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CAP-INDUCED SETTLEMENT EVALUATION FOR REMEDIATION AREA D

Prepared for

Parsons
301 Plainfield Road, Suite 350
Syracuse, New York 13212

CAP-INDUCED SETTLEMENT EVALUATION FOR REMEDIATION AREA D

ONONDAGA LAKE
SYRACUSE, NEW YORK

Prepared by

Geosyntec consultants

engineers | scientists | innovators

1255 Roberts Boulevard, Suite 200
Kennesaw, Georgia 30144

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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. A preliminary dredging plan and the potential maximum and minimum cap thicknesses in Remediation Area D were provided to Geosyntec by Parsons to facilitate settlement evaluations and are shown in Figures 2 and 3, respectively.

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 H of the Draft Capping and Dredge Area and Depth Initial Design Submittal (IDS), 2009]. 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 4. 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 results are presented in Phase I and Phase II Pre-Design Investigation Data Summary Report [Parsons 2007 and 2009]. A summary of those results is presented in Attachment B.

(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 5. 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 5. 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 6 through 13. 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 6 through 13).

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.

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

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

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

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

Secondary Settlement

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

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:

$$T = \frac{c_v t}{H_{dr}^2} \tag{5}$$

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

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

It was assumed that, T is approximately equal to 1 at the end of primary compression (i.e., U = 93%, using Equation 6B). Therefore, t_1 can be calculated using the following equation:

$$t_1 = \frac{H_{dr}^2}{c_v} \tag{7}$$

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.

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 = compressibility.

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

$$\bar{u} = \frac{u}{u_R} \tag{10A}$$

$$\bar{t} = \frac{t}{t_R} \tag{10B}$$

$$\bar{z} = \frac{z}{z_R} \tag{10C}$$

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 14. The FDM equations for a node in a homogeneous layer and at a layer interface are presented in Equations 11A and 11B, respectively.

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

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

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

The dredging plan and the maximum and minimum cap thickness in Remediation Area D were provided to Geosyntec by Parsons, as shown in Figures 2 and 3 respectively. In summary, 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 ft to 5.5 ft. 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 4.

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 15. 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 16.

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 15 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. 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 17. 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. 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.

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.

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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	0.0031
				Mean minus Standard Deviation	0.015	0.0059

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 11. 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 11. 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 10 and 11. 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

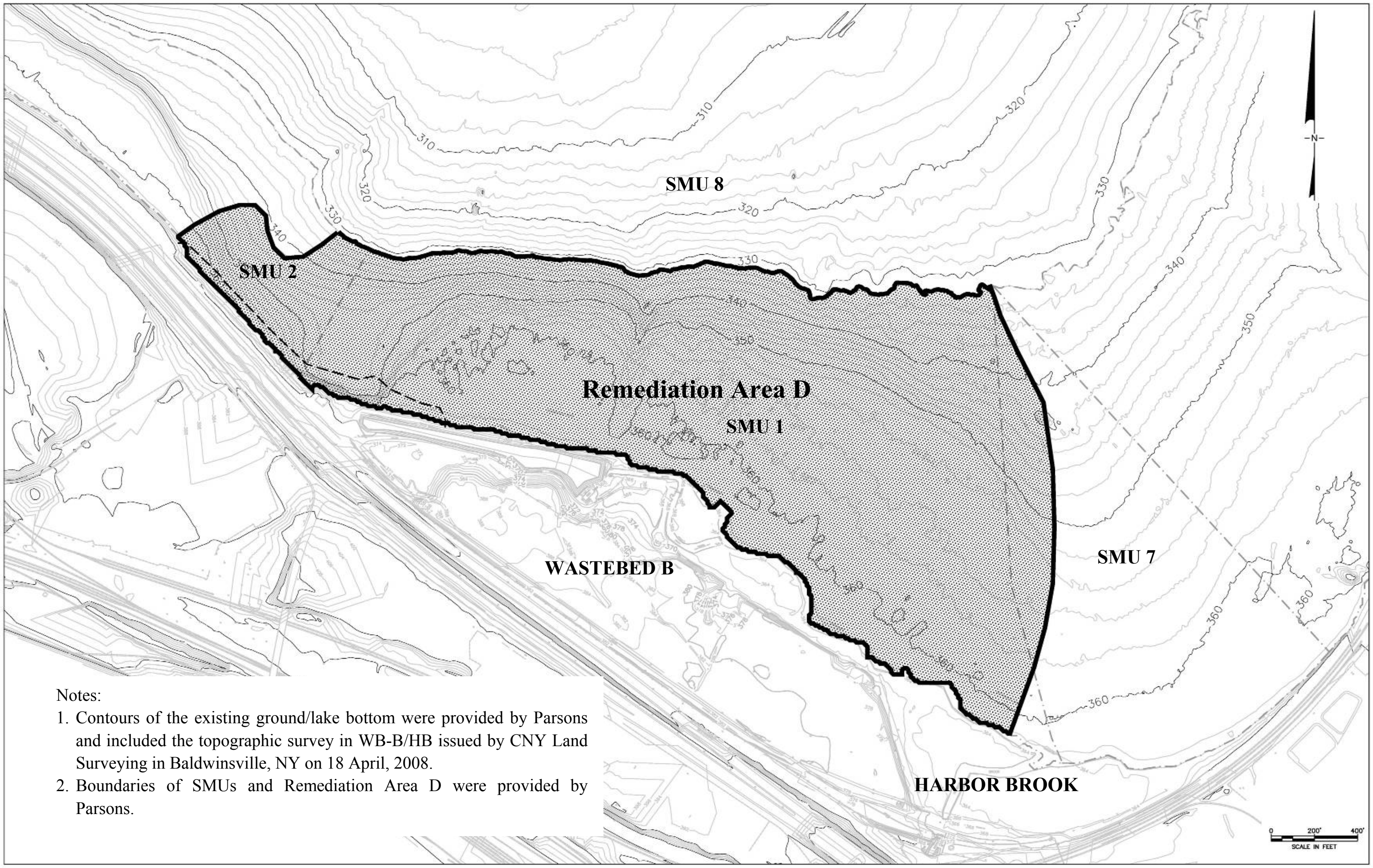


Figure 1. Remediation Area D.

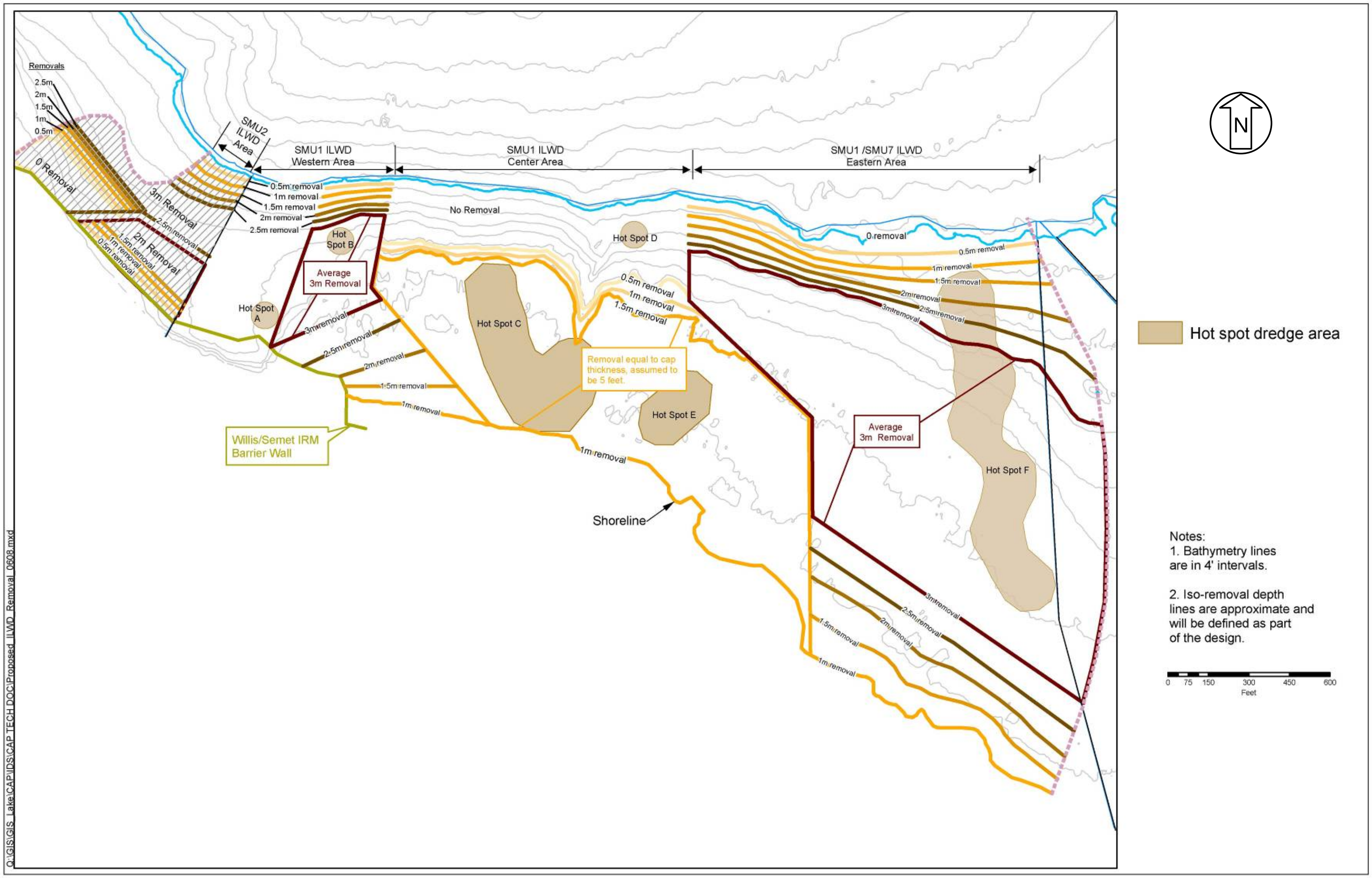


Figure 2. Remediation Area D Preliminary Dredging Plan
(Figure provided by Parsons to Geosyntec).

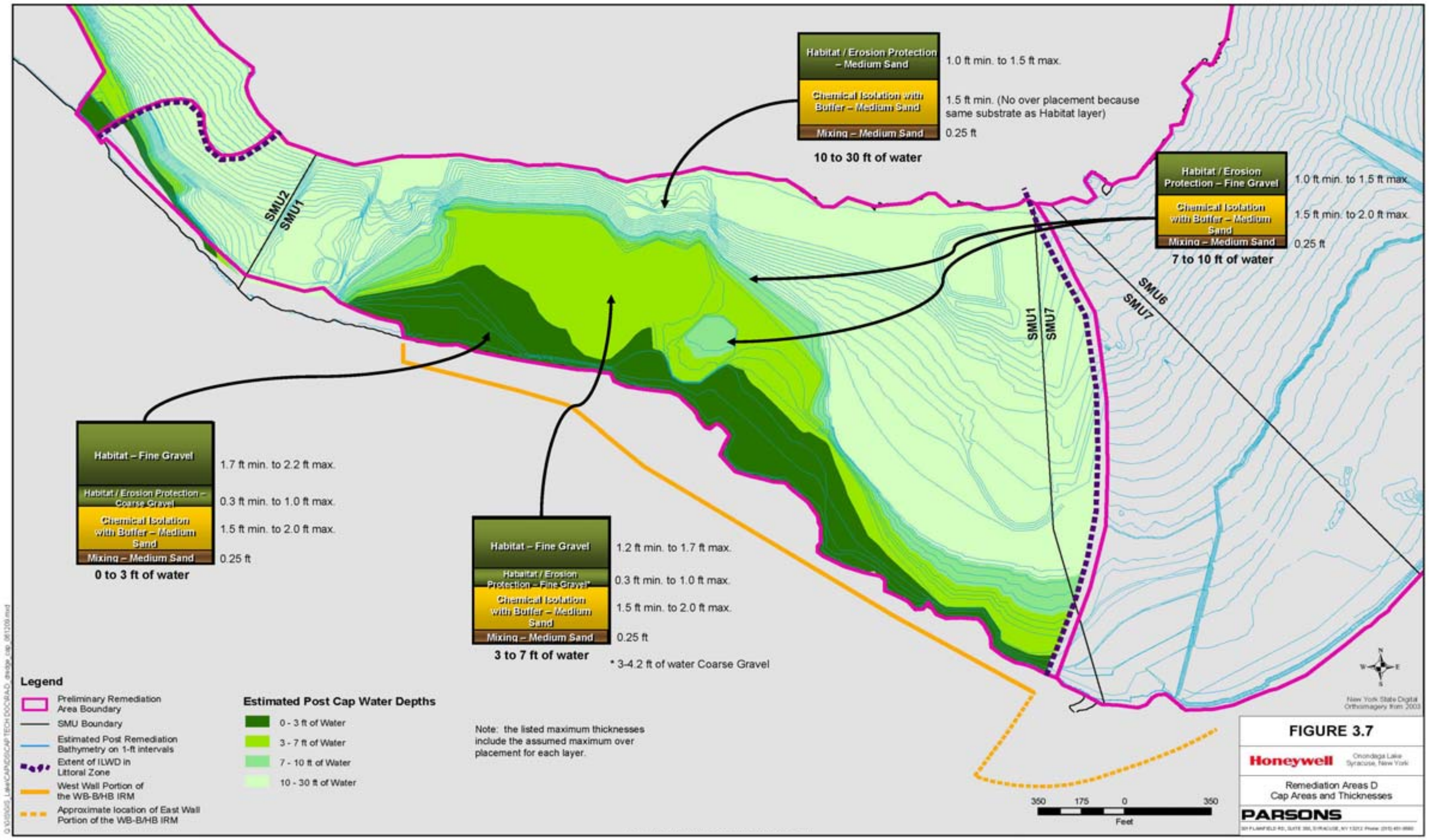
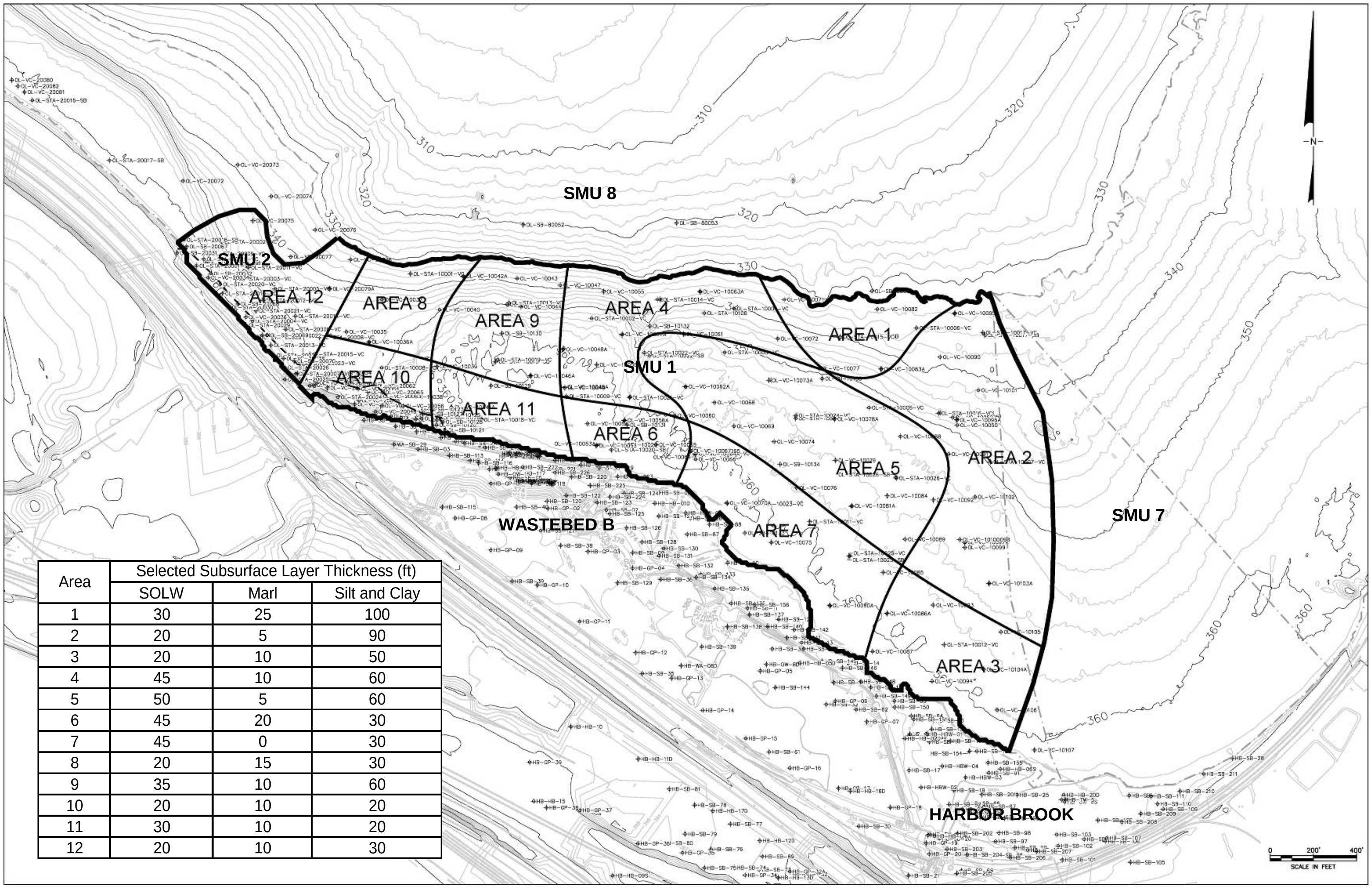


Figure 3. Cap Thickness in Remediation Area D
(Figure provided to Geosyntec by Parsons).

Note:

The above cap configuration was assumed for the purposes of the analyses presented herein. Slight modifications to cap thickness should not impact the outcome of the analyses. As necessary, changes to the cap configuration will be addressed in subsequent design submittals.



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 4. Areas and Subsurface Layer Thicknesses.

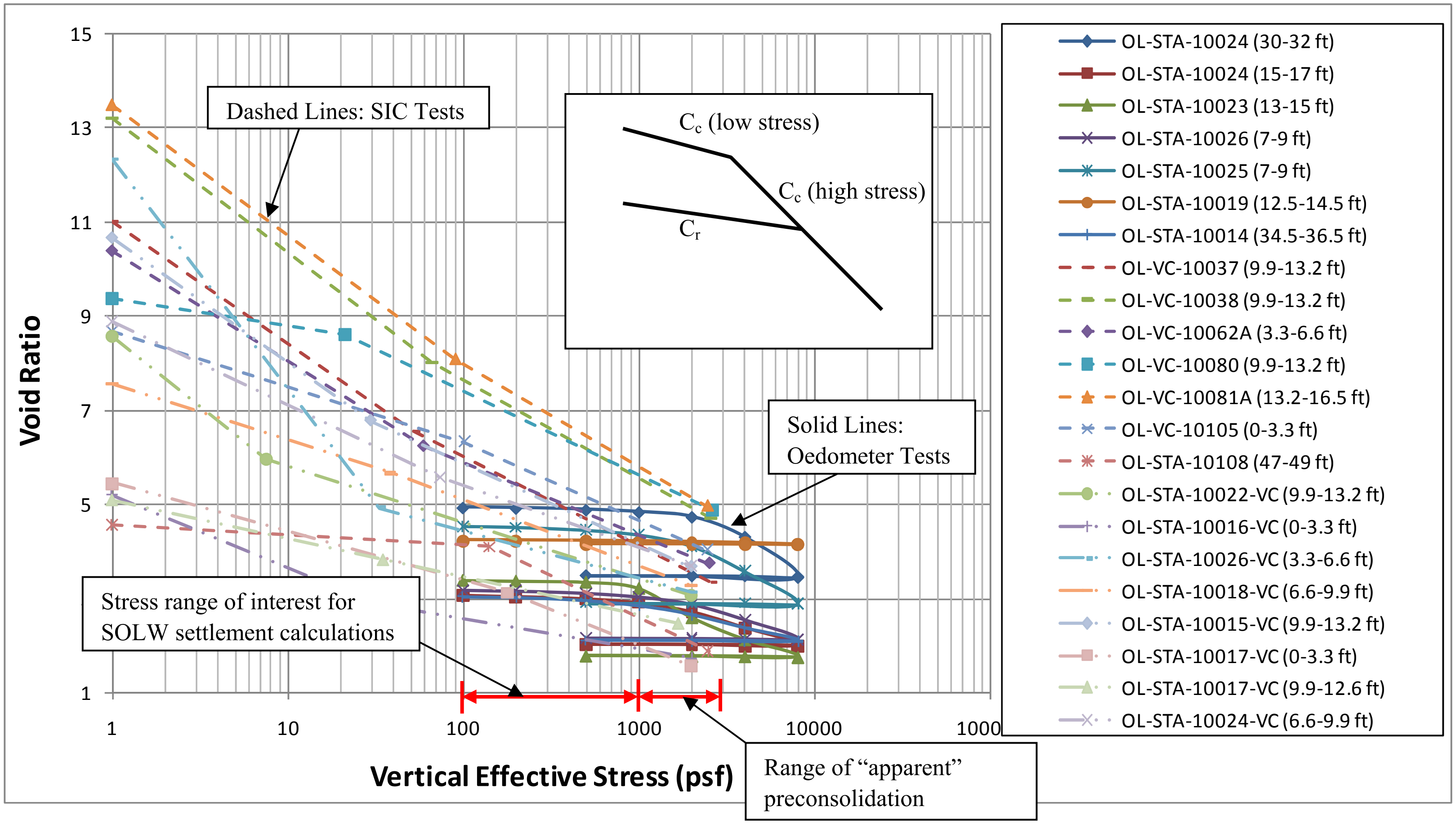


Figure 5. Comparison of Results from Conventional Oedometer Tests and SIC Tests.

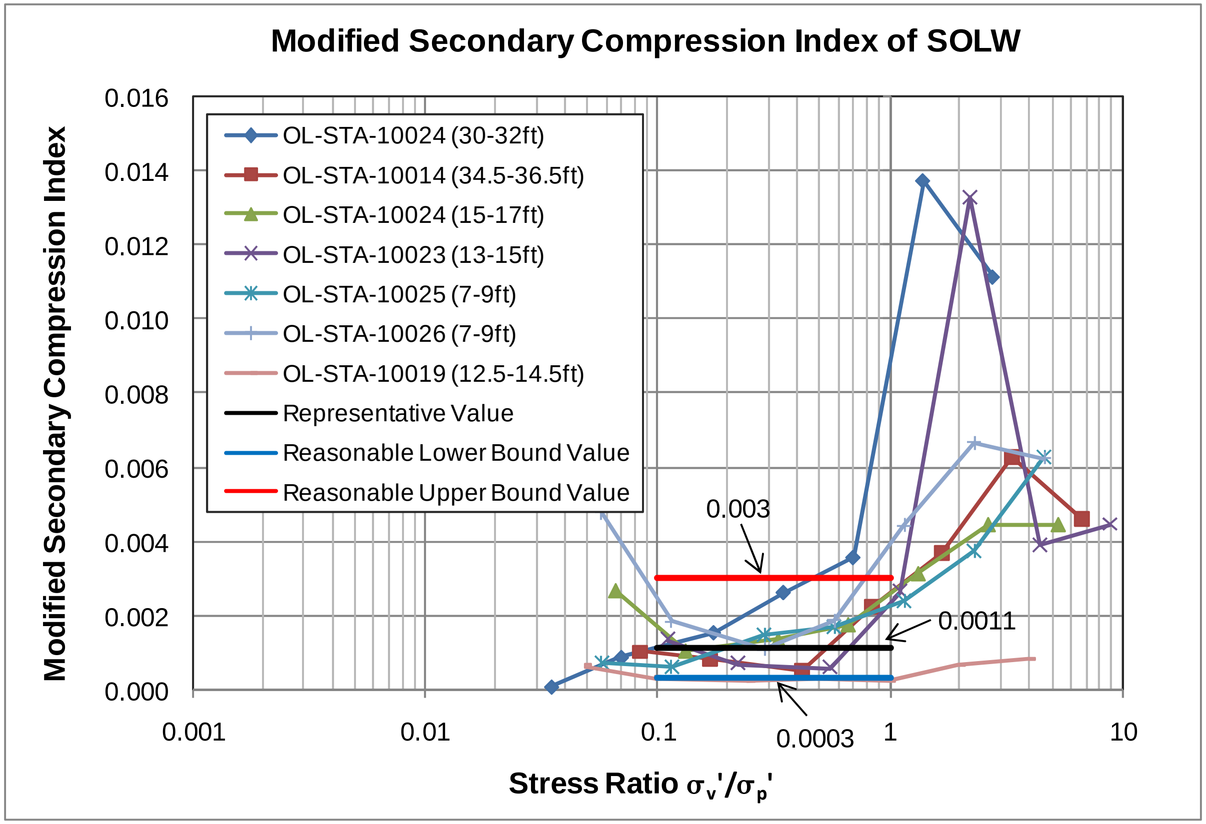


Figure 6. Interpretation of Modified Secondary Compression Index for SOLW.

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.

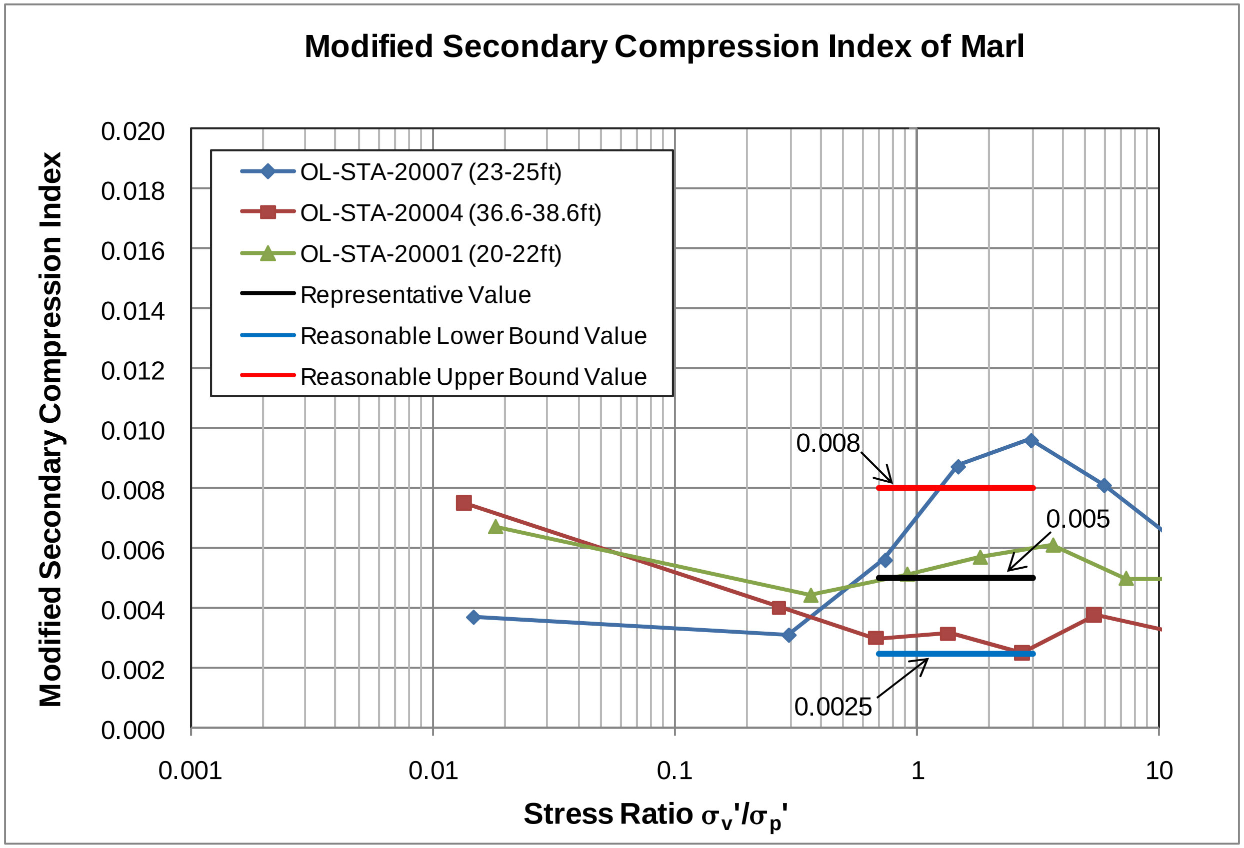


Figure 7. Interpretation of Modified Secondary Compression Index for Marl.

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.

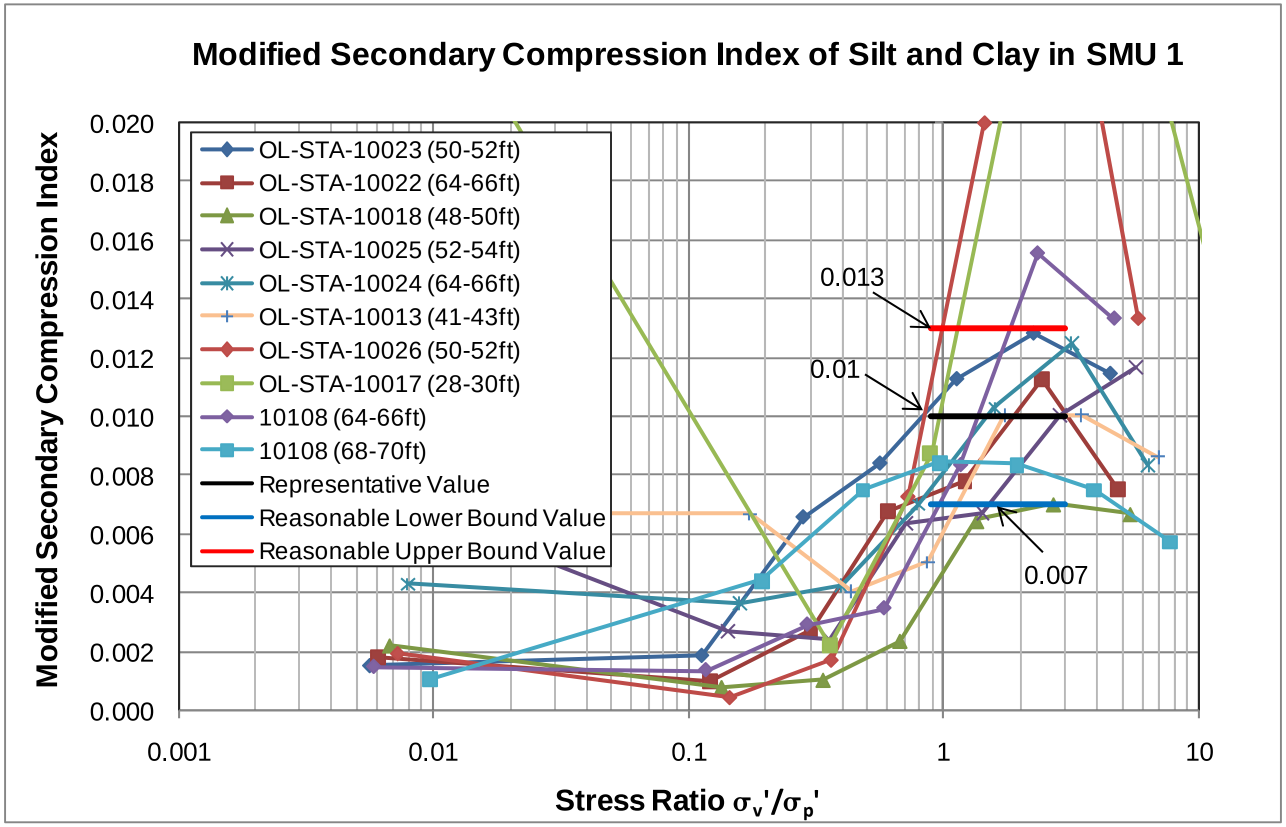


Figure 8. Interpretation of Modified Secondary Compression Index for Silt and Clay in SMU 1.

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.

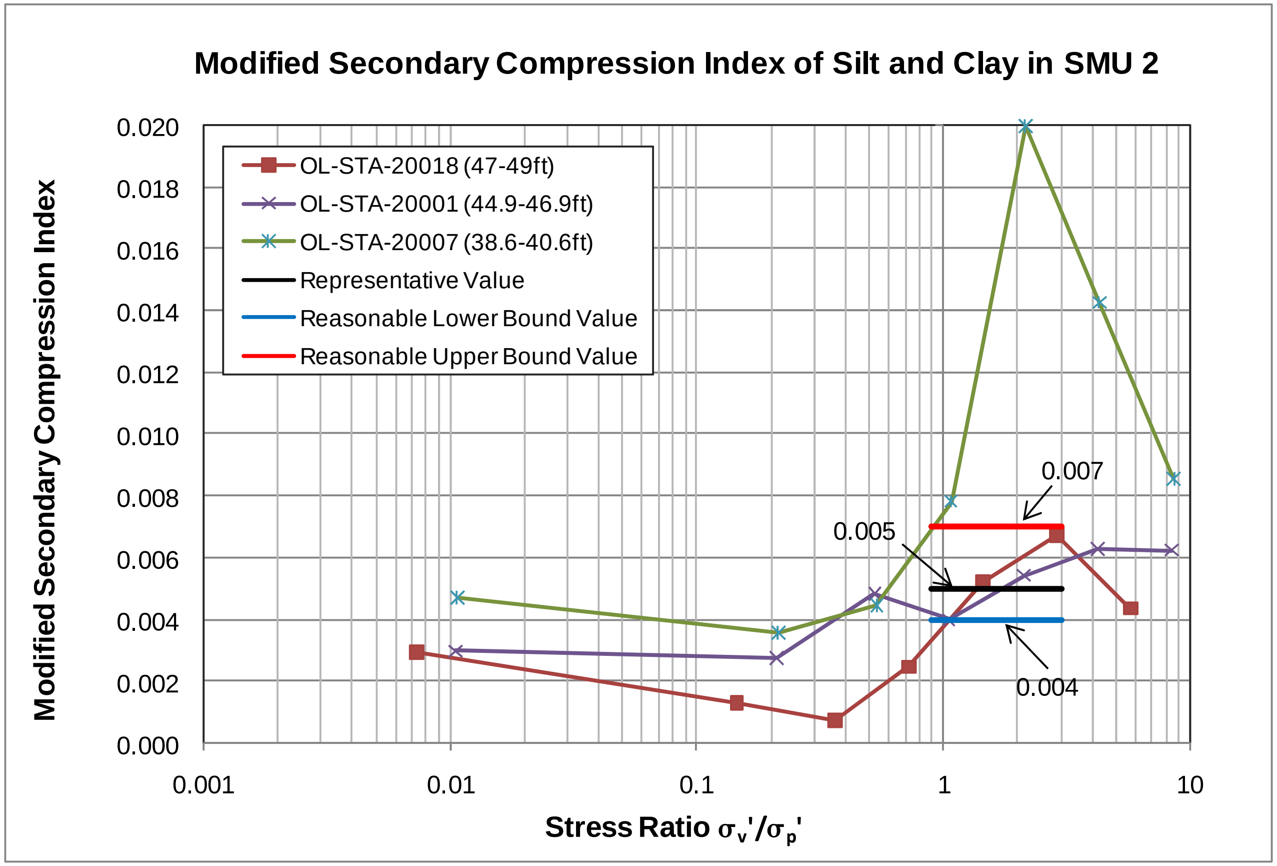


Figure 9. Interpretation of Modified Secondary Compression Index for Silt and Clay in SMU 2.

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.

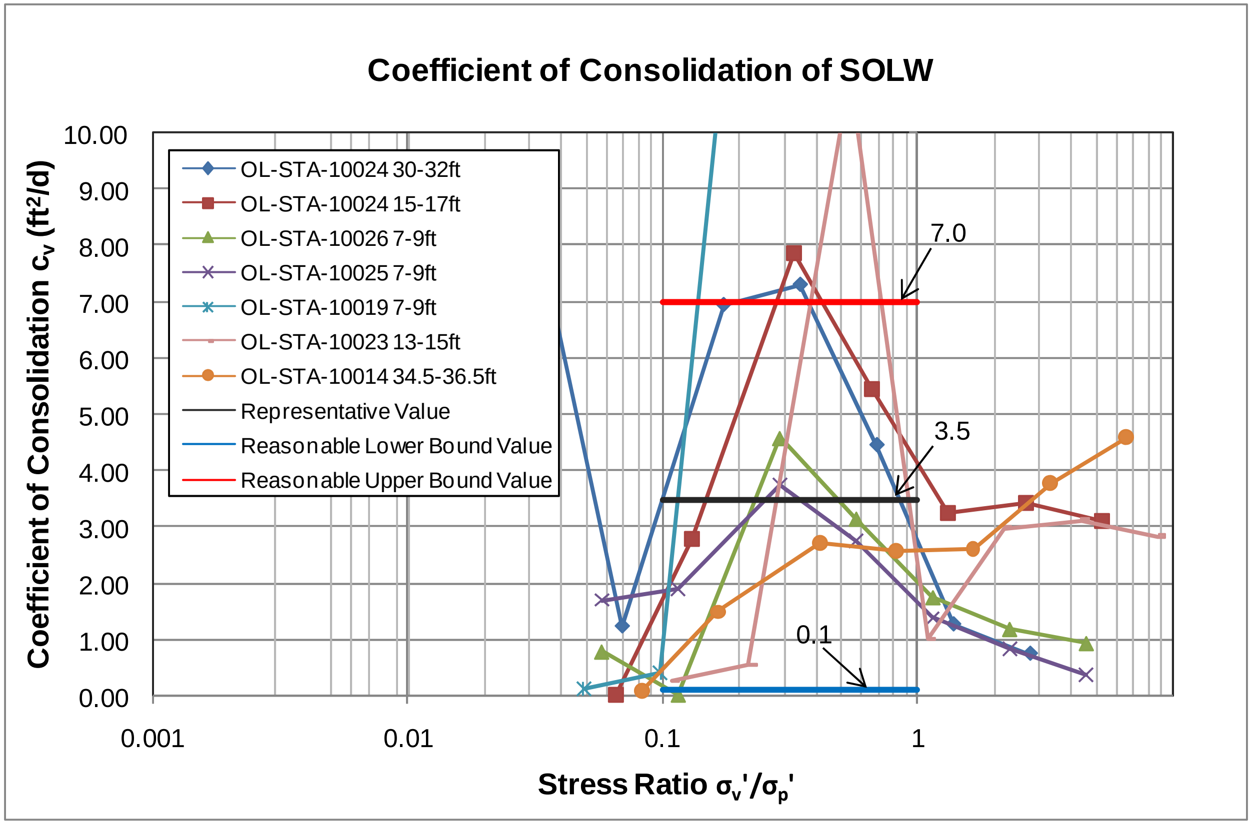


Figure 10. Interpretation of Coefficient of Consolidation Index for SOLW.

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.

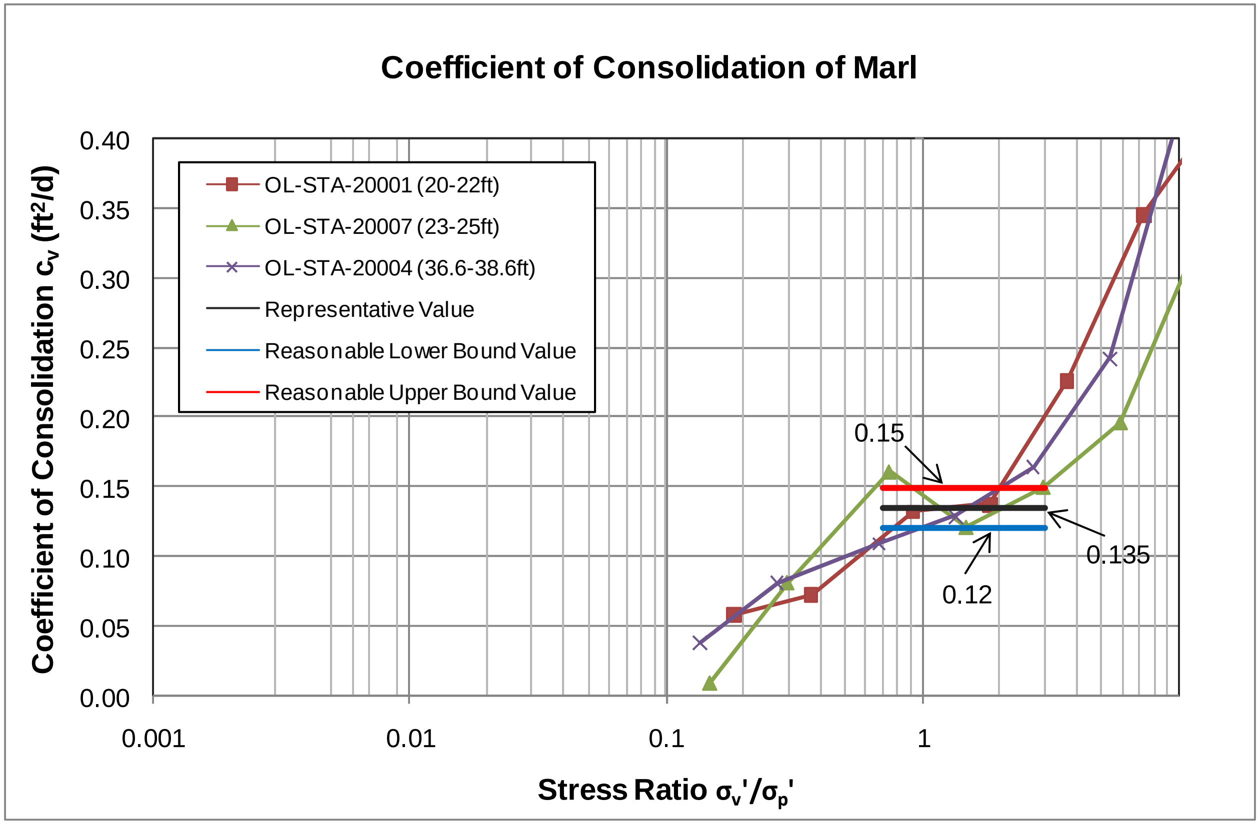


Figure 11. Interpretation of Coefficient of Consolidation Index for Marl.

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.

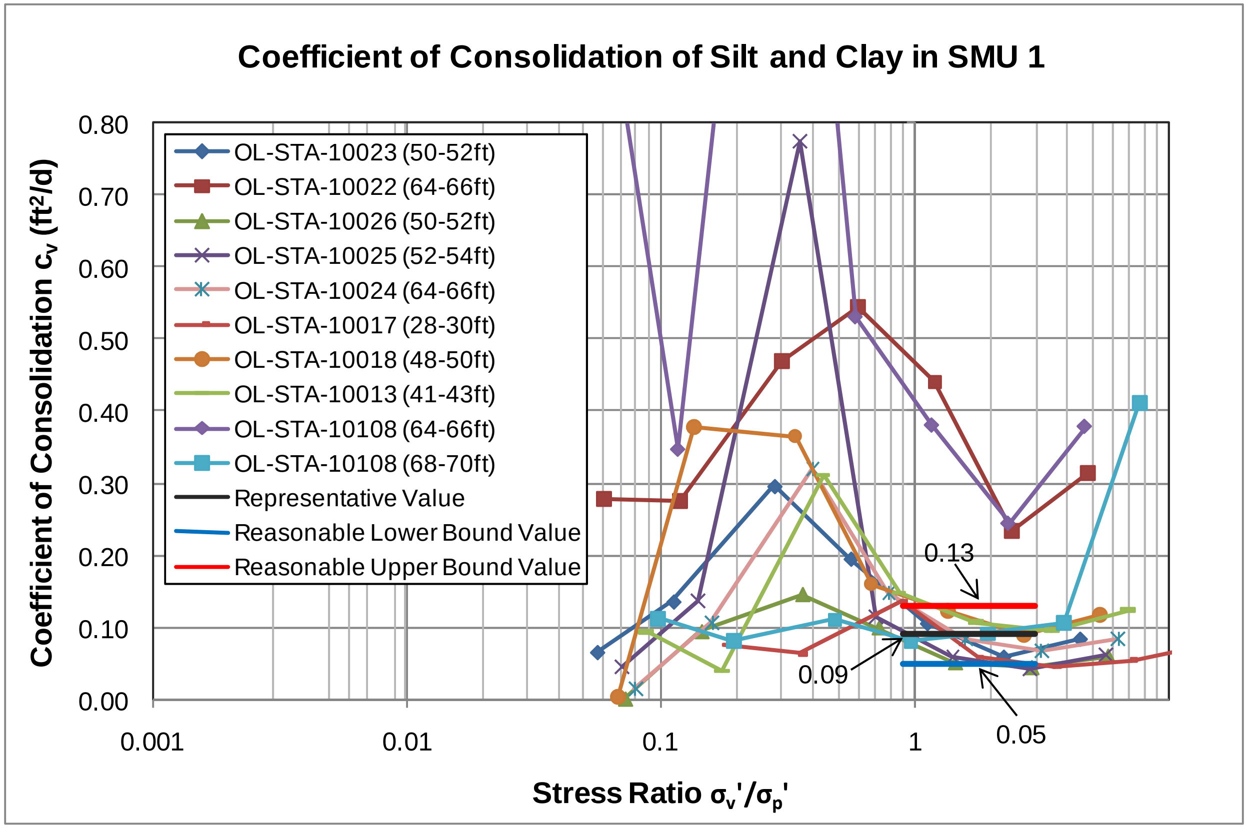


Figure 12. Interpretation of Coefficient of Consolidation Index for Silt and Clay in SMU 1.

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.

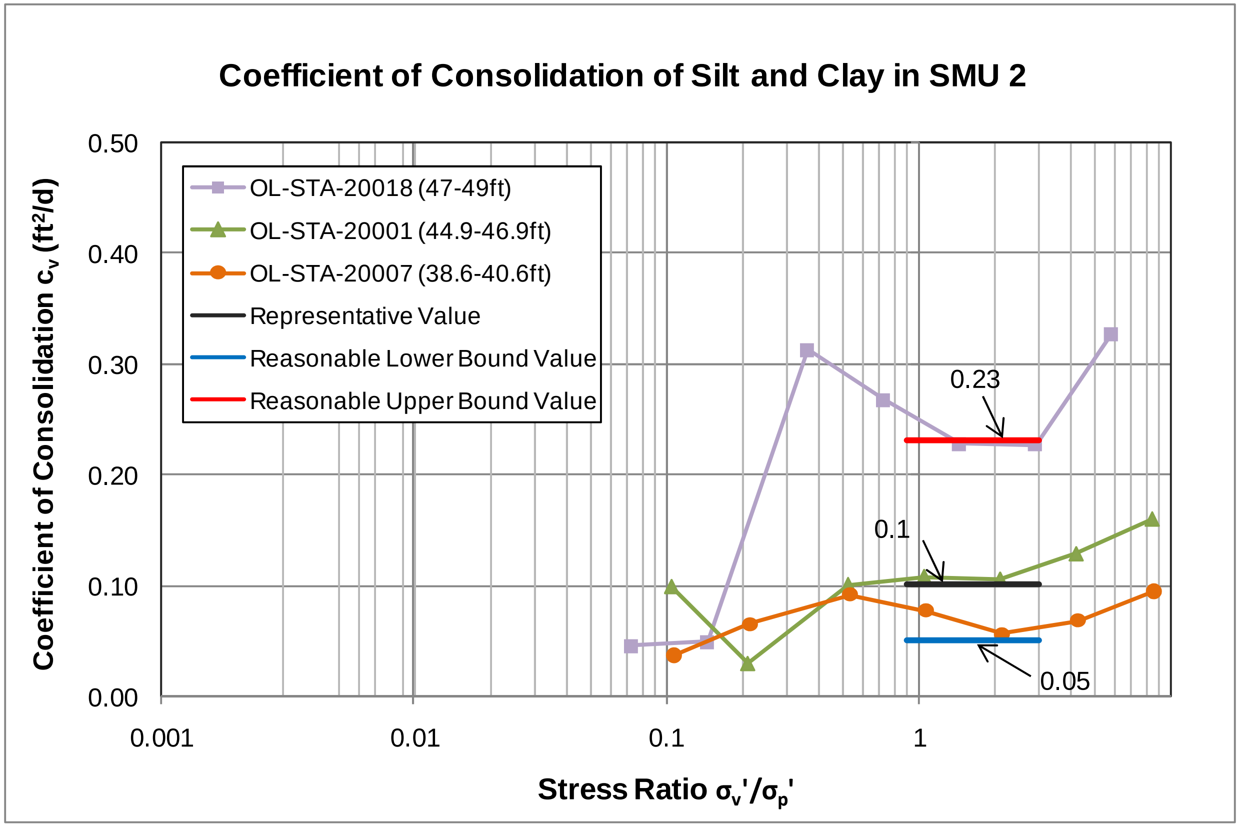
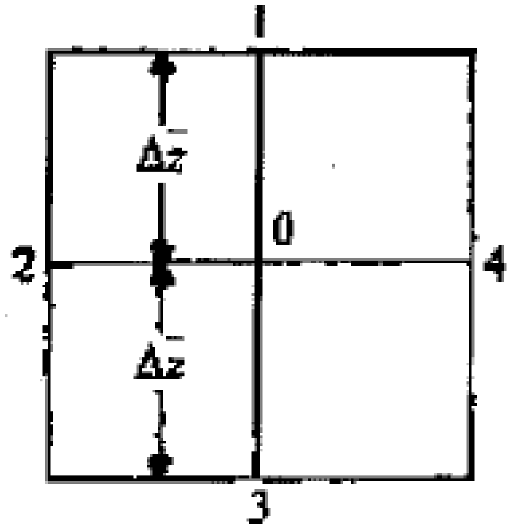


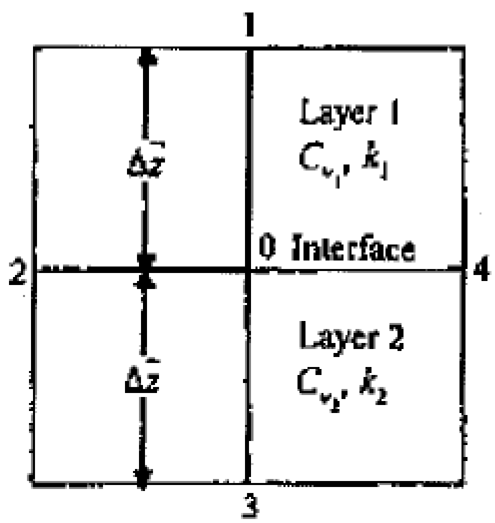
Figure 13. Interpretation of Coefficient of Consolidation Index for Silt and Clay in SMU 2.

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 14. 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)

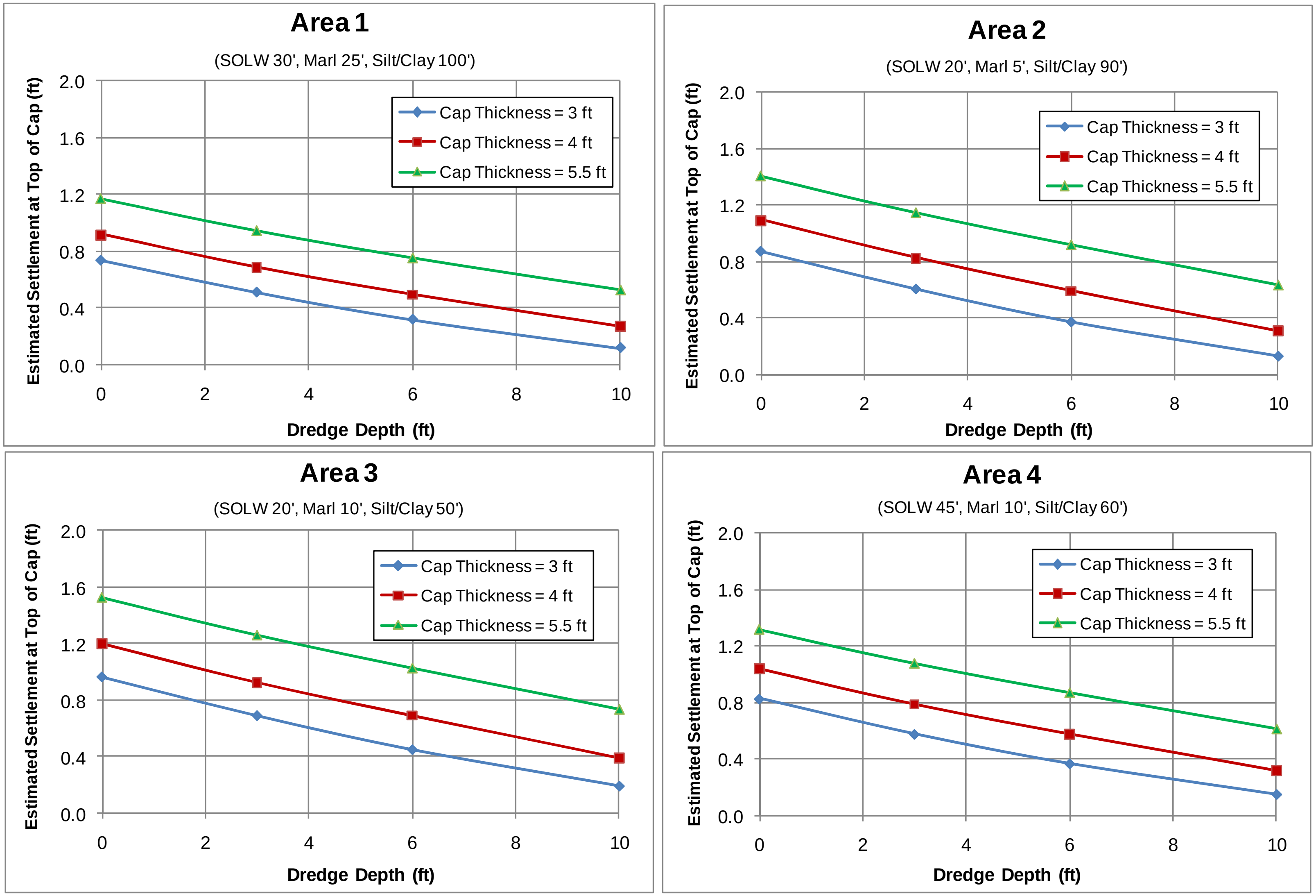


Figure 15. Settlement Analysis Results for Areas 1 to 12 for 30-Year Period.

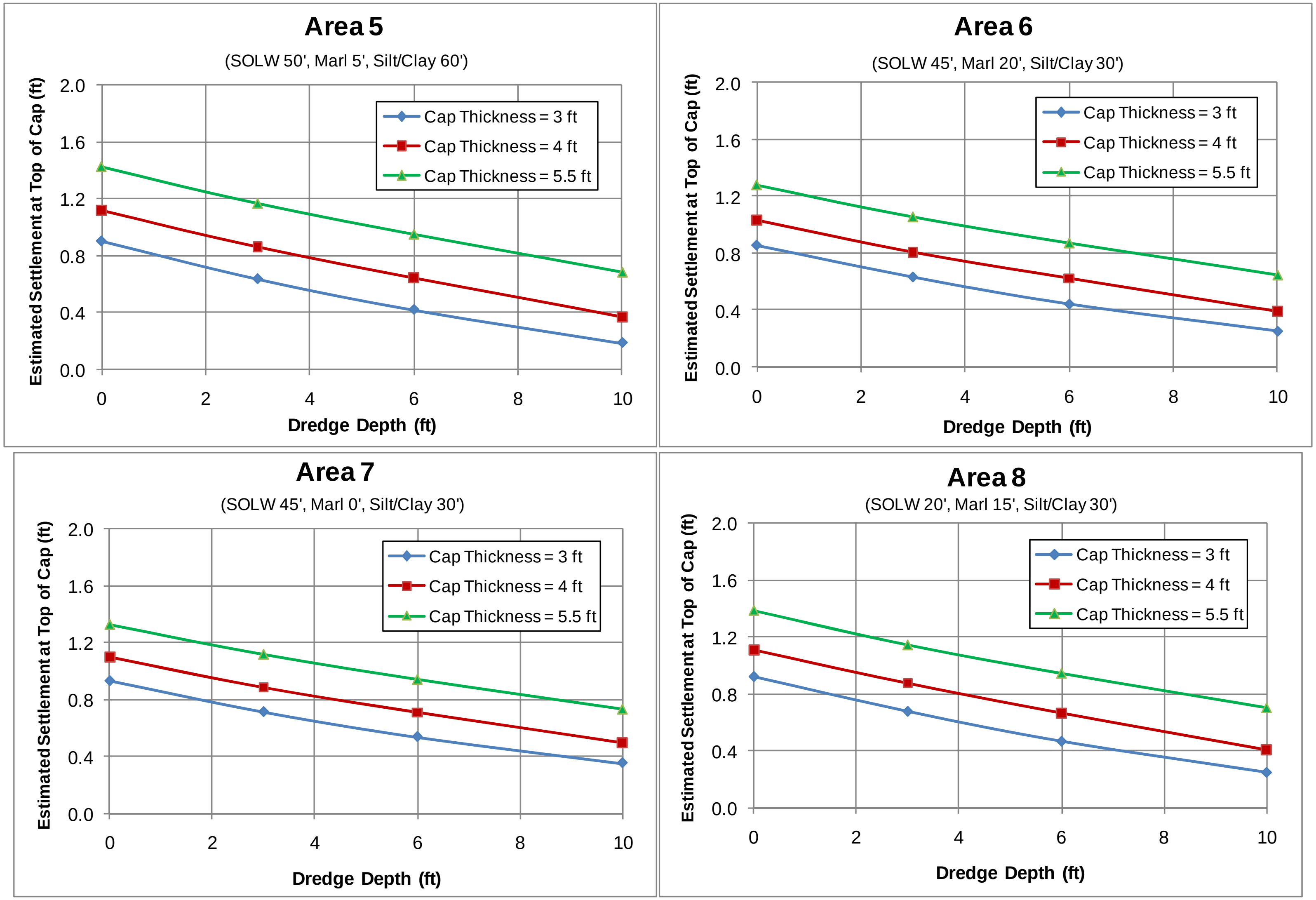


Figure 15. Settlement Analysis Results for Areas 1 to 12 for 30-Year Period (continued).

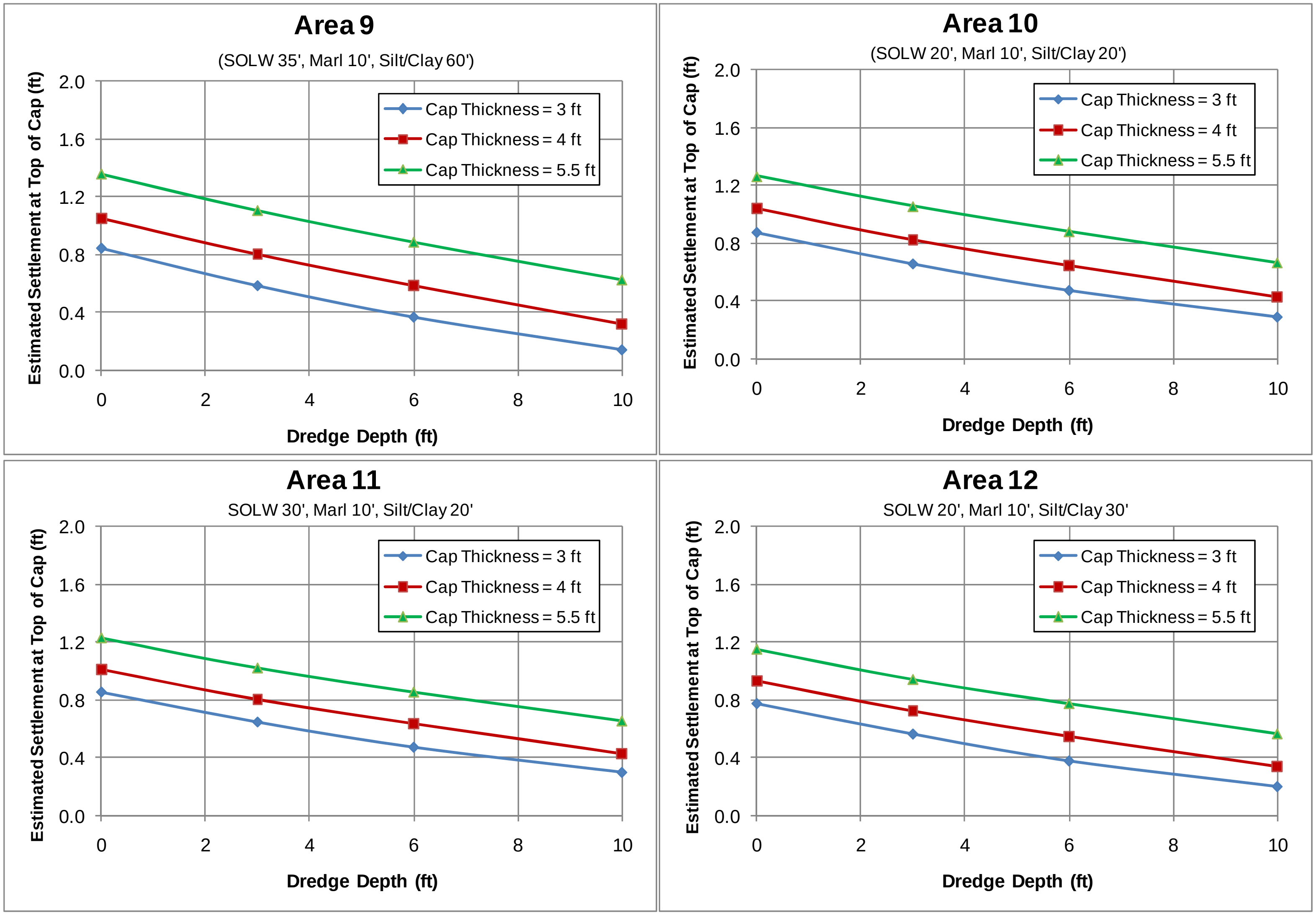


Figure 15. Settlement Analysis Results for Areas 1 to 12 for 30-Year Period (continued).

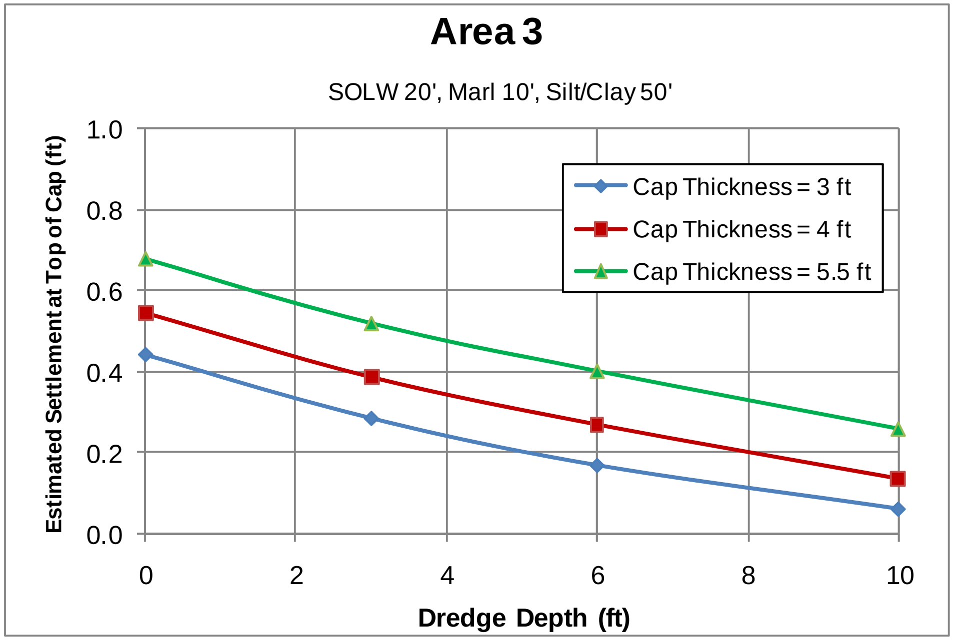


Figure 16. Settlement Analysis Results for Area 3 for 2-Year Period.

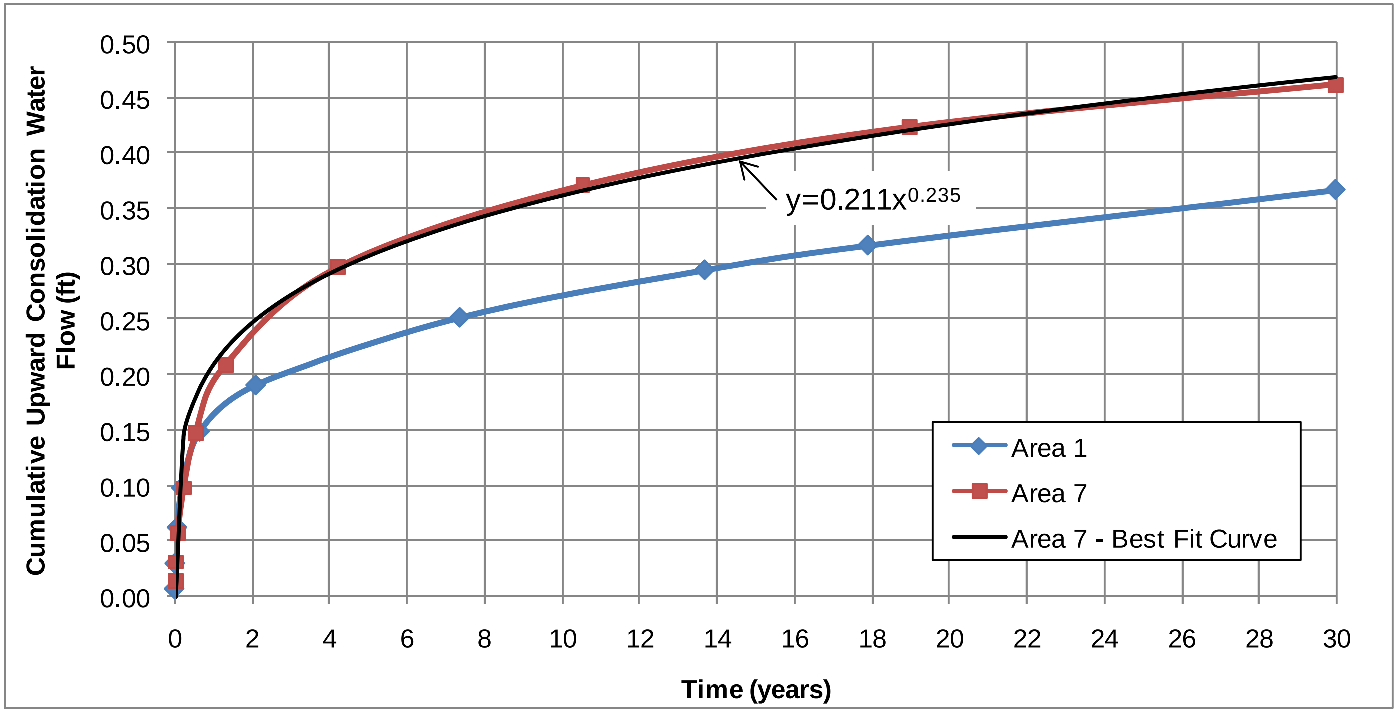


Figure 17. Calculated Cumulative Consolidation Water Flow.

Note:

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

ATTACHMENT A

SUBSURFACE LAYER THICKNESS CONTOURS

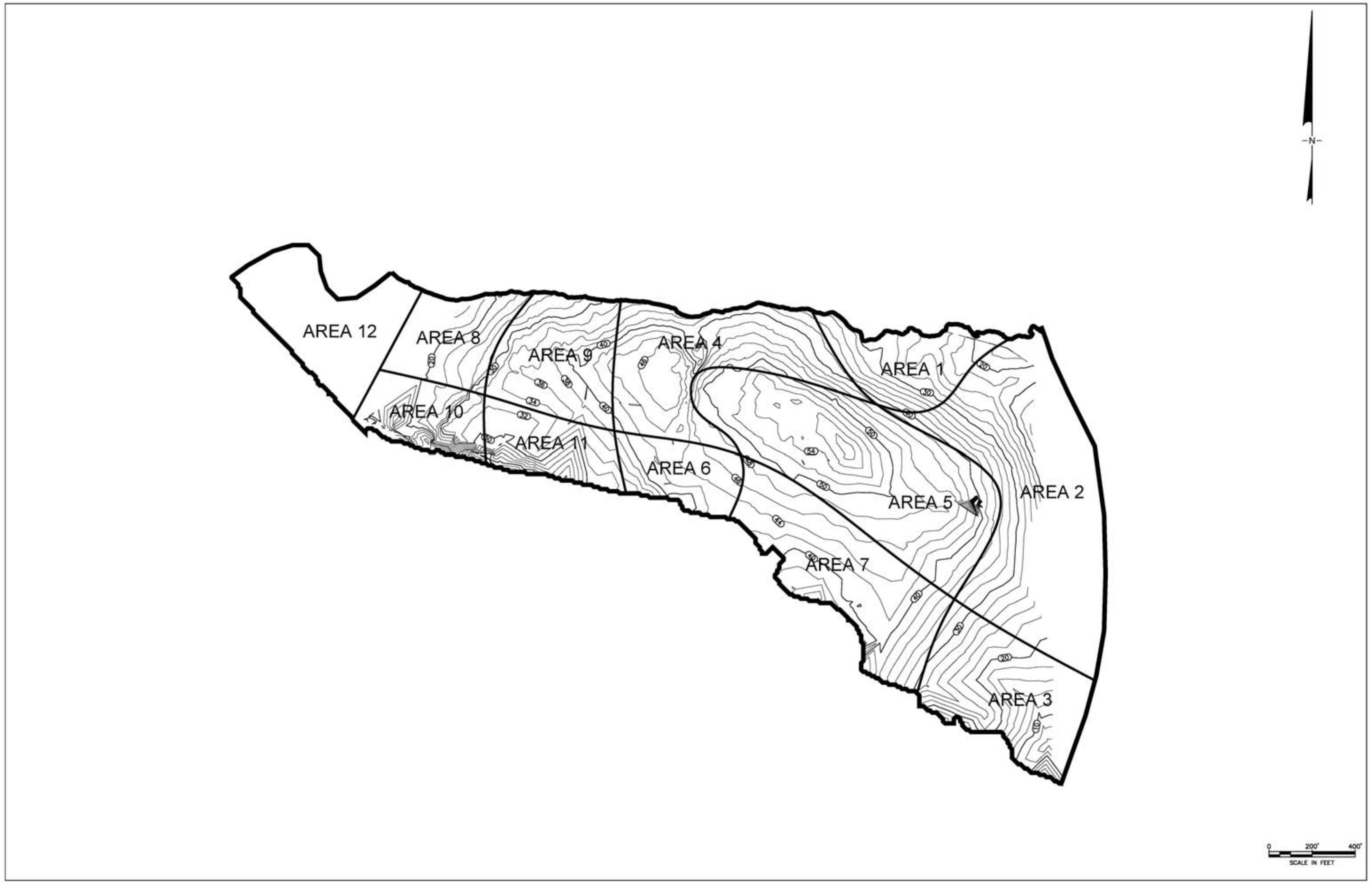


Figure A1. The Thickness of SOLW in Remediation Area D

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.

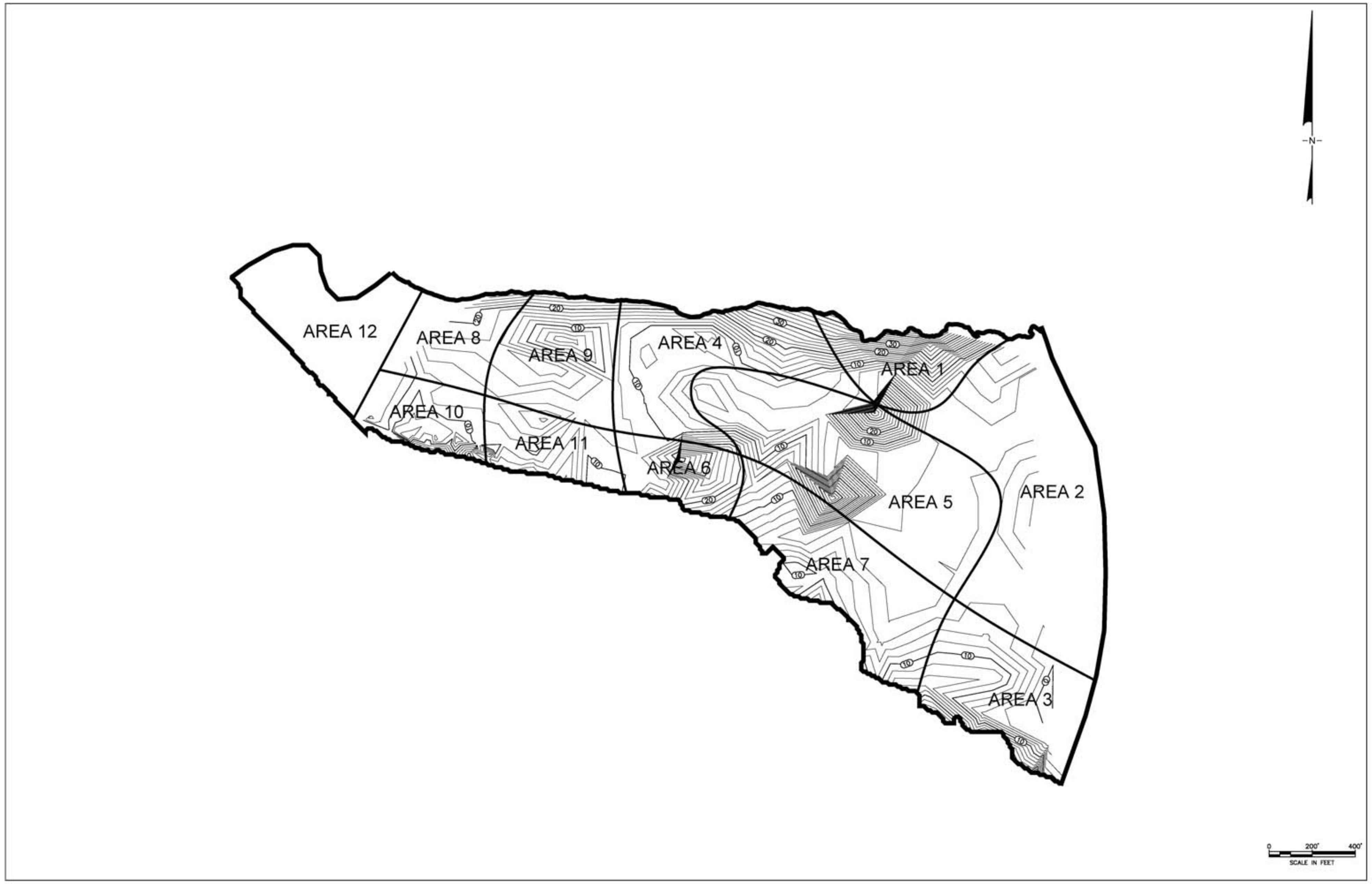


Figure A2. The Thickness of Marl in Remediation Area D

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.

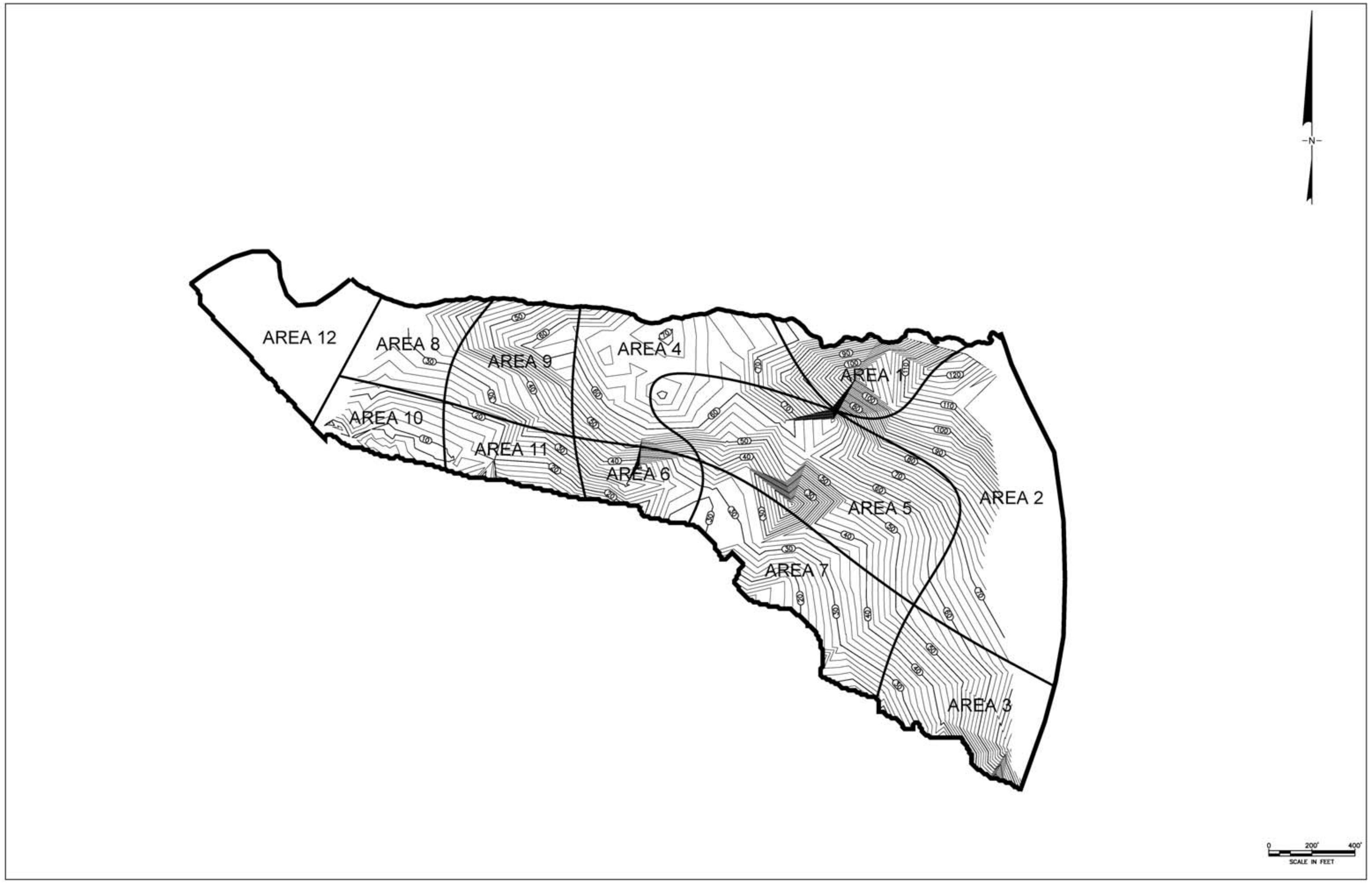


Figure A3. The Thickness of Silt and Clay in Remediation Area D

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. (y)	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 Thickness, m / ft	5
Midpoint Depth from Top of Silt/Clay, m/ft	2.5
Effective Stress Before Dredging, KPa/psf	951
Initial Effective Stress, KPa/psf	828.24
Final Effective Stress, KPa/psf	1058.64
OCR	1
Preconsolidation Pressure, KPa/psf	951
Modified Primary Compression Index, $C_{c\varepsilon}$	0.223
Modified Recompression Index, $C_{r\varepsilon}$	0.025
Modified Secondary Compression Index, $C_{\alpha\varepsilon}$	0.01
ratio of t2 / t1	5.2
Settlements	
Primary Settlement, (m / ft)	0.059
Secondary Settlement (m / ft)	0.036
Total Settlement (m / ft)	0.095

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

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

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

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

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

	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
Z (ft)	z-bar	s1	s2	s3	s4	s5	s6	s7	s8	s9	s10	s10	s10	s10	s10	s10	s10	s10	
	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.

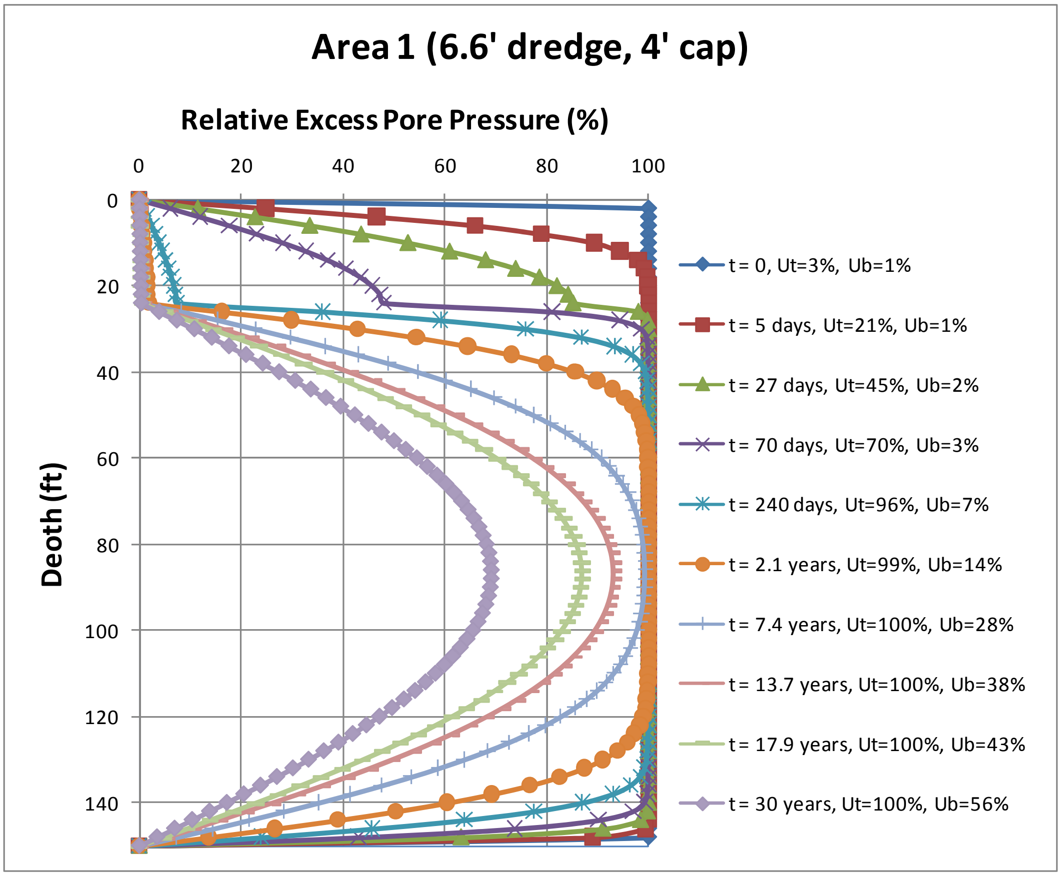
U bar and settlement results summary

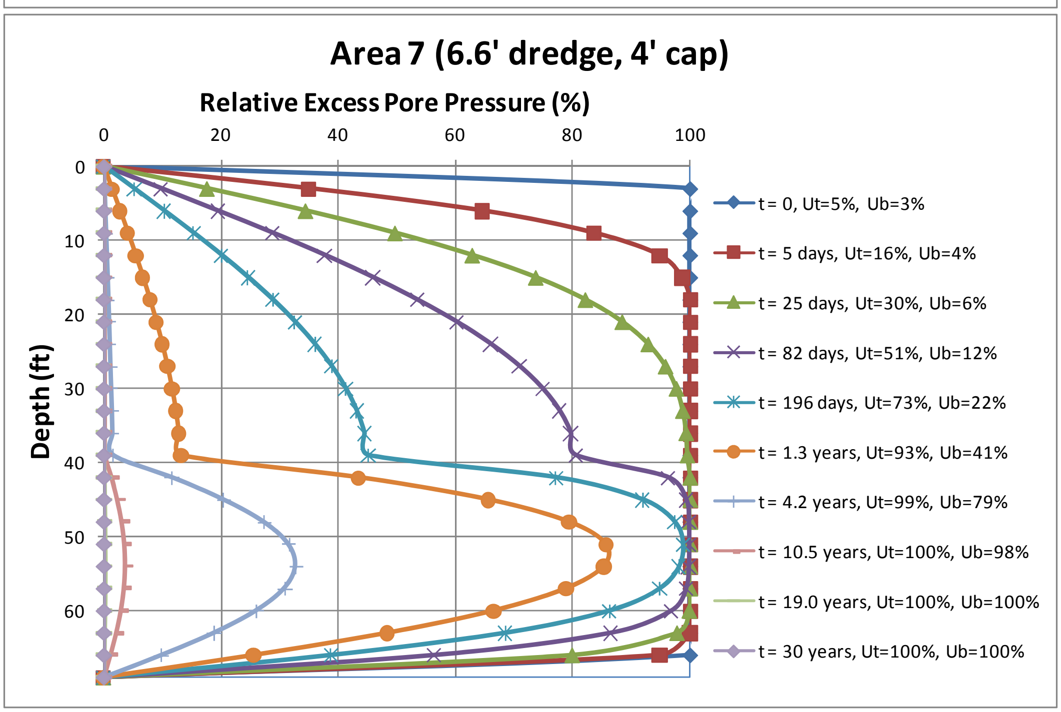
Uave top		5%	16%	30%	51%	73%	93%	99%	100%	100%	100%
Uave bot		3%	4%	6%	12%	22%	41%	79%	98%	100%	100%
t (years)		0.00	0.02	0.07	0.23	0.54	1.29	4.21	10.54	18.97	30.00
t (days)		0.00	5.48	25.19	82.13	196.01	469.75	1536.29	3845.64	6924.78	10950.00
Z (ft)		t = 0, Ut=5%, Ub=	t = 5 days, Ut=16%, Ub	t = 25 days, 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
Deoth (ft)
0
20
40
60
80
100
120
140
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
Depth (ft)
0
10
20
30
40
50
60
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%