REPORT

CAP-INDUCED SETTLEMENT FOR NON-ILWD APPENDIX
ONONDAGA LAKE

Prepared for

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March 2012

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CAP-INDUCED SETTLEMENT EVALUATION
ONONDAGA LAKE

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LIST OF ACRONYMS AND ABBREVIATIONS

ASTM	American Society of Testing and Materials
FS	Feasibility Study
IDS	Initial Design Submittal
ILWD	in-lake waste deposit
Lake	Onondaga Lake
OCR	over-consolidation ratio
pcf	pounds per cubic foot
PDI	pre-design investigation
ROD	Record of Decision
SI	International System of Units
SIC	seepage-induced consolidation

1 INTRODUCTION

This report presents an estimate of the amount of consolidation settlement anticipated after placement of capping materials in portions of Onondaga Lake (Lake; Figure 1). For the purposes of this evaluation, primary and secondary consolidation settlement was predicted based on the results of consolidation testing performed as part of the Onondaga Lake pre-design investigations (PDIs).

The areas evaluated in this memorandum include Remediation Areas A, B, C, and E. Capping is also anticipated in Remediation Area D and, to a small extent, in Remediation Area F. Settlement estimates for Remediation Area D (the in-lake waste deposit; ILWD) are presented in a separate memorandum (Geosyntec Consultants 2011). Because the extent of capping planned in Remediation Area F is limited, separate settlement estimates are not provided for this area.

In each of the remediation areas evaluated, the remedial action selected in the Record of Decision (ROD) includes subaqueous capping, either as a stand-alone remedy or following initial dredging. The basis of design for the limits and extents of the remedial actions are detailed in the Capping and Dredge Area and Depth Initial Design Submittal and refined in the Capping, Dredging, and Habitat Intermediate and Draft Final designs and presented on Figure 1.

The remainder of this memorandum is organized as follows:

- Section 2 – Subsurface Conditions
- Section 3 – Sediment Properties
- Section 4 – Settlement Analysis
- Section 5 – Conclusions
- Figures (see List of Figures)
- Attachment A – Consolidation Test Data Summary
- Attachment B – Settlement Calculations
- Attachment C – Summary of Modeling Inputs and Results

2 SUBSURFACE CONDITIONS

The subsurface conditions used for this analysis in Remediation Areas A, B, C, and E were based on a review of exploration logs from geotechnical borings and vibracores conducted as part of the PDI, as well as historical explorations by others. In general, representative stratigraphic cross-sections were developed for each remediation area (including multiple sections per area, where appropriate) to depict the general subsurface sediment profile. The separations between stratigraphic layers depicted on these cross-sections have been estimated based on visual observations denoted on exploration logs and on index tests performed in the laboratory. These separations are not intended to represent distinct transitions between layers because sediment types and properties often gradually grade from one layer to another in a natural deposit.

The subsurface conditions for each remediation area are generally described below and are depicted on Figures 3, 4, 5, 7, 8, 10, 11, 12, 14, 15, and 16. In addition, Attachment C provides a summary of the idealized subsurface stratification assumed for each settlement analysis case. Explorations advanced indicate a layer containing granular material (e.g., sand and/or gravel) is present at depth in most of the remediation areas. Although the spatial density of explorations penetrating to these depths is not sufficient to determine with certainty whether the sand layers are continuous across the entire site, they have been observed with enough frequency to be accounted for in assessing the drainage paths during the consolidation analysis, as discussed below. The presence (or absence) of these granular layers has an effect on the time rate of consolidation, but not on the magnitude of settlement.

Remediation Area A: Figure 2 presents the locations of explorations advanced within Remediation Area A. Three cross-sections, depicted on Figure 3 (A-A'), Figure 4 (B-B'), and Figure 5 (C-C'), were developed to illustrate the subsurface stratigraphy in Remediation Area A. The generalized subsurface profile consists primarily of a surface layer of gray silt with little clay, fine sand, and calcareous material. The gray silt layer is underlain by sand, which is interbedded with clay in some areas, although this deeper stratum was only observed in some of the deeper nearshore explorations (e.g., 40002, 40003, 40033, and 40036) and one offshore exploration that penetrated deep enough (S305). The thickness of the silt layer appears to be greatest toward shore, at approximately 35 to 40 feet, and thins offshore to approximately 20 feet thick. In the immediate nearshore region on the eastern side of Remediation Area A, a surficial deposit of sand with some silt was observed overlying the silt layer to a depth of approximately 15 feet (see Figure 3 [A-A'] and Figure 5 [C-C']). This sand deposit was underlain by the gray silt layer, followed by the clay and interbedded sand layer observed elsewhere in Remediation Area A, as described above. Although not observed in explorations in the western half of Remediation Area A, it is assumed that the sand drainage layer observed in the eastern half (40002, 40003, S305, etc.) is also present at deeper depths than sampled in the western half. The presence of interbedded sand layers in the deeper strata is expected to serve as a drainage layer below the overlying consolidating silt layer (i.e., the silt layer will be doubly drained).

Remediation Area B: Figure 6 presents the locations of explorations advanced within Remediation Area B. Two cross-sections illustrating the stratigraphy in Remediation Area B are presented on Figure 7 (D-D') and Figure 8 (E-E'). The generalized subsurface profile consists of a surface layer of Solvay waste ranging in thickness from approximately 5 feet nearshore and far offshore to more than 25 feet in the central portions (e.g., halfway between shore and the offshore limit) of Remediation Area B. The Solvay waste layer is underlain by a layer of silt and clay (Marl). The Marl layer was estimated to be approximately 25 feet thick based on a deep exploration (30033). This exploration also indicated that the Marl was underlain by an approximately 11-foot-thick layer of clay, followed by a silt and fine sand layer (approximately 60 to 70 feet below the mudline) that is expected to act as a subsurface drainage layer (i.e., consolidation of overlying layers would be doubly drained).

Remediation Area C: The assumed subsurface conditions in Remediation Area C are based primarily on borings and cores advanced within the eastern portion of Remediation Area C, as well as two deep borings (20016 and 20017) advanced along the shoreline of Remediation Area C but outside of the proposed capping area (see Figure 9). A deep boring from Remediation Area B (30003) was used to create the subsurface profile for the westernmost cross-section of Remediation Area C. The generalized soil profiles for Remediation Area C are presented on Figure 10 (F-F'), Figure 11 (G-G'), and Figure 12 (H-H'). The soil profiles generally consist of a 10- to 20-foot-thick layer of grey and black silt or grey to brown silt and sand overlying soft to stiff brown and gray clay (Marl) extending to approximately 55 to 65 feet below the mudline. Deposits of Solvay waste, ranging from 5 to 20 feet thick, were observed above the Marl and within the silt layer. Below the Marl deposit, a layer of sand was observed in the three deep borings (20016, 20017, and 30003). This sand material is assumed to not undergo significant consolidation and will serve as a drainage layer below the overlying consolidating layers (i.e., the overlying layers will be doubly drained). In a few nearshore borings, the surficial silt layer contained a significant fraction of sand-sized particles, contributing to a lighter brown color.

Remediation Area E: Figure 13 presents the locations of explorations advanced within Remediation Area E. Three cross-sections, depicted on Figure 14 (I-I'), Figure 15 (J-J'), and Figure 16 (K-K'), were developed to illustrate the subsurface stratigraphy in Remediation Area E. The generalized subsurface profile includes a surficial layer approximately 10 to 20 feet thick, consisting of fine to medium sand in the nearshore region, which grades to black silt with decreasing amounts of fine sand with distance from shore. The thickness of the sand layer was observed to decrease with distance from shore and transitions from primarily sand in the most nearshore explorations to silt with some fine sand, and then eventually to just silt in the offshore portion of Remediation Area E.

Beneath the surficial layer of silt and fine sand is a layer of organic silt and clay that extends to the bottom of most explorations conducted within Remediation Area E (approximately 30 to 40 feet below the mudline). This organic silt layer appears consistent with the lacustrine (natural Lake sediments) deposit noted on two historical deep boring logs from Remediation Area D (B-76-1 and B-76-2—not shown on figures) and a deep historical boring (TH-305) on the shoreline of Remediation Area E completed for the design of the sewage treatment plant. In boring TH-305, the lacustrine deposit was observed to extend to approximately 130 feet below the shoreline elevation, with underlying sandy silt. Given that the ground surface near this boring is approximately 20 feet higher than the average mudline within the Lake in Remediation Area E, the depth to the underlying silt and sand layer, which is expected to serve as a subsurface drainage layer (i.e., doubly drained), was assumed to be approximately 110 feet in the eastern portion of Remediation Area E. Based on deep borings advanced in Remediation Area D, the lacustrine deposit on the western side of Remediation Area E (bordering Remediation Area D; see Section I-I' Figure 14) was assumed to extend between approximately 100 and 150 feet below the mudline before transitioning to underlying glacial soils. However, since the underlying glacial soils were described as clay and silt on the historical boring logs, this layer was not assumed to provide for drainage on the western side of Remediation Area E. These assumptions for thickness of the lacustrine deposit are expected to be conservative relative to the time rate of settlement, which is highly dependent on the drainage distance for porewater expelled during consolidation. Therefore, the durations predicted for settlement to occur in Remediation Area E may be overestimated, as discussed in Table 1.

In the western portion of Remediation Area E (along the boundary with Remediation Area D), a thin (approximately 3-feet-thick) surficial layer of very soft organic silt overlies the soil profile described above (see Section I-I' on Figure 14).

3 SEDIMENT PROPERTIES

The geotechnical properties of the sediments used in this analysis were based on the results of relevant PDI sampling available to date (i.e., through Phase IV). In general, the Lake is considered a net depositional area and, therefore, has likely not undergone any significant erosion that could contribute to over-consolidation of the surface sediments. In addition, there is no evidence to suggest that Lake levels have been significantly lower in the recent past, subjecting the sediments to higher effective stress or event air-drying (i.e., desiccation), which could also result in the surface sediment becoming over-consolidated. Based on these observations, the surface sediments in most areas of the Lake are expected to be normally consolidated. The exception to this is the Solvay waste deposits, which are in an over-consolidated condition from the presence of an "apparent" pre-consolidation pressure (Geosyntec Consultants 2011). The effect of this over-consolidation of the Solvay waste is discussed further below.

The unit weight of the sediments was either measured in the laboratory or derived from measurements of moisture content and specific gravity on numerous samples collected within each remediation area. In general, the bulk density of the natural organic silt sediments ranges from approximately 80 to 90 pounds per cubic foot (pcf) near the surface to approximately 105 to 110 pcf at depth (30 to 50 feet below the mudline). Furthermore, the typical unit weight of the lacustrine deposits (deeper silt and clay layers; Marl) is approximately 96 to 102 pcf. These data indicate considerably higher unit weights than assumed during previous settlement analyses presented in the Feasibility Study (FS), where the unit weight of the organic silt was assumed to range from 74 to 81 pcf. This difference translates into smaller settlement estimates because settlement is a function of the increase in stress due to capping relative to the existing stress. With higher unit weights, the existing stress is larger and, therefore, the ratio of increased stress to existing stress is smaller.

The consolidation characteristics of the sediments were based on the results of numerous consolidation tests performed on samples collected during the PDI, including traditional oedometer tests (in accordance with American Society for Testing and Materials [ASTM] Method D2435) conducted on samples from Remediation Areas B, C, and D, as well as numerous seepage-induced consolidation (SIC) tests conducted on samples from all remediation areas.

Oedometer test samples were collected from sample intervals ranging from 10 feet to nearly 50 feet below the mudline representing the major geologic strata in Remediation Areas B and C (primarily silt, clay, and Marl). Attachment A provides a complete summary of the consolidation test results and index properties for the oedometer test samples.

The sample selection process for SIC testing included a review of index properties for a given stratum followed by establishing the range of characteristics that would be representative of that stratum. SIC testing was performed on samples collected from all major geologic strata including Solvay waste, silt, Marl, clay, and silt/sand ranging in depth from surface (beginning at mudline) to 20 feet below the mudline. Finally, samples were selected for testing to represent the range of index properties within each stratum. Attachment A contains a summary of the oedometer and SIC consolidation test results along with index test results for each sample.

The ranges of cases analyzed in the settlement evaluation presented herein included both SIC and oedometer test data from the various strata. Neither the SIC or oedometer test is preferred over the other; each test has its advantages and applicability to certain sediment conditions and sampling techniques. One advantage of the SIC test is the ability to apply relatively small loads in a controlled manner to very soft sediments. The SIC test also provides a mathematical equation describing the consolidation characteristics (void ratio and permeability) as a function of stress. In addition, disturbed samples collected from vibracore samples can be used for SIC testing since all samples are homogenized and processed into a slurry prior to testing, whereas conventional oedometer tests are typically conducted on an undisturbed sample collected using a Shelby tube. However, the SIC test does not allow for determination of the pre-consolidation pressure, which can be used to assess the consolidation state (e.g., normally consolidated versus over-consolidated), since the initial sample is disturbed. The conventional oedometer can be used for this purpose,

As discussed above, the Solvay waste deposits are in an over-consolidated condition from the presence of an “apparent” pre-consolidation pressure. Since the SIC test does not allow complete definition of the stress/strain relationship, the over-consolidation ratio (OCR) cannot be accounted for in settlement estimates using the SIC parameters. However, the fact that the OCR was not accounted for in settlement estimates using SIC is not expected to significantly affect the total predicted settlement. This is due to the fact that the thickness of the Solvay waste deposits in Remediation Area B and Remediation Area C is limited to approximately 5 to 20 feet.

In order to assess the variability in settlement estimates when using SIC versus oedometer test data, a sensitivity analysis was performed. Use of oedometer parameters and SIC parameters for sediments from a similar geologic unit (e.g., two samples from the Solvay waste or two samples from the marl unit) resulted in similar total predicted settlement estimates. This sensitivity analysis using the samples from the Solvay Waste ignored the effects of apparent pre-consolidation, as discussed above.

The results of the standard oedometer test can be interpreted to determine the compressibility characteristics of the sample, as follows:

$$C_c = \frac{e_1 - e_2}{\log \sigma'_2 - \log \sigma'_1} \qquad (3\text{-}1)$$

where:

C_c = compression index

e = void ratio

σ' = effective stress

The SIC test is used to develop a relationship between effective stress, void ratio, and permeability through a set of parameters (A, B, C, D, and Z) that define the compressibility and hydraulic conductivity of the sediments given by the following expressions:

$$\text{Compressibility: } e = A\,(\sigma' + Z)^B \qquad (3\text{-}2)$$

$$\text{Hydraulic Conductivity: } k = C\,e^D \qquad (3\text{-}3)$$

where:

e = void ratio

σ' = effective stress

k = hydraulic conductivity

A, B, C, D, and Z = coefficients determined through the SIC test; dependent on the system of units and presented in Attachment A for International System of Units (SI units)

The properties of the cap materials were selected based on typical sand and gravel soils placed using either mechanical or hydraulic techniques. With these assumptions, the total unit weight of the cap materials was assumed to be approximately 120 pcf.

4 SETTLEMENT ANALYSIS

The compressibility and hydraulic conductivity relationships defined above were used to estimate the amount and rate of primary consolidation expected after the placement of a subaqueous cap. Geotechnical index tests were used to estimate a secondary compression index for the site sediments, which was used in conjunction with the results of several representative primary consolidation analyses to generate an estimated range of secondary compression settlement (see Section 4.3).

4.1 Cap-Induced Load Estimates

The change in stress (i.e., load) resulting from the remedial construction was estimated for each of the cases analyzed with consideration of the reduction in stress from the planned dredging and increase in stress resulting from the cap placement. In areas where dredging will be performed prior to cap placement, the reduction in stress on the subsurface sediments was calculated using the thickness of the dredge cut and the unit weight of the material to be dredged (ranging from approximately 80 to 110 pcf, depending on the material type). The increase in effective stress on the existing or post-dredge sediment surface resulting from the placement of the capping materials was computed using the thickness of the cap and the total unit weight of the capping materials (assumed to be 120 pcf for all caps). Cap thicknesses (and corresponding dredge depths) used in the consolidation settlement calculations included reasonable estimates of over-placement for constructability (i.e., mean over-placement) except in Remediation Area C, where cap thicknesses (and corresponding dredge depths) are based on maximum over-placement, as discussed in Appendix F of the Draft Final Design. It should be noted that the unit weight of the capping materials is approximately 1.1 to 1.5 times larger than the unit weight of the dredge material. Therefore, for a scenario where the dredge depth matches the cap thickness (i.e., no net change in mudline elevation), some amount of settlement would still be predicted because there would be a net increase in stress on the existing sediments.

For cases where a net increase in stress is computed based on the dredge and cap thicknesses, the stress increase was assumed to be constant with depth due to the large spatial extent of the placed caps. This assumption likely results in slightly conservative (over-prediction) estimates of the cap-induced settlement along the very edges of the caps. The change in stress resulting from dredging (where applicable) and subsequent cap placement was used to compute settlement in accordance with the methodology summarized below.

4.2 Settlement Magnitude from Primary Consolidation

The primary consolidation settlement within each geologic layer was estimated using the assumed subsurface profiles described in Section 2 for each remediation area and the equations below. Each layer shown in the subsurface profile was divided into ten equal sub-layers, and the net increase in effective stress (and resulting change in void ratio) for each sub-layer was computed based on the increased stress due to the assumed unit weight and thickness of capping material reduced by the unit weight and thickness of the in situ material dredged. The total settlement for a given profile was then estimated as the sum of the settlement of each sub-layer.

Using oedometer test results (see Attachment B for example calculation), settlement was estimated using the following equation:

$$\Delta H = H \frac{C_c}{1+e_o} \log\left(\frac{\sigma'_o + \Delta\sigma'}{\sigma'_o}\right) \tag{4-1}$$

Using SIC test data (see Attachment B for example calculation), settlement was estimated using the following equation:

$$\Delta H = H \frac{e_o - e_f}{1+e_o} \tag{4-2}$$

where:

ΔH	=	settlement of layer
H	=	initial thickness of layer
σ'_o	=	initial effective stress prior to cap placement at mid-height of layer
$\Delta\sigma'$	=	change in effective stress as a result of cap placement at mid-height of layer

e_o = initial void ratio at effective stress of existing conditions (as predicted using consolidation results)

e_f = final void ratio after primary consolidation (as predicted using consolidation test results)

In the cases where SIC data were used to estimate the settlement of a layer, the initial and final void ratios used in equation 4-2 for a given increase in stress were computed using equation 3-2, which defines the relationship between void ratio and stress, as determined through SIC testing. Attachment B provides a detailed step-by-step example calculation of the settlement estimate using both oedometer and SIC test data.

Based on the field investigations and subsequent lab testing conducted as part of the PDI, some of the geologic units are characterized by a range of thicknesses and/or a range of physical properties over a given remediation area. For instance, laboratory consolidation tests were conducted on multiple samples collected from the same geologic unit, indicating varying compressibility and/or permeability. As indicated previously, the SIC test samples were selected to be representative of the anticipated range of parameters for a given stratum. In order to assess the range of settlement estimates resulting from these observed variations, several "cases" were evaluated for each remediation area. Each case used a unique set of input parameters (e.g., results of laboratory testing on a given sample), and a unique settlement estimate was developed for each case. The range of results for multiple cases within a given remediation area was tabulated, as summarized in Table 1. The example calculation presented in Attachment B represents a single case, and a summary of modeling inputs and results is provided in Attachment C. A complete set of all calculations is provided in digital form as an attachment to this memorandum (see attached compact disc).

4.3 Settlement Magnitude from Secondary Compression

Settlement due to long-term plastic adjustment of the fabric of the soils under constant effective stress (i.e., secondary compression) was evaluated for this analysis. The presence of soft surficial sediments generally warranted the use of SIC test results for estimating primary settlement; however, SIC tests do not provide direct measurements of secondary compression parameters. Therefore, correlations to index properties (Bowles 1996; Holtz and Kovacs

1981) were used in lieu of laboratory-derived consolidation parameters for estimating the secondary compression index properties. Modified secondary compression indices are summarized in Attachment C for each geologic layer and range from 0.002 to 0.07. The modified secondary compression index is related to the secondary compression index by the following equation:

$$c_{\alpha\varepsilon} = \frac{c_{\alpha}}{1+e_f} \quad (4\text{-}3)$$

where:

$c_{\alpha\epsilon}$	=	modified secondary compression index
c_{α}	=	secondary compression index
e_f	=	final void ratio after primary consolidation (as predicted using consolidation test results)

Based on this modified secondary compression index, the magnitude of secondary compression settlement will typically be considerably less than the estimated primary consolidation settlement. Secondary compression was estimated by the following equation:

$$\delta_s = c_{\alpha\varepsilon} H \log\left(\frac{t}{t_p}\right) \quad (4\text{-}4)$$

where:

δ_s	=	estimated settlement due to secondary compression
H	=	initial thickness of layer
t	=	time after application of load
t_p	=	time required to complete consolidation settlement; in theory, this is infinite but it is assumed to occur when 90 percent of the primary consolidation is complete

Similar to primary consolidation, secondary compression within each geologic layer was estimated using the assumed subsurface profiles described in Section 2. Secondary compression settlements were estimated for each module and remediation area across the site, taking into account the varied subsurface geology and variety of dredging and capping situations in each habitat module. For this analysis, secondary compression settlement was estimated during a 30-year period following cap construction. The results of the analysis indicate that secondary compression settlement across the site is estimated to range between 0 and 23 inches with an average of approximately 6 inches, as summarized in Table 1. The wide range of secondary compression estimates is due to variability observed in the explorations and the corresponding geologic profiles used for this analysis. The minimum and maximum ends of this range represent the extremes evaluated in a range of scenarios. It is expected that secondary compression for most areas will be closer to the average than the minimum and maximum.

As discussed above, the modified secondary compression indices utilized in the secondary settlement analysis for the non-ILWD areas were based on correlations with geotechnical index properties because the SIC test does not allow for direct measurement in the laboratory. These correlation-based values were compared with laboratory-derived values for the Solvay Waste within the ILWD. In general, the correlation-based values appear to be within the range of the laboratory data that have a stress ratio of approximately 1 (i.e., normally consolidated, as was assumed for the non-ILWD settlement analysis). The laboratory values for sediments with a stress ratio less than 1 (i.e., over-consolidated as assumed for the ILWD) were generally lower than the correlation-based values. Therefore, a sensitivity analysis was performed for Remediation Area B using lower modified secondary compression values from ILWD samples. This analysis indicated that the lower values generally did not significantly impact the secondary settlement estimates (generally less than 1 inch change in the predicted secondary settlement).

Table 1
Estimated Cap-Induced Settlement

Remediation Area Habitat Module (Water Depth Range)	Cap Thickness [a] (feet)	Dredge Depth [a] (feet)	Estimated Consolidation After 2 Years (inches)	Estimated Total Primary Consolidation (inches)	Estimated Time to Reach 90% Consolidation (years)	Estimated Total Secondary Compression [b] (inches)	Estimated Total Settlement [c] (inches)
Remediation Area A							
Module 1 (-20 to -30 feet)	2.0	0	9 to 12	9 to 12	0.3 to 2	4 to 6	13 to 18
Module 2A (-7 to -20 feet)	2.5 to 3	0	10 to 16	11 to 17	0.3 to 2	4 to 5	15 to 22
Module 3A (-3 to -7 feet)	3.5	0.5 to 5	1 to 17	2 to 18	0.3 to 3	4 to 5	5 to 23
Module 3A (-2 to -3 feet)	4.125	0.5 to 4.5	5 to 19	6 to 20	0.4 to 3	4 to 5	10 to 25
Module 5A and 6A (+1 to -2 feet)	4.125 to 4.375	0.5 to 3.5	7 to 19	7 to 20	0.4 to 3	3 to 5	11 to 25
Remediation Area B							
Modules 1 and 2 (-10 to -30 feet)	3.0	0	9 to 26	16 To 32	1 to >30	0 to 23	22 to 31
Module 2 (-7 to -10 feet)	3.0	0	9 to 26	16 to 32	1 to >30	0 to 23	22 to 51
Module 3A (-4 to -7 feet)	3.5	1 to 5.25	1 to 21	4 to 26	1 to >30	0 to 23	7 to 45
Module 3A (-2 to -3 feet)	4.375	1 to 5.25	1 to 28	7 to 35	1 to >30	0 to 23	9 to 52
Module 5A (-0.5 to -2 feet)	4.375	3.75 to 5.5	0 to 26	5 to 33	1 to >30	0 to 23	8 to 51
Remediation Area C							
Modules 1 and 2 (-10 to -30 feet)	3.75	0	6 to 24	9 to 29	2 to 6	3 to 7	12 to 35

Remediation Area Habitat Module (Water Depth Range)	Cap Thickness [a] (feet)	Dredge Depth [a] (feet)	Estimated Consolidation After 2 Years (inches)	Estimated Total Primary Consolidation (inches)	Estimated Time to Reach 90% Consolidation (years)	Estimated Total Secondary Compression [b] (inches)	Estimated Total Settlement [c] (inches)
Module 2 (-7 to -10 feet)	3.75	0	6 to 24	9 to 29	2 to 6	3 to 7	12 to 35
Module 3B (-4 to -7 feet)	4.25	0.5 to 8	6 to 24	0 to 30	1 to 6	0 to 7	0 to 36
Module 3B (-2 to -3 feet)	5.5	0.5 to 8	0 to 21	0 to 29	0 to 6	0 to 5	0 to 34
Module 5B (-0.5 to -2 feet)	5.5	3.5 to 6.5	1 to 17	2 to 24	4 to 11	2 to 5	4 to 29
Remediation Area E							
Module 1 (-20 to -30 feet)	2.0	0	13 to 23	15 to 29	1 to 9	7 to 17	25 to 42
Module 2 (-7 to -20 feet)	2.625 to 2.875	0 to 4.5	16 to 28	20 to 36	2 to 9	7 to 17	30 to 43
Module 3B (-3 to -7 feet)	3.5	2.5 to 6.25	2 to 25	6 to 41	0.5 to 28	0 to 23	8 to 46
Module 3B (-2 to -3 feet)	4.375	2 to 4.5	1 to 13	1 to 21	1 to 19	0 to 22	2 to 35
Module 5B (-0.5 to -2 feet)	4.375	2 to 4.5	4 to 15	6 to 23	1 to >30	0 to 22	8 to 37
Module 6B (+1 to -1 feet)	4.375	3 to 5	3 to 11	5 to 18	1 to >30	0 to 22	6 to 32

Notes:

General: Each individual case that was analyzed to create this table is summarized in Attachment C.

a. Cap thicknesses used in this analysis represent mean over-placement allowances.

b. Secondary settlement was evaluated during a 30-year timeframe.

c. The minimum and maximum total settlement values presented in this table are based on the individual cases analyzed and summarized in Attachment C. The range of total settlements presented does not necessarily equate to the sum of the primary consolidation and secondary compression ranges shown.

4.4 Settlement Rate

The rate at which the primary consolidation will occur is dependent on a number of factors including the permeability of the compressible sediment, which is used to calculate the coefficient of consolidation, c_v, along with the change in void ratio caused by the placement of the cap, according to the following relationship:

$$c_v = \frac{k(1+e_o)}{\left(\Delta e / \Delta \sigma'_v\right)\gamma_w} \qquad (4\text{-}5)$$

where:

c_v	=	coefficient of consolidation
k	=	permeability
e_o	=	initial void ratio
Δe	=	change in void ratio caused by placement of the cap
$\Delta\sigma'_v$	=	change in vertical effective stress caused by placement of the cap
γ_w	=	unit weight of water

The coefficient of consolidation is related to a non-dimensional number called the time factor, T_v, which is calculated according to the following equation:

$$T_v = \frac{c_v t}{H_{dr}^2} \qquad (4\text{-}6)$$

where:

T_v	=	time factor
c_v	=	coefficient of consolidation
H_{dr}	=	length of drainage path
t	=	time

The time factor can be calculated for various time intervals for each compressible layer. The time factor is also related to the degree of consolidation (i.e., percent consolidation), U, by the following relationships:

$$\text{For U = 0 to 60\%,} \quad T_v = \frac{\pi}{4}\left(\frac{U\%}{100}\right)^2 \tag{4-7}$$

$$\text{For U > 60\%,} \quad T_v = 1.781 - 0.933\log(100 - U\%) \tag{4-8}$$

By mathematically rearranging these relationships, the degree of consolidation can be estimated from the time factor for a given time as follows:

$$\text{For U = 0 to 60\%,} \quad U\% = 100\sqrt{\frac{4T_v}{\pi}} \tag{4-9}$$

$$\text{For U > 60\%,} \quad U\% = 100 - 10^{\left(\frac{T_v - 1.781}{-0.933}\right)} \tag{4-10}$$

Attachment B provides a detailed step-by-step example calculation of the time rate of settlement estimate.

Table 1 provides a summary of the estimated primary consolidation settlement within habitat modules for each remediation area. In addition, the estimated primary settlement 2 years after cap placement is presented, which has been used to support ongoing habitat planning. Finally, the approximate time to achieve 90 percent of the total primary consolidation is also presented for each case. It should be noted that a range of values is presented in most cases, reflecting the range of soil conditions observed in the field and laboratory.

As noted above, a range of results was estimated for most cases based on varying soil conditions. It should be noted that the time rate of primary settlement is highly dependent on the drainage distance (i.e., the distance that porewater expelled during consolidation must flow to a highly permeable layer, such as a sand/gravel layer) within a particular compressible layer. The time rate of settlement is related to the square of the drainage distance; however, it is often difficult to accurately identify minor sand lenses that may act as drainage layers within a natural deposit using traditional exploration techniques (e.g., geotechnical borings with samples collected every 2.5 or 5 feet). Therefore, time rate of settlement estimates could be overestimated if these drainage layers exist, but were not identified during field investigations.

4.5 Total Settlement Results

In general, results of the settlement analysis indicate that primary consolidation settlements predicted across the whole site could vary from 0 to 28 inches within 2 years of placement and from 0 to 41 inches or more during 30 years. Settlements due to secondary compression may occur and are predicted to range from 0 to 23 inches. Table 1 presents the range of primary and secondary settlements as well as total settlements. It should be noted that evaluation scenarios resulting in maximum primary settlement do not necessarily correspond to the maximum secondary settlement. Therefore, the estimated total settlements presented do not necessarily equate to the sum of the primary consolidation and secondary compression ranges shown. A comprehensive set of consolidation estimates presenting the range in consolidation for varying scenarios are presented in Attachment C.

Primary consolidation from dredging and capping in Remediation Area A is predicted to result in settlements of 2 to 20 inches. Most of this settlement (greater than 90 percent) is expected to occur within the first 3 years after capping. Secondary consolidation from dredging and capping in Remediation Area A is predicted to result in settlements of 3 to 6 inches. Total estimated settlements in Remediation Area A are predicted to vary from 5 to 25 inches in 30 years. The range of primary and secondary consolidation settlements take into account the maximum and minimum dredge cuts, the varying subsurface lithology, and a range of capping thicknesses for each habitat module (see Attachment C for a summary of each individual case analyzed).

Primary consolidation from dredging and capping in Remediation Area B is predicted to result in settlements of 4 to 35 inches. Some of this settlement could take more than 30 years to reach 90 percent consolidation, due to the thickness of the compressible deposit and the lack of observed intermediate drainage layers during field investigations. However, as discussed in Section 4.3, if these intermediate drainage layers do exist, the actual time to reach 90 percent consolidation may be significantly reduced. Secondary consolidation from dredging and capping in Remediation Area B is predicted to result in settlements of 0 to 23 inches. Total estimated settlements in Remediation Area B are predicted to vary from 7 to 52 inches in 30 years. The range of primary and secondary consolidation settlements takes into account the maximum and minimum dredge cuts, the varying subsurface lithology, and a range of capping thicknesses for each habitat module.

Primary consolidation from dredging and capping in Remediation Area C is predicted to result in settlements of 0 to 30 inches. Some of this settlement could require more than 10 years to reach 90 percent consolidation, due to the thickness of the compressible deposit and the lack of observed intermediate drainage layers during field investigations. Similar to the discussion above for Remediation Area B, the actual rate of settlement may be quicker if intermediate drainage layers that were not identified during field investigations actually exist in the field. Secondary consolidation from dredging and capping in Remediation Area C is predicted to result in settlements of 0 to 7 inches. Total estimated settlements in Remediation Area C are predicted to vary from 0 to 36 inches in 30 years. The range of primary and secondary consolidation settlements takes into account the maximum and minimum dredge cuts, the varying subsurface lithology, and a range of capping thicknesses for each habitat module.

Primary consolidation from dredging and capping in Remediation Area E is predicted to result in settlements of 1 to 41 inches. Some of this settlement could take more than 30 years to reach 90 percent consolidation. Similar to the discussion above for Remediation Area B and Remediation Area C, the actual rate of settlement may be quicker if intermediate drainage layers that were not identified during field investigations exist in the field. Secondary consolidation from dredging and capping in Remediation Area E is predicted to result in settlements of 0 to 23 inches. Total estimated settlements in Remediation Area E are predicted to vary from 2 to 46 inches in 30 years. The range of primary and secondary consolidation settlements takes into account the maximum and minimum dredge cuts, the varying subsurface lithology, and a range of capping thicknesses for each habitat module.

The areas of largest settlement across the site are typically in habitat modules 1, 2, and 3B, where thin-cut or no dredging will take place. These areas are typically far from shore in deeper water (3 to 20 feet). Settlements of this magnitude are not expected to have adverse impacts on sediment stability or cap effectiveness given the broad areas over which they will occur and the gently sloping bathymetry of the Lake. In addition, these settlement estimates have been accounted for in assessing post-construction water depths as it relates to habitat planning.

4.6 Differential Settlement

Differential settlements were computed by comparing average total settlements (computed from the scenarios tabulated in Attachment C) between adjacent modules in a given remediation area. Based on these comparisons, differential total settlements (primary and secondary) are estimated to range from 0 to 26 inches, with the greatest differential settlement predicted to occur in Remediation Area E between habitat modules 2 and 3b (see Attachment C). However, in reality the difference in dredging depths, capping thicknesses, subsurface stratigraphy, and geotechnical properties will be gradual and will not immediately change when a boundary of two habitat modules is encountered. Instead, the dredge depths and final surfaces will progressively change along the Lake bottom, and the capping will be naturally graded from one thickness to another. As part of this grading, minimum cap thicknesses and habitat layer thicknesses will be met in all areas. Additionally, the lacustrine natural deposits that comprise the geologic profiles likely will vary gradually as well, from one cross-section to another.

In addition to the gradual variation in natural sediment deposits discussed above, the sand and gravel caps that will be placed are "flexible" and tolerant of significant differential settlements without affecting the cap's functionality or environmental protectiveness. The cap will flow seamlessly from one module to another, sloping along the angle of repose of the cap materials. Furthermore, caps will be constructed with a "run-out" beyond the required limits of capping, where the cap tapers off from its full thickness at the edge of the capping area to zero some distance away. This run-out will prevent excessive differential settlement at the edges of the cap areas.

4.7 Cumulative Porewater Expression

For chemical isolation modeling purposes (see Appendix B of the Intermediate Design Report), a relationship was needed to describe the cumulative flux of porewater associated with settlement into the cap over time. As a simplistic, yet appropriately conservative, approach, the maximum total predicted settlement (including primary and secondary consolidation) for each remediation area was used, along with a representative estimate of the time over which 90 percent of that settlement would occur, to define that relationship. Consistent with the method used to define porewater expression in Remediation Area D (GeoSyntec Consultants 2011), a power function was used to define this conservative time-rate of settlement relationship:

$$F = AT^{B} \tag{4-11}$$

where:

T	=	time
A	=	power-fit parameter
B	=	power-fit parameter
F	=	cumulative flux of porewater

The function was developed for each remediation area (A, B, C, and E) by specifying the fit parameters (A and B) needed to achieve the desired total cumulative porewater flux (which ranged from approximately 20 inches in Remediation Area A to 41 inches in Remediation Area E) and the timeframe over which 90 percent of that flux would occur (which ranged from 3 years in Remediation Area A to 30 years in Remediation Area B) for each area. The durations used in the curves reflect typical lower end (i.e., faster) settlement rates, which are expected to represent a conservative case for this analysis. The total cumulative porewater flux used in the curves reflects the approximate maximums for each remediation area. Figure 17 provides the various relationships for each remediation area used for chemical isolation modeling.

4.8 Consideration of Field Testing Program for Settlement Assessment

A cap test fill is often used to confirm theoretical calculations such as constructability or settlement. A cap test fill was considered to further evaluate/refine the predicted settlement results. A cap test would be required to cover a large area with a cap and may take several years to obtain beneficial results. If a test was to be done, it would need to be in an area near one of the current cross-sections on which the settlement analyses are based, or additional sample collection would be required to correlate with the field test results. The test cap would ideally span over several of the habitat modules and be constructed at a large enough scale to create enough surface pressure to influence the deeper soft soils. It may also be desirable to perform some amount of dredging beforehand in portions of the test area in order to obtain final habitat elevations. Dredging would require disposal and cause potential resuspension issues. A cap test like this would need sufficient monitoring for the results to be useful as well. A cap test fill to evaluate settlement predictions was not considered further, given the time limitations and the potential impacts described above.

5 CONCLUSIONS

This memorandum presents an estimate of the amount of primary and secondary consolidation settlement that may be expected following placement of a subaqueous cap in remediation areas A, B, C, and E of the Lake. In general, the existing sediments within the Lake are expected to undergo consolidation settlement following placement of capping materials. The magnitude of settlement is governed by the thickness of the planned caps and the amount (thickness) of planned sediment removal (dredging) prior to cap placement. In general, as dredge depth increases, the amount of post-cap settlement decreases for a constant cap thickness.

As discussed herein, cap-induced settlement predictions were made for a number of "cases" representative of each habitat module based on varying sediment properties and dredge depths. Because it is not possible to pinpoint specific properties and design conditions for each and every habitat module, a range of settlement predictions are provided that can be used to support estimates of the post-construction (following dredging, capping, and long-term settlement) mudline.

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CAP-INDUCED SETTLEMENT EVALUATION FOR REMEDIATION AREA D

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1. INTRODUCTION

This report presents calculations of the amount and rate of consolidation settlement anticipated after dredging and placement of a subaqueous cap in Remediation Area D of the Onondaga Lake Bottom Site. Specifically, this report presents: (i) the total settlement (including primary settlement and secondary settlement) at the end of 30 years after placement of the cap and at the end of two years for the area with the highest estimated settlement; and (ii) the upward flow rate of consolidation water.

Remediation Area D, which is also referred to as the In-Lake Waste Deposit (ILWD), is shown in Figure 1. Remediation Area D consists predominantly of Sediment Management Unit (SMU) 1 with limited portions of SMUs 2 and 7. The dredging plan and the maximum and minimum cap thicknesses in Remediation Area D are documented in the main text of the Capping, Dredging, and Habitat Design Report.

The remainder of this report presents: (i) subsurface conditions; (ii) material properties; (iii) settlement analysis; and (iv) conclusions.

2. SUBSURFACE CONDITIONS

Extensive pre-design investigations (PDIs) were conducted in the ILWD from 2005 to 2007 to characterize the subsurface conditions. Detailed information regarding the subsurface stratigraphy is presented in a calculation package titled "*Summary of Subsurface Stratigraphy and Material Properties*" (referred to as the ILWD Data Package) for the Stability Evaluation of the ILWD [appendix of the Capping, Dredging, and Habitat Design Report]. In summary, the subsurface stratigraphy primarily consists of the following materials: Solvay waste (SOLW), Marl, Silt and Clay, Silt and Sand, Sand and Gravel, Till, and Shale. In isolated areas of the ILWD, thin silt layers are present over the SOLW.

The subsurface profile of the ILWD was developed based on the elevations of each layer from the boring logs. As explained in the ILWD Data Package, elevations for the deeper surfaces (e.g., bottom of Silt and Clay, bottom of Silt and Sand) that are below the depth of the shallow borings were estimated based on a limited number of deeper borings in the ILWD area. The deeper layers (i.e., Silt and Sand, Sand and Gravel, Till, and Shale) were considered as incompressible layers in the settlement analysis.

For the purpose of the settlement analysis presented herein, Remediation Area D was divided into 12 areas based on the thickness of the SOLW, Marl, and Silt and Clay layers. Representative values of SOLW, Marl, and Silt and Clay thicknesses were selected for settlement analysis in each area. The thin isolated silt layers were assumed to be part of the SOLW because their impact on settlement is expected to be insignificant. The divided areas and selected layer thicknesses for the settlement analyses are presented in Figure 2. The subsurface layer thickness contours are presented in Attachment A of this report. It is noted that the selected subsurface thickness values represent a general estimation of the average thickness of each layer in a particular area. The actual subsurface layer thickness at any point within an area may be higher or lower than the selected value.

3. MATERIAL PROPERTIES

The material properties required for settlement analysis include: (i) unit weight of cap and subsurface materials (i.e., SOLW, Marl, and Silt and Clay); and (ii) consolidation parameters of subsurface materials. For the calculation of upward flow rate of consolidation water, the hydraulic conductivities of the subsurface materials were also needed.

Unit Weight

The unit weight of Cap material was assumed to be 120 pcf in the analysis. The unit weight of SOLW, Marl, and Silt and Clay were assumed to be 81 pcf, 98 pcf and 108 pcf, respectively, as presented in the ILWD Data Package.

Consolidation Parameters

The consolidation parameters needed for settlement analysis are: modified compression index ($C_{c\varepsilon}$), modified recompression index ($C_{r\varepsilon}$), modified secondary compression index ($C_{\alpha\varepsilon}$), and coefficient of consolidation (c_v). These parameters were interpreted from consolidation test data.

Two types of consolidation tests were performed, as follows:

(i) Conventional oedometer test: The conventional oedometer test data can be used to determine all the consolidation parameters needed for settlement analyses. Tests were performed on samples of SOLW, Marl, and Silt and Clay. The test reports are included in Attachment B of this report.

(ii) Seepage-induced consolidation (SIC) test: The SIC tests were completed in general accordance with the method presented by Znidarcic, et al. (1992). The test is run on a disturbed sample that has been slurried. A load is then applied by creating a constant flow rate in the sample. Load is then increased to the maximum desired level after constant flow is reached. The change in void ratio and permeability is measured as the loads are applied. Only the compression index can be calculated based on SIC test data. For Remediation Area D, SIC tests were performed primarily on samples of SOLW. The test results are presented in Phase I and Phase II Pre-Design Investigation Data Summary Report [Parsons 2007 and 2009].

As indicated previously, both tests were performed on samples of SOLW. The rationale for interpreting the $C_{c\varepsilon}$ value of SOLW from only the conventional oedometer test results is as follows:

(i) consolidation curves from conventional oedometer tests indicate an “apparent” pre-consolidation pressure between 1,000 to 3,000 psf, as shown by the solid lines in Figure 3. The slope of the consolidation curve is flatter when the vertical effective stress is less than the “apparent” pre-consolidation pressure as compared to when the vertical effective stress is greater than the “apparent” pre-consolidation pressure. It indicates that the compressibility of SOLW under a small stress condition (i.e., less than 1,000 psf) is less than the compressibility under a higher stress condition (i.e., greater than 1,000 psf). As presented in the ILWD Data Package, the consolidated undrained triaxial tests performed for SOLW during the PDI showed higher undrained shear strength ratios under a small stress condition (i.e., less than 1,000 psf) than under higher stress conditions (i.e., greater than 1,000 psf). This is likely due to the overconsolidated condition of the samples in the lab from the presence of an “apparent” pre-consolidation pressure;

(ii) SIC tests were performed on disturbed samples, and as expected, did not indicate any “apparent” pre-consolidation pressure, as indicated by the dashed lines in Figure 3. It is believed that the disturbance of the sample in the SIC tests changed the structure of the sample, and therefore, the SIC tests did not show the "apparent" pre-consolidation pressure; and

(iii) the vertical effective stress of SOLW in the field before and after capping is less than the "apparent" pre-consolidation pressure. Therefore, the $C_{c\varepsilon}$ value of SOLW should be interpreted from the conventional oedometer test, using the portion of the consolidation curve corresponding to the potential stress condition of SOLW in the field before and after capping (i.e., from 100 to 1,000 psf).

The values interpreted from oedometer tests for $C_{c\varepsilon}$ and $C_{r\varepsilon}$ of SOLW, Marl, and Silt and Clay are presented in Tables 1 through 4. The mean values of $C_{c\varepsilon}$ and $C_{r\varepsilon}$ were used for the settlement analysis in all areas. The interpretation of $C_{\alpha\varepsilon}$ and c_v for SOLW, Marl, and Silt and Clay are presented in Figures 4 through 11. The representative values were used for the settlement analysis.

For sensitivity analyses to evaluate the impact of consolidation parameter uncertainty on calculated settlement, reasonable upper and lower bound values were selected for $C_{c\varepsilon}$, $C_{r\varepsilon}$, $C_{\alpha\varepsilon}$, and c_v. For $C_{c\varepsilon}$ and $C_{r\varepsilon}$, the reasonable upper bound values were selected as the smaller of the calculated "mean plus standard deviation" and the maximum value, and the reasonable lower bound values were selected as the larger of the calculated "mean minus standard deviation" and the minimum value (see Tables 1 through 4). For $C_{\alpha\varepsilon}$ and c_v, reasonable upper and lower bound values were selected based on the variability within the stress range of interest (see Figures 4 through 11).

As presented in the ILWD Data Package, comparison of calculated in-situ vertical effective stresses and the "apparent" pre-consolidation pressures interpreted from oedometer tests indicates that Marl has an OCR of about 1.2, and Silt and Clay is normally consolidated. The analyses presented herein assumed that both Marl and Silt and Clay are normally consolidated. This assumption will lead to slightly higher total settlement estimates.

Hydraulic Conductivity

According to the calculation package titled "*Summary of Subsurface Stratigraphy and Material Properties*" (referred to as the West Wall Data Package) for the Onondaga Lake West Wall Final Design [Geosyntec 2009], the measured hydraulic conductivity of SOLW varies from 4.95×10^{-6} cm/s to 2.78×10^{-5} cm/s. The measured hydraulic conductivity of Silt and Clay varies from 4.9×10^{-8} cm/s to 4.41×10^{-7} cm/s. These values are based on hydraulic conductivity tests performed on samples of SOLW and Silt and Clay from the Wastebed B/Harbor Book (WB-B/HB) area. For the purposes of analysis presented herein, the hydraulic conductivities of SOLW and Silt and Clay were assumed as 1×10^{-5} cm/s and 1×10^{-7} cm/s, respectively. These values are also reasonably consistent (i.e., same order of magnitude) as the values being used in the groundwater upwelling evaluations for the ILWD. The hydraulic conductivity of Marl was assumed the same as for Silt and Clay. Hydraulic conductivities were only used for the calculation of excess pore water pressures at layer interfaces as part of the upward flow of consolidation water calculations. Hydraulic conductivity values ranging from 1×10^{-7} cm/sec to 5×10^{-5} cm/sec have minimum impact on the calculated amount of consolidation water because the hydraulic conductivities only affect the calculation of pore water pressure at the interface between soil layers (refer to Equation 11B presented below). The coefficient of consolidation c_v has significant impact on the calculated amount of consolidation water flow at any given time. The c_v is related to the hydraulic conductivity and compressibility, but was calculated directly based on consolidation tests on ILWD samples.

A summary of the material properties used in the analyses is provided in Table 5. The reasonable upper and lower bound consolidation parameters used in the sensitivity analysis are summarized in Table 6.

4. SETTLEMENT ANALYSIS

4.1 Methodology

Consolidation Settlement

Settlement of the SOLW, Marl, and Silt and Clay was calculated using equations for conventional one-dimensional (1-D) consolidation theory used in geotechnical engineering [Holtz and Kovacs, 1981]. Settlement is caused by the following mechanisms:

- primary compression of the SOLW, Marl, and Silt and Clay due to overburden loading imposed by the cap; and
- secondary compression resulting from the plastic realignment of the fabric (i.e., creep) of SOLW, Marl, and Silt and Clay under the sustained loading.

The general forms of the settlement equations are given below:

Primary Settlement

$$S_p = \mathrm{C}_{\mathrm{r}\varepsilon}\ \mathrm{H}\log\left(\frac{\sigma'_{vo} + \Delta\sigma'_v}{\sigma'_{vo}}\right) \text{ for } \sigma'_{vo} + \Delta\sigma'_v \le \sigma'_p \quad (1)$$

$$S_p = \mathrm{C}_{\mathrm{r}\varepsilon}\ \mathrm{H}\log\left(\frac{\sigma'_p}{\sigma'_{vo}}\right) + \mathrm{C}_{\mathrm{c}\varepsilon}\ \mathrm{H}\log\left(\frac{\sigma'_{vo} + \Delta\sigma'_v}{\sigma'_p}\right) \text{ for } \sigma'_{vo} \le \sigma'_p \text{ and } \sigma'_{vo} + \Delta\sigma'_v > \sigma'_p \quad (2A)$$

$$S_p = \mathrm{C}_{\mathrm{c}\varepsilon}\ \mathrm{H}\log\left(\frac{\sigma'_{vo} + \Delta\sigma'_v}{\sigma'_{vo}}\right) \text{ for } \sigma'_{vo} \ge \sigma'_p \quad (2B)$$

Secondary Settlement

$$S_s = \mathrm{C}_{\alpha\varepsilon}\ \mathrm{H}\log\left(\frac{t_2}{t_1}\right) \quad (3)$$

Total Settlement

$$S = S_p + S_s \quad (4)$$

Where,

S_p = primary settlement;
S_s = secondary settlement;
S = total settlement;
$C_{c\varepsilon}$ = modified compression index;
$C_{r\varepsilon}$ = modified recompression index;
$C_{\alpha\varepsilon}$ = modified secondary compression index;
H = initial thickness of compressible layer;
σ'_{vo} = initial effective overburden stress;
σ'_p = preconsolidation pressure;
$\Delta\sigma'_v$ = increase in effective stress due to the loading;
t_1 = time for completion of primary compression; and
t_2 = time when settlement due to secondary compression is computed (i.e., unless stated otherwise, assumed to be 30 years for this analysis).

The following equations related to the time rate of consolidation were used to calculate t_1:

$$T = \frac{c_v t}{H_{dr}^2} \qquad (5)$$

$$T = \frac{\pi}{4}\left(\frac{U\%}{100}\right)^2 \text{ for U < 60\%} \qquad (6A)$$

$$T = 1.781 - 0.933\log(100 - U\%) \text{ for U > 60\%} \qquad (6B)$$

The completion of primary compression was considered as U = 90%, in accordance with common engineering practice. Based on Equation 6B, T = 0.848 when U = 90%. Therefore, t_1 can be calculated using the following equation:

$$t_1 = 0.848\frac{H_{dr}^2}{c_v} \qquad (7)$$

Where,

T = time factor;
c_v = coefficient of consolidation;
H_{dr} = longest drainage path; and
U = average degree of consolidation.

Upward Flow of Consolidation Water

Cumulative upward flow volume of consolidation water from SOLW, Marl, and Silt and Clay at any time can be calculated as follows for use in cap design:

$$V_t = \sum \left(\left(\frac{P_i \%}{100} \right) \left(\frac{U_{i,t} \%}{100} \right) S_{pi} + \left(\frac{P_i \%}{100} \right) S_{si,t} \right) \tag{8}$$

Where,

V_t = cumulative upward flow volume of consolidation water at time t;
P_i = percentage of thickness of layer i contributing to upward flow of consolidation water;
$U_{i,t}$ = average degree of consolidation for layer i at time t;
S_{pi} = ultimate primary settlement of layer i; and
$S_{si,t}$ = secondary settlement of layer i at time t. For simplicity of calculation, secondary settlement was assumed to start when U = 93% (T ≈ 1), even though in the settlement calculation presented above, U=90% was considered as the completion of primary settlement

Both P and U can be calculated from contours of excess pore water pressure variation with depth for different times (i.e., isochrones). Simpson's rule is used to calculate relative areas from contours of excess pore water pressure, which are used to estimate U at different times. The following governing equation for one-dimensional consolidation can be solved using the finite difference method (FDM) to develop isochrones.

$$\frac{\partial u}{\partial t} = \frac{k}{\gamma_w m_v} \frac{\partial^2 u}{\partial z^2} = c_v \frac{\partial^2 u}{\partial z^2} \tag{9}$$

Where,

u = excess pore water pressure;
t = time;
k = hydraulic conductivity;
γ_w = unit weight of water; and
m_v = coefficient of volume change.

The FDM solution is expressed in terms of the following dimensionless (relative) parameters:

$$\bar{u} = \frac{u}{u_R} \quad (10A)$$

$$\bar{t} = \frac{t}{t_R} \quad (10B)$$

$$\bar{z} = \frac{z}{z_R} \quad (10C)$$

Where,

$\bar{u}$ = dimensionless (relative) excess pore water pressure;
u_R = maximum excess pore water pressure induced by the loading;
$\bar{t}$ = dimensionless (relative) time;
t_R = time for 93% consolidation, calculated as $t_R = \frac{z_R^2}{c_v}$;
$\bar{z}$ = relative depth; and
z_R = maximum depth of all layers modeled.

The finite difference nodes are presented in Figure 12. The FDM equations for a node in a homogeneous layer and at a layer interface are presented in Equations 11A and 11B, respectively.

$$\bar{u}_{0,\bar{t}+\Delta\bar{t}} = \frac{\Delta\bar{t}}{(\Delta\bar{z})^2}\left(\bar{u}_{1,\bar{t}} + \bar{u}_{3,\bar{t}} - 2\bar{u}_{0,\bar{t}}\right) + \bar{u}_{0,\bar{t}} \quad (11A)$$

$$\bar{u}_{0,\bar{t}+\Delta\bar{t}} = A\frac{\Delta\bar{t}}{\left(\Delta\bar{z}\right)^2}\left(B\bar{u}_{1,\bar{t}} + C\bar{u}_{3,\bar{t}} - 2\bar{u}_{0,\bar{t}}\right) + \bar{u}_{0,\bar{t}} \qquad (11B)$$

The parameters referred to as A, B, and C can be calculated using the following equations (where k_1 and k_2 are hydraulic conductivities of the top and bottom layers, respectively, and c_{v1} and c_{v2} are coefficients of consolidation of the top and bottom layers, respectively):

$$A = \frac{1 + \frac{k_2}{k_1}}{1 + \left(\frac{k_2}{k_1}\right)\left(\frac{c_{v1}}{c_{v2}}\right)} \qquad (12A)$$

$$B = \frac{2k_1}{k_1 + k_2} \qquad (12B)$$

$$C = \frac{2k_2}{k_1 + k_2} \qquad (12C)$$

For numerical stability of the FDM implementation, the following should be satisfied:

$$\frac{\Delta\bar{t}}{\left(\Delta\bar{z}\right)^2} < 0.5 \qquad (13)$$

4.2 Dredge Cut Depths and Cap Thicknesses Considered

As documented in the main text of the Capping, Dredging, and Habitat Design Report, the proposed dredging depth in Remediation Area D, excluding hot spot removal, is between 0 m and 3 m (or 10 ft). The proposed cap has a thickness of approximately 3 to 4.5 ft assuming average over placement and a maximum thickness of 5.5 ft for maximum overplacement. In the settlement analysis performed herein, dredging depths of 0 ft, 3 ft, 6 ft, and 10 ft, and cap thicknesses of 3 ft, 4 ft, and 5.5 ft were considered for each of the 12 areas identified in Figure 2.

4.3 Settlement Calculations

Settlement Analysis

Cap-induced settlement analyses were performed for each of the 12 areas for all combinations of the considered dredging depths and cap thicknesses. The calculated settlement includes the primary settlement and secondary settlement that will occur within 30 years of cap placement. The following assumptions were made for the purposes of the analyses presented herein:

- Both Marl and Silt and Clay were considered as one layer in the consolidation rate calculation (i.e., the average degree of consolidation at the end of 30 years and the time needed to reach 90% primary consolidation) because their c_v values are comparable. The c_v value of Silt and Clay was applied to this combined layer due to the relatively larger thickness of Silt and Clay compared to Marl.

- The SOLW layer was considered to be a singly drained layer. The combined Marl and Silt and Clay layer was assumed to be a doubly drained layer. The c_v value of SOLW is much larger than that for the combined layer and, therefore, the excess pore water pressure in the SOLW dissipates (in the upward direction) much faster than the excess pore water pressure in the combined layer. The combined layer behaves similar to a doubly drained layer after most of the excess pore water pressure in the SOLW has dissipated. This assumption will be validated in Section 4.4.

- Secondary compression starts when 90% of the primary consolidation is reached.

The settlement calculations were performed using EXCEL® spreadsheets. An example calculation is shown in Attachment C. Analysis results are presented in Figure 13. For each area, the cap-induced settlement can be read or interpolated from the charts for a given proposed dredging depth and cap thickness that is within the range of the values evaluated.

An additional cap-induced settlement analysis was performed to evaluate the settlement that will occur within two years after cap placement. Area 3 was selected for this analysis because it is the area with the largest calculated settlement for the different combinations of dredging depth and cap thickness. The settlement analysis results for Area 3 for a 2-year period are presented in Figure 14.

Sensitivity Analysis

Sensitivity analyses were performed to evaluate the impact of variability in consolidation parameters on the calculated settlement. Analyses were performed for the condition with a 2-m (6.6 ft) dredge and 4-ft cap thickness, which represents the average dredge depth and cap thickness for Remediation Area D. The reasonable upper and lower bound values presented in Table 6 were used to calculate the potential upper bound and lower bound settlement magnitude. In the calculation of potential upper bound of settlement magnitude, Marl and Silt and Clay were considered as one layer in the consolidation rate calculation and the c_v value of Silt and Clay was applied to this layer. In the calculation of potential lower bound of settlement magnitude, all of the SOLW, Marl, and Silt and Clay were assumed as one doubly drained layer for the consolidation rate calculation because the reasonable lower bound c_v values of the three materials are comparable. The c_v value of Silt and Clay was applied to this combined layer.

Based on settlement calculations presented in Figure 13 for a 2-m dredge and 4-ft cap thickness condition, the settlement ranges from 0.5 ft to 0.7 ft. The sensitivity analysis results indicated that the settlement in Remediation Area D may range from 0.2 ft to 1.0 ft for a 2-m dredge and 4-ft cap thickness condition.

4.4 Cumulative Upward Consolidation Water Flow

After cap placement, water stored in the voids of the subsurface soil will be squeezed out due to the consolidation of the subsurface soil. Part of the water will flow upward. For the purpose of the analyses presented herein, the upward flow rate of consolidation water was evaluated for the condition with a 2-m (6.6 ft) dredge and 4-ft cap thickness, which represents the average dredge depth and cap thickness for Remediation Area D. Furthermore, the upward flow rate of consolidation water was also evaluated for the condition of no dredging and a 3-ft cap thickness. These analyses were performed using average/representative parameters. The following assumption was made for this analysis:

- Since Marl and Silt and Clay have comparable c_v values, they were modeled as one layer. The c_v value of Silt and Clay was applied to this combined layer. The SOLW layer was modeled separately because its c_v value is much higher than the value for the Marl and Silt and Clay.

Based on this assumption, the analysis of upward flow rate of consolidation water was performed as follows:

(i) calculate the variation of excess pore water pressure with depth and time, according to the subsurface conditions and material properties; and plot the isochrones of excess pore water pressure;

(ii) based on calculated excess pore water pressures, determine the average degree of consolidation (U) of SOLW and the combined layer at different times;

(iii) based on calculated excess pore water pressures, determine the percentage of consolidation water flowing upward (P) for the SOLW and the combined layer (results indicated P is 100% for SOLW and 50% for the combined layer);

(iv) calculate the ultimate primary settlement of SOLW and upper half of the combined layer; and

(v) calculate the primary and secondary settlement of SOLW and upper half of the combined layer at selected times. The total settlement is the cumulative upward consolidation water flow at the selected times.

The calculations were performed using EXCEL® spreadsheets. An example of the calculation is shown in Attachment C. The calculated cumulative consolidation water variations with time for Areas 1 and 7 are presented in Figure 15. These two areas were selected because they have the smallest and largest calculated settlement corresponding to the condition with a 2-m dredge and 4-ft cap thickness and hence, likely to have the largest and smallest cumulative consolidation water flow, respectively, for that condition. Areas 4, 8, 9, and 10 were selected because they are representative of the no dredge condition outlined in the Capping, Dredging, and Habitat Design Report. The cumulative consolidation water variations with time for these areas are presented in Figure 16. The calculated excess pore water pressure isochrones for Areas 1 and 7 are provided in Attachment D of this report. These isochrones indicated that the excess pore water pressure in SOLW dissipates much faster than in the combined layer. After most of the excess pore water pressure in the SOLW has dissipated, the combined layer behaves similar to a doubly drained layer. Similar behavior was observed for Areas 4, 8, 9, and 10, as well. The approach described above is considered to be sufficiently conservative because areas with less than 2 m of dredging and cap thickness greater than 3 ft only represent a small portion (i.e., approximately 0.6 acres) of the 100-acre ILWD. Additional sensitivity analyses were performed to calculate the upward flow rate of consolidation water using upper bound and lower bound consolidation parameters, as provided in Attachment E of this report. Selection of these upper and lower bound values is described above in Section 3 material properties.

5. CONCLUSIONS

This report presents analyses performed to calculate the amount of consolidation settlement and the upward flow rate of consolidation water that may be expected following dredging and placement of a subaqueous cap in Remediation Area D. Based on the results of the analysis, the following conclusions can be made:

- The subsurface soils are expected to undergo consolidation settlement following placement of the cap. The magnitude of settlement largely depends on the dredging depth and cap thickness. The settlement increases when dredging depth decreases or cap thickness increases.

- The subsurface profiles have limited influence on the calculated settlement. The calculated settlements in all areas are in the range of 0 to 1.5 ft for a 30-year period using average or representative consolidation/compressibility parameters. The calculated settlements are in the range of 0 to 0.7 ft for a 2-year period in the area that has the largest calculated settlement for a 30-year period (i.e., Area 3).

- The calculated consolidation settlement is not very sensitive to the consolidation or compressibility parameters. A sensitivity analysis indicates that using reasonable upper bound values for consolidation/compressibility parameters increases the maximum settlement from 0.7 ft to 1.0 ft for the case with 2-m dredging and a 4-ft cap thickness over a 30-year period.

- Upward flow of consolidation water is expected after placement of the cap. The flow rate will be highest when the cap is placed and will decrease with time. For an average condition (i.e., 2-m dredge and 4-ft cap thickness) using average or representative consolidation/compressibility values, a total cumulative consolidation water of approximately 0.4 ft to 0.5 ft is expected within 30 years of cap material placement. For the no dredge and 3 ft cap condition, a total cumulative consolidation water of approximately 0.6 to 0.7 ft is expected within 30 years of cap material placement. Based on these results, the cumulative consolidation water flow variation for Area 9 has the maximum total flow, and therefore, is used for cap performance modeling.

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TABLES

Table 1. $C_{c\varepsilon}$ and $C_{r\varepsilon}$ from Oedometer Tests for SOLW.

Sample Location ID	Depth (ft)	Initial Void Ratio e_0	C_c	C_r	$C_{c\varepsilon}$ [1]	$C_{r\varepsilon}$ [1]
OL-STA-10025	7-9	4.53	0.18	0.02	0.033	0.0038
OL-STA-10026	7-9	3.17	0.14	0.03	0.033	0.0065
OL-STA-10019	12.5-14.5	4.24	0.02	0.01	0.004	0.0023
OL-STA-10023	13-15	3.38	0.17	0.02	0.039	0.0054
OL-STA-10024	15-17	3.08	0.16	0.02	0.039	0.0047
OL-STA-10024	30-32	4.93	0.10	0.03	0.016	0.0054
OL-STA-10014	34.5-36.5	3.05	0.19	0.01	0.047	0.0036
Mean Value					0.030	0.0045
Maximum Value					0.047	0.0065
Minimum Value					0.004	0.0023
Standard Deviation					0.015	0.0014
Mean plus Standard Deviation					0.045	0.0059
Mean minus Standard Deviation					0.015	0.0031

Notes:

[1]. $C_{c\varepsilon}$ and $C_{r\varepsilon}$ are modified compression index and recompression index, respectively. They are calculated as follows: $C_{c\varepsilon} = C_c / (1+e_0)$ and $C_{r\varepsilon} = C_r / (1+e_0)$.

[2]. C_c and $C_{c\varepsilon}$ values correspond to low stress range only.

Table 2. $C_{c\varepsilon}$ and $C_{r\varepsilon}$ from Oedometer Tests for Marl.

Sample Location ID	Depth (ft)	Initial Void Ratio e_0	C_c	C_r	$C_{c\varepsilon}$ [1]	$C_{r\varepsilon}$ [1]
OL-STA-20001	20-22	1.87	0.37	0.02	0.127	0.0082
OL-STA-20007	23-25	1.89	0.41	0.03	0.142	0.0113
OL-STA-20004	36.6-38.6	0.90	0.16	0.02	0.083	0.0103
				Mean Value	0.117	0.0099
				Maximum Value	0.142	0.0110
				Minimum Value	0.083	0.0080
				Standard Deviation	0.031	0.0016
				Mean plus Standard Deviation	0.148	0.0115
				Mean minus Standard Deviation	0.087	0.0083

Note:
[1]. $C_{c\varepsilon}$ and $C_{r\varepsilon}$ are modified compression index and recompression index, respectively. They are calculated as follows: $C_{c\varepsilon} = C_c / (1+e_0)$ and $C_{r\varepsilon} = C_r / (1+e_0)$.

Table 3. $C_{c\varepsilon}$ and $C_{r\varepsilon}$ from Oedometer Tests for Silt and Clay in SMU 1.

Sample Location ID	Depth (ft)	Initial Void Ratio e_0	C_c	C_r	$C_{c\varepsilon}$ [1]	$C_{r\varepsilon}$ [1]
OL-STA-10013	41-43	1.60	0.51	0.06	0.195	0.0228
OL-STA-10018	48-50	1.06	0.36	0.03	0.175	0.0151
OL-STA-10023	50-52	1.94	0.73	0.07	0.248	0.0255
OL-STA-10026	50-52	1.99	0.69	0.09	0.229	0.0297
OL-STA-10025	52-54	1.88	0.65	0.08	0.227	0.0295
OL-STA-10022	64-66	1.85	0.70	0.06	0.246	0.0212
OL-STA-10024	64-66	1.81	0.57	0.09	0.204	0.0330
OL-STA-10017	28-30	2.74	0.94	0.13	0.252	0.0353
OL-STA-10108	64-66	1.91	0.74	0.06	0.254	0.0206
OL-STA-10108	68-70	1.86	0.58	0.05	0.203	0.0175
				Mean Value	0.223	0.0250
				Maximum Value	0.254	0.0353
				Minimum Value	0.175	0.0151
				Standard Deviation	0.028	0.0067
				Mean plus Standard Deviation	0.251	0.0317
				Mean minus Standard Deviation	0.196	0.0183

Note:

[1]. $C_{c\varepsilon}$ and $C_{r\varepsilon}$ are modified compression index and recompression index, respectively. They are calculated as follows: $C_{c\varepsilon} = C_c / (1+e_0)$ and $C_{r\varepsilon} = C_r / (1+e_0)$.

Table 4. $C_{c\varepsilon}$ and $C_{r\varepsilon}$ from Oedometer Tests for Silt and Clay in SMU 2.

Sample Location ID	Depth (ft)	Initial Void Ratio e_0	C_c	C_r	$C_{c\varepsilon}$ [1]	$C_{r\varepsilon}$ [1]
OL-STA-20007	38.6-40.6	1.33	0.49	0.05	0.210	0.0222
OL-STA-20001	44.9-46.9	0.95	0.26	0.04	0.134	0.0223
OL-STA-20018	47-49	0.91	0.23	0.02	0.119	0.0090
Mean Value					0.154	0.0179
Maximum Value					0.210	0.022
Minimum Value					0.119	0.009
Standard Deviation					0.049	0.0076
Mean plus Standard Deviation					0.203	0.0255
Mean minus Standard Deviation					0.106	0.0102

Note:

[1]. $C_{c\varepsilon}$ and $C_{r\varepsilon}$ are modified compression index and recompression index, respectively. They are calculated as follows: $C_{c\varepsilon} = C_c / (1+e_0)$ and $C_{r\varepsilon} = C_r / (1+e_0)$.

Table 5. Summary of the Material Properties used in Analysis.

Materials	Unit Weight (pcf)	Consolidation Parameters				Hydraulic Conductivity (cm/s)
		$C_{c\varepsilon}$	$C_{r\varepsilon}$	$C_{\alpha\varepsilon}$	c_v (ft^2/d)	
Cap	120	N/A	N/A	N/A	N/A	N/A
SOLW	81	0.030[1]	0.0045	0.0011	3.500	1×10^{-5}
Marl	98	0.117	0.0099	0.0050	0.090 (SMU 1) 0.100 (SMU 2)[2]	1×10^{-7}
Silt and Clay (SMU 1)	108	0.223	0.0250	0.0100	0.090	1×10^{-7}
Silt and Clay (SMU 2)	108	0.154	0.0179	0.0050	0.100	1×10^{-7}

Notes:

[1]. $C_{c\varepsilon}$ value corresponds to low stress range only.

[2]. The interpreted c_v of Marl is 0.135 ft^2/d as presented in Figure 9. However, for the purpose of analysis, the c_v of Marl was assumed to be the same as Silt and Clay (i.e., 0.09 and 0.1 ft^2/d in SMUs 1 and 2, respectively) in settlement calculations, as presented in Section 4.3.

Table 6. Selected Reasonable Upper and Lower Bound Values for Consolidation Parameters.

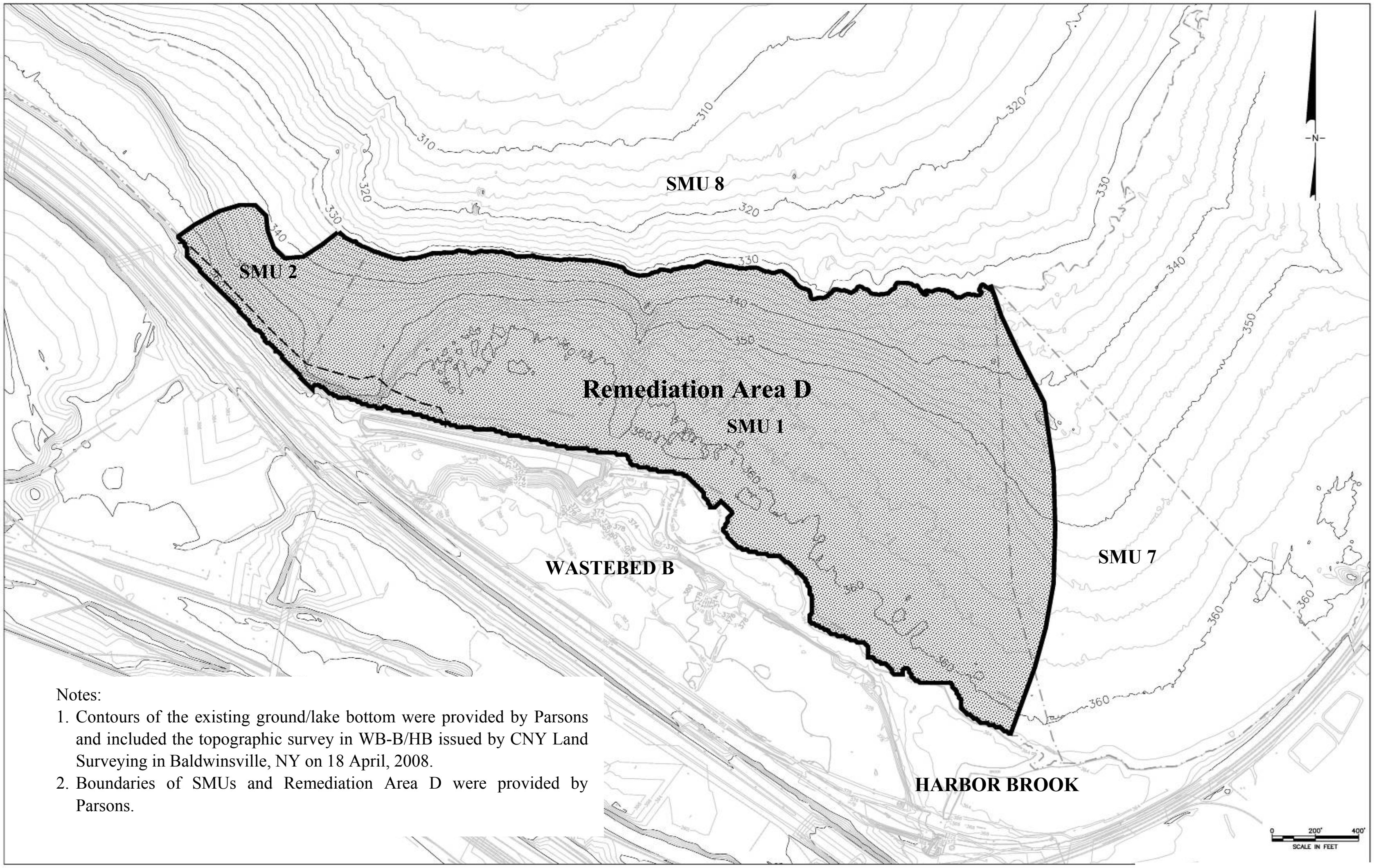
Material	$C_{c\varepsilon}$	$C_{r\varepsilon}$	$C_{\alpha\varepsilon}$	c_v (ft^2/d)
Selected Reasonable Upper Bound Values				
SOLW	0.045	0.0059	0.0030	7.000
Marl	0.142	0.0110	0.0080	0.130 (SMU 1) 0.230 (SMU 2)[1]
Silt and Clay (SMU 1)	0.251	0.0317	0.0130	0.130
Silt and Clay (SMU 2)	0.203	0.0220	0.0070	0.230
Selected Reasonable Lower Bound Values				
SOLW	0.015	0.0031	0.0003	0.050[2]
Marl	0.087	0.0083	0.0025	0.050[2]
Silt and Clay (SMU 1)	0.196	0.0183	0.0070	0.050
Silt and Clay (SMU 2)	0.119	0.0102	0.0040	0.050

Notes:

[1]. The interpreted reasonable upper bound value of c_v of Marl is 0.15 ft^2/d, as presented in Figure 9. However, for the purpose of analysis, the reasonable upper bound value of c_v of Marl was assumed the same as Silt and Clay (i.e., 0.13 and 0.23 ft^2/d in SMUs 1 and 2, respectively) in the settlement calculations, as presented in Section 4.3.

[2]. The interpreted reasonable lower bound values of c_v of SOLW and Marl are 0.1 and 0.12 ft^2/d, respectively, as presented in Figures 8 and 9. However, for the purpose of analysis, the reasonable lower bound values of c_v of SOLW and Marl were assumed the same as Silt and Clay (i.e., 0.05 ft^2/d) in the settlement calculations, as presented in Section 4.3.

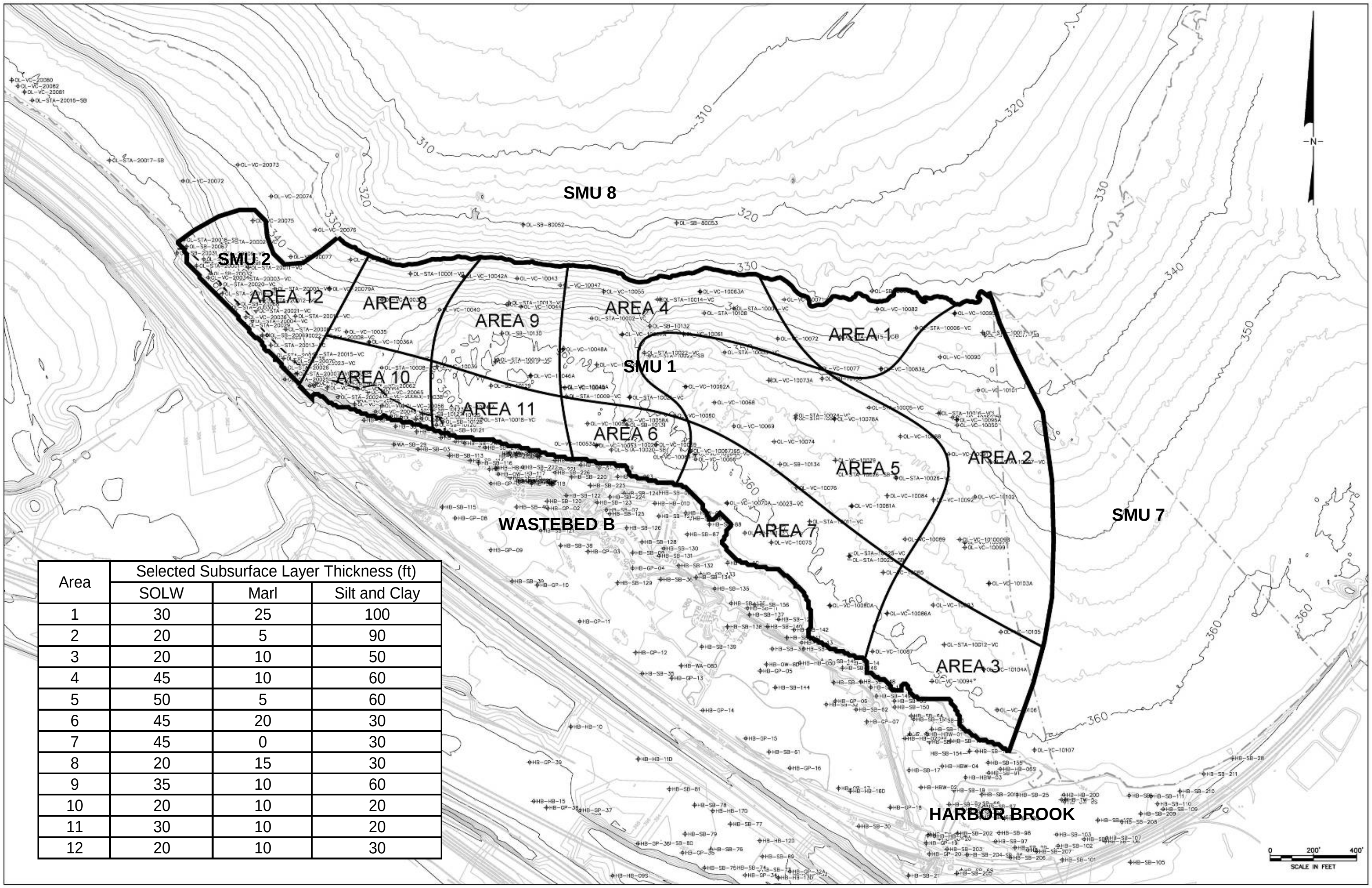
FIGURES



Notes:

1. Contours of the existing ground/lake bottom were provided by Parsons and included the topographic survey in WB-B/HB issued by CNY Land Surveying in Baldwinsville, NY on 18 April, 2008.
2. Boundaries of SMUs and Remediation Area D were provided by Parsons.

Figure 1. Remediation Area D.



Area	Selected Subsurface Layer Thickness (ft)		
	SOLW	Marl	Silt and Clay
1	30	25	100
2	20	5	90
3	20	10	50
4	45	10	60
5	50	5	60
6	45	20	30
7	45	0	30
8	20	15	30
9	35	10	60
10	20	10	20
11	30	10	20
12	20	10	30

Figure 2. Areas and Subsurface Layer Thicknesses.

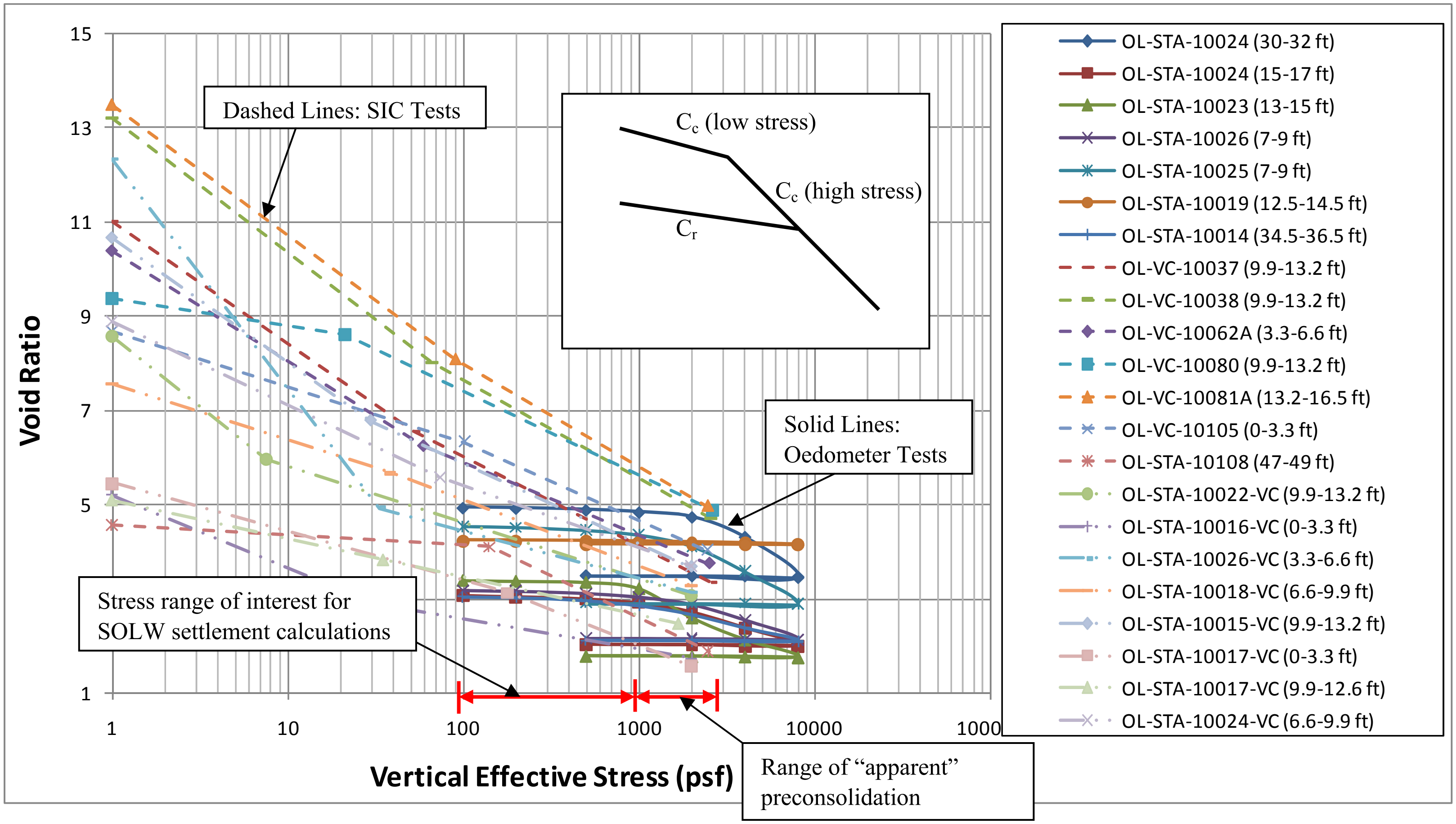


Figure 3. Comparison of Results from Conventional Oedometer Tests and SIC Tests.

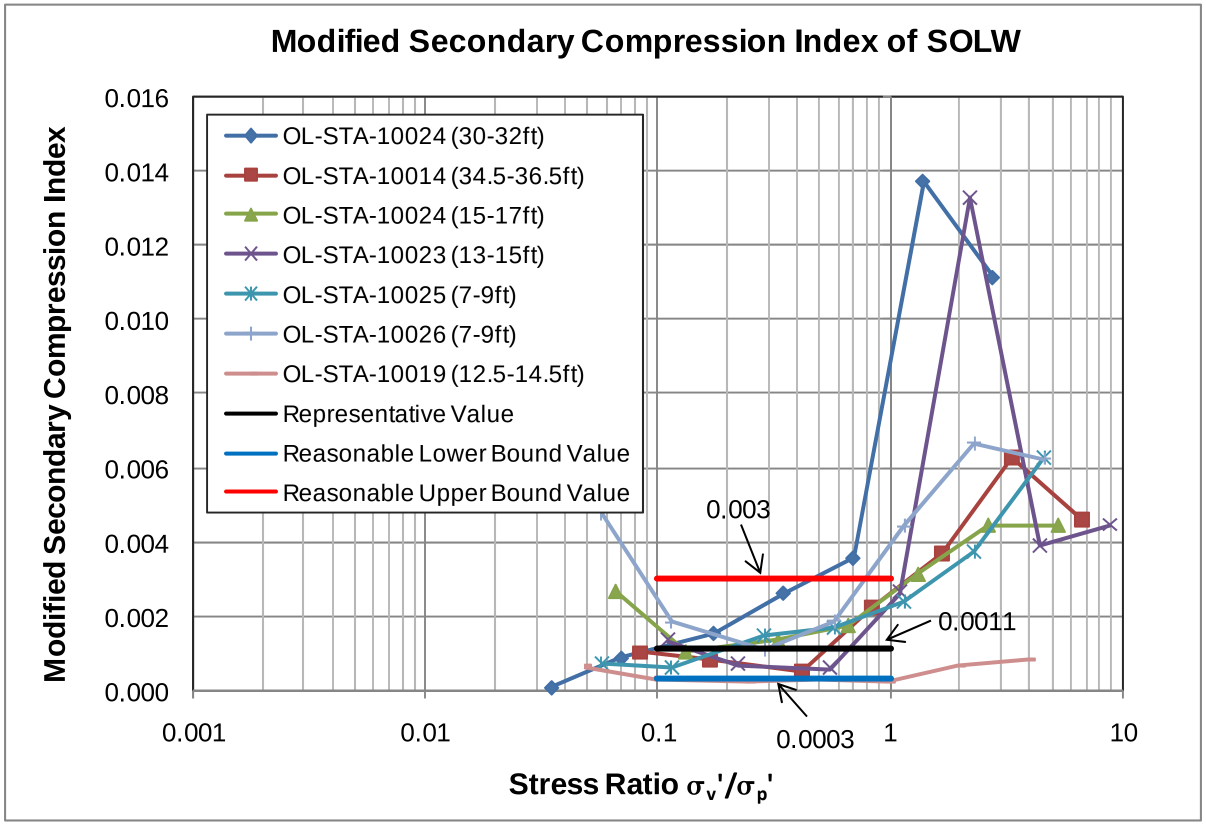


Figure 4. Interpretation of Modified Secondary Compression Index for SOLW.

Note:

The ratio of σ_v'/σ_p' of SOLW in the field before and after capping was estimated to be between 0.1 and 1 according to the assumed subsurface layer thicknesses.

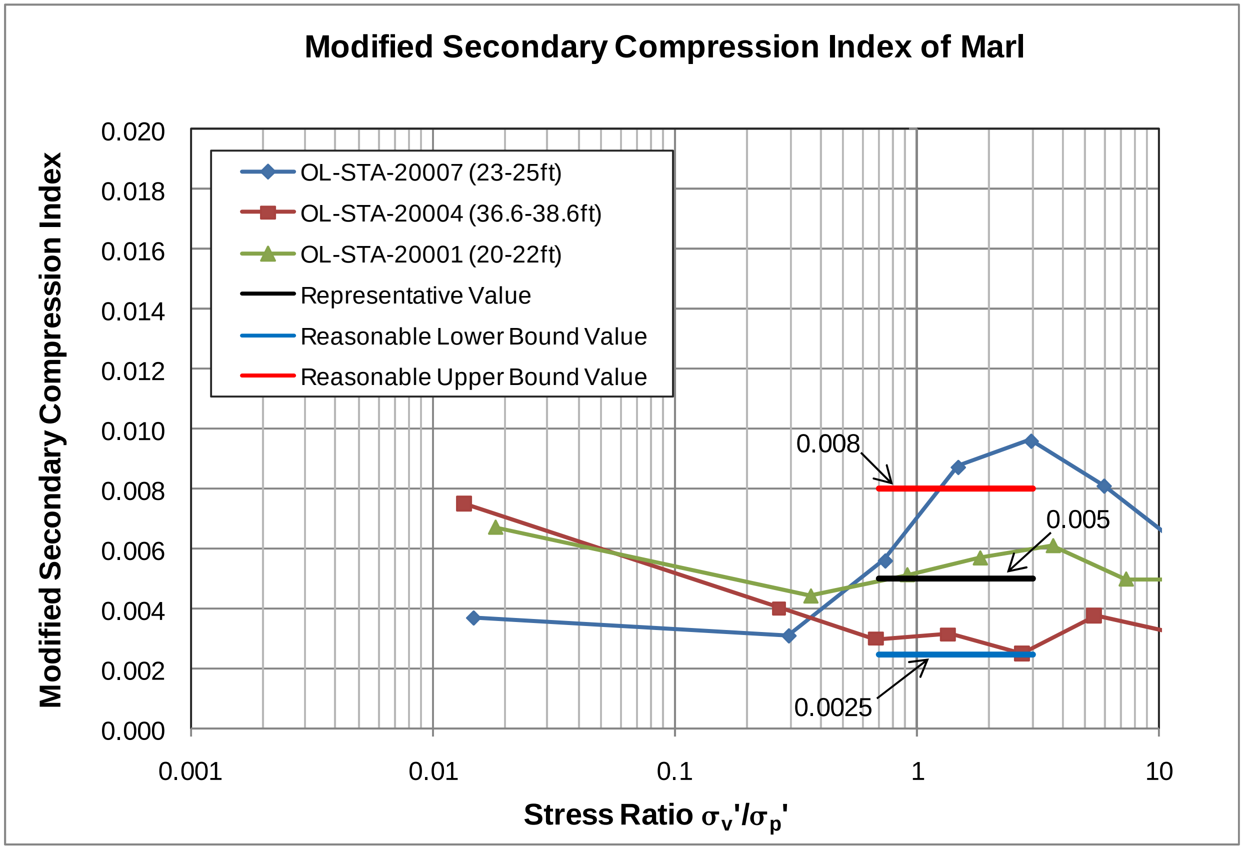


Figure 5. Interpretation of Modified Secondary Compression Index for Marl.

Note:

The ratio of σ_v'/σ_p' of Marl in the field before and after capping was estimated to be between 0.7 and 3 according to the assumed subsurface layer thicknesses.

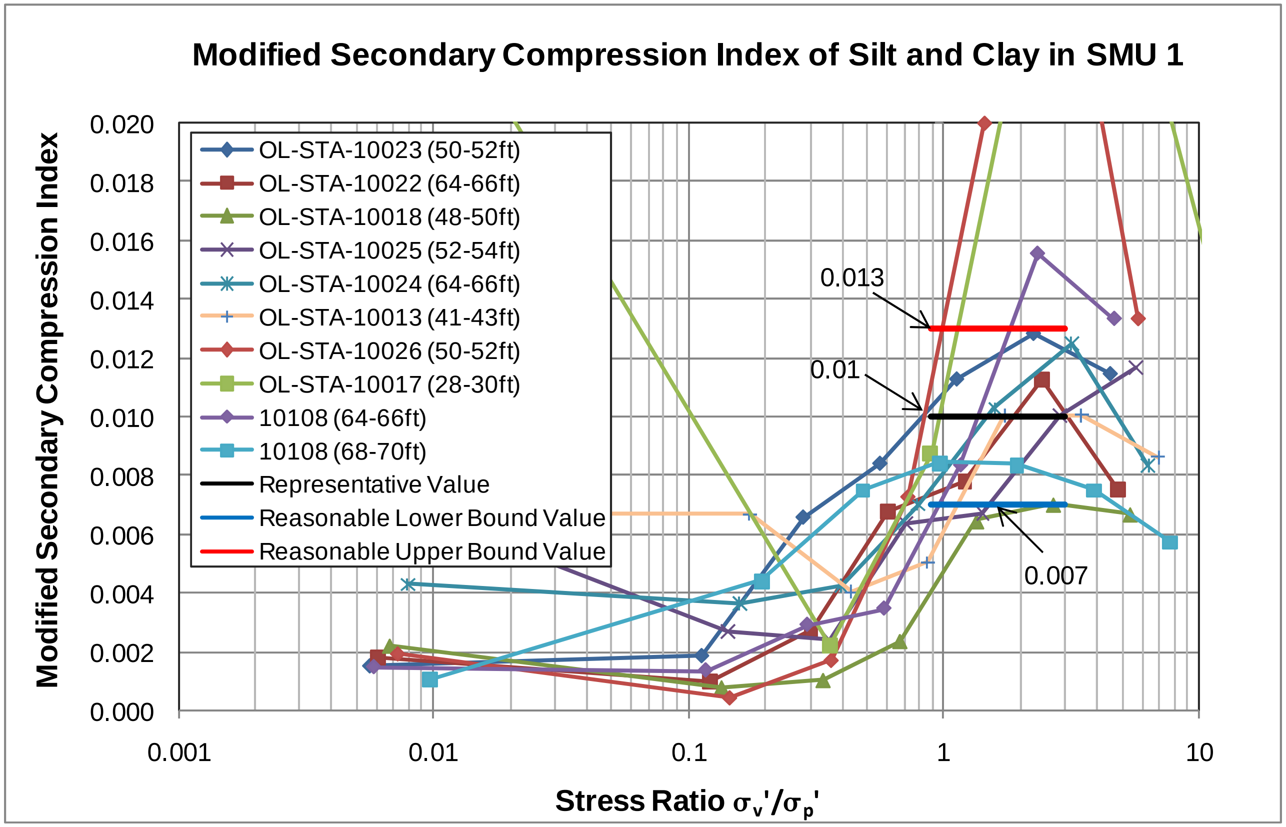


Figure 6. Interpretation of Modified Secondary Compression Index for Silt and Clay in SMU 1.

Note:

The ratio of σ_v'/σ_p' of Silt and Clay in the field before and after capping was estimated to be between 0.9 and 3 according to the assumed subsurface layer thicknesses.

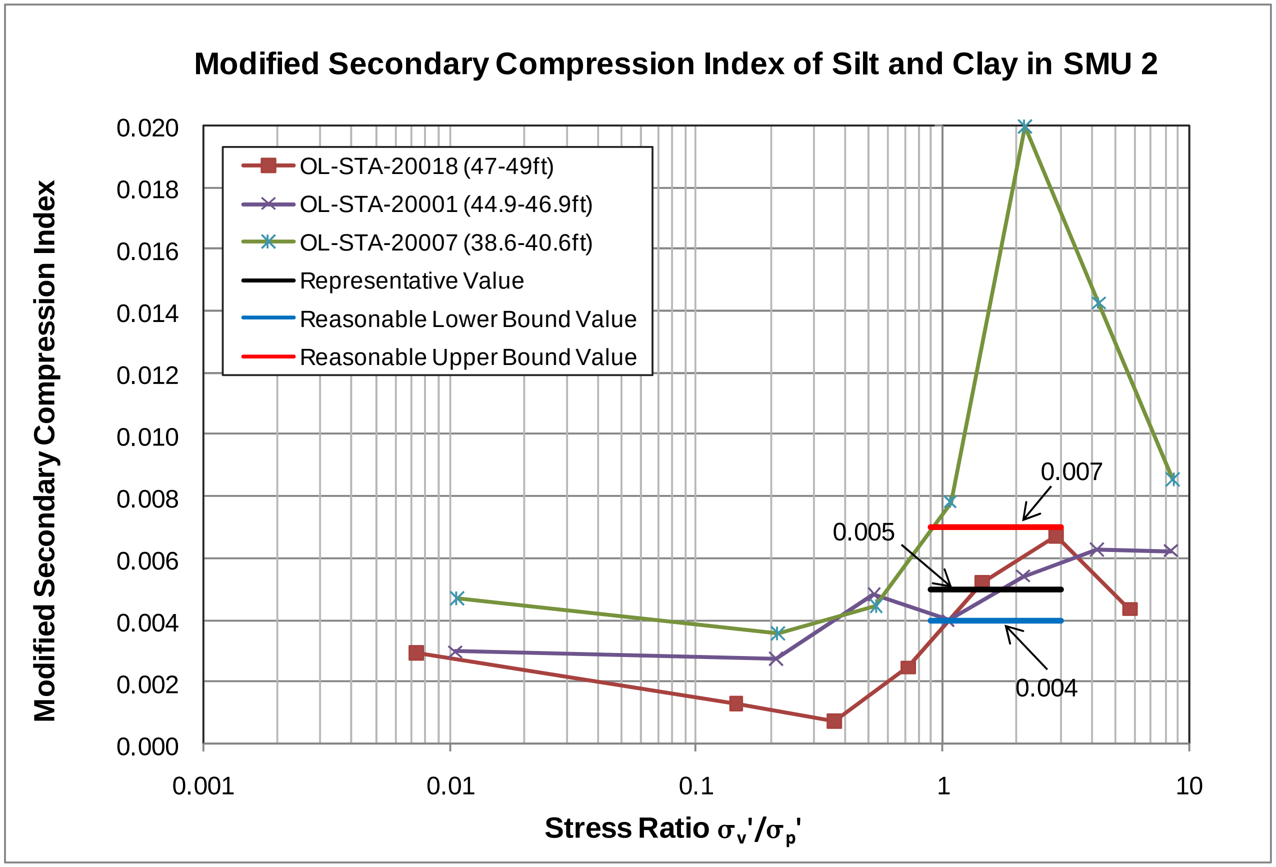


Figure 7. Interpretation of Modified Secondary Compression Index for Silt and Clay in SMU 2.

Note:

The ratio of σ_v'/σ_p' of Silt and Clay in the field before and after capping was estimated to be between 0.9 and 3 according to the assumed subsurface layer thicknesses.

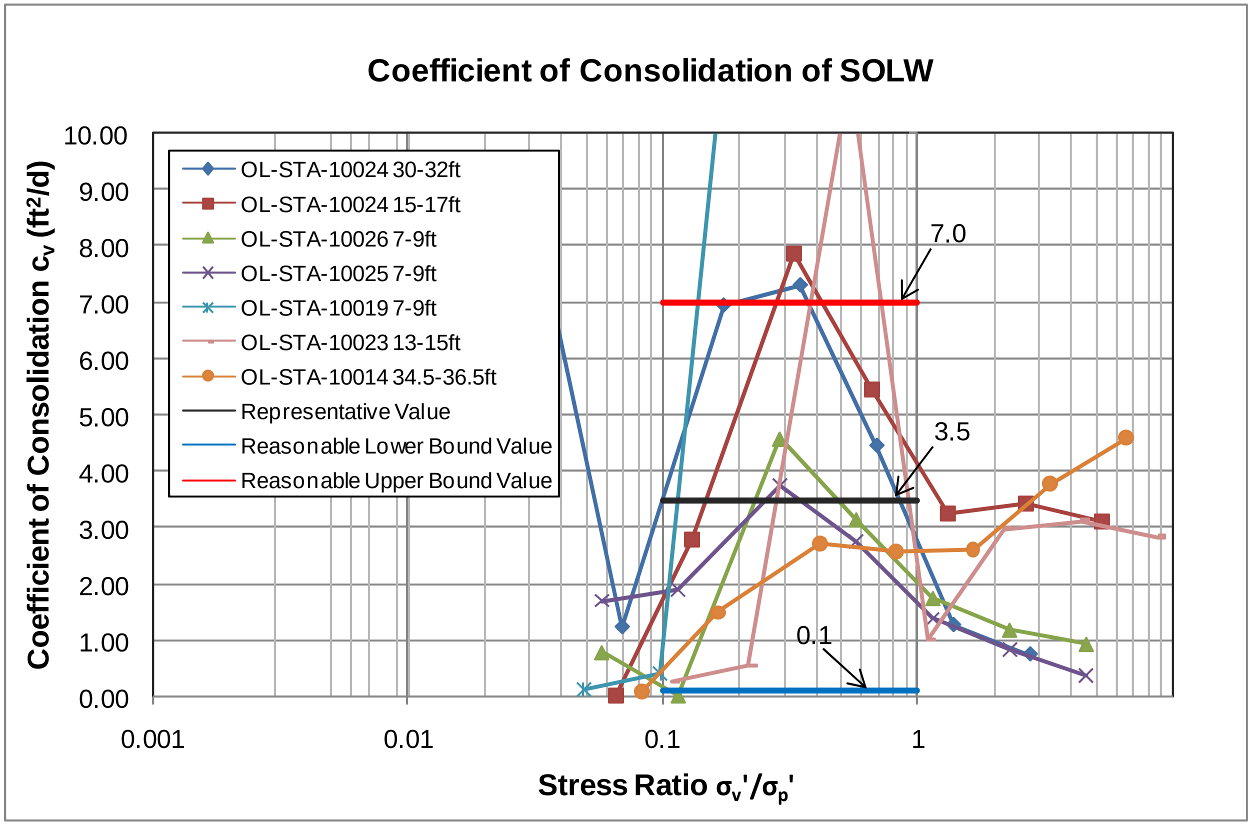


Figure 8. Interpretation of Coefficient of Consolidation Index for SOLW.

Note:
The ratio of σ_v'/σ_p' of SOLW in the field before and after capping was estimated to be between 0.1 and 1 according to the assumed subsurface layer thicknesses.

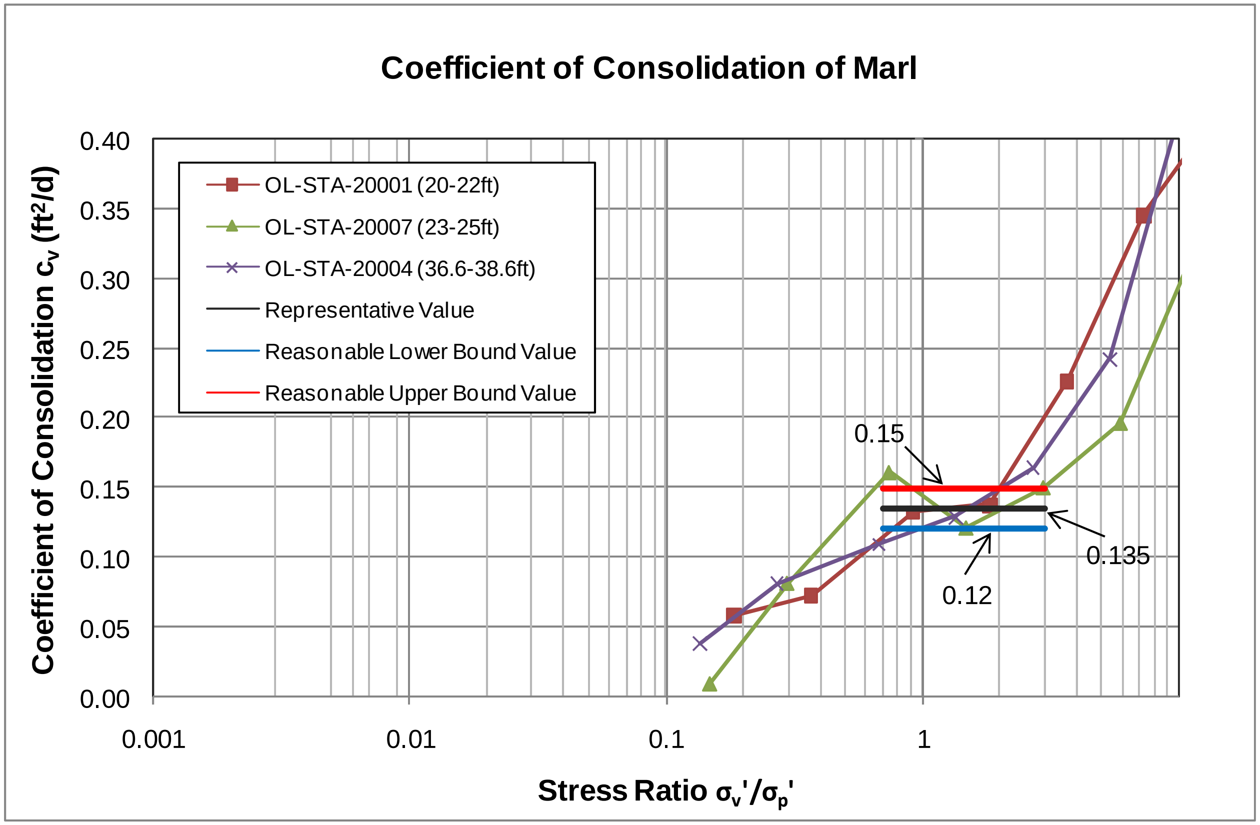


Figure 9. Interpretation of Coefficient of Consolidation Index for Marl.

Note:

The ratio of σ_v'/σ_p' of Marl in the field before and after capping was estimated to be between 0.7 and 3 according to the assumed subsurface layer thicknesses.

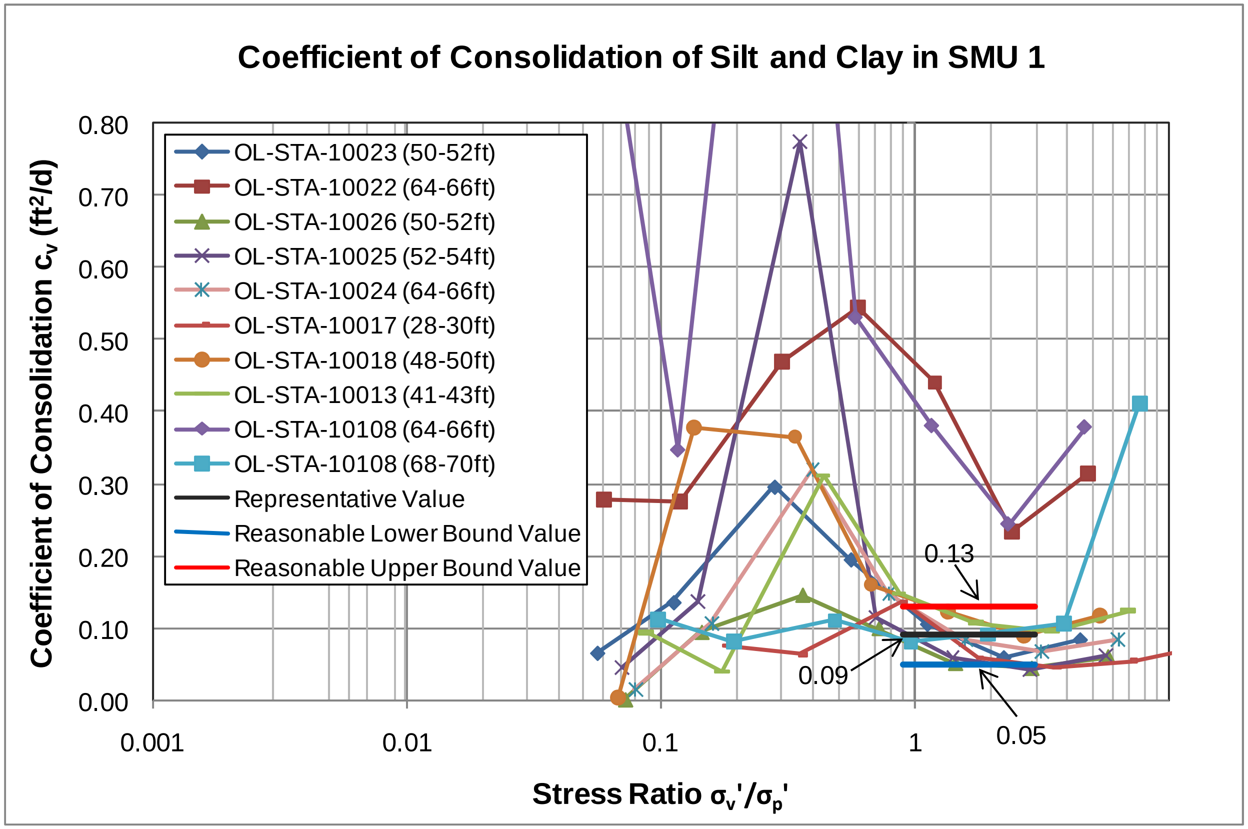


Figure 10. Interpretation of Coefficient of Consolidation Index for Silt and Clay in SMU 1.

Note:

The ratio of σ_v'/σ_p' of Silt and Clay in the field before and after capping was estimated to be between 0.9 and 3 according to the assumed subsurface layer thicknesses.

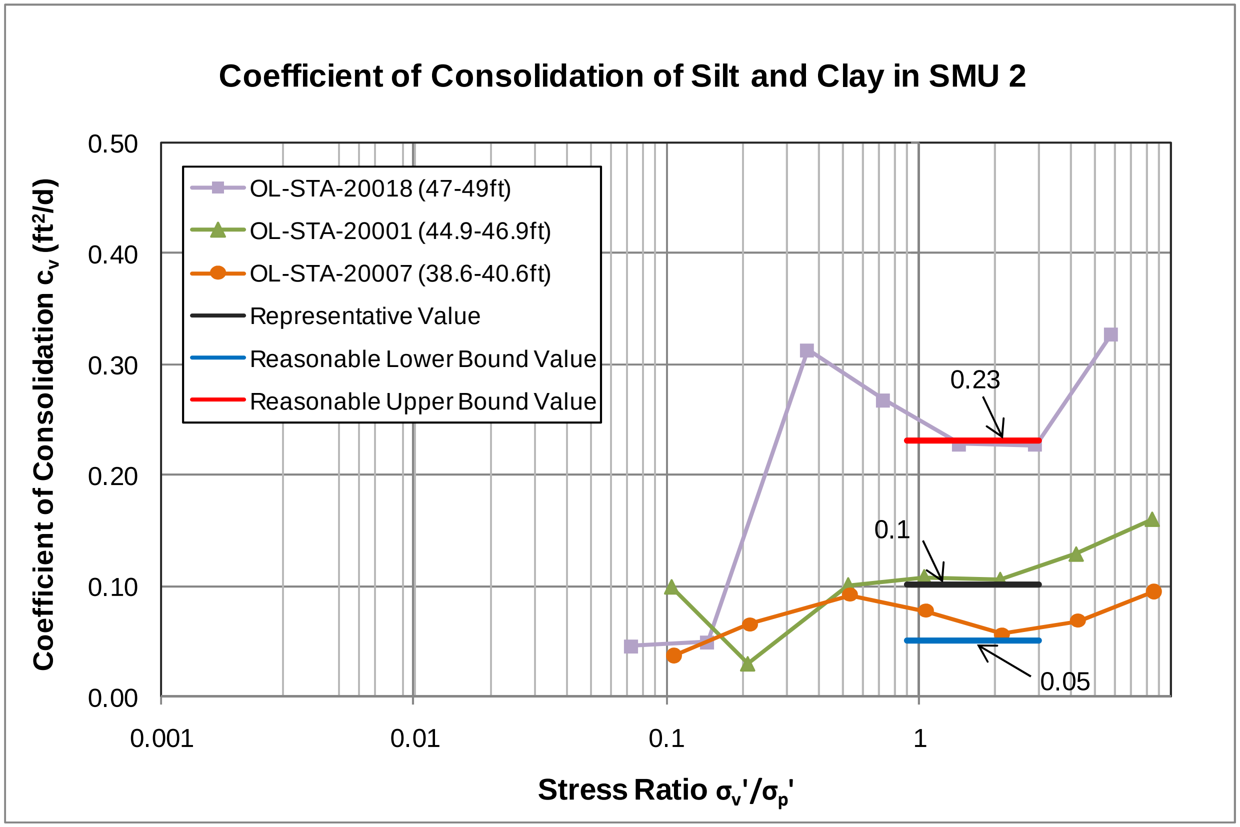
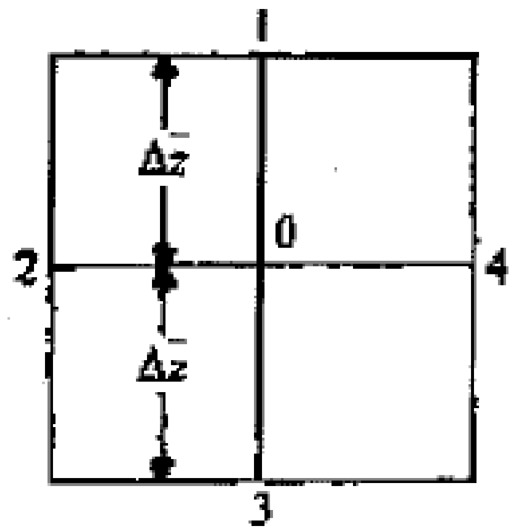


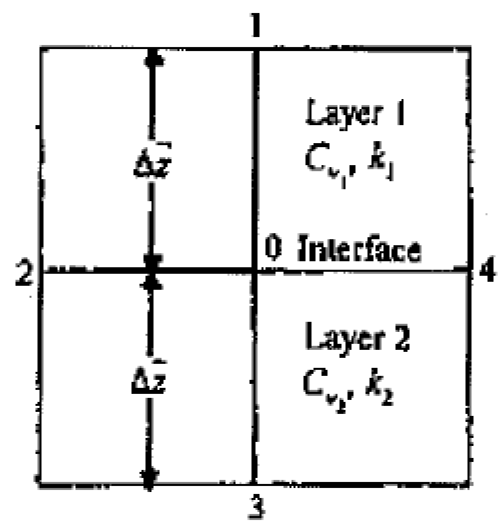
Figure 11. Interpretation of Coefficient of Consolidation Index for Silt and Clay in SMU 2.

Note:

The ratio of σ_v'/σ_p' of Silt and Clay in field before and after capping was estimated to be between 0.9 and 3 according to the assumed subsurface layer thicknesses.



(a)



(b)

Figure 12. Finite difference method based numerical solution for the 1-D consolidation equation: (a) for nodes within homogeneous layers; and (b) for interface node between 2 layers. Note that the consolidation water flow direction is vertical. (source: Das, 2008)

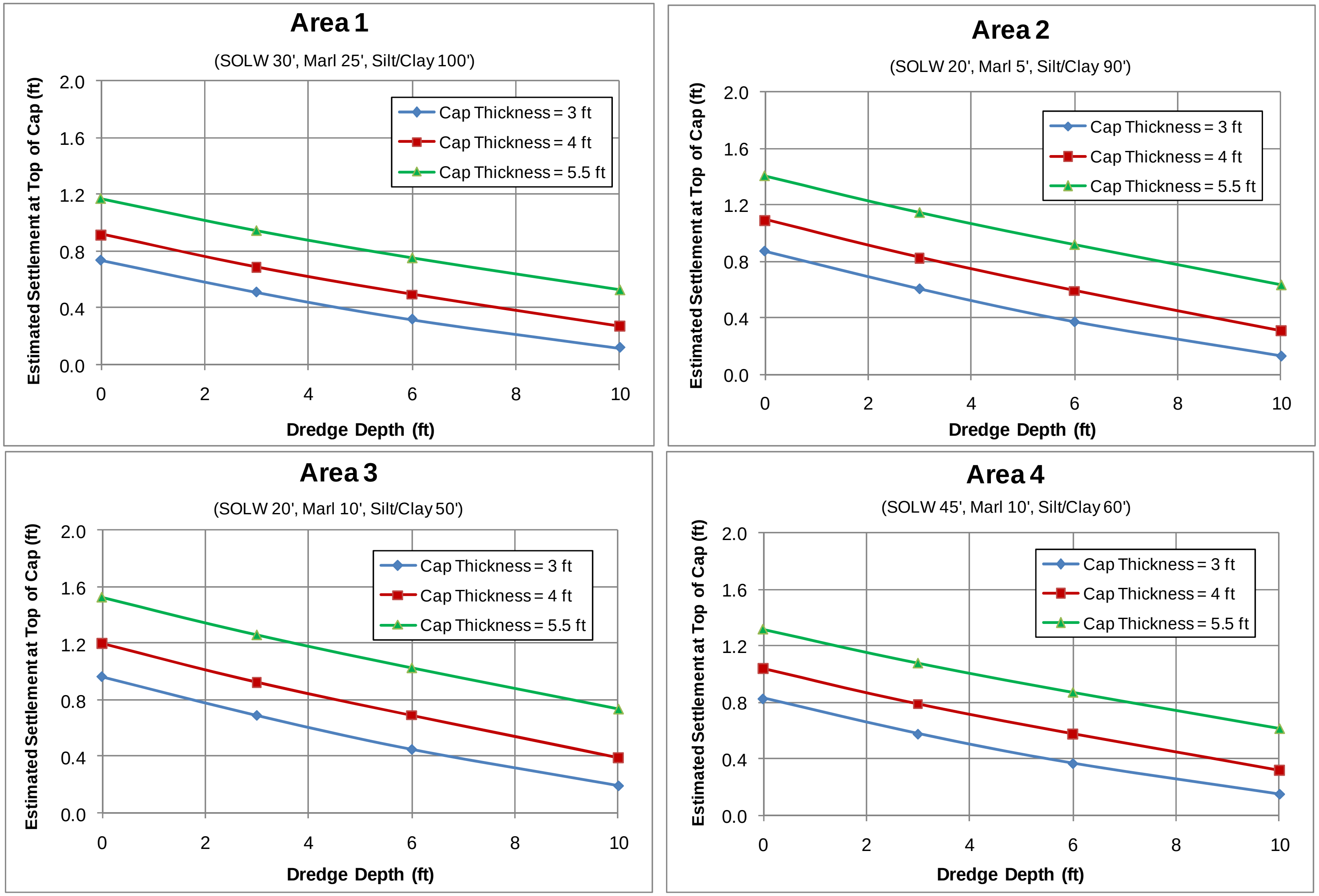


Figure 13. Settlement Analysis Results for Areas 1 to 12 for 30-Year Period.

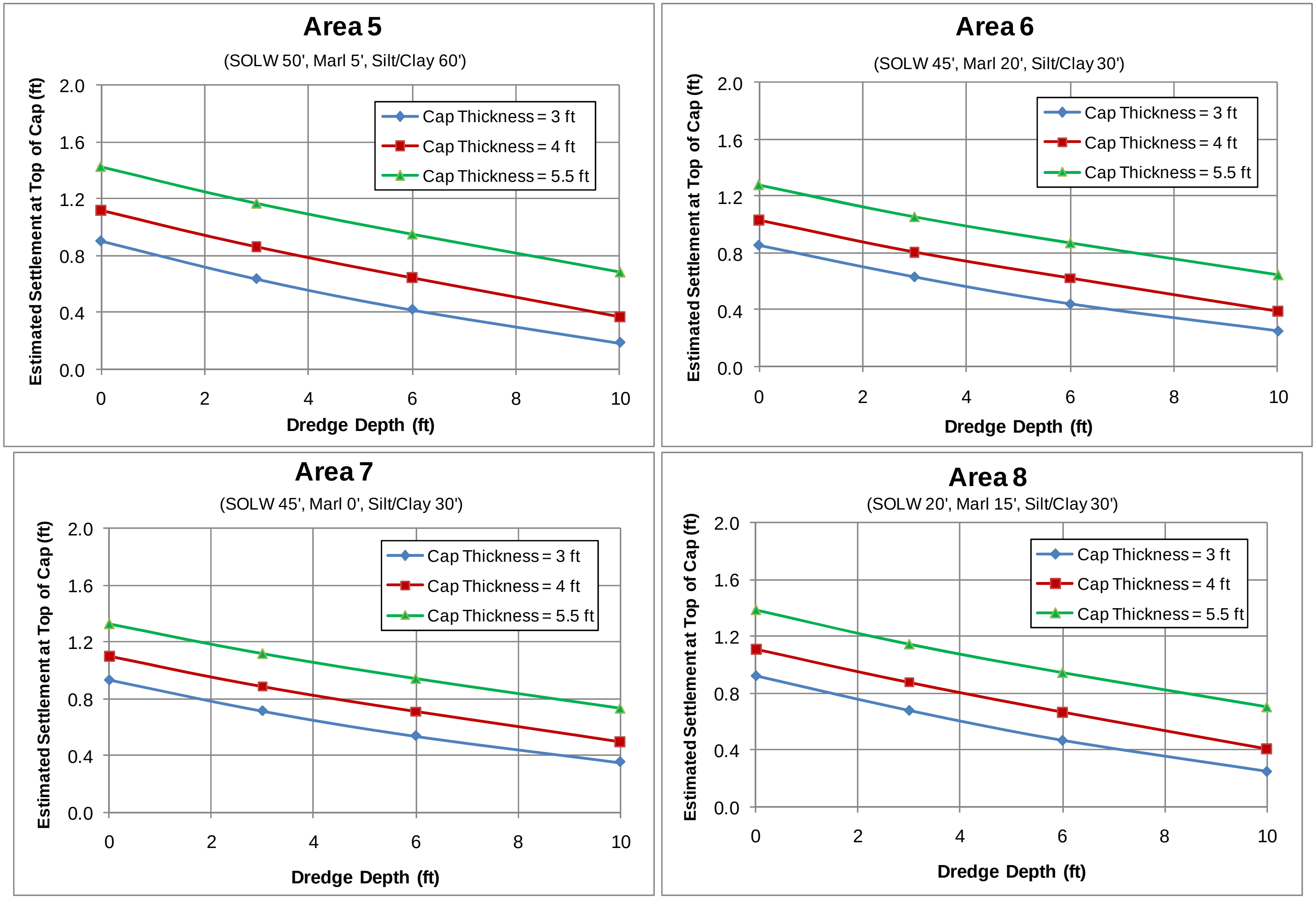


Figure 13. Settlement Analysis Results for Areas 1 to 12 for 30-Year Period (continued).

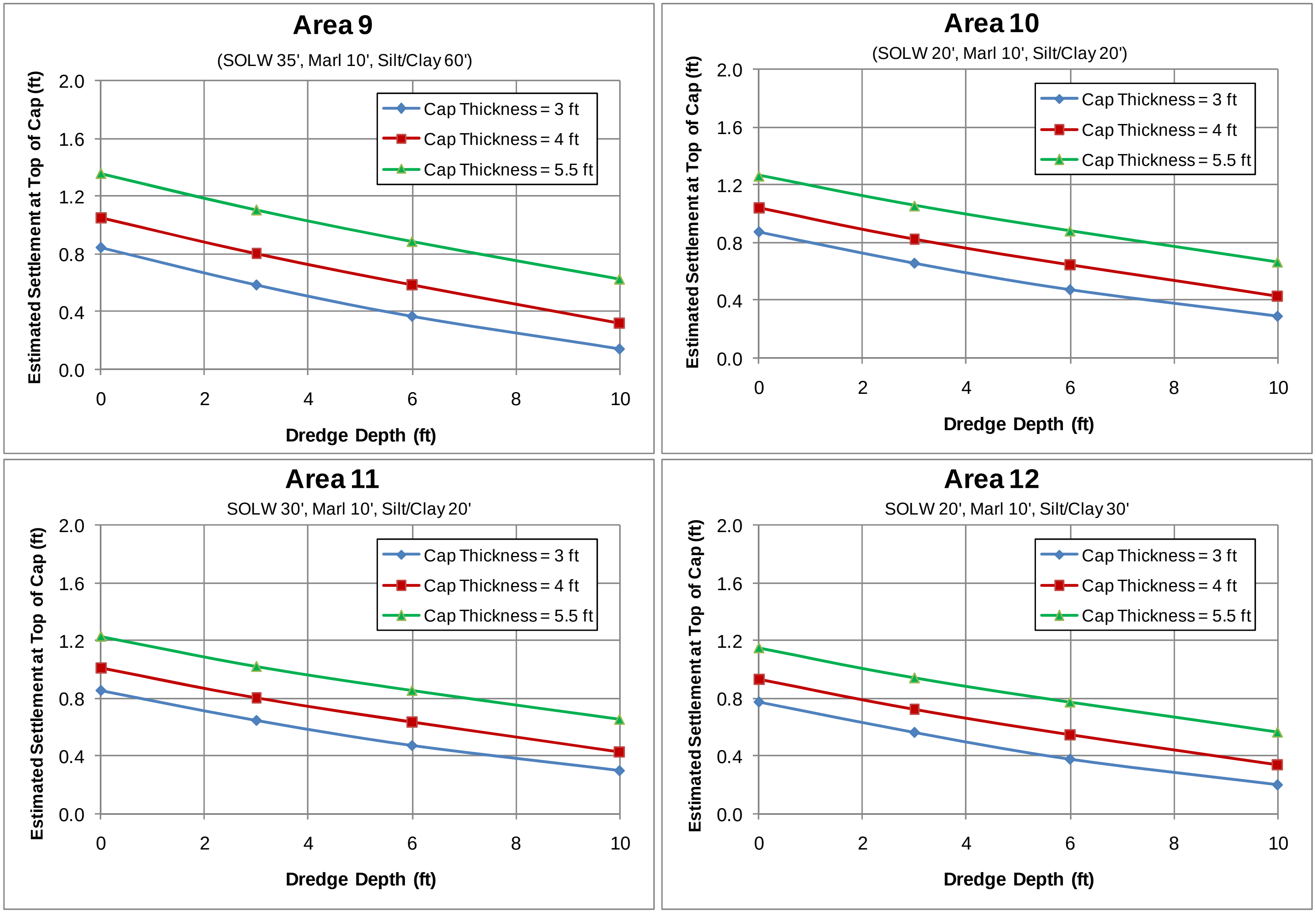


Figure 13. Settlement Analysis Results for Areas 1 to 12 for 30-Year Period (continued).

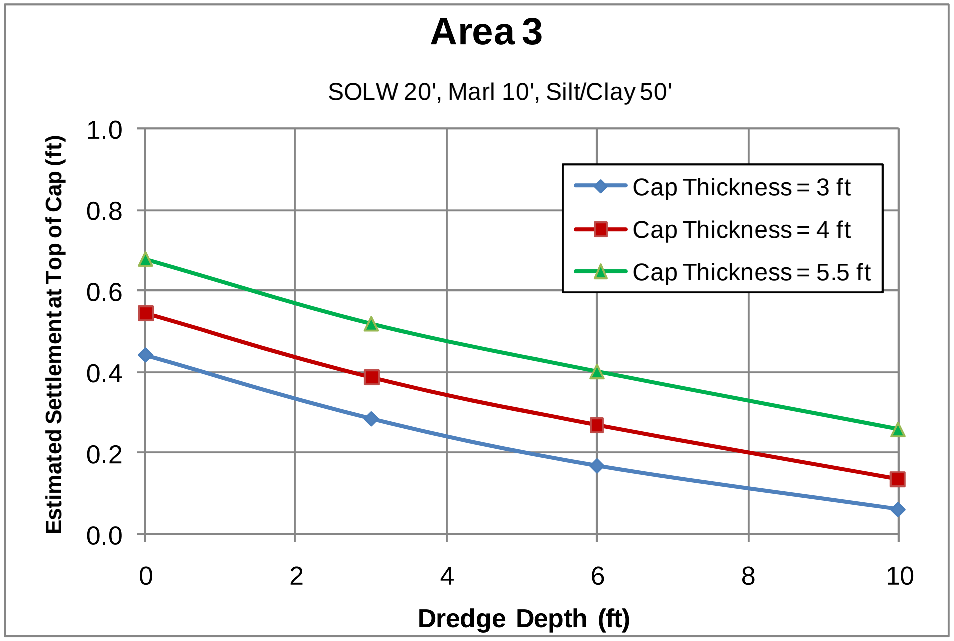


Figure 14. Settlement Analysis Results for Area 3 for 2-Year Period.

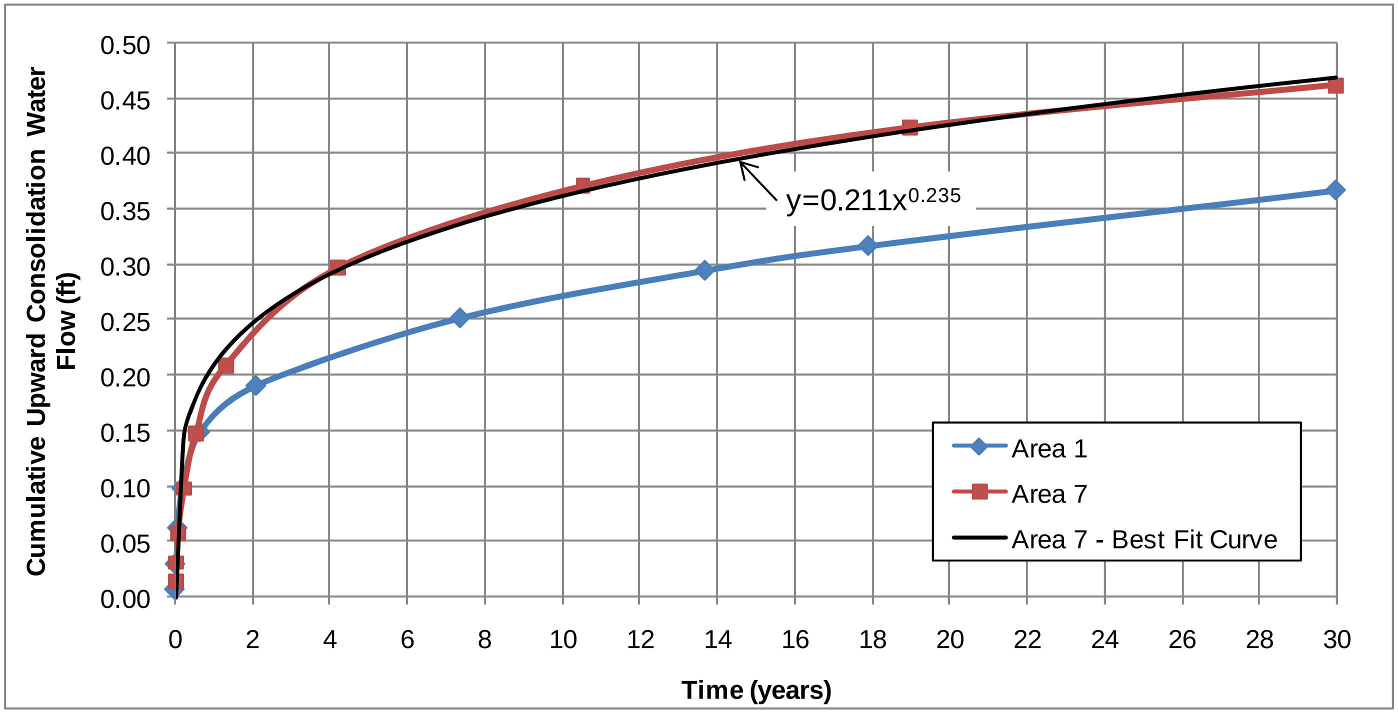


Figure 15. Calculated Cumulative Consolidation Water Flow for Areas 1 and 7.

Note:
Calculations were performed for 2 m dredge and 4 ft thick cap.

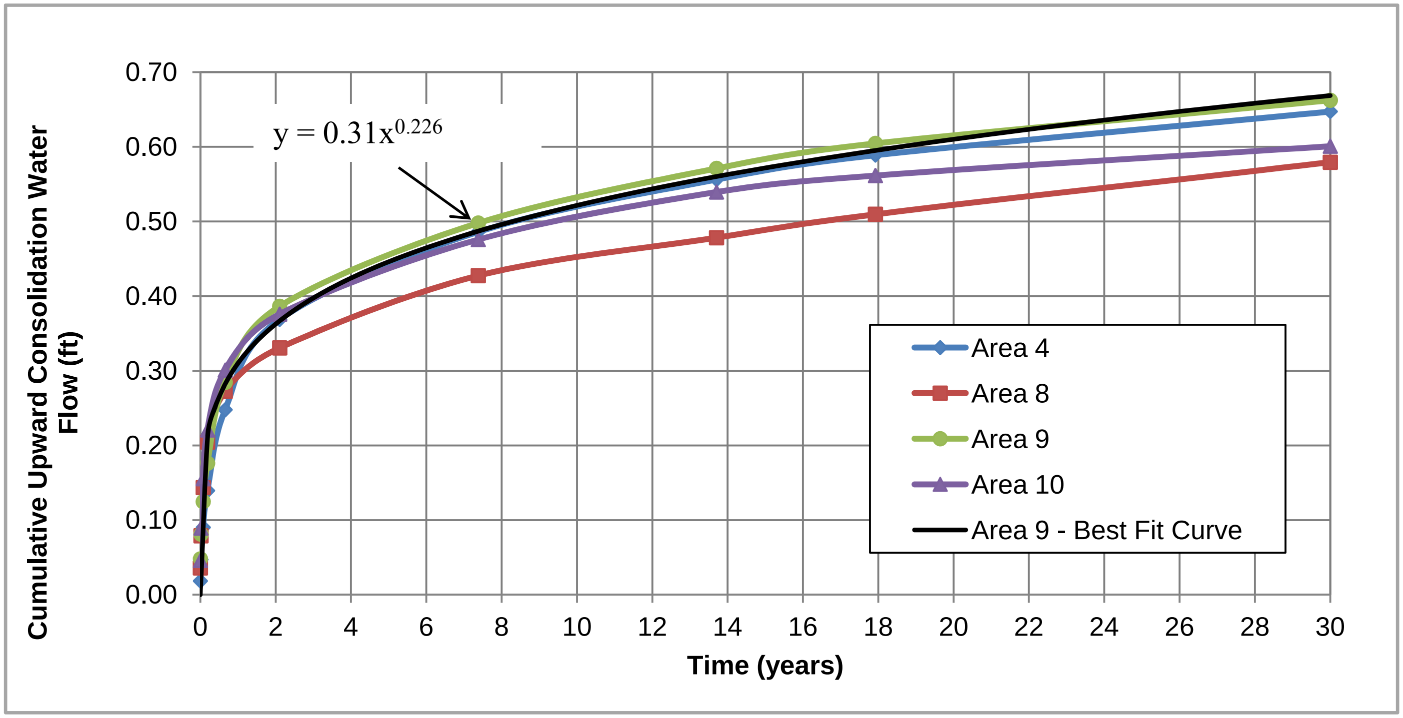


Figure 16. Calculated Cumulative Consolidation Water Flow for Areas 4, 8, 9, and 10.

Note:

Calculations were performed for no dredging and 3 ft thick cap.

ATTACHMENT A

SUBSURFACE LAYER THICKNESS CONTOURS

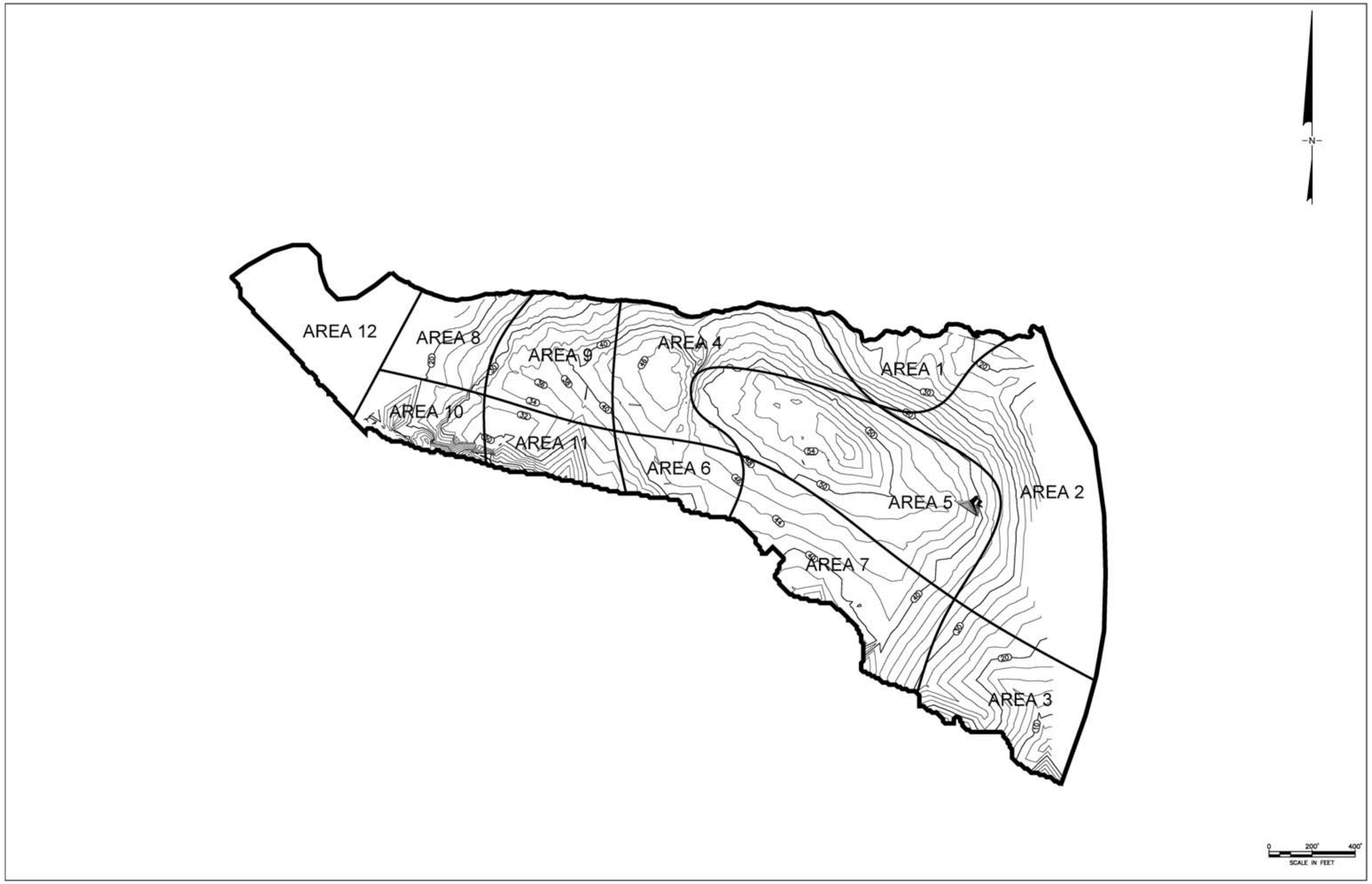


Figure A1. The Thickness of SOLW in Remediation Area D

Note:

1. The subsurface thickness contours were developed based on the elevations of each layer from the boring logs provided by Parsons, as presented in Section 2.
2. The subsurface thickness in the area that is not covered by the contours presented in this figure was estimated based on boring logs provided by Parsons.

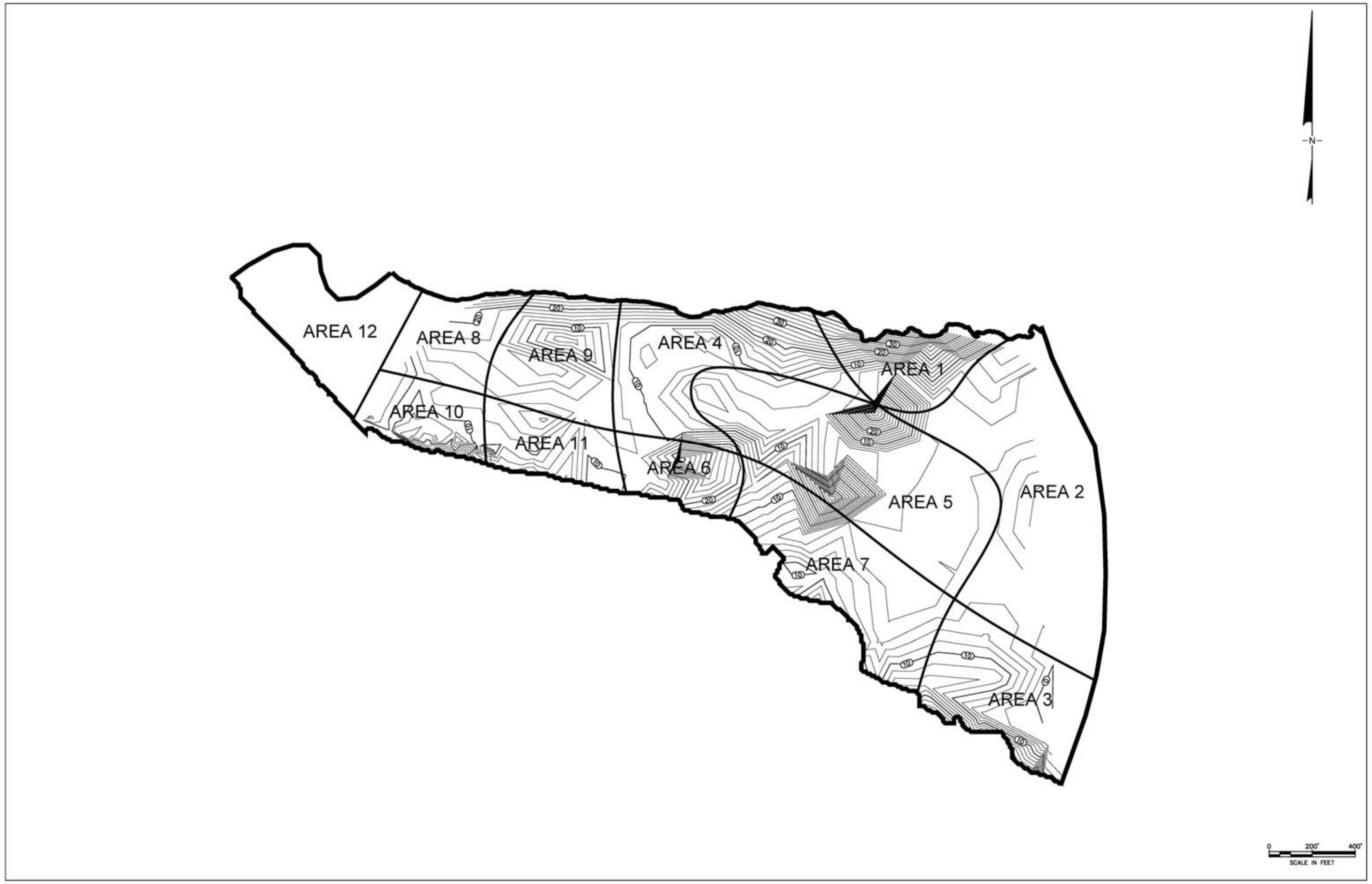


Figure A2. The Thickness of Marl in Remediation Area D

Note:

1. The subsurface thickness contours were developed based on the elevations of each layer from the boring logs provided by Parsons, as presented in Section 2.
2. The subsurface thickness in the area that is not covered by the contours presented in this figure was estimated based on boring logs provided by Parsons.

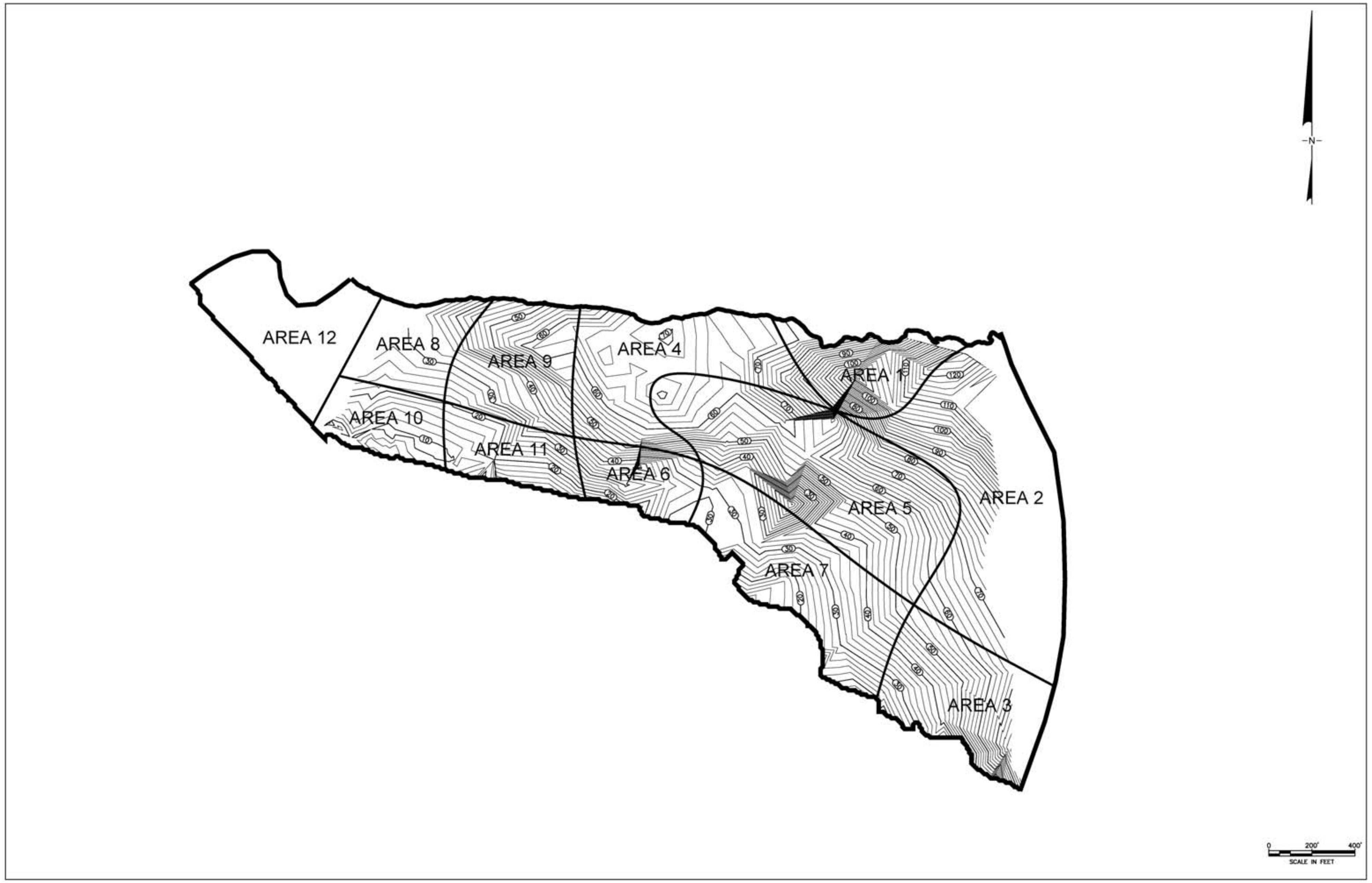


Figure A3. The Thickness of Silt and Clay in Remediation Area D

Note:

1. The subsurface thickness contours were developed based on the elevations of each layer from the boring logs provided by Parsons. The bottom of Silt and Clay was below the depth of the shallow borings and was developed based on a limited number of borings that went to deeper depths in the ILWD, as presented in Section 2.
2. The subsurface thickness in the area that is not covered by the contours presented in this figure was estimated based on boring logs provided by Parsons.

ATTACHMENT B

CONVENTIONAL OEDOMETER TEST RESULTS SUMMARY

Summary of Consolidation Test Data – Phase I PDI

Location ID	Field Sample ID	Depth (ft)	Average Depth (ft)	Compression Index (Cc)	Recompression Index (Cr)	Initial Void Ratio (e_o)	Initial Water Content (%)	Preconsolidation Pressure (tsf)
OL-STA-10013	OL-0110-05	41-43	42	0.51	0.06	1.60	57.6	0.6
OL-STA-10014	OL-0110-08	34.5-36.5	35.5	0.94	0.01	3.05	113.1	0.6
OL-STA-10017	OL-0110-20	28-30	29	0.94	0.13	2.74	103.7	0.3
OL-STA-10018	OL-0110-27	48-50	49	0.36	0.03	1.06	36.5	0.7
OL-STA-10019	OL-0110-30	12.5-14.5	13.5	0.08	0.01	4.24	148.7	1.0
OL-STA-10022	OL-0110-49	64-66	65	0.70	0.06	1.85	67.2	0.8
OL-STA-10023	OL-0052-06	13-15	14	1.59	0.02	3.38	142.2	0.5
OL-STA-10023	OL-0052-04	50-52	51	0.73	0.07	1.94	72.5	0.9
OL-STA-10024	OL-0052-07	15-17	16	1.18	0.02	3.08	120.9	0.8
OL-STA-10024	OL-0052-09	30-32	31	2.84	0.03	4.93	180.0	1.4
OL-STA-10024	OL-0052-12	64-66	65	0.57	0.09	1.81	63.4	0.6
OL-STA-10025	OL-0052-13	7-9	8	2.04	0.02	4.53	183.6	0.9
OL-STA-10025	OL-0052-16	52-54	53	0.65	0.08	1.88	70.3	0.7
OL-STA-10026	OL-0052-19	7-9	8	1.22	0.03	3.17	105.7	0.9
OL-STA-10026	OL-0052-22	50-52	51	0.69	0.09	1.99	76.5	0.7
OL-STA-20001	OL-0072-07	20-22	21	0.37	0.02	1.87	64.2	0.3
OL-STA-20001	OL-0072-09	44.9-46.9	45.9	0.26	0.04	0.95	32.7	0.5
OL-STA-20004	OL-0072-01	12-14	13	0.72	0.01	2.91	102.3	0.3
OL-STA-20004	OL-0072-02	36.6-38.6	37.6	0.16	0.02	0.90	31.4	0.4
OL-STA-20007	OL-0072-04	23-25	24	0.41	0.03	1.89	65.8	0.3
OL-STA-20007	OL-0072-05	38.6-40.6	39.6	0.49	0.05	1.33	48.6	0.5
OL-STA-20016	OL-0110-52	27-29	28	0.19	0.04	0.89	30.9	0.4
OL-STA-20017	OL-0110-57	10-12	11	0.51	0.01	1.42	37.2	0.4
OL-STA-20017	OL-0110-59	42-44	43	0.22	0.03	0.87	31.1	0.6
OL-STA-20018	OL-0110-55	47-49	48	0.23	0.02	0.91	32.7	0.7

Summary of Consolidation Test Data – Phase II PDI

Location ID	Field Sample ID	Depth (ft)	Average Depth (ft)	Compression Index (C_c)	Recompression Index (C_r)	Modified Compression Index ($C_{c\varepsilon}$)	Modified Recompression Index ($C_{r\varepsilon}$)	Initial Void Ratio (e_o)	Initial Water Content (%)	Preconsolidation Pressure (psf)
OL-STA-10108	OL-0267-01	64-66	65	0.74	0.06	0.25	0.02	1.91	70.8	1702
OL-STA-10108	OL-0267-02	68-70	69	0.58	0.05	0.20	0.02	1.86	65.3	1032 (disturbed sample)

Notes:

1. The Cc values of SOLW in this table correspond to high stress (i.e., >1000 psf) range and were not used in analysis.
2. The modified compression index $C_{c\varepsilon}$ and recompression index $C_{r\varepsilon}$ are calculated as follows: $C_{c\varepsilon} = C_c / (1+e_0)$ and $C_{r\varepsilon} = C_r / (1+e_0)$.
3. These summary tables were provided to Geosyntec by Parsons.

ATTACHMENT C

EXAMPLES OF CALCULATIONS

(For Area 7 with 2 m dredge and 4 ft thick cap)

An Example of Settlement Calculations

Input:

Dredging Depth	6.6	ft
Consider Total Settlement in	30	years

Soil Layers	Thickness (ft)	Unit Weight (pcf)	OCR	$C_{c\varepsilon}$	$C_{r\varepsilon}$	C_{α}	Coef. of Con. c_v (ft^2/d)	Time of 90% primary con. (years)	t2/t1 for Secondary Con.	# of Sublayers
Cap	4	120								
SOLW	45	81	1	0.030	0.0045	0.0011	3.500	1.3	22.3	18
Marl	0	98	1	0.117	0.0099	0.0050	0.090	5.8	5.2	0
Silt/Clay	30	108	1	0.223	0.0250	0.0100	0.090	5.8	5.2	6
Water		62.4								

Calculated Settlement (ft):

	Primary Settlement	Secondary Settlement	Total Settlement
SOLW	0.158	0.057	0.215
Marl	0.000	0.000	0.000
Silt/Clay	0.242	0.215	0.457
Total	0.40	0.27	**0.67**

Calculation for SOLW

Layer No.	1
Layer Thickness, m / ft	2.1333333
Midpoint Depth from Dredge Bot, m/ft	1.0666667
Effective Stress Before Dredging, KPa/psf	142.6
Initial Effective Stress, KPa/psf	19.84
Final Effective Stress, KPa/psf	250.24
OCR	1
Preconsolidation Pressure, KPa/psf	142.6
Modified Primary Compression Index, $C_{c\varepsilon}$	0.03
Modified Recompression Index, $C_{r\varepsilon}$	0.0045
Modified Secondary Compression Index, $C_{\alpha\varepsilon}$	0.0011
ratio of t2 / t1	22.3
Settlements	
Primary Settlement, (m / ft)	0.024
Secondary Settlement (m / ft)	0.003
Total Settlement (m / ft)	0.027

Layer No.	2
Layer Thickness, m / ft	2.1333333
Midpoint Depth from Dredge Bot, m/ft	3.2
Effective Stress Before Dredging, KPa/psf	182.28
Initial Effective Stress, KPa/psf	59.52
Final Effective Stress, KPa/psf	289.92
OCR	1
Preconsolidation Pressure, KPa/psf	182.28
Modified Primary Compression Index, $C_{c\varepsilon}$	0.03
Modified Recompression Index, $C_{r\varepsilon}$	0.0045
Modified Secondary Compression Index, $C_{\alpha\varepsilon}$	0.0011
ratio of t2 / t1	22.3
Settlements	
Primary Settlement, (m / ft)	0.018
Secondary Settlement (m / ft)	0.003
Total Settlement (m / ft)	0.021

Layer No.	3
Layer Thickness, m / ft	2.1333333
Midpoint Depth from Dredge Bot, m/ft	5.3333333
Effective Stress Before Dredging, KPa/psf	221.96
Initial Effective Stress, KPa/psf	99.2
Final Effective Stress, KPa/psf	329.6
OCR	1
Preconsolidation Pressure, KPa/psf	221.96
Modified Primary Compression Index, $C_{c\varepsilon}$	0.03
Modified Recompression Index, $C_{r\varepsilon}$	0.0045
Modified Secondary Compression Index, $C_{\alpha\varepsilon}$	0.0011
ratio of t2 / t1	22.3
Settlements	
Primary Settlement, (m / ft)	0.014
Secondary Settlement (m / ft)	0.003
Total Settlement (m / ft)	0.018

Layer No.	4
Layer Thickness, m / ft	2.1333333
Midpoint Depth from Dredge Bot, m/ft	7.4666667
Effective Stress Before Dredging, KPa/psf	261.64
Initial Effective Stress, KPa/psf	138.88
Final Effective Stress, KPa/psf	369.28
OCR	1
Preconsolidation Pressure, KPa/psf	261.64
Modified Primary Compression Index, $C_{c\varepsilon}$	0.03
Modified Recompression Index, $C_{r\varepsilon}$	0.0045
Modified Secondary Compression Index, $C_{\alpha\varepsilon}$	0.0011
ratio of t2 / t1	22.3
Settlements	
Primary Settlement, (m / ft)	0.012
Secondary Settlement (m / ft)	0.003
Total Settlement (m / ft)	0.015

Layer No.	5
Layer Thickness, m / ft	2.1333333
Midpoint Depth from Dredge Bot, m/ft	9.6
Effective Stress Before Dredging, KPa/psf	301.32
Initial Effective Stress, KPa/psf	178.56
Final Effective Stress, KPa/psf	408.96
OCR	1
Preconsolidation Pressure, KPa/psf	301.32
Modified Primary Compression Index, $C_{c\varepsilon}$	0.03
Modified Recompression Index, $C_{r\varepsilon}$	0.0045
Modified Secondary Compression Index, $C_{\alpha\varepsilon}$	0.0011
ratio of t2 / t1	22.3
Settlements	
Primary Settlement, (m / ft)	0.011
Secondary Settlement (m / ft)	0.003
Total Settlement (m / ft)	0.014

Layer No.	6
Layer Thickness, m / ft	2.1333333
Midpoint Depth from Dredge Bot, m/ft	11.733333
Effective Stress Before Dredging, KPa/psf	341
Initial Effective Stress, KPa/psf	218.24
Final Effective Stress, KPa/psf	448.64
OCR	1
Preconsolidation Pressure, KPa/psf	341
Modified Primary Compression Index, $C_{c\varepsilon}$	0.03
Modified Recompression Index, $C_{r\varepsilon}$	0.0045
Modified Secondary Compression Index, $C_{\alpha\varepsilon}$	0.0011
ratio of t2 / t1	22.3
Settlements	
Primary Settlement, (m / ft)	0.009
Secondary Settlement (m / ft)	0.003
Total Settlement (m / ft)	0.013

Layer No.	7
Layer Thickness, m / ft	2.1333333
Midpoint Depth from Dredge Bot, m/ft	13.866667
Effective Stress Before Dredging, KPa/psf	380.68
Initial Effective Stress, KPa/psf	257.92
Final Effective Stress, KPa/psf	488.32
OCR	1
Preconsolidation Pressure, KPa/psf	380.68
Modified Primary Compression Index, $C_{c\varepsilon}$	0.03
Modified Recompression Index, $C_{r\varepsilon}$	0.0045
Modified Secondary Compression Index, $C_{\alpha\varepsilon}$	0.0011
ratio of t2 / t1	22.3
Settlements	
Primary Settlement, (m / ft)	0.009
Secondary Settlement (m / ft)	0.003
Total Settlement (m / ft)	0.012

Layer No.	8
Layer Thickness, m / ft	2.1333333
Midpoint Depth from Dredge Bot, m/ft	16
Effective Stress Before Dredging, KPa/psf	420.36
Initial Effective Stress, KPa/psf	297.6
Final Effective Stress, KPa/psf	528
OCR	1
Preconsolidation Pressure, KPa/psf	420.36
Modified Primary Compression Index, $C_{c\varepsilon}$	0.03
Modified Recompression Index, $C_{r\varepsilon}$	0.0045
Modified Secondary Compression Index, $C_{\alpha\varepsilon}$	0.0011
ratio of t2 / t1	22.3
Settlements	
Primary Settlement, (m / ft)	0.008
Secondary Settlement (m / ft)	0.003
Total Settlement (m / ft)	0.011

Layer No.	9	Layer No.	14
Layer Thickness, m / ft	2.1333333	Layer Thickness, m / ft	2.1333333
Midpoint Depth from Dredge Bot, m/ft	18.133333	Midpoint Depth from Dredge Bot, m/ft	28.8
Effective Stress Before Dredging, KPa/psf	460.04	Effective Stress Before Dredging, KPa/psf	658.44
Initial Effective Stress, KPa/psf	337.28	Initial Effective Stress, KPa/psf	535.68
Final Effective Stress, KPa/psf	567.68	Final Effective Stress, KPa/psf	766.08
OCR	1	OCR	1
Preconsolidation Pressure, KPa/psf	460.04	Preconsolidation Pressure, KPa/psf	658.44
Modified Primary Compression Index, $C_{c\varepsilon}$	0.03	Modified Primary Compression Index, $C_{c\varepsilon}$	0.03
Modified Recompression Index, $C_{r\varepsilon}$	0.0045	Modified Recompression Index, $C_{r\varepsilon}$	0.0045
Modified Secondary Compression Index, $C_{\alpha\varepsilon}$	0.0011	Modified Secondary Compression Index, $C_{\alpha\varepsilon}$	0.0011
ratio of t2 / t1	22.3	ratio of t2 / t1	22.3
Settlements		Settlements	
Primary Settlement, (m / ft)	0.007	Primary Settlement, (m / ft)	0.005
Secondary Settlement (m / ft)	0.003	Secondary Settlement (m / ft)	0.003
Total Settlement (m / ft)	0.010	Total Settlement (m / ft)	0.008

Layer No.	10	Layer No.	15
Layer Thickness, m / ft	2.1333333	Layer Thickness, m / ft	2.1333333
Midpoint Depth from Dredge Bot, m/ft	20.266667	Midpoint Depth from Dredge Bot, m/ft	30.933333
Effective Stress Before Dredging, KPa/psf	499.72	Effective Stress Before Dredging, KPa/psf	698.12
Initial Effective Stress, KPa/psf	376.96	Initial Effective Stress, KPa/psf	575.36
Final Effective Stress, KPa/psf	607.36	Final Effective Stress, KPa/psf	805.76
OCR	1	OCR	1
Preconsolidation Pressure, KPa/psf	499.72	Preconsolidation Pressure, KPa/psf	698.12
Modified Primary Compression Index, $C_{c\varepsilon}$	0.03	Modified Primary Compression Index, $C_{c\varepsilon}$	0.03
Modified Recompression Index, $C_{r\varepsilon}$	0.0045	Modified Recompression Index, $C_{r\varepsilon}$	0.0045
Modified Secondary Compression Index, $C_{\alpha\varepsilon}$	0.0011	Modified Secondary Compression Index, $C_{\alpha\varepsilon}$	0.0011
ratio of t2 / t1	22.3	ratio of t2 / t1	22.3
Settlements		Settlements	
Primary Settlement, (m / ft)	0.007	Primary Settlement, (m / ft)	0.005
Secondary Settlement (m / ft)	0.003	Secondary Settlement (m / ft)	0.003
Total Settlement (m / ft)	0.010	Total Settlement (m / ft)	0.008

Layer No.	11	Layer No.	16
Layer Thickness, m / ft	2.1333333	Layer Thickness, m / ft	2.1333333
Midpoint Depth from Dredge Bot, m/ft	22.4	Midpoint Depth from Dredge Bot, m/ft	33.066667
Effective Stress Before Dredging, KPa/psf	539.4	Effective Stress Before Dredging, KPa/psf	737.8
Initial Effective Stress, KPa/psf	416.64	Initial Effective Stress, KPa/psf	615.04
Final Effective Stress, KPa/psf	647.04	Final Effective Stress, KPa/psf	845.44
OCR	1	OCR	1
Preconsolidation Pressure, KPa/psf	539.4	Preconsolidation Pressure, KPa/psf	737.8
Modified Primary Compression Index, $C_{c\varepsilon}$	0.03	Modified Primary Compression Index, $C_{c\varepsilon}$	0.03
Modified Recompression Index, $C_{r\varepsilon}$	0.0045	Modified Recompression Index, $C_{r\varepsilon}$	0.0045
Modified Secondary Compression Index, $C_{\alpha\varepsilon}$	0.0011	Modified Secondary Compression Index, $C_{\alpha\varepsilon}$	0.0011
ratio of t2 / t1	22.3	ratio of t2 / t1	22.3
Settlements		Settlements	
Primary Settlement, (m / ft)	0.006	Primary Settlement, (m / ft)	0.005
Secondary Settlement (m / ft)	0.003	Secondary Settlement (m / ft)	0.003
Total Settlement (m / ft)	0.009	Total Settlement (m / ft)	0.008

Layer No.	12	Layer No.	17
Layer Thickness, m / ft	2.1333333	Layer Thickness, m / ft	2.1333333
Midpoint Depth from Dredge Bot, m/ft	24.533333	Midpoint Depth from Dredge Bot, m/ft	35.2
Effective Stress Before Dredging, KPa/psf	579.08	Effective Stress Before Dredging, KPa/psf	777.48
Initial Effective Stress, KPa/psf	456.32	Initial Effective Stress, KPa/psf	654.72
Final Effective Stress, KPa/psf	686.72	Final Effective Stress, KPa/psf	885.12
OCR	1	OCR	1
Preconsolidation Pressure, KPa/psf	579.08	Preconsolidation Pressure, KPa/psf	777.48
Modified Primary Compression Index, $C_{c\varepsilon}$	0.03	Modified Primary Compression Index, $C_{c\varepsilon}$	0.03
Modified Recompression Index, $C_{r\varepsilon}$	0.0045	Modified Recompression Index, $C_{r\varepsilon}$	0.0045
Modified Secondary Compression Index, $C_{\alpha\varepsilon}$	0.0011	Modified Secondary Compression Index, $C_{\alpha\varepsilon}$	0.0011
ratio of t2 / t1	22.3	ratio of t2 / t1	22.3
Settlements		Settlements	
Primary Settlement, (m / ft)	0.006	Primary Settlement, (m / ft)	0.004
Secondary Settlement (m / ft)	0.003	Secondary Settlement (m / ft)	0.003
Total Settlement (m / ft)	0.009	Total Settlement (m / ft)	0.007

Layer No.	13	Layer No.	18
Layer Thickness, m / ft	2.1333333	Layer Thickness, m / ft	2.1333333
Midpoint Depth from Dredge Bot, m/ft	26.666667	Midpoint Depth from Dredge Bot, m/ft	37.333333
Effective Stress Before Dredging, KPa/psf	618.76	Effective Stress Before Dredging, KPa/psf	817.16
Initial Effective Stress, KPa/psf	496	Initial Effective Stress, KPa/psf	694.4
Final Effective Stress, KPa/psf	726.4	Final Effective Stress, KPa/psf	924.8
OCR	1	OCR	1
Preconsolidation Pressure, KPa/psf	618.76	Preconsolidation Pressure, KPa/psf	817.16
Modified Primary Compression Index, $C_{c\varepsilon}$	0.03	Modified Primary Compression Index, $C_{c\varepsilon}$	0.03
Modified Recompression Index, $C_{r\varepsilon}$	0.0045	Modified Recompression Index, $C_{r\varepsilon}$	0.0045
Modified Secondary Compression Index, $C_{\alpha\varepsilon}$	0.0011	Modified Secondary Compression Index, $C_{\alpha\varepsilon}$	0.0011
ratio of t2 / t1	22.3	ratio of t2 / t1	22.3
Settlements		Settlements	
Primary Settlement, (m / ft)	0.005	Primary Settlement, (m / ft)	0.004
Secondary Settlement (m / ft)	0.003	Secondary Settlement (m / ft)	0.003
Total Settlement (m / ft)	0.009	Total Settlement (m / ft)	0.007

Calculation for Silt and Clay

Layer No.	1	Layer No.	4
Layer Thickness, m / ft	5	Layer Thickness, m / ft	5
Midpoint Depth from Top of Silt/Clay, m/ft	2.5	Midpoint Depth from Top of Silt/Clay, m/ft	17.5
Effective Stress Before Dredging, KPa/psf	951	Effective Stress Before Dredging, KPa/psf	1635
Initial Effective Stress, KPa/psf	828.24	Initial Effective Stress, KPa/psf	1512.24
Final Effective Stress, KPa/psf	1058.64	Final Effective Stress, KPa/psf	1742.64
OCR	1	OCR	1
Preconsolidation Pressure, KPa/psf	951	Preconsolidation Pressure, KPa/psf	1635
Modified Primary Compression Index, $C_{c\varepsilon}$	0.223	Modified Primary Compression Index, $C_{c\varepsilon}$	0.223
Modified Recompression Index, $C_{r\varepsilon}$	0.025	Modified Recompression Index, $C_{r\varepsilon}$	0.025
Modified Secondary Compression Index, $C_{\alpha\varepsilon}$	0.01	Modified Secondary Compression Index, $C_{\alpha\varepsilon}$	0.01
ratio of t2 / t1	5.2	ratio of t2 / t1	5.2
Settlements		Settlements	
Primary Settlement, (m / ft)	0.059	Primary Settlement, (m / ft)	0.035
Secondary Settlement (m / ft)	0.036	Secondary Settlement (m / ft)	0.036
Total Settlement (m / ft)	0.095	Total Settlement (m / ft)	0.071

Layer No.	2	Layer No.	5
Layer Thickness, m / ft	5	Layer Thickness, m / ft	5
Midpoint Depth from Top of Silt/Clay, m/ft	7.5	Midpoint Depth from Top of Silt/Clay, m/ft	22.5
Effective Stress Before Dredging, KPa/psf	1179	Effective Stress Before Dredging, KPa/psf	1863
Initial Effective Stress, KPa/psf	1056.24	Initial Effective Stress, KPa/psf	1740.24
Final Effective Stress, KPa/psf	1286.64	Final Effective Stress, KPa/psf	1970.64
OCR	1	OCR	1
Preconsolidation Pressure, KPa/psf	1179	Preconsolidation Pressure, KPa/psf	1863
Modified Primary Compression Index, $C_{c\varepsilon}$	0.223	Modified Primary Compression Index, $C_{c\varepsilon}$	0.223
Modified Recompression Index, $C_{r\varepsilon}$	0.025	Modified Recompression Index, $C_{r\varepsilon}$	0.025
Modified Secondary Compression Index, $C_{\alpha\varepsilon}$	0.01	Modified Secondary Compression Index, $C_{\alpha\varepsilon}$	0.01
ratio of t2 / t1	5.2	ratio of t2 / t1	5.2
Settlements		Settlements	
Primary Settlement, (m / ft)	0.048	Primary Settlement, (m / ft)	0.031
Secondary Settlement (m / ft)	0.036	Secondary Settlement (m / ft)	0.036
Total Settlement (m / ft)	0.084	Total Settlement (m / ft)	0.067

Layer No.	3	Layer No.	6
Layer Thickness, m / ft	5	Layer Thickness, m / ft	5
Midpoint Depth from Top of Silt/Clay, m/ft	12.5	Midpoint Depth from Top of Silt/Clay, m/ft	27.5
Effective Stress Before Dredging, KPa/psf	1407	Effective Stress Before Dredging, KPa/psf	2091
Initial Effective Stress, KPa/psf	1284.24	Initial Effective Stress, KPa/psf	1968.24
Final Effective Stress, KPa/psf	1514.64	Final Effective Stress, KPa/psf	2198.64
OCR	1	OCR	1
Preconsolidation Pressure, KPa/psf	1407	Preconsolidation Pressure, KPa/psf	2091
Modified Primary Compression Index, $C_{c\varepsilon}$	0.223	Modified Primary Compression Index, $C_{c\varepsilon}$	0.223
Modified Recompression Index, $C_{r\varepsilon}$	0.025	Modified Recompression Index, $C_{r\varepsilon}$	0.025
Modified Secondary Compression Index, $C_{\alpha\varepsilon}$	0.01	Modified Secondary Compression Index, $C_{\alpha\varepsilon}$	0.01
ratio of t2 / t1	5.2	ratio of t2 / t1	5.2
Settlements		Settlements	
Primary Settlement, (m / ft)	0.041	Primary Settlement, (m / ft)	0.028
Secondary Settlement (m / ft)	0.036	Secondary Settlement (m / ft)	0.036
Total Settlement (m / ft)	0.076	Total Settlement (m / ft)	0.063

An Example Calculation of
Upward Cumulative Consolidation Water Flow

Loading

Cap thickness =	4	ft
Cap unit weight =	120	psf
Load =	230.4	psf

Properties

	Top Layer	Bottom Layer			
Type	SOLW	Silt and Clay			
k =	1.0E-05	1.0E-07	cm/s	A =	0.7272
	1.8E-01	1.8E-03	ft/d	B =	2.0E+00
Cv =	3.50	0.09	ft2/d	C =	2.0E-02
H =	39	30	ft		
Cαε =	0.0011	0.0100			
t90 =	435	2500	days		
	1.2	6.8	years		

Reference Values

zR =	69.0	69.0	ft
uR =	2.30	2.30	psf
tR =	1360	52900	days
	4	145	years

Time Step

Select δt to ensure convergence of solution

	δt =	0.0030	0.0030	years
		1	1	days
	δt-bar =	8.05E-04	2.07E-05	
	δz =	3	3	ft
	δz-bar =	0.04	0.04	
bar	$\delta t_1/(\delta z)^2$ =	0.43	0.01	should be less than 0.5

U-bar values

Z (ft)	z-bar	s1	s2	s3	s4	s5	s6	s7	s8	s9	s10	s10	s10	s10	s10	s10	s10	s10
t (years)		0.00	0.00	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.04	0.04	0.04	0.05	0.05
t (days)		0	1	2	3	4	5	7	8	9	10	11	12	13	14	15	16	18
t-bar		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0.0	100	57	51	42	39	35	33	30	29	27	26	25	24	23	22	22	21
6	0.1	100	100	82	76	69	65	60	57	54	52	49	48	46	44	43	42	41
9	0.1	100	100	100	92	89	84	80	77	74	71	68	66	64	62	61	59	58
12	0.2	100	100	100	100	97	95	92	89	87	84	82	80	78	76	75	73	71
15	0.2	100	100	100	100	100	99	98	96	94	93	91	89	88	86	85	83	82
18	0.3	100	100	100	100	100	100	99	99	98	97	96	95	94	93	92	90	89
21	0.3	100	100	100	100	100	100	100	100	99	99	99	98	97	96	96	95	94
24	0.3	100	100	100	100	100	100	100	100	100	100	100	99	99	98	98	98	97
27	0.4	100	100	100	100	100	100	100	100	100	100	100	100	100	99	99	99	99
30	0.4	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	99
33	0.5	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
36	0.5	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
39	0.6	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
42	0.6	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
45	0.7	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
48	0.7	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
51	0.7	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
54	0.8	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
57	0.8	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
60	0.9	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
63	0.9	100	100	100	100	100	100	100	100	100	100	100	99	99	99	99	99	99
66	1.0	100	99	98	97	96	95	94	93	92	91	90	89	88	87	87	86	85
69	1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Top Layer																	
Initial Area =	3900	3900	3900	3900	3900	3900	3900	3900	3900	3900	3900	3900	3900	3900	3900	3900	3900
Current Area =	3700	3530	3468	3392	3342	3288	3244	3201	3162	3124	3090	3056	3024	2993	2963	2935	2907
U-ave=	5%	9%	11%	13%	14%	16%	17%	18%	19%	20%	21%	22%	22%	23%	24%	25%	25%
Final primary settlement (ft) =	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Current primary settlement (ft) =	0.01	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.04
Current secondary settlement (ft) =	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Current total settlement (ft) =	0.01	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.04
Bottom Layer																	
Initial Area =	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000
Current Area =	2900	2896	2891	2887	2883	2879	2875	2871	2867	2863	2859	2855	2852	2848	2845	2841	2837
U-ave=	3%	3%	4%	4%	4%	4%	4%	4%	4%	5%	5%	5%	5%	5%	5%	5%	5%
Final primary settlement (ft) =	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Current primary settlement (ft) =	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Current secondary settlement (ft) =	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Current total settlement (ft) =	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Total																	
Total current settlement (ft) =	0.01	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.05	0.05	0.05

Note: Due to the limited paper size, only part of the calculation sheet is shown here.

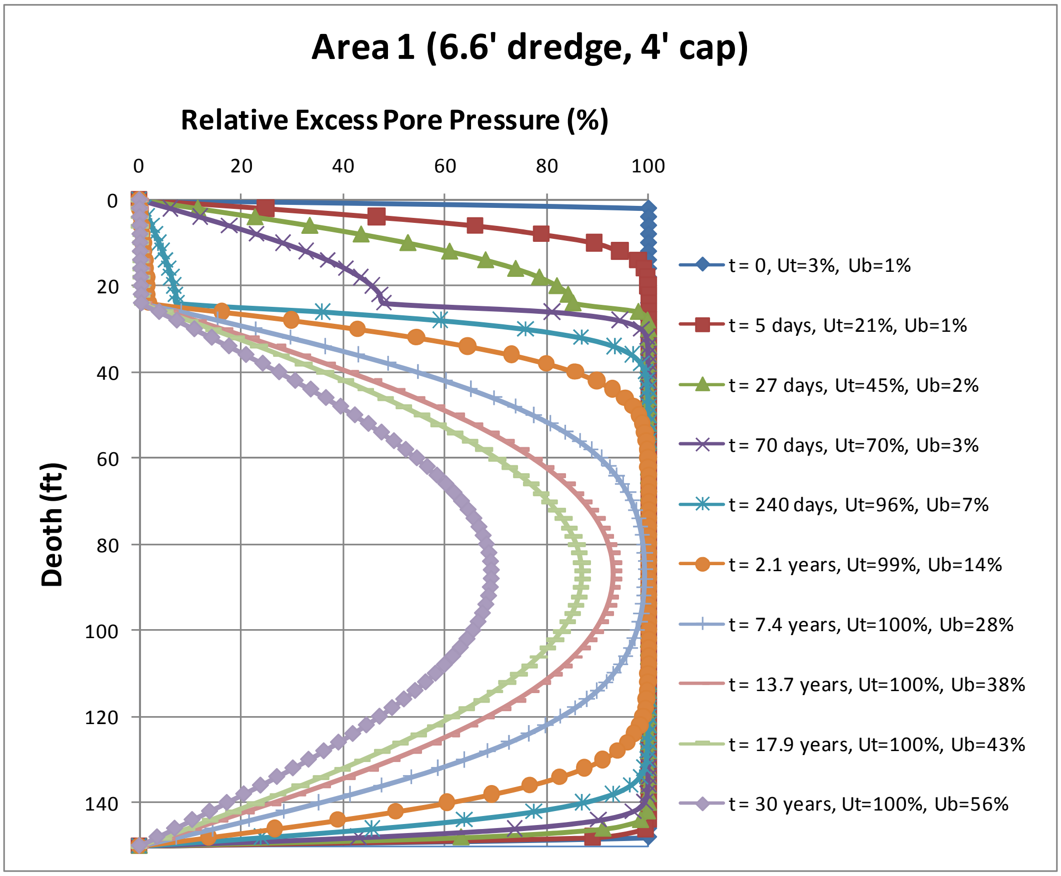
U bar and settlement results summary

Uave top		5%	16%	30%	51%	73%	93%	99%	100%	100%	100%
Uave bot		3%	4%	6%	12%	22%	41%	79%	98%	100%	100%
t (years)		0.00	0.02	0.07	0.23	0.54	1.29	4.21	10.54	18.97	30.00
t (days)		0.00	5.48	25.19	82.13	196.01	469.75	1536.29	3845.64	6924.78	10950.00
Z (ft)		t = 0, Ut=5%, Ub=	t = 5 days, Ut=16%, Ub	t = 25 days, Ut=30%, Ub=6	t = 82 days, Ut=	t = 196 days, U	t = 1.3 years, U	t = 4.2 years, U	t = 10.5 years, U	t = 19.0 years, U	t = 30 years, Ut=100%, Ub=100%
	0	0	0	0	0	0	0	0	0	0	0
	3	100	35	18	10	5	1	0	0	0	0
	6	100	65	34	20	10	3	0	0	0	0
	9	100	84	50	29	15	4	0	0	0	0
	12	100	95	63	38	20	5	1	0	0	0
	15	100	99	74	46	25	7	1	0	0	0
	18	100	100	82	54	29	8	1	0	0	0
	21	100	100	88	60	33	9	1	0	0	0
	24	100	100	93	66	36	10	1	0	0	0
	27	100	100	96	71	39	11	1	0	0	0
	30	100	100	98	75	41	12	1	0	0	0
	33	100	100	99	78	43	12	1	0	0	0
	36	100	100	99	80	45	13	1	0	0	0
	39	100	100	100	81	45	13	2	0	0	0
	42	100	100	100	96	77	43	12	1	0	0
	45	100	100	100	99	92	66	20	2	0	0
	48	100	100	100	100	98	79	27	3	0	0
	51	100	100	100	100	99	86	32	3	0	0
	54	100	100	100	100	98	85	33	4	0	0
	57	100	100	100	99	95	79	31	3	0	0
	60	100	100	100	97	86	67	26	3	0	0
	63	100	100	98	87	69	48	19	2	0	0
	66	100	95	80	57	39	26	10	1	0	0
	69	0	0	0	0	0	0	0	0	0	0
Cumulative Upward Consc		0.01	0.03	0.06	0.10	0.15	0.21	0.30	0.37	0.42	0.46

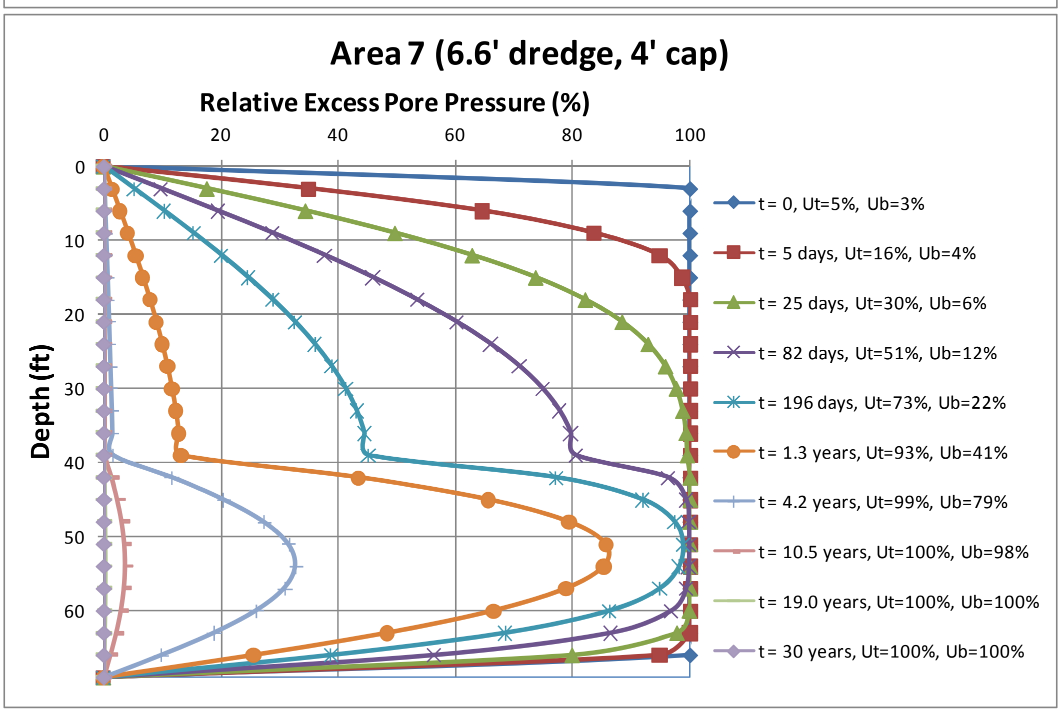
ATTACHMENT D

CALCULATED EXCESS PORE WATER PRESSURE ISOCHRONES

Note:
In the charts presented herein, Ut = the average degree of consolidation of top layer (i.e., SOLW); Ub = the average degree of consolidation of bottom layer (i.e., Marl + Silt and Clay).



Area 1 (6.6' dredge, 4' cap)
Relative Excess Pore Pressure (%)
0
20
40
60
80
100
0
20
40
60
80
100
120
140
Deoth (ft)
t= 0, Ut=3%, Ub=1%
t= 5 days, Ut=21%, Ub=1%
t= 27 days, Ut=45%, Ub=2%
t= 70 days, Ut=70%, Ub=3%
t= 240 days, Ut=96%, Ub=7%
t= 2.1 years, Ut=99%, Ub=14%
t= 7.4 years, Ut=100%, Ub=28%
t= 13.7 years, Ut=100%, Ub=38%
t= 17.9 years, Ut=100%, Ub=43%
t= 30 years, Ut=100%, Ub=56%



Area 7 (6.6' dredge, 4' cap)
Relative Excess Pore Pressure (%)
0
20
40
60
80
100
0
10
20
30
40
50
60
Depth (ft)
t= 0, Ut=5%, Ub=3%
t= 5 days, Ut=16%, Ub=4%
t= 25 days, Ut=30%, Ub=6%
t= 82 days, Ut=51%, Ub=12%
t= 196 days, Ut=73%, Ub=22%
t= 1.3 years, Ut=93%, Ub=41%
t= 4.2 years, Ut=99%, Ub=79%
t= 10.5 years, Ut=100%, Ub=98%
t= 19.0 years, Ut=100%, Ub=100%
t= 30 years, Ut=100%, Ub=100%

ATTACHMENT E

ADDITIONAL SENSITIVITY ANALYSIS FOR CAP-INDUCED SETTLEMENTS

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Memorandum

Date: 13 December 2011

To: Laura Brussel, P.E. and Ed Glaza, P.E.
Parsons

From: Ramachandran Kulasingam, Ph.D., P.E. and J.F. Beech, Ph.D., P.E.
Geosyntec Consultants

Subject: Cap-Induced Settlement Evaluation for Remediation Area D – Additional Sensitivity Analyses, Onondaga Lake, Syracuse, NY

Appendix E.2 (i.e., "Cap-Induced Settlement Evaluation for Remediation Area D" [Geosyntec, 2011]) of the *Draft Onondaga Lake Capping, Dredging, Habitat and Profundal Zone (Sediment Management Unit 8) Draft Final Design* presents calculations of the amount and rate of consolidation settlement anticipated after dredging and placement of a subaqueous cap in Remediation Area D of the Onondaga Lake Bottom Site. In addition, the upward flow rate of consolidation water was provided as part of that appendix. This memorandum presents sensitivity analyses to illustrate the effect of consolidation parameter variability on the calculated upward flow rate of consolidation water.

Specifically, sensitivity analyses were performed to calculate the upward flow rate of consolidation water using upper bound and lower bound consolidation parameters. Selection of these upper and lower bound values is described in Appendix E.2. Table 1 of this memorandum presents the upper bound, lower bound, and average/representative values for the consolidation parameters. Figures 1 and 2 of this memorandum present the calculated cumulative upward consolidation water flow for Areas 7 and 9, respectively, using the lower bound, average, and upper bound parameters. As in Appendix E.2, the representative dredge/cap scenario was evaluated for each area (i.e., 2-m dredge/4-ft cap for Area 7 and no dredge/3-ft cap for Area 9). As presented in Appendix E.2, the consolidation water flow variation with time was fitted with a parabolic curve in the form of $y=ax^b$, where "y" is the calculated cumulative upward consolidation water flow in ft and "x" is the time in years. Parameters "a" and "b" are constants obtained by curve fitting. Table 2 presents the selected values of "a" and "b" for Areas 7 and 9 for the lower bound, average, and upper bound parameters.

REFERENCES

Geosyntec Consultants (2011). Appendix E.2: "Cap-Induced Settlement Evaluation for Remediation Area D", Onondaga Lake, August 2011.

Parsons and Anchor QEA (2011). "Draft Onondaga Lake Capping, Dredging, Habitat and Profundal Zone (Sediment Management Unit 8) Draft Final Design", Syracuse, NY, August 2011.

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TABLES

Table 1. Selected Representative, Reasonable Upper Bound, and Reasonable Lower Bound Values for Consolidation Parameters.

Material	$C_{c\varepsilon}$	$C_{r\varepsilon}$	$C_{\alpha\varepsilon}$	c_v (ft^2/d)
Selected Reasonable Upper Bound Values				
SOLW	0.045	0.0059	0.0030	7.000
Marl	0.142	0.0110	0.0080	0.130 (SMU 1) 0.230 (SMU 2)[1]
Silt and Clay (SMU 1)	0.251	0.0317	0.0130	0.130
Silt and Clay (SMU 2)	0.203	0.0220	0.0070	0.230
Selected Reasonable Lower Bound Values				
SOLW	0.015	0.0031	0.0003	0.050[2]
Marl	0.087	0.0083	0.0025	0.050[2]
Silt and Clay (SMU 1)	0.196	0.0183	0.0070	0.050
Silt and Clay (SMU 2)	0.119	0.0102	0.0040	0.050
Selected Representative Values				
SOLW	0.030	0.0045	0.0011	3.500
Marl	0.117	0.0099	0.0050	0.090 (SMU 1) 0.100 (SMU 2)[3]
Silt and Clay (SMU 1)	0.223	0.0250	0.0100	0.090
Silt and Clay (SMU 2)	0.154	0.0179	0.0050	0.100

Notes:

[1]. The interpreted reasonable upper bound value of c_v of Marl is 0.15 ft^2/d. However, for the purpose of analysis, the reasonable upper bound value of c_v of Marl was assumed the same as Silt and Clay (i.e., 0.13 and 0.23 ft^2/d in SMUs 1 and 2, respectively) in the settlement calculations.

[2]. The interpreted reasonable lower bound values of c_v of SOLW and Marl are 0.1 and 0.12 ft^2/d, respectively. However, for the purpose of analysis, the reasonable lower bound values of c_v of SOLW and Marl were assumed the same as Silt and Clay (i.e., 0.05 ft^2/d) in the settlement calculations.

[3]. The interpreted c_v of Marl is 0.135 ft^2/d. However, for the purpose of analysis, the c_v of Marl was assumed to be the same as Silt and Clay (i.e., 0.09 and 0.1 ft^2/d in SMUs 1 and 2, respectively) in settlement calculations.

Table 2. Selected a and b values to model the variation of cumulative upward flow of consolidation water (y - ft) with time (x – years) using the equation $y=ax^b$

Area	Using Lower Bound Consolidation Parameters		Using Average/Representative Consolidation Parameters		Using Upper Bound Consolidation Parameters	
	a	b	a	b	a	b
7	0.0352	0.470	0.211	0.226	0.341	0.245
9	0.0554	0.410	0.310	0.226	0.521	0.203

FIGURES

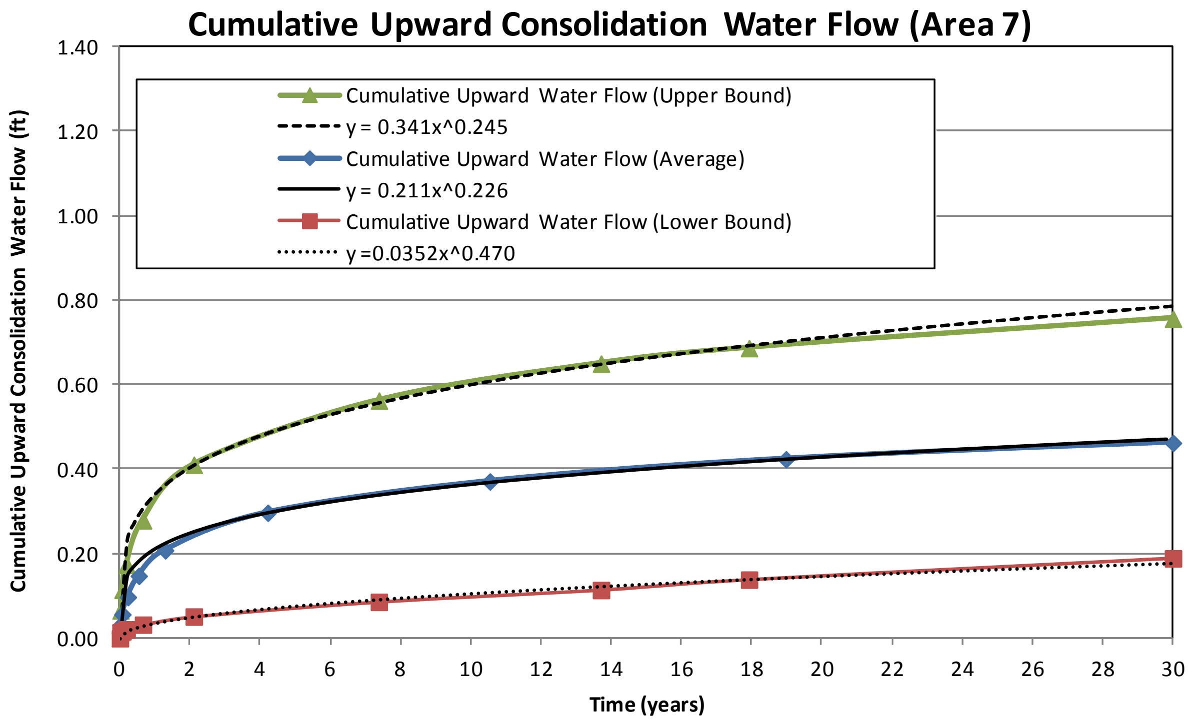

Figure 1. Calculated Cumulative Consolidation Water Flow for Area 7 with Representative, Lower Bound, and Upper Bound Parameters.

Note:
Calculations were performed for 2 m dredge and 4 ft thick cap.

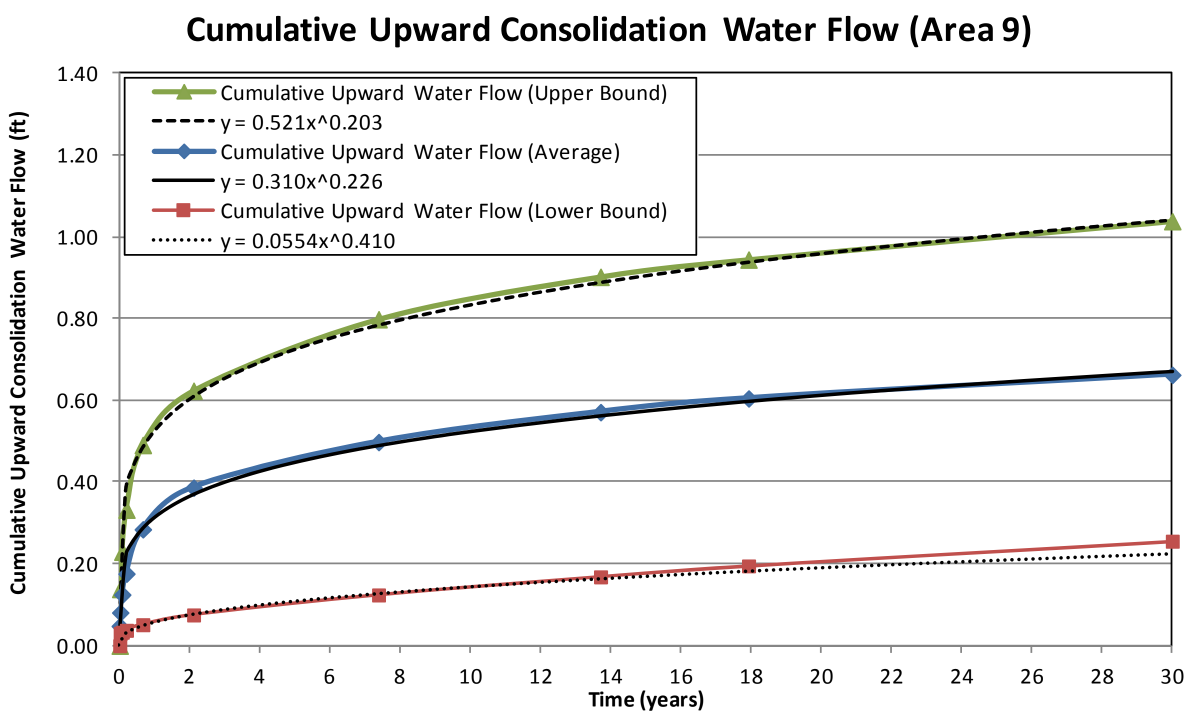

Figure 2. Calculated Cumulative Consolidation Water Flow for Area 9 with Representative, Lower Bound, and Upper Bound Parameters.

Note:
Calculations were performed for no dredging and 3 ft thick cap.