2
889. 79.5 1211. 82.8 2
SOIL  Sand    Solvay
2
110. 110. 0. 30. 0. 0. 1
78. 78. 300. 0. 0. 0. 1
WATER
1 62.4
2
0. 82.8
1211. 82.8
CIRCL2-Bishop circular, search
10 10
0. 200. 300. 500. 0. 9. 0. 0.
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1011FAE

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255. 59.8 300. 63.1 1
300. 63.1 355. 66.4 1
355. 66.4 422. 69.7 1
422. 69.7 500. 73. 1
500. 73. 656. 76.2 1
656. 76.2 889. 79.5 1
889. 79.5 1211. 82.8 1
SOIL  Solvay
1
78. 78. 300. 0. 0. 0. 1
WATER
1 62.4
2
0. 82.8
1211. 82.8
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```
EQUAKE
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CIRCL2-Bishop circular, search
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```

1011FAS

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255. 59.8 300. 63.1 1
300. 63.1 355. 66.4 1
355. 66.4 422. 69.7 1
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500. 73. 656. 76.2 1
656. 76.2 889. 79.5 1
889. 79.5 1211. 82.8 1
SOIL  Solvay
1
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WATER
1 62.4
2
0. 82.8
1211. 82.8
CIRCL2-Bishop circular, search
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0. 200. 300. 500. 0. 9. 0. 0.
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1011SSCE

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800. 64.9 833. 68.2 2
833. 68.2 911. 71.4 2
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1056. 81.3 1089. 84.6 2
1089. 84.6 1134. 87.8 2
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1162. 91.1 1200. 94.4 2
1200. 94.4 1245. 97.7 2
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911. 66.4 978. 69.7 1
978. 69.7 1022. 73. 1
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1056. 76.3 1089. 79.6 1
1089. 79.6 1134. 82.8 1
1134. 82.8 1162. 86.1 1
1162. 86.1 1200. 89.4 1
1200. 89.4 1245. 92.7 1
1245. 92.7 1267. 96. 1
1267. 96. 1289. 99.2 1
1289. 99.2 1500. 102.5 1
1500. 102.5 1889. 105.8 1
SOIL  Solvay  Sand
2
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WATER
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2
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1889. 105.8
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1289. 99.2 1500. 102.5 1
1500. 102.5 1889. 105.8 1
SOIL  Solvay  Sand
2
78. 78. 50. 0. 0. 0. 1
110. 110. 0. 30. 0. 0. 1
WATER
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2
0. 105.8
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1089. 79.6 1134. 82.8 1
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```

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1289. 99.2 1500. 102.5 1
1500. 102.5 1889. 105.8 1
SOIL  Solvay
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WATER
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2
0. 105.8
1889. 105.8
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1200. 89.4 1245. 92.7 1
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1267. 96. 1289. 99.2 1
1289. 99.2 1500. 102.5 1
1500. 102.5 1889. 105.8 1
SOIL  Solvay
1
78. 78. 50. 0. 0. 0. 1
WATER
1 62.4
2
0. 105.8
1889. 105.8
CIRCL2-Bishop circular, search
10 10
600. 1300. 1400. 1800. 0. 13. 0. 0.
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ATTACHMENT I
APPENDIX B

Failure Surfaces – Flatter Slope

Onondaga Lake-Flat Slope
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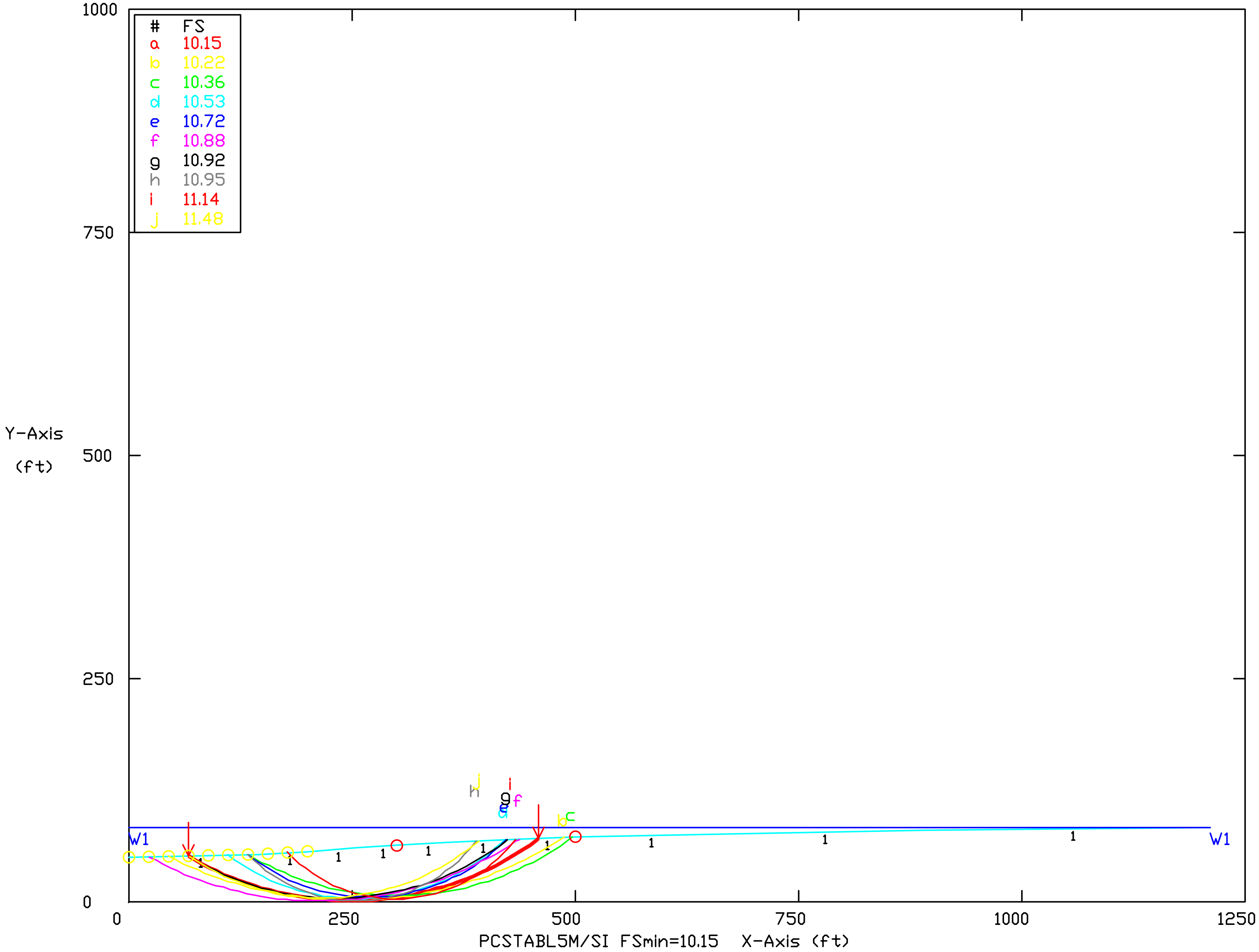

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1 Solvay	78	78	300	0	0	0	W1

Onondaga Lake-Flat Slope Capped

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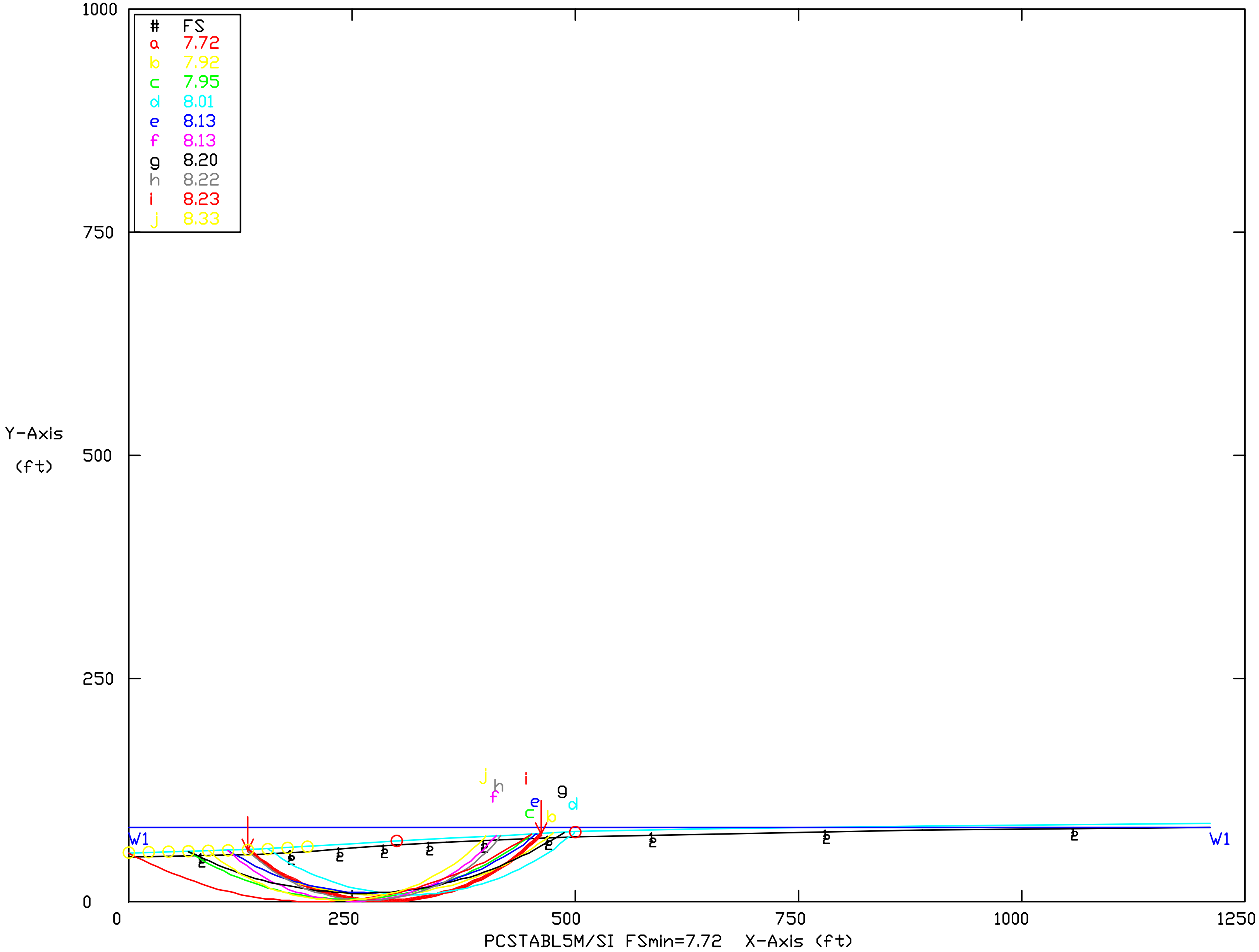

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1 Sand	110	110	0	30	0	0	W1
2 Solvay	78	78	300	0	0	0	W1

Onondaga Lake-Flat Slope Capped with Earthquake
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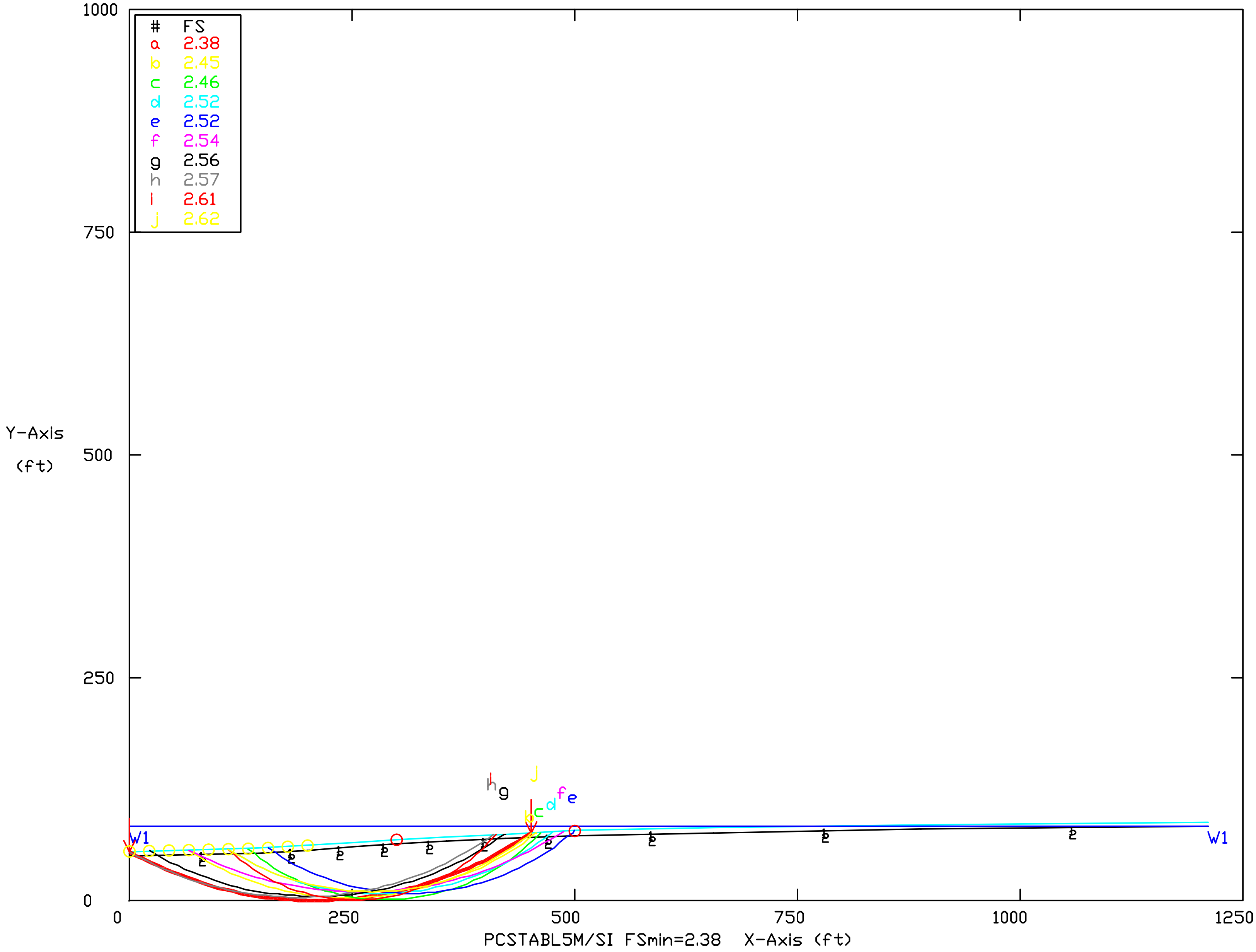

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1	Sand	110	110	0	30	0	0	W1
2	Solvay	78	78	300	0	0	0	W1

Onondaga Lake-Flat Slope with Earthquake
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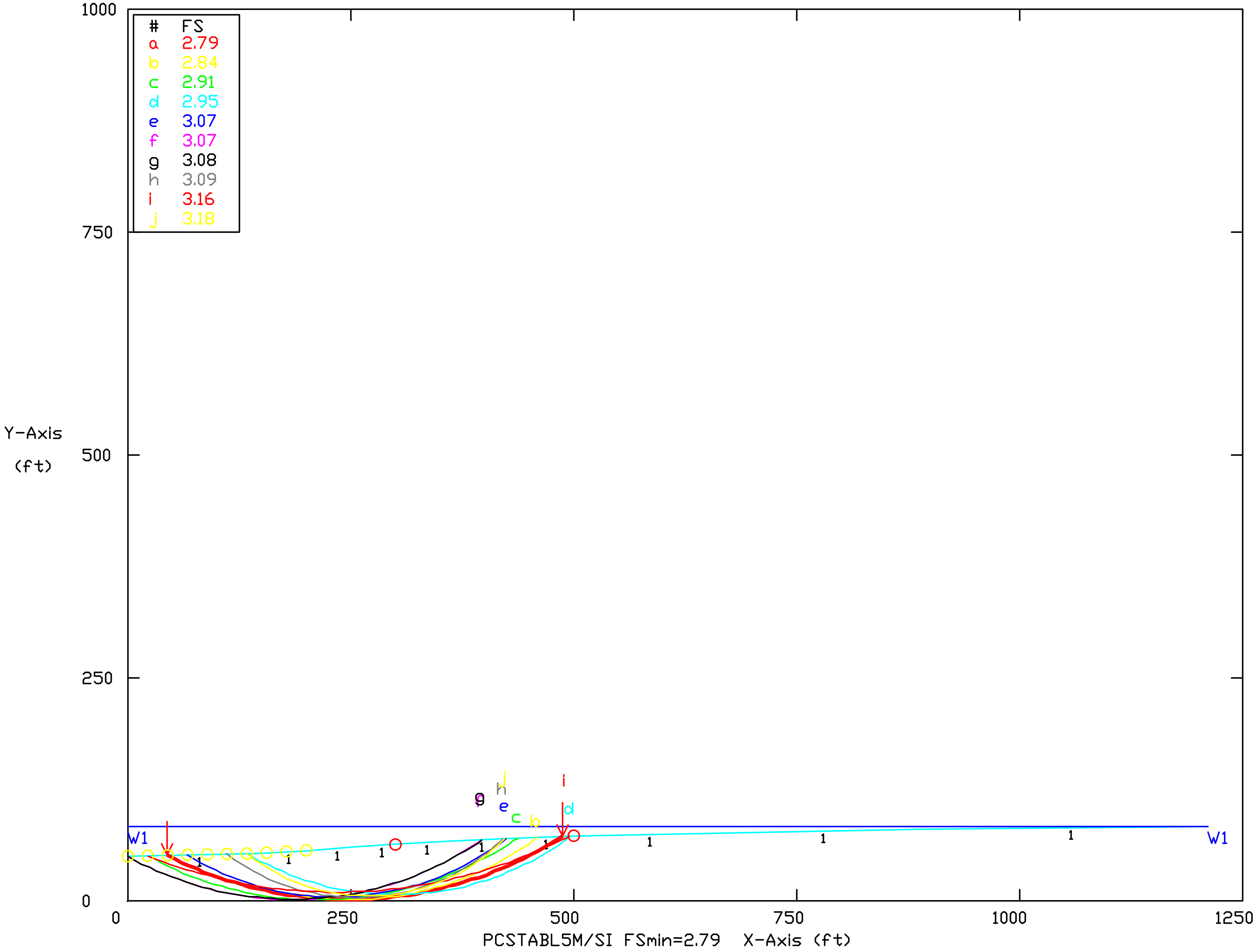

Soil Type No. Label	Total Unit Wt. (pcf)	Saturated Unit Wt. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Param.	Pressure Constant (psf)	Piez. Surface No.
1 Solvay	78	78	300	0	0	0	W1

ATTACHMENT I
APPENDIX C

Failure Surfaces – Steeper Slope

Onondaga Lake-Steep Slope
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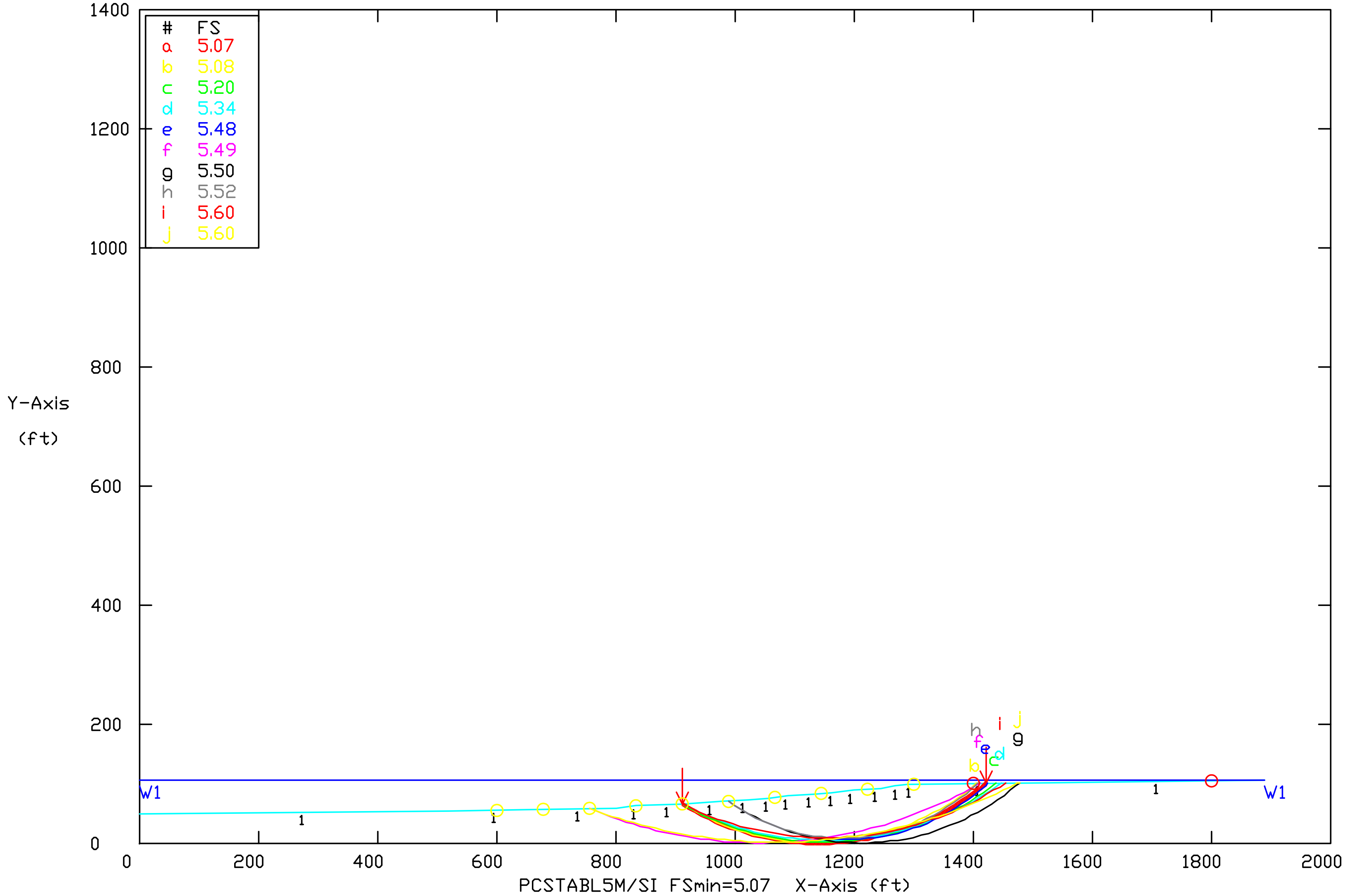

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Soil Type No. Label	Total Unit Wt. (pcf)	Saturated Unit Wt. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Param.	Pressure Constant (psf)	Piez. Surface No.
1 Solvay	78	78	300	0	0	0	W1

Onondaga Lake-Steep Slope Capped

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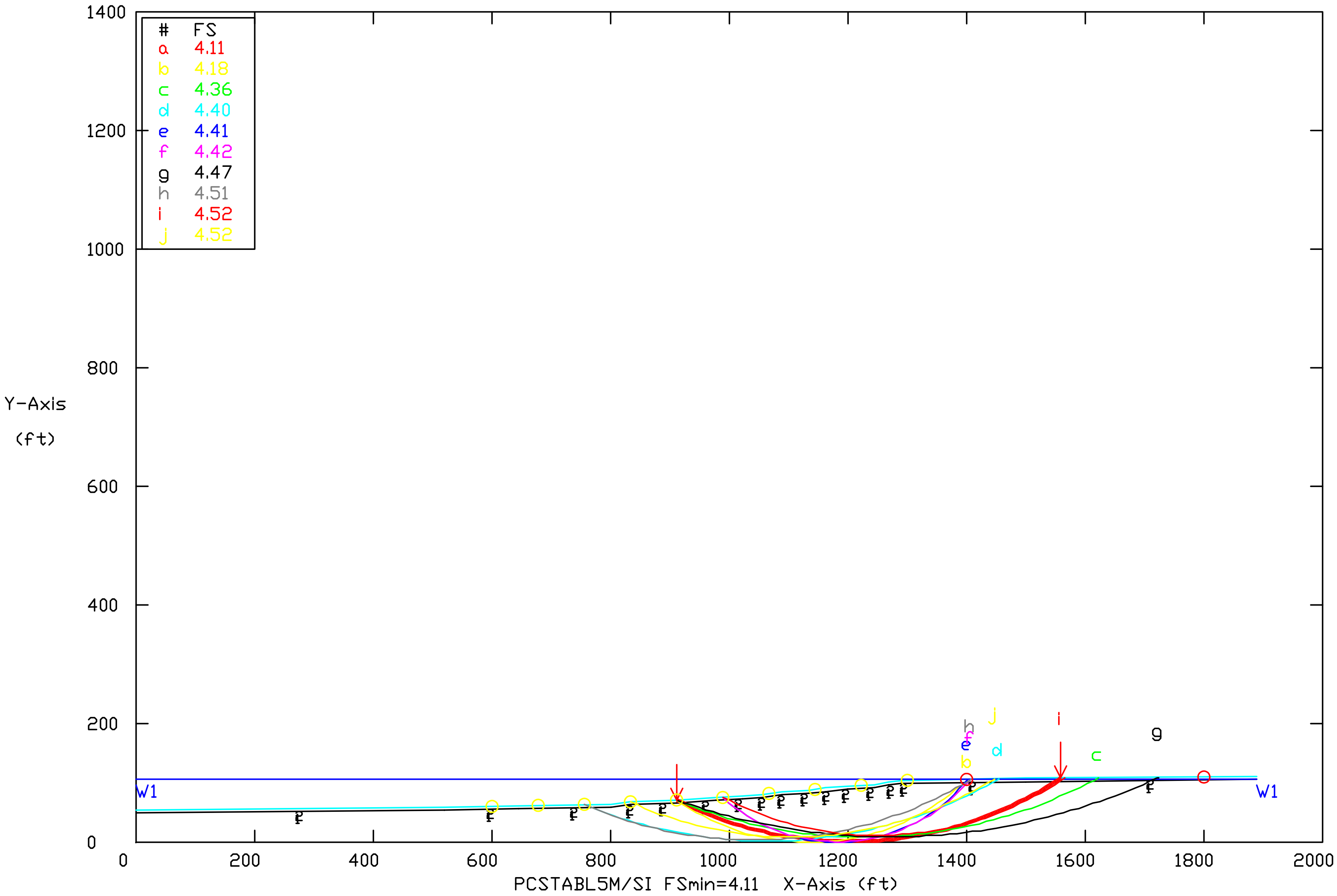

Soil Type No.	Label	Total Unit Wt. (pcf)	Saturated Unit Wt. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Param.	Pressure Constant (psf)	Piez. Surface No.
1	Solvay	78	78	300	0	0	0	W1
2	Sand	110	110	0	30	0	0	W1

Onondaga Lake-Steep Slope Capped with Earthquake

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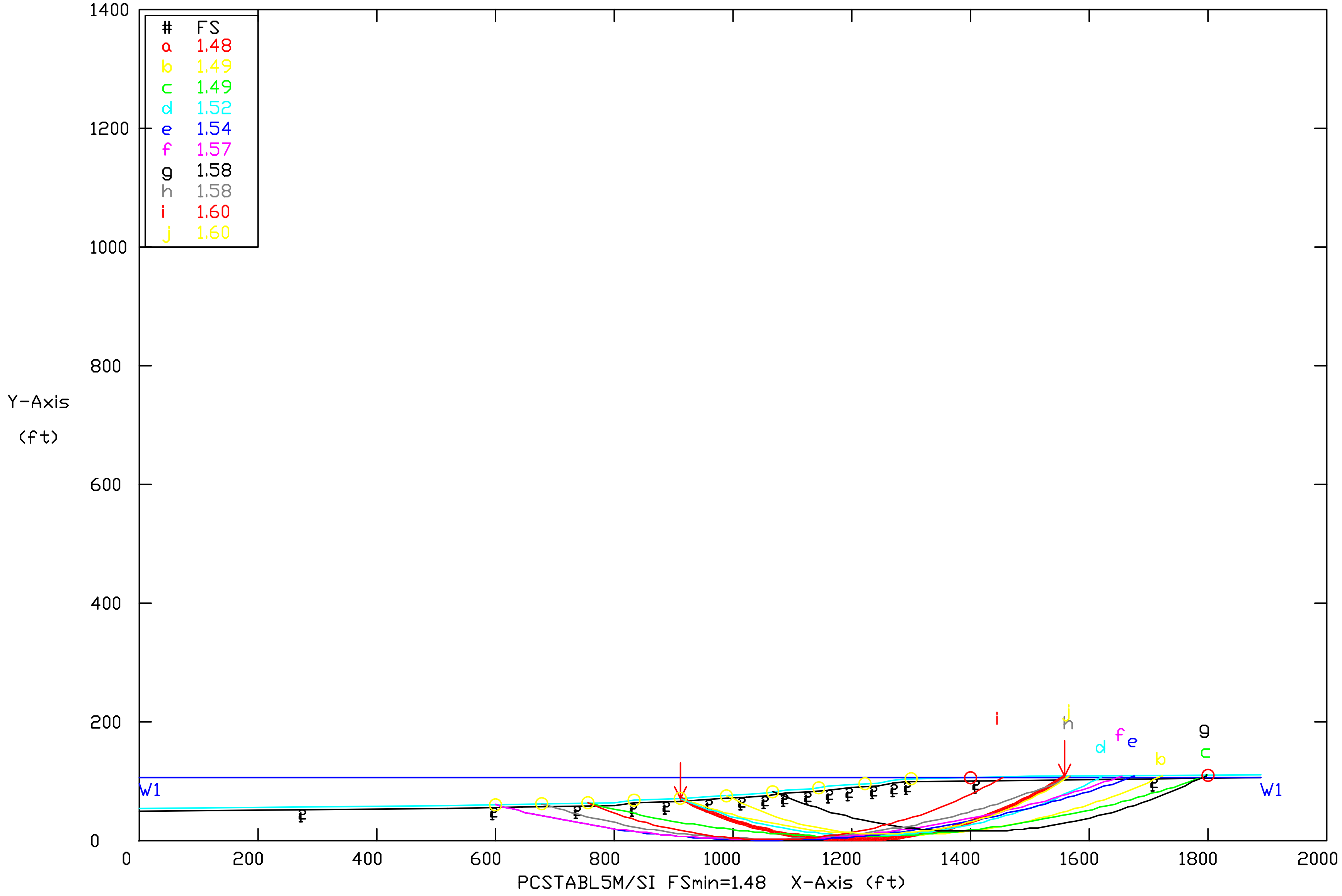

Soil Type No.	Label	Total Unit Wt. (pcf)	Saturated Unit Wt. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Param.	Pressure Constant (psf)	Piez. Surface No.
1	Solvay	78	78	300	0	0	0	W1
2	Sand	110	110	0	30	0	0	W1

Onondaga Lake-Steep Slope with Earthquake
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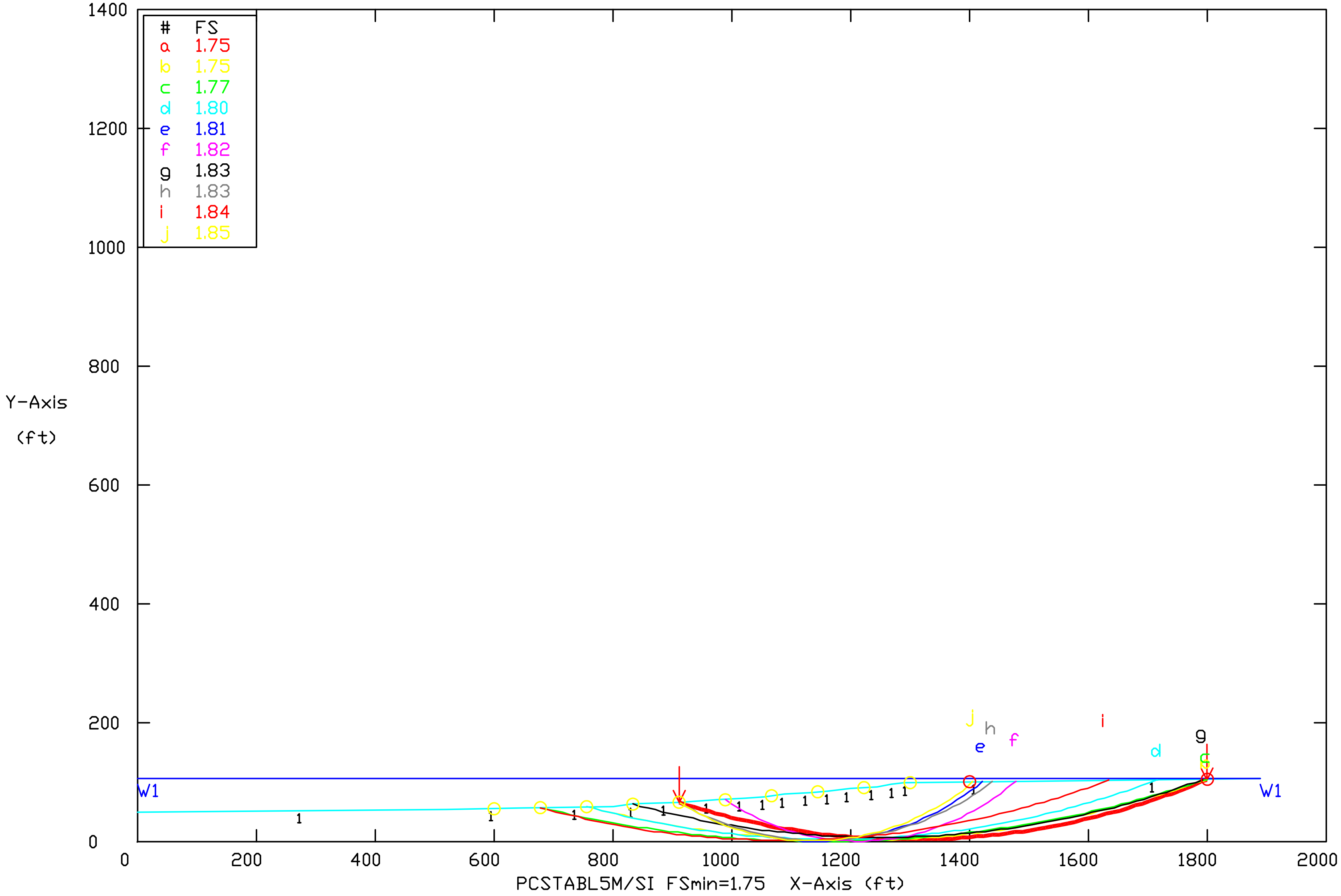


Soil Type No. Label	Total Unit Wt. (pcf)	Saturated Unit Wt. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Param.	Pressure Constant (psf)	Piez. Surface No.
1 Solvay	78	78	300	0	0	0	W1

APPENDIX H
ATTACHMENT J

FLOOD FLOW ANALYSIS – NINEMILE CREEK

ANCHOR ENVIRONMENTAL, L.L.C.

Anchor Environmental, L.L.C.
1423 3rd Avenue, Suite 300
Seattle, Washington 98101
Phone 206.287.9130
Fax 206.287.9131

Memorandum

Written for the Onondaga Lake Feasibility Study

From: Greg Guannel and John Verduin, P.E., Anchor Environmental, L.L.C.

Date: June 3, 2004

Re: Onondaga Lake Feasibility Study - Ninemile Creek Erosion Analysis

---

This memorandum presents the results of an erosion analysis at the mouth of Ninemile Creek, performed at the request of NYSDEC. In a previous memorandum (Anchor Environmental, 2003), we concluded through a preliminary evaluation that Onondaga Creek would have comparable cap erosion potential as Ninemile Creek. Therefore, that memorandum focused only on Onondaga Creek. We evaluated the influence of Onondaga Creek on the Lake's sediments, and found that sediment sizes ranging from medium sand to fine gravel would be necessary to resist currents at the mouth and near the Creek during a design storm event. NYSDEC requested that we also evaluate the effects of Ninemile Creek flow on a cap in Onondaga Lake.

NINEMILE CREEK MODELING

Currents generated by Ninemile Creek flowing into Onondaga Lake were modeled using the same RMA-2 hydraulic model that was used for the previous creek erosion analysis (Anchor Environmental, 2003). Using the lake's bathymetric information, the following main assumptions were made:

- The 100-year flow value, based on modeling results from Limno-Tech's analysis (Limno-Tech, 2003), could be used.
- Bathymetry was raised by 1.5 feet at the mouth of the creek to account for placement of cap material (in reality a 3-foot-cap might be placed, but, because of consolidation of underlying sediment, it is expected that, on average, bathymetry will be raised by only 1.5 feet).

Results of the analysis are presented in Appendix A, and summarized in Table 1 and Figure 1.

Table 1
Current Velocity along Discharge Centerline

Distance Offshore [feet]	Centerline Current Speed [feet/second]	Water Depth [feet]
0	4.9	12
386	3.5	17
552	3.1	20
888	2.8	25
1247	1.6	40
1395	1.3	44

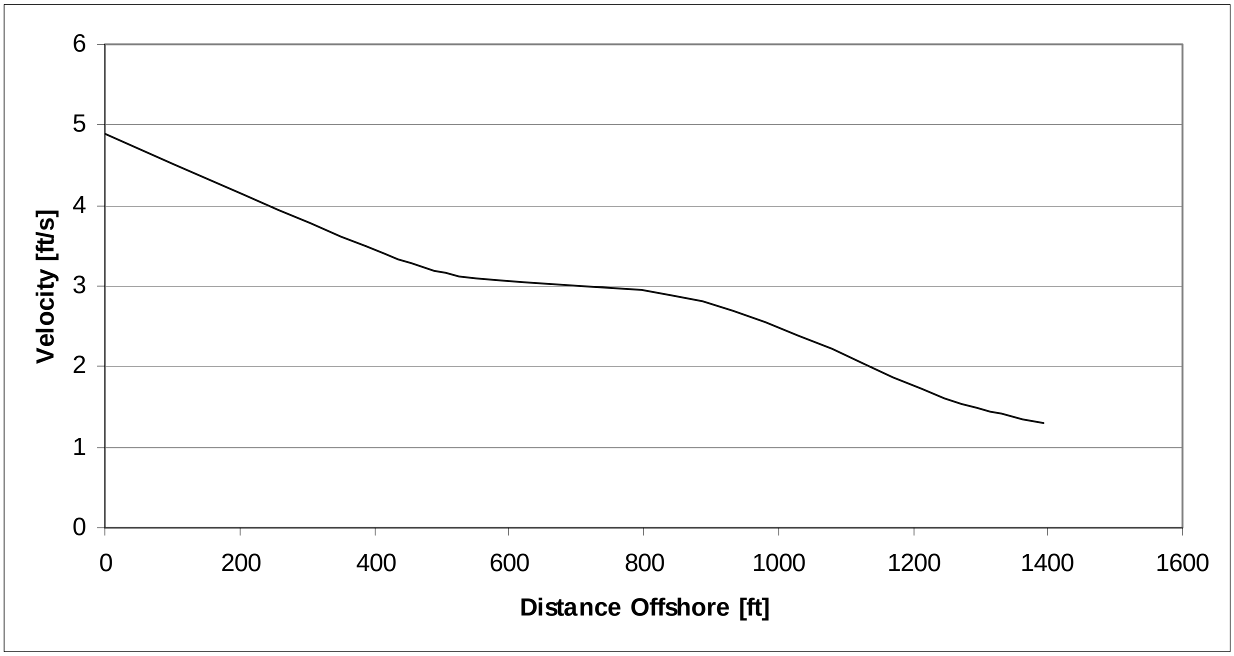


Figure 1
Velocity Field in the Lake due to Ninemile Creek Inflow

STABLE SEDIMENT SIZE TO RESIST CREEK CURRENT VELOCITIES

Based on results of modeling analysis (Appendix A), stable sediment sizes that resist creek flow velocity in the Lake at various water depths are presented in Table 2.

Table 2
Stable Sediment Size that can Resist Velocities from Ninemile Creek for a 100-Year Storm

Distance Offshore [ft]	Depth [ft]	Velocity [ft/s]	Sediment Size [mm]	Sediment Type
0	12	4.9	12	Fine Gravel
386	17	3.5	9	Fine Gravel
552	20	3.1	8	Fine Gravel
888	25	2.8	7.5	Fine Gravel
1247	40	1.6	2.5	Coarse Sand
1395	44	1.3	1.9	Medium Sand

In Table 2, sediment size represents the highest value of stable sediment sizes that were determined based on three different methods (Appendix B):

- Ackers and White, as presented in Gailani (1999)
- Hjustom curve (Vanoni 1975)
- Toffaleti formula (Vanoni 1975)

The different sediment sizes presented in Table 2 are expected to be stable in a channel the width of Ninemile Creek, centered on its mouth. The influence of the creek is expected to diminish further away, laterally, from the mouth, as shown in Figure 3 of Appendix A. Within the channel itself, the creek currents will control required armor size; outside of the main channel wind-wave forces will control armor size. The armor requirements will be refined during final design when final cap elevations and extents are better defined.

REFERENCES

Anchor Environmental, 2003. "*Onondaga Lake Feasibility Study - Creek Erosion Analysis*", memorandum from Greg Guannel and John Verduin, P.E.

Effler, S.W., 1996. "*Limnological and Engineering Analysis of a Polluted Urban Lake*", Springer-Verlag New York, Inc., 832 pp.

Gailani, J., Davis, J., and Pollock, C., 1999. "MODEL: Sediment grain-size depth of residence," DOER Technical Notes Collection (TN DOER-N4), U.S. Army Engineer Research and Development Center, Vicksburg, MS. www.wes.army.mil/el/dots/doer

Limno-Tech, Inc., October 2003. "Baseline and Capping Alternative HEC-RAS Simulation Results for Ninemile Creek and Geddes Brrok", Memorandum from Scott Hinz and Kristen Chaffin to David Johnson and David Babcock, Parsons Engineering and Science.

Vanoni, V.A., 1975. "Sedimentation Engineering", ASCE Manuals and Reports on Engineering Practice – No. 54, ASCE, 745 pp.

ATTACHMENT J
APPENDIX A

ESTIMATION OF VELOCITIES

ATTACHMENT J
APPENDIX B

TABLE SEDIMENT SIZE TO RESIST CURRENT FORCES

ONONDAGA LAKE SEDIMENT REMEDIATION

MEMORANDUM

To: Greg Guannel, Anchor Environmental
From: Henry Hu
Date: May 26, 2004
Subject: ESTIMATION OF VELOCITIES NINEMILE CREEK DISCHARGE

WEST CONSULTANTS, INC.
12509 Bel-Red Road, Suite 100
Bellevue, WA 98005-2535
Phone: (425) 646-8806
Fax: (425) 646-0570
www.westconsultants.com

Introduction and Approach

Anchor Environmental is evaluating sediment remediation alternatives for Onondaga Lake in Syracuse, New York State. One alternative is to dredge and cap contaminated sediments. To size bed materials, they need to know the potential velocities in the lake under design conditions, particularly in the vicinity of creek inflows. This memorandum summarizes the approach and results for evaluating discharge velocities from Ninemile Creek inflows.

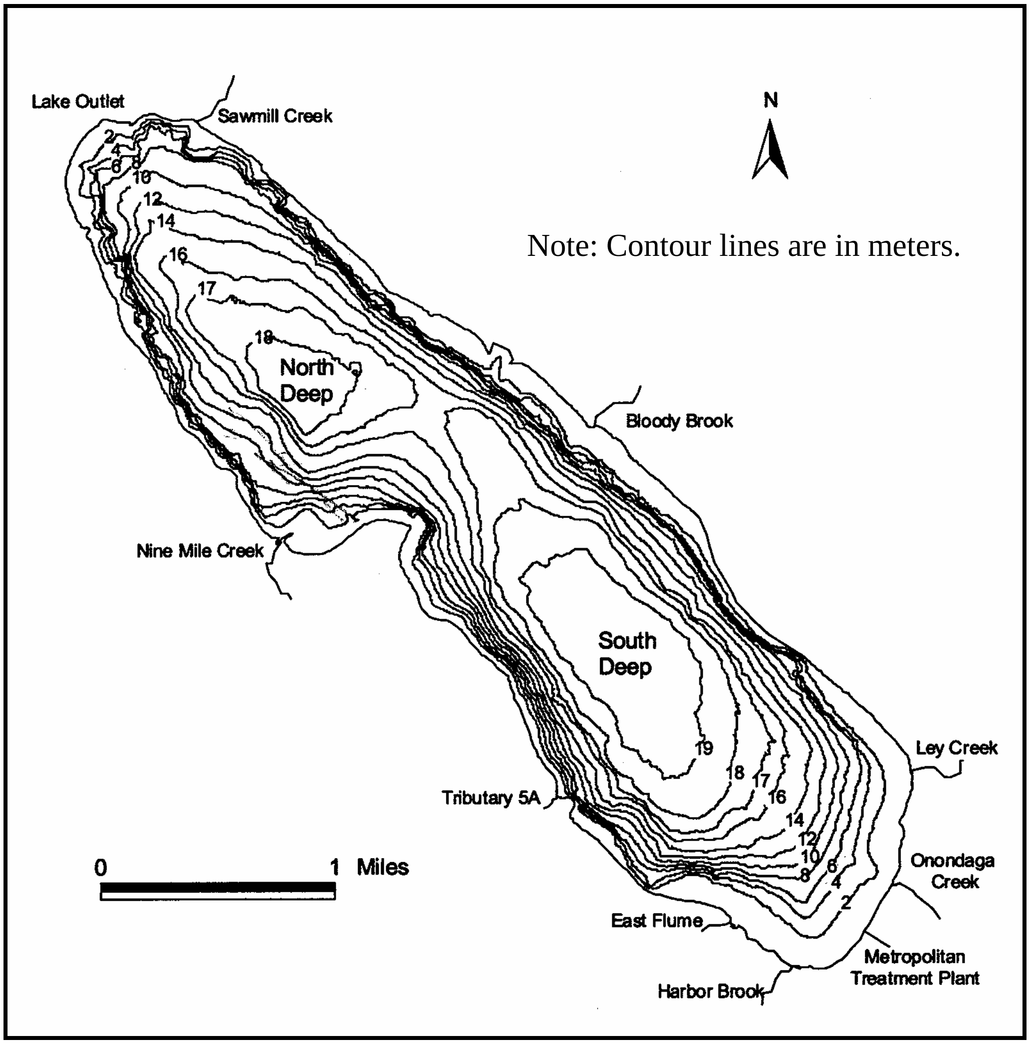
Ninemile Creek flows into the west shore of Onondaga Lake (Figure 1 shows sediment plume from Ninemile Creek and Onondaga Creek). A steady-state two-dimensional model of the discharge region of Ninemile Creek was developed. The computer program selected was the Corps of Engineers' Engineer Research and Development Center (ERDC) model, RMA-2, running in the graphical pre- and post-processor, Surface-Water Modeling System (SMS), Version 7.0.

Figure 1 Aerial View of Onondaga Lake

Model Development and Results

Figure 2 shows the bathymetry of Onondaga Lake. To compute the discharge velocities, the RMA-2 model was developed based on the following information:

- The 100-year flow of 3,756 cfs was modeled. The discharge was taken from an HEC-RAS model developed by Limno-Tech, Inc., for the Ninemile Creek baseline and capping alternative HEC-RAS simulation. The discharge of the Ninemile Creek main channel is approximately 76 feet wide and 11 feet deep.
- The bathymetry of Onondaga Lake was used to interpolate the lake bottom elevation at each grid node.
- The bathymetry in the vicinity of Ninemile Creek inflows was uniformly raised by 1.5 feet to represent the thickness of a cap to be placed on top of existing sediments.



Note: Contour lines are in meters.

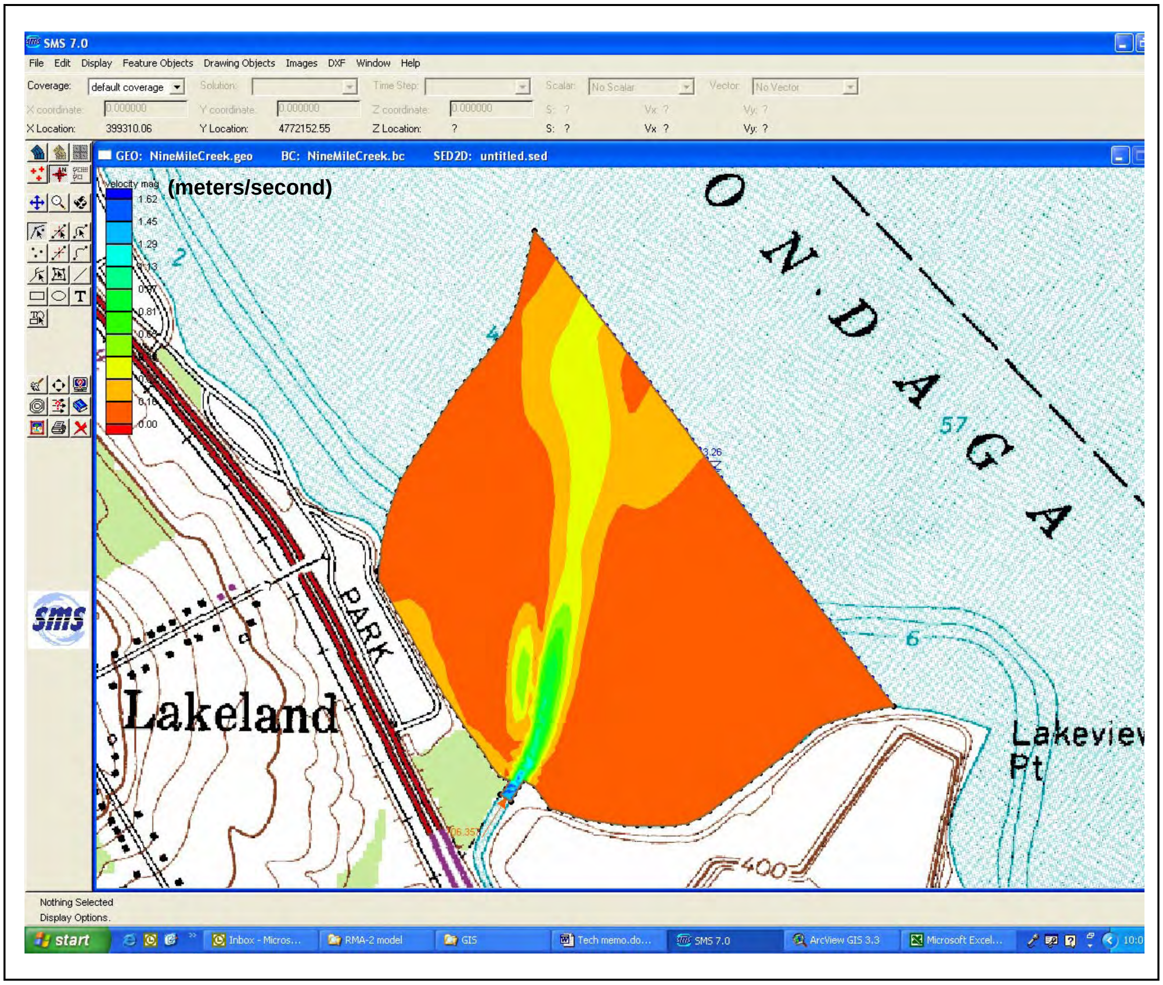
Figure 2 Bathymetric Map of Onondaga Lake

- The eddy viscosity (E) is equal to 20 1b-sec/ft^2, which provides a “conservatively high” estimate of velocities (refer to a memorandum prepared by WEST Consultants, Inc., with the subject of “Estimation of Velocities” for Onondaga Creek inflows, dated December 5, 2003)
- A two-dimensional, finite-element grid was developed approximately 2,300 feet out into the lake, and 4,300 feet along the shore.

Figure 3 shows the distribution of current speeds. Table 1 and Figure 4 show the centerline current speeds (or “velocity magnitudes”). To account for the uncertainties on the estimate of the eddy viscosity, the current speeds in Table 1 may be used to compute the bed shear stress across the entire discharge region of Ninemile Creek because the model computes different influence zones for different values of the eddy viscosity.

Table 1 Current Speeds Along Discharge Centerline

Distance Offshore (feet)	Centerline Current Speed (feet/second)	Water Depth (feet)
0	4.9	12
386	3.5	17
552	3.1	20
888	2.8	25
1247	1.6	40
1395	1.3	44
1772	1.2	53
2011	1.3	59
2407	1.4	64
2742	1.3	69
3149	1.1	71



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Time Step:
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Vector: No Vector
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Y coordinate: 0.000000
Z coordinate: 0.000000
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Vx: ?
Vy: ?
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Y Location: 4772152.55
Z Location: ?
S: ?
Vx ?
Vy: ?

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Display Options.

Figure 3 Velocity Magnitude

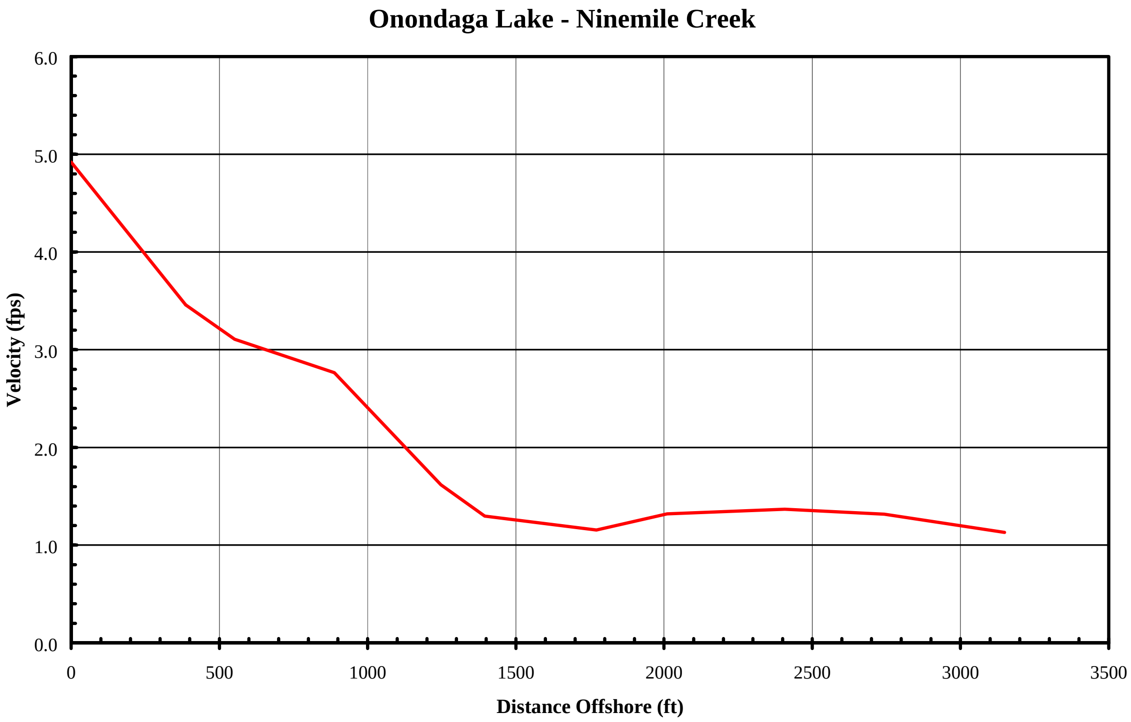

Figure 4 Current Speeds Approximately along Discharge Centerline

TABLE B-1
STABLE SEDIMENT SIZE AT VARIOUS DEPTHS

Distance Offshore [ft]	Depth [ft]	Velocity [ft/s]	Sediment Size [mm]			Design Size [mm]	Sediment Type
			Hjulstrom*	Toffaleti*	Ackers and White*		
0	12	4.9	12	NA	NA	12	Fine Gravel
386	17	3.5	9	NA	NA	9	Fine Gravel
552	20	3.1	8	NA	4	8	Fine Gravel
888	25	2.8	7.5	NA	2.5	7.5	Fine Gravel
1247	40	1.6	2.5	0.71	0.6	2.5	Coarse Sand
1395	44	1.3	1.9	0.35	0.4	1.9	Medium Sand

* Methods used to compute sediments size are presented in the memo, Section 1.