



**THURBER** ENGINEERING LTD.

**PRELIMINARY  
FOUNDATION INVESTIGATION AND DESIGN REPORT  
WOLFE ISLAND FERRY AND DOCKING IMPROVEMENTS  
COUNTY OF FRONTENAC  
G.W.P. 4061-14-00**

**GEOCRES NO.: 31C-243**

Report to:

**Morrison Hershfield**

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**PART 1. FACTUAL INFORMATION**

**1 INTRODUCTION**

This report presents the factual findings obtained from a preliminary foundation investigation completed in support of the Wolfe Island Ferry and Docking Improvements Preliminary Design EA Study. The foundation investigation was completed at the existing Wolfe Island Ferry Terminals at Barrack Street in the Township of Kingston and Marysville and Dawson Point in the Township of Wolfe Island within the County of Frontenac.

The purpose of this investigation was to explore the subsurface conditions at the sites and, based on the data obtained, to provide a borehole location plan, records of boreholes, stratigraphic profile, laboratory test results and a written description of the subsurface conditions. A model of the subsurface conditions was developed from the data obtained in the course of the current investigation and with data available from previous investigations.

To supplement the current investigation, reference has been made to historical Geocres File Nos. 31C-118, 31C-132 and 31C-155. The relevant Record of Borehole sheets from these files are provided in Appendix B and have been incorporated into the Borehole Location and Soil Strata drawings included in Appendix A.

Thurber Engineering Ltd. (Thurber) carried out the current investigation as a sub-consultant to Morrison Hershfield under Contract No. 4014-E-0024.

**2 SITE DESCRIPTION**

The field investigation was completed at all three terminals serviced by the Wolfe Island Ferry consisting of the Barrack Street Terminal located in downtown City of Kingston and the Dawson Point and Marysville Terminals located on Wolfe Island. The Wolfe Islander III typically operates between the Barrack Street and Marysville terminals during summer and between Barrack Street and Dawson Point terminals during the winter months (when ice is present and/or low water conditions are encountered at Marysville). During the time of the investigation, the Wolfe Islander III was undergoing repairs and the replacement ferry was operating along the winter route.

The Barrack Street Terminal is located in an urban setting in downtown City of Kingston. The terminal connects to Ontario St. (Highway 2 outside City limits) which conveys traffic between the downtown core and the LaSalle Causeway. The terminal is bordered by commercial businesses, military barracks and entertainment centers with some buildings



being designated as heritage buildings. The terminal is used as marshalling for vehicles waiting to board the Ferry and day parking is permitted at the end of the terminal.

The Marysville Terminal is located on Wolfe Island in the village of Marysville and connects to Main St. (Highway 96). The terminal is mainly surrounded by single family dwellings and commercial businesses. A queue lane for vehicles waiting to board the ferry is present along the north side of Main St. east of the terminal entrance.

The Dawson Point Terminal is located on Wolfe Island at the north end of Dawson Point Road. The terminal is surrounded by open agricultural land. A queue lane for vehicles waiting to board the ferry is present along the east side of Dawson Point Road southeast of the terminal. Day parking is available in a small lot southwest of the terminal.

Photographs of the terminals are provided in in Photos 1 through 4 in Appendix D.

### **3 SITE INVESTIGATION AND FIELD TESTING**

The current site investigation and field testing program consisted of both an onshore and offshore investigation component. Prior to commencement of drilling, permission from regulatory authorities and utility clearances were obtained for the borehole locations. USL-1, a private utility locator, was retained to provide additional utility location support at the three ferry terminals.

The drilling and sampling operations were supervised on a full time basis by a member of Thurber's technical staff. The drilling supervisor logged the boreholes and processed the recovered soil samples for transport to Thurber's laboratory in Ottawa, Ontario for further examination and test selection.

The approximate borehole locations are shown on the Borehole Location and Soil Strata Drawings included in Appendix A. The coordinates and elevation of the boreholes are provided on the drawings and on the individual Record of Borehole sheets. The Record of Borehole sheets for all boreholes of the current investigation are included in Appendix B.

From the reports referenced earlier (Geocres File Nos. 31C-118, 31C-132 and 31C-155), boreholes used in this report to supplement the subsurface stratigraphy at the terminals are also included in Appendix B for reference.

#### **3.1 Onshore Drilling Investigation**

The onshore drilling was carried out between August 31 and September 2, 2015 and consisted of drilling and sampling three boreholes at the Marysville terminal (identified as M01, M02 and M03), one borehole at the Dawson Point terminal (identified as D01) and two boreholes at the Barrack Street terminal (identified as B01 and B02).

The onshore drilling was carried out by truck mounted CME drill rig utilizing hollow stem augers. Soil samples were obtained at selected intervals using a split spoon sampler in conjunction with Standard Penetration Testing (SPT). Bedrock was cored with NQ casing within each of the boreholes. The boreholes were extended to depths ranging from 5.1 to 16.1 m below the existing surface.

### **3.2 Offshore Drilling Investigation**

The offshore drilling was carried out between September 9 and September 16, 2015 and consisted of drilling and sampling three boreholes near the Marysville terminal (identified as M04, M05 and M06), four boreholes near the Dawson Point terminal (identified as D02 through D05) and three boreholes near the Barrack Street terminal (identified as B04, B05 and B06). In addition, a single probe hole was completed adjacent to the Barrack Street terminal; it was located in direct conflict with ferry operations. Even though the borehole was drilled at night, there was insufficient time to sample overburden and prove bedrock by coring. Given the number of nearby boreholes with overburden sampling, proving bedrock elevation was the primary objective for BH B03.

The offshore drilling was also carried out with a CME drill rig. NW casing was used to advance boreholes through the overburden. Prior to advancing the boreholes, HW casing was lowered to the riverbed encompassing the drilling location and facilitating capture of the drill cuttings. Soil samples were obtained at selected intervals using a split spoon sampler in conjunction with SPT testing. A single Thin Walled Tube sample of a silty clay deposit was retrieved from Borehole B04 at the Barrack Street terminal to obtain a relatively undisturbed soil sample for further laboratory testing. In-situ vane shear testing was conducted in cohesive soils using an MTO "N" vane. Bedrock was cored with NQ coring within each of the boreholes. The boreholes were extended to depths ranging from 6.2 to 13.4 m below the surface of the riverbed. The depth of water, as measured from the barge at the individual borehole locations, varied from 3.7 to 8.9 m during the time of the offshore drilling.

The offshore drilling equipment was floated on a sectional barge and braced at the drilling locations with spuds (Photos 5 & 6, Appendix D **Error! Reference source not found.**) attached to the corners of the barge. The barge was repositioned with the use of a supply boat. The barge and supporting equipment was supplied and operated by ODS Marine.

### **3.3 Offshore Geophysics Investigation**

Geophysics GPR International Inc. (GPR) was retained by Thurber to carry out an offshore seismic reflection survey to map the offshore bedrock surface and collect subsurface data in the vicinity of all three Wolfe Island Ferry terminals. Seismic refraction data collection technology was used where seismic reflection surveys data collection was determined to be insufficient. The field data collection was carried out during the period of November 10 to 23<sup>rd</sup>, 2015 and during a subsequent field investigation on May 11<sup>th</sup>, 2016 to collect supplementary data. The GPR reports, with a description of the methods used and data interpretation, is provided in Appendix E.

### **3.4 Additional Investigation**

A pavement investigation incorporating pavement coring, borehole drilling and ground penetrating radar was also completed at each of the three ferry terminals and connected roadways as part of the scope of this project. The findings from this investigation have been provided in a separate report.

## **4 LABORATORY TESTING**

The recovered soil samples were subjected to visual identification and to natural moisture content determination. Selected samples were also subjected to Atterberg Limit testing and gradation analysis (hydrometer and/or sieve). A single soil sample, obtained with a Thin Walled Tube in Borehole B04, underwent one-dimensional consolidation testing in the Stantec Laboratory in Ottawa. The results of these tests are summarized on the Record of Borehole sheets included in Appendix B and are presented on the laboratory figures included in Appendix C.

## **5 DESCRIPTION OF SUBSURFACE CONDITIONS**

Details of the encountered soil stratigraphy are presented on the Record of Borehole sheets included in Appendix B and the Borehole Location and Soil Strata drawings included in Appendix A. A general description of the stratigraphy, based on the conditions encountered in the boreholes, is given in the following paragraphs. However, the factual data presented on the Record of Borehole sheets takes precedence over this general description for interpretation of the site conditions. It must be recognized that soil conditions may vary between and beyond borehole and sample locations.

### **5.1 Barrack Street Terminal**

In general terms, the site was found to be underlain predominantly by a deposit of silty clay followed by bedrock with the onshore boreholes encountering a layer of fill above silty clay. The boreholes were advanced until terminated after coring 3 m into bedrock. More detailed descriptions of the individual strata based on Boreholes B01 through B06 are presented below.

#### **5.1.1 Fill**

A 90 mm thick layer of asphalt was encountered at the surface in Boreholes B01 and B02. Below the asphalt in B02 was a 90 mm thick layer of granular fill followed by 150 mm thick layer of concrete.

Granular fill was encountered below the asphalt in Borehole B01 and below the concrete in B02. The gradation of the fill varied from sand with gravel to silty sand with gravel to silty gravel with sand with clay. The fill contained pieces of wood and slag. The fill was 2.4 to 4.0 m thick with an underside depth of 2.7 to 4.1 m (elev. 73.7 to 72.3 m).

SPT tests recorded N-values of 4 to 28 blows per 300 mm of penetration in this layer indicating loose to compact relative density. Recorded moisture contents varied from 2 to 28%.

Gradation analyses were completed on selected samples of the fill layer. The results are summarized on the Record of Borehole sheets in Appendix B and the grain size distribution curves for these samples are included in Figure C1 of Appendix C. The results of the laboratory tests are summarized as follows:

Soil Particle	Percentage (%)	
Gravel	19 to 29	
Sand	20 to 76	
Silt	28	5 to 17
Clay	23	

Below the granular fill in Borehole B02 was a deposit containing wood pieces and voids indicative of probable cribbing/trestle remnants. The deposit was encountered at a depth of 2.7 m and extended to a depth of 5.5 m below the ground surface with a bottom elevation at 71.0 m. SPT tests in this deposit recorded N-values of 2 and 28 blows per 300 mm of penetration. The SPT tests returned poor material recovery within the split spoon sampler.

Although not directly encountered within the boreholes, fill material may typically contain a presence of cobbles, boulders or other buried obstructions.

#### 5.1.2 Sand

A veneer of sand varying from silty clayey sand to sand with gravel was encountered at the surface of the riverbed in offshore Boreholes B04 and B05 at a depth ranging from 4.1 to 4.8 m (elev. 70.9 to 70.2 m) below the water surface. A single moisture content of 38% was recorded in this layer.

#### 5.1.3 Silty Clay

A deposit of silty clay was encountered beneath the fill layers in Boreholes B01 and B02, beneath the veneer of sand located at the base of the riverbed in offshore Boreholes B04 and B05 and within the first obtained soil sample in Borehole B06. The investigated thickness of the deposit ranged from 0.8 to 7.7 m with an underside depth at 4.9 to 13.2 m (elev. 71.6 to 63.2 m).

SPT tests performed within the silty clay gave N-values typically ranging from 4 to 18 blows per 300 mm of penetration indicating firm to very stiff relative consistency. Two field vane tests were attempted in Borehole B05 but were unable to shear the soil, indicating undrained shear strengths in excess of 100 kPa. Typical recorded moisture contents ranged from 22 to 39%. A single moisture content as high as 88% was recorded in a sample containing organics obtained below the fill layer in Borehole B01.

Gradation analysis were completed on six selected samples of the silty clay layer. The results are summarized on the Record of Borehole sheets in Appendix B and the grain size distribution curves for these samples are included in Figure C2 of Appendix C. The results of the laboratory tests are summarized as follows.

Soil Particle	Percentage (%)
Gravel	0
Sand	0 to 3
Silt	45 to 66
Clay	34 to 54

Atterberg Limit testing was also completed on selected samples of the silty clay layer. The results are summarized on the Record of Borehole sheets in Appendix B and the Atterberg Limit graph is included in Appendix C. The laboratory results are summarized below and indicate that the silty clay varies from intermediate to high plasticity (CI to CH):

Parameter	Value
Liquid Limit	38 to 54
Plastic Limit	18 to 20
Plasticity Index	18 to 34

An Oedometer (one-dimensional consolidation) test was carried out on a relatively undisturbed sample obtained from a Thin-Walled tube sampler. The results are presented in Appendix C and summarized as follows:

**Table 5-1. Consolidation Test Parameters**

Borehole and Sample	Soil Type	$w_n$ (%)	$\gamma$ (kN/m <sup>3</sup> )	$e_o$ (-)	$p_c'$ (kPa)	$p_o'$ (kPa)	$C_c$ (-)	$C_r$ (-)
B04 (6.8 to 7.4)	CI-CH	31.2	19.2	0.82	470	25	0.27	0.04

The preconsolidation pressure is 445 kPa greater than the effective overburden stress. The ratio of preconsolidation pressure to vertical effective stress ( $OCR = p_c'/p_o'$ ) derived from the oedometer test results indicates that the silty clay is overconsolidated with an approximate OCR of 19. The vertical coefficient of consolidation,  $c_v$ , recorded during the Oedometer test is approximately 0.1 to 0.2 cm<sup>2</sup>/min in the normally consolidated range and 0.3 to 0.4 cm<sup>2</sup>/sec for the overconsolidated range. The compressibility characteristics will vary with depth and location in accordance with moisture content and stress history.

#### 5.1.4 Clayey Silt

A clayey silt layer, 0.2 m in thickness, was encountered under the silty clay in all three offshore boreholes. Recorded moisture contents ranged from 11 to 31%.

#### 5.1.5 Bedrock

Limestone bedrock was encountered below the soil layers and cored in all six boreholes. A summary of the elevation at which bedrock was encountered is shown in the table below.

**Table 5-2. Bedrock Elevation Summary**

Borehole	Elevation (m)
B01	71.6
B02	63.2
B03	64.1
B04	65.7
B05	66.1
B06	66.0

Total Core Recovery (TCR) in the bedrock typically ranged from 97 to 100% indicating a good core recovery. The Rock Quality Designation (RQD) values ranged from 52 to 93% indicating a variable rock quality ranging from fair to excellent. Unconfined compression strength (UCS), interpreted from point load tests conducted on intact cores ranged from 86 to 111 MPa, indicating a strong to very strong rock. Additional core descriptions are tabulated in Appendix C.

## **5.2 Dawson Point Terminal**

An inferred river bottom elevation was interpreted at the offshore borehole locations from drop tape measurements at depths ranging from 7.4 to 8.9 m. Soil sampling commenced at the depth where the drill casing became supported by the riverbed deposits.

In general terms, the site was found to be underlain by silty clay followed by layers of silty sand to sandy silt overlying bedrock. The onshore borehole encountered fill directly over bedrock. The boreholes were terminated after 3 m of rock coring. More detailed descriptions of the individual strata based on Boreholes D01 through D05 are presented below.

### **5.2.1 Fill**

Borehole D01 was advanced onshore and encountered a 20 mm thick layer of asphalt followed by fill until auger advancement refusal at a depth of 1.9 m. The fill varied in composition from sandy gravel to silty gravel with sand.

SPT tests recorded N-values of 16 and 28 blows per 300 mm of penetration in this layer indicating compact relative density. Recorded moisture contents varied from 2 to 16%.

A gradation analysis was completed on a selected sample of the fill layer. The results are summarized on the Record of Borehole sheets in Appendix B and the grain size distribution curve for this sample is included in Figure C4 of Appendix C. The results of the laboratory tests are summarized as follows.

Soil Particle	Percentage (%)
Gravel	40
Sand	29
Silt	13
Clay	18

Although not directly encountered within the boreholes, fill material may typically contain a presence of cobbles, boulders or other buried obstructions.

#### 5.2.2 Silty Clay

A deposit of silty clay was encountered within Boreholes D02 through D05 at sampled depths starting from 8.3 to 10.6 m below the water surface. The sampled thickness of the silty clay ranged from 0.8 to 1.9 m with an underside depth of 9.1 to 12.1 m (elev. 66.0 to 63.0 m).

SPT tests performed within the silty clay gave N-values ranging from weight of hammer to 20 blows per 300 mm of penetration indicating very soft to very stiff relative consistency. Recorded moisture contents ranged from 23 to 36%.

A gradation analysis was completed on a selected sample of the silty clay layer. The results are summarized on the Record of Borehole sheets in Appendix B and the grain size distribution curve for this sample is included in Figure C5 of Appendix C. The results of the laboratory tests are summarized as follows.

Soil Particle	Percentage (%)
Gravel	0
Sand	3
Silt	41
Clay	56

Atterberg Limit testing was also completed on a sample of the silty clay. The results are summarized on the Record of Borehole sheets in Appendix B and the Atterberg Limit graph is included in Appendix C. The laboratory results are summarized below and indicate that the silty clay exhibits intermediate plasticity (CI):

Parameter	Value
Liquid Limit	41
Plastic Limit	19
Plasticity Index	22

#### 5.2.3 Silt

A deposit of silt with sand was encountered below the silty clay in all offshore boreholes. The silt was 1.5 to 4.1 m thick with an underside depth at 12.4 to 15.5 m (elev. 62.7 to 59.6 m).

SPT tests performed within the silt gave N-values ranging from 6 to 30 blows per 300 mm of penetration indicating loose to compact relative density. Recorded moisture contents ranged from 18 to 34%.

Atterberg Limit testing on samples of the silt indicated a non-plastic material. Gradation analysis were completed on four selected samples of the sandy silt layer. The results are

summarized on the Record of Borehole sheets in Appendix B and the grain size distribution curves for these samples are included in Figure C7 of Appendix C. The results of the laboratory tests are summarized as follows and are indicative of a ML material:

Soil Particle	Percentage (%)
Gravel	0 to 8
Sand	16 to 26
Silt	66 to 77
Clay	6 to 10

#### 5.2.4 Sand

Below the silt in all offshore boreholes was a sand deposit varying in gradation from gravelly sand with silt to silty sand with gravel. The sand deposits was 0.8 to 3.2 m thick with an underside depth of 14.7 to 16.3 m (elev. 60.4 to 58.8 m).

SPT tests performed within the sand gave N-values ranging from 7 to 9 blows per 300 mm of penetration indicating loose relative density. Recorded moisture contents ranged from 11 to 22%.

Gradation analysis were completed on three selected samples of the sand layer. The results are summarized on the Record of Borehole sheets in Appendix B and the grain size distribution curves for these samples are included in Figure C8 of Appendix C. The results of the laboratory tests are summarized as follows and are indicative of an SM to SW-SM material:

Soil Particle	Percentage (%)	
Gravel	5 to 26	
Sand	57 to 80	
Silt	24	8 to 15
Clay	6	

#### 5.2.5 Sandy Silt

A layer of sandy silt was encountered below the sand deposit in Boreholes D02 and D05. The sandy silt layer was 0.8 to 1.5 m thick with an underside depth at 15.5 to 17.7 m (elev. 59.6 to 57.4 m). A single SPT tests performed within sandy silt gave an N-value of 5 blows per 300 mm of penetration indicating a loose relative density. Recorded moisture contents ranged from 15 to 21%.

#### 5.2.6 Bedrock

Limestone bedrock was encountered below the soil layers and cored in all five boreholes. A summary of the elevation at which bedrock was encountered is shown in the table below.



**Table 5-3. Bedrock Elevation Summary**

Borehole	Elevation (m)
D01	74.3
D02	59.6
D03	59.5
D04	58.8
D05	57.4

Total Core Recovery (TCR) in the bedrock typically ranged from 72 to 100% indicating a good core recovery. The Rock Quality Designation (RQD) values ranged from 0 to 98%, but generally over 60%, indicating a variable rock quality ranging from poor to excellent. Unconfined compression strength (UCS), interpreted from point load tests conducted on intact cores ranged from 89 to 101 kPa, indicating a strong rock strength. Interpreted UCS strength ranged from 19 to 52 MPa for two samples containing shale seams. Additional core descriptions are tabulated in Appendix C.

### 5.3 Marysville Terminal

An inferred river bottom was interpreted within the offshore boreholes from drop tape measurements at a depth of 3.7 m. Soil sampling commenced at the depth where the drill casing became supported by the riverbed deposits.

In general terms, the site was found to be typically underlain by a deposit of silty clay followed by sand over bedrock. The onshore boreholes encountered a layer of fill followed by silt above bedrock. The boreholes were advanced until terminated upon 3 m of rock coring. More detailed descriptions of the individual strata based on Boreholes M01 through M06 are presented below.

#### 5.3.1 Fill

An 80 to 100 mm thick layer of asphalt was encountered at the surface of Boreholes M01 through M03 which was underlain by sandy gravel fill with an underside depth of 1.1 to 2.6 m (elev. 75.8 to 74.3 m). Frequent cobbles and boulders were encountered in lower parts of the fill.

SPT tests recorded typical N-values of 21 to 85 blows per 300 mm of penetration in the granular fill layer indicating compact to very dense relative density. Recorded moisture contents varied from 2 to 4%.

A gradation analysis was completed on three selected samples of the fill layer. The results are summarized on the Record of Borehole sheets in Appendix B and the grain size distribution curves for these samples are included in Figure C9 of Appendix C. The results of the laboratory tests are summarized as follows:

Soil Particle	Percentage (%)
Gravel	53 to 57
Sand	36 to 40
Silt	3 to 11
Clay	

#### 5.3.2 Silt

A 0.9 m thick deposit of silt with clay was noted below the fill in Borehole M01 with an underside depth at 2.0 m (elev. 74.9 m). An SPT test conducted in this layer recorded an N-value of 43 blows per 300 mm of penetration indicating a dense relative density. A moisture content of 13% was recorded.

#### 5.3.3 Organic Silty Sand

A deposit of organic silty sand with gravel was encountered below the fill in Boreholes M02 and M03. The silt deposit varied from 1.2 to 1.5 m thick with an underside depth of 3.2 to 4.1 m (elev. 73.7 to 72.7 m).

SPT tests in the organic silty sand recorded N-values from weight of hammer to 5 blows per 300 mm of penetration indicating very loose to loose relative density. Recorded moisture contents varied from 66 to 89%.

A gradation analysis was completed on a selected sample of the organic layer. The results are summarized on the Record of Borehole sheets in Appendix B and the grain size distribution curve for this sample is included in Figure C10 of Appendix C. The results of the laboratory tests are summarized as follows:

Soil Particle	Percentage (%)
Gravel	22
Sand	30
Silt	34
Clay	14

#### 5.3.4 Silty Clay

A silty clay deposit was encountered below the organic layer in Boreholes M02 and M03 and within the first obtained soil samples in offshore Boreholes M04 through M06. The sampled thickness of the silty clay varied from 0.7 to 2.5 m with an underside depth of 5.3 to 6.8 m (elev. 71.5 to 68.1 m)

SPT tests performed within the silty clay gave N-values ranging from 4 to 8 blows per 300 mm of penetration indicating firm to very stiff relative consistency. Recorded moisture contents ranged from 19 to 37%.

Gradation analysis were completed on three selected samples of the silty clay layer. The results are summarized on the Record of Borehole sheets in Appendix B and the grain size

distribution curves for these samples are included in Figure C11 of Appendix C. The results of the laboratory tests are summarized as follows.

Soil Particle	Percentage (%)
Gravel	0
Sand	1 to 4
Silt	43 to 61
Clay	35 to 53

Atterberg Limit testing was also completed on three selected samples of the silty clay layer. The results are summarized on the Record of Borehole sheets in Appendix B and the Atterberg Limit graph is included in Appendix C. The laboratory results are summarized below and indicate that the silty clay varies from low to high plasticity (CL to CH):

Parameter	Value
Liquid Limit	26 to 56
Plastic Limit	14 to 24
Plasticity Index	12 to 32

#### 5.3.5 Sandy Silt

A discontinuous sandy silt deposit was encountered below the silty clay in offshore borehole M05. The silt layer was approximately 0.5 m thick with an underside depth at 6.8 m (elev. 68.1 m). A single moisture content of 30% was recorded within this layer.

#### 5.3.6 Silty Sand

Below the silty clay in Boreholes M03, M04 and M06 and below the sandy silt in Borehole M05 was a silty sand deposit. Thin discontinuous silty clay layers were interbedded within the silty sand in Boreholes M04, M05 and M06. The thickness of this layer ranged from 1.2 to 6.6 m with an underside depth at 6.5 to 13.4 m (elev. 70.4 to 61.5 m).

SPT tests performed within the sand gave N-values ranging from 2 to 18 blows per 300 mm of penetration indicating very loose to compact relative density. Recorded moisture contents ranged from 9 to 24%.

Gradation analysis were completed on three selected samples of the sand layer. The results are summarized on the Record of Borehole sheets in Appendix B and the grain size distribution curves for these samples are included in Figure C13 of Appendix C. The results of the laboratory tests are summarized as follows and indicate an SM material:

Soil Particle	Percentage (%)	
Gravel	0	
Sand	54 to 79	
Silt	42	21 to 24
Clay	4	

#### 5.3.7 Bedrock

Limestone bedrock was encountered below the soil layers and cored in all six boreholes. A summary of the elevation at which bedrock was encountered is shown in the table below.

**Table 5-4. Bedrock Elevation Summary**

Borehole	Elevation (m)
M01	74.9
M02	71.1
M03	70.4
M04	66.5
M05	61.5
M06	61.5

Total Core Recovery (TCR) in the bedrock typically ranged from 97 to 100% indicating a good core recovery. The Rock Quality Designation (RQD) values ranged from 14 to 100%, but generally higher than 50%, indicating a variable rock quality ranging from poor to excellent. Unconfined compression strength (UCS), interpreted from point load tests conducted on intact cores ranged from 42 to 94 MPa, indicating a strong rock strength. Additional core descriptions are tabulated in Appendix C.

#### 5.4 Results of Analytical Tests

Nine sample of soil recovered from within the boreholes were selected and submitted for analytical testing including pH, resistivity, chloride and sulphate. The results are summarized below and presented on the Certificate of Analysis included in Appendix C.

**Table 5-5. Samples Selected for Environmental Testing**

Borehole	Sample/ Depth (m)	Material	Conductivity (uS/cm)	pH ( - )	Resistivity (Ohm-m)	Chloride (ug/g)	Sulphate (ug/g)
B01	SS1 (0.2 to 0.7)	Fill	2,640	7.94	3.79	33	4,830
B02	SS3 (1.5 to 2.1)	Fill	1,220	9.18	8.23	246	559
B04	SS5 (9.1 to 9.7)	Silty Clay	335	8.32	29.9	9	119
B05	SS2 (6.1 to 6.7)	Silty Clay	174	7.77	57.4	8	8
D01	SS1 (0 to 0.6)	Fill	194	8.08	51.6	9	74
D05	SS1 (11.4 to 12.0)	Silty Clay	134	8.04	74.5	5	<5
M01	SS2 (0.8 to 1.4)	Fill	287	8.02	34.8	60	66
M03	SS1 (0.2 to 0.8)	Fill	1,140	8.52	8.73	100	1,370
M05	SS2A (6.9 to 7.2)	Silty Clay	253	8.14	39.6	8	56

## 5.5 Of-Shore Geophysical Testing

The methodology and results of the off-shore geophysical testing are presented in Appendix E. Geophysics GPR International Inc. (GPR) was provided with the borehole investigation results for use in calibrating their observations. The results are presented as series of drawings with the interpreted bedrock elevation and overburden thickness.

## 6 MISCELLANEOUS

Borehole locations were selected relative to existing site features, anticipated foundation locations and existing borehole information. Ground surface elevations were interpreted from topographic survey data.

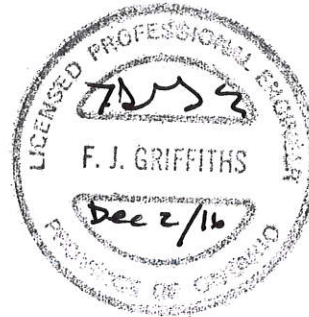
Eastern Ontario Diamond Drilling Ltd. from Hawkesbury, Ontario supplied the drill rigs and conducted the drilling, sampling and in-situ testing for the field program. The field investigation was supervised on a full time basis by Mr. Chris Murray, E.I.T. and Mr. Justin Gray, E.I.T of Thurber. Overall supervision of the investigation program was conducted by Mr. Stephen Peters, P.Eng. Geophysics GPR International Inc. of Mississauga carried out the off-shore geophysical investigation.

Routine geotechnical laboratory testing was carried out by Thurber's laboratory in Ottawa, Ontario. One-dimensional consolidation testing was completed by Stantec's laboratory in Ottawa, Ontario. Analytical testing was carried out by Paracel Laboratories Ltd. in Ottawa, Ontario. Interpretation of the data and preparation of this report were carried out by Dr. Fred Griffiths, P.Eng. and Mr. Stephen Peters, P.Eng. The report was reviewed by Mr. Alastair Gorman, P.Eng and Dr. P.K. Chatterji, P.Eng a Designated Principal Contact for MTO Foundation Projects.

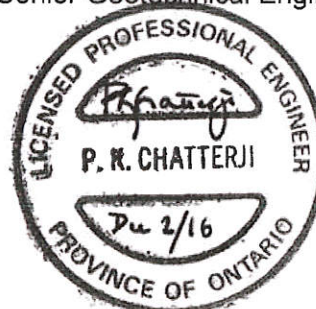
Thurber Engineering Ltd.  
Report Prepared By:



Stephen Peters, P.Eng.  
Geotechnical Engineer



Fred Griffiths, P.Eng., Ph.D.  
Senior Associate  
Senior Geotechnical Engineer



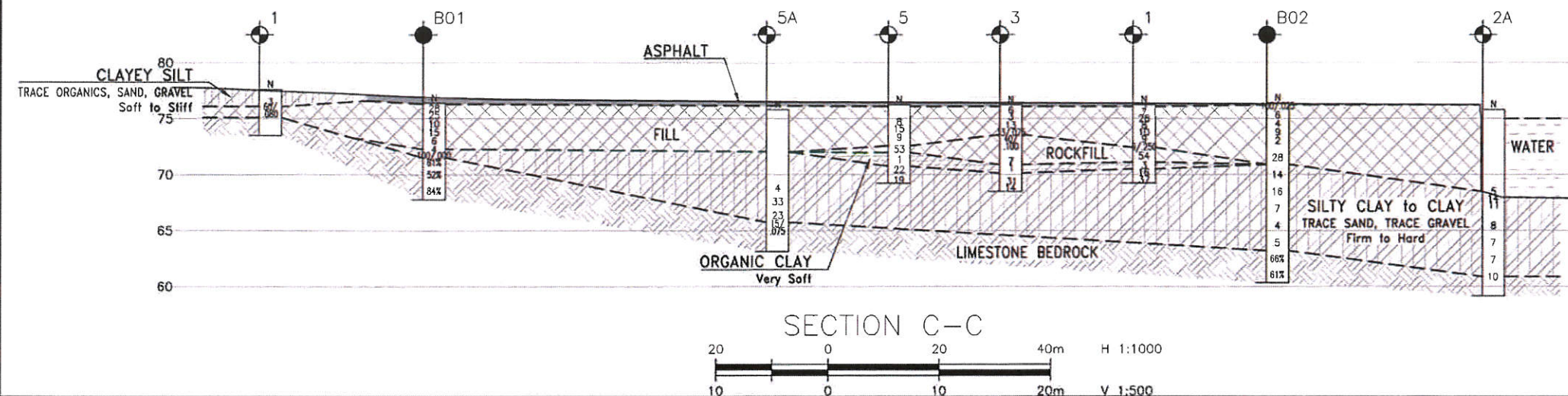
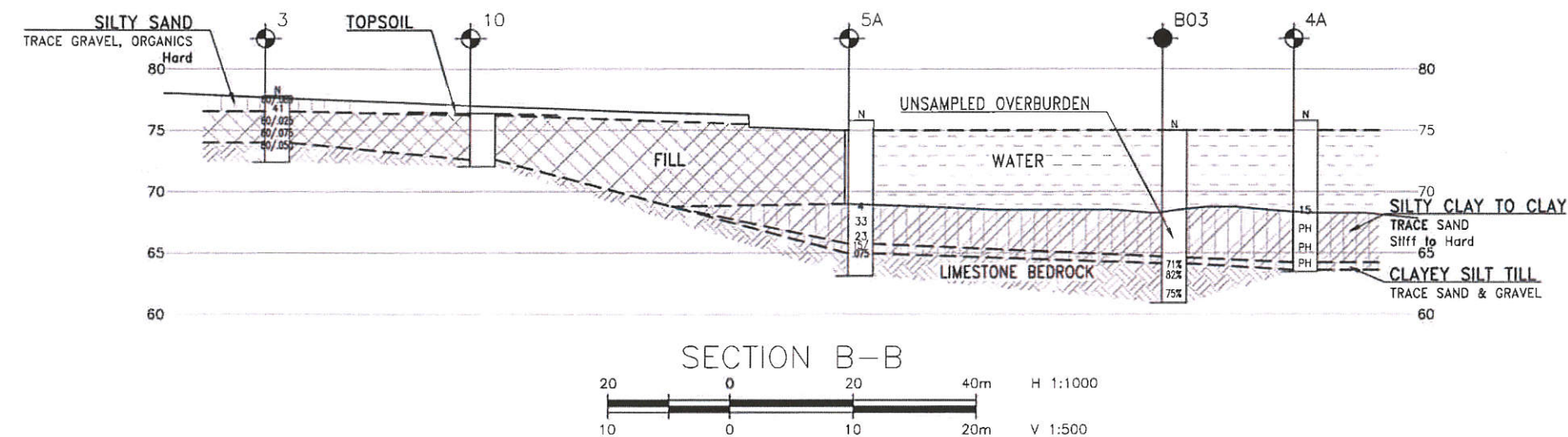
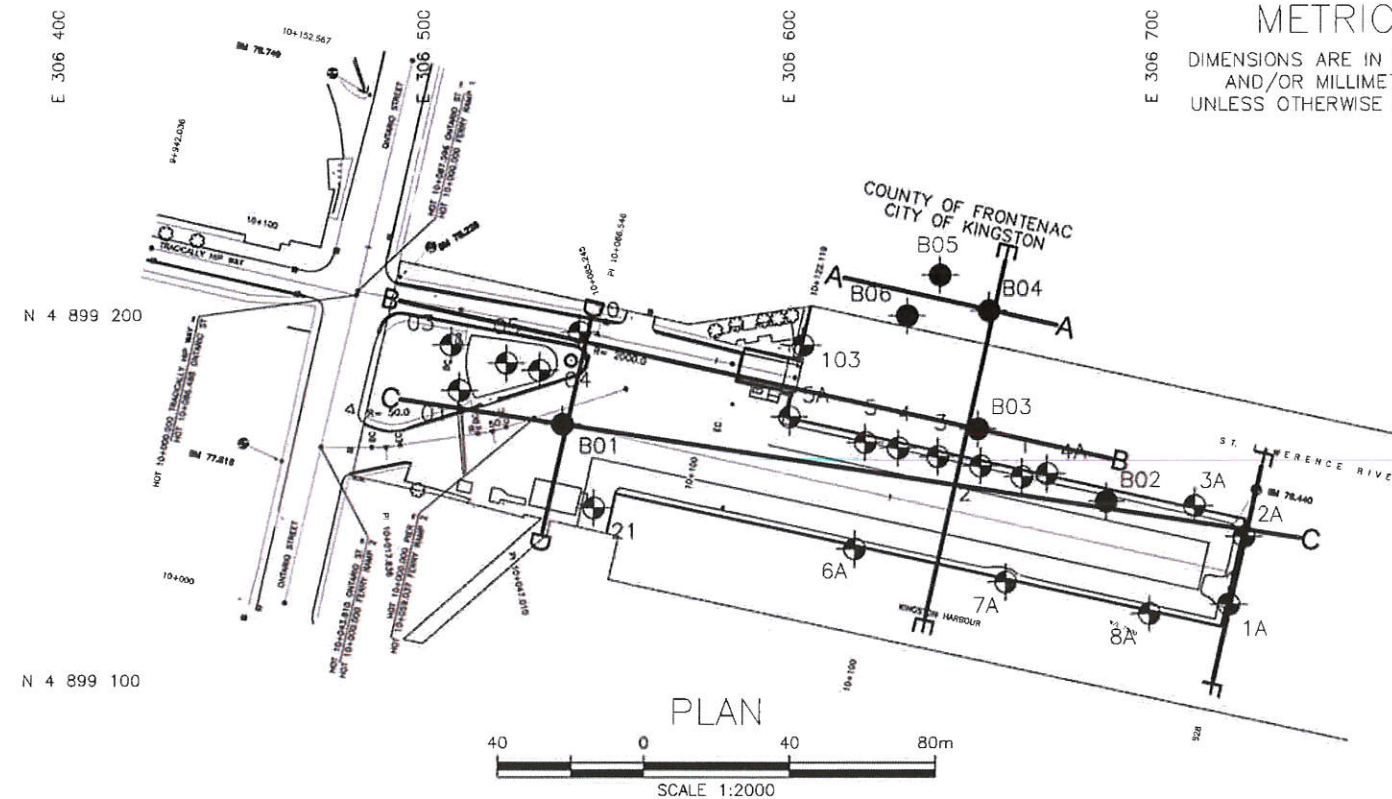
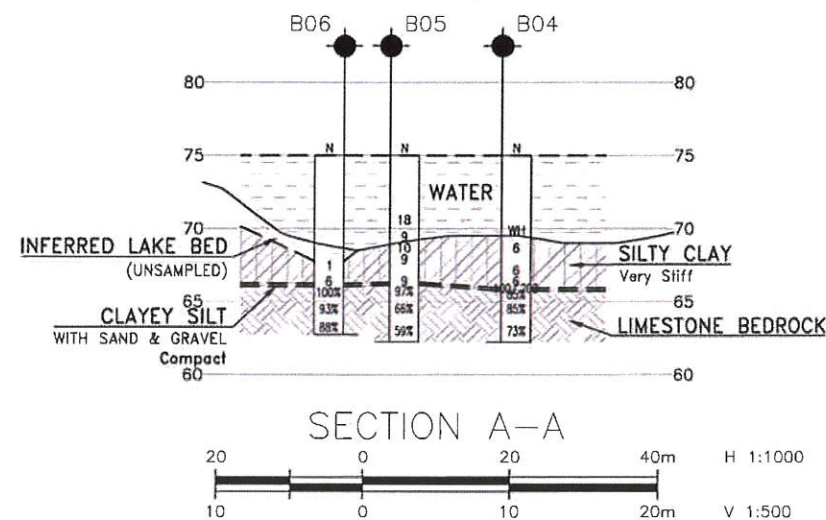
P.K. Chatterji, P.Eng., Ph.D.  
Review Principal  
Senior Geotechnical Engineer

Alastair Gorman, P.Eng.  
Senior Associate  
Senior Geotechnical Engineer

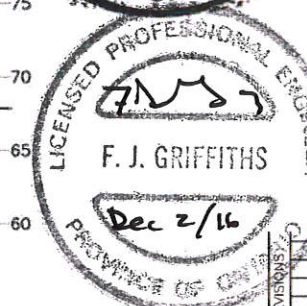
**Appendix A.**

**Borehole Location Plan and Stratigraphic Drawings**





NO	ELEVATION	NORTHING	EASTING
4A	75.8	4 899 158.2	306 673.1
5	76.2	4 899 186.7	306 623.1
5A	75.8	4 899 173.7	306 602.2
6A	75.8	4 899 137.6	306 620.2
7A	75.8	4 899 128.5	306 661.7
8A	75.8	4 899 119.8	306 701.4
01	77.6	4 899 180.9	306 511.7
03	77.8	4 899 193.4	306 509.5
04	77.5	4 899 186.4	306 533.6
05	77.3	4 899 188.4	306 524.5
10	76.4	4 899 196.9	306 544.4
21	76.4	4 899 148.8	306 548.5
103	74.7	4 899 193.3	306 605.9



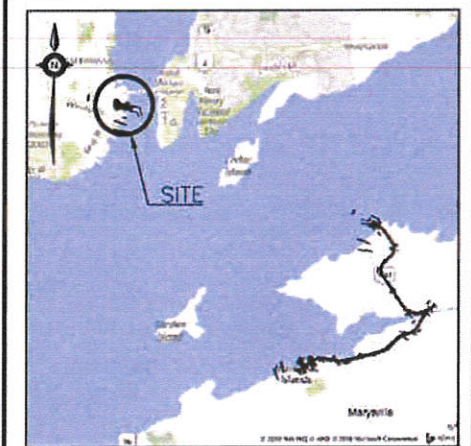
CONT No  
GWP No 4061-14-00

WOLFE ISLAND  
FERRY DOCKS  
BARRACK STREET DOCK  
BOREHOLE LOCATIONS AND SOIL STRATA

SHEET








**THURBER ENGINEERING LTD.**



## KEYPLAN

L E G E N D

- |   |  |
|---|--|
|    | Borehole (Present Investigation by Thurber)  |
|  | Borehole (Previous Investigations by Others) |
| N   | Blows /0.3m (Std Pen Test, 475J/blow)        |
| CONE  | Blows /0.3m (60' Cone, 475J/blow)            |
| PH  | Pressure, Hydraulic                          |
|  | Water Level                                  |
|  | Head Artesian Water                          |
|  | Piezometer                                   |
| 90%   | Rock Quality Designation (RQD)               |
| A/R   | Auger Refusal                                |

NO	ELEVATION	NORTHING	EASTING
B01	76.4	4 899 171.7	306 539.9
B02	76.4	4 899 150.6	306 689.4
B03	75.0	4 899 170.4	306 653.8
B04	75.0	4 899 202.8	306 656.8
B05	75.0	4 899 212.6	306 643.4
B06	75.0	4 899 201.4	306 634.4
1	76.2	4 899 157.3	306 666.1
1A	75.8	4 899 122.4	306 723.1
2	76.2	4 899 160.3	306 654.7
2A	75.8	4 899 140.9	306 727.2
3	76.2	4 899 162.9	306 642.9
3A	75.8	4 899 149.3	306 713.7
4	76.2	4 899 165.2	306 632.1

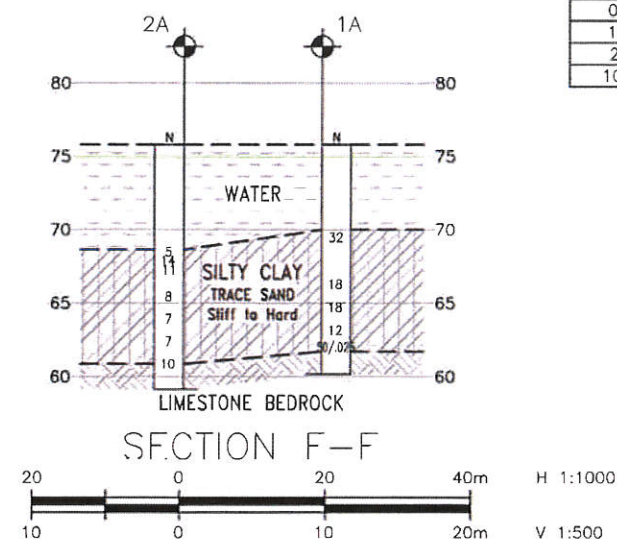
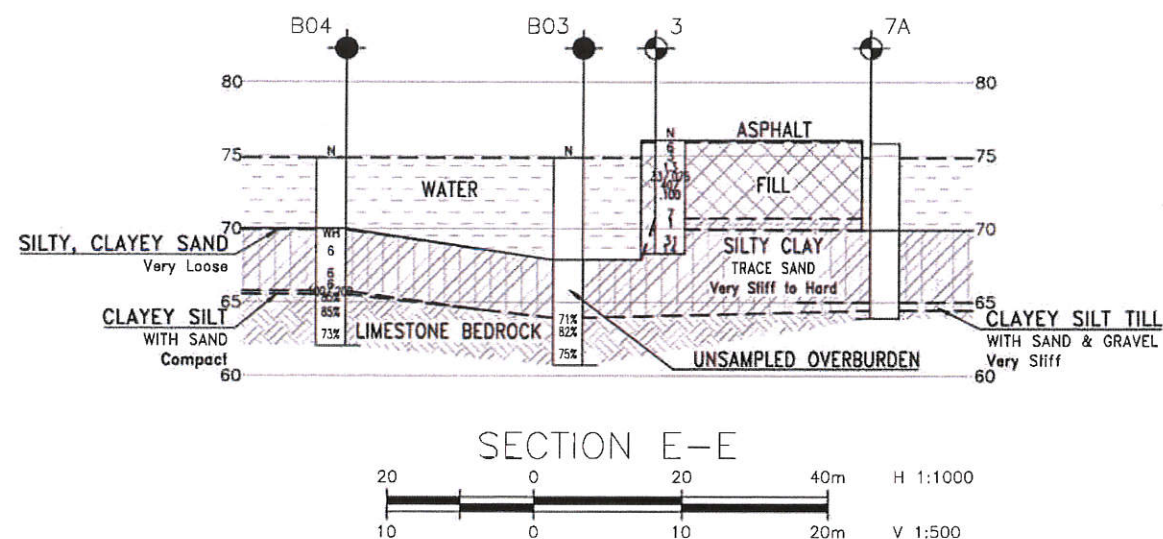
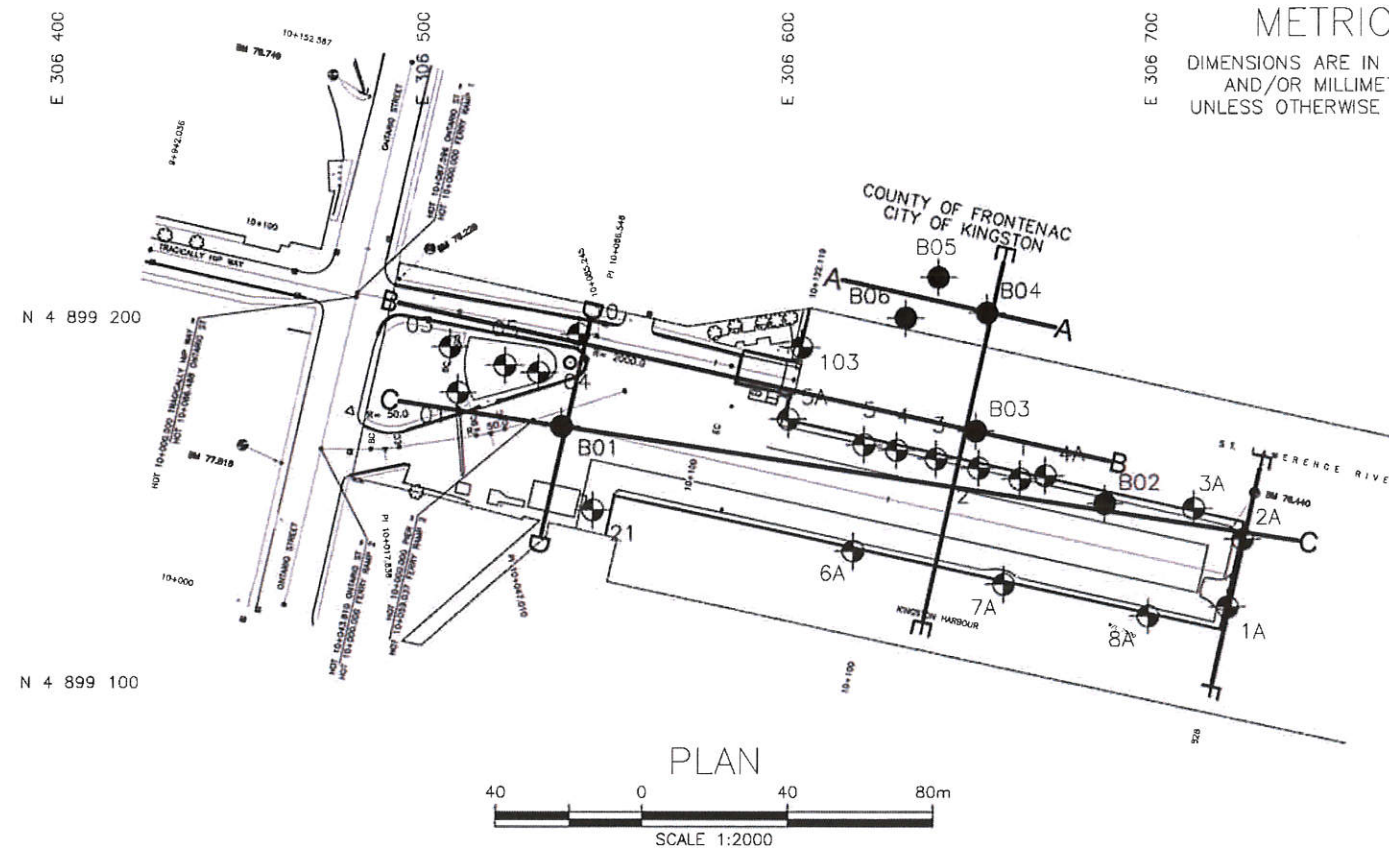
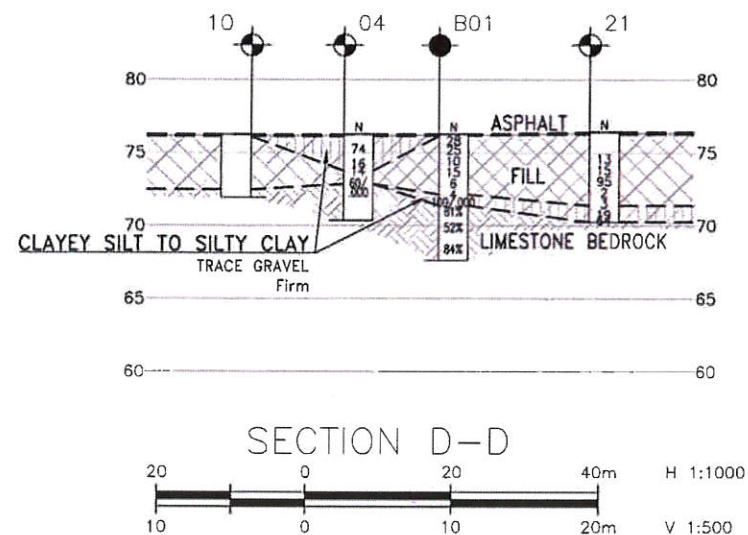
-NOTES-

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- 2) This drawing is for subsurface information only. Surface details and features are for conceptual illustration.

**GEOCRES No. 31C-243**

REVISIONS		DATE	BY	DESCRIPTION			
DESIGN	SP	CHK	-	LOAD		DATE	DEC 2016
DRAWN	MFA	CHK	SP	SITE	STRUCT	IPWG	1





NO	ELEVATION	NORTHING	EASTING
4A	75.8	4 899 158.2	306 673.1
5	76.2	4 899 166.7	306 623.1
5A	75.8	4 899 173.7	306 602.2
6A	75.8	4 899 137.6	306 620.2
7A	75.8	4 899 128.5	306 661.7
8A	75.8	4 899 119.8	306 701.4
01	77.6	4 899 180.9	306 511.7
03	77.8	4 899 193.4	306 509.5
04	77.5	4 899 186.4	306 533.6
05	77.3	4 899 188.4	306 524.5
10	76.4	4 899 196.9	306 544.4
21	76.4	4 899 148.8	306 548.5
103	74.7	4 899 193.3	306 605.9

NO	ELEVATION	NORTHING	EASTING
B01	76.4	4 899 171.7	306 539.9
B02	76.4	4 899 150.6	306 689.4
B03	75.0	4 899 170.4	306 653.8
B04	75.0	4 899 202.8	306 656.8
B05	75.0	4 899 212.6	306 643.4
B06	75.0	4 899 201.4	306 634.4
1	76.2	4 899 157.3	306 666.1
1A	75.8	4 899 122.4	306 723.1
2	76.2	4 899 160.3	306 654.7
2A	75.8	4 899 140.9	306 727.2
3	76.2	4 899 162.9	306 642.9
3A	75.8	4 899 149.3	306 713.7
4	76.2	4 899 165.2	306 632.1

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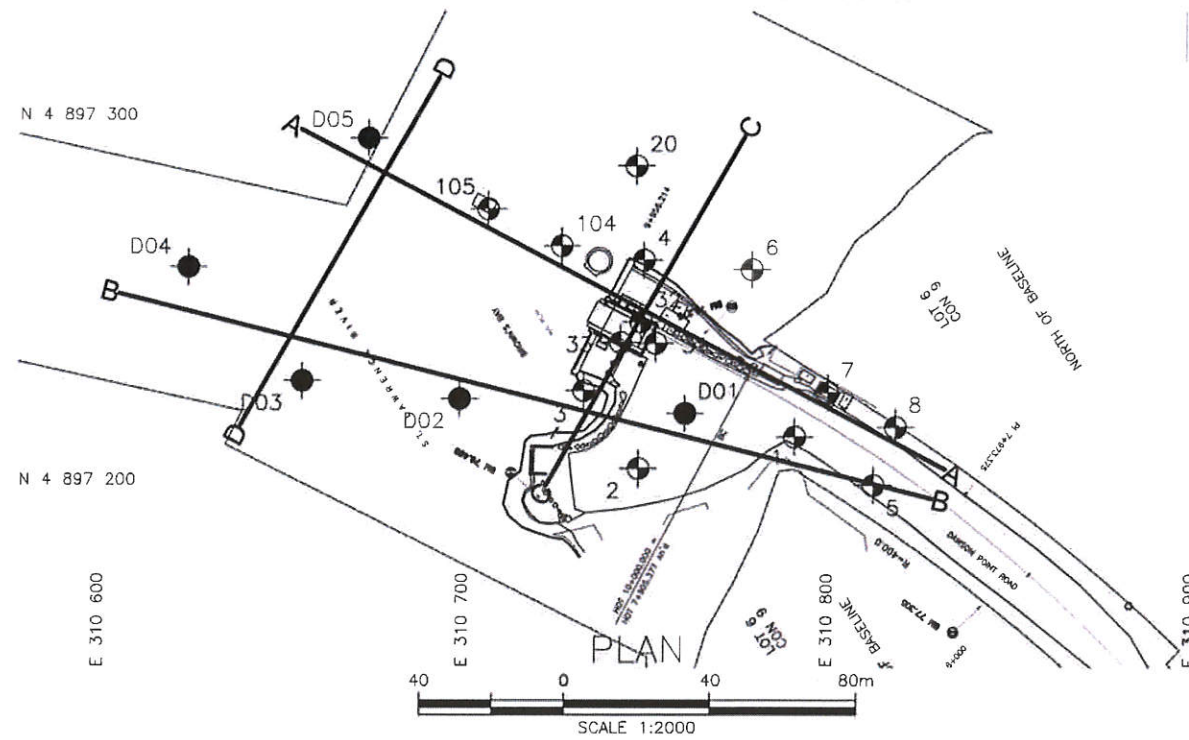
GEOCRES No. 31C-243

REVISIONS							
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			STRUCT	IDWG	2		

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METRIC  
DIMENSIONS ARE IN METRES  
AND/OR MILLIMETRES  
UNLESS OTHERWISE SHOWN



NO	ELEVATION	NORTHING	EASTING
20	74.9	4 897 287.4	310 749.3
31	75.9	4 897 238.7	310 754.7
32	75.8	4 897 244.6	310 750.7
33	75.3	4 897 238.9	310 745.1
104	74.7	4 897 265.5	310 728.9
105	74.7	4 897 275.6	310 708.5

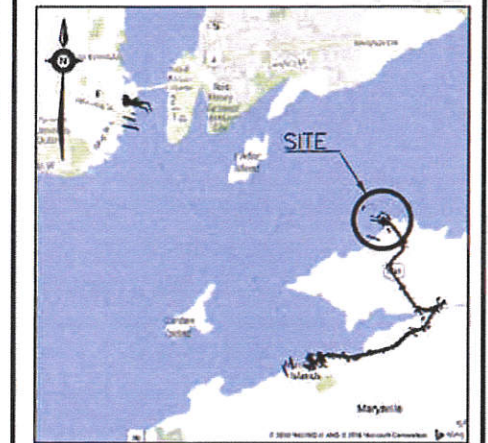
CONT No  
GWP No 4061-14-00

WOLFE ISLAND  
FERRY DOCKS  
DAWSON'S POINT DOCK  
BOREHOLE LOCATIONS AND SOIL STRATA



SHEET

THURBER ENGINEERING LTD.



KEYPLAN  
LEGEND

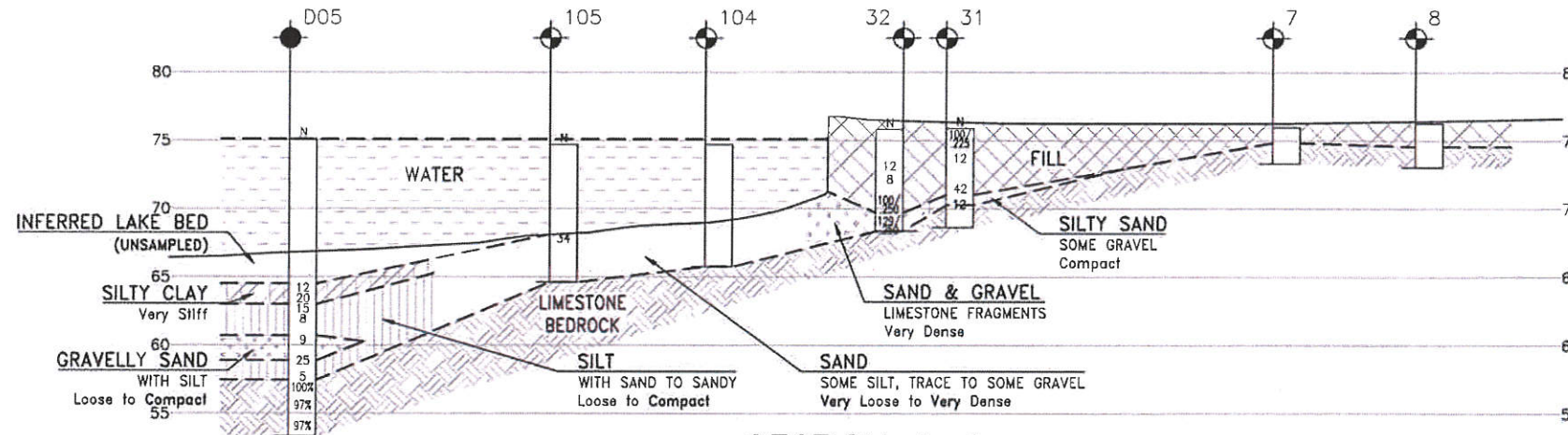
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- Borehole (Previous Investigations by Others)
- N Blows /0.3m (Std Pen Test, 475J/blow)
- CONE Blows /0.3m (60' Cone, 475J/blow)
- PH Pressure, Hydraulic
- W Water Level
- HA Head Artesian Water
- P Piezometer
- 90% Rock Quality Designation (RQD)
- A/R Auger Refusal

NO	ELEVATION	NORTHING	EASTING
D01	76.3	4 897 219.6	310 762.8
D02	75.1	4 897 223.6	310 700.8
D03	75.1	4 897 228.5	310 657.7
D04	75.1	4 897 259.7	310 626.5
D05	75.1	4 897 295.0	310 675.6
1	75.8	4 897 213.1	310 792.9
2	74.9	4 897 204.5	310 750.1
3	74.9	4 897 225.8	310 735.1
4	74.9	4 897 261.6	310 751.5
5	76.1	4 897 199.9	310 814.4
6	74.9	4 897 258.9	310 780.9
7	76.0	4 897 225.3	310 801.8
8	76.3	4 897 215.8	310 820.5

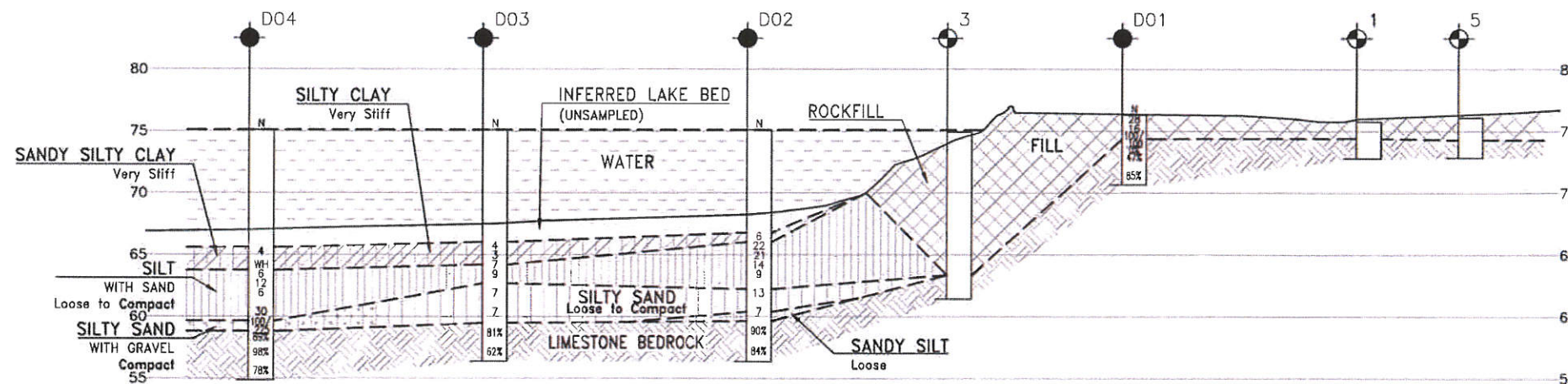
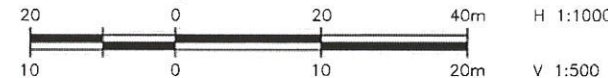
-NOTES-

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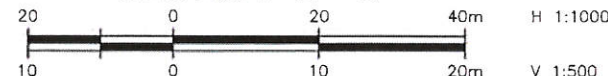
GEOCRES No. 31C-243



SECTION A-A



SECTION B-B



DATE	BY	DESCRIPTION
DESIGN	SP	CHK - CODE
DRAWN	MFA	CHK SP SITE
		STRUCT
		DWG 3



METRIC  
DIMENSIONS ARE IN METRES  
AND/OR MILLIMETRES  
UNLESS OTHERWISE SHOWN

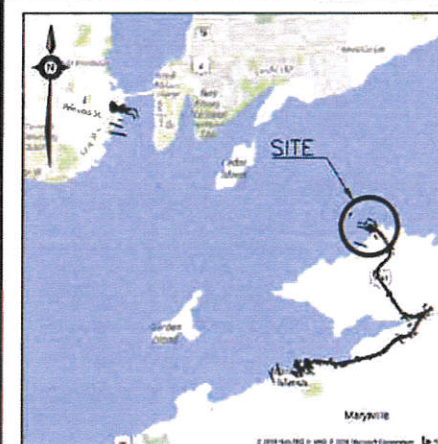
CONT No  
GWP No 4061-14-00

WOLFE ISLAND  
FERRY DOCKS  
DAWSON'S POINT DOCK  
BOREHOLE LOCATIONS AND SOIL STRATA

SHEET








**THURBER** ENGINEERING LTD.



## KEYPLAN

LEGEND

- |   |  |
|---|--|
|    | Borehole (Present Investigation by Thurber)  |
|   | Borehole (Previous Investigations by Others) |
| N   | Blows /0.3m (Std Pen Test, 475J/blow)        |
| CONE  | Blows /0.3m (60" Cone, 475J/blow)            |
| PH  | Pressure, Hydraulic                          |
|  | Water Level                                  |
|  | Head Artesian Water                          |
|  | Piezometer                                   |
| 90%   | Rock Quality Designation (RQD)               |
| A/R   | Auger Refusal                                |

NO	ELEVATION	NORTHING	EASTING
D01	76.3	4 897 219.6	310 762.8
D02	75.1	4 897 223.6	310 700.8
D03	75.1	4 897 228.5	310 657.8
D04	75.1	4 897 259.7	310 629.8
D05	75.1	4 897 295.0	310 675.8
1	75.8	4 897 213.1	310 792.8
2	74.9	4 897 204.5	310 750.8
3	74.9	4 897 225.8	310 735.8
4	74.9	4 897 261.6	310 751.8
5	76.1	4 897 199.9	310 814.8
6	74.9	4 897 258.9	310 780.8
7	76.0	4 897 225.3	310 801.8
8	76.3	4 897 215.8	310 820.8

-NOTES-

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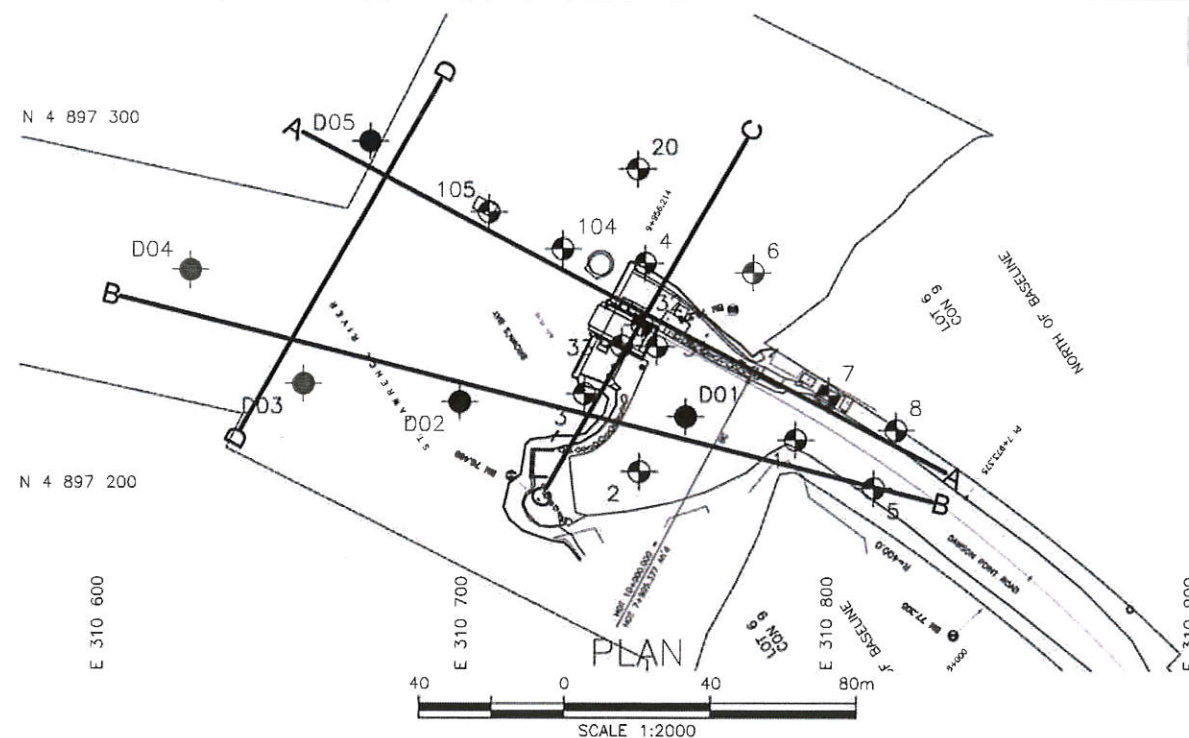
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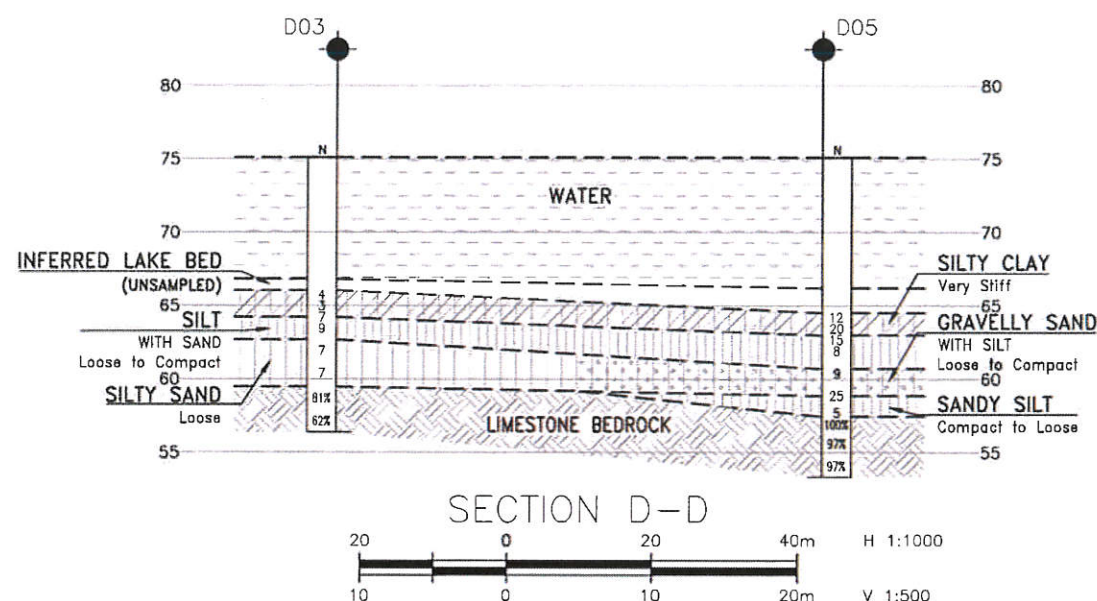
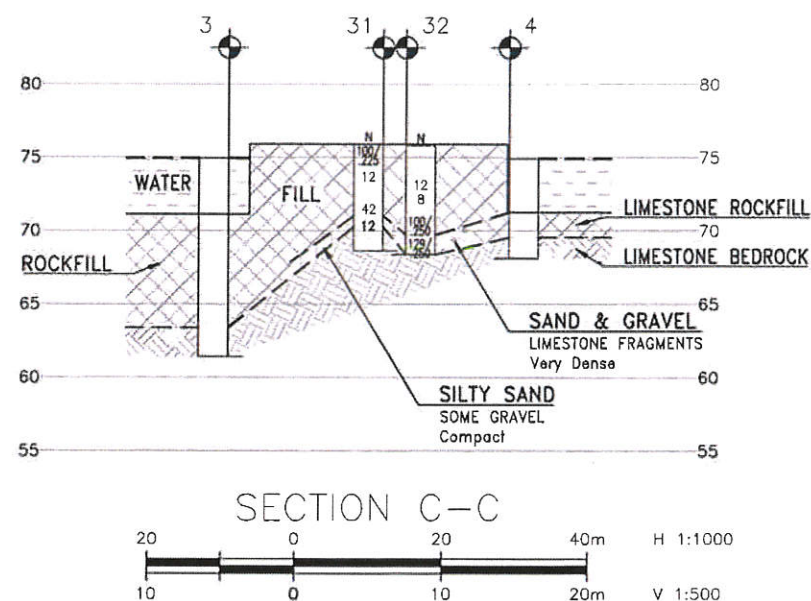
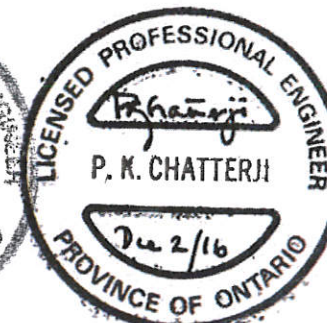
REVISIONS

DATE	BY	DESCRIPTION						
DESIGN SP	CHK -	CODE			LOAD	DATE DEC 20		
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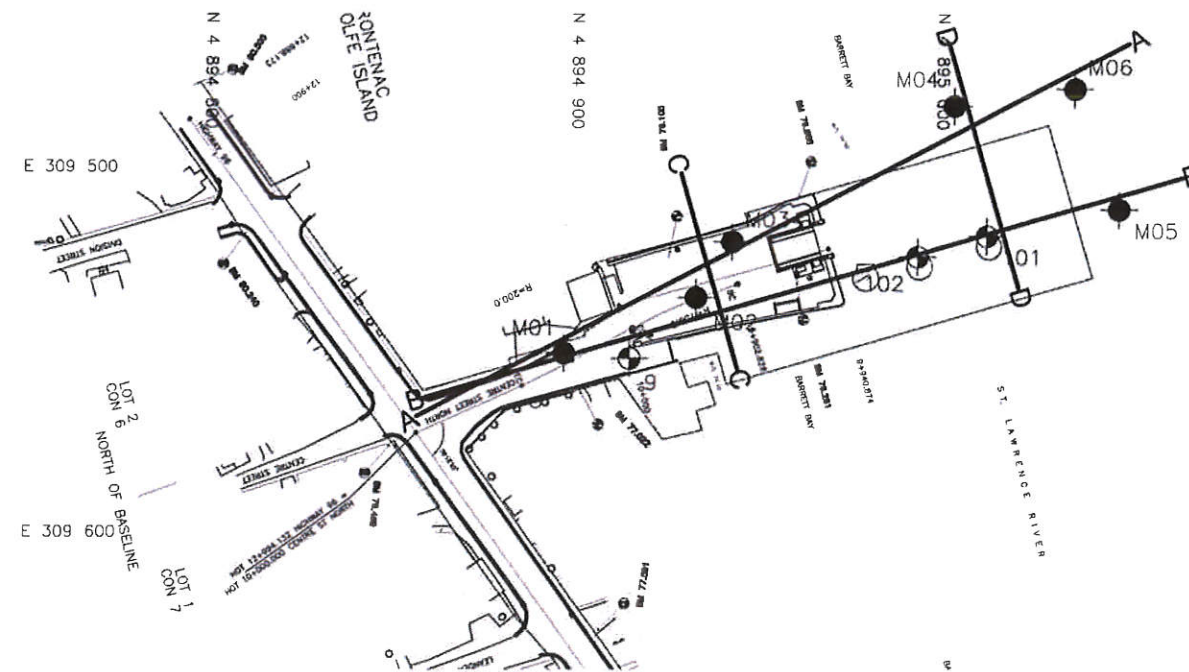
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NO	ELEVATION	NORTHING	EASTING
20	74.9	4 897 287.4	310 749.3
31	75.9	4 897 238.7	310 754.7
32	75.8	4 897 244.6	310 750.7
33	75.3	4 897 238.9	310 745.1
104	74.7	4 897 265.5	310 728.9
105	74.7	4 897 275.6	310 708.5



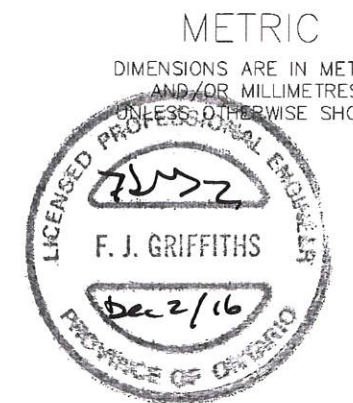




PLAN

SCALE 1:2000

N 4 895 100



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GWP No 4061-14-00

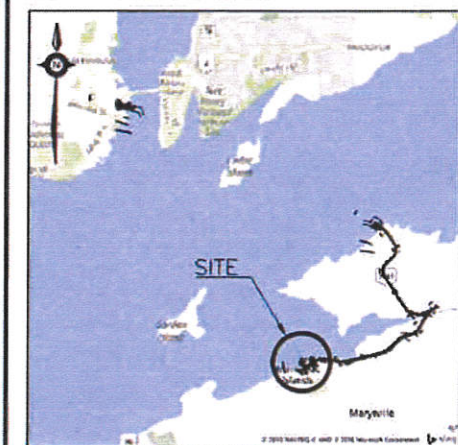
WOLFE ISLAND  
FERRY DOCKS  
MARYSVILLE DOCK  
BOREHOLE LOCATIONS AND SOIL STRATA



SHEET



THURBER ENGINEERING LTD.



KEYPLAN

LEGEND

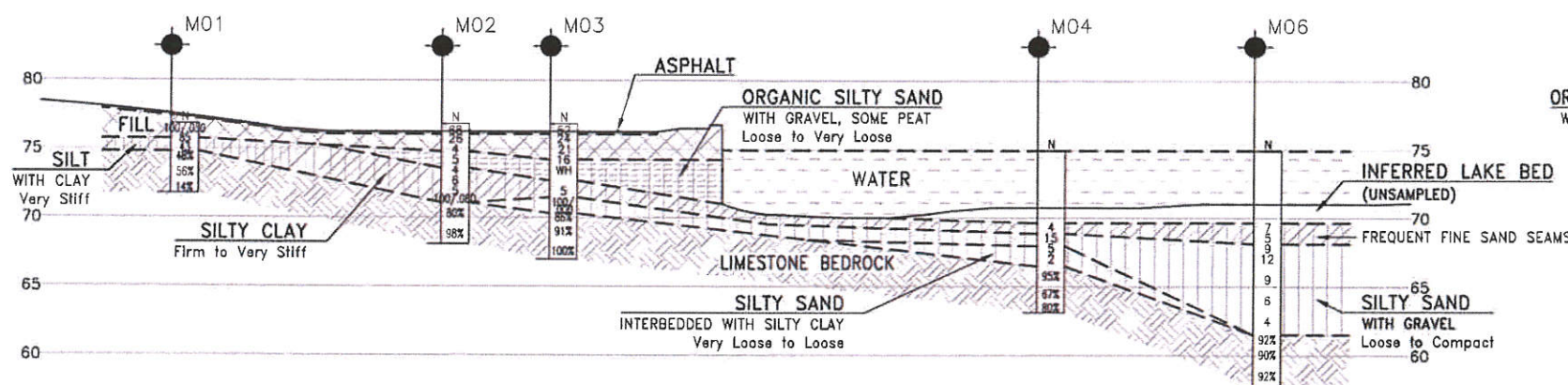
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- Borehole (Previous Investigations by Others)
- N Blows /0.3m (Std Pen Test, 475J/blow)
- CONE Blows /0.3m (60° Cone, 475J/blow)
- PH Pressure, Hydraulic
- W Water Level
- W Head Artesian Water
- P Piezometer
- 90% Rock Quality Designation (RQD)
- A/R Auger Refusal

NO	ELEVATION	NORTHING	EASTING
M01	76.9	4 894 898.0	309 552.5
M02	76.9	4 894 934.2	309 537.2
M03	76.9	4 894 943.9	309 521.9
M04	74.9	4 895 004.5	309 484.7
M05	74.9	4 895 049.7	309 513.0
M06	74.9	4 895 037.6	309 480.0
9	76.3	4 894 916.0	309 553.9
101	74.7	4 895 013.7	309 520.4
102	74.7	4 894 994.6	309 526.0

-NOTES-

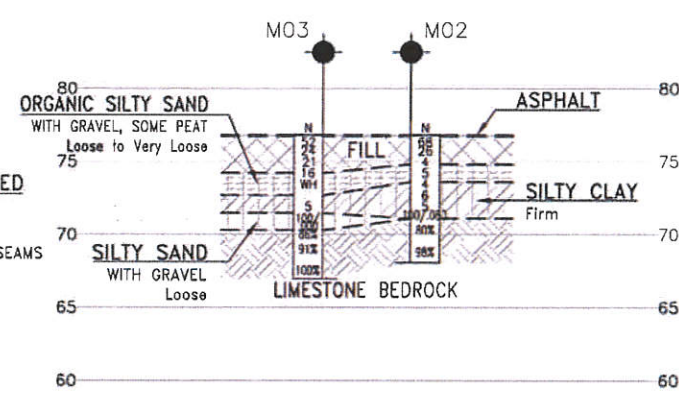
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GEOCREs No. 31C-243



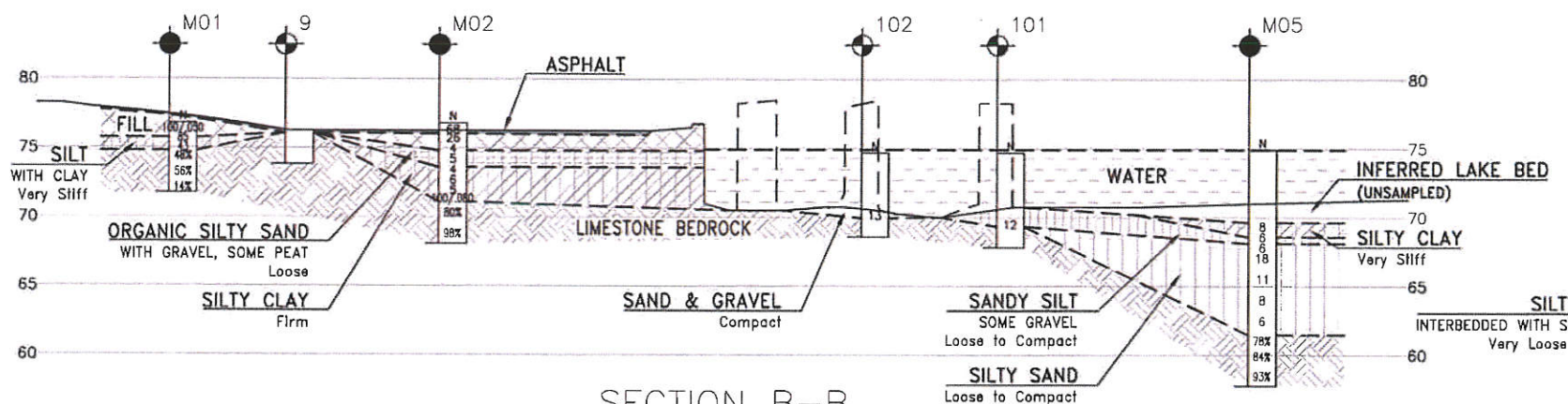
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10 0 10 20m V 1:500



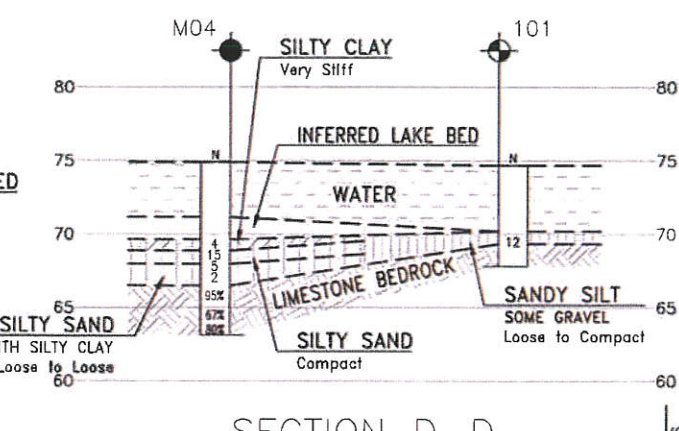
SECTION C-C

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10 0 10 20m V 1:500



SECTION B-B

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10 0 10 20m V 1:500



SECTION D-D

20 0 20 40m H 1:1000  
10 0 10 20m V 1:500

DATE	BY	DESCRIPTION
DESIGN	SP	CHK -
DRAWN	MFA	CHK SP
SITE	STRUCT	DATE DEC 2016

**Appendix B.**

**Record of Borehole Sheets**





## **SYMBOLS, ABBREVIATIONS AND TERMS USED ON TEST HOLE RECORDS**

### **TERMINOLOGY DESCRIBING COMMON SOIL GENESIS**

Topsoil	mixture of soil and humus capable of supporting vegetative growth
Peat	mixture of fragments of decayed organic matter
Till	unstratified glacial deposit which may include particles ranging in sizes from clay to boulder
Fill	material below the surface identified as placed by humans (excluding buried services)

### **TERMINOLOGY DESCRIBING SOIL STRUCTURE:**

Desiccated	having visible signs of weathering by oxidization of clay materials, shrinkage cracks, etc.
Fissured	having cracks, and hence a blocky structure
Varved	composed of alternating layers of silt and clay
Stratified	composed of alternating successions of different soil types, e.g. silt and sand
Layer	> 75 mm in thickness
Seam	2 mm to 75 mm in thickness
Parting	< 2 mm in thickness

### **RECOVERY:**

For soil samples, the recovery is recorded as the length of the soil sample recovered.

### **N-VALUE:**

Numbers in this column are the field results of the Standard Penetration Test: the number of blows of a 63.5 kg hammer falling 0.76 m, required to drive a 50 mm O.D. split spoon sampler 0.3 m into undisturbed soil. For samples where insufficient penetration was achieved and N-value cannot be presented, the number of blows are reported over the sampler penetration in millimetres (e.g. 50/75).

### **DYNAMIC CONE PENETRATION TEST (DCPT):**

Dynamic cone penetration tests are performed using a standard 60 degree apex cone connected to an "A" size drill rods with the same standard fall height and weight as the Standard Penetration Test. The DCPT value is the number of blows of the hammer required to drive the cone 0.3 m into the soil. The DCPT is used as a probe to assess soil variability.

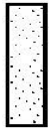


### STRATA PLOT:

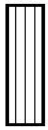
Strata plots symbolize the soil and bedrock description. They are combinations of the following basic symbols. The dimensions within the strata symbols are not indicative of the particle size, layer thickness, etc.



Boulders  
Cobbles  
Gravel



Sand



Silt



Clay



Organics



Asphalt



Concrete



Fill



Bedrock

### TEXTURING CLASSIFICATION OF SOILS

Classification	Particle Size
Boulders	Greater than 200 mm
Cobbles	75 – 200 mm
Gravel	4.75 – 75 mm
Sand	0.075 – 4.75 mm
Silt	0.002 – 0.075 mm
Clay	Less than 0.002 mm

### SAMPLE TYPES

SS	Split spoon samples
ST	Shelby tube or thin wall tube
DP	Direct push sample
PS	Piston sample
BS	Bulk sample
WS	Wash sample
HQ, NQ, BQ etc.	Rock core sample obtained with the use of standard size diamond coring equipment

### TERMS DESCRIBING CONSISTENCY (COHESIVE SOILS ONLY)

Descriptive Term	Undrained Shear Strength (kPa)
Very Soft	12 or less
Soft	12 – 25
Firm	25 – 50
Stiff	50 – 100
Very Stiff	100 – 200
Hard	Greater than 200

NOTE: Clay sensitivity is defined as the ratio of the undisturbed strength over the remolded strength.

### TERMS DESCRIBING CONSISTENCY (COHESIONLESS SOILS ONLY)

Descriptive Term	SPT “N” Value
Very Loose	Less than 4
Loose	4 – 10
Compact	10 – 30
Dense	30 – 50
Very Dense	Greater than 50

### MODIFIED UNIFIED SOIL CLASSIFICATION

Major Divisions		Group Symbol	Typical Description
COARSE GRAINED SOIL	GRAVEL AND GRAVELLY SOILS	GW	Well-graded gravels or gravel-sand mixtures, little or no fines.
		GP	Poorly-graded gravels or gravel-sand mixtures, little or no fines.
		GM	Silty gravels, gravel-sand-silt mixtures.
		GC	Clayey gravels, gravel-sand-clay mixtures.
	SAND AND SANDY SOILS	SW	Well-graded sands or gravelly sands, little or no fines.
		SP	Poorly-graded sands or gravelly sands, little or no fines.
		SM	Silty sands, sand-silt mixtures.
		SC	Clayey sands, sand-clay mixtures.
FINE GRAINED SOILS	SILT AND CLAY SOILS $W_L < 35\%$	ML	Inorganic silts, very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity.
		CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.
		OL	Organic silts and organic silty-clays of low plasticity.
	SILT AND CLAY SOILS $35\% < W_L < 50\%$	MI	Inorganic compressible fine sandy silt with clay of medium plasticity, clayey silts.
		CI	Inorganic clays of medium plasticity, silty clays.
		OI	Organic silty clays of medium plasticity.
	SILT AND CLAY SOILS $W_L > 50\%$	MH	Inorganic silts, micaceous or diatomaceous fine sandy of silty soils, elastic silts.
		CH	Inorganic clays of high plasticity, fat clays.
		OH	Organic clays of high plasticity, organic silts.
HIGHLY ORGANIC SOILS		Pt	Peat and other organic soils.

Note -  $W_L$  = Liquid Limit





## EXPLANATION OF ROCK LOGGING TERMS

### ROCK WEATHERING CLASSIFICATION

Fresh (FR)	No visible signs of weathering.
Fresh Jointed (FJ)	Weathering limited to surface of major discontinuities.
Slightly Weathered (SW)	Penetrative weathering developed on open discontinuity surfaces, but only slight weathering of rock materials.
Moderately Weathered (MW)	Weathering extends throughout the rock mass, but the rock material is not friable.
Highly Weathered (HW)	Weathering extends throughout the rock mass and the rock is partly friable.
Completely Weathered (CW)	Rock is wholly decomposed and in a friable condition, but the rock texture and structures are preserved.

### TERMS

Total Core Recovery: (TCR)	Core recovered as a percentage of total core run length.
Solid Core Recovery: (SCR)	Percent ratio of solid core of full cylindrical shape recovered. Expressed with respect to the total length of core run.
Rock Quality Designation: (RQD)	Total length of sound core recovered in pieces 0.1 m in length or larger, as a percentage of total core length
Unconfined Compressive Strength: (UCS)	Axial stress required to break the specimen.
Fracture Index: (FI)	Frequency of natural fractures per 0.3 m of core run.

### DISCONTINUITY SPACING

Bedding	Bedding Plane Spacing
Very thickly bedded	Greater than 2 m
Thickly bedded	0.6 to 2 m
Medium bedded	0.2 to 0.6 m
Thinly bedded	60 mm to 0.2 m
Very thinly bedded	20 to 60 mm
Laminated	6 to 20 mm
Thinly laminated	Less than 6 mm

### STRENGTH CLASSIFICATION

Rock Strength	Approximate Uniaxial Compressive Strength (MPa)
Extremely Strong	Greater than 250
Very Strong	100 – 250
Strong	50 – 100
Medium Strong	25 – 50
Weak	5 – 25
Very Weak	1 – 5
Extremely Weak	0.25 – 1

**Appendix B-1.  
Barrack Street**

# RECORD OF BOREHOLE No B01

1 OF 1

METRIC

GWP# 4061-14-00 LOCATION Barrack Street Dock N 4 899 171.7 E 306 539.9 ORIGINATED BY JG  
 HWY Wolfe Island Ferry Docks BOREHOLE TYPE Hollow Stem Auger COMPILED BY JG  
 DATUM Geodetic DATE 2015.01.09 - 2015.01.09 CHECKED BY FJG

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT				PLASTIC LIMIT      NATURAL MOISTURE CONTENT      LIQUID LIMIT			UNIT WEIGHT  γ  kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%)
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa				WATER CONTENT (%)				
76.4								20	40	60	80	100				
0.0	Asphalt 90mm															
0.1	Sandy <b>GRAVEL</b> compact grey dry		1	SS	28		76									
75.7																
0.8	<b>FILL</b>  Silty <b>SAND</b> with Gravel compact brown moist		2	SS	25		75									22   61   17 (SI+CL)
	<b>FILL</b> black coal, slag		3	SS	10											
73.7			4	SS	15		74									
2.7	<b>SAND</b> with Gravel some wood loose brown wet		5	SS	6		73									19   76   5 (SI+CL)
72.3			6	SS	4											
4.1	Silty <b>CLAY</b> trace gravel, trace wood pieces Firm Grey		7	SS	100/ 0mm		72									
71.6																
4.9	<b>LIMESTONE</b> , Grey, Slightly Weatherd, Strong, Horizontally Bedded		1	RUN			71									RUN #1 TCR=100% SCR=91% RQD=61%
			2	RUN			70									RUN #2 TCR=100% SCR=52% RQD=52%
			3	RUN			69									RUN #3 TCR=100% SCR=98% RQD=84%
67.8							68									
8.6	End of Borehole at 8.6 m															

ONTMT4S 19-479-154 WOLFE ISLAND FERRY DOCKS.GPJ 2012TEMPLATE(MTO).GDT 2/12/16

+<sup>3</sup>, ×<sup>3</sup>: Numbers refer to  
Sensitivity

20  
15  
10

(%) STRAIN AT FAILURE

# RECORD OF BOREHOLE No B02

1 OF 2

METRIC

GWP# 4061-14-00 LOCATION Barrack Street Dock N 4 899 150.6 E 306 689.4 ORIGINATED BY JG  
 HWY Wolfe Island Ferry Docks BOREHOLE TYPE Hollow Stem Auger COMPILED BY JG  
 DATUM Geodetic DATE 2015.02.09 - 2015.02.09 CHECKED BY FJG

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT				UNIT WEIGHT  $\gamma$ kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%)								
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa													
76.4								20	40	60	80	100									
0.0	Asphalt 90mm		1	SS	100/25mm		76														
0.1																					
76.1	Sandy GRAVEL																				
0.2																					
0.3	Concrete 150mm																				
	Silty GRAVEL with Sand with Clay loose brown moist FILL		2	SS	6		75											29	20	28	23
			3	SS	4																
			4	SS	9		74														
73.7																					
2.7	WOOD with voids wet		5	SS	2		73														
			6	SS	28		72														
							71														
71.0																					
5.5	Silty CLAY very stiff to firm grey		7	SS	14		70											0	3	54	43
			8	SS	16		69														
							68														
			9	SS	7		67														

Continued Next Page

+<sup>3</sup>, ×<sup>3</sup>: Numbers refer to  
Sensitivity

20  
15  
10  
(%) STRAIN AT FAILURE

# RECORD OF BOREHOLE No B02

2 OF 2

METRIC

GWP# 4061-14-00 LOCATION Barrack Street Dock N 4 899 150.6 E 306 689.4 ORIGINATED BY JG  
 HWY Wolfe Island Ferry Docks BOREHOLE TYPE Hollow Stem Auger COMPILED BY JG  
 DATUM Geodetic DATE 2015.02.09 - 2015.02.09 CHECKED BY FJG

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT			UNIT WEIGHT  $\gamma$ kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%)
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa				
								20 40 60 80 100	PLASTIC LIMIT	NATURAL MOISTURE CONTENT		
Continued From Previous Page								W P W W L				
								WATER CONTENT (%)				
								○ UNCONFINED + FIELD VANE				
								● QUICK TRIAXIAL × LAB VANE				
								20 40 60 80 100				
								20 40 60				

ONTMT4S 19-479-154 WOLFE ISLAND FERRY DOCKS.GPJ 2012TEMPLATE(MTO).GDT 2/12/16

## METRIC

+ 3, × 3: Numbers refer to Sensitivity

# RECORD OF BOREHOLE No B03

2 OF 2

METRIC

GWP# 4061-14-00 LOCATION Barrack Street Dock N 4 899 170.4 E 306 653.8 ORIGINATED BY CM  
 HWY Wolfe Island Ferry Docks BOREHOLE TYPE Casing / NQ Coring COMPILED BY CM  
 DATUM Geodetic DATE 2015.09.16 - 2015.09.19 CHECKED BY FJG

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					UNIT WEIGHT  $\gamma$ kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%)
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa						
	Continued From Previous Page							20 40 60 80 100						
								PLASTIC LIMIT NATURAL MOISTURE CONTENT LIQUID LIMIT						
								W P W W L						
								WATER CONTENT (%)						
								20 40 60						

ONTMT4S 19-479-154 WOLFE ISLAND FERRY DOCKS.GPJ 2012TEMPLATE(MTO).GDT 2/12/16

## METRIC

SOIL PROFILE			SAMPLES		GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT		PLASTIC LIMIT NATURAL MOISTURE CONTENT LIQUID LIMIT		UNIT WEIGHT $\gamma$ kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%)
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE			"N" VALUES	20 40 60 80 100	W P W W L	20 40 60		
75.0 0.0	<b>WATER</b>											
70.2 4.9	Silty, Clayey <b>SAND</b> Very Loose Brown Wet		1	SS	WH							
	<b>SILTY CLAY</b> Very Stiff Grey		2	SS	6							
			3	TW								0 1 45 54
			4	SS	6							0 0 66 34
			5	SS	6							
65.9 9.3	Clayey <b>SILT</b> with Sand Compact Grey Moist		6	SS	100/200mm							
	<b>LIMESTONE</b> , Grey, Slightly Weathered to Fresh, Strong, Horizontally Bedded		1	RUN								RUN #1 TCR=100% SCR=100% RQD=85%

+ 3, × 3: Numbers refer to Sensitivity



# RECORD OF BOREHOLE No B04

2 OF 2

METRIC

GWP# 4061-14-00 LOCATION Barrack Street Dock N 4 899 202.8 E 306 656.8 ORIGINATED BY CM  
 HWY Wolfe Island Ferry Docks BOREHOLE TYPE Casing / NQ Coring COMPILED BY CM  
 DATUM Geodetic DATE 2015.10.09 - 2015.10.09 CHECKED BY FJG

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					PLASTIC LIMIT NATURAL MOISTURE CONTENT LIQUID LIMIT			UNIT WEIGHT $\gamma$ kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa					WATER CONTENT (%)				
							20	40	60	80	100	W <sub>p</sub>	W	W <sub>L</sub>			
	Continued From Previous Page		2	RUN													
			3	RUN													
62.2																	
12.8	End of Borehole at 12.8 m																

ONTMT4S 19-479-154 WOLFE ISLAND FERRY DOCKS.GPJ 2012TEMPLATE(MTO).GDT 2/12/16

# RECORD OF BOREHOLE No B05

1 OF 2

METRIC

GWP# 4061-14-00 LOCATION Barrack Street Dock N 4 899 212.6 E 306 643.4 ORIGINATED BY CM  
 HWY Wolfe Island Ferry Docks BOREHOLE TYPE Casing / NQ Coring COMPILED BY CM  
 DATUM Geodetic DATE 2015.09.09 - 2015.10.09 CHECKED BY FJG

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT		PLASTIC NATURAL LIQUID LIMIT MOISTURE CONTENT LIMIT			UNIT WEIGHT  $\gamma$  kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%)  GR SA SI CL
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa		WATER CONTENT (%)				
75.0								20 40 60 80 100		w <sub>p</sub> w w <sub>L</sub>				
0.0	<b>WATER</b>							○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × LAB VANE						
								20 40 60 80 100		20 40 60				

ONTMT4S 19-479-154 WOLFE ISLAND FERRY DOCKS.GPJ 2012TEMPLATE(MTO).GDT 2/12/16

Continued Next Page

+<sup>3</sup>, ×<sup>3</sup>: Numbers refer to Sensitivity  
 20  
 15 10 5  
 (%) STRAIN AT FAILURE

# RECORD OF BOREHOLE No B05

2 OF 2

METRIC

GWP# 4061-14-00 LOCATION Barrack Street Dock N 4 899 212.6 E 306 643.4 ORIGINATED BY CM  
 HWY Wolfe Island Ferry Docks BOREHOLE TYPE Casing / NQ Coring COMPILED BY CM  
 DATUM Geodetic DATE 2015.09.09 - 2015.10.09 CHECKED BY FJG

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT				PLASTIC LIMIT      NATURAL MOISTURE CONTENT      LIQUID LIMIT			UNIT WEIGHT  $\gamma$  kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%)
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			20    40    60    80    100	W P                      W                      W L	WATER CONTENT (%)						
								SHEAR STRENGTH kPa ○ UNCONFINED      + FIELD VANE ● QUICK TRIAXIAL    × LAB VANE								
	Continued From Previous Page		2	RUN			64								RUN #2 TCR=100% SCR=79% RQD=66%	
			3	RUN			63								RUN #3 TCR=100% SCR=64% RQD=59%	
62.2 12.7	End of Borehole at 12.7 m															

ONTMT4S 19-479-154 WOLFE ISLAND FERRY DOCKS.GPJ 2012TEMPLATE(MTO).GDT 2/12/16

## METRIC

SOIL PROFILE			SAMPLES		GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT		PLASTIC LIMIT NATURAL MOISTURE CONTENT LIQUID LIMIT		UNIT WEIGHT $\gamma$ kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%)
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE			"N" VALUES	20 40 60 80 100	20 40 60 80 100	W <sub>P</sub> W W <sub>L</sub>		
75.0 0.0	<b>WATER</b>											
68.9 6.1	Inferred Lake Bed											
67.8 7.2	<b>SILTY CLAY</b> Very Stiff Grey		1	SS	1							0 2 47 51
66.2 8.8	Clayey <b>SILT</b> with sand and gravel		2	SS	6							
66.0 9.0	Compact Grey Wet  <b>LIMESTONE</b> , Grey, Slightly Weathered to Fresh, Strong, Horizontally Bedded		1	RUN								RUN #1 TCR=100% SCR=100% RQD=100%

+<sup>3</sup>, ×<sup>3</sup>: Numbers refer to Sensitivity

# RECORD OF BOREHOLE No B06

2 OF 2

METRIC

GWP# 4061-14-00 LOCATION Barrack Street Dock N 4 899 201.4 E 306 634.4 ORIGINATED BY CM  
 HWY Wolfe Island Ferry Docks BOREHOLE TYPE Casing / NQ Coring COMPILED BY CM  
 DATUM Geodetic DATE 2015.10.09 - 2015.10.09 CHECKED BY FJG

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					PLASTIC LIMIT      NATURAL MOISTURE CONTENT      LIQUID LIMIT			UNIT WEIGHT  γ  kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%)  GR   SA   SI   CL
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa					WATER CONTENT (%)				
								○ UNCONFINED      + FIELD VANE ● QUICK TRIAXIAL      × LAB VANE									
	Continued From Previous Page							20	40	60	80	100		W P	W	W L	
62.7			2	RUN			64										RUN #2 TCR=100% SCR=100% RQD=93%
12.3	End of Borehole at 12.3 m		3	RUN			63										RUN #3 TCR=98% SCR=95% RQD=88%

ONTMT4S 19-479-154 WOLFE ISLAND FERRY DOCKS.GPJ 2012TEMPLATE(MTO).GDT 2/12/16

# RECORD OF BOREHOLE No 01

METRIC

W P 222-86-00 LOCATION CO-ORDS. N 4898 958.8; E 306 487.7 ORIGINATED BY P.M.  
 DIST 8 HWY N/A BOREHOLE TYPE CONTINUOUS FLIGHT AUGER (C.S.) COMPILED BY P.M.  
 DATUM GEODETIC DATE 89-03-07 TO 89-03-09 CHECKED BY \_\_\_\_\_

SOIL PROFILE		SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT		PLASTIC LIMIT W <sub>p</sub>	NATURAL MOISTURE CONTENT W	LIQUID LIMIT W <sub>L</sub>	UNIT WEIGHT Y	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE			'N' VALUES	20 40 60 80 100					
77.6	GROUND LEVEL												
0.0	CLAYEY SILT TRACE ORGANICS, SAND, GRAVEL		1	AS									
	SOFT TO STIFF		2	SS									
	BOULDERS		3	SS									
	FILL		4	AS									
	WEATHERED												
	Unweathered limestone		5	RC									
	BEDROCK												
	END OF BOREHOLE												
	* WATER LEVEL NOT ESTABLISHED												

OFFICE REPORT ON SOIL EXPLORATION



# RECORD OF BOREHOLE No 03

METRIC

W P 222-86-00

LOCATION Co-ords N 4 898 971.3; E 306 485.5

ORIGINATED BY P.M.

DIST 8 HWY N/A

BOREHOLE TYPE CONTINUOUS FLIGHT AUGER (S.S.)

COMPILED BY P.M.

DATUM GEODETIC

DATE 89-03-07 to 89-03-09

CHECKED BY

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT 20 40 60 80 100 SHEAR STRENGTH UNCONFINED + FIELD VANE QUICK TRIAXIAL X LAB VANE 20 40 60 80 100	PLASTIC LIMIT W <sub>p</sub> NATURAL MOISTURE CONTENT W LIQUID LIMIT W <sub>L</sub> WATER CONTENT (%)	UNIT WEIGHT γ	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL	
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	N' VALUES							
77.8 0.0	GROUND LEVEL											
	SILTY SAND		1	SS	60	8.9cm						
	TRACE OF GRAVEL, ORGANICS, HARD		2	SS	71							
	BOULDERS		3	SS	60	2.5cm						
	FILL		4	SS	60	7.5cm						
74.0 3.8	Weathered -		5	SS	60	5.0cm						
	Unweathered		6	RC	100%							
72.4 5.4	Bedrock		7	BQ								
	END OF BOREHOLE											
	*WATER LEVEL NOT ESTABLISHED											

# RECORD OF BOREHOLE No 04

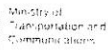
METRIC

W P 222-86-00 LOCATION CO-ORDS. N 4 898 964.3; E 306 509.6 ORIGINATED BY P.H.  
 DIST 8 HWY N/A BOREHOLE TYPE CONTINUOUS FLIGHT AUGER (C.S.S.) COMPILED BY P.H.  
 DATUM GEODETIC DATE 89-03-07 to 89-03-08 CHECKED BY \_\_\_\_\_

SOIL PROFILE		SAMPLES		GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT 20 40 60 80 100	PLASTIC LIMIT W <sub>p</sub>	NATURAL MOISTURE CONTENT W	LIQUID LIMIT W <sub>L</sub>	UNIT WEIGHT Y	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER TYPE VALUES								
77.5	GROUND LEVEL										
0.0											
5	CLAYEY SILT AND TRACE GRAVEL TO TRACE OF SAND CONCRETE ORGANICS HARD TO STIFF		1 SS 74								
			2 SS 16								
			3 SS 12								
10	FILL BOULDERS WEATHERED		4 SC 60/0.0cm								
15	Unweathered Limestone Bedrock		5 RC 97% BO *								
20	END OF BOREHOLE		6 RC 95% BO								
25	* WATER LEVEL NOT ESTABLISHED										
30											
35											
40											
45											
50											
55											
60											
65											
70											
75											
80											
85											
90											
95											
100											

OFFICE REPORT ON SOIL EXPLORATION





## METRIC

W P 222-86-00 LOCATION CO-ORDS. N 4 898.966.3; E 306 500.5 ORIGINATED BY P.M.  
DIST 8 HWY N/A BOREHOLE TYPE CONTINUOUS FLIGHT AUGER (C.S.) COMPILED BY P.M.  
DATUM GEODETIC DATE 89-03-08 CHECKED BY \_\_\_\_\_

[illegible]

OFFICE REPORT ON SOIL EXPLORATION

+2, x<sup>5</sup>: Numbers refer to "positivity"

15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 (%) STRAIN AT FAILURE

MINISTRY OF TRANSPORTATION AND COMMUNICATIONS-ONTARIO

ENGINEERING SERVICES BRANCH-GEOTECHNICAL OFFICE - SOIL MECHANICS SECTION

RECORD OF BOREHOLE NO 1

WO 76-16003 LOCATION Sta. 2+11.5 ; 6.5' Rt. of Edge of Dock ORIGINATED BY SM  
DIST 8 HWY N/A BORING DATE August 4, 1976 COMPILED BY SM  
DATUM Geodetic BOREHOLE TYPE Washboring BX Rock Coring CHECKED BY *OP*

SOIL PROFILE			SAMPLES			GROUND WATER	DYNAMIC CONE PENETRATION RESISTANCE PLOT					LIQUID LIMIT — $w_L$ PLASTIC LIMIT — $w_p$ WATER CONTENT — $w$			UNIT WEIGHT $\gamma$	REMARKS
ELEV DEPTH	DESCRIPTION	STRAT. PLOT	NUMBER	TYPE	N' VALUES		20	40	60	80	100	$w_p$	$w$	$w_L$		
250.1	Dock Surface					ELEV										
0.0	6" Asphalt					250										
	Fill - gravel & sand, some silty clay.		1	SS	7											
			2	SS	7											
	Firm to Very Stiff		3	SS	26											
243.1			4	SS	8											
7.0	Timbers, some gravel, sand & silty clay. Cavities throughout.		5	SS	10											
			6	SS	9	240										
237.6	Loose		7	SS	6	10"										
12.5	Rock Fill															
	some silt		8	SS	54											
233.3			9	BX-RC	-											
16.8	Organic clay															
231.3	Very Soft		10	SS	3	26"										
18.8	Silty Clay		11	SS	16	230										
	Very Stiff to Hard		12	SS	37											
227.1																
23.0	End of Borehole															

MINISTRY OF TRANSPORTATION AND COMMUNICATIONS-ONTARIO  
ENGINEERING SERVICES BRANCH-GEOTECHNICAL OFFICE-SOIL MECHANICS SECTION

RECORD OF BOREHOLE NO 2

WO 76-16003 LOCATION Sta. 1 + 73.5; 5' Rt. of Edge of Dock ORIGINATED BY SM  
DIST 8 HWY N/A BORING DATE August 5, 1976 COMPILED BY SM  
DATUM Geodetic BOREHOLE TYPE Washboring, BX Rock Coring CHECKED BY *[Signature]*

SOIL PROFILE			SAMPLES			GROUND WATER ELEV	DYNAMIC CONE PENETRATION RESISTANCE PLOT					LIQUID LIMIT $w_L$ PLASTIC LIMIT $w_p$ WATER CONTENT $w$			UNIT WEIGHT $\gamma$	REMARKS
ELEV DEPTH	DESCRIPTION	STRAT. PLOT	NUMBER	TYPE	'N' VALUES		20	40	60	80	100	$w_p$	$w$	$w_L$		
250.1	Dock Surface					250										GR SA SI CL
0.0	6" Asphalt															
	Fill - gravel & sand, some silty clay.		1	SS	5											
	Firm to Very Stiff		2	SS	29											
243.1			3	SS	11											
7.0	Sand, silt, silt and some burnt wood chips				1											
	Cavities throughout		4	SS	5	240										
	Loose		5	SS	7											
235.3			6	SS	8	4"										
14.8	Rock Fill		7	RC	-											
234.0	Organic Clay															
16.1	Very Soft															
230.1	Silty clay		8	SS	13	230										
20.0	Stiff to Very Stiff		9	SS	21											
226.6																
23.5	End of Borehole															

MINISTRY OF TRANSPORTATION AND COMMUNICATIONS-ONTARIO

ENGINEERING SERVICES BRANCH-GEOTECHNICAL OFFICE-SOIL MECHANICS SECTION

RECORD OF BOREHOLE NO 3


WO 76-16003 LOCATION Sta. 1 + 36.5; 5' Rt. of Edge of Dock ORIGINATED BY SM  
DIST 8 HWY n/a BORING DATE August 5 & 6, 1976 COMPILED BY SM  
DATUM Geodetic BOREHOLE TYPE Washboring CHECKED BY *CP*

SOIL PROFILE			SAMPLES			GROUND WATER ELEV	DYNAMIC CONE PENETRATION RESISTANCE PLOT					LIQUID LIMIT $W_L$ PLASTIC LIMIT $W_P$ WATER CONTENT $W$			UNIT WEIGHT $\gamma$	REMARKS
ELEV DEPTH	DESCRIPTION	STRAT. PLOT	NUMBER	TYPE	N' VALUES		20	40	60	80	100	$W_P$	$W$	$W_L$		
250.1	Dock Surface					250										GR SA SI CL
0.0	6" Asphalt		1	SS	6											
	Fill - gravel & sand, some silty clay.		2	SS	3											
			3	SS	13											
241.4	Soft to Hard		4	SS	33	3"										
8.7						240										
	Rock fill		5	SS	40	4"										
	some sand & gravel															
232.6	some timber		6	SS	6											
17.5	Organic clay				1											
230.1	Very Soft		7	SS	1	230										
20.0	Silty Clay															
	Stiff to Hard		8	SS	31											
224.7			9	SS	14											
25.4	End of Borehole															

MINISTRY OF TRANSPORTATION AND COMMUNICATIONS-ONTARIO

ENGINEERING SERVICES BRANCH-GEOTECHNICAL OFFICE-SOIL MECHANICS SECTION

RECORD OF BOREHOLE NO 4

WO 76-16003 LOCATION Sta. 1 + 00.5: 5' Rt. of Edge of Dock ORIGINATED BY SM  
 DIST 8 HWY N/A BORING DATE August 6 & 9, 1976 COMPILED BY SM  
 DATUM Geodetic BOREHOLE TYPE Washboring CHECKED BY 

SOIL PROFILE			SAMPLES			GROUND WATER ELEV	DYNAMIC CONE PENETRATION RESISTANCE PLOT					LIQUID LIMIT $w_L$ PLASTIC LIMIT $w_p$ WATER CONTENT $w$			UNIT WEIGHT $\gamma$	REMARKS
ELEV DEPTH	DESCRIPTION	STRAT. PLOT	NUMBER	TYPE	'N' VALUES		20	40	60	80	100	$w_p$	$w$	$w_L$		
250.1	Dock Surface					250										GR SA SI CL
0.0	6" Asphalt															
	Fill - gravel & sand, some silty clay.		1	SS	6											
			2	SS	20											
			3	SS	12											
	Firm to Stiff		4	SS	13											
240.1						240										
10.0	Rock Fill - some gravel and sand.		5	SS	8											
	Timber at bottom.		6	SS	33											
235.4																
14.7	Organic Clay															
	Very Soft															
231.3			7	SS	25											
18.8						230										
	Silty Clay		8	SS	39											
	Very Stiff to Hard		9	SS	17											
220.1			10	SS	17											
30.0	End of Borehole															

MINISTRY OF TRANSPORTATION AND COMMUNICATIONS-ONTARIO

ENGINEERING SERVICES BRANCH-GEOTECHNICAL OFFICE-SOIL MECHANICS SECTION

RECORD OF BOREHOLE NO 5

WO 76-16003 LOCATION Sta. 0 + 68.5; 6.5' Rt. of Edge of Dock  
DIST 8 HWY N/A BORING DATE August 9, 1976  
DATUM Geodetic BOREHOLE TYPE Washboring

ORIGINATED BY SM  
COMPILED BY SM  
CHECKED BY *EP*

SOIL PROFILE			SAMPLES			GROUND WATER ELEV	DYNAMIC CONE PENETRATION RESISTANCE PLOT					LIQUID LIMIT $w_L$ PLASTIC LIMIT $w_p$ WATER CONTENT $w$			UNIT WEIGHT $\gamma$	REMARKS
ELEV DEPTH	DESCRIPTION	STRAT. PLOT	NUMBER	TYPE	N° VALUES		20	40	60	80	100	$w_p$	$w$	$w_L$		
250.1	Dock Surface					250										GR SA SI CL
0.0	6" Asphalt															
	Fill - gravel & sand, some silty clay.															
	Firm to Stiff		1	SS	8											
			2	SS	15											
			3	SS	9	240										
238.1																
12.0	Rock Fill - some sand trace of gravel.															
236.1	Timber at bottom		4	SS	53											
14.0	Organic Clay															
	Very Soft		5	SS	1											
232.1																
18.0	Silty Clay		6	SS	22	230										
	Very Stiff															
227.1			7	SS	19											
23.0	End of Borehole															

MINISTRY OF TRANSPORTATION AND COMMUNICATIONS-ONTARIO  
ENGINEERING SERVICES BRANCH-GEOTECHNICAL OFFICE-SOIL MECHANICS SECTION

**RECORD OF BOREHOLE NO 4 A** (Formerly BH#4 W.O.72-11164)

WO 76-16003 LOCATION Sta. 2 + 45 o/s 2.0' Lt. of Edge of Dock ORIGINATED BY CP  
 DIST 8 HWY N/A BORING DATE February 15 & 16, 1973 COMPILED BY JB  
 DATUM Geodetic BOREHOLE TYPE Washboring and Cone Test CHECKED BY [Signature]

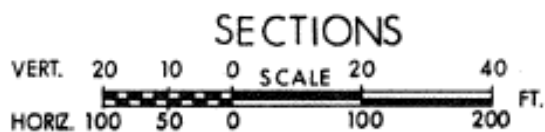
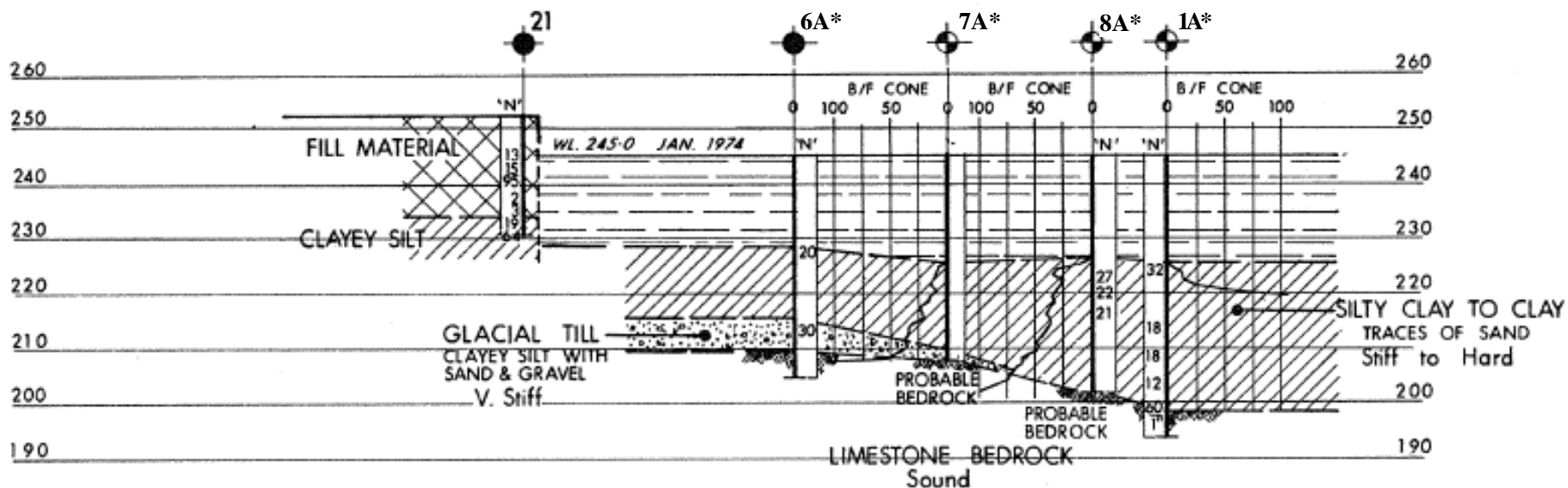
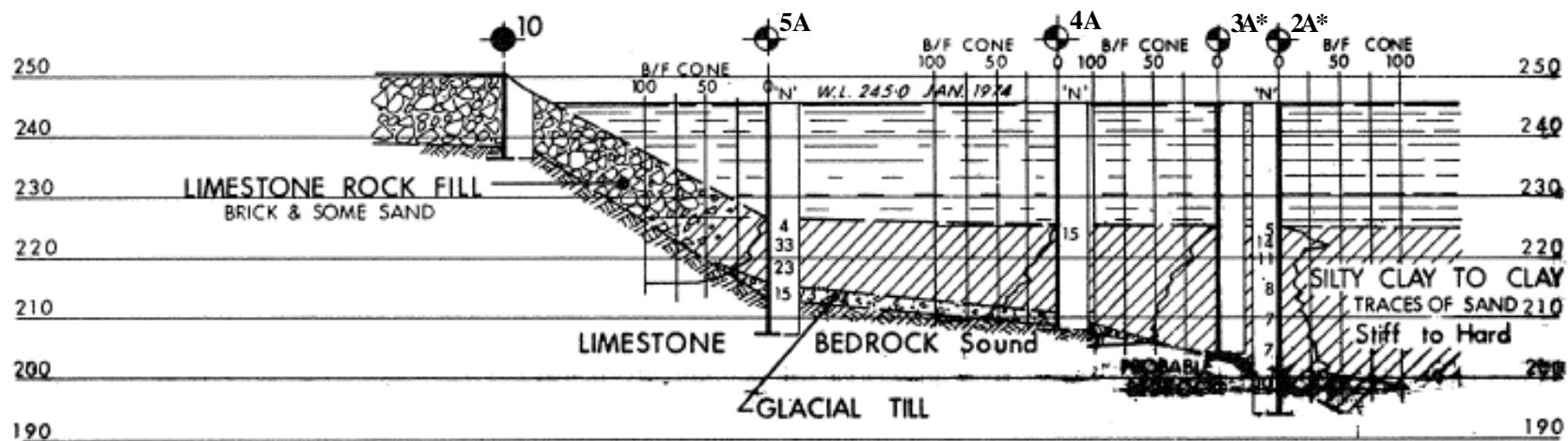
SOIL PROFILE			SAMPLES			GROUND WATER ELEV	DYNAMIC CONE PENETRATION RESISTANCE PLOT					LIQUID LIMIT $w_L$ PLASTIC LIMIT $w_P$ WATER CONTENT $w$			UNIT WEIGHT $\gamma$ PCF	REMARKS
ELEV DEPTH	DESCRIPTION	STRAT. PLOT	NUMBER	TYPE	'N' VALUES		20	40	60	80	100	$w_p$	$w$	$w_L$		
248.7	River Level															
0.0																
	WATER					240										
						230										
225.7																
23.0	Silty clay to clay with traces of sand.		1	SS	15											
	Grey		2	TW	PH	220										
	Stiff to Hard		3	TW	PH											
210.7																
38.0	Clayey silt with traces of sand & gravel (Glacial Till)		4	TW	PH	210										
208.2	Limestone Bedrock															
40.5	End of Borehole															

## RECORD OF BOREHOLE NO 5A (formerly BH#5 W.O.72-11164)

[illegible]

15  $\phi$  5 % STRAIN AT FAILURE





\* No borehole log is available on Geocres

DESIGN SERVICES BRANCH

FOUNDATIONS OFFICE

## RECORD OF BOREHOLE NO 10

JOB 73-11071

LOCATION AS Shown on Drawing

ORIGINATED BY J.B.

W.P. 25-73-01

BORING DATE September 25, 1973

COMPILED BY C.S.D.

DATUM

BOREHOLE TYPE Washboring and BX Rock Core

 CHECKED BY *[Signature]*

SOIL PROFILE			SAMPLES			ELEV. SCALE	DYNAMIC PENETRATION RESISTANCE BLOWS / FOOT _____		LIQUID LIMIT _____ $w_L$ PLASTIC LIMIT _____ $w_p$ WATER CONTENT _____ $w$ $w_p$ — $w$ — $w_L$		BULK DENSITY $\gamma$ P.C.F.	REMARKS
ELEV. DEPTH	DESCRIPTION	STRAT. PLOT	NUMBER	TYPE	BLOWS/FOOT		SHEAR STRENGTH P.S.F. ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL x LAB VANE		WATER CONTENT %			
250.6	Ground Level											
0.0	Topsoil					250						
0.5	Fill material -											
	Limestone rock fill, bricks and some sand.											
			1	BX RC	43% Rec	240						
			2	BX RC	10% Rec							
238.2	Bedrock -		3	BX RC	70% Rec							
12.4	limestone											
236.4	Gray fractured		4	BX RC	100% Rec							
14.2	End of Borehole.											
						230						

DESIGN SERVICES BRANCH

FOUNDATIONS OFFICE

## RECORD OF BOREHOLE NO 21

JOB 73-11071

LOCATION As Shown on Drawing

ORIGINATED BY J.B.

W.P. 25-73-01

BORING DATE October 9 - 10, 1973

COMPILED BY C.S.P.

DATUM Geodetic

BOREHOLE TYPE Wash Borings and BX Rock Core

CHECKED BY *[Signature]*

SOIL PROFILE			SAMPLES			ELEV. SCALE	DYNAMIC PENETRATION RESISTANCE BLOWS / FOOT			LIQUID LIMIT $w_L$ PLASTIC LIMIT $w_p$ WATER CONTENT $w$			BULK DENSITY $\gamma$ P.C.F.	REMARKS	
ELEV. DEPTH	DESCRIPTION	STRAT. PLOT	NUMBER	TYPE	BLOWS/FOOT		SHEAR STRENGTH P.S.F. ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL x LAB VANE			$w_p$ $w$ $w_L$ WATER CONTENT % 10 20 30					
250.6 0.0	Ground Level					250									
243.1 7.5	Fill Material					240									
	Gravel, sand, silt and trace of organics		1	SS	13										
			2	SS	15										
			3	SS	95		bouncing								
			4	SS	2										
234.1 16.5	Wood and Sand		5	SS	3										
			6	SS	19										
			7	SS	64	bouncing									
230.4 20.2	Clayey silt, some sand and gravel Grey														
	Very stiff to hard														
	End of Borehole.					230									
	Probably bedrock														

DESIGN SERVICES BRANCH

FOUNDATIONS OFFICE

## RECORD OF BOREHOLE № 103

JOB 73-11071

LOCATION As Shown on Drawing

ORIGINATED BY CSP

W.P. 25-73-01

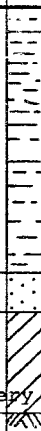
BORING DATE      January 17 - 18, 1974

COMPILED BY CSP

DATUM I.G.L.D.

BOREHOLE TYPE Wash Boring

CHECKED BY SR

m. 74.7		SOIL PROFILE		SAMPLES			DYNAMIC PENETRATION RESISTANCE		LIQUID LIMIT		BULK DENSITY	REMARKS	
		ELEV. DEPTH ft.	DESCRIPTION	STRAT. PICT	NUMBER	TYPE	BLOWS/FOOT (0.3 m.)	ft. / m.	W <sub>p</sub>	W <sub>L</sub>			
		245.0	Water Level										
		0.0	Water										
68.3	224.0												
6.4	21.0	sand-some gravel		1	SS	1/2	ft.						
67.4	221.0	black-very loose		2	SS	20	67						
7.3	24.0	Silty clay with trace of sand		3	TW	PM							
64.9	213.0	Grey-Stiff to very stiff											
9.8	32.0	End of Borehole Probably Bedrock											

20  
15  $\phi$  5 % STRAIN AT FAILURE  
10

**Appendix B-2.**

**Dawson Point**

# RECORD OF BOREHOLE No D01

1 OF 1

METRIC

GWP# 4061-14-00 LOCATION Dawson's Point Dock N 4 897 219.6 E 310 762.8 ORIGINATED BY JG  
 HWY Wolfe Island Ferry Docks BOREHOLE TYPE Hollow Stem Auger COMPILED BY JG  
 DATUM Geodetic DATE 2015.01.09 - 2015.01.09 CHECKED BY FJG

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					UNIT WEIGHT  $\gamma$ kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%)  GR SA SI CL
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa						
								○ UNCONFINED + FIELD VANE						
								● QUICK TRIAXIAL × LAB VANE						
					WATER CONTENT (%)									

ONTMT4S 19-479-154 WOLFE ISLAND FERRY DOCKS.GPJ 2012TEMPLATE(MTO).GDT 2/12/16

## METRIC

[illegible]

+<sup>3</sup>, ×<sup>3</sup>: Numbers refer to Sensitivity

ONTMT4S 19-479-154 WOLFE ISLAND FERRY DOCKS.GPJ 2012TEMPLATE(MTO).GDT 2/12/16

# RECORD OF BOREHOLE No D02

2 OF 2

METRIC

GWP# 4061-14-00 LOCATION Dawson's Point Dock N 4 897 223.6 E 310 700.8 ORIGINATED BY CM  
 HWY Wolfe Island Ferry Docks BOREHOLE TYPE Casing / NQ Coring COMPILED BY CM  
 DATUM Geodetic DATE 2015.09.13 - 2015.09.14 CHECKED BY FJG

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT				PLASTIC LIMIT      NATURAL MOISTURE CONTENT      LIQUID LIMIT			UNIT WEIGHT  γ  kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%)  GR   SA   SI   CL	
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa				WATER CONTENT (%)					
								○ UNCONFINED      + FIELD VANE ● QUICK TRIAXIAL      × LAB VANE				w <sub>p</sub> w      w <sub>L</sub>					
	Continued From Previous Page							20	40	60	80	100					
			3	SS	21		65							○			
			4	SS	14		64							○			
			5	SS	9									○			
							63										
62.2																	
12.9	Silty <b>SAND</b> Compact to Loose Brown Wet		6	SS	13		62							○			5   80   15 (SI+CL)
							61										
60.4														○			
14.7	Sandy <b>SILT</b> Loose Grey Wet		7	SS	7									○			
							60										
59.6																	
15.5	<b>LIMESTONE</b> , Grey, Slightly Weatherd to Fresh, Medium Strong, Horizontally Bedded		1	RUN			59										RUN #1 TCR=100% SCR=92% RQD=90%
			2	RUN			58										RUN #2 TCR=100% SCR=99% RQD=84%
56.4							57										
18.7	End of Borehole at 18.7 m																

+<sup>3</sup>, ×<sup>3</sup>: Numbers refer to Sensitivity 20 15 10 5 0 (%) STRAIN AT FAILURE

ONTMT4S 19-479-154 WOLFE ISLAND FERRY DOCKS.GPJ 2012TEMPLATE(MTO).GDT 2/12/16



## METRIC

Continued Next Page

(%) STRAIN AT FAILURE

# RECORD OF BOREHOLE No D03

2 OF 2

METRIC

GWP# 4061-14-00 LOCATION Dawson's Point Dock N 4 897 228.5 E 310 657.7 ORIGINATED BY CM  
 HWY Wolfe Island Ferry Docks BOREHOLE TYPE Casing / NQ Coring COMPILED BY CM  
 DATUM Geodetic DATE 2015.12.09 - 2015.12.09 CHECKED BY FJG

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					PLASTIC LIMIT NATURAL MOISTURE CONTENT LIQUID LIMIT			UNIT WEIGHT  $\gamma$  kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%)  GR SA SI CL
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa					WATER CONTENT (%)				
								20 40 60 80 100					20 40 60				
								○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × LAB VANE									
	Continued From Previous Page		2	SS	3		65										
64.2	SILT with SAND Compact to Loose Grey Wet		3	SS	7		64										
10.9			4	SS	9		63										
62.7							62										
12.4		Silty SAND Loose Grey Wet		5	SS	7		61									
			6	SS	7		60										
59.5	LIMESTONE, Grey, Slightly Weathered to Fresh, Medium Strong, Horizontally Bedded		1	RUN			59										
15.6			2	RUN			58										
56.4							57										
18.7	End of Borehole at 18.7 m																

ONTMT4S 19-479-154 WOLFE ISLAND FERRY DOCKS.GPJ 2012TEMPLATE(MTO).GDT 2/12/16

## METRIC

SOIL PROFILE						SAMPLES						
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT	SHEAR STRENGTH kPa	WATER CONTENT (%)	UNIT WEIGHT	REMARKS & GRAIN SIZE DISTRIBUTION (%)
75.1 0.0	<b>WATER</b>						75				γ kN/m <sup>3</sup>	GR SA SI C
							74					
							73					
							72					
							71					
							70					
							69					
							68					
66.5 8.6	Inferred Lake Bed						67					
65.6 9.5	SILTY CLAY, sandy, frequent fine sand seams Very Stiff		1	SS	4							

+<sup>3</sup>, ×<sup>3</sup>: Numbers refer to Sensitivity

ONTMT4S 19-479-154 WOLFE ISLAND FERRY DOCKS.GPJ 2012TEMPLATE(MTO).GDT 2/12/16

# RECORD OF BOREHOLE No D04

2 OF 3

METRIC

GWP# 4061-14-00 LOCATION Dawson's Point Dock N 4 897 259.7 E 310 626.5 ORIGINATED BY CM  
 HWY Wolfe Island Ferry Docks BOREHOLE TYPE Casing / NQ Coring COMPILED BY CM  
 DATUM Geodetic DATE 2015.11.09 - 2015.11.09 CHECKED BY FJG

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT				PLASTIC LIMIT NATURAL MOISTURE CONTENT LIQUID LIMIT			UNIT WEIGHT  $\gamma$  kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%)  GR SA SI CL
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa				WATER CONTENT (%)				
								20 40 60 80 100				W P W W L				
								○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × LAB VANE								
	Continued From Previous Page															
63.7 11.4	Grey		2	SS	WH		65									
	<b>SILT</b> with Sand Loose to Compact Grey Wet		3	SS	6		64									
			4	SS	12		63									
			5	SS	6		62									
			6	SS	30		61									
			7	SS	100/ 225mm		60									
59.6	Silty <b>SAND</b> with gravel Compact Grey Wet		1	RUN		59										
58.8	<b>LIMESTONE</b> , Grey, Slightly Weatherd to Fresh, Strong, Horizontally Bedded		2	RUN		58										
16.3			3	RUN		57										
						56										



Continued Next Page

+<sup>3</sup>, ×<sup>3</sup>: Numbers refer to  
Sensitivity

20  
15  
10  
(%) STRAIN AT FAILURE

ONTMT4S 19-479-154 WOLFE ISLAND FERRY DOCKS.GPJ 2012TEMPLATE(MTO).GDT 2/12/16

## METRIC

SOIL PROFILE		SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT		PLASTIC LIMIT      NATURAL MOISTURE CONTENT      LIQUID LIMIT		UNIT WEIGHT  γ  kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%)  GR SA SI CL
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE			"N" VALUES	20   40   60   80   100	W P      W      W L	20   40   60		
	Continued From Previous Page											
							SHEAR STRENGTH kPa ○ UNCONFINED      + FIELD VANE ● QUICK TRIAXIAL      × LAB VANE 20   40   60   80   100					

[illegible]

# RECORD OF BOREHOLE No D05

1 OF 3

METRIC

GWP# 4061-14-00 LOCATION Dawson's Point Dock N 4 897 295.0 E 310 675.6 ORIGINATED BY CM  
 HWY Wolfe Island Ferry Docks BOREHOLE TYPE Casing / NQ Coring COMPILED BY CM  
 DATUM Geodetic DATE 2015.11.09 - 2015.12.09 CHECKED BY FJG

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT				PLASTIC LIMIT W <sub>p</sub>	NATURAL MOISTURE CONTENT W	LIQUID LIMIT W <sub>L</sub>	UNIT WEIGHT γ kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa								
75.1 0.0							20	40	60	80	100	20	40	60		
	<b>WATER</b>						75									
							74									
							73									
							72									
							71									
							70									
							69									
							68									
							67									
66.2 8.9	Inferred Lake Bed						66									

Continued Next Page

+<sup>3</sup>, ×<sup>3</sup>: Numbers refer to  
Sensitivity 20  
15 10 5 (%) STRAIN AT FAILURE

ONTMT4S 19-479-154 WOLFE ISLAND FERRY DOCKS.GPJ 2012TEMPLATE(MTO).GDT 2/12/16



# RECORD OF BOREHOLE No D05

2 OF 3

METRIC

GWP# 4061-14-00 LOCATION Dawson's Point Dock N 4 897 295.0 E 310 675.6 ORIGINATED BY CM  
 HWY Wolfe Island Ferry Docks BOREHOLE TYPE Casing / NQ Coring COMPILED BY CM  
 DATUM Geodetic DATE 2015.11.09 - 2015.12.09 CHECKED BY FJG

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT				UNIT WEIGHT  $\gamma$  kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%)
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa					
								20 40 60 80 100					
								○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × LAB VANE					
Continued From Previous Page							WATER CONTENT (%)						
							20 40 60						
64.5							65						
10.6	SILTY <b>CLAY</b> Very Stiff Grey		1	SS	12		64						
			2	SS	20								
63.0							63						
12.1	<b>SILT</b> with Sand Loose Grey Wet		3	SS	15								
			4	SS	8		62						0 18 76 6
							61						
60.7													
14.4	Gravelly <b>SAND</b> with silt Loose to Compact Grey to Brown Wet		5	SS	9		60						
58.9							59						26 66 8 (SI+CL)
16.2	Sandy <b>SILT</b> Compact to Loose Brown to Grey Wet		6	SS	25								
							58						
			7	SS	5								
57.4													
17.7	<b>LIMESTONE</b> , Grey, Slightly Weatherd to Fresh, Medium Strong, Horizontally Bedded with Shale Interbedding		1	RUN			57						RUN #1 TCR=100% SCR=100% RQD=100%
			2	RUN			56						RUN #2 TCR=100% SCR=97% RQD=97%

Continued Next Page

+<sup>3</sup>, ×<sup>3</sup>: Numbers refer to  
Sensitivity

20  
15  
10  
(%) STRAIN AT FAILURE

ONTMT4S 19-479-154 WOLFE ISLAND FERRY DOCKS.GPJ 2012TEMPLATE(MTO).GDT 2/12/16

# RECORD OF BOREHOLE No D05

3 OF 3

METRIC

GWP# 4061-14-00 LOCATION Dawson's Point Dock N 4 897 295.0 E 310 675.6 ORIGINATED BY CM  
 HWY Wolfe Island Ferry Docks BOREHOLE TYPE Casing / NQ Coring COMPILED BY CM  
 DATUM Geodetic DATE 2015.11.09 - 2015.12.09 CHECKED BY FJG

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					UNIT WEIGHT  $\gamma$ kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa						
								20 40 60 80 100						
	Continued From Previous Page							20 40 60 80 100						
								20 40 60 80 100						
								20 40 60 80 100						
								20 40 60 80 100						
								20 40 60 80 100						
								20 40 60 80 100						
								20 40 60 80 100						
								20 40 60 80 100						
								20 40 60 80 100						
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ONTMT4S 19-479-154 WOLFE ISLAND FERRY DOCKS.GPJ 2012TEMPLATE(MTO).GDT 2/12/16

DESIGN SERVICES BRANCH

FOUNDATIONS OFFICE

# RECORD OF BOREHOLE NO 1

JOB 73-11071

LOCATION As Shown on Drawing

ORIGINATED BY C.S.P.

W.P. 25-73-01




BORING DATE September 12 - 13, 1973

COMPILED BY C.S.P.

DATUM Geodetic

BOREHOLE TYPE Washboring, BX Rock Core

CHECKED BY

SOIL PROFILE			SAMPLES			ELEV. SCALE	DYNAMIC PENETRATION RESISTANCE BLOWS / FOOT			LIQUID LIMIT — $w_L$ PLASTIC LIMIT — $w_p$ WATER CONTENT — $w$ $w_p$ — $w$ — $w_L$			BULK DENSITY $\gamma$ P.C.F.	REMARKS
ELEV. DEPTH	DESCRIPTION	STRAT. PLOT	NUMBER	TYPE	BLOWS/FOOT		SHEAR STRENGTH P.S.F. ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL x LAB VANE			WATER CONTENT %				
248.6	Ground Level													
0.0	Fill material.													GR. SA. SI. CL.
244.1	sand and gravel (with cobbles)													246.1
4.5	Bedrock - Limestone		1	BX RC	96% Rec	240								
238.8	Grey - sand													
9.8	End of Borehole					230								

OFFICE REPORT SOIL EXPLORATION

DESIGN SERVICES BRANCH

FOUNDATIONS OFFICE

## RECORD OF BOREHOLE NO 2

JOB 73-11071

LOCATION As Shown on Drawing

ORIGINATED BY C.S.P.

W.P. 25-73-01

BORING DATE September 20 - 21, 1973

COMPILED BY C.S.P.

DATUM Geodetic

BOREHOLE TYPE Washboring, BX Rock Core

CHECKED BY *ME*

SOIL PROFILE		STRAT. PLOT	SAMPLES			ELEV. SCALE	DYNAMIC PENETRATION RESISTANCE				LIQUID LIMIT — $w_L$				BULK DENSITY	REMARKS
ELEV. DEPTH	DESCRIPTION		NUMBER	TYPE	BLOWS/FOOT		BLOWS / FOOT				PLASTIC LIMIT — $w_p$					
							SHEAR STRENGTH P.S.F.				WATER CONTENT — $w$					
245.8	Lake Level															
0.0	Water															
237.5																
8.3	Rock fill and/or cobbles, boulders.															
232.5																
13.3	fractured		1	BX RC	98% Rec											
	Bedrock - Limestone		2	BX RC	95% Rec											
228.4	Grey sound		3	BX RC	90% Rec											
17.4	End of Borehole.															
										</						

DESIGN SERVICES BRANCH

FOUNDATIONS OFFICE

## RECORD OF BOREHOLE NO 3

JOB 73-11071

LOCATION As Shown on drawing

ORIGINATED BY C.S.P.

W.P. 25-71-01

BORING DATE September 17 - 20, 1973

COMPILED BY C.S.P.

DATUM Geodetic

BOREHOLE TYPE Washboring, BX Rock Core

CHECKED BY *ML*

SOIL PROFILE			SAMPLES		ELEV. SCALE	DYNAMIC PENETRATION RESISTANCE				LIQUID LIMIT — $w_L$				BULK DENSITY $\gamma$	REMARKS	
ELEV. DEPTH	DESCRIPTION	STRAT. PLOT	NUMBER	TYPE		BLOWS/FOOT	BLOWS / FOOT				PLASTIC LIMIT — $w_p$					
							SHEAR STRENGTH P.S.F.				WATER CONTENT — $w$					
							○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL x LAB VANE				$w_p$ — $w$ — $w_L$					
245.8 0.0	Lake Level													P.C.F.	GR.SA.SI.C	
	Water															
233.3 12.5	Rock fill and/or cobbles, boulders  (with sand, seams below elevation 223)															
			1	BX RC	50% Rec											
			2	BX RC	50% Rec											
			3	BX RC	42% Rec											
			4	BX RC	10% Rec											
			5	BX RC	90% Rec											
			6	BX RC	44% Rec											
207.2 37.9	Bedrock - limestone		7	BX RC	97% Rec											
201.5 44.3	Grey sand  End of Borehole															

DESIGN SERVICES BRANCH

FOUNDATIONS OFFICE

## RECORD OF BOREHOLE NO 4

JOB 73-11071

LOCATION As Shown on Drawing

ORIGINATED BY C.S.P.

W.P. 25-73-01

BORING DATE September 17, 1973

COMPILED BY C.S.P.

DATUM Geodetic

BOREHOLE TYPE Wash Boring, BX Rock Core

CHECKED BY *SR*

SOIL PROFILE			SAMPLES			ELEV. SCALE	DYNAMIC PENETRATION RESISTANCE		LIQUID LIMIT — $w_L$		BULK DENSITY	REMARKS
ELEV. DEPTH	DESCRIPTION	STRAT. PLT	NUMBER	TYPE	BLOWS/FOOT		BLOWS / FOOT	SHEAR STRENGTH P.S.F.	PLASTIC LIMIT — $w_p$	WATER CONTENT — $w$		
245.8	Lake Level											
0.0	Water											
233.8	Limestone rock fill with concrete pieces.		1	BX RC	33% Rec	230						
228.2	Bedrock - limestone		2	BX RC	90% Rec							
223.5	Grey sand		3	BX RC	100% Rec							
22.5	End of Borehole.					220						




DESIGN SERVICES BRANCH

FOUNDATIONS OFFICE

# RECORD OF BOREHOLE NO 5

JOB 73-11071 LOCATION As Shown on Drawing ORIGINATED BY C.S.P.  
 W.P. 25-73-01 BORING DATE September 13, 1973 COMPILED BY C.S.P.  
 DATUM Geodetic BOREHOLE TYPE Washboring, BX Rock Core CHECKED BY CML

SOIL PROFILE			SAMPLES			ELEV. SCALE	DYNAMIC PENETRATION RESISTANCE BLOWS / FOOT			LIQUID LIMIT ——— $w_L$ PLASTIC LIMIT ——— $w_p$ WATER CONTENT ——— $w$ $w_p$ ——— $w$ ——— $w_L$ WATER CONTENT %			BULK DENSITY $\gamma$ P.C.F. GR.SA.SI.CL.	REMARKS
ELEV. DEPTH	DESCRIPTION	STRAT. PLOT	NUMBER	TYPE	BLOWS/FOOT		SHEAR STRENGTH P.S.F. ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × LAB VANE							
249.6 0.0	Ground Level Fill material		1	BX RC	93% Rec	240								▼245.8
243.7 5.9	sand & gravel (with silt, cobbles and chunks of asphalt)													
239.0 10.6	Bedrock - Limestone													
	Grey sand													
	End of Borehole													
						230								

OFFICE REPORT SOIL EXPLORATION

DESIGN SERVICES BRANCH

FOUNDATIONS OFFICE

## RECORD OF BOREHOLE NO 6

JOB 73-11071

LOCATION As Shown on Drawing

ORIGINATED BY C.S.P.

W.P. 25-73-01

BORING DATE September 21, 1973

COMPILED BY C.S.P.

DATUM Geodetic

BOREHOLE TYPE Washboring and BX Rock Core

CHECKED BY *SR*

SOIL PROFILE			SAMPLES			ELEV. SCALE	DYNAMIC PENETRATION RESISTANCE		LIQUID LIMIT — $w_L$		BULK DENSITY	REMARKS
ELEV. DEPTH	DESCRIPTION	STRAT. PLT	NUMBER	TYPE	BLOWS/FOOT		BLOWS / FOOT	SHEAR STRENGTH P.S.F.	PLASTIC LIMIT — $w_p$	WATER CONTENT — $w$		
							<input type="radio"/> UNCONFINED + FIELD VANE <input checked="" type="radio"/> QUICK TRIAXIAL x LAB VANE	$w_p$ — $w$ — $w_L$ WATER CONTENT %		$\gamma$ P.C.F. GR. SA. SI. CL.		
245.8	Lake Level											
0.0	Water											
239.6						240						
6.2	Cobbles											
7.0	Bedrock - Limestone		1	BX RC	93% Rec							
233.6	Grey sand											
12.2	End of Borehole					230						

DESIGN SERVICES BRANCH

FOUNDATIONS OFFICE

# RECORD OF BOREHOLE NO 7

JOB 73-11071

LOCATION As Shown on Drawing

ORIGINATED BY J.B.

W.P. 25-73-01

BORING DATE September 24, 1973

COMPILED BY C.S.P.

DATUM Geodetic

BOREHOLE TYPE Washboring and BX Rock Core

CHECKED BY [Signature]

SOIL PROFILE			SAMPLES			ELEV. SCALE	DYNAMIC PENETRATION RESISTANCE			LIQUID LIMIT — $w_L$			BULK DENSITY	REMARKS
ELEV. DEPTH	DESCRIPTION	STRAT. PLOT	NUMBER	TYPE	BLOWS/FOOT		BLOWS / FOOT			PLASTIC LIMIT — $w_p$				
							SHEAR STRENGTH P.S.F.			WATER CONTENT — $w$				
							<input type="checkbox"/> UNCONFINED	+ FIELD VANE		$w_p$	$w$	$w_L$		
							<input checked="" type="checkbox"/> QUICK TRIAXIAL	x LAB VANE		WATER CONTENT %			$\gamma$	
249.2	Ground Level													GR.SA.SI.CL.
0.0	Fill material - sand and gravel													247.2
245.5	Gray		1	BX RC	100% Rec									
3.7	Bedrock - Limestone		2	BX RC	100% Rec									
240.5	Gray sand													
8.7	End of Borehole.					240								

DESIGN SERVICES BRANCH

FOUNDATIONS OFFICE

## RECORD OF BOREHOLE NO 8

JOB 73-11071

LOCATION As Shown on Drawing

ORIGINATED BY J.B.

W.P. 25-73-01

BORING DATE September 24, 1973

COMPILED BY C.S.P.

DATUM Geodetic

BOREHOLE TYPE Washboring and BX Rock Core

CHECKED BY *[Signature]*

SOIL PROFILE			SAMPLES			ELEV. SCALE	DYNAMIC PENETRATION RESISTANCE BLOWS / FOOT			LIQUID LIMIT $W_L$ PLASTIC LIMIT $W_P$ WATER CONTENT $W$			BULK DENSITY $\gamma$	REMARKS
ELEV. DEPTH	DESCRIPTION	STRAT. PLOT	NUMBER	TYPE	BLOWS/FOOT		SHEAR STRENGTH P.S.F. ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL x LAB VANE			$W_P$ — $W$ — $W_L$ WATER CONTENT %				
250.2	Ground Level												P.C.F.	GR. SA. SI. CL.
0.0	Fill material - sand, gravel, and cobbles													248.2
244.6	Brown sand													
5.6	Bedrock - Limestone		1	BX RC	90% Rec									
			2	BX RC	100% Rec									
239.6	Grey sand					240								
10.6	End of Borehole.													

DESIGN SERVICES BRANCH

FOUNDATIONS OFFICE

## RECORD OF BOREHOLE NO 20

JOB 73-11071

LOCATION As Shown on Drawing

ORIGINATED BY J.B.

W.P. 25-73-01

BORING DATE October 4 - 9, 1973

COMPILED BY C.S.P.

DATUM Geodetic

BOREHOLE TYPE Wash Boring and BX Rock Core

CHECKED BY *MC*

SOIL PROFILE			SAMPLES			ELEV. SCALE	DYNAMIC PENETRATION RESISTANCE BLOWS / FOOT				LIQUID LIMIT $W_L$ PLASTIC LIMIT $W_P$ WATER CONTENT $W$			BULK DENSITY $\gamma$ P.C.F.	REMARKS
ELEV. DEPTH	DESCRIPTION	STRAT. PLT	NUMBER	TYPE	BLOWS/FOOT		SHEAR STRENGTH P.S.F. O UNCONFINED + FIELD VANE * QUICK TRIAXIAL x LAB VANE				WATER CONTENT % 10 20 30				
245.8	Lake Level														
0.0	Water														
228.8															
17.0	Gravel, some sand (with boulders below elevation 226)		1	SS	7										
224.4	Grey Loose														
21.4	Bedrock - limestone		2	RC	Rec										
221.4	Grey sound		3	RC	Rec										
24.2	End of Borehole														

DESIGN SERVICES BRANCH

FOUNDATIONS OFFICE

## RECORD OF BOREHOLE NO 31

JOB 73-11071

LOCATION As shown on Drawing 73-11071A

ORIGINATED BY JB

W.P. 25-73-01

BORING DATE April 16, 1974

COMPILED BY CP

DATUM I.G.L.D.

BOREHOLE TYPE Hollow Stem Auger, BX Rock Core

CHECKED BY

SOIL PROFILE			SAMPLES			ELEV. SCALE	DYNAMIC PENETRATION RESISTANCE BLOWS / FOOT			LIQUID LIMIT ——— $w_L$ PLASTIC LIMIT ——— $w_p$ WATER CONTENT ——— $w$ $w_p$ ——— $w$ ——— $w_L$			BULK DENSITY $\gamma$ P.C.F.	REMARKS
ELEV. DEPTH ft.	DESCRIPTION	STRAT. PLOT	NUMBER	TYPE	BLOWS/FOOT (0.3 m)		SHEAR STRENGTH P.S.F. ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL x LAB VANE			WATER CONTENT % 10 20 30				
75.9	249.0	Ground Level												
0.0	0.0	Fill Material rock fill with occ. lenses of grey silty clay	1	SS	100/B"									▼ 247.0 75.3
73.8	242.0		2	SS	bouncing									
2.1	7.0	Sand, silt and gravel with pockets of organics	3	SS	12	240				o				4,88, ( 8 )
			4	SS	42	73.2								
71.0	233.0													23,63,12, 2
4.9	16.0	Silty sand with some gravel. Compact	5	SS	12	230				o				9,55,32, 4
70.3	230.5		6	PC	80"	70.1								
5.6	18.5	Bedrock Limestone												
68.6	225.1	Grey Sound	7	BX	91%									
7.3	23.9	End of Borehole												
						220								
						67.1								



DESIGN SERVICES BRANCH

# RECORD OF BOREHOLE NO 32

FOUNDATIONS OFFICE

JOB 73-11071

LOCATION As shown on drawing 73-11071A

ORIGINATED BY JB

W.P. 25-73-01

BORING DATE April 18, 1974

COMPILED BY Cp

DATUM I.G.L.D.

BOREHOLE TYPE Hollow Stem Auger, BX Rock Core

CHECKED BY

SOIL PROFILE		STRAT. PLOT	SAMPLES		ft/m	ELEV. SCALE	DYNAMIC PENETRATION RESISTANCE		LIQUID LIMIT $w_L$		BULK DENSITY	REMARKS
ELEV. DEPTH ft.	DESCRIPTION		NUMBER	TYPE			BLOWS/FOOT (0-3m)	BLows / foot	PLASTIC LIMIT $w_p$	WATER CONTENT $w$		
75.8	Ground Level											
0.0	Fill Material											
	Rock Fill											
73.3			1	SS	12	240						
2.7	Sand, gravel, traces of silt & clay with occ. inclusion of organics.		2	SS	8	73.2						
69.7			3	SS	1007	0" 230						19, 63, (18)
6.1	Sand & gravel with fragments of limestone		4	SS	1297	0"						21, 52, 24, 3
68.4	Very Dense		5	EC	-							
7.4	End of Borehole Probably limestone bedrock											
						220						
						67.1						

OFFICE REPORT OF SOIL EXPLORATION

DESIGN SERVICES BRANCH

FOUNDATIONS OFFICE

# RECORD OF BOREHOLE NO 33

JOB 73-11071 LOCATION As Shown on Drawing 73-11071A ORIGINATED BY JB  
W.P. 25-73-01 BORING DATE April 17, 1974 COMPILED BY CSP  
DATUM I.G.L.D. BOREHOLE TYPE How Stem Auger, BX Rock Core CHECKED BY [Signature]

SOIL PROFILE			SAMPLES			ft/m	DYNAMIC PENETRATION RESISTANCE		LIQUID LIMIT $w_L$		BULK DENSITY	REMARKS
ELEV. DEPTH	DESCRIPTION	STRAT. PLOT	NUMBER	TYPE	BLOWS/FOOT		BLOWS / FOOT	PLASTIC LIMIT $w_p$	WATER CONTENT $w$	WATER CONTENT %		
75.3	247.1	Ground Level										
0.0	0.0	Fill Material										
		Rock fill										
73.0	239.6					240						
2.3	7.5	Silt, sand and decayed wood pieces.	1	SS	54	73.2						
			2	SS	38/5	bouncing						
69.2	227.1					230						
6.1	20.0	Gravel, traces of sand with occ. cobbles.	3	RC BX	-	70.1						
67.7	222.1											
7.6	25.0	Bedrock Limestone	4	RC BX	100% Rec	220						
65.2	217.1	Grey Sand				67.1						
9.1	30.0	End of Borehole										
						210						
						64.0						

OFFICE REPORT ON SOIL EXPLORATION

DESIGN SERVICES BRANCH

FOUNDATIONS OFFICE

## RECORD OF BOREHOLE NO 104

JOB 73-11071

LOCATION As Shown on Drawing

ORIGINATED BY CSP

W.P. 25-73-01

BORING DATE January 22, 1974

COMPILED BY CSP

DATUM I.G.L.D.

BOREHOLE TYPE Dynamic Cone Penetration Test

CHECKED BY SR

SOIL PROFILE			SAMPLES			DYNAMIC PENETRATION RESISTANCE BLOWS / FOOT (0.3m)			LIQUID LIMIT — W <sub>L</sub> PLASTIC LIMIT — W <sub>P</sub> WATER CONTENT — W			BULK DENSITY γ	REMARKS	
ELEV. DEPTH ft.	DESCRIPTION	STRAT. PLOT	NUMBER	TYPE	BLOWS/FOOT m.	ELEV. SCALE (ft./m)	SHEAR STRENGTH P.S.F. ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL x LAB VANE			W <sub>P</sub> — W — W <sub>L</sub> WATER CONTENT %				
245.0	Water Level												P.C.F.	GR.SA.SI.CL.
0.0	Water						240							
							73							
							230							
226.5							70							
18.5	probably sand, some silt, trace of gravel						220							
215.7	very loose to compact						67				1004"			
29.3	End of Cone Test						210							
							64							

OFFICE REPORT OF OIL EXPLORATION

DESIGN SERVICES BRANCH

FOUNDATIONS OFFICE

## RECORD OF BOREHOLE NO 105

JOB 73-11071

LOCATION As Shown on Drawing

ORIGINATED BY CSP

W.P. 25-73-01

BORING DATE January 22, 1974

COMPILED BY CSP

DATUM T.G.L.D.

BOREHOLE TYPE Wash boring and dynamic cone penetration

CHECKED BY SR

SOIL PROFILE		SAMPLES		DYNAMIC PENETRATION RESISTANCE		LIQUID LIMIT $W_L$		BULK DENSITY	REMARKS
ELEV. / ft.	DEPTH / ft.	DESCRIPTION	STRAT. PLT	NUMBER	TYPE	BLOWS / FOOT (0.3m)	PLASTIC LIMIT $W_P$		
74.7	245.0	Water Level							
0.0	0.0	Water							
68.1	223.5								
67.5	221.5	Sand, some silt, gravel		1	SS	34			
7.2	23.5	End of Borehole							
64.6	212.0	Probably sand, some silt and gravel							
10.1	33.0	compact-v. dense							
		End of Cone Test							

**Appendix B-3.**

**Marysville**

# RECORD OF BOREHOLE No M01

1 OF 1

METRIC

GWP# 4061-14-00 LOCATION Marysville Dock N 4 894 898.0 E 309 552.5 ORIGINATED BY JG  
 HWY Wolfe Island Ferry Docks BOREHOLE TYPE Hollow Stem Auger COMPILED BY JG  
 DATUM Geodetic DATE 2015.08.31 - 2015.08.31 CHECKED BY FJG

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					UNIT WEIGHT  $\gamma$  kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%)  GR SA SI CL
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa						
76.9														
0.0	Asphalt 100mm													
0.1	<b>GRAVEL</b> with Silt and Sand with cobble very dense grey dry		1	SS	100/ 50mm									
75.8			2	SS	85									
1.1	<b>SILT</b> with Clay very stiff grey moist													
			3	SS	43									
74.9														
2.0	<b>LIMESTONE</b> , Grey, Slightly Weatherd, Medium Strong, Horizontally Bedded		1	RUN										RUN #1 TCR=100% SCR=97% RQD=48%
			2	RUN										RUN #2 TCR=100% SCR=97% RQD=56%
			3	RUN										RUN #3 TCR=100% SCR=71% RQD=14%
71.8														
5.1	End of Borehole at 5.1 m													

ONTMT4S 19-479-154 WOLFE ISLAND FERRY DOCKS.GPJ 2012TEMPLATE(MTO).GDT 2/12/16



# RECORD OF BOREHOLE No M02

1 OF 1

METRIC

GWP# 4061-14-00 LOCATION Marysville Dock N 4 894 934.2 E 309 537.2 ORIGINATED BY JG  
 HWY Wolfe Island Ferry Docks BOREHOLE TYPE Hollow Stem Auger COMPILED BY JG  
 DATUM Geodetic DATE 2015.08.31 - 2015.08.31 CHECKED BY FJG

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					UNIT WEIGHT $\gamma$ kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%)						
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa												
76.9								20	40	60	80	100								
0.0	Asphalt 90mm																			
0.1	<b>GRAVEL</b> with Silt and Sand very dense to loose grey moist		1	SS	68		76												54 39 7 (SI+CL)	
			2	SS	26															
	frequent cobbles and boulders		3	SS	4		75													
74.9	Organic Silty <b>SAND</b> with Gravel some fine fibrous peat loose dark brown wet		4	SS	5		74												22 30 34 14	
2.0																				
73.7	Silty <b>CLAY</b> firm, blocky grey to brown		5	SS	4		73													
3.2			6	SS	6														0 4 43 53	
			7	SS	5		72													
			8	SS	100/ 80mm		71												RUN #1 TCR=97% SCR=75% RQD=80%	
71.1	<b>LIMESTONE</b> , Grey, Slightly Weatherd to Fresh, Medium Strong, Horizontally Bedded		1	RUN			70												RUN #2 TCR=100% SCR=100% RQD=98%	
5.7			2	RUN			69													
68.1																				
8.7	End of Borehole at 8.7 m																			

ONTMT4S 19-479-154 WOLFE ISLAND FERRY DOCKS.GPJ 2012TEMPLATE(MTO).GDT 2/12/16

# RECORD OF BOREHOLE No M03

1 OF 1

METRIC

GWP# 4061-14-00 LOCATION Marysville Dock N 4 894 943.9 E 309 521.9 ORIGINATED BY JG  
 HWY Wolfe Island Ferry Docks BOREHOLE TYPE Hollow Stem Auger COMPILED BY JG  
 DATUM Geodetic DATE 2015.08.31 - 2015.08.31 CHECKED BY FJG

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT				PLASTIC LIMIT      NATURAL MOISTURE CONTENT      LIQUID LIMIT				UNIT WEIGHT  $\gamma$  kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%)		
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa				W P      W      W L							
								○ UNCONFINED      + FIELD VANE ● QUICK TRIAXIAL      × LAB VANE				WATER CONTENT (%)							
76.9							20	40	60	80	100								
0.0	Asphalt 80mm																		
0.1	<b>GRAVEL</b> with Sand very dense to compact grey dry to wet		1	SS	52														
			2	SS	24														
	frequent cobbles and boulders		3	SS	21														
74.3			4	SS	16														
2.6	Organic Silty <b>SAND</b> with Gravel some fine fibrous peat very loose dark brown wet		5	SS	WH														
72.7																			
4.1	Silty <b>CLAY</b> firm, blocky grey to brown		6	SS	5														
71.5																			
5.3	Silty <b>SAND</b> with Gravel loose brown wet		7	SS	100/ 0mm														
70.4																			
6.5	<b>LIMESTONE</b> , Grey, Slightly Weathered to Fresh, Medium Strong, Horizontally Bedded		1	RUN															
			2	RUN															
			3	RUN															
67.0																			
9.9	End of Borehole at 9.9 m																		

+<sup>3</sup>, ×<sup>3</sup>: Numbers refer to Sensitivity 20 15 10 5 0 (%) STRAIN AT FAILURE

ONTMT4S 19-479-154 WOLFE ISLAND FERRY DOCKS.GPJ 2012TEMPLATE(MTO).GDT 2/12/16

# RECORD OF BOREHOLE No M04

1 OF 2

METRIC

GWP# 4061-14-00 LOCATION Marysville Dock N 4 895 004.5 E 309 484.7 ORIGINATED BY CM  
 HWY Wolfe Island Ferry Docks BOREHOLE TYPE Casing / NQ Coring COMPILED BY CM  
 DATUM Geodetic DATE 2015.09.14 - 2015.09.14 CHECKED BY FJG

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT				UNIT WEIGHT  $\gamma$ kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%)  GR SA SI CL
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa					
								20 40 60 80 100					
								○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × LAB VANE					
74.9													
0.0	WATER												
71.2													
3.7	Inferred Lake Bed												
69.6													
5.3	SILTY CLAY Very Stiff Grey Moist		1	SS	4								
68.9													
6.0	Silty SAND Compact Brown Wet		2	SS	15								0 54 42 4
68.0													
6.9	Silty SAND interbedded with silty clay Very Loose to Loose Grey Wet		3	SS	5								
			4	SS	2								
66.5													
8.4	LIMESTONE, Grey, Slightly Weathered to Fresh, Medium Strong, Horizontally Bedded with Shale Interbedding		1	RUN									RUN #1 TCR=100% SCR=100% RQD=95%

Continued Next Page

+<sup>3</sup>, ×<sup>3</sup>: Numbers refer to Sensitivity  
 20  
15  
10  
(%) STRAIN AT FAILURE

ONTMT4S 19-479-154 WOLFE ISLAND FERRY DOCKS.GPJ 2012TEMPLATE(MTO).GDT 2/12/16

# RECORD OF BOREHOLE No M04

2 OF 2

METRIC

GWP# 4061-14-00 LOCATION Marysville Dock N 4 895 004.5 E 309 484.7 ORIGINATED BY CM  
 HWY Wolfe Island Ferry Docks BOREHOLE TYPE Casing / NQ Coring COMPILED BY CM  
 DATUM Geodetic DATE 2015.09.14 - 2015.09.14 CHECKED BY FJG

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					PLASTIC LIMIT  W P	NATURAL MOISTURE CONTENT  W	LIQUID LIMIT  W L	UNIT WEIGHT  $\gamma$  kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%)  GR SA SI CL
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × LAB VANE									
	Continued From Previous Page							20	40	60	80	100					
			2	RUN			64										RUN #2 TCR=100% SCR=85% RQD=67%
			3	RUN													RUN #3 TCR=100% SCR=100% RQD=80%
63.1																	
11.8	End of Borehole at 11.8 m																

ONTMT4S 19-479-154 WOLFE ISLAND FERRY DOCKS.GPJ 2012TEMPLATE(MTO).GDT 2/12/16

## METRIC

+<sup>3</sup>, ×<sup>3</sup>: Numbers refer to Sensitivity

ONTMT4S 19-479-154 WOLFE ISLAND FERRY DOCKS.GPJ 2012TEMPLATE(MTO).GDT 2/12/16

# RECORD OF BOREHOLE No M05

2 OF 2

METRIC

GWP# 4061-14-00 LOCATION Marysville Dock N 4 895 049.7 E 309 513.0 ORIGINATED BY CM  
 HWY Wolfe Island Ferry Docks BOREHOLE TYPE Casing / NQ Coring COMPILED BY CM  
 DATUM Geodetic DATE 2015.09.14 - 2015.09.14 CHECKED BY FJG

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT				PLASTIC LIMIT      NATURAL MOISTURE CONTENT      LIQUID LIMIT			UNIT WEIGHT  γ  kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%)	
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa				WATER CONTENT (%)					
								20   40   60   80   100				w <sub>p</sub> w   w <sub>L</sub>					
								○ UNCONFINED      + FIELD VANE ● QUICK TRIAXIAL      × LAB VANE									
	Continued From Previous Page																
	- occasional clay seams below 11 m		6	SS	8		64										
							63										
			7	SS	6		62										
61.5																	
13.4		LIMESTONE, Grey, Slightly Weatherd to Fresh, Medium Strong, Horizontally Bedded		1	RUN		61								RUN #1 TCR=100% SCR=100% RQD=78%		
			2	RUN		60								RUN #2 TCR=98% SCR=98% RQD=84%			
			3	RUN		59								RUN #3 TCR=100% SCR=100% RQD=93%			
57.8							58										
17.1	End of Borehole at 17.1 m																

ONTMT4S 19-479-154 WOLFE ISLAND FERRY DOCKS GPJ 2012TEMPLATE(MTO).GDT 2/12/16

## METRIC

SOIL PROFILE				SAMPLES	
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES
74.9 0.0	WATER				
71.2 3.7	Inferred Lake Bed				
69.6 5.3	SILTY CLAY, frequent fine sand seams Very Stiff Grey		1	SS	7
			2	SS	5
68.1 6.8	Silty SAND Loose to Compact Grey to Brown Wet		3	SS	9
			4	SS	12
	- occasional clay seams below 9.1 m		5	SS	9

+<sup>3</sup>, ×<sup>3</sup>: Numbers refer to Sensitivity



# RECORD OF BOREHOLE No M06

2 OF 2

METRIC

GWP# 4061-14-00 LOCATION Marysville Dock N 4 895 037.6 E 309 480.0 ORIGINATED BY CM  
 HWY Wolfe Island Ferry Docks BOREHOLE TYPE Casing / NQ Coring COMPILED BY CM  
 DATUM Geodetic DATE 2015.09.15 - 2015.09.15 CHECKED BY FJG

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT				PLASTIC LIMIT      NATURAL MOISTURE CONTENT      LIQUID LIMIT			UNIT WEIGHT  $\gamma$  kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%)
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa				WATER CONTENT (%)				
	Continued From Previous Page							20   40   60   80   100				w <sub>P</sub> w                      w <sub>L</sub>				
								○ UNCONFINED      + FIELD VANE								
								● QUICK TRIAXIAL      × LAB VANE								
								20   40   60   80   100				20   40   60				
					</											

ONTMT4S 19-479-154 WOLFE ISLAND FERRY DOCKS GPJ 2012TEMPLATE(MTO).GDT 2/12/16

DESIGN SERVICES BRANCH

FOUNDATIONS OFFICE

RECORD OF BOREHOLE NO 9

JOB 73-11071

LOCATION As Shown on Drawing

ORIGINATED BY J.B.

W.P. 25-73-01

BORING DATE September 24, 1973

COMPILED BY C.S.P.

DATUM Geodetic

BOREHOLE TYPE Washboring and BX Rock Core

CHECKED BY [Signature]

SOIL PROFILE			SAMPLES			ELEV. SCALE	DYNAMIC PENETRATION RESISTANCE BLOWS / FOOT				LIQUID LIMIT — $w_L$ PLASTIC LIMIT — $w_p$ WATER CONTENT — $w$ $w_p$ — $w$ — $w_L$				BULK DENSITY $\gamma$ P.C.F.	REMARKS
ELEV. DEPTH	DESCRIPTION	STRAT. PLOT	NUMBER	TYPE	BLOWS/FOOT		SHEAR STRENGTH P.S.F. ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL x LAB VANE				WATER CONTENT %					
250.7	Ground Level															
0.0	Topsoil		1	BX RC	50% Rec	250										
0.6	Bedrock - fract. & weath. sound Limestone		2	BX RC	100% Rec											
242.7	Grey															
8.0	End of Borehole.					240										

OFFICE REPORT SOIL EXPLORATION

DESIGN SERVICES BRANCH

FOUNDATIONS OFFICE

# RECORD OF BOREHOLE NO 101

JOB 73-11071

LOCATION As Shown on Drawing

ORIGINATED BY C.S.P.

W.P. 25-73-01

BORING DATE Jan. 8 - 9, 1974

COMPILED BY C.S.P.

DATUM I.G.L.D.

BOREHOLE TYPE Washboring and BX Rock Core

CHECKED BY

SOIL PROFILE		SAMPLES			ELEV. SCALE ELEV. IN FEET	DYNAMIC PENETRATION RESISTANCE BLOWS / FOOT		LIQUID LIMIT ——— $w_L$ PLASTIC LIMIT ——— $w_p$ WATER CONTENT — $w$ $w_p$ — $w$ — $w_L$		BULK DENSITY $\gamma$	REMARKS	
ELEV. DEPTH Ft.	DESCRIPTION	STRAT. PLOT	NUMBER	TYPE		BLOWS/FOOT (0-30)	SHEAR STRENGTH P.S.F. ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × LAB VANE		WATER CONTENT %			
74.7 0.0	245.0 0.0	Water Level									P.C.F.	GR.SA.SI.CL
		Water				240 73						
70.2	230.2					230						
14.5 69.4	14.7 227.5	Silt, sand some gravel Grey loose to compact	1A	SS	wt. of 70 rods							
5.3	17.5	Bedrock - Limestone	1	SS	12							
67.9	222.5	Grey Sound	2	BX RC	95% Rec							
6.8	22.5	End of Borehole				220 67						

OFFICE REPORT ON OIL EXPLORATION

DESIGN SERVICES BRANCH

FOUNDATIONS OFFICE

# RECORD OF BOREHOLE No 102

JOB 73-11071

LOCATION As Shown on Drawing

ORIGINATED BY C.S.P.

W.P. 25-73-01

BORING DATE Jan. 9 - 10, 1974

COMPILED BY C.S.P.

DATUM I.G.L.D.

BOREHOLE TYPE Washboring and BX Rock Core

CHECKED BY

SOIL PROFILE			SAMPLES			ELEV. SCALE ft m	DYNAMIC PENETRATION RESISTANCE BLOWS / FOOT				LIQUID LIMIT $W_L$ PLASTIC LIMIT $W_P$ WATER CONTENT $W$				BULK DENSITY $\gamma$	REMARKS
ELEV. DEPTH ft.	DESCRIPTION	STRAT. PLOT	NUMBER	TYPE	BLOWS/FOOT (U.S. 30")		SHEAR STRENGTH P.S.F. O UNCONFINED + FIELD VANE ● QUICK TRIAXIAL x LAB VANE				WATER CONTENT % $W_P$ $W$ $W_L$					
74.7	245.0	Water Level														
0.0	0.0	Water				240 73										
70.4	230.8					230 75										
4.3	14.2	Sand and gravel, coarse	1	SS	13											
4.7	15.5	Bedrock - Limestone	2	BX	97%											
68.6	225.0	Grey Sand		RC	Rec.											
6.1	20.0	End of Borehole				220 67										

OFFICE REPORT ON SOIL EXPLORATION

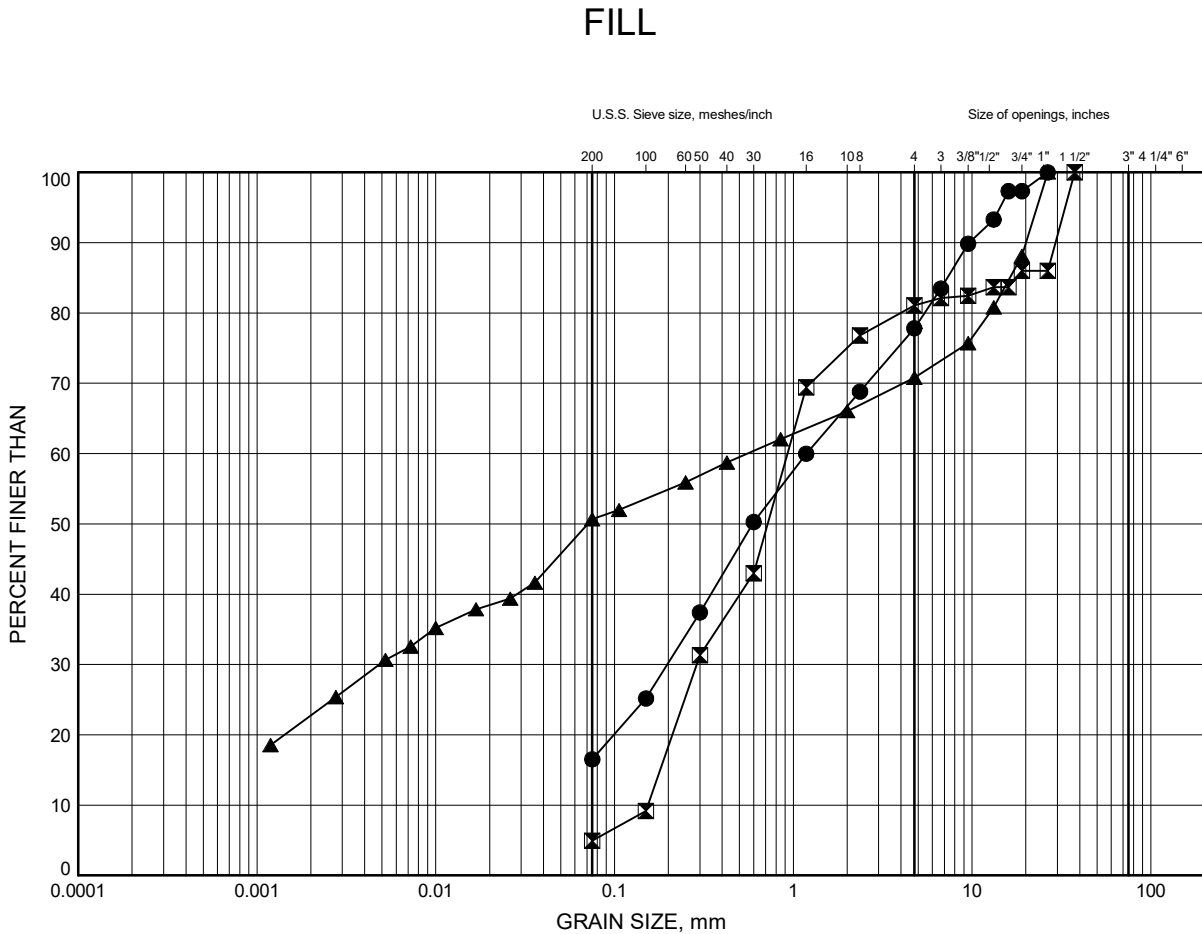
**Appendix C.**

**Laboratory Testing**

**Appendix C-1.  
Barrack Street**

# Barrack Street Dock GRAIN SIZE DISTRIBUTION

FIGURE C1



SILT and CLAY	FINE	MEDIUM	COARSE	FINE	COARSE	COBBLE SIZE
FINE GRAINED	SAND			GRAVEL		

## LEGEND

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	B01	1.07	75.37
⊠	B01	3.35	73.09
▲	B02	1.07	75.37

Date December 2016  
GWP# 4061-14-00



Prep'd JG  
Chkd. FJG

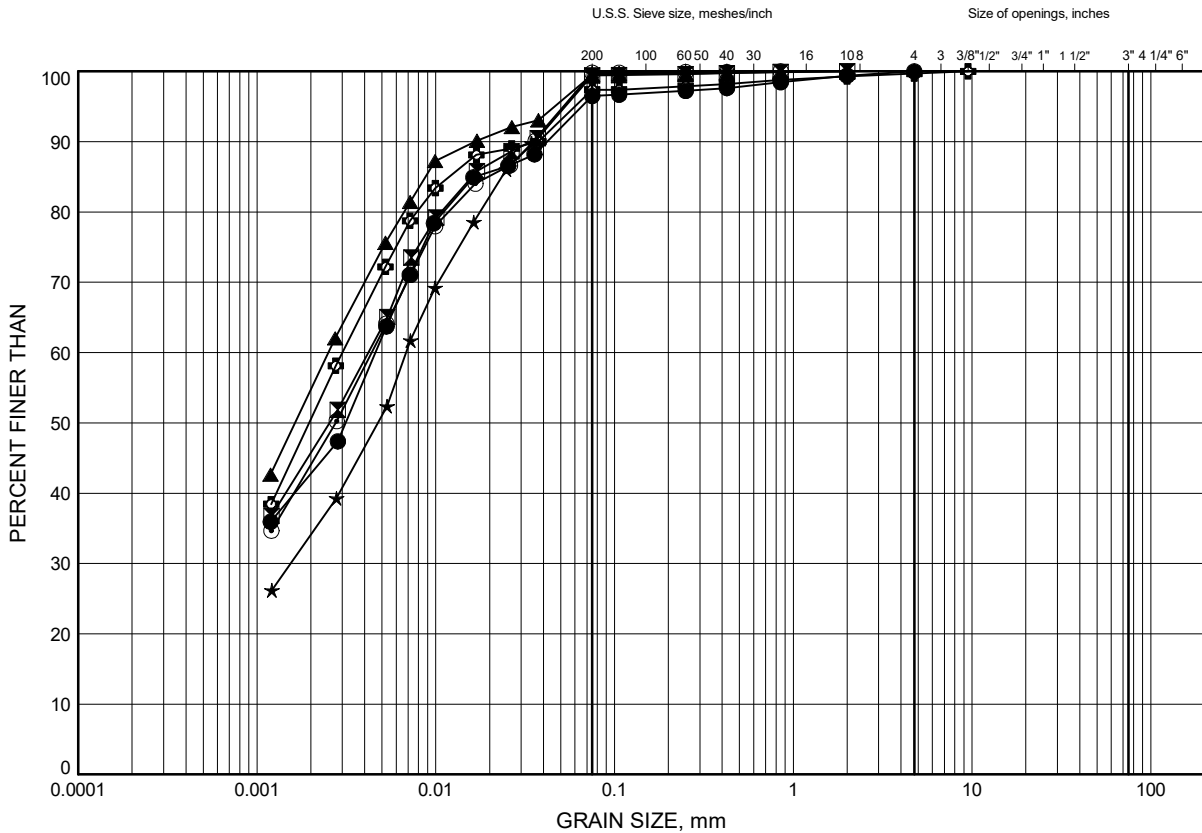


# Barrack Street Dock

## GRAIN SIZE DISTRIBUTION

FIGURE C2

### Silty CLAY



SILT and CLAY	FINE	MEDIUM	COARSE	FINE	COARSE	COBBLE SIZE
FINE GRAINED	SAND			GRAVEL		

### LEGEND

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	B02	6.40	70.04
⊠	B02	10.97	65.47
▲	B04	7.09	67.91
★	B04	7.85	67.14
⊙	B05	6.32	68.67
⊕	B06	7.54	67.45

Date December 2016

GWP# 4061-14-00



Prep'd JG

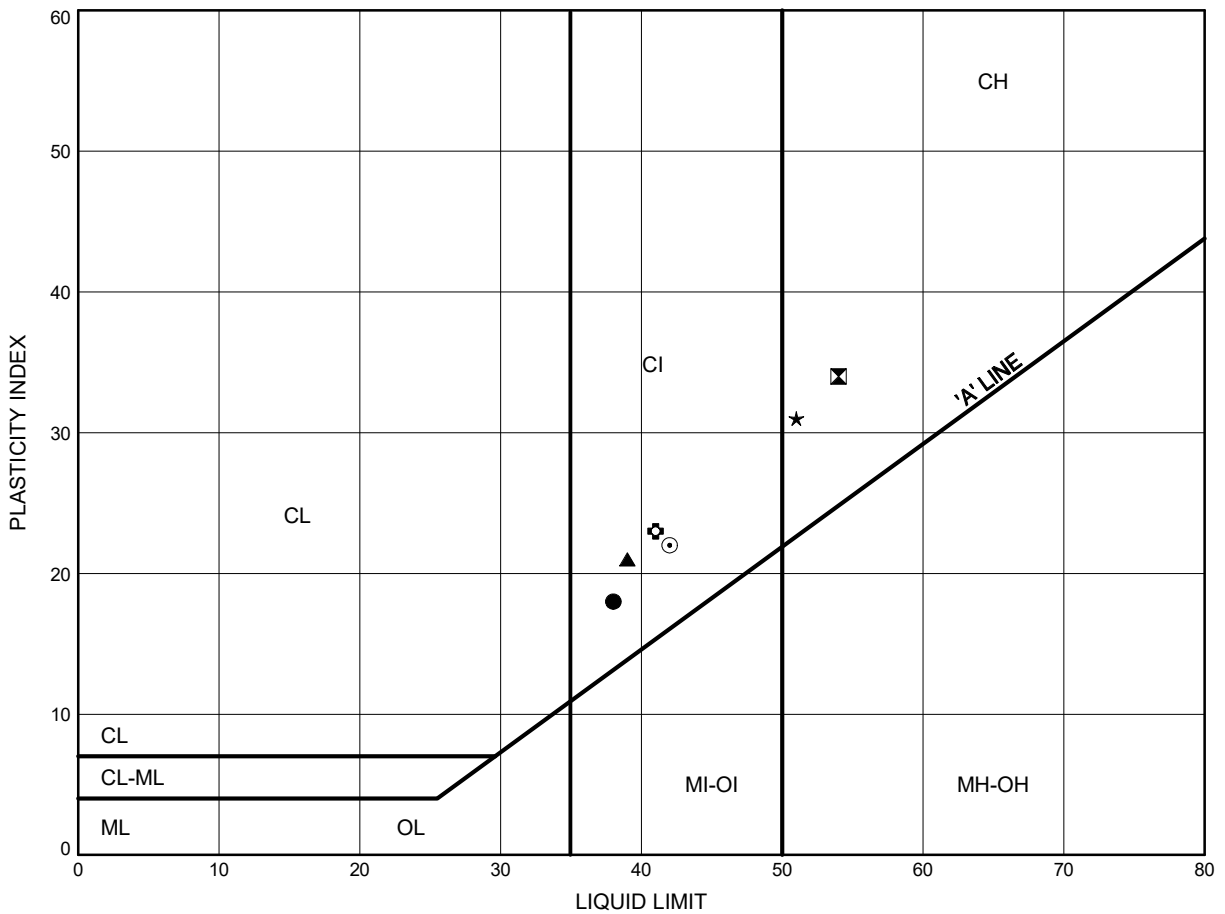
Chkd. FJG

Barrack Street Dock

# ATTERBERG LIMITS TEST RESULTS

FIGURE C3

Silty CLAY



## LEGEND

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	B02	6.40	70.04
⊠	B02	10.97	65.47
▲	B04	7.09	67.91
★	B04	7.85	67.14
⊙	B05	6.32	68.67
⊕	B06	7.54	67.45

Date December 2016  
GWP# 4061-14-00



Prep'd JG  
Chkd. FJG



**Stantec Consulting Ltd.**  
400 - 1331 Clyde Avenue  
Ottawa ON K2C 3G4  
Tel: (613) 722-4420  
Fax: (613) 722-2799

January 18, 2016  
File: 122410864

**Attention: Stephen Peters**  
Thurber Engineering Ltd.  
104 – 2460 Lancaster Road  
Ottawa, Ontario, Canada, K1B 4S5  
Tel: 613-274-2121  
e-mail: speters@thurber.ca

Dear Mr. Peters,

**Reference: Consolidation Test Results for Wolfe Island Ferry Docks Thurber File# (19-479-154):  
Sample TW3 B04**

This letter presents the results of a one-dimensional consolidation test carried out on the above referenced sample in accordance with ASTM D2435. The test results are provided in the attached table and figure.

This letter provides test results only and does not constitute any interpretation or engineering recommendations with respect to material suitability or specification compliance.

We trust the information presented herein meets your present requirements. Should you have any questions or require additional information, please do not hesitate to contact us.

Regards,

**STANTEC CONSULTING LTD.**

Raymond Hache, M.Sc., P.Eng.  
Principal Geotechnical Engineer  
Phone: (613) 738-6055  
Fax: (613) 722-2799  
Raymond.Hache@stantec.com

Attachment: Consolidation test results (1 table + 1 Figure)

Project Wolfe Island Ferry Docks, File# 19-479-154  
 Sample No. TW-3, B04

Project No. 122410864  
 Sample Depth (m) 8.077

**Sample Data**

Initial Ht. of soil,  $H_i$  19.03 mm  
 Initial sample volume,  $V_i$  38.66 cm<sup>3</sup>  
 Specific gravity,  $G_s$  2.750 Assumed  
 Initial Water Content 31.2 %  
 Wet mass of soil 75.49 g  
 Dry mass of soil 58.53 g

Wet unit weight 19.15 kN/m<sup>3</sup>  
 Dry unit weight 14.85 kN/m<sup>3</sup>  
 Initial height of voids,  $H$  0.855 cm  
 Ht. of solids,  $H_s$  1.048 cm  
 Initial Void Ratio,  $e_o$  0.82  
 Degree of Saturation 97.6 %

Odometer B  
 ASTM Method A  
 Load Duration 24 hrs  
 Start Date 13-Oct-15  
 End Date 2-Nov-15

Stage	Test Type	Stress Increment (kPa)	End of Load Deformation (cm)	Strain $\epsilon = \Delta H/H_i$	$\Delta e = \Delta H/H_s$	Void Ratio $e$	End of Load Height (cm)	Corrected deformation $\Delta H_{50}$ (cm)	Specimen height $H_{50}$ (cm)	Time $t_{50}$ (min)	Coefficient of Consolidation $c_v$ (cm <sup>2</sup> /min)	Time $t_{90}$ (min)	Coefficient of Consolidation $c_v$ (cm <sup>2</sup> /min)
Seating	Seating	0.00	0			0.817							
1	Consolidation	10.59	0.0038	0.00200	0.004	0.813	1.899	0.0012	1.9018			1.85	0.4145
2	Consolidation	20.44	0.0072	0.00378	0.007	0.810	1.896	0.0048	1.8982			1.79	0.4267
3	Consolidation	41.28	0.0140	0.00736	0.013	0.803	1.889	0.0095	1.8935			1.20	0.6334
4	Consolidation	81.11	0.0256	0.01345	0.024	0.792	1.877	0.0189	1.8841			2.30	0.3272
5	Consolidation	119.34	0.0318	0.01671	0.030	0.786	1.871	0.0279	1.8751			5.80	0.1285
6	Consolidation	160.75	0.0396	0.02081	0.038	0.779	1.863	0.0334	1.8696			2.60	0.2850
7	Consolidation	240.40	0.0492	0.02585	0.047	0.770	1.854	0.0424	1.8606			1.70	0.4317
8	Consolidation	320.05	0.0636	0.03342	0.061	0.756	1.839	0.0548	1.8482			13.00	0.0557
9	Consolidation	479.35	0.0830	0.04362	0.079	0.737	1.820	0.0692	1.8338			4.80	0.1485
10	Consolidation	639.79	0.1032	0.05423	0.099	0.718	1.800	0.0894	1.8136			9.00	0.0775
11	Consolidation	1280.40	0.1760	0.09249	0.168	0.649	1.727	0.1281	1.7749			1.70	0.3929
12	Consolidation	2559.34	0.2606	0.13694	0.249	0.568	1.642	0.2079	1.6951			1.70	0.3583
13	Rebound	1280.40	0.2530	0.13295	0.242	0.575	1.650						
14	Rebound	320.05	0.2338	0.12286	0.223	0.593	1.669						
15	Rebound	81.11	0.2074	0.10899	0.198	0.619	1.696						
16	Rebound	20.44	0.1842	0.09679	0.176	0.641	1.719						
17	Rebound	4.88	0.1702	0.08944	0.162	0.654	1.733						

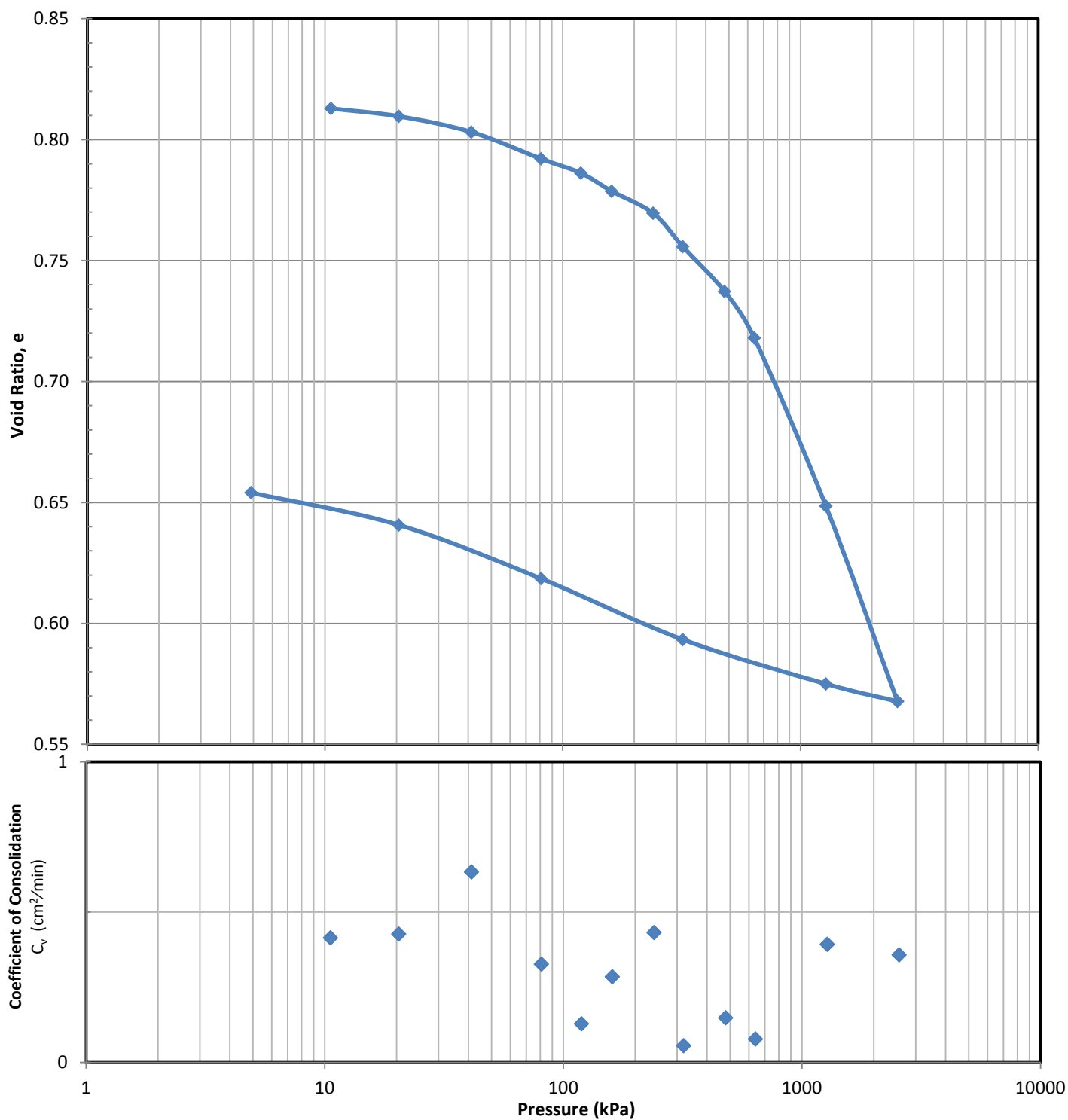
Notes: Test Method A loading  
 Specimen from 457 mm from top of tube

Conducted by: DR

Checked by: AN

**Project**  
**Project No.**  
**Sample No.**  
**Sample Depth (m)**

**Wolfe Island Ferry Docks, File# 19-479-154**  
**122410864**  
**TW-3, B04**  
**8.077**

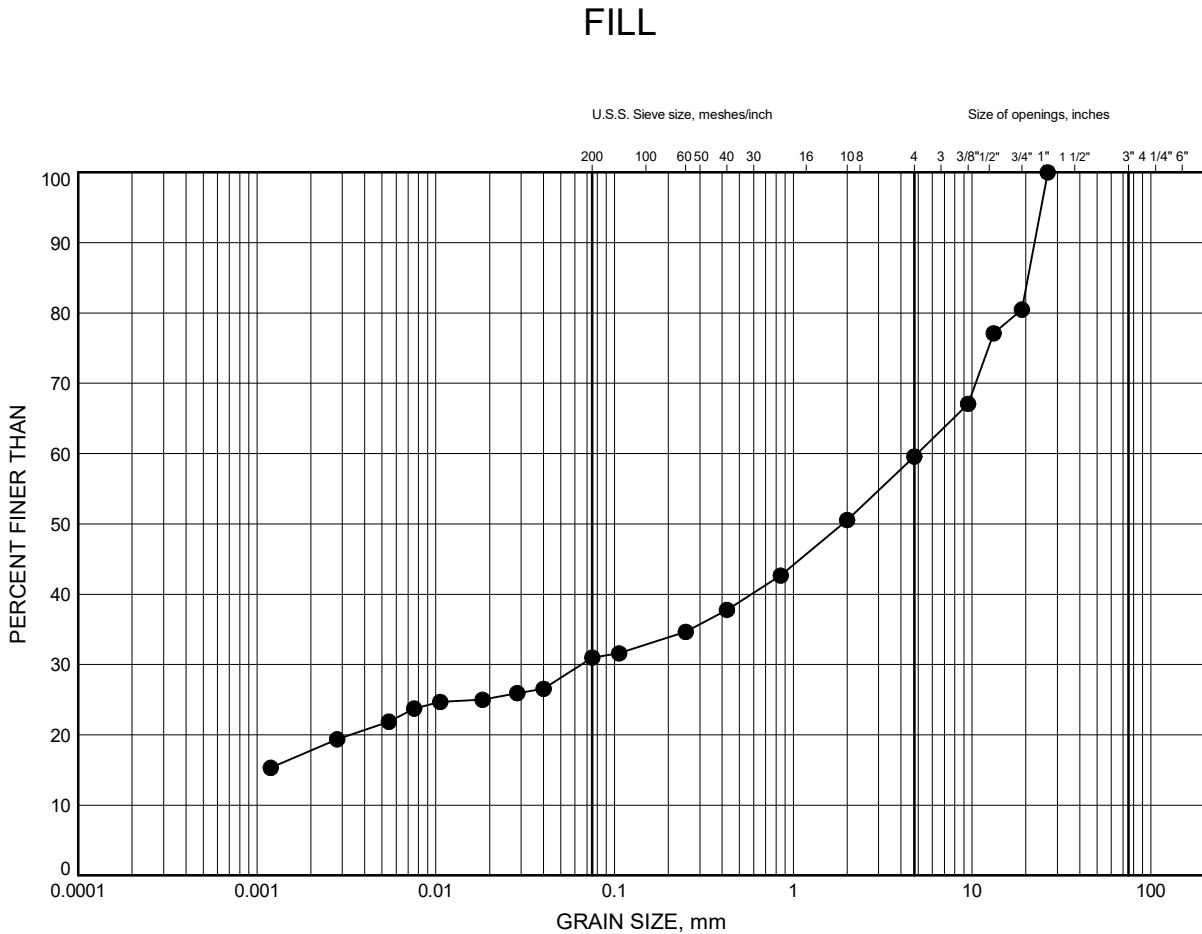


**Appendix C-2.**

**Dawson Point**

# Dawson's Point Dock GRAIN SIZE DISTRIBUTION

FIGURE C4



SILT and CLAY	FINE	MEDIUM	COARSE	FINE	COARSE	COBBLE SIZE
FINE GRAINED	SAND			GRAVEL		

## LEGEND

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	D01	1.07	75.20

Date December 2016  
GWP# 4061-14-00

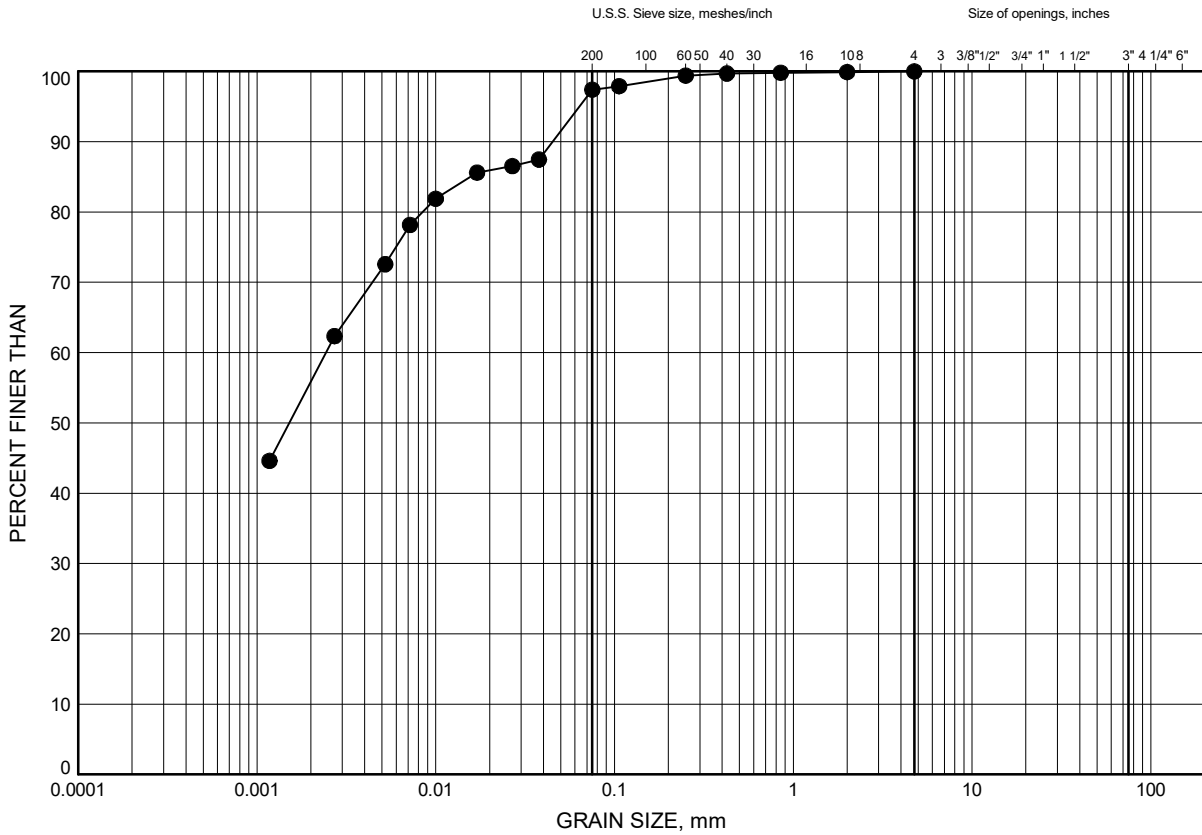


Prep'd JG  
Chkd. FJG

# Dawson's Point Dock GRAIN SIZE DISTRIBUTION

FIGURE C5

## Silty CLAY



SILT and CLAY	FINE	MEDIUM	COARSE	FINE	COARSE	COBBLE SIZE
FINE GRAINED	SAND			GRAVEL		

## LEGEND

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	D03	9.37	65.73

Date December 2016  
GWP# 4061-14-00



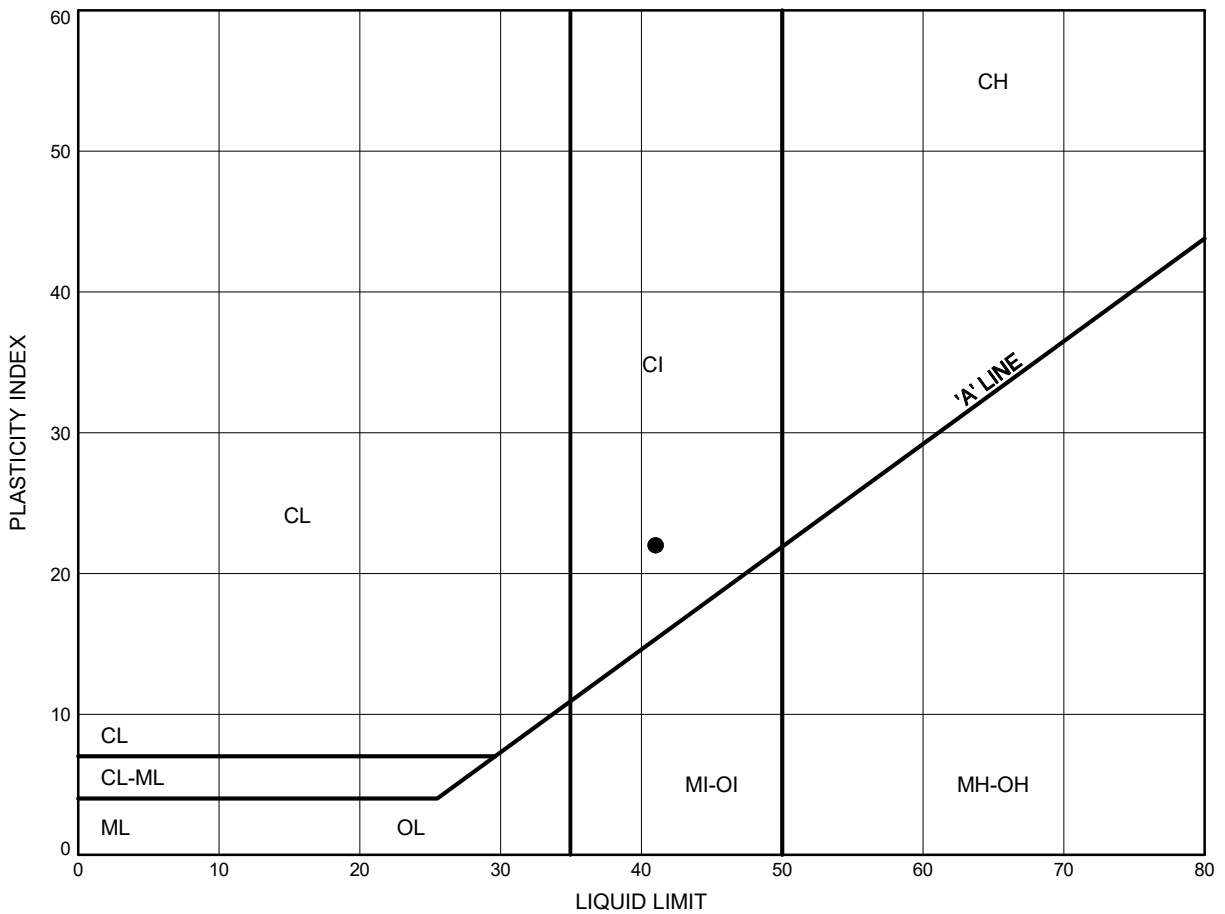
Prep'd JG  
Chkd. FJG



Dawson's Point Dock  
**ATTERBERG LIMITS TEST RESULTS**

FIGURE C6

Silty CLAY



**LEGEND**

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	D03	9.37	65.73

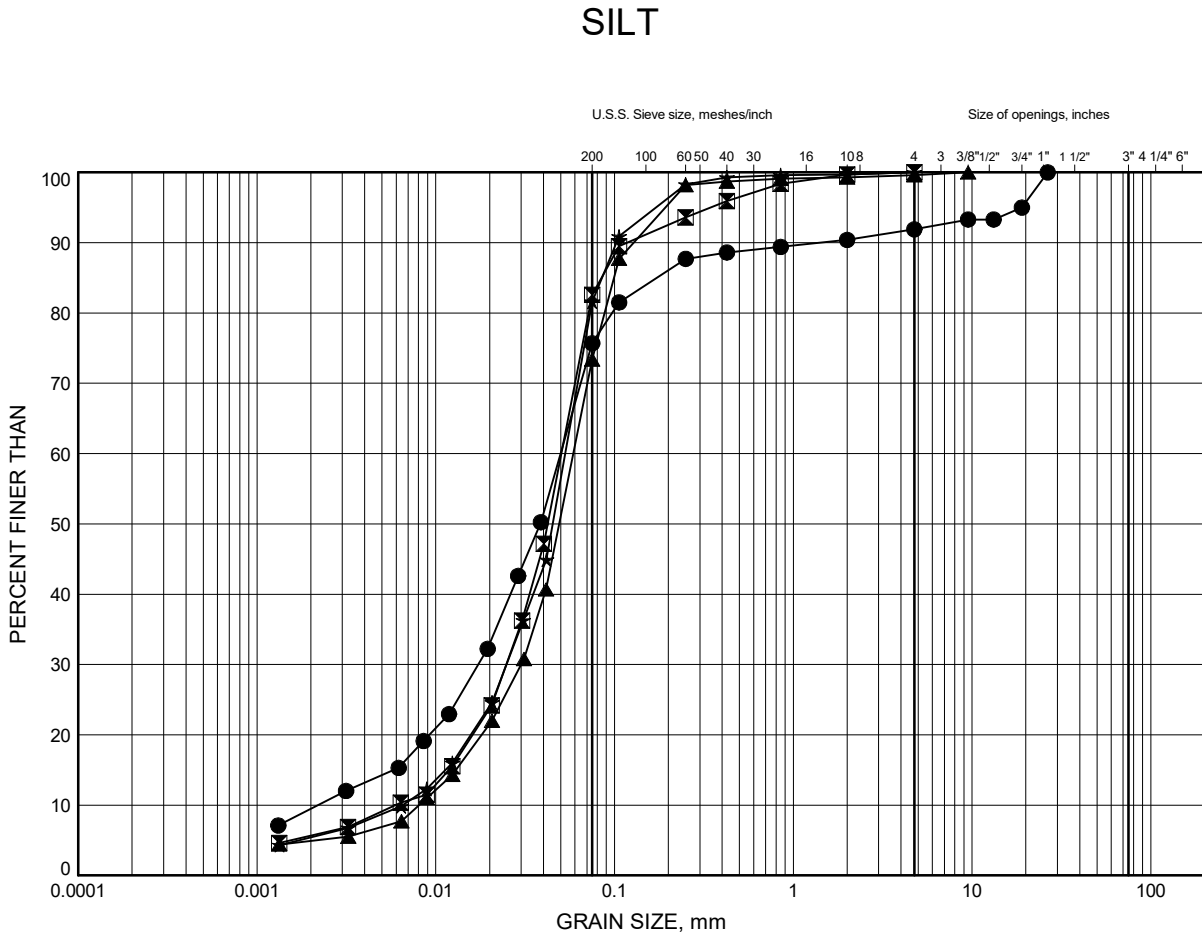
Date December 2016  
 GWP# 4061-14-00



Prep'd JG  
 Chkd. FJG

# Dawson's Point Dock GRAIN SIZE DISTRIBUTION

FIGURE C7



SILT and CLAY	FINE	MEDIUM	COARSE	FINE	COARSE	COBBLE SIZE
FINE GRAINED	SAND			GRAVEL		

## LEGEND

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	D02	9.37	65.73
⊠	D03	11.66	63.44
▲	D04	13.18	61.92
★	D05	13.18	61.92

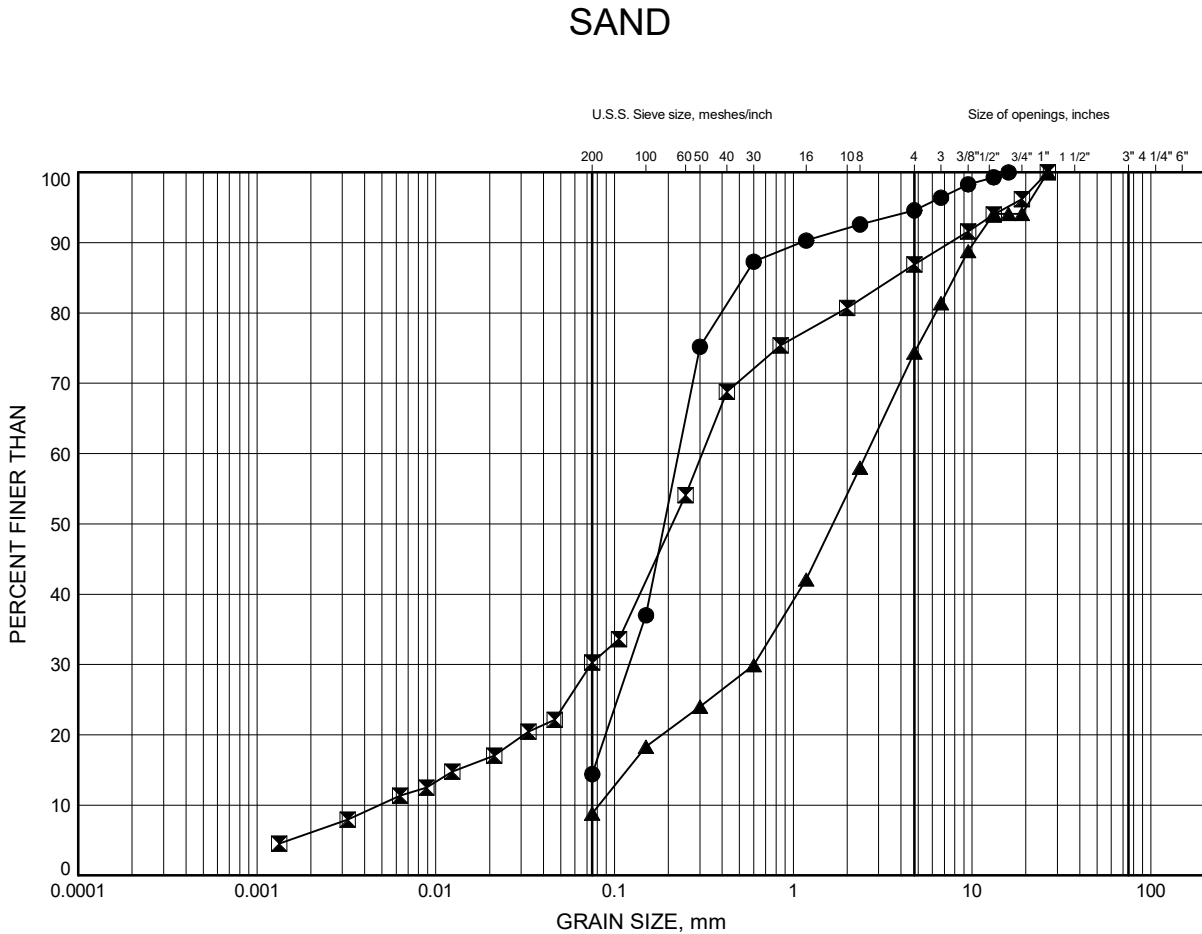
Date December 2016  
GWP# 4061-14-00



Prep'd JG  
Chkd. FJG

# Dawson's Point Dock GRAIN SIZE DISTRIBUTION

FIGURE C8



SILT and CLAY	FINE	MEDIUM	COARSE	FINE	COARSE	COBBLE SIZE
FINE GRAINED	SAND			GRAVEL		

## LEGEND

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	D02	13.18	61.92
⊠	D04	16.12	58.98
▲	D05	16.08	59.02

Date December 2016

GWP# 4061-14-00



Prep'd JG

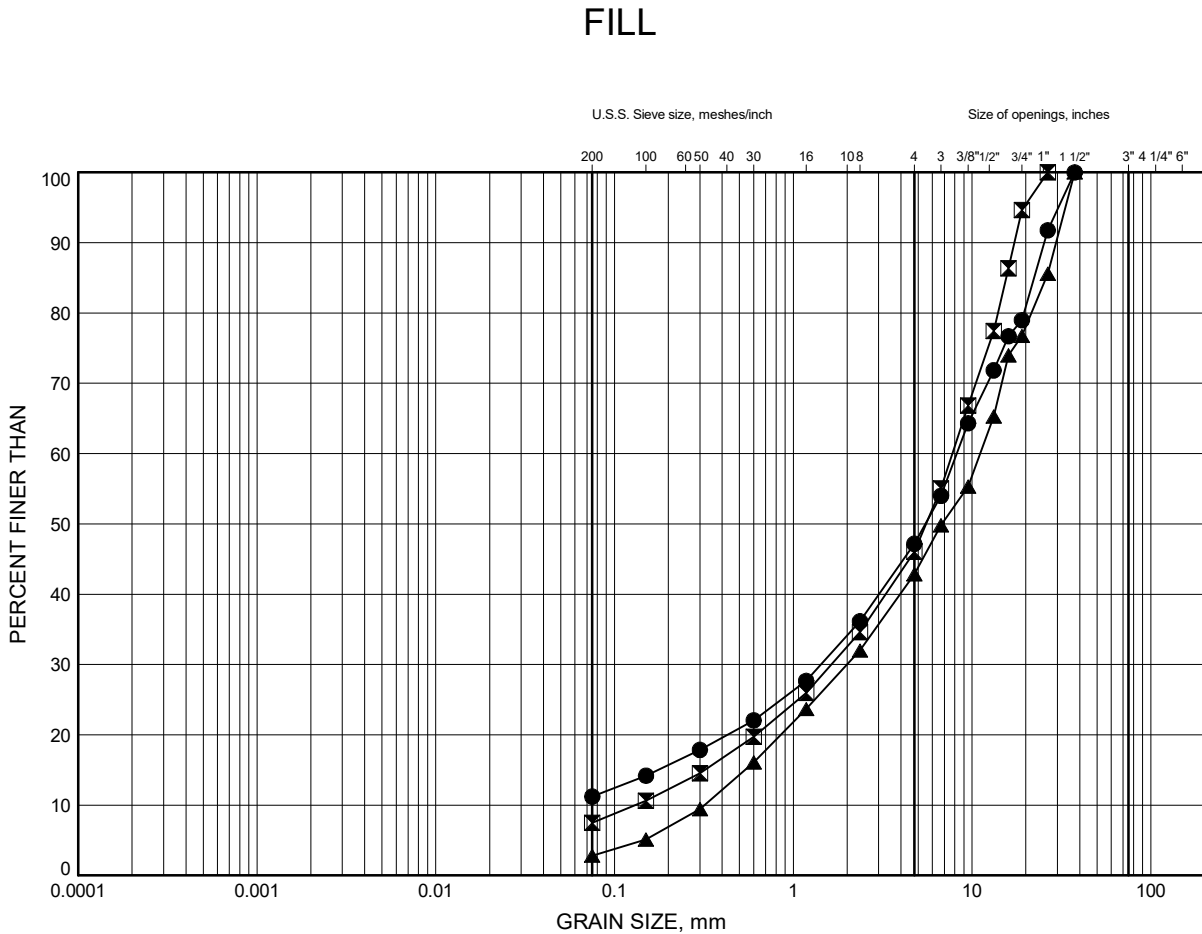
Chkd. FJG

**Appendix C-3.**

**Marysville**

# Marysville Dock GRAIN SIZE DISTRIBUTION

FIGURE C9



SILT and CLAY	FINE	MEDIUM	COARSE	FINE	COARSE	COBBLE SIZE
FINE GRAINED	SAND			GRAVEL		

## LEGEND

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	M01	1.07	75.79
⊠	M02	1.07	75.79
▲	M03	1.07	75.79

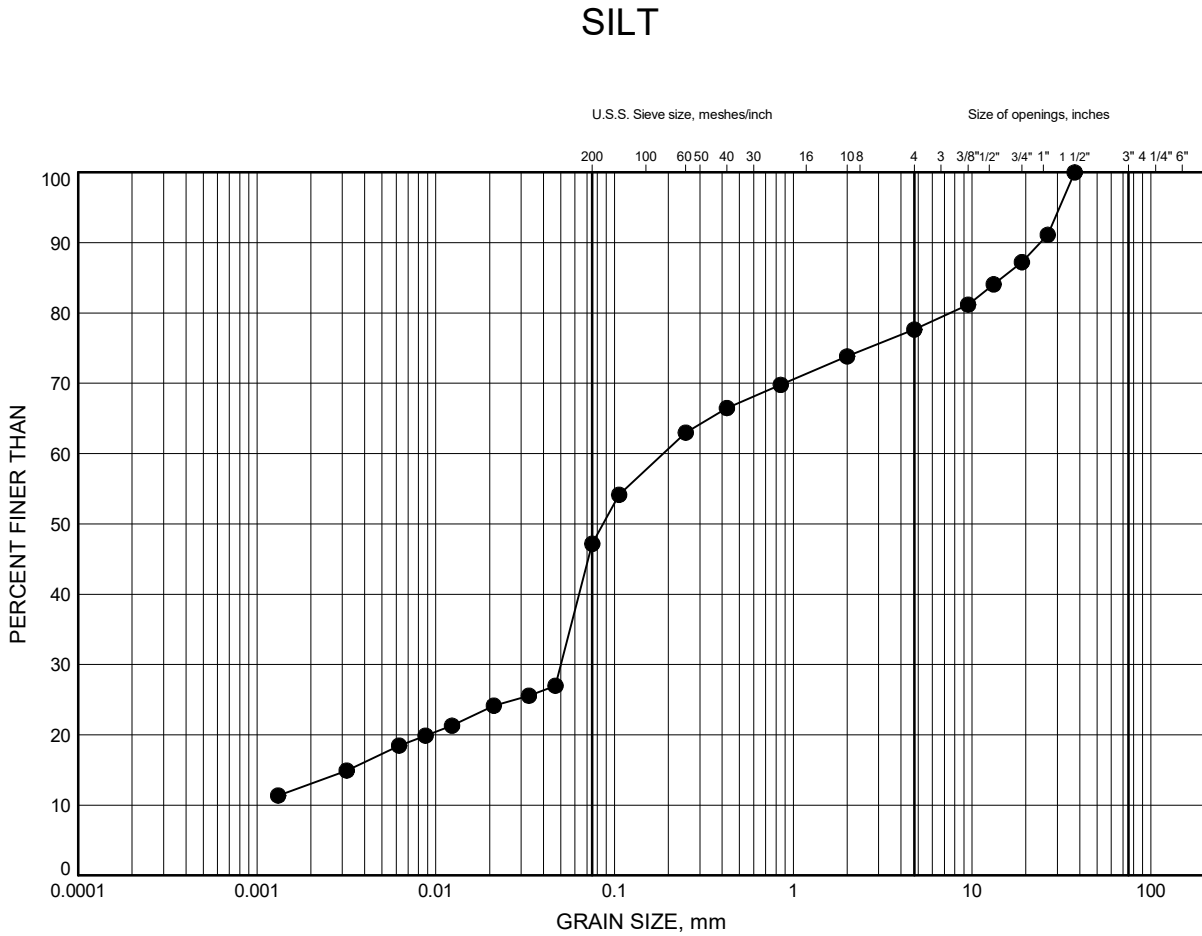
Date December 2016  
GWP# 4061-14-00



Prep'd JG  
Chkd. FJG

# Marysville Dock GRAIN SIZE DISTRIBUTION

FIGURE C10



SILT and CLAY	FINE	MEDIUM	COARSE	FINE	COARSE	COBBLE SIZE
FINE GRAINED	SAND			GRAVEL		

## LEGEND

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	M02	2.59	74.27

Date December 2016  
GWP# 4061-14-00

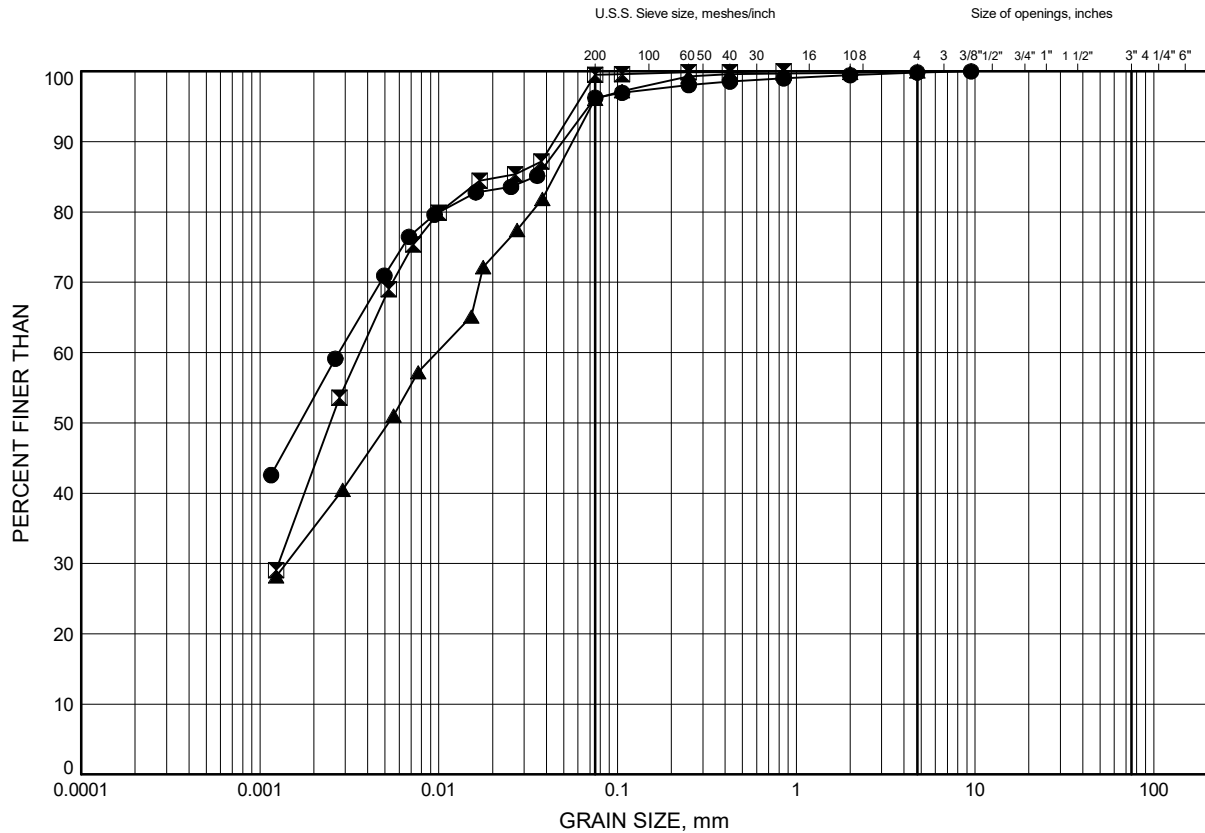


Prep'd JG  
Chkd. FJG

# Marysville Dock GRAIN SIZE DISTRIBUTION

FIGURE C11

## Silty CLAY



SILT and CLAY	FINE	MEDIUM	COARSE	FINE	COARSE	COBBLE SIZE
FINE GRAINED	SAND			GRAVEL		

## LEGEND

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	M02	4.11	72.75
⊠	M05	5.56	69.34
▲	M06	6.32	68.57

Date December 2016  
GWP# 4061-14-00

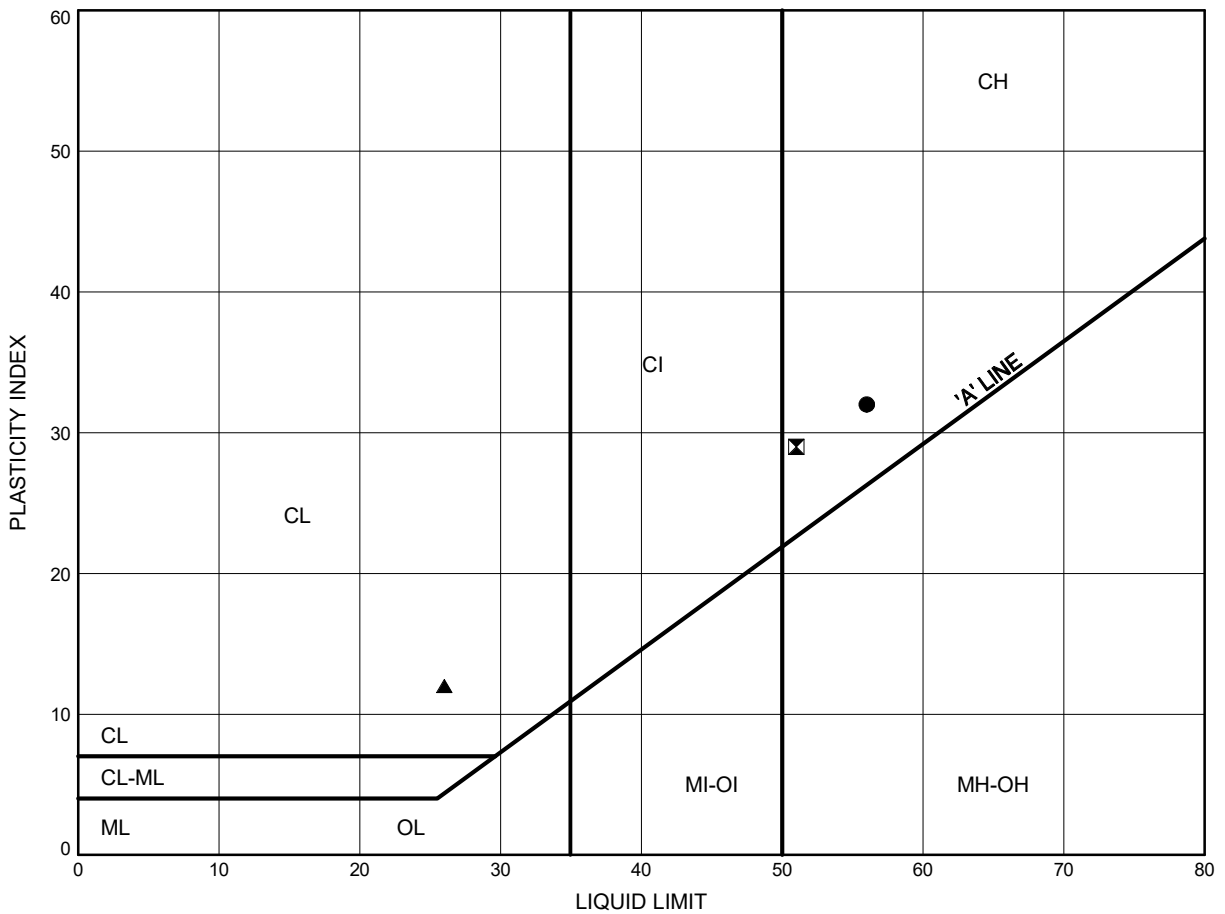


Prep'd JG  
Chkd. FJG

Marysville Dock  
**ATTERBERG LIMITS TEST RESULTS**

FIGURE C12

Silty CLAY



**LEGEND**

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	M02	4.11	72.75
⊠	M05	5.56	69.34
▲	M06	6.32	68.57

Date December 2016  
 GWP# 4061-14-00

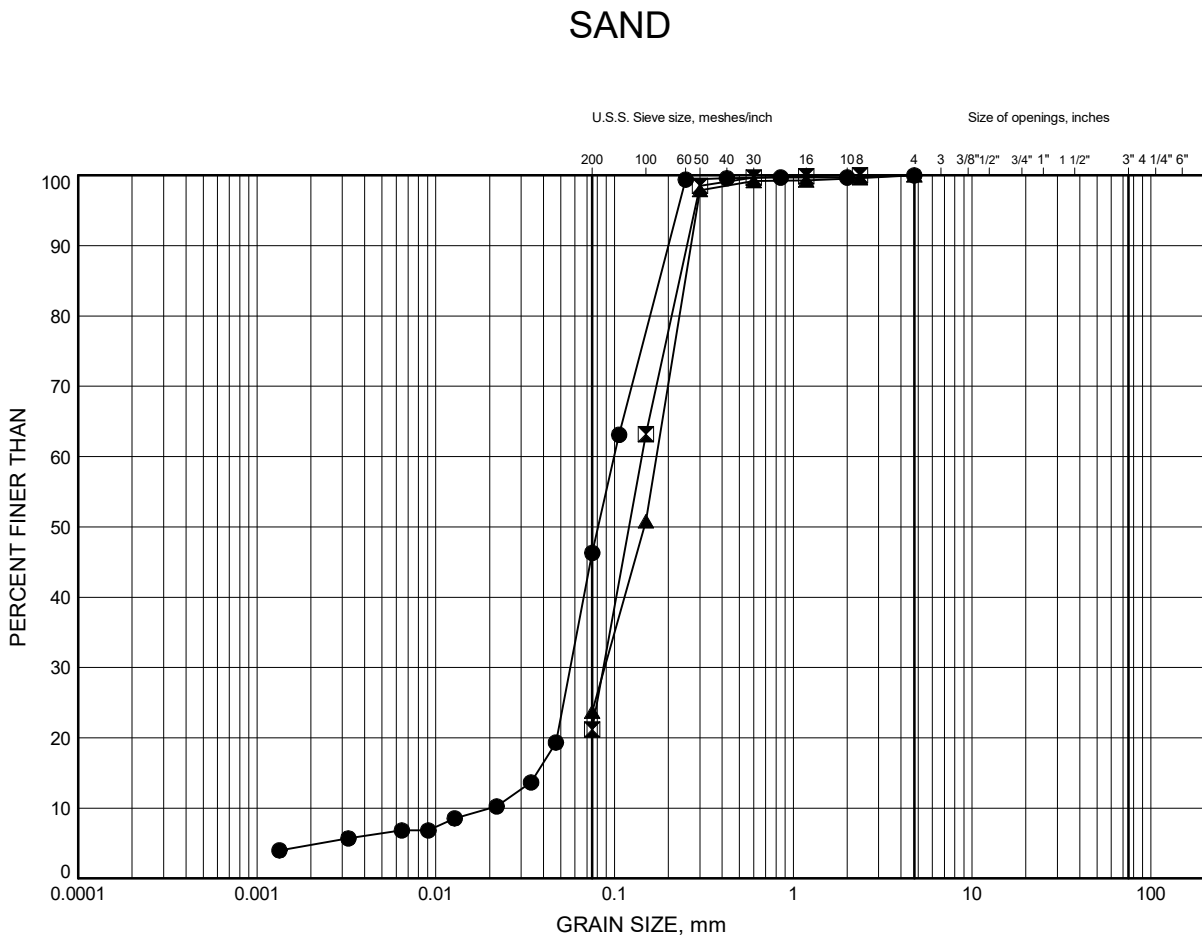


Prep'd JG  
 Chkd. FJG



# Marysville Dock GRAIN SIZE DISTRIBUTION

FIGURE C13



SILT and CLAY	FINE	MEDIUM	COARSE	FINE	COARSE	COBBLE SIZE
FINE GRAINED	SAND			GRAVEL		

## LEGEND

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	M04	6.32	68.57
⊠	M05	7.85	67.05
▲	M06	10.90	64.00

Date December 2016  
GWP# 4061-14-00



Prep'd JG  
Chkd. FJG

**Appendix C-4.  
Analytical Testing**

## Certificate of Analysis

### Thurber Engineering Ltd.

2460 Lancaster Rd, Suite 104  
Ottawa, ON K1B4S5  
Attn: Chris Murray

Client PO: 19-479-154  
Project: 19-479-154  
Custody:

Report Date: 24-Sep-2015  
Order Date: 18-Sep-2015

**Order #: 1538389**

This Certificate of Analysis contains analytical data applicable to the following samples as submitted:

Paracel ID	Client ID
1538389-01	B01 SS1 (8"-2'2")
1538389-02	B02 SS3 (5"-7")
1538389-03	B04 SS5 (30"-32")
1538389-04	B05 SS2 (20"-22")
1538389-05	D01 SS1 (0"-2")
1538389-06	D05 SS1 (37'6"-39'6")
1538389-07	M01 SS2 (2'6"-4'6")
1538389-08	M03 SS1 (6"-2'6")
1538389-09	M05 SS2A (22'6"-23'6")

Approved By:



Mark Foto, M.Sc.  
Lab Supervisor

## Certificate of Analysis

Client: **Thurber Engineering Ltd.**Client PO: **19-479-154**

Report Date: 24-Sep-2015

Order Date: 18-Sep-2015

Project Description: **19-479-154****Analysis Summary Table**

Analysis	Method Reference/Description	Extraction Date	Analysis Date
Anions	EPA 300.1 - IC, water extraction	22-Sep-15	22-Sep-15
Conductivity	MOE E3138 - probe @25 °C, water ext	24-Sep-15	24-Sep-15
pH	EPA 150.1 - pH probe @ 25 °C, CaCl buffered ext.	21-Sep-15	21-Sep-15
Resistivity	EPA 120.1 - probe, water extraction	24-Sep-15	24-Sep-15
Solids, %	Gravimetric, calculation	21-Sep-15	21-Sep-15

**Certificate of Analysis**
**Client: Thurber Engineering Ltd.**
**Client PO: 19-479-154**
**Report Date: 24-Sep-2015**
**Order Date: 18-Sep-2015**
**Project Description: 19-479-154**

<b>Client ID:</b>	B01 SS1 (8"-2'2")	B02 SS3 (5"-7")	B04 SS5 (30"-32")	B05 SS2 (20"-22")
<b>Sample Date:</b>	01-Sep-15	01-Sep-15	10-Sep-15	10-Sep-15
<b>Sample ID:</b>	1538389-01	1538389-02	1538389-03	1538389-04
<b>MDL/Units</b>	Soil	Soil	Soil	Soil

**Physical Characteristics**

% Solids	0.1 % by Wt.	97.1	65.5	74.7	78.3
----------	--------------	------	------	------	------

**General Inorganics**

Conductivity	5 uS/cm	2640	1220	335	174
pH	0.05 pH Units	7.94	9.18	8.32	7.77
Resistivity	0.10 Ohm.m	3.79	8.23	29.9	57.4

**Anions**

Chloride	5 ug/g dry	33	246	9	8
Sulphate	5 ug/g dry	4830	559	119	8

<b>Client ID:</b>	D01 SS1 (0"-2")	D05 SS1 (37'6"-39'6")	M01 SS2 (2'6"-4'6")	M03 SS1 (6"-2'6")
<b>Sample Date:</b>	01-Sep-15	11-Sep-15	31-Aug-15	31-Aug-15
<b>Sample ID:</b>	1538389-05	1538389-06	1538389-07	1538389-08
<b>MDL/Units</b>	Soil	Soil	Soil	Soil

**Physical Characteristics**

% Solids	0.1 % by Wt.	96.8	79.1	97.0	96.2
----------	--------------	------	------	------	------

**General Inorganics**

Conductivity	5 uS/cm	194	134	287	1140
pH	0.05 pH Units	8.08	8.04	8.02	8.52
Resistivity	0.10 Ohm.m	51.6	74.5	34.8	8.73

**Anions**

Chloride	5 ug/g dry	9	5	60	100
Sulphate	5 ug/g dry	74	<5	66	1370

<b>Client ID:</b>	M05 SS2A (22'6"-23'6")	-	-	-
<b>Sample Date:</b>	14-Sep-15	-	-	-
<b>Sample ID:</b>	1538389-09	-	-	-
<b>MDL/Units</b>	Soil	-	-	-

**Physical Characteristics**

% Solids	0.1 % by Wt.	76.1	-	-	-
----------	--------------	------	---	---	---

**General Inorganics**

Conductivity	5 uS/cm	253	-	-	-
pH	0.05 pH Units	8.14	-	-	-
Resistivity	0.10 Ohm.m	39.6	-	-	-

**Anions**

Chloride	5 ug/g dry	8	-	-	-
Sulphate	5 ug/g dry	56	-	-	-

Certificate of Analysis

Client: **Thurber Engineering Ltd.**

Client PO: 19-479-154

Report Date: 24-Sep-2015

Order Date: 18-Sep-2015

Project Description: 19-479-154

**Method Quality Control: Blank**

Analyte	Result	Reporting Limit	Units	Source Result	%REC	%REC Limit	RPD	RPD Limit	Notes
<b>Anions</b>									
Chloride	ND	5	ug/g						
Sulphate	ND	5	ug/g						
<b>General Inorganics</b>									
Conductivity	ND	5	uS/cm						
Resistivity	ND	0.10	Ohm.m						

Certificate of Analysis

Client: **Thurber Engineering Ltd.**

Client PO: 19-479-154

Report Date: 24-Sep-2015

Order Date: 18-Sep-2015

Project Description: 19-479-154

**Method Quality Control: Duplicate**

Analyte	Result	Reporting Limit	Units	Source Result	%REC	%REC Limit	RPD	RPD Limit	Notes
<b>Anions</b>									
Chloride	2030	25	ug/g dry	2110			3.9	20	
Sulphate	98.1	5	ug/g dry	98.3			0.2	20	
<b>General Inorganics</b>									
Conductivity	3540	5	uS/cm	3620			2.2	6.2	
pH	6.89	0.05	pH Units	6.98			1.3	10	
Resistivity	2.82	0.10	Ohm.m	2.76			2.2	20	
<b>Physical Characteristics</b>									
% Solids	83.4	0.1	% by Wt.	83.5			0.1	25	

## Certificate of Analysis

Client: **Thurber Engineering Ltd.**

Client PO: 19-479-154

Report Date: 24-Sep-2015

Order Date: 18-Sep-2015

Project Description: 19-479-154

**Method Quality Control: Spike**

Analyte	Result	Reporting Limit	Units	Source Result	%REC	%REC Limit	RPD	RPD Limit	Notes
<b>Anions</b>									
Chloride	10.4		mg/L	ND	104	78-113			
Sulphate	19.9		mg/L	9.83	101	78-111			



Certificate of Analysis

Client: **Thurber Engineering Ltd.**

Client PO: **19-479-154**

Report Date: 24-Sep-2015

Order Date: 18-Sep-2015

**Project Description: 19-479-154**

**Qualifier Notes:**

None

**Sample Data Revisions**

None

**Work Order Revisions / Comments:**

None

**Other Report Notes:**

n/a: not applicable

ND: Not Detected

MDL: Method Detection Limit

Source Result: Data used as source for matrix and duplicate samples

%REC: Percent recovery.

RPD: Relative percent difference.

Soil results are reported on a dry weight basis when the units are denoted with 'dry'.

Where %Solids is reported, moisture loss includes the loss of volatile hydrocarbons.

Client Name: <b>Thurber Engineering</b>	Project Reference: <b>19-479-154</b>	TAT: <input checked="" type="checkbox"/> Regular <input type="checkbox"/> 3 Day
Contact Name: <b>Chris Murray</b>	Quote #	<input type="checkbox"/> 2 Day <input type="checkbox"/> 1 Day
Address: <b>Suite 104, 2460 Lancaster Road Ottawa, ON, K1B 4S5</b>	PO # <b>19-479-154</b>	Date Required: _____
Telephone: <b>613-818-7805</b>	Email Address: <b>CMurray@thurber.ca</b>	

Criteria: ☐ O. Reg. 153 (As Amended) Table ☐ RSC Filing ☐ O. Reg. 558/00 ☐ PWQO ☐ CCME ☐ SUB (Storm) ☐ SUB (Sanitary) Municipality: \_\_\_\_\_ ☐ Other: \_\_\_\_\_

Matrix Type: S (Soil/Sed.) GW (Ground Water) SW (Surface Water) SS (Storm/Sanitary Sewer) P (Paint) A (Air) O (Other)

### Required Analyses

Parcel Order Number:		Matrix	Air Volume	# of Containers	Sample Taken		PHCs F1-F4+BTEX	VOCs	PAHs	Metals by ICP	Hg	CrVI	B (HWS)	Chlorides, Sulphate Resistivity, pH Conductivity						
Sample ID/Location Name					Date	Time														
1	B01 SS1 (8"- 2'2")			1	1/9/15		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2	B02 SS3 (5'- 7')			1	1/9/15		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3	B04 SS5 (30'- 32')			1	10/9/15		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
4	B05 SS2 (20'- 22')			1	10/9/15		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
5	D01 SS1 (0'- 2')			1	1/9/15		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
6	D05 SS1 (37'6"- 39'6")			1	11/9/15		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
7	M01 SS2 (2'6"- 4'6")			1	31/8/15		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
8	M03 SS1 (6"- 2'6")			1	31/8/15		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
9	M05 SS2A (22'6"- 23'6")			1	14/9/15		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
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Comments:	Method of Delivery: <b>Walkin</b>
-----------	-----------------------------------

Relinquished By (Sign): <b>Chris Murray</b>	Received by Driver/Depot:	Received at Lab: <b>D. Charebois</b>	Verified By: <b>D. Charebois</b>
Relinquished By (Print): <b>Chris Murray</b>	Date/Time:	Date/Time: <b>Sept 18/15 3:38</b>	Date/Time: <b>Sept 18/15 3:45</b>
Date/Time: <b>18/9/15 3:38 PM</b>	Temperature: _____ °C	Temperature: <b>24.3°C</b>	pH Verified <input checked="" type="checkbox"/> By <b>JVA</b>

**Appendix D**

**Site Photographs**

# **WOLFE ISLAND FERRY AND DOCKING IMPROVEMENTS COUNTY OF FRONTENAC**

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**Photo 1. Barrack Street Terminal Looking Eastward from Ontario Street.**



**Photo2. Barrack Street Terminal Looking Westward from End of Terminal.**

## **WOLFE ISLAND FERRY AND DOCKING IMPROVEMENTS COUNTY OF FRONTENAC**

---



**Photo 3. Dawson Point Terminal Looking Westward.**



**Photo 4. Marysville Terminal Looking Northward from Main Street.**



**WOLFE ISLAND FERRY AND DOCKING IMPROVEMENTS  
COUNTY OF FRONTENAC**

---



**Photo 5. Barge Drilling Adjacent to Barrack Terminal**



**Photo 6. Barge Setup, Supported with Spuds, Near Barrack Terminal**

**Appendix E**

**Geophysics GPR International Inc.**

**BEDROCK DEPTH MAPPING AT THE  
BARRACKS (KINGSTON), AND DAWSON  
POINT DOCKS FOR THE WOLFE ISLAND  
FERRY SERVICE**

Presented to:

**Thurber Engineering Ltd.**  
104 – 2460 Lancaster Road  
Ottawa, Ontario  
K1B 4S5

Presented by:

**GEOPHYSICS GPR INTERNATIONAL  
INC.**  
6741 Columbus Rd., Unit 14  
Mississauga (Ontario)  
L5T 2G9

**January 2016**

**T-15821**





**BEDROCK DEPTH MAPPING AT THE BARRACKS (KINGSTON), AND DAWSON POINT DOCKS  
FOR THE WOLFE ISLAND FERRY SERVICE**

Presented to:

**Thurber Engineering Ltd.**  
104-2460 Lancaster Road  
Ottawa, Ontario  
K1B 4S5

Presented by:

**GEOPHYSICS GPR INTERNATIONAL INC.**  
6741 Columbus Rd., Unit 14  
Mississauga (Ontario)  
L5T 2G9

**January 2016**

**T-15821**



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## **1. INTRODUCTION**

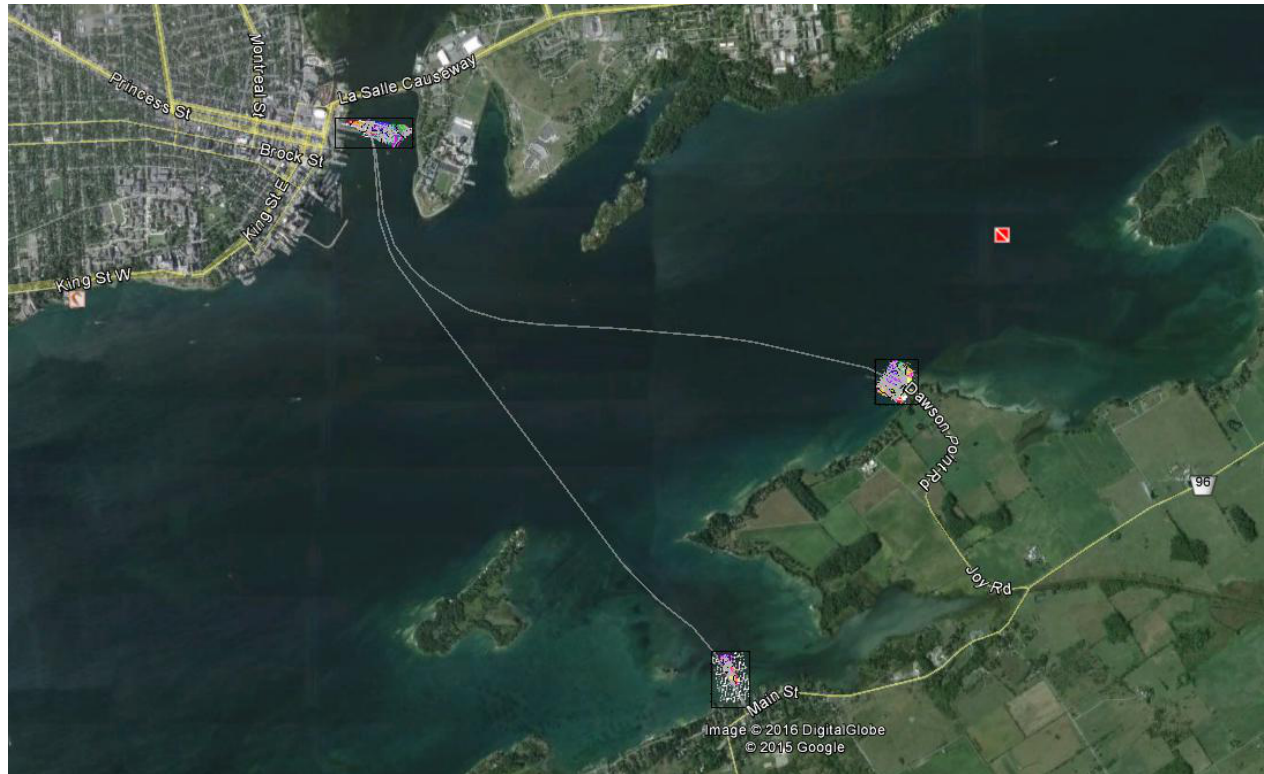
Geophysics GPR International Inc. was requested to map the bedrock depth contour around the docks that service the Wolfe Island Ferry service, namely the Barracks Dock in Kingston and the Dawson Point Dock on Wolfe Island.

Two seismic methods were proposed that will be described in terms of devices and methodology. These surveys were undertaken from November 10<sup>th</sup> to 23<sup>rd</sup>, 2015.

## **2. SITE LOCATION**

The surveys took place within a block close to the existing docks. The general locations of the docks are shown in Figure 1. The ferry routes are shown between the docks in Kingston, Ontario.





**Figure 1: General locations of the investigated sites**

### 3. **SCOPE OF WORK**

The seismic surveys aimed to determine the depth and topography of the bedrock beneath the lake beds as a component of future engineering infrastructure. Table 1 provides a breakdown of the block size, sub-bottom profiler survey line distances and refraction seismic survey distances.

Generally the sub-bottom profiler data was collected with a 20 m line spacing in one direction and a 75 m to 100 m line spacing in the other.

**Table 1: Marine Survey Coverage**

	<b>Barracks Dock</b>	<b>Dawson Point Dock</b>
Survey Block Dimensions (approx.)	420 m × 120 m	260 m × 200 m
Sub-bottom Profiler Line metres	2,700 m	3,400 m
Seismic Refraction Line metres	580 m	na

The initial geotechnical information available for each site suggested that the Dawson Point geology would pose a challenge to the sub-bottom profiler technique because the bottom was composed of sand and gravel rather than softer clays and silts. It was recommended that some seismic refraction be employed sparingly as it is more time consuming to collect but more certain to succeed.

### 4. **METHODOLOGY**

#### 4.1. **Line Positioning and Navigation**

A general survey block was provided by the client in the form of a polygon overlain on an earth image. This was used to extract coordinates for the boundary of the survey blocks. The boat operator utilizes HYPACK Hydrographic Survey Software to present graphically the real-time boat position and provide a track plot of where the boat should travel to get even coverage based upon the line spacing that is predesignated. In this case a 20 m line spacing was designated. Each of the respective drawings has a thin line which represents the actual boat track.

A “NovAtel” GPS positioning system was installed on the boat. This system uses dual frequency ionospheric corrected observations combined with pseudo-range with real time WAAS correction (precision 0.6 m-1.0 m) for horizontal positioning.

Water levels were obtained from the Fisheries and Oceans Canada website for the Kingston (Portsmouth) tidal station. The water level was approximately 0.3 m to 0.4 m above the chart datum during the survey period.

The geodetic system used was the North American Datum 1983 (NAD83). The



projection used was the Modified Transverse Mercator (MTM) Zone 9. For vertical positioning, the International Great Lakes Datum 1985 (IGLD85). All the positional data were projected to the Chart Datum.

Equipment and survey positioning sensors were measured from the vessel's common reference point (CRP), which corresponds to the GPS antenna positioning in this case. Offsets were carefully measured by tape and then entered into the navigation software.

#### **4.2. Bathymetry**

Geophysics GPR International Inc was not mandated to collect or present bathymetry although it could have been collected simultaneously as all the other geophysical data sets.

#### **4.3. sub-bottom Profiling (single channel seismic reflection)**

Sub-bottom profiling consists of emitting a seismic wave into the water and recording the echo generated by the reflection of the emitted wave on geological contacts of different impedance (different density). The survey was carried using the EDGETECH 3200 sub-bottom profiler system coupled with a SB-216S tow fish. The system utilized EDGETECH's Full Spectrum CHIRP technology to send and record a seismic sweep from 2 KHz to 10 kHz, which according to the manufacturer specifications enables imagery of the sub-bottom structures with a high resolution to a depth of up to 80 m in clays and up to 6 m in sands. The 3200 system's vertical resolution is 6-10 cm. Data were collected with the instrument range set to a window of 0 to 50 m or 0 to 100 ms.

During data acquisition, the vessel speed was kept between 2 and 4 knots, while the tow fish was kept 2 metres beneath the surface. The high resolution imagery of the sub structure was recorded in an EdgeTech's proprietary JSF format. The tow fish beam width is 17°. Figure 2 is a graphic representation of the path of a single channel reflection pulse with the exception that the source and receiver are contained within the same device. A photo of the instrument can be found in Appendix C.

Appendix A contains the spec sheet for the device.



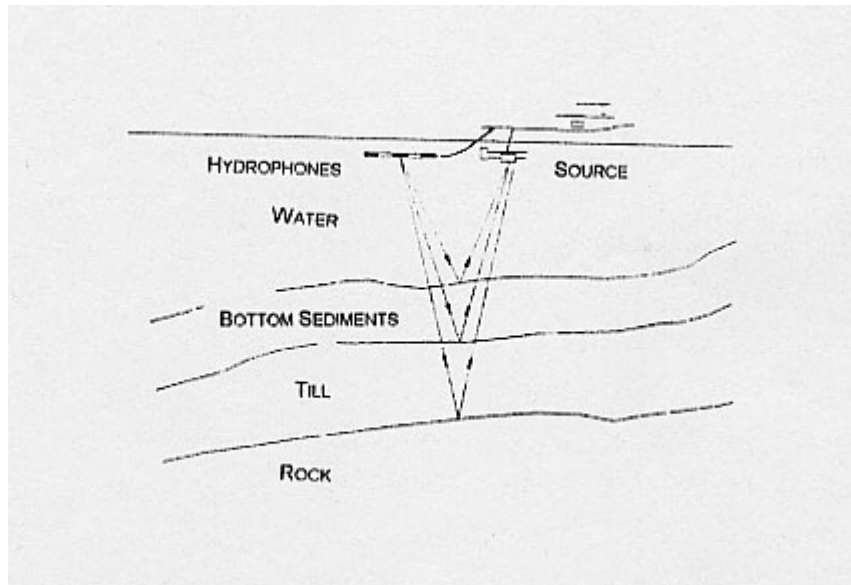


Figure 2: Graphic Representation of a single channel reflection

#### 4.4. Seismic Refraction Profiling

##### **Basic Theory**

The seismic refraction method relies on measuring the transit time of the wave that takes the shortest time to travel from the shot-point to each geophone. The fastest seismic waves are the compressional (P) or acoustic waves, where displaced particles oscillate in the direction of wave propagation. The energy that follows this first arrival, such as reflected waves and transverse (S) waves, is not considered under routine seismic refraction interpretation. Figure 3 illustrates the basic operating principle for refraction surveys on land. The same principle was used in this case whereby both ends of the hydrophone cable were anchored to the lake bottom so that the receivers stayed stationary. A second boat was used to do the seismic pulses.

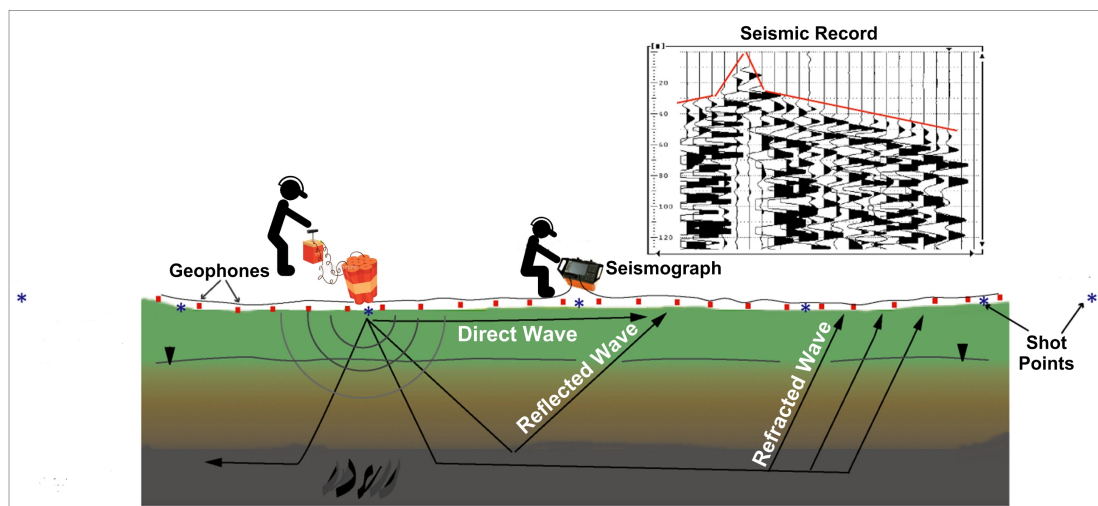


FIGURE 3: Seismic refraction basic field operating set-up



### **Seismic Source**

One advantage to working on water, is that a smaller seismic source can be used than would be required for a land survey. The source is a device called an "air gun". It operates with a compressed air tank. It has a small 4 cubic inch chamber that releases the air into the water instantly.

The entire project required one large compressed gas bottle.

### **Survey Design**

A seismic spread typically consists of 24 vibration monitoring devices (hydrophones) connected in line (spread) to a seismograph (ABEM Terraloc MK8 V.2) by one 24 connector cable. Seismic pulses (shots) are then generated at various locations with respect to the spread using the airgun in a separate small boat. The seismic survey generally used a geophone spacing of 7.5 m. Typically, five shots were executed: one shot at the centre of the profile, two shots at the ends and two far shots on either external side of the spread to provide the true velocity of the rock surface.

### **Quality Control**

Throughout the surveys, a procedure for quality control including field-work and interpretation was followed. The purpose of implementing the following measures is to ensure the acquisition of high quality seismic refraction data:

- The first arrival times on each seismic record must be as clean and precise as possible. The quality of the records is increased if there are multiple air gun shots. In this case the hydrophones are already within water so there is no concern about contact with the surrounding medium;
- No more than two traces should be absent (except if seismic cable are damaged, and without possible repair without delaying the survey works);
- No end traces (geophone G1, G2, G23, G24), which are used for the time-distance curve closure time should be absent;
- Closure times should be within  $\pm 2$  ms.

### **Interpretation Method and Accuracy of Results**

Interpretation of the seismic data was done using the Hawkins method. The Hawkins method (from the family of the "Common Reciprocal Method") allows the computation of rock depth and rock mechanical quality for every geophone. It is based on the closure times of the inner shots. It allows the calculation of the true velocities of the upper portion of the bedrock, using the apparent seismic velocities, with the information provided by the outer shots. A description of the method can also be found in the report *Seismic Refraction Exploration for Engineering Site Investigations* by B.B. Redpath (1973).

The seismic refraction method typically allows the determination of the bedrock profile with a precision of 10% or better for depths greater than 10 m (soils, not including water) and a precision of 1 m for depths less than 10 m. The precision in the determination of





rock velocities is plus or minus 3%. The vertical contacts (lateral velocity change), usually associated with faults and deep valleys, are generally accurate to within 7.5 m in width; although, this is somewhat site specific.

The two most significant problem areas for refraction mapping are the “hidden” layer and the effect of velocity inversions.

A “hidden” layer or “blind zone” is a stratigraphic layer that is not possible to discern from the arrival time data due to insufficient velocity variation or thickness. The unknown presence of a hidden layer has the effect of making the interpreted bedrock depth too shallow. The presence of a “hidden” layer is typically revealed through borehole data and calculations can be made to compensate for the presence of such a layer.

Velocity inversions occur when the velocity does not increase with depth. The velocity inversion can result from the presence of a low or high velocity layer. Refractions from low-velocity layers cannot be determined from the arrival time data. The unknown presence of a low velocity layer has the effect of making the interpreted depths deeper than actual depths. At this particular site there was no evidence of velocity inversions.

Appendix B contains a much-expanded version of the technical principals of the method.

## 5.0 **RESULTS**

The sub-bottom profiler had mixed results. Where there was signal penetration the images are quite clear but there seemed to be areas where the signal penetration seemed to be stifled very close to the lake bottom. There are two principal reasons for lack of signal penetration; hard sediments at surface and/or gas in the sediments.

1) Hard sediments will reflect too much signal from the lake bottom so there is very little left to penetrate to lower layers. When the bottom sediments are softer and the sediments firm up gradually, the seismic pulse will progress and small portions of the pulse will reflect back to surface. If the bottom is rock then almost all the signal will reflect.

2) Gaseous sediments will disperse signal in all directions so it does not pass through or reflect but is just absorbed into the sediments. Gaseous sediments can be natural or contaminant related. Natural gas content most often occurs in the sediments of quiet/stagnant water bodies due to the decay of organic material. Contaminants, even small quantities can occur if there are hydrocarbons near the lake bottom.

Figure 4 is an example of a sub-bottom section, which shows how signal disappears and on either side of the 'dead' zones is a clear image of the top of rock.



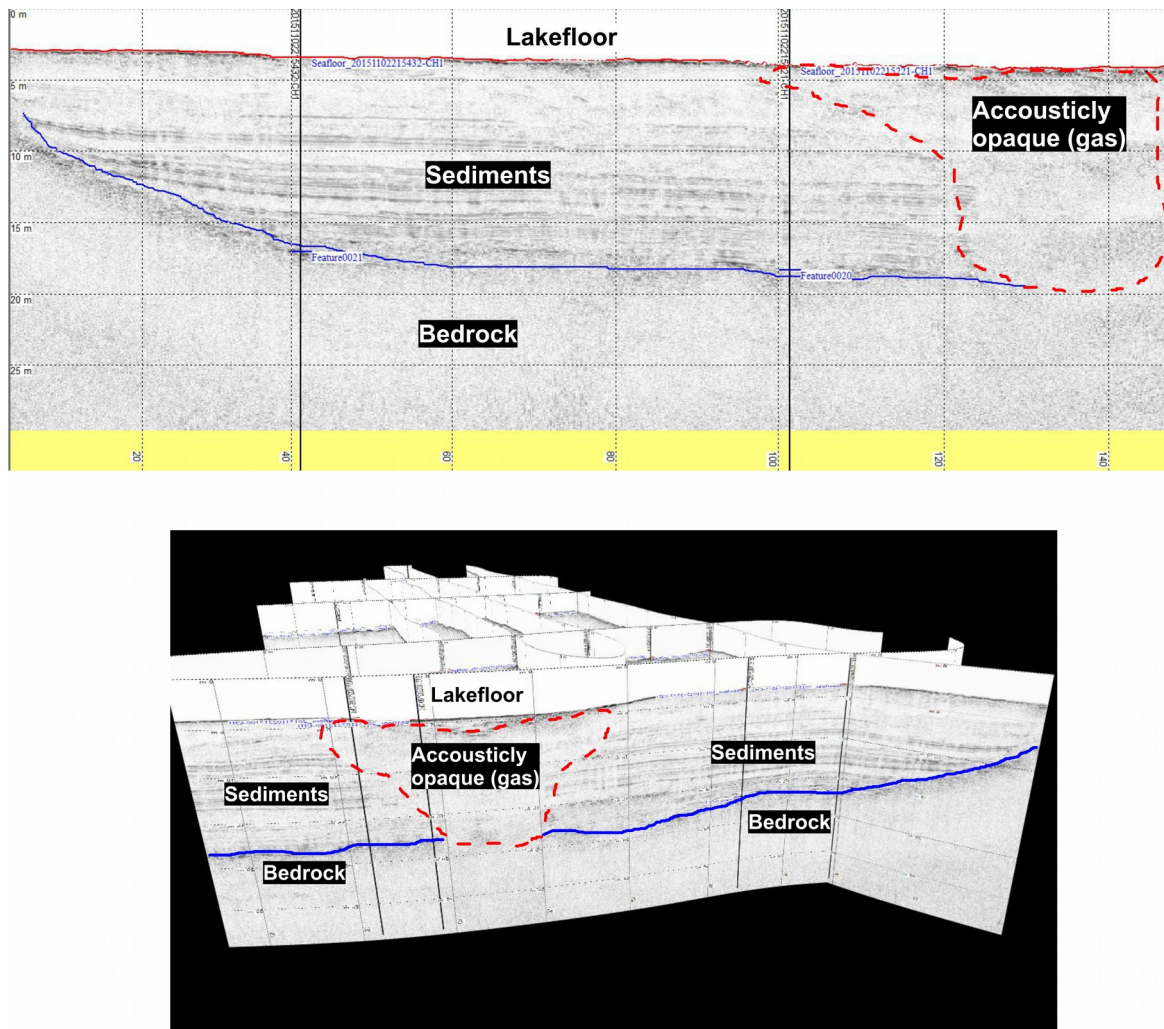


Figure 4: Example sub-bottom profiler data.

### Barracks Dock

There were six sub-bottom profiles collected parallel with the Kingston dock (20 m apart) and three perpendicular sub-bottom profiles for a total of 2,700 m of data.

While in the field observing the raw sub-bottom data it was determined that there were deficiencies in the sub-bottom profiler data therefore it was deemed that some supplementary data were needed to define the reflectors and map the deepest rock areas in the middle of the channel. As a result 580 m of seismic refraction data were collected in the form of five individual spreads.

It required 2.5 days to collect the refraction data because the technique required fixed spreads (anchoring the receivers in a fixed position much like on land). The alternative to fixed spreads is a towed array however this would not have been easily done given the very limited space a boat could move with a straight row of hydrophones over 100 metres long. The array of hydrophones would have been too bent which would have compromised the accuracy of the depth calculation.



The colour contoured data set contained in Drawing T-15821\_A1 was produced with the combined data from both methods.

The deepest rock depths are calculated to be over 27 metres beneath chart datum for Kingston Harbour. The boreholes were close to shore but generally agreed with the rock depths from the geophysical data.

#### Dawson Point

There were twelve profiles perpendicular to the shore (20 m apart) and three parallel with the shore collected with the sub-bottom profiler for a total of 3,400 m of data.

It was initial thought, based upon some very old geotechnical data that the lake bottom material would be too hard (sands are gravels) for the sub-bottom profiler to be effective. However, roughly half the data proved quite adequate for mapping down to bedrock.

The colour contoured data set contained in Drawing T-15821\_A2 was produced with sub-bottom profiler data only.

The deepest rock depths are calculated to be over 17 metres beneath chart datum.

The four boreholes were scattered within 100 m of the dock. D05 was in complete agreement. D04 disagrees with the nearest contour by over 2 m but the contours are quite steep so there could be a combination of geophysical data smoothing and error margin in the position of the borehole which would be in agreement if it were 5 m to the east. Boreholes D02 and D03 report a rock depth roughly 3.5 m deeper than the contours but the contours are interpolated and the nearest geophysical data is 10 to 20 m away.



## 6. **CONCLUSION**

On October 2015, Thurber Engineering mandated Geophysics GPR International Inc. to carry out seismic surveys around three docks that service the Wolfe Island Ferry service in Kingston, Ontario.

The Barracks Dock (Kingston) survey consists of 3,280 m of combined sub-bottom profiling and seismic refraction data. The contoured data set can be found in Drawing T15821\_A1.

The Dawson Point Dock (Wolfe Island) consists of 3,400 m of sub-bottom profiling data only. The contoured data set can be found in Drawing T15821\_A2.

The sub-bottom data has been interpreted by Nicolas Beaulieu. The refraction seismic data was interpreted by Micheline Poulin. The report has been written by Milan Situm, P.Geo.

---

Milan Situm P.Geo.  
Manager



## **APPENDIX A**

### **Edgetech sub-bottom Profiler 216S**







# 3100

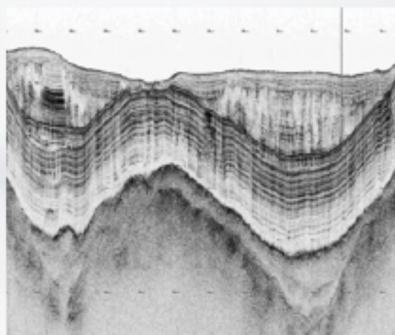
## PORTABLE SUB-BOTTOM PROFILING SYSTEM

### FEATURES

- Portable
- Low power requirement (runs on AC or DC)
- Choice of towfish depending on the application
- Pole mount option for shallow water surveys
- Easy to setup and operate

### APPLICATIONS

- Geological Surveys
- Geohazard Surveys
- Buried Object Location
- Mining/Dredging Surveys
- Bridge/Shoreline Scour Surveys
- Pipeline and Cable Location



The 3100 is EdgeTech's portable version of their highly successful sub-bottom profiler product line. The system utilizes EdgeTech's Full Spectrum CHIRP technology which provides higher resolution imagery of the sub-bottom structure and greater penetration.

The 3100 is ideally suited for use in rivers, lakes, ponds and shallow water ocean applications up to 300m max depth. The system was designed for customers that require a portable system that can be used from smaller boats while not wanting to sacrifice image quality.

A 3100 system comes with a choice of two towfish; either the SB-424 or SB-216S. These towfish operate at different frequency ranges and selection between the two depends on the type of application. The 424 operates at 4-24 kHz and will provide slightly higher resolution but less penetration. The 216S operates at 2-16 kHz and provides slightly less resolution but greater penetration. Along with a towfish, the 3100 system comes with a portable splash-proof topside processor with laptop computer running EdgeTech's DISCOVER software for display of the sonar data. The system comes standard with a 35m tow cable with customer-specified lengths also available.

For more information please visit [EdgeTech.com](http://EdgeTech.com)

[info@EdgeTech.com](mailto:info@EdgeTech.com) | USA 1.508.291.0057





# 3100

## PORTABLE SUB-BOTTOM PROFILING SYSTEM

### KEY SPECIFICATIONS

TOWFISH	SB- 216S	SB- 424
Frequency Range	2-16 kHz	4-24 kHz
Vertical Resolution (depends on pulse selected)	6-10 cm	4-8 cm
Penetration		
In coarse calcareous sand	6m	2m
In clay	80m	40m
Length	105 cm (41")	77 cm (30")
Width	67 cm (26")	50 cm (20")
Height	40 cm (16")	34 cm (13")
Weight In Air	76 kg (167 lbs.)	45 kg (100 lbs.)
Weight In Water	32 kg (70 lbs.)	18 kg (40 lbs.)
Max Depth Rating of Towfish	300 meters	
TOPSIDE PROCESSOR		
Hardware	Rugged, portable splashproof enclosure	
Operating System	Windows 7	
Display	Splashproof semi-rugged laptop	
Archive	DVD-R/W	
File Format	JSF, SEG-Y & XTF	
I/O	Ethernet	



SB-216S TOWFISH



SB-424 TOWFISH



## **APPENDIX B**

### **Seismic Refraction Method**

## THE SEISMIC REFRACTION METHOD

The seismic refraction survey is used to infer subsurface conditions on the basis of contrasting seismic wave velocities. The primary goal of the seismic survey is to rapidly and efficiently obtain subsurface information, thereby reducing direct investment costs, such as drilling. Geological information typically obtained from a well-planned and executed seismic refraction survey will include: depth and shape of bedrock surface, nature and competency of bedrock, such as degree of fracturing and alteration, whether it is faulted or sheared, nature of overburden and depth to the water table. Modern portable equipment makes the method accessible to remote and rough regions. A review of the seismic refraction theory, field methods and interpretational procedures can be found in Dobrin (1976) and Telford et al (1990).

### **INSTRUMENTATION**

The instrumentation involved in a seismic refraction survey consists of an energy source to generate seismic waves (typically explosives), a line of geophones to detect the seismic energy and a seismograph which is essentially a highly accurate stopwatch. By measuring the arrival times of the first seismic waves at various distances from the energy source, or shotpoints, depths to interfaces and seismic velocities can be determined. Seismographs are usually 12 or 24-channel, in they can simultaneously record the vibrations at 12 or 24 geophones. The record of these vibrations is a seismogram. Digital seismographs (e.g. ABEM Terraloc MK6-v2, EG&G SMARTSEIS S-24) acquire data with a built-in computer. The energy source must be coupled to the seismograph so that the instant of detonation or impact can be recorded. A recording time step of 50  $\mu$ s was used to permit very accurate estimates of arrival times.

### **FUNDAMENTAL PRINCIPLES**

The seismic refraction method relies on measuring the transit time of the wave that takes the shortest time to travel from the shotpoint to each geophone. The fastest seismic waves are the compressional (P) or acoustic waves, where displaced particles oscillate in the direction of wave propagation. The energy that follows this first arrival, such as reflected waves or transverse (S) waves, is not considered under routine seismic refraction interpretation.

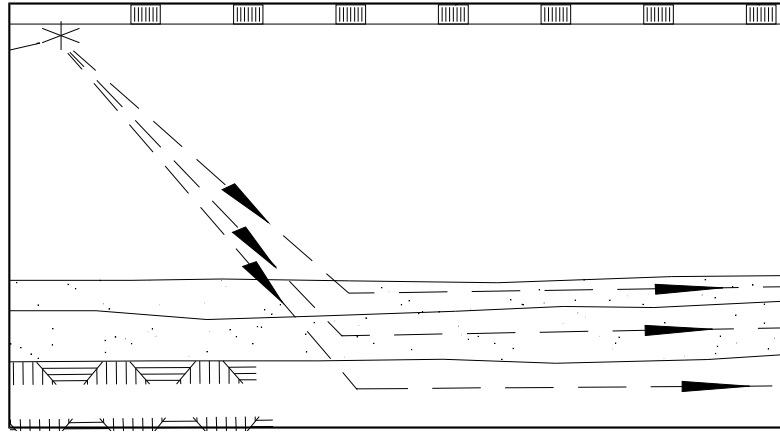
Figure B-1 shows a simple geological structure, where a layer with a velocity of  $V_1$  overlies a second layer with a higher velocity,  $V_2$ . At one end of the spread, a shotpoint is detonated and the vibrations at each geophone are recorded. Seismic waves will travel via the direct path from the source to each of the geophones. Waves may also be refracted at some critical angle along the interface and travel at the higher velocity  $V_2$ . Energy is continually leaked back to the surface as it travels along the interface. A time-distance graph may be constructed, plotting the first arrival transit times as a function of position along the seismic line.



The first arrival at the closest geophones is the direct wave. However, at the critical or crossover distance ( $X_c$ ) the refracted wave which travels along the higher velocity layer overtakes the direct arrival. The inverse slope of a straight line segment of the time-distance curve is equal to the velocity in that layer. The crossover distance is directly proportional to the depth of the interface.

## **INTERPRETATION**

The simplest methods of interpretation are illustrated in figure B-1. Having determined the velocity of compressional waves through each layer, one may calculate the depths according to crossover distance or the intercept time formulas. The case of a horizontal interface, illustrated in figure B-1, becomes slightly more complicated if the planar interface is dipping. The general case of an irregular interface can be handled by more complex interpretational schemes, including various delay-time methods, the reciprocal and generalized reciprocal methods and ray tracing. One method may be better suited than another to a particular geological environment.



**FIGURE B-1**

PRINCIPLES OF SEISMIC REFRACTION

## **SEISMIC VELOCITIES VERSUS GEOLOGICAL MATERIALS**

The seismic refraction differentiates the overburden layers from the bedrock. In general, a layer of overburden material, with associated velocities of 300 - 500 m/sec is seen followed by a second layer under the water table with a velocity corresponding to an impermeable material 1400 - 1600 m/sec.

In some cases, certain limitations may arise, such as differentiation between two different layers having approximately the same velocity. As an example:

- a contact within sand under the water table
- a contact between till and sand, under the water table (both at 1500 m/sec)

As a guideline, the following figure shows a classification of geological material by seismic velocities.

### **Seismic velocities in the overburden**

Variations in the overburden layer can vary over a wide range as a function of its age, its depth of burial, differences in the granular state, degree of porosity, and whether water or air fills the voids (Telford 1976).

### **Seismic velocities in bedrock**

A significant variation in seismic velocities for a particular rock mass may be caused by several factors. These factors include a change in the rock quality when the rock is weathered, sheared, faulted or fractured, a radical topographic change or a rock type change. Other features, such as the distribution of rock types, mineral content, the bonding of the minerals, joints opening, rock pressure, saturation and chemical composition of the minerals may all affect the velocities to some degree, explaining the differences of velocities in sound rock.

### **Rock type or change in bedrock quality**

A rock type change will generally result in a different velocity because of differences in crystallization, mineralization or other physiochemical properties.

In the same way, a change in rock quality such as the presence of large open joints or several small open joints will undoubtedly bring about a velocity change for the same type of rock. Features such as a weathered, sheared, fractured or faulted rock will cause a drop in the velocity.

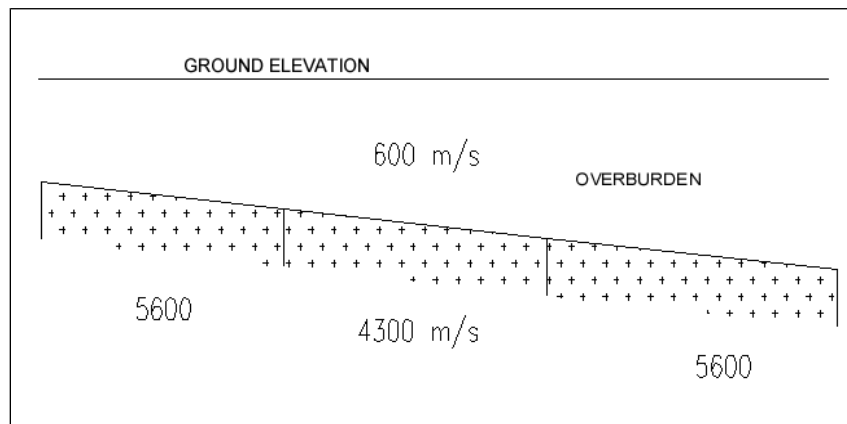
### **Faults, deep valleys**

A radical topographic change in the bedrock profile may also cause a drop in the measured velocity. The cause of this is geometric and the use of specialized interpretative methods permits an estimation of the true depth of bedrock. A fault will also cause a similar velocity anomaly in the bedrock.

These anomalies may be due to either a deep valley or a cavity like feature (which may be water or sediment filled), or a physical feature in the rock such as a fault or open joints. Since the analysis of the time distance curve does not allow the differentiation of the anomalies, the two possible interpretations are presented on the drawings. In such a case, borehole data gives the best information to assess the true nature of the anomaly.

### *CAUSES OF LATERAL VELOCITY ANOMALIES IN BEDROCK*

Velocity changes in rock may represent a change in rock quality, a radical topographic effect or a rock type change. We will discuss each possibility in turn using figure B-3 as a reference.

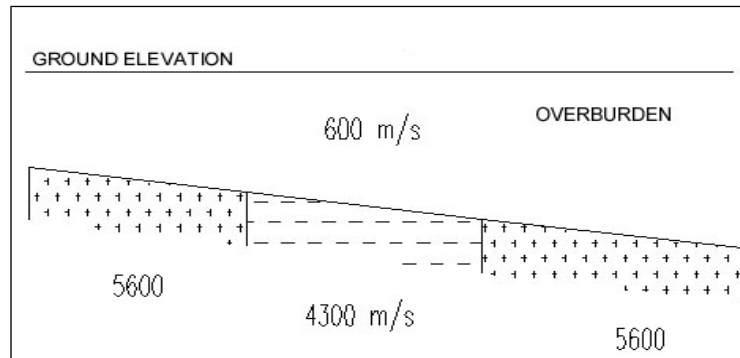


**Figure B-3**

In the above case, a survey was done using a geophone spacing of 7,5 metres. A zone whose velocity is 4 300 m/sec was measured between the two zones of sound bedrock with a seismic velocity of 5 600 m/sec.

### **Case 1 – Rock Type Change**

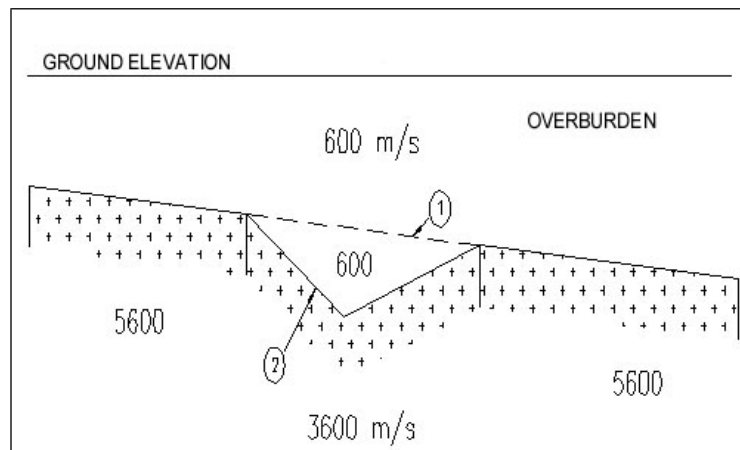
A rock type change will result in a velocity change. For example, a sandstone resting on a gneissic rock may bring about the case shown in figure B-4. In this case, the rock may be of good quality, however, the lower velocity represents a physiochemical difference.



**Figure B-4**

### **Case 2 – Topographic effects**

A radical topographic change in the bedrock profile, such as a fault with a vertical displacement or a buried valley may bring about a velocity change. The cause of this is geometric and the use of specialized interpretative methods will permit the determination of the true velocity, as seen in figure B-5.



- (1) Topography before correction
- (2) Topography after correction

**Figure B-5**

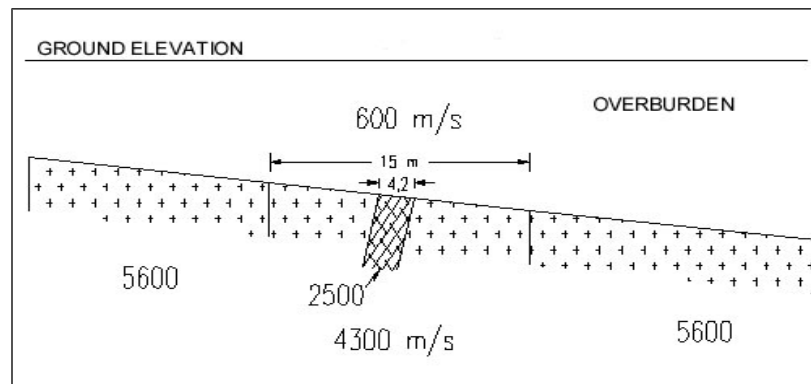


### **Case 3 – Rock quality change**

A change in rock quality will also bring about a velocity change as illustrated in the following cases:

a) Open joint

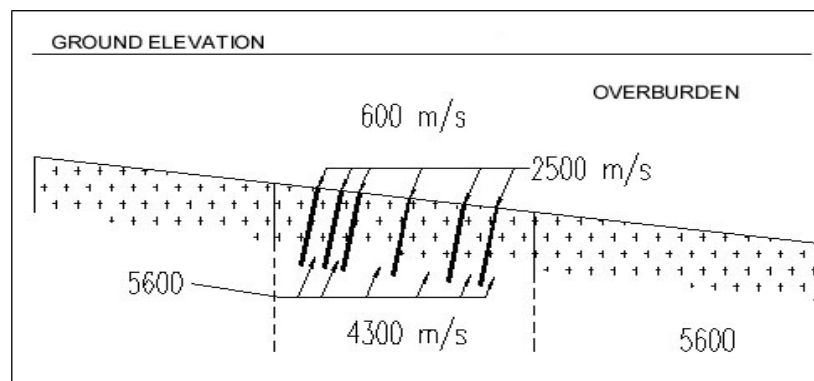
The presence of a large open joint will bring about a velocity change. Using a 7,5 metres geophone spacing, the zone may appear to be 15 metres large, (as shown). However, in reality, the joint is 4,7 metres large with a velocity of 2 500 m/sec (Figure B-6).



**Figure B-6**

b) Several small open joints

An important number (6) of small joints, 0,7 metres in width, having a velocity of 2 500 m/sec will cause the velocity to drop as seen in figure B-7.



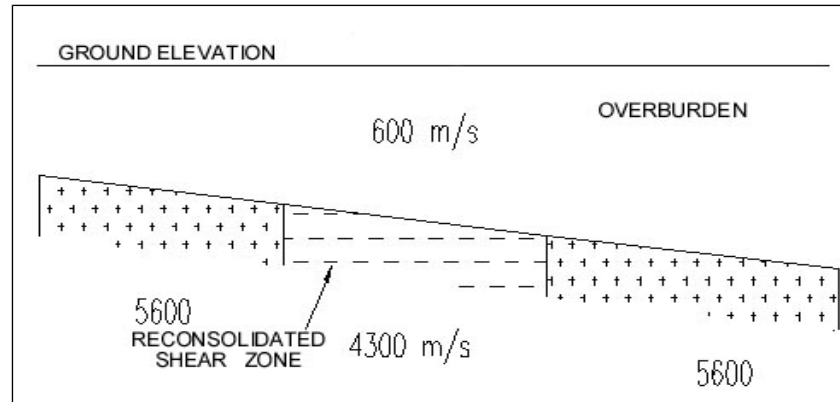
**Figure B-7**





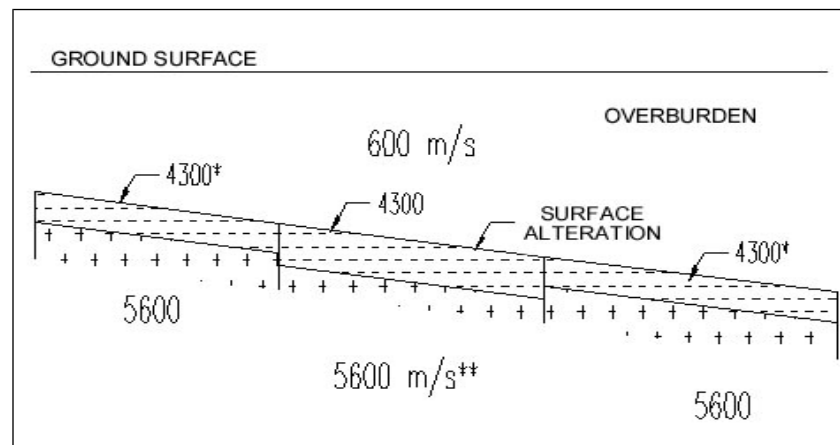
c) Healed Faults

A healed fault of a zone of filled fractures will also show the same aspect, figure B-8.



**Figure B-8**

**More important weathered zone**



**Figure B-9**

\* These rock weathered zones are not to be identified if too thin

\*\* The 5 600 m/s seismic velocity is not measured if the width of the zone is too small

## *DESCRIPTIVE CLASSIFICATION OF BEDROCK*

### **SEISMIC VELOCITIES WITH RQD VALUES**

Seismic velocities depend on a wide variety of parameters and it is always difficult to relate them to borehole logging. However, there is a way which involves measuring compressional wave velocities in the field and in the laboratory.

The field and laboratory velocities are different. The field velocity is measured on a large scale and depends on the bedrock type and its fracturing degree. The laboratory velocity is measured on a small core sample and depends more on the microscopic features of the bedrock. From these velocities, one can define the velocity index.

The classification of Coon and Merritt is based upon the velocity index property of in-situ rock which is a measure of the discontinuities in the rock mass. According to Coon and Merritt, the velocity index is defined as the square of the ratio of seismic field velocity to laboratory compressional wave velocities, measured on a core sample, representative of a sound rock. The field seismic velocities are normalized by the laboratory results in order to minimize the influence of lithology. Hence as the number of joints decreases, the ratio of the velocities will approach 1. This ratio is then squared to make the velocity index equivalent to the ratio of dynamic module.

The following table is extracted from a study by Coon and Merritt (ASTM STP 477) and illustrates the relationship of the velocity index versus the RQD values (Rock Quality Designation).

We must keep in mind that the seismic refraction usually measures the velocity of the bedrock as is shallow (0 - 100 metres in depth).

**TABLE B-1**

ENGINEERING CLASSIFICATION FOR IN SITU ROCK <sup>(1)</sup>			
RQD (%)	VELOCITY INDEX	DESCRIPTION	SEISMIC DESCRIPTION
0 - 25	0.00 - 0.20	Very poor	Low velocity
25 - 50	0.20 - 0.40	Poor	Low velocity
50 - 75	0.40 - 0.60	Fair	Intermediate
75 - 90	0.60 - 0.80	Good	Sound rock
90 - 100	0.80 - 1.00	Excellent	Sound rock

- (1) Taken and adapted from: Coon, R.F. and Merritt, A.H., **Predicting in-situ Modulus of Deformation using Rock Quality Indexes**, Determination of the in-situ modulus of deformation of rock, ASTM STP 477, American Society for testing and materials 1970, pp. 154-173.

It is important to note that the RQD can be affected by the drilling, whereas the velocity measurements are not. The relation between the RQD values and the seismic velocities have always been a concern of geologists and geophysicists. This empirical relation could, thus, be useful. The only additional data needed to compute the velocity index, would be the core laboratory seismic velocity.

Without laboratory calibration, we used one of the highest seismic velocity measured on both sites as reference (6100 m/s), which lead to :

for a geophysical (seismic) appreciation :

$$\begin{array}{lll} V_p \geq 4800 \text{ m/s} & \rightarrow & \text{Sound rock} \\ 3900 \leq V_p < 4800 \text{ m/s} & \rightarrow & \text{Intermediate} \\ V_p < 3900 \text{ m/s} & \rightarrow & \text{Low velocity} \end{array}$$

or, for an equivalent geotechnical classification:

$$\begin{array}{lll} V_p \geq 5550 \text{ m/s} & \rightarrow & \text{Excellent} \\ 4800 \leq V_p < 5549 \text{ m/s} & \rightarrow & \text{Good} \\ 3900 \leq V_p < 4799 \text{ m/s} & \rightarrow & \text{Fair} \\ 2800 \leq V_p < 3899 \text{ m/s} & \rightarrow & \text{Poor} \\ V_p < 2800 \text{ m/s} & \rightarrow & \text{Very poor} \end{array}$$

## **HIDDEN LAYER AND SEISMIC VELOCITY INVERSION**

For seismic refraction surveys for assistance to the geotechnical investigations, relatively simple geological models are considered. These basic models, used for the interpretation of the seismic data must respect some assumptions relating to the overburden laying on the rock:

- The different overburden layers are sub-parallel to the surface;
- These layers presents increasing seismic velocities with depth;
- The seismic velocities are considered constant enough over short lateral distances within the layers;
- The thickness of each layer should be sufficient to permit its detection.

When one or several of these hypotheses are transgressed importantly, some errors may be induced within the calculations results relatively to the thickness of the layers in cause. These errors are then due to the attribution of seismic wave delay time to a seismic erroneous mean velocity. This mean seismic velocity might be under-evaluated if a subjacent layer of a higher seismic velocity could not be detected and by the fact even sees itself neglected. This can occur when a thick layer of overburden covers one second thin layer. One speaks then about "**hidden layer**". The opposite case is also possible, where the average seismic speed of the layers of materials is overestimated being given the absence of critical refraction of the seismic wave necessary to detection of a subjacent layer. This phenomenon occurs when a layer of material presents a seismic velocity lower than that of the layer of material covering it. It is the case known under the name of "**velocity inversion**".

**The hidden layer** effect results with an under-estimation of the overburden thickness laying on the rock.

"The most important source of uncertainty, at the time of seismic calculation, comes from the grounds which one cannot detect. In the presence of three grounds, when the second is thin, it is possible that the waves refracted with the roof of the third marker arrive at the geophones before those which are refracted with the roof of the second " (p.24).<sup>1</sup>

The phenomenon of *hidden layer* is related to the limitation of the seismic refraction to detect a layer of material associated with a too weak seismic velocity contrast and/or with a too low thickness of the layer. The existence of the aforementioned "*hidden layer*" not being recognized, the time of course of the seismic wave in the *hidden layer* and the layer of material which is overlying of it is attributed to the only layer of material covering the hidden layer, faster seismically. The thickness of the overlying stratum to the hidden layer is then exaggerated, but remains lower than the thicknesses sum of the two layers joined together. Thus, the rock

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1

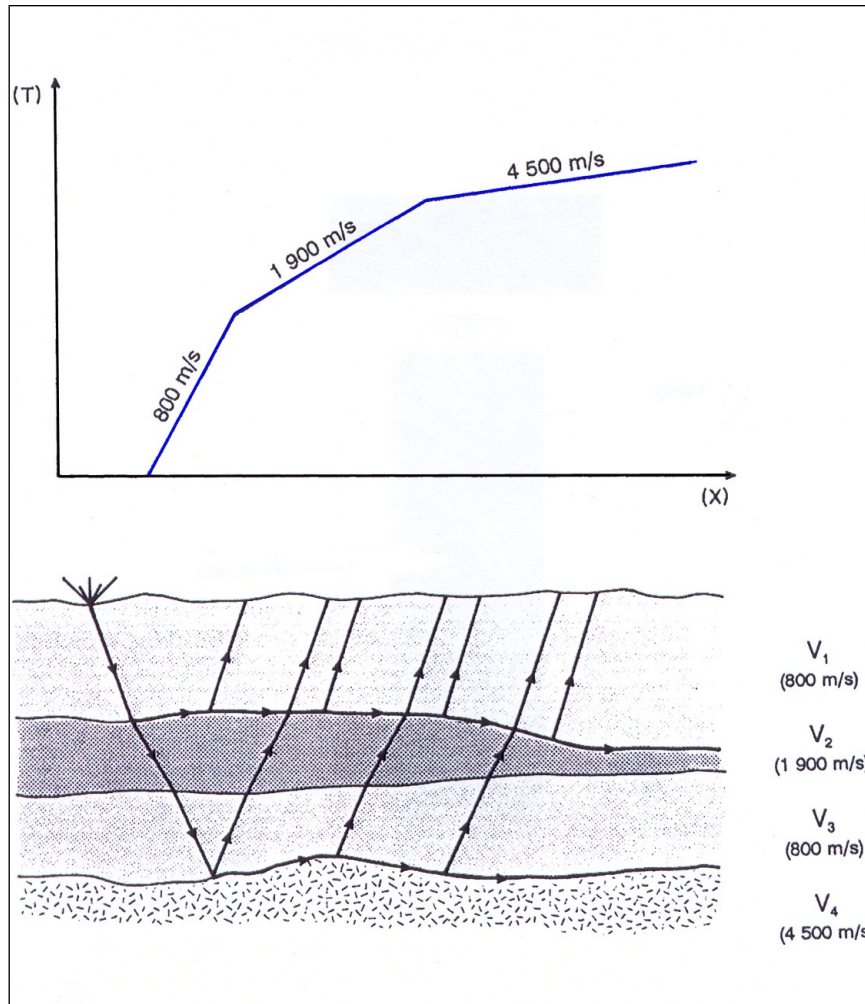
Denis-Jacques Dion  
« La méthode sismique réfraction appliquée au génie géologique, notions  
d'interprétation »  
DV-8506  
M.E.R.Q., 1986

substrate will appear less deep than it is really. The B-10 figure illustrates the evolution of an acoustic wave in a geological medium implying a *hidden layer*.

The phenomenon of *hidden layer* generally arises on banks of lakes or rivers where the thickness of the saturated movable deposits decreases gradually towards the firm ground, and also in the case of deposits strong thickness where the materials are increasing in density with depth.

**The seismic velocity inversion** produces an over-estimate thickness of a layer of material by neglecting the existence of a layer subjacent slower, which leads to an exaggeration real depth of the rock.

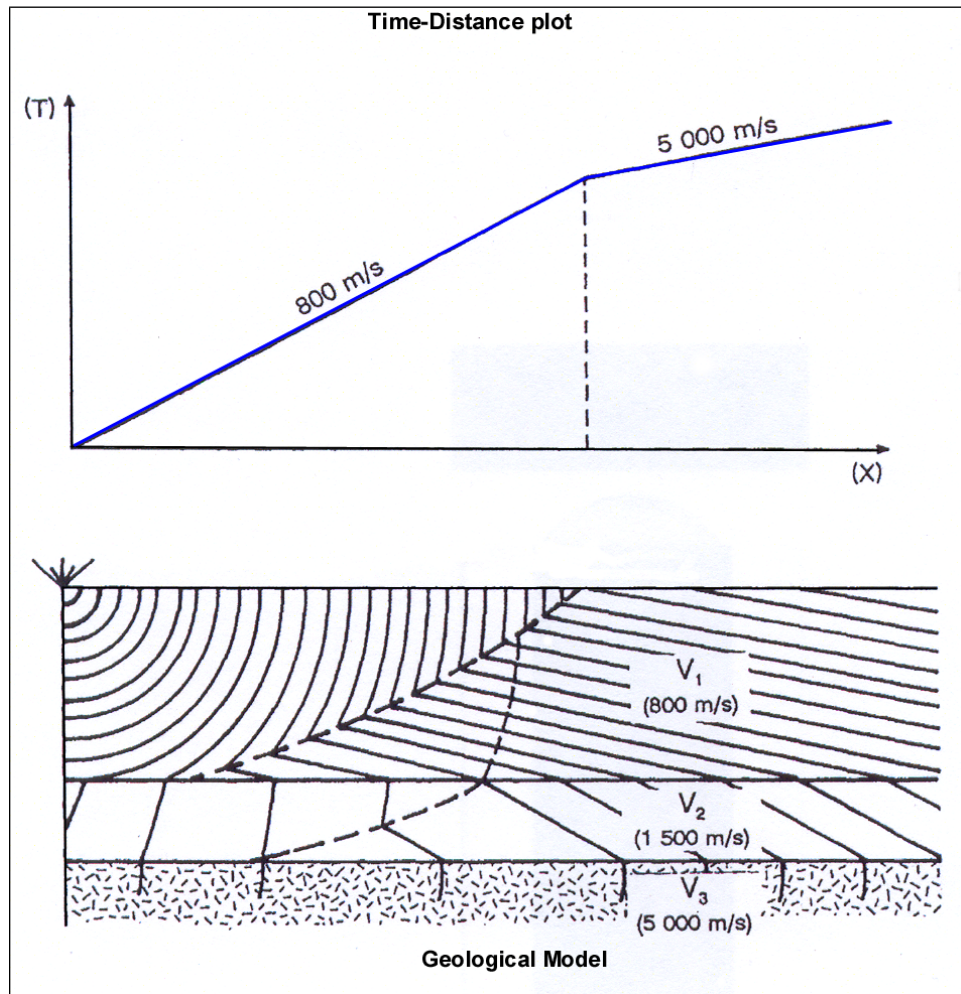
In seismic refraction, only the first arrivals of the acoustic waves are usually considered for calculations. These arrivals can come from direct waves (surfacing) or from refracted waves. These last ones are the product of the phenomenon of critical refraction obeying to the law of Snell-Descartes. There cannot however be critical refraction when a seismic wave passes from a material of seismic speed higher than the one of the layer of subjacent material. Thus, this seismically slower layer could not be detected even if the total time of the way of the seismic wave in were affected (figure B-11). The ignorance of the existence of this second inserted slow layer will carry the attribution of the time of course of the seismic wave of the fast layer and the slow layer subjacent with the only fast layer. The thickness calculated for the fast layer thus appears higher than the real total thickness of this layer and the subjacent slow layer, both will be joined together. There cannot however be critical refraction when a seismic wave passes from a material seismic velocity higher than that of the layer of subjacent material. The phenomenon of *velocity inversion* is rather rare in the cases of shallow seismic refraction. One meets it most of the time in tropical areas and Northern areas with permafrost and/or temporarily thick frozen upper part of overburden. The velocity inversion is most often associated the presence of a hardened soil horizon or a suspended ice lens (permafrost, intermittent permafrost).



1.

2. **FIGURE B-10**  
**Hidden layer**

An overburden *hidden layer* is said *hidden* when the refracted seismic waves from this layer arrive after those refracted from the roof of the subjacent material.



3. **FIGURE B-11**  
**Seismic velocity inversion**

The absence of critical refraction of the seismic wave with the roof of the layer "V3", preventing its detection on the Time-Distance plot.

The existence of a case of **hidden layer** or a case of seismic **velocity inversion** can be revealed by boreholes or by seismic reflection and can be seen specified by seismic surveys "up-hole". When these phenomena are identified, one can consider the geological condition of the investigated site for the seismic calculations.

The seismic profile is then calibrated compared to the results of drillings. This makes it possible to obtain an approximate topography of the rock but the precision for its depth can be seen reduced, particularly when the geological conditions are variable. In spite of the mathematical artifices, the calibration can not allow a complete seismic recognition of the stratigraphy since a layer of materials could not be detected.

The cases of *hidden layer* and seismic *velocity inversion* cause problems for calculations depth of the rock but do not affect the precision of the seismic velocity in the rock, which can be used to evaluate its quality.



## **APPENDIX B**

### **Survey Photos**



**Operating system with navigation**



Edgetech 216S towfish



**Boat Setup**





**Kingston**



**Richard Reid with support boat in background**



**Beniot Maille with air gun and Ferry**

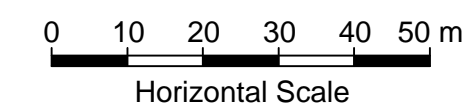
**APPENDIX C**

**Drawing T-15821\_A1 and T-15821\_A2**







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**BEDROCK DEPTH MAPPING AT MARYSVILLE  
DOCK FOR THE KINGSTON – WOLFE ISLAND  
FERRY SERVICE**

Presented to:

**Thurber Engineering Ltd.**  
104 – 2460 Lancaster Road  
Ottawa, Ontario  
K1B 4S5

Presented by:

**GEOPHYSICS GPR INTERNATIONAL  
INC.**  
6741 Columbus Rd., Unit 14  
Mississauga (Ontario)  
L5T 2G9

**June 2016**

**T-16898**



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## **1. INTRODUCTION**

Geophysics GPR International Inc. was requested to map the bedrock depth contour around the Marysville dock that service the Kingston – Wolfe Island Ferry.

Initially sub-bottom profiler survey was applied to map subsurface features. This survey was undertaken from November 10<sup>th</sup> to 23<sup>rd</sup>, 2015. The initial field review of the data was positive but that proved to be a premature interpretation. Only a small part of the data set was found adequate for mapping down to bedrock and seismic refraction method was proposed to solve the problem. The seismic refraction data were collected on May 11<sup>th</sup>, 2016.

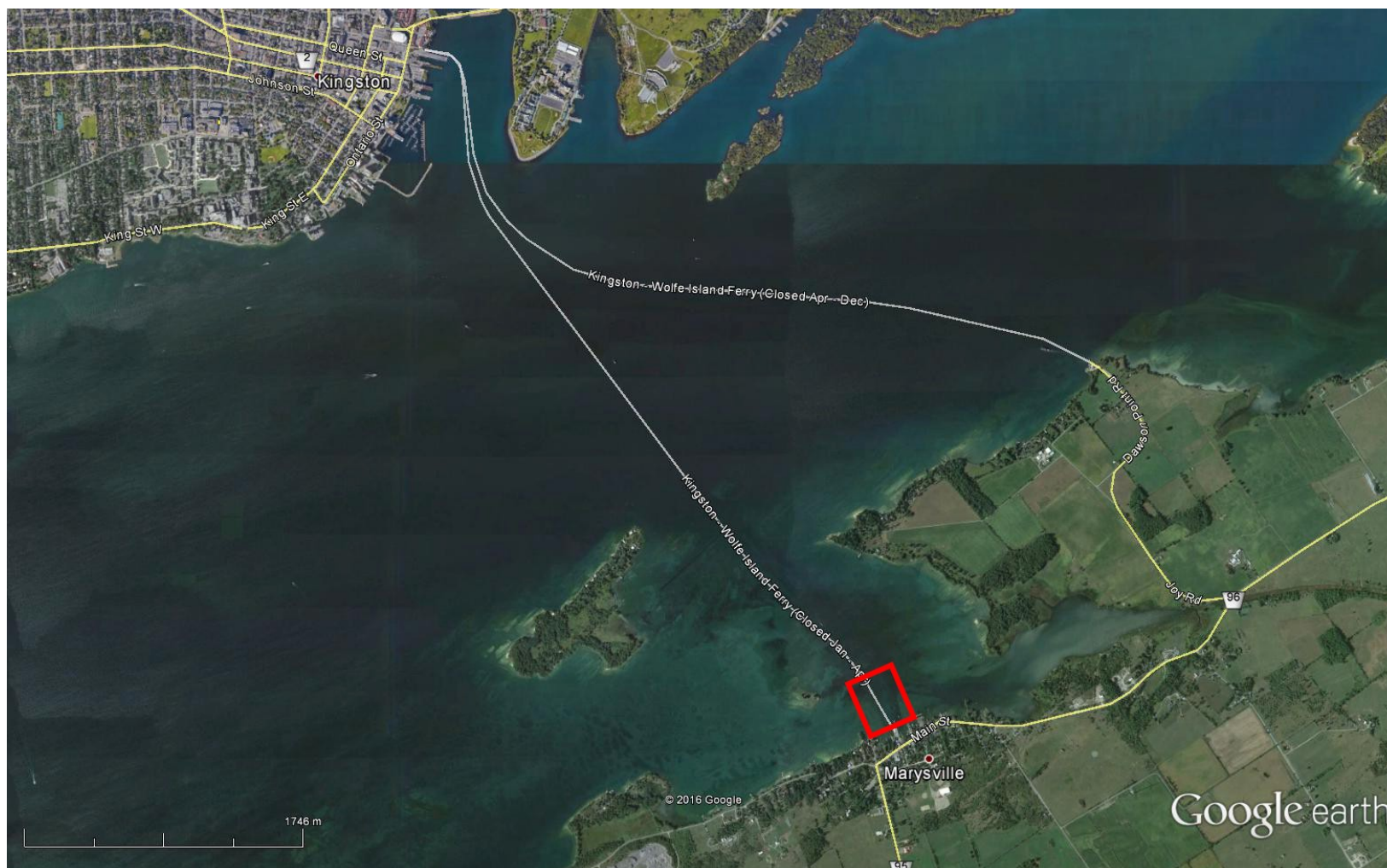
This report deals with the various aspects of the survey including field techniques, interpretation techniques, and finally an interpretation in the form of tabulated data and depth to bedrock contoured map.

## **2. SITE LOCATION**

The survey took place within a block close to the existing dock. The general location of the block is shown in Figure 1. The ferry routes are shown between the docks in Kingston, Ontario.







**Figure 1: General location of the investigated site**





Figure 2: Site map indicating approximate sub-bottom profiler lines locations





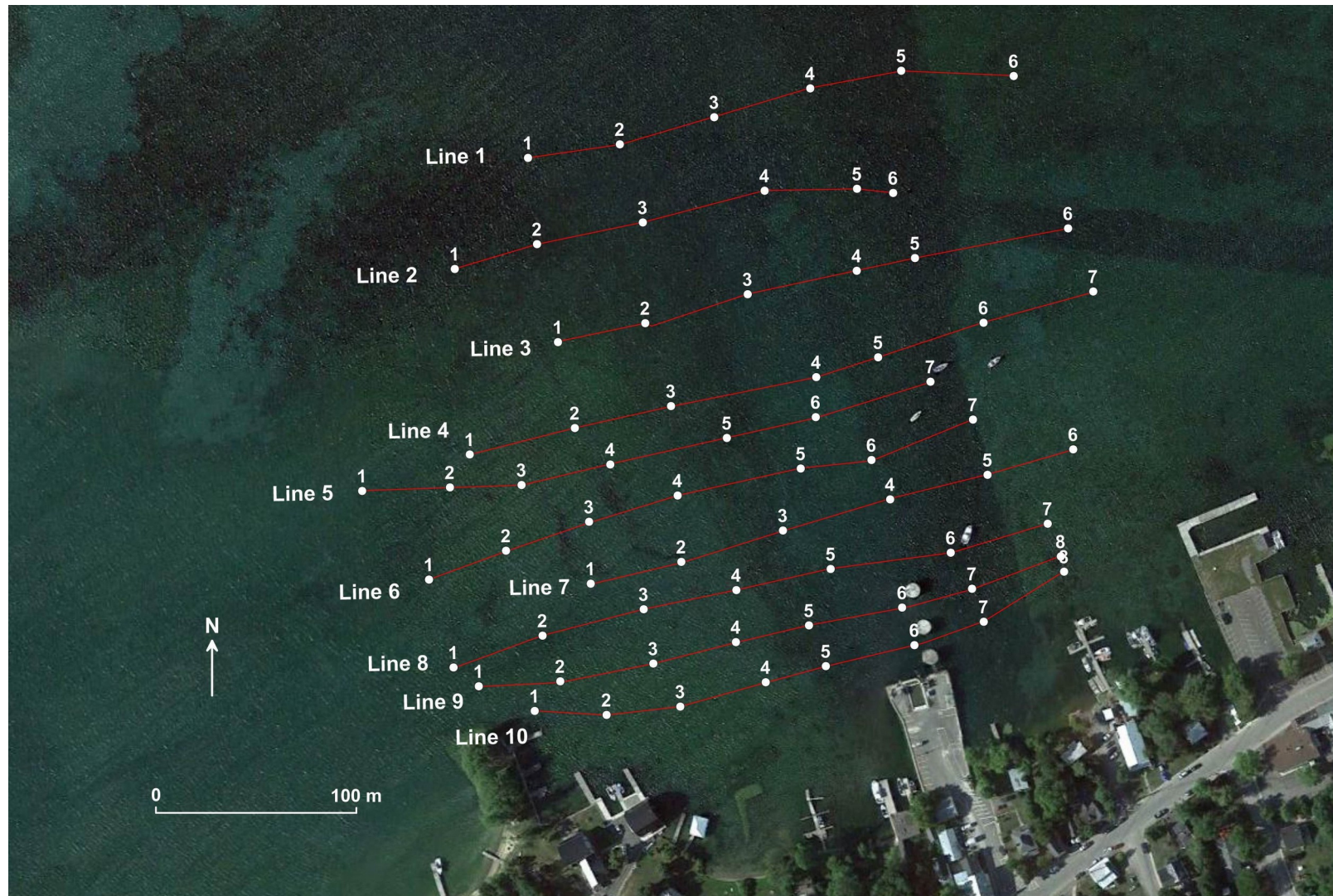


Figure 3: Site map indicating approximate refraction seismic lines locations



### 3. **SCOPE OF WORK**

The seismic survey aimed to determine the depth and topography of the bedrock beneath the lake bed as a component of future engineering infrastructure. The data were collected within a block with dimensions approximately 320 m × 280 m.

Generally the sub-bottom profiler data were collected with a 20 m line spacing in the direction perpendicular to the shore and a 90 m to 100 m line spacing in the other direction. A total of approximately 4800 meters of data were collected. The location of sub-bottom profiler lines is shown in Figure 2.

The review of the data proved that the site geology had posed a challenge to the sub-bottom profiler technique. As a result, only a portion of the data set in the north of the grid was interpreted. Interpreted lines which were used to produce a contoured map are marked in Figure 2.

Refraction seismic data were acquired along ten survey lines parallel to the shore line. At each survey line from 6 to 8 seismic records (soundings) were obtained, with a total of 68 soundings. The location of seismic survey lines is shown in Figure 3.

Line spacings used for the refraction survey were 20-25 m for lines between line 4 and line 10 (closer to the shore) and 40-50 m for lines between line 1 and line 4. A total of approximately 3000 meters of refraction seismic data were collected.

### 4. **METHODOLOGY**

#### 4.1. **Line Positioning and Navigation**

A general survey block was provided by the client in the form of a polygon overlain on an earth image. This was used to extract coordinates for the boundary of the survey blocks. The boat operator utilizes HYPACK Hydrographic Survey Software to present graphically the real-time boat position and provide a track plot of where the boat should travel to get even coverage based upon the line spacing that is predesignated.

A “NovAtel” GPS positioning system was installed on the boat. This system uses dual frequency ionospheric corrected observations combined with pseudo-range with real time WAAS correction (precision 0.6 m-1.0 m) for horizontal positioning.

Water levels were obtained from the Fisheries and Oceans Canada website for the Kingston (Portsmouth) tidal station. The water level was approximately 0.8 m to 0.9 m above the chart datum during the survey period.

The geodetic system used was the North American Datum 1983 (NAD83). The projection used was the Universal Transverse Mercator (UTM) Zone 18T. For vertical positioning, the International Great Lakes Datum 1985 (IGLD85). All the positional data were projected to the Chart Datum.

Equipment and survey positioning sensors were measured from the vessel's common reference point (CRP), which corresponds to the GPS antenna positioning in this case.



Offsets were carefully measured by tape and then entered into the navigation software.

The depth measurements are noted as depth from the chart datum.

All geophysical measurements were collected in SI units.

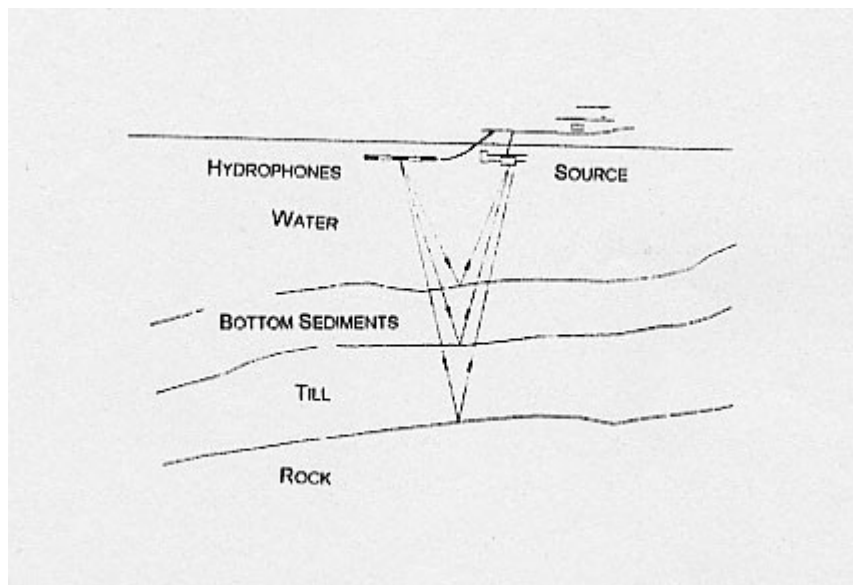
#### **4.2. Bathymetry**

Geophysics GPR International Inc was not mandated to collect or present bathymetry although it could have been collected simultaneously as all the other geophysical data sets.

#### **4.3. Sub-bottom Profiling (single channel seismic reflection)**

Sub-bottom profiling consists of emitting a seismic wave into the water and recording the echo generated by the reflection of the emitted wave on geological contacts of different impedance (different density). The survey was carried using the EdgeTech 3200 sub-bottom profiler system coupled with a SB-216S tow fish. The system utilized EdgeTech's Full Spectrum CHIRP technology to send and record a seismic sweep from 2 KHz to 10 kHz, which according to the manufacturer specifications enables imagery of the sub-bottom structures with a high resolution to a depth of up to 80 m in clays and up to 6 m in sands. The 3200 system's vertical resolution is 6-10 cm. Data were collected with the instrument range set to a window of 0 to 50 m or 0 to 100 ms.

During data acquisition, the vessel speed was kept between 2 and 4 knots, while the tow fish was kept 2 metres beneath the surface. The high resolution imagery of the sub structure was recorded in an EdgeTech's proprietary JSF format. The tow fish beam width is 17°. Figure 4 is a graphic representation of the path of a single channel reflection pulse with the exception that the source and receiver are contained within the same device.



**Figure 4: Graphic representation of a single channel reflection**

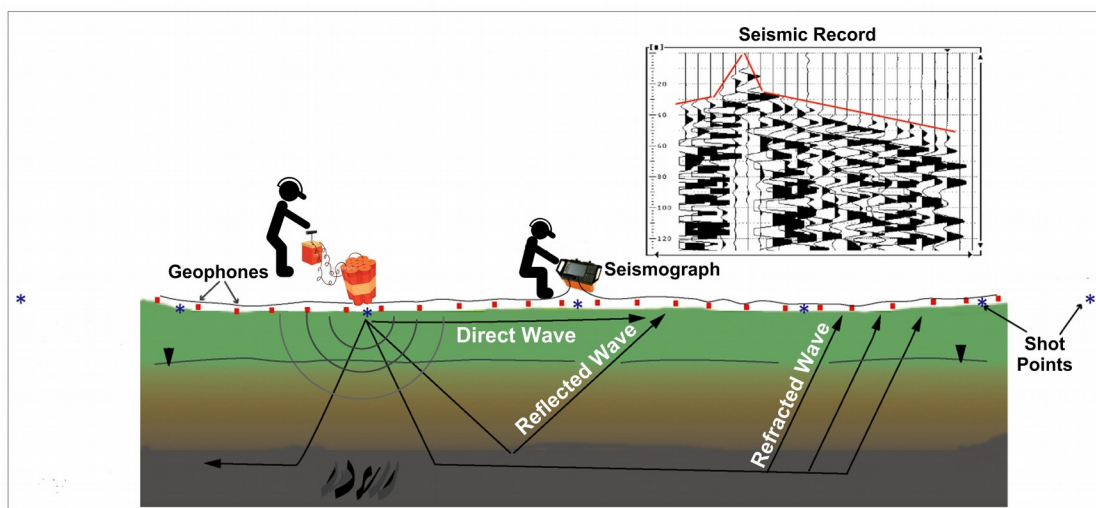




### 4.3. Seismic Refraction Profiling

#### **Basic Theory**

The seismic refraction method relies on measuring the transit time of the wave that takes the shortest time to travel from the shot-point to each geophone. The fastest seismic waves are the compressional (P) or acoustic waves, where displaced particles oscillate in the direction of wave propagation. The energy that follows this first arrival, such as reflected waves and transverse (S) waves, is not considered under routine seismic refraction interpretation. Figure 5 illustrates the basic operating principle for refraction surveys on land. The same principle was used in this case whereby the hydrophone cable was towed behind the vessel together with a seismic source.



**Figure 5: Seismic refraction basic field operating set-up**

#### **Seismic Source**

One advantage to working on water, is that a smaller seismic source can be used than would be required for a land survey. The source is a device called an “air gun”. It operates with a compressed air tank. It has a small 4 cubic inch chamber that releases the air into the water instantly.

The entire project required one large compressed gas bottle.

#### **Survey Design**

This particular investigation utilized set of 24 vibration monitoring devices (hydrophones) connected in line (spread) to a seismograph (ABEM Terraloc MK8 V.2) by one 24 connector cable. The cable was towed behind the vessel moving along the seismic profile line at steady speed. Seismic pulses (shots) were initiated at set intervals along the line using the airgun towed close to the vessel. The seismic survey used a hydrophone spacing of 3 m. Typically, the shot offset was 5 m from the first hydrophone; this offset was increased to 11 m for some of the lines. The average distance between shots was 50 m. From 6 to 8 shots were executed per line.



During data acquisition, the vessel speed was kept at approximately 0.5 km/h, while the hydrophone cable was kept between 0.5 and 0.75 metres beneath the surface.

### ***Quality Control***

Throughout the survey, a procedure for quality control including field-work and interpretation was followed. The purpose of implementing the following measures is to ensure the acquisition of high quality seismic refraction data:

- The first arrival times on each seismic record must be as clean and precise as possible. In this case the hydrophones are already within water so there is no concern about contact with the surrounding medium;
- No more than two traces should be absent (except if seismic cable are damaged, and without possible repair without delaying the survey works);

### ***Interpretation Method and Accuracy of Results***

Interpretation of the refraction seismic data was performed using the critical distance and seismic tomography methods. Critical distance calculations allow determination of the depth to bedrock approximately below the shot point (considering horizontally layered model). The seismic refraction tomography provides 2D velocity model for a given seismic line. The main processing sequence involved plotting, picking, and 2D inversion of the seismic shot records using the SeisimagerSW™ software package.

The seismic refraction method typically allows the determination of the bedrock profile with a precision of 10% or better for depths greater than 10 m (soils, not including water) and a precision of 1 m for depths less than 10 m; although, this is somewhat site specific.

The main sources of error for refraction mapping are the “hidden” layer and the effect of velocity inversions.

A “hidden” layer or “blind zone” is a stratigraphic layer that is not possible to discern from the arrival time data due to insufficient velocity variation or thickness. The unknown presence of a hidden layer has the effect of making the interpreted bedrock depth too shallow. The presence of a “hidden” layer is typically revealed through borehole data and calculations can be made to compensate for the presence of such a layer.

Velocity inversions occur when the velocity does not increase with depth. The velocity inversion can result from the presence of a low or high velocity layer. Refractions from low-velocity layers cannot be determined from the arrival time data. The unknown presence of a low velocity layer has the effect of making the interpreted depths deeper than actual depths. At this site there was no evidence of velocity inversions.

Other source of error, characteristic for this particular site, is dipping refractor. The most significant effect it has on critical distance method as this method is devised as simple solution for planar layers. The tomography method allows the determination of the geometry of dipping interfaces for certain extent; although, it utilizes 2D model and any refractor's depth variations in the direction perpendicular to the profile line may provide



sources for error. An additional source of error for tomography method is in the modelling/inversion process. As with most inversion problems, the solution is non-unique and must be judged geologically realistic.

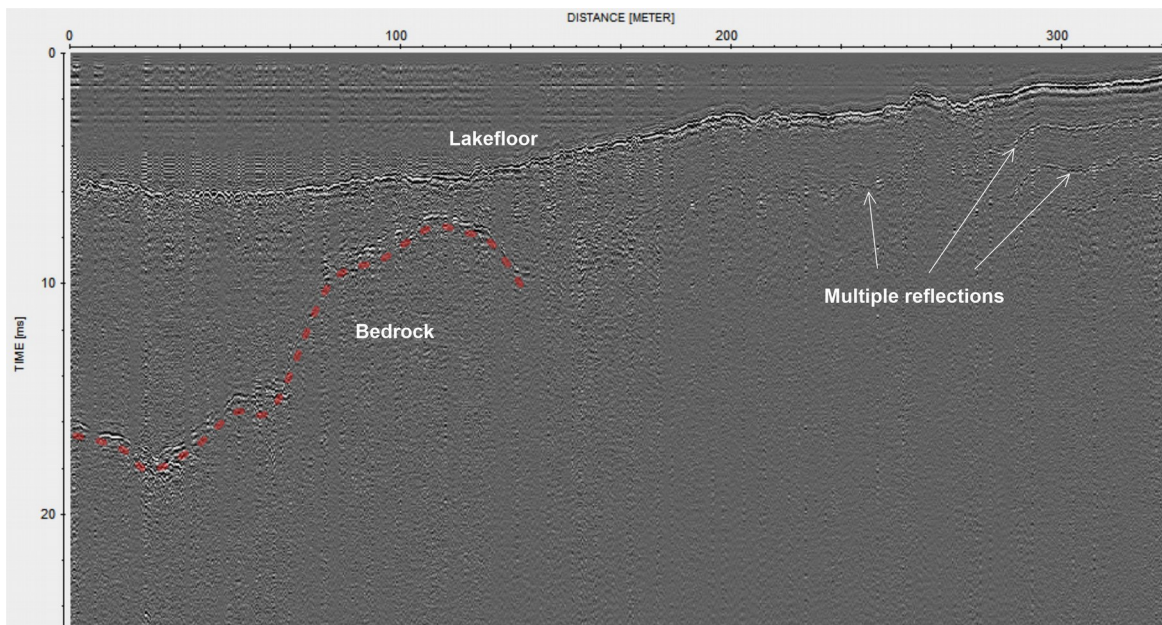
Considering all the above factors, the error in depth to bedrock determination for this site is estimated to be plus or minus 15%.

Appendix B contains a much-expanded version of the technical principles of the method.

## 5.0 RESULTS

The sub-bottom profiler had mixed results. Where there was signal penetration the images are quite clear but there were areas where the signal penetration seemed to be stifled very close to the lake bottom. It is believed that the principal reason for lack of signal penetration is hard lakefloor. Hard sediments will reflect too much signal from the lake bottom so there is very little left to penetrate to lower layers. When the bottom sediments are softer and the sediments firm up gradually, the seismic pulse will progress and small portions of the pulse will reflect back to surface.

Figure 6 is an example of a sub-bottom section from this particular site, which shows how signal from the top of rock, clearly visible at chainages from 0 to 140, disappears and on the rest of the section only multiple reflections from the lakefloor can be seen.



**Figure 6: Example sub-bottom profiler data**

The usable sub-bottom profiler data were only found in the middle of the northern part of the site. This data were used to corroborate the seismic refraction interpretation.

Seismic refraction data were interpreted using the critical distance and seismic tomography methods. The results of the seismic survey are presented in Figure 4. The colour contoured map contained in Figure 4 is based on detailed tomography and sub-



bottom profiler cross-sections. The depths to bedrock as determined from critical distance calculations are plotted on the map in the form of circled numbers. The plotted depth represents roughly the area within the circle due to uncertainty in positioning of the calculated depth value relatively to the seismic spread in the case of dipping refractor.

The deepest rock depths are calculated to be over 25 metres beneath chart datum for the surveyed site. In its central part, there is a pronounced sublatitudinal depression extended along lines 4, 5 and 6. In the rest of the area, the calculated depth to bedrock ranges from approximately 3 m to 16 m beneath chart datum.

Three test boreholes were close to shore but generally agreed with the rock depths from the geophysical data.

An average of measured apparent bedrock velocities was 5300 m/s. This velocity is typical for competent rock. The sediments characteristics cannot be defined from most of the refraction data due to insufficient velocity variation (comparing to compressional wave velocity in water) and thickness. There is a layer that can be observed in a portion of the data set in the middle of the grid where bedrock depths are deepest (lines 4, 5 and 6). This layer has an apparent velocity range of approximately 1750 m/ to 2200 m/s, the typical velocity range for firm till. The layer depth is approximately from 4 to 6 m beneath chart datum. It is possible that this layer is also present in the rest of the area but is "hidden" for the refraction method.

The depths to bedrock as determined from critical distance calculations are summarized in Table 1. The table contains the coordinates of the 68 refraction soundings, calculated depths and elevations. The coordinate system is UTM NAD27 zone 18T.





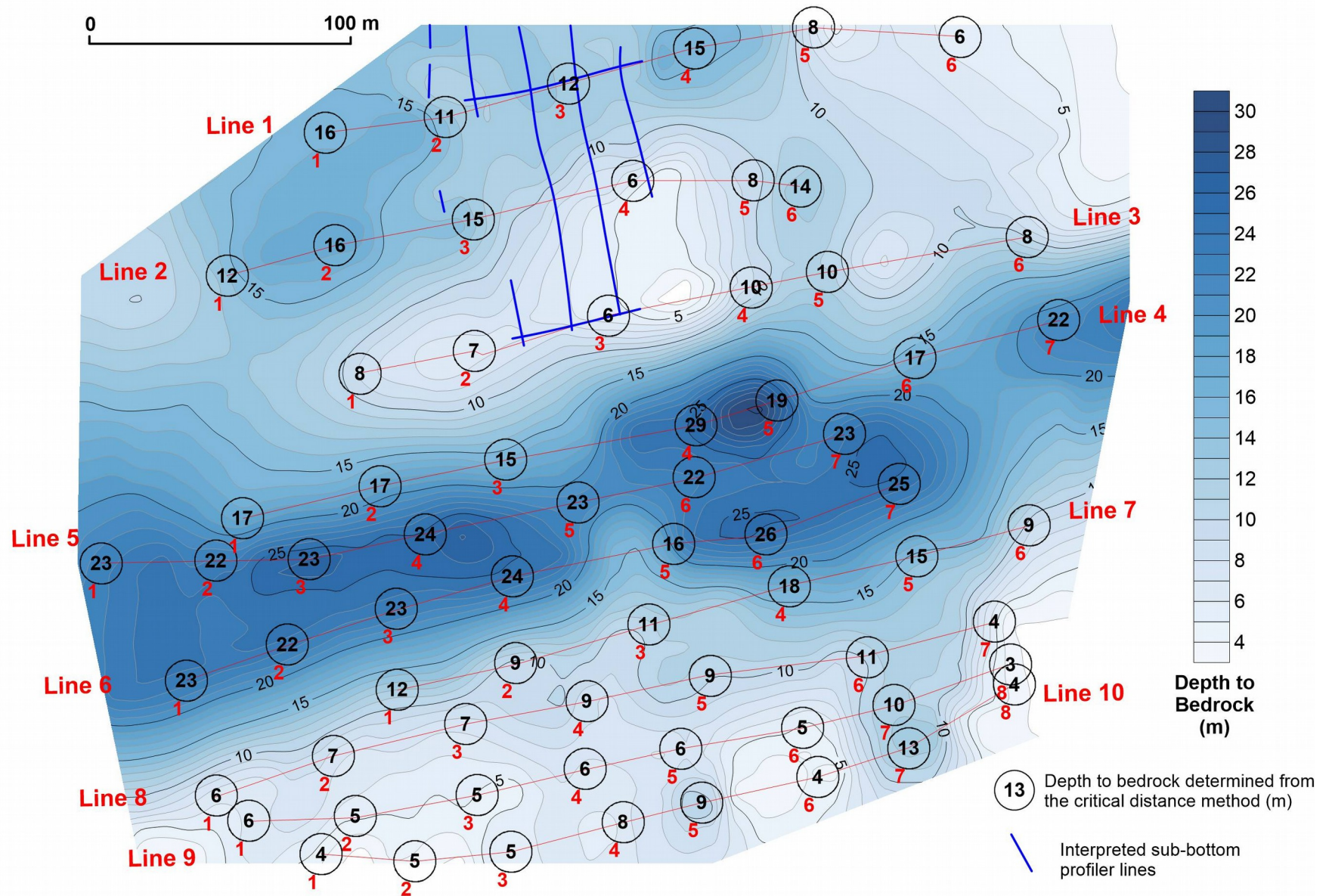


Figure 7: Bedrock depth contour map based on tomography/sub-bottom profiler data and depths to bedrock from critical distance calculations





Line	Point	Easting (E)	Northing (N)	Depth, m	Elevation, m	Line	Point	Easting (E)	Northing (N)	Depth, m	Elevation, m
1	1	4894773.9	384665.5	16.1	58.1	6	3	4894591.9	384692.8	22.9	51.3
1	2	4894779.9	384711.5	11.2	63.0	6	4	4894604.2	384737.2	24.4	49.8
1	3	4894792.6	384758.8	12.4	61.8	6	5	4894616.6	384798.9	15.9	58.3
1	4	4894806.2	384807.0	15.0	59.2	6	6	4894620.3	384834.3	26.2	48.0
1	5	4894814.2	384852.5	8.2	66.0	6	7	4894639.5	384885.3	24.9	49.3
1	6	4894810.5	384908.6	6.0	68.2	7	1	4894561.0	384693.1	11.9	62.3
2	1	4894719.2	384628.0	11.8	62.4	7	2	4894571.1	384738.5	9.1	65.1
2	2	4894730.8	384669.2	15.9	58.3	7	3	4894585.9	384789.5	11.0	63.2
2	3	4894740.7	384722.2	14.8	59.4	7	4	4894600.5	384843.3	18.2	56.0
2	4	4894755.5	384783.3	6.1	68.1	7	5	4894611.9	384892.1	15.3	58.9
2	5	4894755.7	384829.4	8.1	66.1	7	6	4894623.8	384935.1	9.1	65.1
2	6	4894753.3	384847.4	13.6	60.6	8	1	4894520.4	384623.9	6.1	68.1
3	1	4894681.8	384678.8	8.2	66.0	8	2	4894535.5	384668.6	7.4	66.8
3	2	4894690.5	384722.6	6.9	67.3	8	3	4894547.8	384719.3	6.9	67.3
3	3	4894704.0	384774.0	6.1	68.1	8	4	4894556.5	384765.7	8.8	65.4
3	4	4894714.8	384828.6	10.3	63.9	8	5	4894566.3	384813.0	9.1	65.1
3	5	4894720.6	384857.8	10.3	63.9	8	6	4894573.3	384873.1	11.4	62.8
3	6	4894734.1	384934.5	8.0	66.2	8	7	4894586.9	384921.7	4.1	70.1
4	1	4894626.5	384633.8	16.7	57.5	9	1	4894510.8	384636.3	6.1	68.1
4	2	4894638.8	384686.5	16.7	57.5	9	2	4894512.6	384677.0	5.2	69.0
4	3	4894648.9	384734.7	15.4	58.8	9	3	4894520.6	384723.6	5.2	69.0
4	4	4894662.1	384807.5	28.7	45.5	9	4	4894530.6	384765.0	6.1	68.1
4	5	4894671.4	384838.5	18.9	55.3	9	5	4894538.3	384801.7	6.5	67.7
4	6	4894687.8	384891.4	16.9	57.3	9	6	4894546.4	384848.3	4.6	69.6
4	7	4894702.4	384946.5	21.6	52.6	9	7	4894555.2	384883.4	9.7	64.5
5	1	4894609.3	384579.8	22.8	51.4	9	8	4894570.5	384928.0	3.5	70.7
5	2	4894610.3	384623.7	22.4	51.8	10	1	4894498.0	384664.0	4.1	70.1
5	3	4894610.8	384659.4	22.9	51.3	10	2	4894495.4	384699.9	4.6	69.6
5	4	4894620.3	384703.9	24.4	49.8	10	3	4894498.9	384736.7	5.0	69.2
5	5	4894632.5	384762.3	22.8	51.4	10	4	4894510.3	384779.6	8.0	66.2
5	6	4894642.1	384806.9	22.4	51.8	10	5	4894517.8	384809.7	9.1	65.1
5	7	4894658.8	384864.4	22.9	51.3	10	6	4894527.5	384854.1	4.2	70.0
6	1	4894564.5	384612.4	22.8	51.4	10	7	4894538.6	384888.9	12.5	61.7
6	2	4894578.2	384651.1	22.4	51.8	10	8	4894562.9	384929.5	3.7	70.5

**Table 1:** Seismic refraction soundings locations, calculated depth to bedrock and bedrock elevation



## 6. **CONCLUSION**

Geophysics GPR International Inc. was mandated by Thurber Engineering to carry out seismic survey around the Marysville dock that service the Kingston – Wolfe Island Ferry.

The purpose of the investigation was to map the depth and topography of the bedrock beneath the lake bed around the dock.

The survey consists of approximately 7800 m of combined sub-bottom profiling and seismic refraction data. Table 1 lists the UTM coordinates of the 68 refraction soundings.

The background seismic noise levels at this site were low. The quality of the refraction data is considered very good to excellent. The usable sub-bottom profiler data can only be found in the middle of the northern part of the site.

The results of the investigation are presented in Figure 4, Table 1 and discussed in the results section. For this particular site it was estimated for the refraction method to allow the determination of the bedrock depth with a precision of 15%. The sub-bottom profiler interpretation included in the colour contoured data set is considered to be more accurate.

The calculated depth to bedrock at the site ranged from approximately 3 m to over 25 m beneath chart datum. A pronounced depression, approximately 80 m in width, extended along lines 4, 5 and 6 could be observed on the contour map (Figure 4) in the middle of the surveyed area.

Additional borehole data can be used to further refine/corroborate the interpretation.

The sub-bottom data has been interpreted by Nicolas Beaulieu. The refraction seismic data was interpreted by Ilia Gusakov. The report has been written by Milan Situm, P.Geo.

---

Milan Situm P.Geo.  
Manager



## **APPENDIX A**

**EdgeTech Sub-bottom Profiler 216S**





# 3100

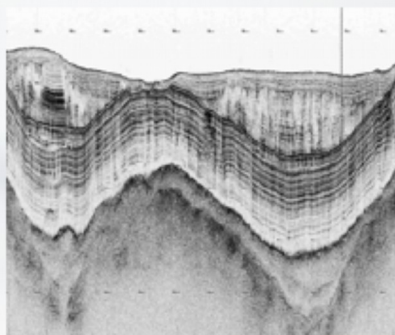
## PORTABLE SUB-BOTTOM PROFILING SYSTEM

### FEATURES

- Portable
- Low power requirement (runs on AC or DC)
- Choice of towfish depending on the application
- Pole mount option for shallow water surveys
- Easy to setup and operate

### APPLICATIONS

- Geological Surveys
- Geohazard Surveys
- Buried Object Location
- Mining/Dredging Surveys
- Bridge/Shoreline Scour Surveys
- Pipeline and Cable Location



The 3100 is EdgeTech's portable version of their highly successful sub-bottom profiler product line. The system utilizes EdgeTech's Full Spectrum CHIRP technology which provides higher resolution imagery of the sub-bottom structure and greater penetration.

The 3100 is ideally suited for use in rivers, lakes, ponds and shallow water ocean applications up to 300m max depth. The system was designed for customers that require a portable system that can be used from smaller boats while not wanting to sacrifice image quality.

A 3100 system comes with a choice of two towfish; either the SB-424 or SB-216S. These towfish operate at different frequency ranges and selection between the two depends on the type of application. The 424 operates at 4-24 kHz and will provide slightly higher resolution but less penetration. The 216S operates at 2-16 kHz and provides slightly less resolution but greater penetration. Along with a towfish, the 3100 system comes with a portable splash-proof topside processor with laptop computer running EdgeTech's DISCOVER software for display of the sonar data. The system comes standard with a 35m tow cable with customer-specified lengths also available.

For more information please visit [EdgeTech.com](http://EdgeTech.com)

[info@EdgeTech.com](mailto:info@EdgeTech.com) | USA 1.508.291.0057



# 3100

## PORTABLE SUB-BOTTOM PROFILING SYSTEM

### KEY SPECIFICATIONS

TOWFISH	SB- 216S	SB- 424
Frequency Range	2-16 kHz	4-24 kHz
Vertical Resolution (depends on pulse selected)	6-10 cm	4-8 cm
Penetration		
In coarse calcareous sand	6m	2m
In clay	80m	40m
Length	105 cm (41")	77 cm (30")
Width	67 cm (26")	50 cm (20")
Height	40 cm (16")	34 cm (13")
Weight In Air	76 kg (167 lbs.)	45 kg (100 lbs.)
Weight In Water	32 kg (70 lbs.)	18 kg (40 lbs.)
Max Depth Rating of Towfish	300 meters	
TOPSIDE PROCESSOR		
Hardware	Rugged, portable splashproof enclosure	
Operating System	Windows 7	
Display	Splashproof semi-rugged laptop	
Archive	DVD-R/W	
File Format	JSF, SEG-Y & XTF	
I/O	Ethernet	



SB-216S TOWFISH



SB-424 TOWFISH

## **APPENDIX B**

### **Seismic Refraction Method**

## THE SEISMIC REFRACTION METHOD

The seismic refraction survey is used to infer subsurface conditions on the basis of contrasting seismic wave velocities. The primary goal of the seismic survey is to rapidly and efficiently obtain subsurface information, thereby reducing direct investment costs, such as drilling. Geological information typically obtained from a well-planned and executed seismic refraction survey will include: depth and shape of bedrock surface, nature and competency of bedrock, such as degree of fracturing and alteration, whether it is faulted or sheared, nature of overburden and depth to the water table. Modern portable equipment makes the method accessible to remote and rough regions. A review of the seismic refraction theory, field methods and interpretational procedures can be found in Dobrin (1976) and Telford et al (1990).

### **INSTRUMENTATION**

The instrumentation involved in a seismic refraction survey consists of an energy source to generate seismic waves (typically explosives), a line of geophones to detect the seismic energy and a seismograph which is essentially a highly accurate stopwatch. By measuring the arrival times of the first seismic waves at various distances from the energy source, or shotpoints, depths to interfaces and seismic velocities can be determined. Seismographs are usually 12 or 24-channel, in they can simultaneously record the vibrations at 12 or 24 geophones. The record of these vibrations is a seismogram. Digital seismographs (e.g. ABEM Terraloc MK6-v2, EG&G SMARTSEIS S-24) acquire data with a built-in computer. The energy source must be coupled to the seismograph so that the instant of detonation or impact can be recorded. A recording time step of 50  $\mu$ s was used to permit very accurate estimates of arrival times.

### **FUNDAMENTAL PRINCIPLES**

The seismic refraction method relies on measuring the transit time of the wave that takes the shortest time to travel from the shotpoint to each geophone. The fastest seismic waves are the compressional (P) or acoustic waves, where displaced particles oscillate in the direction of wave propagation. The energy that follows this first arrival, such as reflected waves or transverse (S) waves, is not considered under routine seismic refraction interpretation.

Figure B-1 shows a simple geological structure, where a layer with a velocity of  $V_1$  overlies a second layer with a higher velocity,  $V_2$ . At one end of the spread, a shotpoint is detonated and the vibrations at each geophone are recorded. Seismic waves will travel via the direct path from the source to each of the geophones. Waves may also be refracted at some critical angle along the interface and travel at the higher velocity  $V_2$ . Energy is continually leaked back to the surface as it travels along the interface. A time-distance graph may be constructed, plotting the first arrival transit times as a function of position along the seismic line.

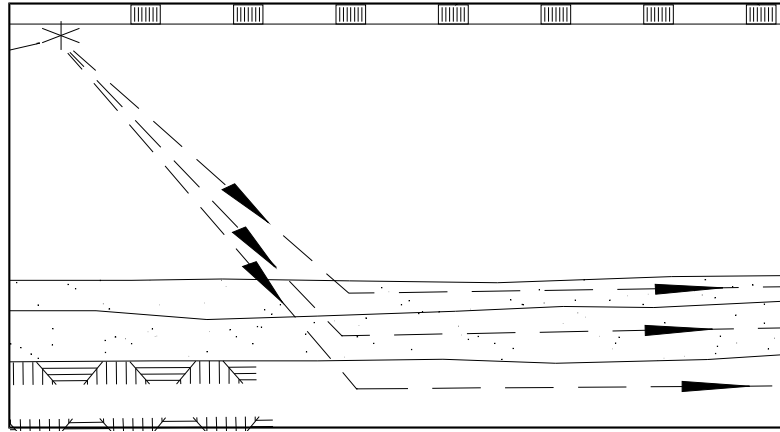




The first arrival at the closest geophones is the direct wave. However, at the critical or crossover distance ( $X_c$ ) the refracted wave which travels along the higher velocity layer overtakes the direct arrival. The inverse slope of a straight line segment of the time-distance curve is equal to the velocity in that layer. The crossover distance is directly proportional to the depth of the interface.

## **INTERPRETATION**

The simplest methods of interpretation are illustrated in figure B-1. Having determined the velocity of compressional waves through each layer, one may calculate the depths according to crossover distance or the intercept time formulas. The case of a horizontal interface, illustrated in figure B-1, becomes slightly more complicated if the planar interface is dipping. The general case of an irregular interface can be handled by more complex interpretational schemes, including various delay-time methods, the reciprocal and generalized reciprocal methods and ray tracing. One method may be better suited than another to a particular geological environment.



**FIGURE B-1**

PRINCIPLES OF SEISMIC REFRACTION

## **SEISMIC VELOCITIES VERSUS GEOLOGICAL MATERIALS**

The seismic refraction differentiates the overburden layers from the bedrock. In general, a layer of overburden material, with associated velocities of 300 - 500 m/sec is seen followed by a second layer under the water table with a velocity corresponding to an impermeable material 1400 - 1600 m/sec.

In some cases, certain limitations may arise, such as differentiation between two different layers having approximately the same velocity. As an example:

- a contact within sand under the water table
- a contact between till and sand, under the water table (both at 1500 m/sec)

As a guideline, the following figure shows a classification of geological material by seismic velocities.

### **Seismic velocities in the overburden**

Variations in the overburden layer can vary over a wide range as a function of its age, its depth of burial, differences in the granular state, degree of porosity, and whether water or air fills the voids (Telford 1976).

### **Seismic velocities in bedrock**

A significant variation in seismic velocities for a particular rock mass may be caused by several factors. These factors include a change in the rock quality when the rock is weathered, sheared, faulted or fractured, a radical topographic change or a rock type change. Other features, such as the distribution of rock types, mineral content, the bonding of the minerals, joints opening, rock pressure, saturation and chemical composition of the minerals may all affect the velocities to some degree, explaining the differences of velocities in sound rock.

### **Rock type or change in bedrock quality**

A rock type change will generally result in a different velocity because of differences in crystallization, mineralization or other physiochemical properties.

In the same way, a change in rock quality such as the presence of large open joints or several small open joints will undoubtedly bring about a velocity change for the same type of rock. Features such as a weathered, sheared, fractured or faulted rock will cause a drop in the velocity.

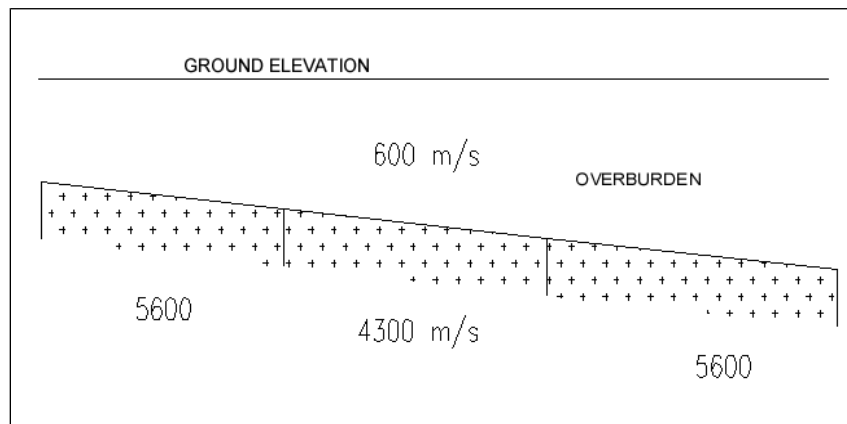
### **Faults, deep valleys**

A radical topographic change in the bedrock profile may also cause a drop in the measured velocity. The cause of this is geometric and the use of specialized interpretative methods permits an estimation of the true depth of bedrock. A fault will also cause a similar velocity anomaly in the bedrock.

These anomalies may be due to either a deep valley or a cavity like feature (which may be water or sediment filled), or a physical feature in the rock such as a fault or open joints. Since the analysis of the time distance curve does not allow the differentiation of the anomalies, the two possible interpretations are presented on the drawings. In such a case, borehole data gives the best information to assess the true nature of the anomaly.

## *CAUSES OF LATERAL VELOCITY ANOMALIES IN BEDROCK*

Velocity changes in rock may represent a change in rock quality, a radical topographic effect or a rock type change. We will discuss each possibility in turn using figure B-3 as a reference.

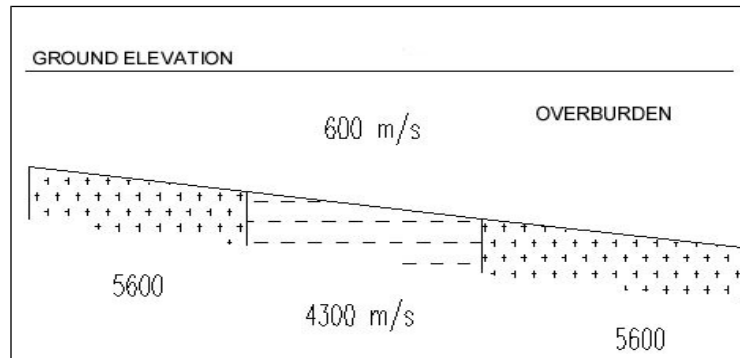


**Figure B-3**

In the above case, a survey was done using a geophone spacing of 7,5 metres. A zone whose velocity is 4 300 m/sec was measured between the two zones of sound bedrock with a seismic velocity of 5 600 m/sec.

### **Case 1 – Rock Type Change**

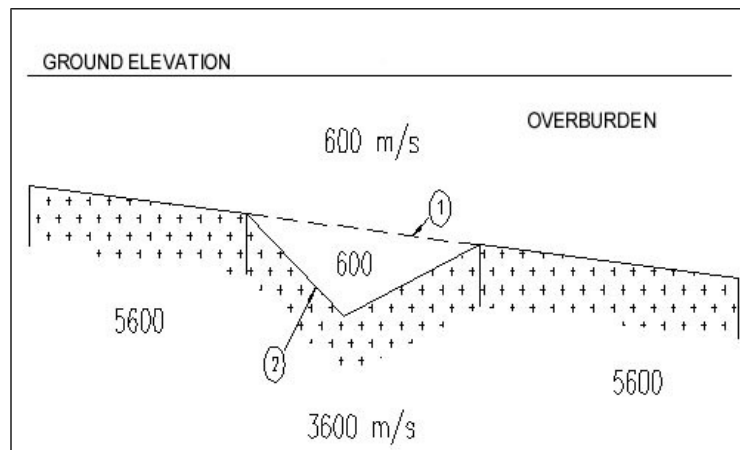
A rock type change will result in a velocity change. For example, a sandstone resting on a gneissic rock may bring about the case shown in figure B-4. In this case, the rock may be of good quality, however, the lower velocity represents a physiochemical difference.



**Figure B-4**

### **Case 2 – Topographic effects**

A radical topographic change in the bedrock profile, such as a fault with a vertical displacement or a buried valley may bring about a velocity change. The cause of this is geometric and the use of specialized interpretative methods will permit the determination of the true velocity, as seen in figure B-5.



- (1) Topography before correction
- (2) Topography after correction

**Figure B-5**

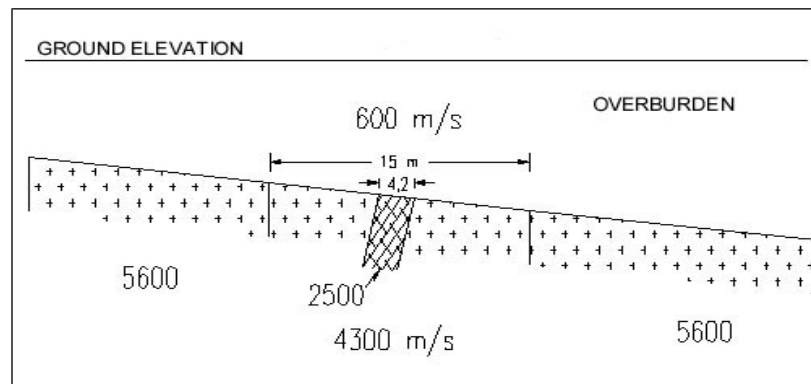


### **Case 3 – Rock quality change**

A change in rock quality will also bring about a velocity change as illustrated in the following cases:

a) Open joint

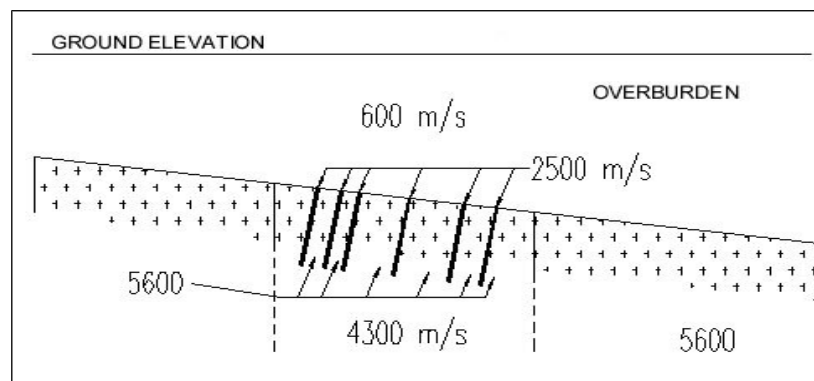
The presence of a large open joint will bring about a velocity change. Using a 7,5 metres geophone spacing, the zone may appear to be 15 metres large, (as shown). However, in reality, the joint is 4,7 metres large with a velocity of 2 500 m/sec (Figure B-6).



**Figure B-6**

b) Several small open joints

An important number (6) of small joints, 0,7 metres in width, having a velocity of 2 500 m/sec will cause the velocity to drop as seen in figure B-7.

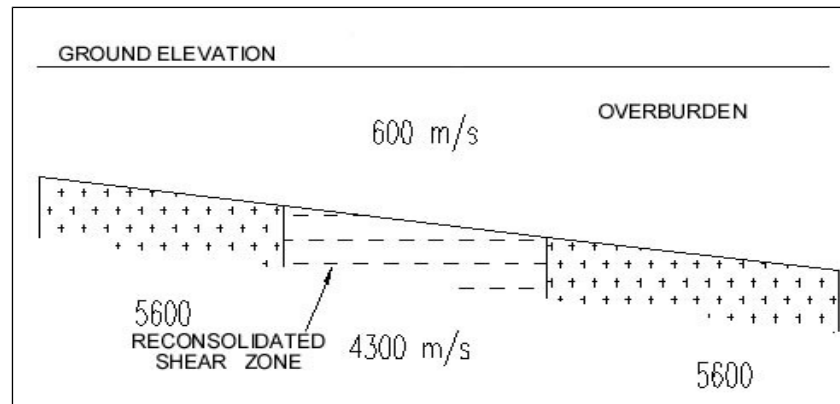


**Figure B-7**



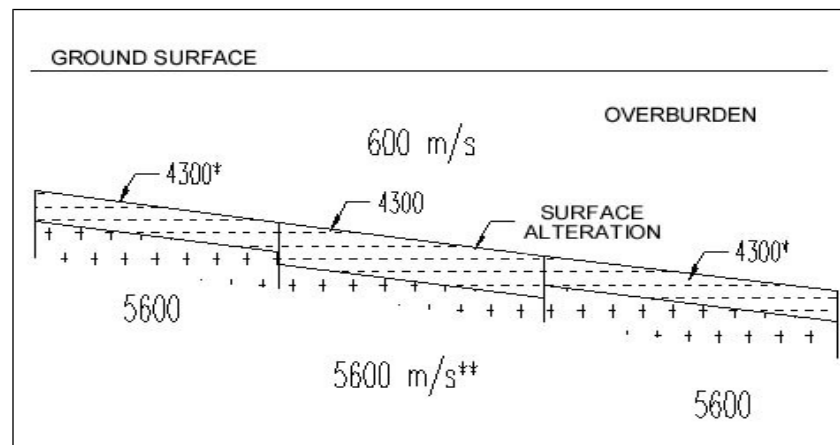
c) Healed Faults

A healed fault of a zone of filled fractures will also show the same aspect, figure B-8.



**Figure B-8**

**More important weathered zone**



**Figure B-9**

\* These rock weathered zones are not to be identified if too thin

\*\* The 5 600 m/s seismic velocity is not measured if the width of the zone is too small



## *DESCRIPTIVE CLASSIFICATION OF BEDROCK*

### **SEISMIC VELOCITIES WITH RQD VALUES**

Seismic velocities depend on a wide variety of parameters and it is always difficult to relate them to borehole logging. However, there is a way which involves measuring compressional wave velocities in the field and in the laboratory.

The field and laboratory velocities are different. The field velocity is measured on a large scale and depends on the bedrock type and its fracturing degree. The laboratory velocity is measured on a small core sample and depends more on the microscopic features of the bedrock. From these velocities, one can define the velocity index.

The classification of Coon and Merritt is based upon the velocity index property of in-situ rock which is a measure of the discontinuities in the rock mass. According to Coon and Merritt, the velocity index is defined as the square of the ratio of seismic field velocity to laboratory compressional wave velocities, measured on a core sample, representative of a sound rock. The field seismic velocities are normalized by the laboratory results in order to minimize the influence of lithology. Hence as the number of joints decreases, the ratio of the velocities will approach 1. This ratio is then squared to make the velocity index equivalent to the ratio of dynamic module.

The following table is extracted from a study by Coon and Merritt (ASTM STP 477) and illustrates the relationship of the velocity index versus the RQD values (Rock Quality Designation).

We must keep in mind that the seismic refraction usually measures the velocity of the bedrock as is shallow (0 - 100 metres in depth).

**TABLE B-1**

ENGINEERING CLASSIFICATION FOR IN SITU ROCK <sup>(1)</sup>			
RQD (%)	VELOCITY INDEX	DESCRIPTION	SEISMIC DESCRIPTION
0 - 25	0.00 - 0.20	Very poor	Low velocity
25 - 50	0.20 - 0.40	Poor	Low velocity
50 - 75	0.40 - 0.60	Fair	Intermediate
75 - 90	0.60 - 0.80	Good	Sound rock
90 - 100	0.80 - 1.00	Excellent	Sound rock

- (1) Taken and adapted from: Coon,R.F. and Merritt,A.H.,**Predicting in-situ Modulus of Deformation using Rock Quality Indexes**, Determination of the in-situ modulus of deformation of rock, ASTM STP 477, American Society for testing and materials 1970, pp. 154-173.

It is important to note that the RQD can be affected by the drilling, whereas the velocity measurements are not. The relation between the RQD values and the seismic velocities have always been a concern of geologists and geophysicists. This empirical relation could, thus, be useful. The only additional data needed to compute the velocity index, would be the core laboratory seismic velocity.

Without laboratory calibration, we used one of the highest seismic velocity measured on both sites as reference (6100 m/s), which lead to :

for a geophysical (seismic) appreciation :

$$\begin{array}{lll} V_p \geq 4800 \text{ m/s} & \rightarrow & \text{Sound rock} \\ 3900 \leq V_p < 4800 \text{ m/s} & \rightarrow & \text{Intermediate} \\ V_p < 3900 \text{ m/s} & \rightarrow & \text{Low velocity} \end{array}$$

or, for an equivalent geotechnical classification:

$$\begin{array}{lll} V_p \geq 5550 \text{ m/s} & \rightarrow & \text{Excellent} \\ 4800 \leq V_p < 5549 \text{ m/s} & \rightarrow & \text{Good} \\ 3900 \leq V_p < 4799 \text{ m/s} & \rightarrow & \text{Fair} \\ 2800 \leq V_p < 3899 \text{ m/s} & \rightarrow & \text{Poor} \\ V_p < 2800 \text{ m/s} & \rightarrow & \text{Very poor} \end{array}$$

## **HIDDEN LAYER AND SEISMIC VELOCITY INVERSION**

For seismic refraction surveys for assistance to the geotechnical investigations, relatively simple geological models are considered. These basic models, used for the interpretation of the seismic data must respect some assumptions relating to the overburden laying on the rock:

- The different overburden layers are sub-parallel to the surface;
- These layers presents increasing seismic velocities with depth;
- The seismic velocities are considered constant enough over short lateral distances within the layers;
- The thickness of each layer should be sufficient to permit its detection.

When one or several of these hypotheses are transgressed importantly, some errors may be induced within the calculations results relatively to the thickness of the layers in cause. These errors are then due to the attribution of seismic wave delay time to a seismic erroneous mean velocity. This mean seismic velocity might be under-evaluated if a subjacent layer of a higher seismic velocity could not be detected and by the fact even sees itself neglected. This can occur when a thick layer of overburden covers one second thin layer. One speaks then about "**hidden layer**". The opposite case is also possible, where the average seismic speed of the layers of materials is overestimated being given the absence of critical refraction of the seismic wave necessary to detection of a subjacent layer. This phenomenon occurs when a layer of material presents a seismic velocity lower than that of the layer of material covering it. It is the case known under the name of "**velocity inversion**".

**The hidden layer** effect results with an under-estimation of the overburden thickness laying on the rock.

"The most important source of uncertainty, at the time of seismic calculation, comes from the grounds which one cannot detect. In the presence of three grounds, when the second is thin, it is possible that the waves refracted with the roof of the third marker arrive at the geophones before those which are refracted with the roof of the second " (p.24).<sup>1</sup>

The phenomenon of *hidden layer* is related to the limitation of the seismic refraction to detect a layer of material associated with a too weak seismic velocity contrast and/or with a too low thickness of the layer. The existence of the aforementioned "*hidden layer*" not being recognized, the time of course of the seismic wave in the *hidden layer* and the layer of material which is overlying of it is attributed to the only layer of material covering the hidden layer, faster seismically. The thickness of the overlying stratum to the hidden layer is then exaggerated, but remains lower than the thicknesses sum of the two layers joined together. Thus, the rock

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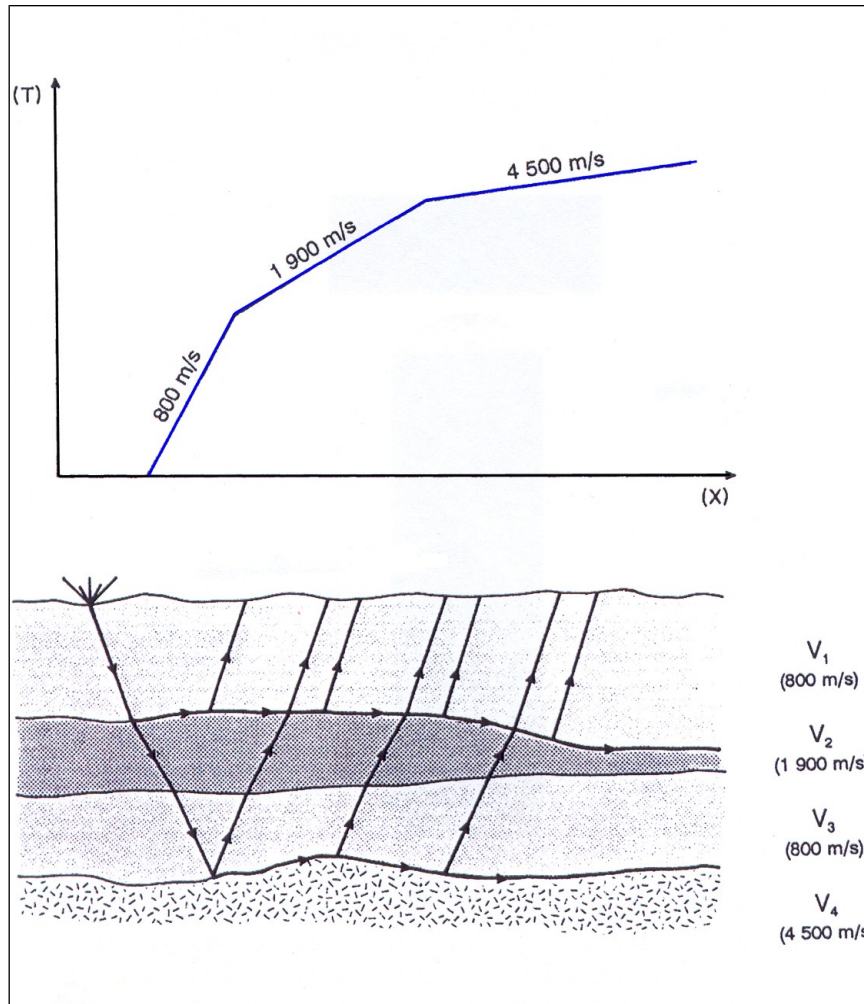
Denis-Jacques Dion  
«La méthode sismique réfraction appliquée au génie géologique, notions  
d'interprétation»  
DV-8506  
M.E.R.Q., 1986

substrate will appear less deep than it is really. The B-10 figure illustrates the evolution of an acoustic wave in a geological medium implying a *hidden layer*.

The phenomenon of *hidden layer* generally arises on banks of lakes or rivers where the thickness of the saturated movable deposits decreases gradually towards the firm ground, and also in the case of deposits strong thickness where the materials are increasing in density with depth.

**The seismic velocity inversion** produces an over-estimate thickness of a layer of material by neglecting the existence of a layer subjacent slower, which leads to an exaggeration real depth of the rock.

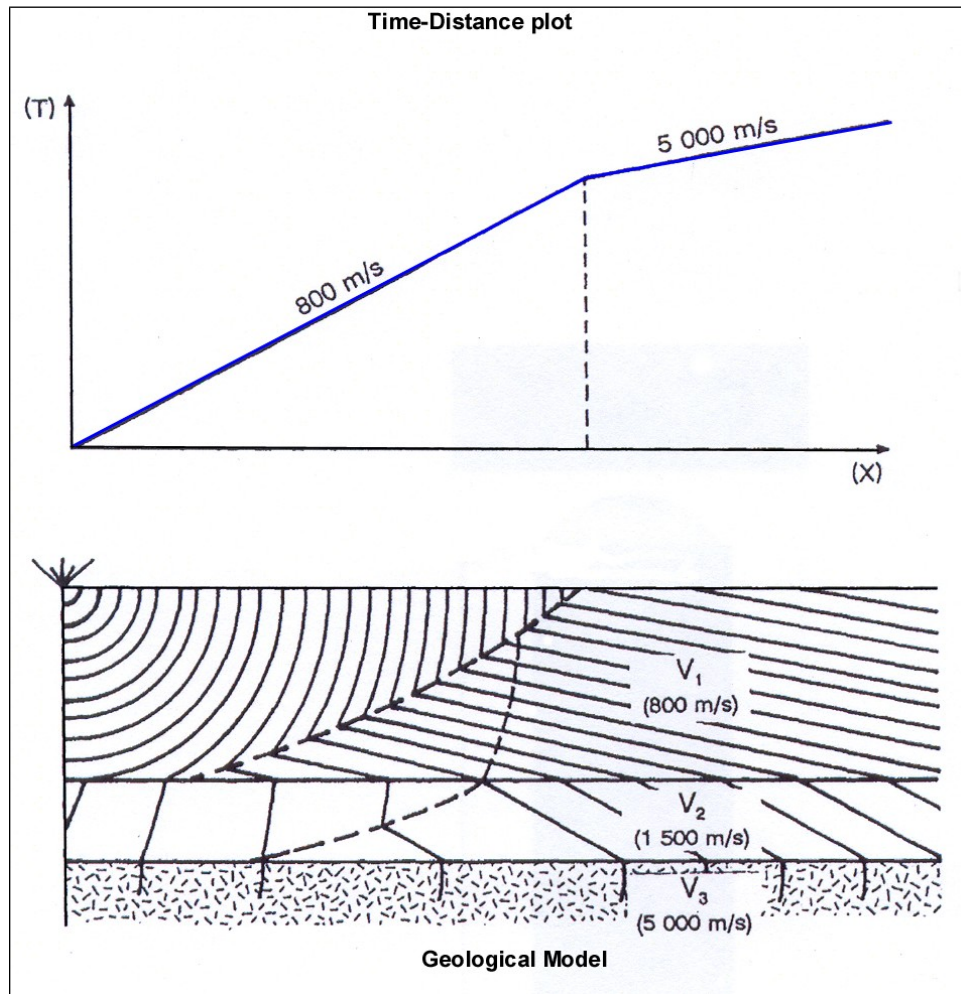
In seismic refraction, only the first arrivals of the acoustic waves are usually considered for calculations. These arrivals can come from direct waves (surfacing) or from refracted waves. These last ones are the product of the phenomenon of critical refraction obeying to the law of Snell-Descartes. There cannot however be critical refraction when a seismic wave passes from a material of seismic speed higher than the one of the layer of subjacent material. Thus, this seismically slower layer could not be detected even if the total time of the way of the seismic wave in were affected (figure B-11). The ignorance of the existence of this second inserted slow layer will carry the attribution of the time of course of the seismic wave of the fast layer and the slow layer subjacent with the only fast layer. The thickness calculated for the fast layer thus appears higher than the real total thickness of this layer and the subjacent slow layer, both will be joined together. There cannot however be critical refraction when a seismic wave passes from a material seismic velocity higher than that of the layer of subjacent material. The phenomenon of *velocity inversion* is rather rare in the cases of shallow seismic refraction. One meets it most of the time in tropical areas and Northern areas with permafrost and/or temporarily thick frozen upper part of overburden. The velocity inversion is most often associated the presence of a hardened soil horizon or a suspended ice lens (permafrost, intermittent permafrost).



1.

2. **FIGURE B-10**  
**Hidden layer**

An overburden *hidden layer* is said *hidden* when the refracted seismic waves from this layer arrive after those refracted from the roof of the subjacent material.



3. **FIGURE B-11**  
**Seismic velocity inversion**

The absence of critical refraction of the seismic wave with the roof of the layer "V3", preventing its detection on the Time-Distance plot.

The existence of a case of **hidden layer** or a case of seismic **velocity inversion** can be revealed by boreholes or by seismic reflection and can be seen specified by seismic surveys "up-hole". When these phenomena are identified, one can consider the geological condition of the investigated site for the seismic calculations.

The seismic profile is then calibrated compared to the results of drillings. This makes it possible to obtain an approximate topography of the rock but the precision for its depth can be seen reduced, particularly when the geological conditions are variable. In spite of the mathematical artifices, the calibration can not allow a complete seismic recognition of the stratigraphy since a layer of materials could not be detected.

The cases of *hidden layer* and seismic *velocity inversion* cause problems for calculations depth of the rock but do not affect the precision of the seismic velocity in the rock, which can be used to evaluate its quality.