6.0 SITE SUBSURFACE CONDITIONS

The following provides the results of the Site subsurface investigation:

- The subsurface conditions encountered in the boreholes along with the results of the Nilcon vane testing and direct push sampling are shown on the Record of Borehole and Drillhole sheets in Appendix A. The results of the water content and Atterberg limit testing are also indicated on the Record of Borehole sheets.
- The CPT profiles for normalized cone resistance, sleeve friction, and porewater pressure during pushing together with an interpreted profile of the stratigraphy are presented in Appendix B.
- The results of grain size distribution testing carried out on the surficial silty sand, silty layer within the silty clay, deep sandy silt and glacial till are provided in Appendix C.
- A summary of the measured undrained shear strength from the Nilcon vane testing as well as undrained shear strength profiles interpreted from the CPTs are provided in Appendix D.
- A summary of the sensitivity of the silty clay is provided in Appendix E.
- Plasticity charts for the weathered and unweathered silty clay, consolidation test results and secondary compression test results are provided in Appendix F.
- Summaries of the measured/interpreted coefficients of vertical and horizontal consolidation from the laboratory oedometer consolidation tests and the porewater pressure dissipation tests from the CPTs are provided in Appendix G.
- A graphical summary of selected engineering properties is provided in Appendix H.
- Photographs of the direct push soil samples are provided in Appendix I.
- Photographs of the bedrock core samples are provided in Appendix J.
- The results of the geophysical VSP testing are provided in a memorandum in Appendix K.

The following presents a summary of the subsurface conditions encountered within the on-Site boreholes.

6.1 Topsoil/Peat

Between 0.05 metres and 0.3 metres of topsoil/peat is encountered at ground surface at all of the borehole locations.

6.2 Surficial Silty Sand and Silt

The topsoil is underlain by between 0 to 2.7 metres of sand, silty sand, and/or sandy silt with trace to some clay. Standard penetration tests carried out within the sandy soils resulted in ‘N’ values of between 2 and 12 blows per 0.3 metres of penetration indicating a very loose to compact state of packing.

The measured natural water contents in the surficial silty sand soils at locations 12-1 and 12-3 were about 19% and 23%. The results of grain size distribution testing on 13 samples of this material are shown on Figure C1 in Appendix C.

Layers of weathered silty clay were encountered within the surficial silty sand soils at borehole locations 13-6 and 13-17, with thicknesses between about 0.1 and 0.4 metres. A layer of clayey silt with some sand was encountered within the surficial silty sand soils at location 13-8 with a thickness of about 0.1 metres.

6.3 Silty Clay

The surficial silty sand soils are underlain by a thick deposit of silty clay. The silty clay was fully penetrated to depths between approximately 27 and 36 metres below the existing ground surface at the first seven investigation locations (i.e., 12-1 through 12-4 and 13-5 through 13-7).

The upper 0.1 to 1.3 metres of the silty clay at 18 of the 25 investigation locations has been weathered to a red brown crust (referred to as 'weathered crust'). Layers and seams of silty sand, sand and clayey silt were also encountered within the weathered portion of the silty clay. Standard penetration tests carried out in the weathered material gave 'N' values of between 2 and 4 blows per 0.3 metres of penetration indicating a stiff consistency (based on local experience with the correlation to undrained shear strength).

The results of Atterberg limit testing on several samples of the weathered silty clay indicate plasticity index values ranging from about 16% to 46%, and liquid limit values ranging from about 32% to 69%, which generally indicates a silty clay to clay of medium to high plasticity. These values are summarized on Figure F1 in Appendix F. One result did plot within the lower plasticity region of the plasticity chart. The measured natural water contents of several samples of the weathered crust ranged from about 21% to 46%. These values are generally below the measured liquid limits.

The silty clay below the surficial silty sand and silt or weathered crust (where present) is unweathered. The results of *in-situ* Nilcon vane testing in this unweathered material gave undrained shear strengths ranging from about 4 kilopascals (kPa) (a single measurement) to greater than 100 kPa, generally increasing with depth. These results indicate a generally soft consistency to about 9 to 10 metres depth, followed by a firm consistency to about 15 to 18 metres depth, followed by stiff to very stiff for the remainder of the deposit. The results of the Nilcon vane testing are summarized on the Record of Borehole sheets as well as provided on Figure D6 in Appendix D.

Undrained shear strength profiles of the silty clay have also been evaluated from the results of the CPTs, using the following equation:

$$S_u = (q_t - \sigma_{vo}) / N_{kt}$$

Where: S_u = Calculated undrained shear strength (kPa);

q_t = Measured net tip resistance (kPa);

σ_{vo} = Calculated total vertical stress (kPa);

N_{kt} = Correlation factor, which ranges from 11 to 15 for this Site.

The undrained shear strength profiles for the silty clay, interpreted from the results of the CPTs, as described above, are summarized on Figures D1 to D5 in Appendix D. The CPT results indicate undrained shear strengths that are generally consistent with the *in-situ* Nilcon vane testing results.

The measured sensitivity of the unweathered silty clay deposit, as indicated from the Nilcon vane tests, ranges from about 1 to 17, but is more generally in the range of 4 to 14, indicating a medium sensitive to extrasensitive soil. These values are summarized on Figure E1 in Appendix E.

The results of Atterberg limit testing carried out on several samples of the unweathered silty clay gave plasticity index values generally ranging from about 27% to 58% and liquid limits values from about 46% to 84%. These results indicate a relatively high plasticity soil. The results of one sample from location 12-1-3 indicated particularly high values, with a plasticity index of 80% and a liquid limit of 114%. These values are summarized on Figure F2 in Appendix F.

The measured water contents of the samples of the unweathered silty clay material were between about 20% and 90%. However, more generally, the following observations are made:

- The water content above about 20 metre depth is typically in the range of 65% to 85%; and,
- The water content below about 20 metre depth is generally slightly less, being typically in the range of 60% to 70%.

The natural water content is also generally at or above the measured liquid limit.

Laboratory oedometer consolidation tests were carried out on 17 thin-walled Shelby tube samples of the unweathered silty clay. The results of that testing are provided on Figures F3 to F19 in Appendix F and are summarized in Table 6-1 below.

Table 6-1: Summary of Oedometer Consolidation Tests

Borehole Location/Sample Number	Sample Depth/Elevation (m)	Unit Weight (kN/m^3)	σ'_p (kPa)	C_c	C_r	e_0
12-1-3 / 1	2.5 / 73.5	15.7	55	1.59	0.010	1.98
12-1-3 / 4	13.3 / 62.7	15.0	180	4.23	0.008	2.47
12-1-3 / 5	18.7 / 57.3	15.3	170	1.70	0.024	2.35
12-2-3 / 1	4.5 / 72.4	14.7	55	2.57	0.032	2.47
12-2-3 / 2	8.5 / 68.4	15.0	110	3.06	0.017	2.35
12-2-3 / 6	24.0 / 52.9	16.1	260	1.40	0.015	1.81
12-3-3 / 6	29.4 / 46.8	16.3	270	1.10	0.018	1.71
12-3-5 / 1	5.7 / 70.5	14.8	85	3.71	0.015	2.46
12-3-5 / 2	15.7 / 60.5	15.9	185	1.58	0.025	1.93
12-4-3 / 1	3.3 / 72.6	16.0	60	1.31	0.015	1.73
12-4-3 / 3	11.1 / 64.8	16.0	115	1.58	0.009	1.80
12-4-3 / 6	26.2 / 49.7	16.4	285	1.32	0.017	1.63
13-6-3 / 3	10.0 / 66.7	15.1	110	3.41	0.010	2.29
13-6-3 / 4	18.4 / 58.3	15.4	210	2.80	0.011	2.08
13-6-5 / 1	6.4 / 70.2	14.8	80	2.30	0.025	2.44

Notes:
kN/m^3 – kilonewtons per cubic metre
σ'_p – Apparent preconsolidation pressure; C_r –Recompression index; C_c – Compression index; e_0 – Initial void ratio

Longer term (i.e., sustained load) laboratory oedometer consolidation tests were carried out on 2 of the 17 thin-walled Shelby tube samples of the unweathered silty clay, one from each of boreholes 12-1-3 (sample 2) and 12-3-5 (sample 1), stressed to about the anticipated final effective stress level at the depths of the samples (i.e., once the landfill weight is applied), to evaluate the secondary compression (i.e., creep) characteristics of the deposit. The results of the secondary compression tests are provided on Figures 20 to 21 in Appendix F and are summarized in Table 6-2 below.

Table 6-2: Summary of Secondary Compression Oedometer Consolidation Tests

Borehole Location/Sample Number	Sample Depth/Elevation (m)	Unit Weight (kN/m^3)	σ'_p (kPa)	C_c	C_α	e_0
12-1-3 / 2	6.4 / 69.6	16.6	45	0.69	0.011	1.50
12-3-5 / 1	5.6 / 70.6	14.9	70	2.04	0.019	2.44

Notes:
kN/m^3 – kilonewtons per cubic metre; kPa – kilopascals
σ'_p – Apparent preconsolidation pressure; C_α – Secondary compression index; C_c – Compression index; e_o – Initial void ratio

It should be noted that a higher load increment ratio (‘LIR’ – which is the ratio of the magnitude of the each load increment to the magnitude of the previous total load) was used when loading these samples to the design stress level, versus the general consolidation testing program, which could impact on the accuracy of the interpreted preconsolidation pressure. An LIR of about 1.0 was used for these tests.

The vertical coefficient of consolidation values (c_v) interpreted from the results of the laboratory oedometer consolidation tests are shown on Figure G1 in Appendix G. It should be noted that most of the oedometer consolidation tests were carried out using a relatively low LIR, which assists with defining the preconsolidation pressure for a sensitive and structured clay, such as present at this Site, but can yield unrepresentative c_v values. However, the calculated c_v values for the two sustained load (i.e., secondary compression) tests are also shown on this figure, and they were carried out using a higher and more conventional LIR.

The *horizontal* coefficient of consolidation (c_h) values were evaluated from the porewater pressure dissipation tests carried out using the CPT unit at seven of the investigation locations. The results of the dissipation tests are summarized Table 6-3 below and provided in Appendix G.

Table 6-3: Summary of Porewater Pressure Dissipation Tests

Location (CPT)	Test Depth/Elevation (m ASL)	C_h (m^2/sec)	M (MPa)	K_h (m/sec)
12-1-1	7.7 / 68.3	2.61×10^{-7}	0.88	2.91×10^{-9}
12-1-1	12.7 / 63.3	2.93×10^{-7}	2.32	1.24×10^{-9}
12-1-1	18.6 / 57.4	7.81×10^{-7}	3.71	2.06×10^{-9}
12-1-1	23.6 / 52.4	1.30×10^{-6}	3.64	3.51×10^{-9}
12-2-1	9.3 / 67.7	4.20×10^{-7}	1.57	2.62×10^{-9}
12-2-1	14.9 / 62.1	5.33×10^{-7}	2.99	1.75×10^{-9}
12-2-1	19.7 / 57.3	8.43×10^{-7}	3.68	2.24×10^{-9}
12-2-1	23.9 / 53.1	1.63×10^{-6}	7.50	2.13×10^{-9}
12-3-1	9.9 / 66.3	3.18×10^{-7}	2.51	1.24×10^{-9}
12-3-1	14.8 / 61.3	6.95×10^{-7}	5.09	1.34×10^{-9}
12-3-1	19.8 / 56.3	9.52×10^{-7}	6.55	1.43×10^{-9}
12-3-1	24.9 / 51.3	2.06×10^{-6}	9.57	2.11×10^{-9}
12-4-1	5.2 / 70.6	6.19×10^{-7}	0.43	1.43×10^{-8}
12-4-1	10.1 / 65.8	3.53×10^{-7}	2.26	1.53×10^{-9}
12-4-1	16.1 / 59.7	1.02×10^{-6}	3.27	3.06×10^{-9}
12-4-1	23.2 / 52.7	9.55×10^{-7}	4.84	1.93×10^{-9}
13-5-1	8.1 / 68.2	3.75×10^{-7}	1.13	3.24×10^{-9}
13-5-1	14.7 / 61.7	8.19×10^{-7}	2.46	3.26×10^{-9}
13-5-1	20.7 / 55.6	1.15×10^{-6}	3.97	2.85×10^{-9}
13-5-1	27.35 / 49.0	1.70×10^{-6}	6.90	2.41×10^{-9}
13-6-1	7.1 / 69.8	2.97×10^{-5}	1.61	1.81×10^{-7}
13-6-1	14.0 / 62.8	6.04×10^{-7}	3.35	1.77×10^{-9}
13-6-1	21.1 / 55.8	1.29×10^{-6}	3.31	3.82×10^{-9}
13-6-1	28.1 / 48.8	1.87×10^{-6}	4.97	3.70×10^{-9}
13-7-1	7.0 / 69.3	1.98×10^{-7}	0.36	5.37×10^{-9}
13-7-1	14.1 / 62.2	7.11×10^{-7}	1.45	4.80×10^{-9}
13-7-1	21.0 / 55.3	9.50×10^{-7}	3.07	3.03×10^{-9}

Notes:
MPa – Mega Pascals
C_h – Coefficient of consolidation in the horizontal direction; k_h – Soil permeability
M – One-dimensional constrained modulus of compressibility

The above coefficient of horizontal consolidation (c_h) values are also summarized on Figure G2 in Appendix G.

A continuous layer of sandy silt to silty sand, trace clay was encountered within the upper portion of the silty clay at depths between about 4 and 6 metres (referred to as the silty layer). This layer was observed both within the sampled boreholes as well as from the results of the CPTs and varies in thickness from about 0.1 metres to 0.6 metres.

The results of grain size distribution testing carried out on 10 samples of this silty layer material are shown on Figure C2 in Appendix C and indicate that the layer consists of sandy silt or silt with trace clay.

Other discontinuous seams/layers of mainly silt were encountered at various depths within the silty clay deposit. In particular, a deep sandy silt layer was encountered at about 34.5 metres depth within the silty clay deposit just above the glacial till at borehole 12-1-7. The results of grain size distribution testing on one sample of the approximately 1.3 metre thick deep sandy silt layer are shown on Figure C3 in Appendix C. A similar approximately 0.5 metre thick deep silty sand/sandy silt layer was also encountered within the silty clay deposit at location 12-2 at about 33.8 metres depth, just above the glacial till.

6.4 Glacial Till

The silty clay is underlain by a deposit of glacial till. Based on the retrieved samples and observations of the sampler/drilling resistance, the glacial till is considered to generally consist of a heterogeneous mixture of gravel, cobbles and boulders in a matrix of sand and silt with a trace to some clay. This deposit was fully penetrated to depths between about 33.4 and 40.8 metres below the existing ground surface. Where penetrated, the thickness ranges from about 2 to 9 metres.

Standard penetration tests carried out within the glacial till resulted in ‘N’ values of between 6 and greater than 100 blows per 0.3 metres of penetration indicating a loose to very dense state of packing. However, the higher standard penetration test ‘N’ values encountered in the glacial till likely reflect the presence of cobbles and boulders in the deposit. In borehole 13-6, diamond drilling techniques were required to penetrate through the boulders in the glacial till deposit.

The measured natural water contents of the glacial till at locations 12-1 and 12-3 were about 9% and 10%. The results of grain size distribution testing carried out on two samples of this deposit are shown on Figure C4 in Appendix C. However, it should be noted that the samples were retrieved using a 35-millimetre inside diameter sampler and therefore the results don’t reflect the boulder, cobble or full gravel content.

Naturally occurring gas was encountered within the glacial till layer during drilling at locations 12-4, 13-5 and 13-6.

6.5 Bedrock

Coring of the bedrock was carried out at the first seven investigation locations (i.e., 12-1 through 12-4 and 13-5 through 13-7). The following table provides details of the cored boreholes.

Table 6-4: Summary of Cored Bedrock Boreholes

Borehole Location	Date Drilled	Ground Surface Elevation (m ASL)	Depth to Bedrock (metres)	Bedrock Surface Elevation (m ASL)	Total Depth Cored (metres)
12-1-3	November 15 to 19, 2012	76.01	40.61	35.40	5.86
12-1-3-1	November 23, 2012	76.10	39.78	36.32	5.59
12-2-3	January 11 and 14, 2013	76.94	36.74	40.20	5.21
12-3-3	December 3 to 5, 2012	76.22	39.84	36.38	5.58
12-4-3	January 31 to February 15, 2013	75.92	37.80	38.12	5.81
13-5-3	June 14 to 18, 2013	76.51	34.23	42.28	6.10
13-6-3	March 11 to 15, 2013	76.69	40.79	35.90	4.26
13-7-2	June 10 to 13, 2013	76.35	33.37	42.98	6.10

The boreholes cored into bedrock beneath the CRRRC Site all encountered the Carlsbad Formation. The majority of the Site is underlain by the shaley member of the formation consisting of dark grey, very thinly to thinly interbedded shale and calcareous shale with thin to medium interbeds of argillaceous to shaley limestone and occasional beds of bioclastic limestone typical of the Carlsbad sequence beneath the limestone cap. The shale and calcareous shale beds comprised approximately 47% to 86% of the bedrock investigated in the 8 core holes, averaging 71%.

The limestone caprock layer marking the top of the Carlsbad Formation was encountered at the south end of the CRRRC Site in BH12-2-3 where five metres of thinly to medium bedded limestone with approximately 10% shale interbeds was intersected.

The Rock Quality Designation (RQD) values measured on recovered bedrock core samples typically range from about 59% to 100%, indicating a fair to excellent quality rock. However, two lower RQD values of 12% and 29% were measured within the upper portion of the bedrock at borehole locations 12-3-3 and 12-2-3, respectively, indicating poorer quality bedrock.

6.6 Geophysical Testing

The results of the geophysical VSP testing that was carried out within boreholes 12-2-3 and 12-3-3 are provided in the memorandum in Appendix K. The results indicate a measured average shear-wave velocity from ground surface to a depth of 30 metres of 117 m/sec for borehole 12-2-3 and 112 m/sec for borehole 12-3-3. These results show the Boundary Road Site to be Class E as it relates to seismic design as set out in the National Building Code of Canada (NRC, 2010) and the Ontario Building Code (MMAH, 2012). This agrees with the seismic site class map of the Ottawa area (Hunter et. al., 2012)

6.7 Additional Borehole Investigations

Following the initial Site investigation, additional boreholes were completed as part of supplementary investigations. Two boreholes were drilled in the vicinity of the proposed Site entrance off of Boundary Road. The boreholes are identified at A13-1 and A13-2, and the borehole locations are shown on Figure 2-1. Boreholes A13-1 and A13-2 provided investigation of the geology in the northwestern extent of the property, and permitted the installation of monitoring wells for the collection of additional groundwater levels in the surficial silty sand. Following the installation of the monitoring wells in A13-1 and A13-2, these locations were added to the monthly groundwater level monitoring program for the Site. The geological conditions encountered at locations A13-1 and A13-2, as well as the monitoring well completion details are provided on the borehole records in Appendix A (following the Site investigation borehole logs).

Ten additional boreholes were drilled as part of a dug well assessment completed at the Site. The boreholes were drilled to confirm the geological conditions in the vicinity of two on-Site dug wells and to permit the installation of groundwater monitoring wells. The first dug well is located in the northeastern portion of the Site along Frontier Road and is identified as Frontier-1 on Figure 2-1. The second dug well is located near the western Site boundary in the central part of the Site. The second dug well is identified as Boundary-2 on Figure 2-1.

The boreholes drilled as part of the dug well assessment are identified as B13-1 through B13-10, and the borehole locations are shown on Figure 2-1. Two of the boreholes (B13-1 and B13-2) were drilled in the vicinity of Frontier-1. The monitoring wells installed within these boreholes allowed for the observation of groundwater levels in the shallow overburden during typical operation of a dug well (i.e., the residence where this dug well is located is still occupied). Boreholes B13-3 through B13-10 were drilled in the vicinity of Boundary-2. The monitoring wells installed within these boreholes allowed for the observations of groundwater levels in the shallow overburden during a pumping test completed using Boundary-2. The geological conditions encountered at locations B13-1 through B13-10, as well as the monitoring well completion details are provided on the borehole records in Appendix A (following the Site investigation borehole logs). The results of the dug well assessment are discussed in a separate technical memorandum provided in Appendix M.

A review of the borehole logs for locations A13-1, A13-2 and B13-1 through B13-10 indicates the native geological materials encountered are consistent with those observed during the original Site investigation (i.e., at locations 12-1 through 12-4 and 13-5 through 13-25 shown on Figure 2-1), although some locations have more fill material.