



# Terraprobe

*Consulting Geotechnical & Environmental Engineering  
Construction Materials Inspection & Testing*

## **GEOTECHNICAL INVESTIGATION VOLUME 1: FACTUAL REPORT**

### **ZONE 1 INTERCONNECTING WATERMAIN BURLOAK WPP TO KITCHEN RESERVOIR REGION OF HALTON ONTARIO**

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## 1.0 INTRODUCTION

Terraprobe was retained by R.V. Anderson Associates Ltd. (“RVA”) to conduct a geotechnical subsurface investigation for the proposed Halton Region Zone 1 Interconnecting Watermain. This Factual Report presents the findings from the subsurface investigation conducted by Terraprobe, as well as the findings from previously-conducted subsurface investigations by various consultants (including Terraprobe) within the study area.

### 1.1 The Project

The proposed watermain is intended to connect the Kitchen Reservoir and the Burloak Water Purification Plant (WPP). The proposed watermain will be located within a corridor following Burloak Drive from the Burloak WPP at Rebecca Street to Upper Middle Road and along an unopened road allowance across Bronte Creek to the Kitchen Reservoir on Trawden Way. Portions of the watermain running along the east and west sides of Burloak Drive will be located in the municipalities of Oakville and Burlington, respectively. A site location plan showing the proposed alignment is provided as Figure 1.

There are two primary functional requirements for the proposed Zone 1 Watermain. It will augment water conveyance from the Burloak WPP to the Kitchen Reservoir. It will also supply water to a future Zone 2 Booster Pumping Station (BPS) located to the south of the Burloak Drive / QEW interchange, in a parcel of land that has been acquired by the Region of Halton. The south leg of the Zone 1 Watermain, extending from Burloak WPP to the proposed Zone 2 BPS, will become the supply line for the Zone 2 BPS feed into the Zone 2 distribution system.

The watermain is to be constructed within a tunnel advanced through bedrock. The annular space of the tunnel will be filled with cellular grout. There will be no tunnel liner along most of the alignment, with the possible exception of the MTO/QEW crossing, where the MTO may require one. The connections with the Burloak WPP and Kitchen Reservoir facilities will be constructed as open cut sections.

A portion of the proposed watermain tunnel will be advanced beneath Bronte Creek, which lies within a 35-40 m deep valley located in Bronte Creek Provincial Park (BCPP). The approximate elevation of Bronte Creek at this location is Elev. 105 ± m. Bronte Creek has been designated as an environmentally sensitive area.

### 1.2 Profile and Alignment

The Preliminary Design Report (R.V. Anderson Associates, Ref No. 112525, dated April 18, 2013) proposes that the entire watermain alignment be tunnelled through Queenston Formation bedrock. The watermain is to comprise a minimum 2440 mm diameter tunnel conveying a 1500 to 1800 mm diameter watermain from Burloak WPP to Kitchen Reservoir, with connections to the Burloak WPP and Kitchen

Reservoir facilities constructed as open cut sections. The proposed alignment is shown on Figures 1 and 2, and the proposed shaft locations are summarized in the following table.

**Table 1-1: Summary of Proposed Shaft Locations**

Station	Shaft Location	Function <sup>1</sup>	Diameter (m)	Tunnel Invert Elev.
1+000	<b>Burloak WPP Shaft</b>	O&M access and construction (TBM egress) & Watermain Shaft	2 @ 3.6	76.8 m
3+085	<b>Main Shaft</b>	O&M access and construction (mucking, TBM access)	15.0 ±	74.7 m
4+981	<b>Ontario Parks Shaft</b>	O&M access and construction (optional mucking, TBM access)	3.6	83.5 ±
7+300	<b>Kitchen Reservoir Shaft</b>	Watermain Shaft & O&M access and construction (TBM egress)	2 @ 3.6	94.1 m

Revisions to the watermain profile were made by RVA as the findings from the geotechnical field investigation became available. Previous iterations of the design have proposed various open-cut sections of watermain installation. These include portions of the south leg of the alignment as well as the end portion of the north leg of the alignment at Kitchen Reservoir. Shallow boreholes were advanced along those potential open-cut sections, should that information be required at tender.

For the proposed “V” tunnel configuration, the tunnel would grade down towards the shaft at the Zone 2 BPS from both the north and south, at 0.46% and 0.1% respectively.

### 1.3 Sources of Geotechnical Information

The current Terraprobe investigation involved advancing twenty-eight (28) exploratory boreholes along the proposed watermain alignment. The locations of the boreholes are provided on the Borehole Plan and Profile as Figure 2. The boreholes were laid out in consultation with RVA.

The terms of reference provided to Terraprobe included previous investigations completed by Terraprobe and other engineering consultants in the vicinity of the site. The locations of the previously-advanced boreholes are included on the Borehole Plan and Profile as Figures 2A-F (shown in blue). The geotechnical investigation reports from those previous investigations are as follows:

- Coffey Geotechnics Inc., “Report on Preliminary Geotechnical Investigation, Zone 1 Interconnecting Watermain, Bronte Creek Provincial Park, Burlington, Ontario.” Project No. GEOTMARK00158AA, dated September 28, 2011.

<sup>1</sup> Source: R.V. Anderson Associates, *Preliminary Design Report: Zone 1 Watermain*, Ref. No. 112525, April 18, 2013.

- Coffey Geotechnics Inc., “Geotechnical Investigation for the Land Acquisition of the Proposed Zone 2 Booster Pumping Station Site, 945 Syscon Road, Burlington, Ontario.” Project No. ENVSETOB10863AB, dated November 9, 2011.
- Geo-Canada Ltd., “Report on Geotechnical Investigation, Burloak Water Purification Plant, Intake Tunnel, On-Land Section, The Regional Municipality of Halton. Vol. 1: Factual Data” Project No. G-04.1003, dated January 2005.
- Geo-Canada Ltd., “Report on Geotechnical Investigation, Burloak Water Purification Plant, Intake Tunnel, On-Land Section, The Regional Municipality of Halton. Vol. 2: Geotechnical Interpretation and Recommendations” Project No. G-04.1003A, dated February 2005.
- O’Connor Associates, “Environmental Site Assessment, Bronte Junction Facility, Burloak Drive, Oakville.” Job No. 10-6709, dated August 2003.
- Terraprobe Ltd., “Geotechnical Investigation, Upper Middle Road and Burloak Drive, Burlington, Ontario.” Project No. 7-05-0163, dated August 6, 2008.
- Terraprobe Ltd., “Additional Geotechnical Investigation, Upper Middle Road and Burloak Drive, Burlington, Ontario.” Project No. 7-05-0163-1, dated June 1, 2009.
- Thurber Engineering Ltd., “Geotechnical Investigation, Proposed 750 mm Watermain, Burloak Drive at QEW, Oakville, Ontario.” File No. 19-4717-0, dated February 21, 2006.
- Trow Consulting Engineers Ltd., “Geotechnical Investigation, Proposed Residential Development, Burloak Drive and Rebecca Street, Oakville, Ontario.” Project No. BRGE0060387a, dated June 22, 2001.
- Trow Consulting Engineers Ltd., “Geotechnical Evaluation, Proposed Road Construction, Rebecca Street and Great Lakes Blvd., Oakville, Ontario.” Project No. BRGE0058013f, dated February 27, 2002.

A geophysical survey of the Bronte Creek valley was presented by Coffey Geotechnics as an appendix to the September 2011 report on the subsurface conditions surrounding the valley. The geophysical survey was conducted by Geophysics GPR International Inc. (May 2010) for the purposes of conducting non-destructive testing of the depth to bedrock in the valley. The geophysical study is appended to the Coffey Geotechnics (September 2011) report.

Boreholes advanced as part of Terraprobe’s current (2012-13) investigative effort are named using the proposed watermain alignment chainage, and are shown on Figures 2A-F in red. Previously completed boreholes (by others) are accompanied by a prefix to denote which consultant advanced each borehole. The results of the individual boreholes from the 2012-13 investigation are recorded on the Borehole Logs in Appendix A. A summary of the 2012-13 geotechnical laboratory tests is provided as Appendix B. Rock core photographs are provided as Appendix C. Boreholes advanced within the vicinity of the proposed watermain during previous investigations are provided as Appendix D.

## 2.0 BACKGROUND REVIEW

### 2.1 Physiography and Geology

The study area for the proposed watermain gently slopes downward from Upper Middle Road (Elev. 145 ± m) to the south end of the alignment (Elev. 90 ± m) and continues sloping down to Lake Ontario, which is located around 1.5 km south of the study area. The high water level for Lake Ontario in this area is around Elev. 75 ± m. The alignment is intersected at around Stn. 5+900 by Bronte Creek, which has formed a 35-40 m deep valley in the bedrock.

The study area falls within two physiographic areas of Southern Ontario (Chapman and Putnam, *The Physiography of Southern Ontario*, 1984). The southern portion of the alignment from Burloak WPP to Mainway is located within the Iroquois Plain region. The northern half of the alignment is located within the South Slope region.

The study area and the surrounding region are characterized by shallow bedrock overlain by a thin glacial till deposit known as the Halton Till, which has a matrix of clay and silt. Bedrock formations underlying the study area are of Upper Ordovician age. The uppermost of these is the Queenston Formation (exposed along the Bronte Creek valley walls) which gradually overlies the Georgian Bay Formation. The tunnelled length of the proposed watermain is anticipated to be constructed entirely within the Queenston Formation.

The Queenston Formation is a dark red, low-fissility shale/siltstone with green mottling. The green mottled zones are occasionally harder than the softer red shale (which appears as recessive horizons along the Bronte Creek valley outcrop), possibly indicating a higher carbonate content which is called “limestone” by local convention. However, the Queenston shale within the study area is generally calcareous, and is interbedded with stronger calcareous sandstone and silty bioclastic carbonate (which are observed as the protruding horizons along the Bronte Creek valley outcrop)<sup>2</sup>. Minor amounts of gypsum, in nodules and laminae, are found throughout. These, along with occasional weathered clay seams and partings, indicate the presence of ground water within the bedrock.

The bedrock of the Georgian Bay Formation is a deposit predominantly comprised of thin to medium bedded grey shale. The shale contains interbedded light grey calcareous shale, limestone/dolostone and calcareous sandstone which are discontinuous and nominally 50 to 300 mm thick, but as much as 600 mm thick.

<sup>2</sup> Brogly, P.J., Martini, I.P., and Middleton, G.V. (1998). “The Queenston Formation: shale dominated, mixed terrigenous-carbonate deposits of Upper Ordovician, semiarid, muddy shores in Ontario, Canada.” *Can J. Earth Sci.* **35**: 702-719.

## 2.2 Bedrock Properties

A summary of information with respect to the Queenston Formation was presented in the Ontario Ministry of Transportation and Communications document RR229, *Evaluation of Shales for Construction Projects* (March 1983), as follows.

**Table 2-1: Summary of Parameters (MTO 1983), Queenston Formation**

	Uniaxial Compressive Strength (MPa)	Young's Modulus (GPa)	Dynamic Modulus (GPa)	Poisson's Ratio
Average	8.7	1.3	n/a	0.32
Range	7.2 to 9.6	0.5 to 2.3	n/a	0.28 to 0.35

A summary of information with respect to the Georgian Bay Formation was presented in document RR229, *Evaluation of Shales for Construction Projects* (March 1983), as follows.

**Table 2-2: Summary of Parameters (MTO 1983), Georgian Bay Formation**

	Uniaxial Compressive Strength (MPa)	Young's Modulus (GPa)	Dynamic Modulus (GPa)	Poisson's Ratio
Average	28	4.0	19	0.19
Range	8 to 41	0.5 to 12	6 to 38	0.1 to 0.25

There is typically a zone of weathering at the contact between the rock of the Queenston Formation and the glacial soil overburden. In document RR229, *Evaluation of Shales for Construction Projects*, there is a typical weathering profile of a low durability shale reproduced from Skempton, Davis, and Chandler, that characterizes the shale surface into three grades of weathering and four zones described as follows.

**Table 2-3: Typical Weathering Profile of Low Durability Shale**

	Zone	Description	Notes
<b>Fully Weathered</b>	IVb	soil like matrix only	indistinguishable from glacial drift deposits, slightly clayey, may be fissured
<b>Partially Weathered</b>	IVa	soil like matrix with occasional pellets of shale less than 3 mm dia.	little or no trace of rock structure, although matrix may contain relic fissures
	III	soil like matrix with frequent angular shale particles up to 25 mm dia.	moisture content of matrix greater than the shale particles
	II	angular blocks of unweathered shale with virtually no matrix separated by weaker chemically weathered but intact shale	spheroidal chemical weathering of shale pieces emanating from relic joints and fissures, and bedding planes
<b>Unweathered (Sound)</b>	I	shale	regular fissuring

The surface of the rock having been scoured and involved by the base of glacial ice, Shale Zone III and IV are not present in an identifiable form. At the base of the overlying glacial till deposit in the Oakville/Burlington area, there is sometimes found a zone of till and fragmented shale that can be interpreted as the lowest portion of the till or as partially weathered rock of Zone III. The distinction is subjective and depends on the investigator. The differences between the partially weathered classes of rock are not profound.

The jointing and crush zones in the rock are related to the state of stress in the deposit. Research in the Greater Toronto Area has revealed that the bedrock contains locked in horizontal stresses that could be remnants of the for-shortening that occurred in the earth's crust during continental glaciation several thousand years ago. Documented experiments have indicated that the major principal stress is of the order of 2 MPa in the upper 1 to 2 metres of the deposit where the rock is weathered and contains more fractures. Intact rock can have an internal major principal stress as high as 4 to 5 MPa.

The Queenston Formation produces nominally small quantities of gas when penetrated, which are addressed with constant ventilation. While there was no specific indication of gas emissions from the borings made in this investigation, the potential for gas emissions from this formation is recognized as a design issue to be addressed with proper ventilation. It should be noted that the underlying Georgian Bay Formation has been known to issue gases when penetrated. There are instances where both methane and hydrogen sulphide gas emissions have been detected in excavations made in the Georgian Bay Formation.

## **2.3 Previous Geotechnical Investigations**

Terraprobe was provided with ten (10) previous geotechnical investigation reports, as outlined in Section 1.3. A total of seventy-seven (77) boreholes were advanced as part of these investigations, within close proximity to the proposed watermain.

Some of the previous geotechnical reports were prepared for purposes including roadway construction (Terraprobe 2008, Terraprobe 2009, Trow 2002), residential subdivision construction (Trow 2001), Environmental Site Assessment (O'Connor 2003), open-cut watermain construction (Thurber 2006), and Burloak WPP intake tunnel construction (Geo-Canada 2005). Sixty-six (66) of the 77 previous boreholes were advanced for these purposes within close proximity of the proposed watermain alignment.

Previous geotechnical reports by other consultants pertaining to the proposed Zone 1 watermain were prepared by Coffey Geotechnics for the Zone 2 BPS (November, 2011) and for the Bronte Creek crossing (September, 2011). Eleven (11) of the 77 previous boreholes were advanced as part of the present project, and pertain directly to the proposed construction.

Each of the previously-advanced borehole locations are shown in blue on the Borehole Plan and Profile provided as Figures 2A-F. The log of each previously-advanced borehole was reproduced by Terraprobe

for uniformity of scale and data presentation. The factual data from each of the previous investigations is presented on the attached Log of Borehole sheets as Appendix D. For the purposes of clarity, boreholes that were not advanced by Terraprobe have a prefix attached to the borehole ID, to indicate which consultant originally reported it. A summary of previously-advanced boreholes is provided in the following table.

**Table 2-4: Summary of Previously-Advanced Boreholes**

Consultant	Borehole ID prefix	No. of boreholes included <sup>3</sup>	Area	Year reported	Encountered tunnel elevation?	Rock coring
Coffey Geotechnics Inc.	COF-BC-	4	BCPP, at valley crossing	2011	Yes	4 boreholes, started at 3 – 5 m BG
Coffey Geotechnics Inc.	COF-	7	Zone 2 BPS, Main Shaft	2011	No <sup>4</sup>	1 borehole, started at 6 m BG
Geo-Canada Ltd.	GC-	3	Burloak WPP	2005	Yes	3 boreholes, started at 3 – 5 m BG
O'Connor Associates	OCON-	11	Upper Middle Rd. and Burloak Dr.	2003	No	8 boreholes, started at 1 – 4 m BG
Terraprobe Inc.	TER-	19	Burloak Dr.	2008, 2009	No	No rock coring
Thurber Ltd.	THU-	12	Zone 2 WM at QEW	2006	No	12 boreholes, started at 2 – 8 m BG
Trow Consulting Engineers Ltd.	TRW-	21	Great Lakes Blvd.	2001, 2002	No	No rock coring

The boreholes were made along the portion of alignment along Burloak Drive/Great Lakes Blvd. (Stn. 1+000 to 5+500), with the exception of the four Coffey boreholes (COF-BC-1 to COF-BC-4) located adjacent to Bronte Creek for the purpose of characterizing the valley crossing.

Twenty-eight (28) of the 77 boreholes recovered rock core. The interpretation and reporting of sound/unweathered bedrock varies between consultants, and the distinction is subjective and depends on the investigator. Generally, the boreholes encountered a 2 to 6 m thick layer of weathered bedrock (both inferred and directly observed from rock cores) at the top of bedrock.

<sup>3</sup> Refers to the number of borehole logs included in this report. Fewer boreholes may be provided in profiles (Figures 2A-F).

<sup>4</sup> Coffey Geotechnics boreholes at the Zone 2 BPS were advanced in the vicinity of the proposed shaft.

### 3.0 FIELD PROCEDURE

The Terraprobe geotechnical field investigation for this study was conducted from August 7, 2012, to February 5, 2013. A total of twenty-eight (28) exploratory boreholes were drilled and sampled, and extended to depths ranging from 4.0 to 70.1 metres below existing grade. Twenty (20) of the boreholes recovered rock core; those cored boreholes were advanced to elevations ranging from Elev. 67.4 to 113.0 m. Eight (8) of the boreholes were advanced through overburden soil and weathered bedrock only, for the purpose of providing overburden and top of bedrock information.

### 3.1 Borehole Schedule

The borehole schedule was created in consultation with R.V. Anderson, and was determined based on several factors including the possibility of open-cut construction, proximity to proposed shafts, proximity to sensitive areas (e.g. Bronte Creek, CN tracks, MTO lands, Hydro One easement), as well as other considerations. The following table provides a summary of the present investigation borehole schedule, comprising twenty-eight (28) boreholes:

**Table 3-1: Terraprobe (2013) Borehole Schedule**

Borehole ID	Geographical Location	Ground Elevation (m)	Bottom Elevation (m)	Total Depth (m)	Length of Rock Coring (m)	Rock Core Size	Monitoring Wells <sup>5</sup>
BH 0+940	<b>SHAFT: Burloak WPP</b>	91.3	80.6	10.7	n/a	n/a	
BH 1+080	Rebecca St.	91.2	87.1	4.2	n/a	n/a	
BH 1+200	Great Lakes Blvd. @ Rebecca St.	92.1	70.6	21.6	17.0	HQ (64 mm)	Shallow and deep 50 mm MW
BH 1+615	Great Lakes Blvd.	96.6	70.2	26.4	22.0	HQ (64 mm)	
BH 1+720	Great Lakes Blvd.	96.1	91.4	4.7	n/a	n/a	
BH 2+020	Burloak Dr.	99.2	95.2	4.0	n/a	n/a	
BH 2+055	Burloak Dr.	99.9	70.4	29.6	25.0	HQ (64 mm)	
BH 2+240	Burloak Dr.	102.0	96.6	5.5	n/a	n/a	
BH 2+335	Burloak Dr.	103.0	96.9	6.2	n/a	n/a	
BH 2+425	Hydro One Crossing Burloak Dr.	103.7	68.7	35.1	31.8	HQ (64 mm)	Shallow and deep 50 mm MW
BH 2+585	CNR crossing Burloak Dr.	105.7	67.6	38.1	35.2	HQ (64 mm)	

<sup>5</sup> "Shallow" wells are screened at the bedrock-overburden contact, whereas "deep" wells are screened within the bedrock.

Borehole ID	Geographical Location	Ground Elevation (m)	Bottom Elevation (m)	Total Depth (m)	Length of Rock Coring (m)	Rock Core Size	Monitoring Wells <sup>5</sup>
BH 2+640	CNR crossing Burloak Dr.	105.6	67.4	38.2	35.3	HQ (64 mm)	Deep 50 mm MW
BH 3+065	<b>SHAFT: Main Shaft</b>	112.6	71.4	41.2	38.4	HQ (64 mm)	Shallow and deep 50 mm MW
BH 3+450	QEW crossing Burloak Dr.	119.7	67.8	52.0	47.4	HQ (64 mm)	
BH 3+930	Burloak Dr. @ N. Service Rd.	127.6	68.6	59.1	55.7	HQ (64 mm)	
BH 4+495	Burloak Dr. @ Mainway Rd.	131.4	72.2	59.2	55.1	HQ (64 mm)	Shallow and deep 50 mm MW
BH 4+990	Burloak Dr.	137.2	71.6	65.6	60.9	HQ (64 mm)	
BH 5+060	<b>SHAFT: Ontario Parks</b>	138.1	71.2	66.9	62.5	HQ (64 mm)	Shallow and deep 50 mm MW
BH 5+855	BCPP valley crossing	106.3	95.5	10.8	6.6	Other (76 mm)	
BH 5+885	BCPP valley crossing	105.6	95.9	9.7	7.4	Other (76 mm)	
BH 5+900	BCPP valley crossing	105.8	95.7	10.1	7.5	Other (76 mm)	
BH 5+935	BCPP valley crossing	105.4	96.2	9.1	7.8	Other (76 mm)	
BH 6+390	BCPP East of valley	139.2	69.1	70.1	65.3	NQ (48 mm)	
BH 7+020	Upper Middle Rd.	134.8	113.0	21.7	17.2	HQ (64 mm)	
BH 7+145	Upper Middle Rd. @ Col. Williams Pkwy	132.8	71.5	61.2	49.1	HQ (64 mm)	Shallow and deep 50 mm MW
BH 7+165x	Upper Middle Rd. @ Trawden Way	131.4	121.6	9.8	n/a	n/a	
BH 7+250x	Trawden Way @ Kitchen Reservoir	131.4	123.2	8.2	n/a	n/a	
BH 7+270	<b>SHAFT: Kitchen Reservoir</b>	132.8	84.4	48.4	37.3	HQ (64 mm)	Shallow and deep 50 mm MW

Boreholes 7+165x and 7+250x were advanced for an alternative alignment (since superceded) which extended past Colonel Williams Parkway to Trawden Way, and then north to the front of Kitchen Reservoir. These boreholes IDs are appended with an “x” to denote their offset from the PDR alignment.

## 3.2 Drilling Procedure

Borehole locations and elevations outside of the valley were surveyed using DGPS (minimum accuracy: 5 ± cm vertical, 2 ± cm horizontal) by Strata Survey Inc. and provided to Terraprobe. Boreholes advanced within the Bronte Creek valley were surveyed by Terraprobe by transit level, using survey stakes of

known location and elevation as laid out by Halton Region's surveyor. Borehole 5+060 was surveyed by Underground Engineering Services (at the request of RVA) and provided to Terraprobe. Elevations are provided relative to vertical geodetic datum (NAD 83). Borehole locations are provided relative to the Universal Transverse Mercator geographic coordinate system (UTM Zone 17T).

The drilling work was carried out by a drilling contractor and was observed and recorded by Terraprobe on a full time basis. The samples of the penetrated overburden soil and weathered bedrock strata were obtained using the Split-Barrel Method technique (ASTM D1586). The samples were taken at intervals. The conventional interval sampling procedure used for this investigation does not recover continuous samples of soil at any borehole location. There is consequently some interpolation of the borehole layering between samples and indications of changes in stratigraphy as shown on the borehole logs are approximate.

In general, the boreholes were advanced using solid and hollow stem augers, and HQ- and NQ-sized rock coring equipment. Some of the boreholes (BH 3+930, BH 4+495, and BH 6+390) were daylighted to expose/protect adjacent underground utilities, as directed by the utility owners.

The boreholes within Bronte Creek valley (BHs 5+855, 5+885, 5+900, and 5+935) were advanced through overburden by hand auger, and cored using restricted-access rock coring equipment with a non-standard bit size (O.D. = 89 mm, I.D. = 76 mm).

The Terraprobe technician logged the boreholes and examined the samples as they were obtained. The soil samples obtained were sealed in clean, air-tight containers and transferred to the Terraprobe laboratory, where they were reviewed for consistency of description by a geotechnical engineer. Laboratory testing consisted of water content determination on all soil samples. Sieve, hydrometer and Atterberg Limits tests were conducted on selected soil samples. The measured natural water content for individual samples are plotted on the corresponding borehole logs at respective sampling depths, and the results of the geotechnical laboratory analyses from the current investigation are provided in Appendix B.

The rock core samples were labelled and photographed in the field before being transported to the Terraprobe laboratory, where they were reviewed for consistency of description and accuracy of measurement by a geotechnical engineer. Rock Quality Designation (RQD) was measured in the field prior to transport, and was verified in the lab. Unconfined compressive strength (UCS) and bulk density tests were performed by Terraprobe on selected samples of rock. Samples were selected for testing based on their depths, and the location of the tunnelling zone as well as the potential presence of a shaft at that location. The measured UCS and bulk densities for individual samples are plotted on the corresponding rock core logs, as provided in Appendix A along with Terraprobe's rock core terminology and abbreviation sheet. Core photographs taken in the field are provided as Appendix C.

Laboratory tests to determine the swell potential and swell pressure of the bedrock were conducted by an external laboratory. The results of the swell potential testing are provided as Appendix E.

### **3.3 Water Levels**

Water levels were monitored in the open boreholes upon completion of drilling, with the exception of boreholes that were filled with drilling fluid upon completion. Standpipe type wells consisting of 50 mm PVC tubing were installed in selected boreholes advanced to facilitate shallow and deep ground water monitoring. The PVC tubing is slotted near its base and fitted with a bentonite clay seal as shown on the accompanying borehole logs. The water levels in the wells were measured several times after ground water levels had stabilized. The most recent results of the stabilized ground water monitoring are summarized in Section 4.4 of this report. A complete summary of water level measurements made across the site is provided as Appendix F.

### **3.4 Geological Mapping**

Geological engineers from Terraprobe visited the Bronte Creek valley on November 5, 2012. The purpose of this site visit was to delineate the presence of jointing within a partially weathered and exposed bedrock outcrop approximately 400 metres northeast of the boreholes advanced within the Bronte Creek valley, and approximately 50 metres southeast of the proposed watermain alignment. The outcrop consists of red shale of the Queenston Formation. Visible joints were mapped to identify joint sets and establish joint set orientation (strike and dip).

## 4.0 SUBSURFACE CONDITIONS

The subsurface soil, rock and ground water conditions encountered in the boreholes (105 total) are presented on the attached Log of Borehole sheets as Appendix A (present investigation, 28 boreholes total) and Appendix D (previous investigations, 77 boreholes total). Photographs of the recovered rock core from the 2013 investigation are provided in Appendix C. A terminology guide is provided as part of Appendix A.

The stratigraphic boundaries indicated on the Terraprobe Log of Borehole sheets are inferred from non-continuous samples and observations of drilling resistance and typically represent a transition from one soil or rock type to another. These boundaries should not be interpreted to represent exact planes of geological change. The subsurface conditions have been confirmed in a series of widely spaced boreholes, and will vary between and beyond the borehole locations. The discussion has been simplified in terms of the major soil and rock strata for the purposes of geotechnical design.

It should be noted that the subsurface conditions are confirmed at the borehole locations only, and may vary at other locations, particularly with respect to depth and condition of earth fill and topsoil. The topsoil thickness indicated on the borehole logs is approximate only and should not be used in estimating quantities of depths of topsoil for stripping purposes. A series of test pits should be excavated if a better assessment of anticipated topsoil stripping depths and quantities is required.

The following stratigraphy is based on the borehole findings from both the present and previous investigations, as well as the geotechnical laboratory testing conducted on selected representative soil and rock samples.

### 4.1 Overburden

All of the 105 boreholes encountered overburden soils, which vary in composition widely and generally consist of glacial till deposits with a matrix predominantly comprising clayey silt. Most of the boreholes (84 of 105) encountered surficial earth fill, pavement structure, and/or topsoil. A thicker layer of overburden was observed along the portion of alignment from 7+000 to the Kitchen Reservoir shaft. The following table summarizes the quantities of overburden encountered in the boreholes, along with the Standard Penetration Test (SPT) results (N-values).

**Table 4-1: Summary of Overburden Thicknesses, All Boreholes**

	Burloak WPP Shaft to Stn. 7+000			Stn. 7+000 to Kitchen Reservoir Shaft		
	Earth Fill* (thickness, m)	Native Overburden Soils (thickness, m)	N-value, native soils	Earth Fill (thickness, m)	Native Overburden Soils (thickness, m)	N-value, native soils
<b>Average</b>	0.8	1.2	30	2.1	8.2	47
<b>Standard Deviation</b>	1.0	0.9	20	0.7	2.2	21
<b>Minimum</b>	0.0	0.0	2	1.5	5.9	14
<b>Maximum</b>	4.4	4.5	100	3.0	10.5	104
<b>No. of Boreholes</b>	101			4		

\* Includes surficial fill, pavements, and earth fill materials.

The four (4) shaft locations are summarized in Table 1-1. The overburden encountered at each of the four shaft locations is summarized in the following table.

**Table 4-2: Summary of Overburden at Shaft Locations**

Station	Shaft Location	Boreholes	Earth Fill*		Native Soils	
			Thickness (m)	N-value Avg. (Range)	Thickness (m)	N-value Avg. (Range)
1+000	<b>Burloak WPP Shaft</b>	BH 0+940, GC-A, GC-C	1.5 to 2.3	13 (9 to 18)	0.75 to 1.5	39 (17 to >50)
3+085	<b>Main Shaft</b>	BH 3+065, COF-1 to COF-7	0 to 1.5	12 (7 to 30)	0.7 to 1.5	over 50 (10 to 100)
4+981	<b>Ontario Parks Shaft</b>	BH 4+990, BH 5+060	0 to 1.0	20	0 to 1.5	22
7+300	<b>Kitchen Reservoir Shaft</b>	BH 7+270	1.5	6 to 19	9.6	44 (29 to >50)

\* Includes surficial fill, pavements, and earth fill materials.

The native overburden from 0+900 to 7+000 was generally observed to be the reddish brown glacial till deposits known as the Halton Till. This till deposit is characterized by a matrix of silt to clayey silt, a reddish brown to red colour, and a damp to moist state. Shale fragments were frequently observed in the Halton Till. Four of the boreholes (BH 7+165x, OCON-18, OCON-19, and THU-WM5) encountered wet silts within this layer, and twelve (12) of the boreholes encountered greyish to grey soils.

Thicker glaciolacustrine deposits of relatively coarse-grained soils were observed towards the end of the proposed alignment near the Kitchen Reservoir, comprising deposits of silts, sands, and gravelly sands from post-glacial deltas. The glaciolacustrine deposits, where observed, were 5 to 6 metres thick and were overlain by the Halton Till. SPT N-values measured in the glaciolacustrine soils were on average over 50 blows per 300 mm of penetration, but ranged from 47 to 104.

Geotechnical laboratory testing was conducted on selected representative soil samples for the purpose of soil identification. The results of the geotechnical laboratory soil testing are provided as Appendix B.

## **4.2 Queenston Formation**

Bedrock was encountered/inferred in 100 of the 105 boreholes. Of these, forty-eight (48) boreholes recovered and logged rock core, and directly observed bedrock.

The bedrock underlying the overburden within the study area is of the Queenston Formation. The bedrock of the Queenston Formation is a deposit predominantly comprising thin to medium bedded red shale/siltstone, with green mottling, of Ordovician age. The shale is generally calcareous with low fissility and contains interbedded harder bands of calcareous shale, limestone/dolostone and calcareous sandstone ("limestone"), which are discontinuous and nominally 50 to 300 mm thick. The shale is a relatively low strength (weak) rock, whereas the harder calcareous beds are generally considered medium strength rock.

### **4.2.1 Weathering**

A detailed description of weathered bedrock and shale weathering profiles may be found in Section 2.2. Where rock core was not retrieved, inferred bedrock was defined based on auger cuttings, samples from split spoons, and drilling observations alone. Inferred bedrock is grouped together with weathered bedrock on the basis that sound bedrock was not directly observed and that inferred bedrock occurs immediately underlying overburden soils, within the weathering zone.

Weathered bedrock was encountered/inferred in ninety-nine (99) of the boreholes. The top of weathered/inferred bedrock was encountered at between 0.6 and 12.1 m below grade. Boreholes encountered varying thicknesses of weathered/inferred bedrock at bedrock elevation, which was on average 2.6 m but ranged from 0.1 to 8.7 m (inferred from Borehole GC-A). Standard Penetration Test (SPT) results (N-values) measured in the weathered bedrock were generally over 50 blows per 300 mm of penetration.

Generally, weathered bedrock was observed overlying the sound bedrock. Occasional weathering zones were also observed within the sound bedrock. For discussion purposes, weathered bedrock depths and thicknesses in this section refer to the portion of overlying weathered bedrock only.

The surface of the rock having been scoured and involved by the base of glacial ice, Shale Zone III and IV are not present in an identifiable form. At the base of the glacial till deposit, there is sometimes found a zone of silt and fragmented shale that can be interpreted as the lowest portion of the till or as partially weathered rock of Zone III. The distinction is subjective and depends on the investigator. A summary of bedrock elevations is tabulated as follows.

**Table 4-3: Summary of Bedrock Depths and Elevations**

Borehole ID	Ground Elev. (m)	Top of Weathered Bedrock Depth / Elevation (m)	Top of Sound Bedrock Depth / Elevation (m)	Method of observation
BH 0+940	91.3	3.8 / 87.5	n/a	Auger cuttings & drilling observations
BH 1+080	91.2	3.5 / 87.7	n/a	Auger cuttings & drilling observations
BH 1+200	92.1	2.3 / 89.8	5.0 / 87.1	Recovered rock core
BH 1+615	96.6	3.1 / 93.6	6.0 / 90.6	Recovered rock core
BH 1+720	96.1	2.5 / 93.6	n/a	Auger cuttings & drilling observations
BH 2+020	99.2	1.9 / 97.4	n/a	Auger cuttings & drilling observations
BH 2+055	99.9	0.8 / 99.2	4.6 / 95.4	Recovered rock core
BH 2+240	102.0	2.3 / 99.8	n/a	Auger cuttings & drilling observations
BH 2+335	103.0	3.0 / 100.0	n/a	Auger cuttings & drilling observations
BH 2+425	103.7	1.5 / 102.2	6.0 / 97.7	Recovered rock core
BH 2+585	105.7	1.5 / 104.2	6.9 / 98.8	Recovered rock core
BH 2+640	105.6	1.5 / 104.1	7.7 / 97.9	Recovered rock core
BH 3+065	112.6	0.8 / 111.8	4.2 / 108.4	Recovered rock core
BH 3+450	119.7	1.7 / 118.0	6.8 / 112.9	Recovered rock core
BH 3+930	127.6	3.3 / 124.3	8.0 / 119.6	Recovered rock core
BH 4+495	131.4	2.4 / 129.0	6.4 / 125.0	Recovered rock core
BH 4+990	137.2	1.0 / 136.2	8.4 / 128.8	Recovered rock core
BH 5+060	138.1	1.5 / 136.6	9.3 / 128.8	Recovered rock core
BH 5+855	106.3	4.3 / 102.0	4.8 / 101.5	Recovered rock core
BH 5+885	105.6	2.3 / 103.3	3.0 / 102.6	Recovered rock core
BH 5+900	105.8	2.6 / 103.2	4.2 / 101.6	Recovered rock core
BH 5+935	105.4	1.3 / 104.1	2.8 / 102.6	Recovered rock core
BH 6+390	139.2	1.5 / 137.7	5.8 / 133.4	Recovered rock core
BH 7+020	134.8	2.3 / 132.5	8.4 / 126.4	Recovered rock core
BH 7+145	132.8	12.1 / 120.7	15.4 / 117.4	Recovered rock core
BH 7+270	132.8	11.1 / 121.7	11.2 / 121.6	Recovered rock core
BH 7+165x	131.4	n/a	n/a	Bedrock not encountered
BH 7+250x	131.4	n/a	n/a	Bedrock not encountered
COF-1	115.4	2.3 / 113.1	6.2 / 109.2	Recovered rock core
COF-2	116.5	2.3 / 114.2	n/a	Auger cuttings & drilling observations (by others)
COF-3	115.7	2.5 / 113.2	n/a	Auger cuttings & drilling observations (by others)
COF-4	116.6	3.0 / 113.6	n/a	Auger cuttings & drilling observations (by others)
COF-5	112.6	n/a	n/a	Bedrock not encountered
COF-6	112.6	2.3 / 110.3	n/a	Auger cuttings & drilling observations (by others)
COF-7	113.7	2.3 / 111.4	n/a	Auger cuttings & drilling observations (by others)
COF-BC-1	144.5	1.5 / 143.0	6.2 / 138.3	Recovered rock core
COF-BC-2	142.4	4.6 / 137.8	6.8 / 135.6	Recovered rock core
COF-BC-3	138.6	1.5 / 137.1	8.0 / 130.6	Recovered rock core
COF-BC-4	139.1	1.5 / 137.6	7.6 / 131.5	Recovered rock core

Borehole ID	Ground Elev. (m)	Top of Weathered Bedrock Depth / Elevation (m)	Top of Sound Bedrock Depth / Elevation (m)	Method of observation
GC-A	89.9	2.3 / 87.6	11.0 / 78.9	Recovered rock core
GC-B	91.0	2.7 / 88.3	8.0 / 83.0	Recovered rock core
GC-C	89.3	2.4 / 86.9	7.8 / 81.5	Recovered rock core
OCON-10	144.2	0.9 / 143.3	1.3 / 142.9	Recovered rock core
OCON-11	145.4	1.1 / 144.4	1.4 / 144.0	Recovered rock core
OCON-12	145.1	1.4 / 143.8	1.5 / 143.6	Recovered rock core
OCON-14	144.7	1.3 / 143.4	n/a	Auger cuttings & drilling observations (by others)
OCON-16	143.4	1.2 / 142.2	1.5 / 141.9	Recovered rock core
OCON-18	145.0	n/a	n/a	Bedrock not encountered
OCON-19	145.0	n/a	n/a	Bedrock not encountered
OCON-4	145.0	1.5 / 143.6	1.4 / 143.6	Recovered rock core
OCON-7	144.5	2.0 / 142.5	2.2 / 142.3	Recovered rock core
OCON-8	145.5	1.0 / 144.5	1.7 / 143.8	Recovered rock core
OCON-9	144.8	3.4 / 141.5	3.7 / 141.1	Recovered rock core
TER-1	125.8	1.6 / 124.2	n/a	Auger cuttings & drilling observations (by others)
TER-101	127.7	0.9 / 126.8	n/a	Auger cuttings & drilling observations (by others)
TER-102	128.4	1.4 / 127.0	n/a	Auger cuttings & drilling observations (by others)
TER-103	128.1	2.2 / 126.0	n/a	Auger cuttings & drilling observations (by others)
TER-104	131.0	1.9 / 129.1	n/a	Auger cuttings & drilling observations (by others)
TER-105	132.5	2.4 / 130.1	n/a	Auger cuttings & drilling observations (by others)
TER-106	135.8	2.2 / 133.6	n/a	Auger cuttings & drilling observations (by others)
TER-107	137.8	1.5 / 136.3	n/a	Auger cuttings & drilling observations (by others)
TER-108	143.0	2.3 / 140.7	n/a	Auger cuttings & drilling observations (by others)
TER-109	142.9	1.7 / 141.3	n/a	Auger cuttings & drilling observations (by others)
TER-110	128.1	1.6 / 126.5	n/a	Auger cuttings & drilling observations (by others)
TER-2	129.5	2.2 / 127.3	n/a	Auger cuttings & drilling observations (by others)
TER-201	144.0	1.5 / 142.5	n/a	Auger cuttings & drilling observations (by others)
TER-202	143.5	0.8 / 142.7	n/a	Auger cuttings & drilling observations (by others)
TER-203	142.0	0.8 / 141.2	n/a	Auger cuttings & drilling observations (by others)
TER-3	134.1	1.9 / 132.2	n/a	Auger cuttings & drilling observations (by others)
TER-4	139.9	1.5 / 138.4	n/a	Auger cuttings & drilling observations (by others)
TER-5		2.3	n/a	Auger cuttings & drilling observations (by others)
TER-6		2.2	n/a	Auger cuttings & drilling observations (by others)
THU-HML-16/16A	118.1	4.1 / 114.0	8.4 / 109.7	Recovered rock core
THU-UC1	118.9	1.4 / 117.5	4.6 / 114.3	Recovered rock core
THU-WM1	106.9	2.3 / 104.6	3.0 / 103.9	Recovered rock core
THU-WM10	123.9	1.7 / 122.2	3.0 / 120.9	Recovered rock core
THU-WM2	107.7	1.4 / 106.3	3.6 / 104.1	Recovered rock core
THU-WM3	110.2	1.4 / 108.8	2.4 / 107.8	Recovered rock core

Borehole ID	Ground Elev. (m)	Top of Weathered Bedrock Depth / Elevation (m)	Top of Sound Bedrock Depth / Elevation (m)	Method of observation
THU-WM4	112.9	2.1 / 110.8	5.0 / 107.9	Recovered rock core
THU-WM5	116.1	6.4 / 109.7	6.7 / 109.4	Recovered rock core
THU-WM6	118.4	4.3 / 114.1	9.8 / 108.6	Recovered rock core
THU-WM7	118.3	0.7 / 117.6	7.2 / 111.1	Recovered rock core
THU-WM8	121.1	2.2 / 118.9	5.4 / 115.7	Recovered rock core
THU-WM9	121.8	1.3 / 120.6	8.2 / 113.6	Recovered rock core
TRW-1	90.2	1.5 / 88.7	n/a	Auger cuttings & drilling observations (by others)
TRW-29	100.1	4.0 / 96.1	n/a	Auger cuttings & drilling observations (by others)
TRW-37	98.9	1.6 / 97.3	n/a	Auger cuttings & drilling observations (by others)
TRW-45	97.6	2.5 / 95.1	n/a	Auger cuttings & drilling observations (by others)
TRW-46	96.5	1.5 / 95.0	n/a	Auger cuttings & drilling observations (by others)
TRW-53	95.7	0.8 / 94.9	n/a	Auger cuttings & drilling observations (by others)
TRW-54	95.9	0.6 / 95.3	n/a	Auger cuttings & drilling observations (by others)
TRW-55	95.6	0.9 / 94.7	n/a	Auger cuttings & drilling observations (by others)
TRW-63	94.3	1.5 / 92.8	n/a	Auger cuttings & drilling observations (by others)
TRW-64	94.4	1.5 / 92.9	n/a	Auger cuttings & drilling observations (by others)
TRW-67	94.8	1.8 / 93.0	n/a	Auger cuttings & drilling observations (by others)
TRW-71	93.3	1.1 / 92.2	n/a	Auger cuttings & drilling observations (by others)
TRW-72	93.4	1.3 / 92.1	n/a	Auger cuttings & drilling observations (by others)
TRW-73	93.0	1.0 / 92.0	n/a	Auger cuttings & drilling observations (by others)
TRW-77	92.6	1.2 / 91.4	n/a	Auger cuttings & drilling observations (by others)
TRW-80	91.9	1.6 / 90.3	n/a	Auger cuttings & drilling observations (by others)
TRW-81	92.6	4.0 / 88.6	n/a	Auger cuttings & drilling observations (by others)
TRW-85	91.4	1.6 / 89.8	n/a	Auger cuttings & drilling observations (by others)
TRW-86	91.3	0.9 / 90.4	n/a	Auger cuttings & drilling observations (by others)
TRW-88	90.8	1.3 / 89.5	n/a	Auger cuttings & drilling observations (by others)
TRW-94	98.5	2.1 / 96.4	n/a	Auger cuttings & drilling observations (by others)

Sound bedrock was observed at depths ranging from 1.3 to 15.4 m below grade. In these boreholes, rock cores were recovered to depths ranging from 4.6 to 70.1 m below grade.

The borehole findings observed a thicker overburden layer along the portion of alignment from Station 7+000 (approximately) to the Kitchen Reservoir shaft. The depth to bedrock within this area is compared with the rest of the alignment in the following table.

**Table 4-4: Variations in Bedrock Depth, before and after Stn. 7+000**

	Burloak WPP to Stn. 7+000		Stn. 7+000 to Kitchen Reservoir	
	Weathered bedrock, depth (m)	Sound bedrock, depth (m)	Weathered bedrock, depth (m)	Sound bedrock, depth (m)
<b>Average</b>	<b>2.0</b>	<b>5.7</b>	<b>11.6</b>	<b>13.3</b>
<b>Standard Deviation</b>	1.0	3.0	n/a	n/a
<b>Minimum</b>	0.6	1.3	11.1	11.2
<b>Maximum</b>	6.4	15.0	12.1	15.4
<b>No. of Boreholes</b>	98	46	2	2

Terraprobe boreholes observed occasional weathered seams and joints within the sound bedrock. These seams and joints were typically infilled with wet clay, and were open. Other weathered seams were characterized by low RQD, water, reduced field strength, or a combination thereof. Weathered parting thicknesses ranged from 0.1 to 2.0 m, but were on average 0.5 m thick. Planar horizontal joints with gypsum infill (usually gapped) were also frequently observed.

The sound and weathered bedrock depths encountered at each of the five shaft locations is summarized in the following table.

**Table 4-5: Summary of Bedrock at Shaft Locations**

Station	Shaft Location	Boreholes	Weathered bedrock encountered at		Sound bedrock encountered at	
			Depth (m)	Elevation (m)	Depth (m)	Elevation (m)
1+000	<b>Burloak WPP Shaft</b>	BH 0+940, GC-A	3.0 (2.3 to 3.8)	87.5 ±	8.0	82 ±
3+085	<b>Main Shaft</b>	BH 3+065, COF-1 to COF-7	2.2 (0.8 to 3.0)	112.5 ± (110.3 to 114.2)	5.1 (4.2 to 6.0)	109 ± (108.4 to 109.4)
4+981	<b>Ontario Parks Shaft</b>	BH 4+990, BH 5+060	1.2 (1.0 to 1.5)	136.5 ± (136.2 to 136.6)	8.9 (8.4 to 9.3)	128.8 ±
7+300	<b>Kitchen Reservoir Shaft</b>	BH 7+270	11.1	121.7 ±	11.2	121.6 ±

## 4.2.2 Calcareous Beds

Twenty-eight (28) of the boreholes recorded the location and quantity of stronger calcareous beds. The percentage of stronger calcareous beds (“limestone”, or “hard layers”) encountered is reported on the rock core logs where they were observed. The percentage of harder calcareous beds (“limestone”) found in the Queenston Formation, where it was measured over the entire borehole (20 boreholes total), ranged from

7% to 21% (on average 15%). Where it was measured on a per run basis (8 boreholes total, generally 1.5 m/run), the percentage of limestone found in the Queenston Formation ranged from 0% to 60% (on average 16%).

#### **4.2.3 Discontinuities, RQD**

The bedding of the Queenston Formation is generally flat lying. There are known to be orthogonal subvertical joint sets within the shale. Sometimes associated with the principal directions of these joint sets, there are stress relief features found within the formation. These zones (commonly referred to as shear zones) manifest themselves as vertically oriented zones of rock rubble. These features defy discovery in borehole investigations. Joints occurring within the Queenston shale are closely spaced to moderately close, and occasionally weathered with a veneer to coating of clay. Widely-spaced subvertical joints (closed, planar, clean) were also observed within the shale.

Natural fracture frequency refers to the number of natural fractures per 0.3 m of recovered core. It does not include mechanical or drill-induced breaks in the core. Within weathered bedrock of the Queenston Formation, the natural fracture frequency ranges from 0 to over 25 fractures per 0.3 m of core, and is on average 4 fractures/0.3 m of core. Within the sound Queenston Formation bedrock, the natural fracture frequency ranges from 0 to over 10 fractures per 0.3 m of core, and is on average 1 fracture/0.3 m of core.

Rock Quality Designation (RQD) refers to the total length of those pieces of sound core which are 100 mm or greater in length in a core run, expressed as a percentage of the total length of that core run. Sound pieces of rock are those pieces separated by natural fractures or bedding partings, and not machine-induced or artificial breaks. RQD can be an inaccurate indicator of the condition of shale and other stratified, sedimentary rock. Since the bedding is horizontal in this formation, and there are many bedding layers within this rock mass, the measured RQD is typically low and is a function of the regular repeating bedding planes, not of stress induced fractures leading to a weaker rock mass. The results of this investigation in this regard are typical for the formation.

The measured RQD in this type of stratified rock can vary significantly by altering the drilling process, as aggressive drilling can break sound rock along closed discontinuities or bedding planes. The distinction between mechanical/induced fractures and natural discontinuities is subjective and depends on the investigator.

The overall RQD of the recovered rock cores (619 runs total) within the Queenston Formation varies between 0 and 100%, with an average of 85%. Other investigators measured average RQDs ranging from 64% to 90%. A summary of RQD measurements made in the Queenston Formation is provided as follows.

**Table 4-6: Summary of RQD values, Queenston Formation**

	Terraprobe Inc.			Coffey Geotechnics Inc.	Geo-Canada Ltd.	O'Connor Associates	Thurber Ltd.	ALL
	RQD (%), weathered bedrock	RQD (%), sound bedrock	RQD (%), overall	RQD (%)	RQD (%)	RQD (%)	RQD (%)	RQD (%)
<b>Average</b>	66	93	<b>89</b>	<b>90</b>	<b>69</b>	<b>64</b>	<b>74</b>	<b>85</b>
<b>Minimum</b>	0	48	0	0	0	8	0	<b>0</b>
<b>Maximum</b>	100	100	100	100	100	100	100	<b>100</b>
<b>No. of Runs</b>	52	249	301	139	52	50	77	<b>619</b>
<b>Total Length</b>	108 m	564 m	672 m	210 m	75 m	73 m	105 m	<b>1134 m</b>

Two prominent subvertical joint sets were observed and measured during geological mapping of the exposed bedrock at the Bronte Creek valley wall. The two subvertical joint sets are summarized as follows, along with their average strike and dip:

- Joint Set #1: Average strike = 255°, Average dip = 85°
- Joint Set #2: Average strike = 105°, Average dip = 85°

Isolated fractures present which had strikes and dips dissimilar to the two aforementioned joint sets cannot be accounted for due to the partially weathered condition of the exposed outcrop. In addition, an accurate assessment of the joint spacing was unable to be conducted due to the partially weathered condition of the exposed outcrop. Joint sets not explicitly measured may exist, and isolated joints and fractures will be encountered. The conditions are documented as found at the bedrock outcrop location only, and will not necessarily be the same either laterally or vertically.

#### 4.2.4 Laboratory Testing

Thirty-seven (37) of the boreholes from the present and previous investigations provide laboratory testing data on rock samples selected from the Queenston Formation. These include measurements of unconfined compressive strength (UCS), bulk density ( $\gamma$ ), Young's modulus (E), Poisson's ratio ( $\nu$ ), Moh's hardness, swell potential, as well as point load index (PLI) testing (axial and diametral orientation). A summary of laboratory rock testing is presented in the following table.

**Table 4-7: Summary of Laboratory Rock Testing**

Field Investigation, reported	Laboratory testing, rock samples
Terraprobe, 2013	UCS, $\gamma$ , swell potential
Coffey Geotechnics, Sept 2011	UCS, E, $\gamma$ , v, PLI, hardness
Coffey Geotechnics, Nov 2011	PLI
Geo-Canada, 2005	UCS, E, $\gamma$ , PLI
Thurber, 2005	UCS

The results of the laboratory tests (UCS, Young's modulus, bulk density, point load index) conducted the rock samples of the Queenston Formation are summarized on the Log of Borehole sheets provided in Appendix A (present investigation) and Appendix D (previous investigations). These results are summarized in the following table. Samples are normally distributed unless otherwise noted.

**Table 4-8: Summary of Laboratory Test Results (Terraprobe 2013 & other consultants), Queenston Formation**

	Queenston Formation				
	UCS* (MPa)	Bulk density, $\gamma$ (kN/m <sup>3</sup> )	Young's modulus, E (GPa)	Point load index (MPa)**	
				Axial*, PL <sub>A</sub>	Diametral*, PL <sub>D</sub>
<b>Average</b>	<b>19.1</b>	<b>25.8</b>	<b>4.9</b>	<b>28.7</b>	<b>9.2</b>
<b>Standard Deviation</b>	0.55 (lognormal)	0.3	2.2	0.66 (lognormal)	0.75 (lognormal)
<b>Minimum</b>	1.0	24.5	0.9	5.0	2.0
<b>Maximum</b>	101.5	26.5	8.9	156.0	114.0
<b>No. of Tests</b>	259	225	15	135	93
<b>No. of Boreholes</b>	34	25	5	8	5

\* Lognormally distributed. Average and standard deviation computed based on lognormal distribution.

\*\* Point load index values are reported as inferred UCS values (see Coffey Geotechnics, Sept 2011, Coffey Geotechnics, Nov 2011, and Geo-Canada 2005).

The Queenston Formation is composed of weak shale beds ("shale") interbedded with harder calcareous beds ("limestone"). Test results from the current investigation were sorted and compared by rock type, to determine the variation of each parameter according to rock type. The results are summarized in the following table.

**Table 4-9: Mechanical properties versus rock type (Terraprobe 2013), Queenston Formation**

Queenston Formation Rock Types	UCS*			Bulk Density		
	Average* (MPa)	Range $\pm$ 1 St.Dev*	Number of tests	Average (kN/m <sup>3</sup> )	Range $\pm$ 1 St.Dev	Number of tests
Limestone	21.1	14.1 to 31.6	60	25.8	25.5 to 26.1	60
Shale	18.2	11.6 to 28.5	110	25.9	25.6 to 26.2	110
Shale & Limestone**	20.8	13.6 to 31.8	43	25.8	25.5 to 26.1	43

\* UCS is lognormally distributed. Average and standard deviation computed based on lognormal distribution.

\*\* Both rock types present in sample as tested.

Hardness testing completed on samples of the Queenston Formation (Coffey Geotechnics, Sept 2011) found that the Moh's hardness of rock recovered from this formation ranged from 2 to 3, but was mostly 2. Poisson ratio measurements made as part of that same investigation yielded an average value of 0.24, but ranged from 0.17 to 0.33.

#### 4.2.5 Swelling Potential

The swelling potential of the Queenston Formation bedrock within the study area was measured as part of the 2013 investigation. Samples of rock from the Queenston Formation were selected in the field based on their proximity to the proposed tunnel depth (since revised), and sealed with wax to preserve their in situ pore water properties. The samples were then transferred to an external laboratory, which conducted the swell potential testing as per Madsen<sup>6</sup> and Lo et al.<sup>7</sup>. The results of the swell potential laboratory testing are provided as Appendix E.

Eight (8) sealed rock core samples were submitted for free swell testing. Of these, six were tested in fresh water and two were tested in a saline solution (200 g NaCl/L). The free swell potential testing method consisted of submerging a cut core sample (trimmed to a cube) in either distilled water (6 samples) or saline solution (200 g/L NaCl, 2 samples), and measuring the axial strain in three directions. The saline concentration agrees with Queenston shale pore water salinity measurements made by Lo and Lee<sup>8</sup>. The results are shown in the following table.

<sup>6</sup> F.T. Madsen, *Suggested methods for laboratory testing of swelling rocks*, ISRM **36** 291-307 (1999).

<sup>7</sup> K.Y. Lo, R.S.C. Wai et al., *Time-dependent deformation of shaly rocks in Southern Ontario*, Can. Geotech. J. **15** 537-547 (1978).

<sup>8</sup> K.Y. Lo and Y.N. Lee, *Time-dependent deformation of Queenston shale*, Can. Geotech. J. **27**, 461-471 (1990).

**Table 4-10: Free Swell Potential, Queenston Formation samples**

Sample (Terraprobe 2013)	Duration (days)	Submerging liquid	Max. Strain (% , swell is +ve)			% strain per log cycle time (10 to 100 days)		
			Vertical	Horizontal A	Horizontal B	Vertical	Horizontal A	Horizontal B
BH 2+640 28.0 - 28.3 m BG (Elev. 77.5 ± m)	44	distilled water	1.20	0.28	0.32	0.69	0.22	0.19
BH 3+065 34.6 - 35.0 m BG (Elev. 77.8 ± m)	120	distilled water	0.82	-0.14	0.16	0.49	-0.06	0.09
BH 4+495 51.5 - 51.8 m BG (Elev. 79.8 ± m)	120	distilled water	1.59	0.36	0.43	0.75	0.17	0.21
BH 3+930 50.5 - 50.9 m BG (Elev. 76.9 ± m)	76	distilled water	0.88	0.19	0.28	0.46	0.09	0.08
BH 3+930 51.7 - 52.0 m BG (Elev. 75.8 ± m)	117	distilled water	1.17	0.20	0.24	0.42	0.04	0.05
BH 4+990 56.2 - 56.6 m BG (Elev. 80.7 ± m)	72	distilled water	1.08	0.11	0.22	0.33	0.06	0.13
BH 2+425 26.5 - 27.0 m BG (Elev. 77.0 ± m)	114*	NaCl solution	0.08	0.04	0.09	0.08	0.03	0.06
BH 2+585 28.8 - 29.1 m BG (Elev. 76.7 ± m)	71	NaCl solution	0.44	0.12	0.07	0.06	0.12	0.11

\* Last portion of test (75 – 120 days) removed due to salt accumulation between transducer and pedestal

Six (6) sealed rock core samples were submitted for swell pressure testing. Of these, six were tested in fresh water and two were tested in a saline solution (200 g/L NaCl). The swell pressure testing method consisted of restraining the sample and the vertical and radial directions, and measuring the swell pressure induced in the vertical direction. The results are shown in the following table.

**Table 4-11: Swell Pressure Potential, Queenston Formation samples**

Sample (Terraprobe 2013)	Duration (days)	Submerging liquid	Vertical Strain Range (%, swell is +ve)	Maximum Pressure (kPa)	Final Pressure (kPa)
BH 3+065, 32.1 - 32.4 m BG (Elev. 80.4 ± m)	119	distilled water	-0.08 to 0.04	115	115
BH 4+495, 49.5 - 49.9 m BG (Elev. 81.7 ± m)	119	distilled water	-0.10 to 0.06	95	65
BH 2+640, 29.5 - 29.9 m BG (Elev. 75.9 ± m)	55	distilled water	-0.02 to 0.05	121	121
BH 4+990, 56.6 - 57.0 m BG (Elev. 80.3 ± m)	55	distilled water	-0.01 to 0.03	156	156
BH 2+585, 30.7 - 30.8 m BG (Elev. 74.9 ± m)	39	NaCl solution	-0.04 to 0.04	12	12
BH 2+425, 27.3 - 27.6 m BG (Elev. 76.3 ± m)	65	NaCl solution	0 to -0.12	0.8	0.8

#### 4.2.6 In Situ Testing

In situ testing consisting of hydraulic conductivity and elastic modulus (dilatometer) testing was conducted in boreholes within the study area. A summary of the in situ testing is provided in the following table.

**Table 4-12: Summary of In Situ Rock Testing, Queenston Formation**

Field Investigation, report date	In situ testing
Terraprobe, 2013	Elastic modulus (dilatometer), hydraulic conductivity (rising head test)
Coffey Geotechnics, Sept 2011	Hydraulic conductivity (packer test)
Geo-Canada, 2005	Hydraulic conductivity (packer test)

As part of the Terraprobe investigation, the elastic (Young's) modulus of the in situ rock mass was measured using a Probex borehole dilatometer (rock pressuremeter). The probe requires a 75 mm diameter borehole to ensure proper contact between the membrane and the borehole walls. Subsequently, Borehole 6+390 was advanced using NQ-sized coring equipment to obtain the proper borehole size. The probe, consisting of a very stiff thick-walled elastic membrane, is equipped to measure volume change accurately at the probe itself, eliminating volume change error due to expansion of the hydraulic lines. Pressure is measured at surface using a pressure transducer and analog gauges. The raw data is corrected for membrane stiffness and compression to obtain a measurement of the in situ elastic modulus of the rock mass at each depth.

Tests were carried out along a profile of depths close to the proposed tunnelling zone (since revised). The in situ elastic modulus of the Queenston Formation ranged from 1.4 to 6.0 GPa, and was on average 4.5 GPa. The results are provided on the borehole logs in Appendix A, and are summarized as follows.

**Table 4-13: Young's modulus, from Probex dilatometer (Terraprobe 2013, BH 6+390)**

Depth / Elevation, m (BH 6+390)	In situ Young's modulus ( $E_{PM}$ ), GPa
47.2 / Elev. 92.0 m	6.0
49.4 / Elev. 89.8 m	5.8
51.8 / Elev. 87.4 m	1.4
53.3 / Elev. 85.9 m	2.2
54.9 / Elev. 84.3 m	5.7
56.9 / Elev. 82.3 m	5.9

Rising head tests were conducted by Terraprobe at seven (7) locations (BH 1+200, BH 2+425, BH 3+065, BH 4+495, BH 5+060, BH 7+145, and BH 7+270). The tested monitoring wells were screened within Queenston Formation bedrock. The analyses were completed using the Bouwer and Rice method. In situ hydraulic conductivity (rising head test) results generally ranged from  $10^{-7}$  to  $10^{-9}$  cm/s, with the notable exception of BH 1+200 which was screened at a relatively shallow depth ( $12 \pm$  m below grade) and measured an in situ hydraulic conductivity of  $10^{-4}$  cm/s. The results of the hydraulic conductivity analyses are summarized below.

**Table 4-14: Hydraulic Conductivity (Rising Head Test), Queenston Formation**

Monitoring Well	Well Screen Depth (m BG)	Well Screen Elevation (m)	Hydraulic Conductivity (rising head test, cm/s)
BH 1+200	12.2 to 15.2 $\pm$	80.0 to 76.9 $\pm$	$1 \times 10^{-4}$
BH 2+425	24.7 to 27.7 $\pm$	79.1 to 76.0 $\pm$	$2 \times 10^{-8}$
BH 3+065	31.1 to 34.3 $\pm$	81.5 to 78.3 $\pm$	$7 \times 10^{-8}$
BH 4+495	49.1 to 52.1 $\pm$	82.4 to 79.3 $\pm$	$3 \times 10^{-7}$
BH 5+060	50.9 to 55.2 $\pm$	87.2 to 82.9 $\pm$	$6 \times 10^{-8}$
BH 7+145	50.9 to 54.0 $\pm$	81.9 to 78.8 $\pm$	$3 \times 10^{-7}$
BH 7+270	35.1 to 38.1 $\pm$	97.8 to 94.7 $\pm$	$2 \times 10^{-9}$

Hydraulic conductivity testing by packer test was conducted by Coffey Geotechnics (2011) and Geo-Canada (2005), at thirty-five (35) intervals located within seven (7) boreholes. Testing pressures varied in accordance with the position of the piezometric water level<sup>9</sup>. The hydraulic conductivity results from previous investigations are presented on the borehole logs in Appendix D, and are summarized as follows.

<sup>9</sup> See Coffey Geotechnics (Nov 2011) and Geo-Canada (2005) for further details.

**Table 4-15: Hydraulic Conductivity (Packer Test), Queenston Formation**

Borehole	Testing Intervals			Range of hydraulic conductivity (from Packer Testing, cm/s) <sup>10</sup>
	Depth	Elevation	Intervals	
COF-BC-1	6.1 – 54.9 m	Elev. 138.4 – 89.6 m	7	$9 \times 10^{-7}$ to $2 \times 10^{-6}$
COF-BC-2	36.6 – 51.5 m	Elev. 105.8 – 90.9 m	3	$5 \times 10^{-7}$
COF-BC-3	33.5 – 47.9 m	Elev. 105.1 – 90.7 m	3	$2 \times 10^{-7}$ to $3 \times 10^{-7}$
COF-BC-4	16.2 – 46.0 m	Elev. 122.9 – 93.1 m	5	$5 \times 10^{-7}$ to $1 \times 10^{-4}$
GC-A	4.0 – 28.5 m	Elev. 85.9 – 61.4 m	6	$3 \times 10^{-6}$ to $1 \times 10^{-3}$
GC-B	6.3 – 27.9 m	Elev. 84.7 – 63.1 m	5	$6 \times 10^{-6}$ to $2 \times 10^{-3}$
GC-C	5.2 – 28.0 m	Elev. 84.1 – 61.3 m	6	$3 \times 10^{-6}$ to $2 \times 10^{-3}$

### 4.3 Georgian Bay Formation

Within the study area, the Queenston Formation is gradually underlain by the Georgian Bay Formation. The bedrock of the Georgian Bay Formation is a deposit predominantly comprising thin to medium bedded shale, which is grey and fissile. The shale contains interbedded layers of light grey calcareous shale, limestone/dolostone and calcareous sandstone (“limestone”) which are discontinuous and nominally 50 to 300 mm, but as much as 600 mm, thick. Within the study area, the bedrock of the Georgian Bay Formation was observed to be unweathered/fresh/sound.

Seven (7) of the boreholes (Boreholes 4+990, 5+060, 6+390, 7+145, GC-A, GC-B, and GC-C) encountered the Georgian Bay Formation. The top of the Georgian Bay Formation was encountered at Elev. 62 ± m at the south end of the study area near Burloak WPP (Boreholes GC-A, GC-B, and GC-C), and at Elev. 73 to 80 ± m towards the north end of the study area at Upper Middle Road (Boreholes 4+990, 5+060, 6+390, and 7+145). These measurements indicate that the Georgian Bay Formation contact is gradually dipping downward from north to south. It was located below the proposed tunnel invert elevation where encountered.

#### 4.3.1 Calcareous Beds

Each of the six boreholes recorded the location and quantity of stronger calcareous beds interbedded within the Georgian Bay shale. The percentage of stronger calcareous beds (“limestone”, or “hard layers”) encountered is reported on the rock core logs. Where it was measured over the entire borehole (Boreholes 4+990, 5+060, 6+390, and 7+145), the percentage of limestone found in the Georgian Bay Formation

<sup>10</sup> Data do not include tests where no water take was recorded.

ranged from 24% to 40% (on average 33%). Where it was measured on a per run basis (Boreholes GC-A, GC-B, and GC-C), the percentage of limestone found in the Georgian Bay Formation ranged from 5% to 69% (on average 27%).

#### 4.3.2 Discontinuities, RQD

The bedding of the Georgian Bay Formation is normally flat lying. Georgian Bay Formation shale is typically fissile, and fractures/delaminates easily along thinly laminated bedding planes. Since the bedding is horizontal in this formation, and there are many bedding layers within this rock mass, the RQD is typically low and is a function of the regular repeating bedding planes. There are known to be at least two orthogonal near vertical joint sets within the shale with the predominant set trending roughly east to west. Sometimes associated with the principal directions of these joint sets there are stress relief features found within the formation. These zones (commonly referred to as shear zones) manifest themselves as vertically oriented zones of rock rubble. These features defy discovery in borehole investigations.

The RQD of the recovered rock cores varies between 0 and 100%, with an average of 86%. A summary table of RQD measurements is provided as follows.

**Table 4-16: Summary of RQD values, Queenston Formation**

	RQD (%)		
	Terraprobe Inc.	Geo-Canada Ltd.	OVERALL
<b>Average</b>	93	84	86
<b>Minimum</b>	61	46	46
<b>Maximum</b>	100	98	100
<b>Runs</b>	8	56	64
<b>Length</b>	12.8 m	85.2 m	98.0 m

Within sound bedrock of the Georgian Bay Formation, the natural fracture frequency ranges from 0 to over 10 fractures per 0.3 m of core, and is on average 2 fractures/0.3 m of core.

#### 4.3.3 Laboratory Testing

The results of selected laboratory tests (UCS, Young's modulus, bulk density, point load index), conducted on the rock samples of the Georgian Bay Formation, are summarized on the Log of Borehole sheets provided in Appendix A (present investigation) and Appendix D (previous investigations). These results are summarized in the following table.

**Table 4-17: Summary of Laboratory Test Results, Georgian Bay Formation**

	Georgian Bay Formation			
	UCS (MPa)*	Bulk density, $\gamma$ (kN/m <sup>3</sup> )	Young's modulus, E (GPa)	Point load** index, axial PL <sub>A</sub> (MPa)*
<b>Average</b>	<b>21.9</b>	<b>25.9</b>	<b>6.9</b>	<b>29.0</b>
<b>Standard Deviation</b>	0.3 (lognormal)	0.2	n/a	0.4 (lognormal)
<b>Minimum</b>	13.8	25.6	5.3	10.0
<b>Maximum</b>	30.5	26.3	8.4	55.0
<b>No. of Tests</b>	8	9	2	53
<b>No. of Boreholes</b>	3	3	1	3

\* Lognormally distributed. Average and standard deviation computed based on lognormal distribution.

\*\* Point load index values are reported as inferred UCS values (see Geo-Canada 2005).

#### 4.3.4 In Situ Testing

Hydraulic conductivity measurements were made in the Georgian Bay Formation by Geo-Canada (2005), adjacent to the Burloak WPP. The in situ hydraulic conductivity of the Georgian Bay Formation was determined by packer testing, at twenty (20) intervals within three (3) boreholes. Testing pressures varied in accordance with the position of the piezometric water level (see Geo-Canada (2005) for further details). The hydraulic conductivity results from previous investigations are presented on the borehole logs in Appendix D, and are summarized as follows.

**Table 4-18: Hydraulic Conductivity from Packer Testing, Georgian Bay Formation**

Borehole	Testing Intervals			Range of hydraulic conductivity (from Packer Testing)*
	Depth	Elevation	Intervals	
GC-A	28.5 – 61.2 m	Elev. 61.4 – 28.7 m	8	$2 \times 10^{-7}$ to $3 \times 10^{-6}$
GC-B	30.0 – 55.2 m	Elev. 61.1 – 35.8 m	6	$9 \times 10^{-7}$ to $3 \times 10^{-6}$
GC-C	28.0 – 53.6 m	Elev. 61.3 – 35.7 m	6	$7 \times 10^{-7}$ to $9 \times 10^{-6}$

\* Data do not include tests where no water take was recorded.

## 4.4 Ground Water

The depth of ground water and caving was measured in each of the boreholes immediately following the drilling. Monitoring wells were installed in twenty-five (25) of the boreholes upon completion of drilling. Stabilized ground water levels were measured in each of the monitoring wells at least one week after the completion of drilling. The ground water measurements are shown on the Borehole Logs and are summarized in a table provided as Appendix F. The most recent stabilized water level measurements are summarized as follows.

**Table 4-19: Stabilized Water Level Measurements (Most Recent)**

Borehole No.	Depth of borehole (m)	Screen Elevation, midpoint (m)	Strata Screened Within	Most Recent Water Level in Well	
				Water Level (Depth/Elev, m)	Date (dd-mon-yy)
BH 1+200	21.6	89.3	Overburden - Bedrock Interface	3.9 / 88.2	12-Feb-13
BH 1+200	21.6	78.4	Bedrock	5.1 / 87.1	12-Feb-13
BH 2+425	35.1	100.7	Overburden - Bedrock Interface	3.2 / 100.6	12-Feb-13
BH 2+425	35.1	77.5	Bedrock	5.3 / 98.4	12-Feb-13
BH 2+640	38.2	76.4	Bedrock	8.8 / 96.8	12-Feb-13
BH 3+065	41.2	109.5	Overburden - Bedrock Interface	2.2 / 110.4	12-Feb-13
BH 3+065	41.2	79.9	Bedrock	6.8 / 105.8	12-Feb-13
BH 4+495	59.2	128.4	Overburden - Bedrock Interface	2.0 / 129.4	12-Feb-13
BH 4+495	59.2	80.8	Bedrock	24.2 / 107.3	12-Feb-13
BH 5+060	66.9	134.8	Overburden - Bedrock Interface	3.1 / 135.2	9-Aug-13
BH 5+060	66.9	85.1	Bedrock	48.2 / 89.9	9-Aug-13
BH 7+145	61.2	129.7	Overburden	4.3 / 128.4	7-Jan-13
BH 7+145	61.2	80.3	Bedrock	15.0 / 117.7	7-Jan-13
BH 7+270	48.4	124.0	Overburden - Bedrock Interface	8.4 / 124.4	13-Mar-13
BH 7+270	48.4	96.5	Bedrock	37.6 / 95.2	13-Mar-13
COF-1	9.3	107.7	Overburden - Bedrock Interface	5.2 / 110.1	16-Feb-12
COF-2	6.2	111.7	Overburden - Bedrock Interface	3.5 / 113.0	16-Feb-12
COF-6	6.2	107.9	Overburden - Bedrock Interface	4.6 / 108.0	16-Feb-12
COF-BC-1	60.7	98.6	Bedrock	26.7 / 117.8	5-Apr-11
COF-BC-2	56.2	99.0	Bedrock	19.5 / 122.9	23-Jul-10
COF-BC-3	53.5	98.4	Bedrock	17.6 / 121.0	5-Apr-11
COF-BC-4	53.3	101.3	Bedrock	13.9 / 125.2	5-Apr-11
GC-A	61.2	88.5	Overburden	1.8 / 88.1	2-Dec-04
GC-A	61.2	67.2	Bedrock	22.1 / 67.8	29-Nov-04
GC-B	56.5	37.6	Bedrock	23.6 / 67.4	2-Dec-04
GC-C	55.1	66.9	Bedrock	3.4 / 85.9	29-Nov-04
OCON-18	4.4	142.2	Bedrock	1.7 / 143.3	5-May-04
OCON-19	4.4	142.3	Bedrock	1.7 / 143.3	5-May-04

Borehole No.	Depth of borehole (m)	Screen Elevation, midpoint (m)	Strata Screened Within	Most Recent Water Level in Well	
				Water Level (Depth/Elev, m)	Date (dd-mon-yy)
THU-UC1	4.6	116.5	Bedrock	2.1 / 116.8	14-Dec-06
THU-WM1	9.8	97.4	Bedrock	1.2 / 105.7	6-Dec-05
THU-WM3	9.9	100.8	Bedrock	1.6 / 108.6	6-Dec-05
THU-WM5	14.3	102.6	Bedrock	4.3 / 111.8	6-Dec-05
THU-WM7	17.8	101.3	Bedrock	1.6 / 116.7	6-Dec-05
THU-WM9	17.7	104.8	Bedrock	4.4 / 117.4	6-Dec-05
TRW-45	4.6	94.6	Overburden - Bedrock Interface	dry	1-Sep-00
TRW-77	4.6	89.5	Overburden - Bedrock Interface	3.4 / 89.2	6-Sep-00

Most of the monitoring wells installed by O'Connor Associates (OCON-4 to OCON 16 inclusive) have no associated water level measurements reported.

Ground water levels may fluctuate with time and seasonally depending on the amount of precipitation and surface runoff.

Rising head and hydraulic conductivity (by packer) testing was conducted within the Queenston and Georgian Bay Formations, to measure the in situ hydraulic conductivity. The results are presented in Sections 4.2.6 and 4.3.4, respectively.

## 4.5 Chemical Analysis

As part of the Terraprobe investigation, a chemical analysis programme was undertaken to investigate the environmental subsurface soil conditions. Samples were collected and identified for testing based on visual observation. Samples were scheduled from each borehole based on the proposed tunneling depth, locations of proposed/potential shafts, as well as previous potential open-cut sections.

It should be noted that the results of the chemical analysis refer only to the samples analysed which were obtained from specific locations, and the chemistry may vary between and beyond the locations of the samples tested. Therefore, materials to be used on site or transported to other sites must be inspected during excavation for indication of variance in composition or any chemical/environmental constraints. If conditions indicate, further chemical testing should be carried out if deemed necessary. Further, the sites accepting fill may have aesthetic or engineering property requirements, in addition to the chemical requirements for accepting soil.

Changes in 2011 to Environmental Protection Act Part XV.1 Record of Site Condition (O.Reg. 153/04) specify specific requirements for sampling and analysis of soil being brought to sites which have or will have a Record of Site Condition (RSC). Further consultation and sampling, including the preparation of a fill management plan will be required under these circumstances.

#### 4.5.1 Soil Chemistry

Thirty-four (34) different soil samples were collected for chemical analysis. The soil chemistry Certificate of Analysis is provided as Appendix G. The soil samples were submitted to AGAT Laboratories Ltd. for the following O.Reg 153/04 (as amended) parameters:

- Metals and inorganics (M&I)
- Volatile organic compounds (VOCs)
- Polycyclic aromatic hydrocarbons (PAHs)
- Petroleum hydrocarbons (PHCs, CCME F1-F4, BH 5+060 only)

The results of the soil sampling were compared to O.Reg. 153/04 (as amended) Table 1 Standards as found in *Soil, Ground Water and Sediment Standards for Use Under Part XV. I of the Environmental Protection Act* (April 15, 2011). The results of the analysis indicate that there are exceedences of the O.Reg. 153/04 (as amended) Ministry of the Environment Table 1, *Full Depth Background Site Condition Standards*, for the following parameters:

- Chromium
- Barium
- Zinc
- Cadmium
- Electrical Conductivity (2:1)
- Sodium Adsorption Ratio

Samples of weathered bedrock collected by split spoon sampler are included in this section, as the sample was not pulverized and milled and was extracted by split spoon sampler. This indicates that the sample matrix more accurately reflects a soil than a rock, for chemical analysis purposes. The samples selected for testing were located as follows.

**Table 4-20: Summary of Chemical Analyses, Soil Samples**

Sample ID.	Borehole / Sample	Depth (m)	Approximate Elevation (m)	Representing	Test Type	Exceedences of Table 1
3769399	BH 0+940 SS2	1.1	90.2	Fill	M&I	Cadmium, Zinc
3769400	BH 0+940 SS2	1.1	90.2	Fill	PAH	none
3769401	BH 0+940 SS3	1.8	89.5	Fill	VOC	none
3709678	BH 1+080 SS2	1.1	90.2	Fill	M&I	Chromium
3709681	BH 1+080 SS3	1.8	89.4	Fill	PAH	none
3709679	BH 1+080 SS3	1.8	89.4	Fill	VOC	none
3703971	BH 1+200 SS2	1.1	91.1	Clayey Silt Till	M&I	none
3703979	BH 1+200 SS3	1.8	90.3	Clayey Silt Till	PAH	none
3703977	BH 1+200 SS3	1.8	90.3	Clayey Silt Till	VOC	none
3609741	BH 1+720 SS2	1.1	95.0	Silt	M&I	none

Sample ID.	Borehole / Sample	Depth (m)	Approximate Elevation (m)	Representing	Test Type	Exceedences of Table 1
3609742	BH 1+720 SS3	1.8	94.2	Clayey Silt Till	PAH	none
3609743	BH 1+720 SS3	1.8	94.2	Clayey Silt Till	VOC	none
3609737	BH 2+020 SS2	1.1	98.1	Silt Till	M&I	none
3609739	BH 2+020 SS3a	1.7	97.5	Silt Till	PAH	none
3609740	BH 2+020 SS3a	1.7	97.5	Silt Till	VOC	none
3709663	BH 2+240 SS2	1.1	101.0	Clayey Silt Till	M&I	none
3709677	BH 2+240 SS3	1.8	100.2	Clayey Silt Till	PAH	none
3709675	BH 2+240 SS3	1.8	100.2	Clayey Silt Till	VOC	none
3722742	BH 2+335 SS2	1.1	102.0	Clayey Silt Till	M&I	Barium
3722745	BH 2+335 SS3	1.8	101.2	Clayey Silt Till	PAH	none
3722743	BH 2+335 SS3	1.8	101.2	Clayey Silt Till	VOC	none
3603185	BH 2+425 SS2	1.1	102.7	Clayey Silt	M&I	none
3603184	BH 2+425 SS3	1.8	101.9	Weathered Bedrock	PAH	none
3603186	BH 2+425 SS3	1.8	101.9	Weathered Bedrock	VOC	none
3599674	BH 3+065 SS2	1.1	111.5	Weathered Bedrock	M&I	none
3602853	BH 3+065 SS3	1.7	110.8	Weathered Bedrock	PAH	none
3602853	BH 3+065 SS3	1.7	110.8	Weathered Bedrock	VOC	none
4569523	BH 5+060 SS1	0.3	137.8	Clayey Silt (Weathered)	M&I	none
4569533	BH 5+060 SS2	1.0	137.1	Clayey Silt Till	PAH	none
4569525	BH 5+060 SS3	1.7	136.4	Weathered Bedrock	PHC (F1-F4)	none
4569510	BH 5+060 SS5	3.3	134.8	Weathered Bedrock	VOC	none
3738422	BH 7+020 SS1a	0.4	134.4	Fill	PAH	none
3738423	BH 7+020 SS3b	1.9	132.9	Clayey Silt Till	PAH	none
3738417	BH 7+020 SS2	1.1	133.7	Fill	VOC	none
3700802	BH 7+145 AS1	0.8	131.9	Fill	M&I	Electrical conductivity (2:1), Sodium adsorption ratio
3700809	BH 7+145 SS2	1.8	130.9	Clayey Silt	PAH	none
3700807	BH 7+145 SS2	1.8	130.9	Clayey Silt	VOC	none
3700787	BH 7+165x AS1	0.8	130.5	Fill	M&I	Electrical conductivity (2:1), Sodium adsorption ratio
3700794	BH 7+165x SS2a	1.7	129.7	Fill	PAH	none
3700793	BH 7+165x SS2a	1.7	129.7	Fill	VOC	none
3700795	BH 7+250x AS1	0.8	130.6	Fill	M&I	none
3700799	BH 7+250x SS2	1.8	129.6	Fill	PAH	none
3700796	BH 7+250x SS2	1.8	129.6	Fill	VOC	none
4127370	BH 7+270 SS2	1.1	131.7	Fill	M&I	none
4127372	BH 7+270 SS3	1.7	131.1	Clayey Silt Till	PAH	none
4127373	BH 7+270 SS11	10.8	122.0	Gravel and Sand	VOC	none

The O.Reg. 153/04 (as amended) Table 1 Standards are the highest standards for determining exceedences, and are applicable for Full Depth Background Site Condition Standards. It should be noted that some of the parameters exceeding Table 1 in the above table do meet Table 3 Standards.

#### 4.5.2 Rock Chemistry

Eighteen (18) samples of solid rock core were collected for chemical analysis. The samples were selected from boreholes corresponding to potential shaft locations. The rock chemistry Certificate of Analysis is provided as Appendix H. The samples were submitted to Maxxam Analytics for the following O.Reg 153/04 (as amended) parameters:

- Metals and inorganics (M&I)
- Volatile organic compounds (VOCs)
- Polycyclic aromatic hydrocarbons (PAHs)

The samples were received by Maxxam as solid rock cores. Prior to analytical processing, the samples were crushed to a consistent grain size of approximately < 2 mm using a Vibratory Ring Pulverizer. Aliquots of the crushed rock were processed in accordance with the preparation and analysis requirements for a soil matrix, for each requested analysis.

Rock is considered to be a non-soil material by O.Reg. 153/04 (as amended); as such, there are no MOE guidelines for the chemical analysis of unweathered bedrock. The samples selected for testing were located as follows.

**Table 4-21: Summary of Chemical Analyses, Rock Samples**

Sample ID.	Borehole / Sample	Approx. Midpoint (m)		Representing	Test Type	Exceedences
		Depth	Elevation			
PE9708	BH 1+200	5.4	86.7	Sound Bedrock	M&I, VOC, PAH	n/a
PE9709	BH 1+200	12.1	80.0	Sound Bedrock	M&I, VOC, PAH	n/a
PE9710	BH 1+200	18.4	73.7	Sound Bedrock	M&I, VOC, PAH	n/a
OT9363	BH 2+425	7.0	96.7	Sound Bedrock	M&I, VOC, PAH	n/a
OT9364	BH 2+425	20.6	83.1	Sound Bedrock	M&I, VOC, PAH	n/a
OT9365	BH 2+425	28.9	74.8	Sound Bedrock	M&I, VOC, PAH	n/a
OT9362	BH 3+065	10.8	101.8	Sound Bedrock	M&I, VOC, PAH	n/a
OT9361	BH 3+065	18.3	94.3	Sound Bedrock	M&I, VOC, PAH	n/a
OW4979	BH 3+065	39.2	73.4	Sound Bedrock	M&I, VOC, PAH	n/a
OR7006	BH 4+495	11.9	119.5	Sound Bedrock	M&I, VOC, PAH	n/a
OT9359	BH 4+495	34.2	97.2	Sound Bedrock	M&I, VOC, PAH	n/a
OT9360	BH 4+495	53.8	77.6	Sound Bedrock	M&I, VOC, PAH	n/a
SJ2311	BH 5+060	10.0	128.1	Sound Bedrock	M&I, VOC, PAH	n/a
SJ2312	BH 5+060	30.6	107.5	Sound Bedrock	M&I, VOC, PAH	n/a

Sample ID.	Borehole / Sample	Approx. Midpoint (m)		Representing	Test Type	Exceedences
		Depth	Elevation			
SJ2313	BH 5+060	49.8	88.3	Sound Bedrock	M&I, VOC, PAH	n/a
QM6930	BH 7+270	12.3	120.6	Sound Bedrock	M&I, VOC, PAH	n/a
QM6931	BH 7+270	25.0	107.8	Sound Bedrock	M&I, VOC, PAH	n/a
QM6932	BH 7+270	42.8	90.0	Sound Bedrock	M&I, VOC, PAH	n/a

### 4.5.3 Ground Water Chemistry

Ground water samples from seven (7) selected monitoring wells were submitted to investigate the environmental subsurface ground water conditions. Sampling was conducted in monitoring wells screened within the bedrock, to investigate ground water conditions within the bedrock. Monitoring well construction details are provided on the corresponding Borehole Logs as Appendix A. No monitoring wells installed during previous investigations were sampled.

The ground water chemistry Certificates of Analysis are provided as Appendix I. The samples were submitted to AGAT Laboratories Ltd. for chemical analysis for the following O.Reg 153/04 (as amended) parameters:

- Metals and inorganics (M&I)
- Volatile organic compounds (VOC)
- Polycyclic aromatic hydrocarbons (PAH)

The results of the analyses were compared to O.Reg. 153/04 (as amended) Table 1 Standards as found in *Soil, Ground Water and Sediment Standards for Use Under Part XV. 1 of the Environmental Protection Act* (April 15, 2011). The analyses indicate that there are exceedences of the O.Reg. 153/04 (as amended) Ministry of the Environment Table 1, *Full Depth Background Site Condition Standards*, for the following parameters listed in the following table.

**Table 4-22: Summary of Chemical Analyses, Ground Water Samples**

Sample ID.	Borehole / Monitoring Well	Screen Elevation, midpoint (m)	Representing	Test Type / Parameters	Exceedences of Table 1
3738392 / 4127970	BH 1+200	78.4	Ground water within bedrock	M&I, VOC, PAH	Vinyl Chloride, Boron, Selenium, Sodium, Chloride
3787072 / 4127972	BH 2+425	77.5	Ground water within bedrock	M&I, VOC, PAH	Cadmium, Selenium, Sodium, Chloride
3787076 / 4127976	BH 3+065	79.9	Ground water within bedrock	M&I, VOC, PAH	Selenium

Sample ID.	Borehole / Monitoring Well	Screen Elevation, midpoint (m)	Representing	Test Type / Parameters	Exceedences of Table 1
3892560 / 4127980	BH 4+495	80.8	Ground water within bedrock	M&I, VOC, PAH	Benzene, Beryllium, Boron, Chromium, Cobalt, Copper, Nickel, Selenium, Uranium, Vanadium, Sodium, Chloride
4645580	BH 5+060	85.1	Ground water within bedrock	M&I, VOC, PAH	Antimony, Barium, Cadmium, Chloride, Cobalt, Copper, Molybdenum, Nickel, Selenium, Silver, Sodium, Thallium, Uranium
3805539	BH 7+145	80.3	Ground water within bedrock	M&I, VOC, PAH	Antimony, Chromium, Molybdenum, Nickel, Selenium
4161564	BH 7+270	96.5	Ground water within bedrock	M&I, VOC, PAH	Chloride, Cobalt, Copper, Molybdenum, Nickel, Uranium, Sodium, Toluene

The O.Reg. 153/04 (as amended) Table 1 Standards are the highest standards for determining exceedences, and are applicable for Full Depth Background Site Condition Standards. A more detailed analysis of ground water parameter exceedences as compared to Tables 1, 2 and 3 may be found in Terraprobe's Hydrogeological Report (under separate cover). It should be noted that some of the exceedences noted in the above table do meet Table 3 Standards.

Ground water samples from four (4) selected monitoring wells were submitted to AGAT Laboratories Ltd. for chemical analysis for O.Reg 153/04 (as amended) Petroleum Hydrocarbons ("PHC", CCME F1 to F4) parameters. The ground water chemistry Certificates of Analysis are provided as Appendix I. The analyses indicate that there are no exceedences of the O.Reg. 153/04 (as amended) Ministry of the Environment Table 1, *Full Depth Background Site Condition Standards*, as shown in the following table.

**Table 4-23: Summary of PHC Analyses, Ground Water Samples**

Sample ID.	Borehole / Monitoring Well	Screen Elevation, midpoint (m)	Representing	Test Type / Parameters	Exceedences of Table 1
4127970	BH 1+200	78.4	Ground water within bedrock	PHC	none
4127972	BH 2+425	77.5	Ground water within bedrock	PHC	none
4127976	BH 3+065	79.9	Ground water within bedrock	PHC	none
4127980	BH 4+495	80.8	Ground water within bedrock	PHC	none
4645580	BH 5+060	85.1	Ground water within bedrock	PHC	none

Ground water samples from six (6) selected monitoring wells were analysed by AGAT Laboratories Ltd. for Halton Region Storm, Sanitary, and Combined Sewer Use By-Law parameters. The monitoring well

in BH 7+270 was also sampled, but not enough water was recovered to allow for a full suite of parameters to be tested. The Sewer Use By-Law Certificates of Analysis are provided as Appendix J.

The results of the Storm and Sanitary Sewer Use By-Law analysis indicate that there are parameters which exceed sanitary and combined sewer use by-law limits relating to total suspended solids (TSS) and the associated metals concentrations (total iron, total aluminum, and total manganese). There was also one exceedance of microbiological parameters relating to storm sewer disposal (E.coli).

**Table 4-24: Summary of Chemical Analysis, Sewer Use By-Law**

Sample ID.	Borehole / Monitoring Well	Screen Elevation, midpoint (m)	Representing	Test Type / Parameters	Exceedences of Halton Sewer Use By-Law
3838665	BH 1+200	78.4	Ground water within bedrock	Sewer Use By-Law	Total Aluminum, Total Iron, TSS
3838683	BH 2+425	77.5	Ground water within bedrock	Sewer Use By-Law	TSS
3838699	BH 3+065	79.9	Ground water within bedrock	Sewer Use By-Law	Total Manganese, TSS
3838714	BH 4+495	80.8	Ground water within bedrock	Sewer Use By-Law	none
4637329	BH 5+060	85.1	Ground water within bedrock	Sewer Use By-Law	E.coli, Total Aluminum, Total Iron, Total Manganese, TSS
3838732	BH 7+145	80.3	Ground water within bedrock	Sewer Use By-Law	none

Ground water samples from each of the three (3) selected monitoring wells were analysed by AGAT Laboratories Ltd. for corrosivity parameters. The Corrosivity Certificates of Analysis are provided as Appendix K.

#### 4.5.4 Corrosivity

Three (3) ground water samples were selected and tested for a suite of corrosivity parameters consisting of pH, Resistivity, Electrical Conductivity, Redox Potential, Sulphate, Sulphide, Chloride, and Alkalinity. A copy of the Certificate of Analyses is included in Appendix K.

These parameters are used for assessing ground water aggressivity, according to the Aggressivity Index described in the American Water Work Association (AWWA) C400-77 standard (1977). It should be noted that the analytical results only provide an indication of the potential for corrosion, with reference to the index ranges. According to the Aggressivity Index, two ground water samples (BH 1+200, BH 2+425) were assessed as “moderately aggressive”, while one ground water sample (BH 3+065) was assessed as “non-aggressive”.

The above samples were also analysed for soluble sulphate concentration. The analytical results were compared to the Canadian Standard CAN3/CSA A23.1-M94 Table 3, *Additional Requirements for Concrete Subjected to Sulphate Attack*. It is anticipated that these results would be used to determine the type of cementing materials to be used to produce concrete for this project. Comparison of the test results indicates that the water soluble sulphate concentrations in soil are lower than 1,500 mg/L. Based on this result, the Table provides an S-3 class (or “moderate” degree of exposure).

## **4.6 Bronte Creek**

The Bronte Creek watercourse has been identified as an area of importance, through the Risk Management Workshop process. Four (4) boreholes were advanced at locations within the valley that intersect the proposed alignment. The boreholes within Bronte Creek valley (BHs 5+855, 5+885, 5+900, and 5+935) were advanced through overburden by hand auger, and cored using restricted-access rock coring equipment. The acquired overburden and bedrock information in this area is similar to the bedrock information secured across the site.

## **5.0 LIMITATIONS AND USE OF REPORT**

### **5.1 Procedures**

This investigation has been carried out using investigation techniques and engineering analysis methods consistent with those ordinarily exercised by Terraprobe and other engineering practitioners, working under similar conditions and subject to the time, financial and physical constraints applicable to this project. The discussions and recommendations that have been presented are based on the factual data obtained from this investigation, as well as factual data reported by other engineering consultants and made available to Terraprobe.

Some of the factual data presented and summarized in this report was obtained by other engineering consultants in the area of study. Terraprobe takes no responsibility for the quality or accuracy of data reported by other engineering consultants.

It must be recognized that there are special risks whenever engineering or related disciplines are applied to identify subsurface conditions. A comprehensive sampling and testing programme implemented in accordance with the most stringent level of care may fail to detect certain conditions. Terraprobe has assumed for the purposes of providing design parameters and advice, that the conditions that exist between sampling points are similar to those found at the sample locations.

It may not be possible to drill a sufficient number of boreholes or sample and report them in a way that would provide all the subsurface information and geotechnical advice to completely identify all aspects of the site and works that could affect construction costs, techniques, equipment and scheduling. Contractors bidding on or undertaking work on the project must be directed to draw their own conclusions as to how the subsurface conditions may affect them, based on their own investigations and their own interpretations of the factual investigation results, and their approach to the construction works, cognizant of the risks implicit in the subsurface investigation activities.

### **5.2 Changes in Site and Scope**

It must be recognized that the passage of time, natural occurrences, and direct or indirect human intervention at or near the site have the potential to alter subsurface conditions. In particular, caution should be exercised in the consideration of contractual responsibilities as they relate to control of seepage, disturbance of soils, and frost protection.

### **5.3 Use of Report**

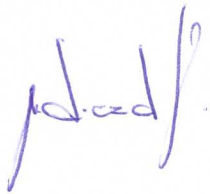
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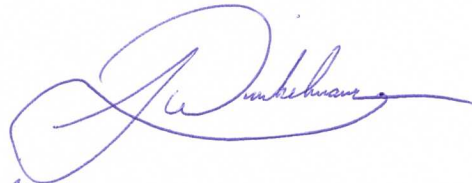
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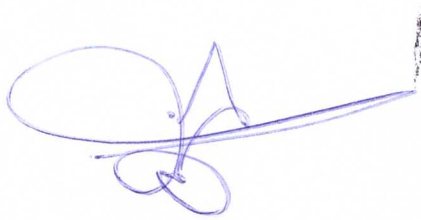
## **Terraprobe Inc.**



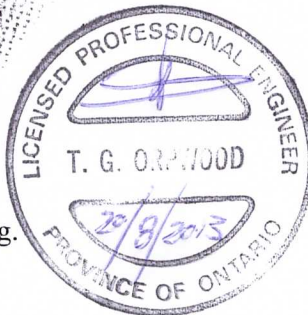
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Geotechnical Engineer



for Jason Crowder, Ph.D., P.Eng.  
Associate

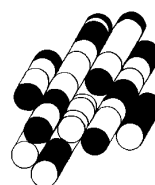


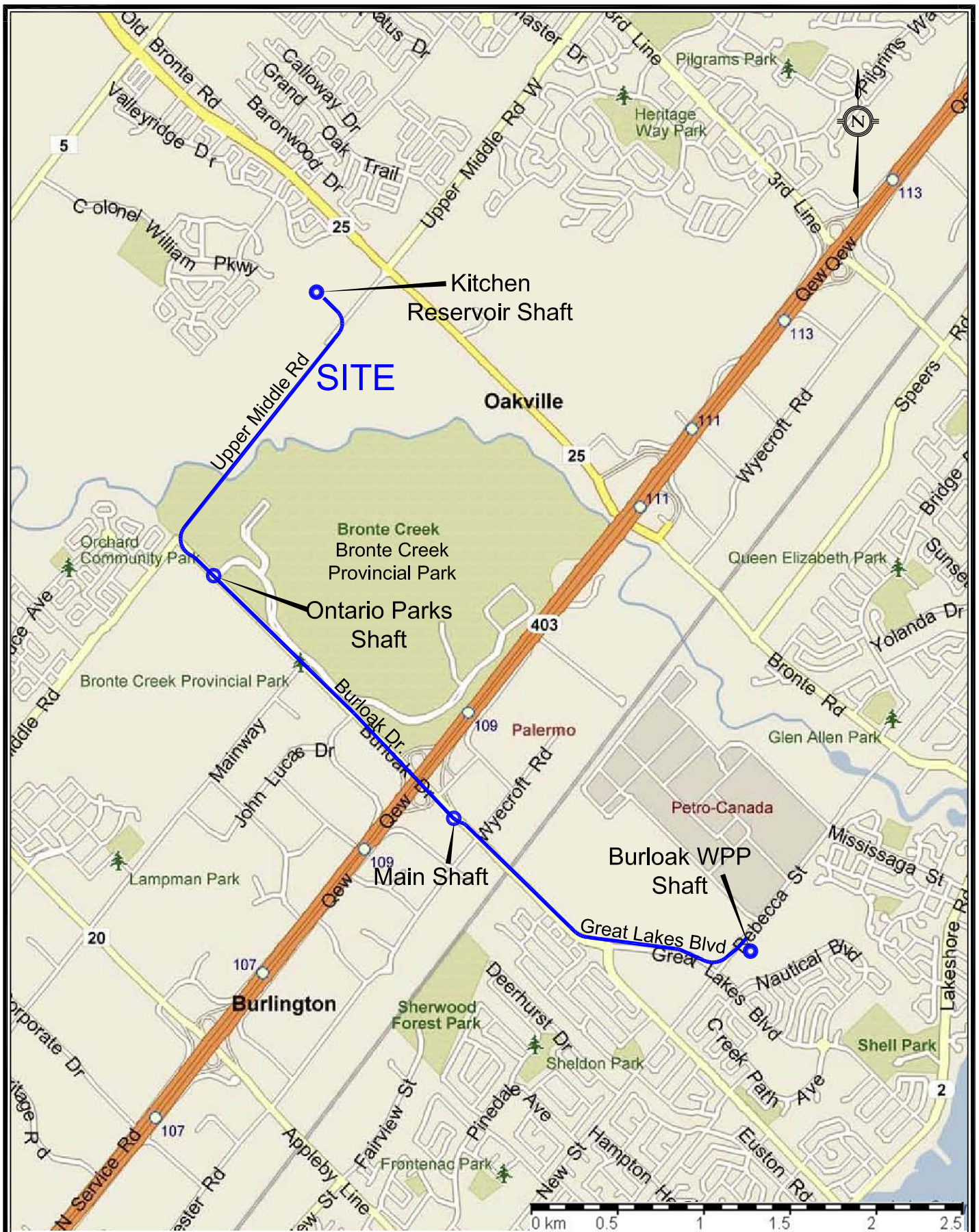
Tim Orpwood, M.A.Sc., P.Geo., P.Eng.  
Principal



# FIGURES

**TERRAPROBE INC.**





**Terraprobe**

11 Indell Lane, Brampton, Ontario, L6T 3Y3  
Tel: (905) 796-2650 Fax: (905) 796-2250

Title:

## SITE LOCATION PLAN

File No.

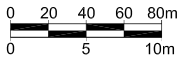
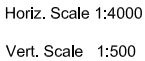
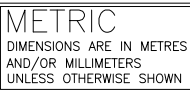
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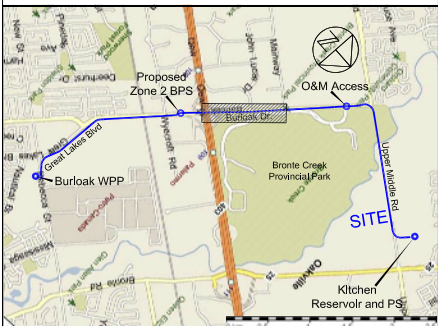










BOREHOLE LOCATIONS AND PROFILE



11 Indell Lane - Brampton Ontario L6T 3Y3 (905) 796-2650



KEY PLAN

LEGEND	
	Terraprobe Borehole 2012
	Previous Terraprobe Borehole
	Borehole By Others
'N'	Blows/0.3m (Std Pen Test, 475 J/blow)
	WL in Piezometer
	Piezometer
90%	Rock Quality Designation
	Overburden Soils
	Bedrock

[illegible]

**NOTE**

The boundaries between soil strata have been established only at borehole locations. Between borehole the boundaries are inferred from geological evidence.

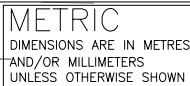
This drawing is for subsurface information only. Surface details and features are for conceptual illustration.

REVISIONS			
	DATE	BY	DESCRIPTION

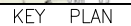
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FIGURE No.:





BOREHOLE LOCATIONS AND PROFILE



	Terraprobe Borehole 2012
	Previous Terraprobe Borehole
	Borehole By Others
'N'	Blows/0.3m (Std Pen Test, 475 J/blow)
	WL in Piezometer
	Piezometer
90%	Rock Quality Designation
	Overburden Soils
	Bedrock

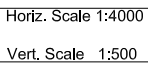
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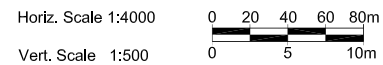
The boundaries between soil strata have been established only at borehole locations. Between borehole the boundaries are inferred from geological evidence.

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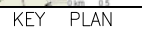
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Halton Zone 1 Watermain  
Burlington–Oakville, Ontario  
PROJECT No. 11-12-2073

 **Terraprobe Inc.**  
Consulting Geotechnical & Environmental Engineering  
Construction Materials, Inspection & Testing  
11 Indell Lane - Brampton Ontario L6T 3Y3 (905) 796-2650



	Terraprobe Borehole 2012
	Previous Terraprobe Borehole
	Borehole By Others
'N'	Blows/0.3m (Std Pen Test, 475 J/blow)
	WL in Piezometer
	Piezometer
90%	Rock Quality Designation
	Overburden Soils
	Bedrock

**NOTE**

The boundaries between soil strata have been established only at borehole locations. Between borehole the boundaries are inferred from geological evidence.

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

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