

# FOUNDATION INVESTIGATION AND DESIGN REPORT FOR TUNNELING

WEST WHITBY TRUNK SANITARY  
SEWER, DURHAM REGION, ONTARIO

Regional Municipality of Durham

MTO GEOCRES No. **30M15-269**

Project No.: 141-15350-00

Date: January 4, 2016

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January 4, 2016

Aaron Christie  
Regional Municipality of Durham  
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**Subject: Foundation Investigation and Design Report for Tunneling  
West Whitby Trunk Sanitary Sewer  
Regional Municipality of Durham, Ontario  
Project No. 141-15350-00**

Dear Mr. Christie,

We are pleased to submit a geotechnical Foundation Investigation and Design Report for the proposed West Whitby Trunk Sanitary Sewer, which is to be constructed from the proposed Jeffery Street Sewage Pumping Station, northerly along Jeffery Street, and crossing the Highway 401 and CNR / Go Transit corridor beneath Coronation Road terminating at Dundas Street. WSP is currently preparing the detailed design and engineering specifications for the project, on behalf of the Region of Durham.

The proposed Highway 401 crossing will be constructed by tunneling and requires Ministry of Transportation (MTO) approvals including an Encroachment Permit. The project is rated as High Complexity under the MTO RAQs system. Therefore, WSP has prepared this report to MTO standards and we have retained Hatch Mott MacDonald (a registered consultant) for high complexity peer review services. HMM's comments and tunneling recommendations are appended, and have been incorporated herein.

This report describes methodology and findings of our field investigations, as well as geotechnical design recommendations for the tunnel crossing, and was completed in accordance with the Terms of Reference provided by the Regional Municipality of Durham. Our geotechnical team has worked closely with the WSP design team to formulate the preferred construction approach and methods. MTO formatted borehole logs, profile drawings and laboratory test results are appended.

A geotechnical data report, which will include the factual components of the investigation, is to be provided under separate cover for the contract tender package.

We trust that this report satisfies your current requirements. Please contact us if you have any questions.

Yours truly,  
WSP Canada Inc.

J. Stephen Ash, P. Eng., P. Geo.  
Director, Environment



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January 05, 2016

J. Stephen Ash, P.Eng., P.Geo.  
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Dear Mr. Stephen Ash

**Subject: Peer Review of Foundation Investigation and Design Report for Tunnelling  
West Whitby Trunk Sanitary Sewer  
Region of Durham  
HMM Project: 358397  
WSP Project: 141-15350-00**

Dear Sir,

This is to confirm that we have reviewed the above-noted Foundation Investigation and Design Report (FIDR) completed by WSP Canada Inc. for the Region of Durham. We are satisfied that our comments (contained therein and made relative to previous draft of that document) as well as Ministry of Transportation Ontario (MTO) comments (made relative to draft dated October 8, 2015) have been addressed and that the current report now meets the requirements of an MTO High Complexity Tunnelling under RAQS submission.

It is understood that the revised FIDR dated January 4, 2016 that contains our comments will be provided to MTO as part of encroachment Permit Application and that the report will form part of the contract package for bidders.

Please contact us if you have any further questions.

Yours faithfully,



**G.J.E. Kramer, P.Eng.**  
Senior Vice President

**Reza Shobayry, P.Eng.**  
Senior Project Engineer  
GK:gd



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# 1 INTRODUCTION

WSP Canada Inc. (WSP) was retained by the Regional Municipality of Durham (Region) to complete a geotechnical investigation, detailed design and specifications, and a contract tender package for the proposed construction of the West Whitby Trunk Sanitary Sewer. The trunk sanitary sewer will extend northerly from the proposed Jeffery Street Sewage Pumping Station, west adjacent to Highway 401, and will cross Highway 401 and the adjacent CNR / Go Transit corridor beneath Coronation Road terminating at Dundas Street. The site location and plan and subsurface profile drawings for the full length of the project are included as Figures 1 through 10.

This Foundation Investigation and Design Report for Tunneling was prepared specifically for the portion of the proposed trunk sanitary sewer alignment that will cross beneath Highway 401 and CNR / Go Transit corridors, between proposed Manhole No. 2 and Manhole No. 3 (i.e. project chainage 1+280 to 1+780). Refer to Figures 6 and 7 for location geotechnical details for this section. The trunk sanitary sewer within this 500 m long section is to be installed via tunneling, and geotechnical design falls under the High Complexity designation in the Ontario Ministry of Transportation's (MTO) RAQs system. Therefore, this report must be reviewed and approved by MTO, to secure the Encroachment Permit that will allow tunneling project to proceed beneath the highway corridor.

This report presents the methodology and findings of our field investigations, and our design recommendations. We have worked closely with WSP's Infrastructure Group, which is designing the project for the Region. This report has been peer reviewed and approved by Hatch Mott MacDonald (a RAQs registered consultant) to meet the High Complexity RAQs requirements. HMM's comments are appended and have been incorporated herein.

It is noted that this report is specifically intended for the project Design Team and MTO reviewers, for securing the required permits and approvals. A separate geotechnical data report (GDR) is to be included in the contract Tender Package. Recommendations in this report should not be construed as instructions to Contractors, who are required to form their own opinions about site conditions for tendering, and determination of equipment and procedures to complete the work according to specifications. It is also noted that this document is not intended to be a Geotechnical Baseline Report (GBR) for contract administration purposes.

# 2 PHYSICAL SETTING

The West Whitby Trunk Sanitary Sewer project lies within the Lake Iroquois Plain Physiographic Region (as per The Physiography of Southern Ontario, Chapman and Putnam, 1972; The Physiography of Southern Ontario, Third Edition, Chapman and Putnam, 1984), which has been characterized mainly as a clay plain overlying glacial till (diamicton) deposits. Surficial physiographic units in the study area are indicated on Figure 1.

Surficial geology mapping identifies Pleistocene age glacial till deposits throughout much of the trunk sanitary sewer alignment, which are locally overlain by glaciolacustrine materials comprising fine sand, silt and clay (Quaternary geology, seamless coverage of the Province of Ontario, Data Set 14 Revised, Ontario Geological Survey, 2000). The till deposits typically comprise undifferentiated, stone-poor, sandy silt to silty sand textured material, typically rich in clasts (i.e. Newmarket Till). The till deposits are often high in total matrix carbonate content and are also known to contain isolated sand and gravel deposits, which may be water-bearing and used as a supply source by local water wells.



Bedrock beneath the site comprises of Middle Ordovician age shale, limestone, dolostone, arkose, and sandstone, representing the Ottawa Group, Simcoe Group, and Shadow Lake Formations (MRD 126 – Revision 1, 1:250,000 Scale Bedrock Geology of Ontario, MNDM, 2011). Bedrock was encountered at all borehole locations, and is described further in Section 4. An irregular transitional zone of till and bedrock, referred to as the Shale-Till Complex in this report, was encountered at the bedrock interface. This zone comprises a dense/hard mixture of fine and coarse glacial till materials, with inferred very weathered and broken bedrock slabs, cobbles and gravel.

## 3 INVESTIGATION PROCEDURES

### 3.1 BOREHOLE INVESTIGATION (MTO CORRIDOR)

The subject borehole investigation within the MTO (and CNR / Go Transit) corridor area was completed at various permitted times between August 29, 2014 and January 19, 2015. The investigation included boreholes in the MTO Encroachment area designated as BH14-4 and BH14-10, and borehole BH14-5 was advanced south of the railway corridor (at proposed Manhole No. 2). These borehole locations are shown on Figures 6 and 7 of the attached drawing set. Information for the adjacent boreholes beyond the Encroachment Area is plotted on the other drawings, and details are provided in a factual data report for the project Tender Package.

It is appreciated that the MTO Tunneling Guideline indicates that boreholes for tunnel investigations should be spaced at 50 m intervals. However, safe access for work crews did not permit closer spacing and MTO did not permit drilling in the highway corridor. WSP and HMM are satisfied that the borehole spacing provided is sufficient for the geologic setting and site conditions. Below the highway, the bedrock surface elevation changes by less than 0.5 m (see BH14-4 and BH14-10) and the bedrock surface is approximately 10 m above the tunnel invert. The inferred 2% slope on the bedrock surface is not large over the 220 m tunnel length, and is consistent with flat lying, horizontally-bedded limestone deposits well known in the site area.

The subject Encroachment area boreholes were advanced from existing ground level and were terminated at depths ranging from 21.7 m to 24.4 m below ground level (BGL), as determined by the proposed trunk sewer construction depths. All boreholes were terminated in bedrock after being advanced through the soil overburden. Table 3-1 summarizes borehole locations and depth information.

**Table 3-1: Summary of Borehole Locations and Depths**

Borehole Identification	Groundwater Monitoring Well Identification (if installed)	Date Drilled	UTM (Zone 17T)		Approximate Ground Surface Elevation (mASL) <sup>1</sup>	Approximate Elevation of Proposed Sewer Invert (mASL) <sup>1</sup>	Approximate Depth of Borehole from Ground Level (mBGL)	Approximate Bottom of Borehole (mASL) <sup>1</sup>
			Easting (m)	Northing (m)				
BH14-4	MW14-4	Dec 10, 2014	663253	4858960	82.0	64.3	24.4	58.1
BH14-5	MW14-5	Aug 29, 2014	663314	4858800	83.0	63.8	21.7	61.0
BH14-10	MW14-10	Jan 19, 2015	663288	4858872	82.0	63.8	21.7	60.4

<sup>1</sup> mASL = meters above sea level (NAD 83 datum)

Buried utility locates were obtained in advance of drilling, and where necessary prescribed borehole locations were moved slightly to avoid conflicts with existing utility services. WSP worked with several agencies and private contractors to secure the proper clearances, including the Central Lake Ontario Conservation Authority (CLOCA).

Drilling and soil sampling was completed using track-mounted commercial drill rigs operating under the supervision of experienced WSP technicians and engineers. Boreholes were advanced to the sampling depths by means of 210 mm outside diameter (OD) continuous flight hollow stem augers. Soil sampling



was completed at 0.75 m to 1.5 m intervals using a split-spoon sampler driven in accordance with Standard Penetration Test (SPT) procedures (ASTM D1586). Wider sample spacing was considered acceptable given that tunnelling will be in the bedrock zone. SPT N-values were recorded for the sampled intervals as the number of blows required to drive a split-spoon sampler 305 mm into the soil, using a 63.5 kg drop hammer falling 750 mm. N-values were considered in this report to assess consistency for cohesive soils and relative density for non-cohesive materials.

Sampled material from discrete surficial topsoil, fill and pavement layers and subsurface soil units were logged in the field using visual and tactile methods. Selected samples were placed in labelled plastic bags for transport, future reference, possible laboratory testing, and storage. Soils for laboratory moisture content testing were placed in sealed laboratory jars for transport.

Rock cores were taken continuously for the full depth of bedrock penetration, and stored at our facilities in Aurora, Ontario. Rock Quality Designation (RQD) was calculated at the time of coring, and universal point load testing was performed at WSP's in-house laboratory facilities to assess unconfined compressive strengths (UCS) of sampled intervals.

Groundwater conditions within the boreholes were observed during drilling. Upon completion of inspections, 50 mm OD groundwater monitoring wells were installed at all borehole locations. Where necessary, WSP returned to borehole locations to add additional material where backfill settled slightly. Some additional minor settlement of the borehole fill may occur over time and additional fill material may need to be added. Monitoring well installations and borehole abandonment are considered to be in accordance with O. Reg. 903 requirements, as amended from time to time.

It is noted that prior to tunnel construction, any boreholes or monitoring wells located in the tunnel pathway shall be decommissioned in accordance with O. Reg. 903 requirements. Boreholes in bedrock shall be backfilled with 25 MPa structural grout. Overburden may be sealed with grout or hydrated bentonite hole-plug. Monitoring wells required for construction should be offset a sufficient distance, as required by the Hydrogeologist, to facilitate water level monitoring but not compromise tunnel integrity. A minimum offset distance of 3 m is suggested, subject to Hydrogeological review.

## 4 SUBSURFACE CONDITIONS

Subsurface conditions for the Highway 401 crossing were assessed at the three (3) subject borehole locations designated as BH14-4, BH14-5, and BH14-10. These borehole locations are shown on plan and subsurface profile drawings included as Figures 6 and 7 of this report. Borehole logs (MTO formatted) are provided in Appendix A and geotechnical test results are included in Appendix B and C, for tests completed on the soil and bedrock samples respectively.

Three lithologically distinct bedrock units were encountered beneath the penetrated overburden, including a unit of shale, a unit of shale and siltstone, and a unit of shaley limestone. Bedrock units are interpreted to be part of the Lower Whitby and Lindsay / Cobourg Formations. The bedrock is overlain by variable glacial till deposits and shallow layers of silt to silty clay as noted.

### 4.1 SUBSURFACE SOIL UNIT DESCRIPTIONS

Descriptions of individual subsurface soil units encountered in the boreholes are provided on this section. Visual interpretations of the estimated stratigraphy are provided in Figures 2 through 10 (see Figures 6 and 7 specifically for the MTO Highway crossing profile).

#### 4.1.1 TOPSOIL

A surficial layer of topsoil was found at borehole locations BH14-4 and BH14-5, and was 0.8 metres and 1.5 meters in thickness, respectively. The topsoil is generally described as brown silty sand with organic material, and was found to be moist/damp at the time of drilling. No topsoil was reported at BH14-10.

#### 4.1.2 SILTY CLAY

Brown silty clay was penetrated in BH14-4 from 1.5 mBGL to 3.0 mBGL (el. 80.5 to 79.0 mASL). Atterberg Limits tests completed on two selected samples of this material are plotted on the borehole log and summarized as follows:

**Table 4-1: Summary of Atterberg Limits Tests (shallow silty clay at BH14-4)**

Silty Clay (CL)	
Liquid Limit (LL)	24 to 41 %
Plastic Limit (PL)	15 to 22 %
Plasticity Index (PI)	9 to 19 %

The Atterberg Limits and moisture content results classify the material as inorganic silty clay of low plasticity (CL type). The moisture content ranged from approximately 15 to 21 percent, or about plastic limit (APL).

Results of laboratory particle size analyses (ASTM D422) for the selected samples of silty clay from BH14-4 are summarized below (Unified System).

**Table 4-2: Summary of Particle Size Distribution Tests for Silty Clay**

Parameter	Percent Content
Gravel (4.75 mm to 75 mm)	0 %
Sand (0.075 mm to 4.75 mm)	7 %
Silt and Clay (< 0.075 mm)	93 %

SPT N-values recorded in the silty clay layer ranged from 8 to 22 blows, and are indicative of firm to very stiff material.

#### 4.1.3 SILTY SAND (TILL)

Dark grey silty sand till with occasional cobbles was encountered at BH14-4, from a depth of 3.0 mBGL to 8.4 mBGL (el. 79.0 mASL to 73.6 mASL). With the exception of the initial sample, N values exceeded 50 indicating the material is very dense. Moisture content ranged from 5 to 12 % based on laboratory tests.

Light brown to brown sandy silt to silty sand till also was penetrated at borehole BH14-5, from 0.8 to 9.8 m BGL (el. 82.2 mASL to 73.3 mASL), and from surface to 5.8 mBGL (el. 82.0 mASL to 76.2 mASL) in BH14-10. The material is compact to very dense based on N values, and laboratory determined moisture contents range from approximately 4 to 13 %. Results of particle size analyses completed on six (6) selected samples of the silty sand (to sandy silt) till are summarized in Table 4-3, below.



**Table 4-3: Summary of Particle Size Distribution Tests for Till Layer (n=6)**

Parameter	Percent Content
Gravel (4.75 mm to 75.00 mm)	9 to 29 %
Sand (0.075 mm to 4.75 mm)	31 to 42 %
Silt and Clay (< 0.075 mm)	33 to 60 %

Atterberg Limits tests were completed on two (2) selected samples of the till material to examine plasticity characteristics. Results are as follows:

**Table 4-4: Summary of Atterberg Limits Tests (BH14-5, samples 3SS and 8SS)**

	Till
Liquid Limit (LL)	21 %
Plastic Limit (PL)	13 to 15 %
Plasticity Index (PI)	6 to 8 %

#### 4.1.4 GRAVELLY INTERBEDS

Localized lenses and layers of gravelly sand and gravel were penetrated in the boreholes and are interpreted as reworked tills or minor spillway channels associated with the accepted glaciofluvial / glaciolacustrine provenance. These gravel-rich discontinuous layers were noted in the borehole BH14-4 and BH14-5 profiles.

#### 4.1.5 SHALE-TILL COMPLEX

Discontinuous zones of reworked tills with gravel-sized shale fragments previously noted in the lower sections of BH14-4, BH14-5 and BH14-10 are interpreted to have been scoured from the bedrock before being deposited in spillway channels and depressions. Presumed weathered shale boulders with clayey silt matrix could not be penetrated at BH14-4 and coring was required to sample this material. Within BH14-5 there appears to be a 4 m thick transitional soil to weathered bedrock zone from approximate elevation 73.3 mASL to 69.3 mASL, which contains a mixture of sandy clayey silt (till) materials and shale fragments (cobbles and boulders). This zone is very hard/dense with N values greater than 100. A very dense (N>100) layer of silty sand with shale fragments and presumed boulders/slabs also was encountered at borehole location BH14-10, between elevations 76.2 mASL and 73.4 mASL. This layer also required core sampling.

### 4.2 SUBSURFACE BEDROCK UNIT DESCRIPTIONS

The subject boreholes in the Highway 401 crossing section were terminated in bedrock. Three bedrock units were identified and are described in the following sections: Shale, Shale and Siltstone, and Shaley Limestone.

#### 4.2.1 SHALE

Beds of very fine-grained dark grey to black non-calcareous slightly bituminous and organic shale were encountered beneath the overburden at all borehole locations. The inferred depths (elevations in brackets) of the shale bedrock are summarized as follows:

- BH14-4: 9.8 mBGL (72.2 mASL)
- BH14-5: 13.8 mBGL (69.3 mASL)\*
- BH14-10: 8.6 mBGL (73.4 mASL)

\* (Note: Significant weathered shale fragment and soil mixture penetrated from el. 73.3 mASL as noted on log)

The shale is horizontally-bedded and sparsely fossiliferous, and may occasionally contain combustible gases, including methane. Core samples can be scratched by pointed steel indicating a relative hardness

of 5 or less on Mohs Scale, and a petroliferous odour may be released when the rock is scratched. The shale stratum is interpreted to belong to the Blue Mountain Formation (Lower Whitby Formation).

The soil / bedrock interface was highly weathered at borehole location BH14-5, and Rock Quality Designations (RQD's) in the upper bedrock zone were generally poor. Rock appeared to be less weathered and fractured below approximate elevation 66 mASL, and RQD values generally improved to fair or better as discussed below.

Rock Quality Designations (RQD's) were determined during coring, and were subsequently confirmed by a professional geoscientist in the laboratory. RQD values measure the length of the recovered core samples that are greater than 100 mm and determine their sum length as a percentage of the core run. For the shale core samples, RQD's vary from 9 to over 90 percent (very poor to excellent quality), and are generally over 80 percent (good RQD) proximal to the tunnel horizon. RQD values may tend to underestimate in situ rock quality in fissile shale units as it is structurally governed. The proposed tunnel alignment is shown on Figures 2 through 10 (and specifically 6 and 7 for the Highway 401 crossing), with RQD values and ratings summarized for the cored intervals.

Point load tests were performed on selected samples of the shale taken near the proposed tunnel elevation. Axial unconfined compressive strengths (UCS) ranged from 61 to 114 MPa, whereas approximate diametral UCS values were much lower and ranged from only 2 to 3 MPa. As expected, the shale unit is demonstrated through the point load test results to have a preferred direction of weakness with bedding direction.

**Table 4-5: Summary of Subsurface Bedrock Unit Point Load Tests**

Borehole Identification	Depth Tested (mBGL/e.l.)	Interpreted Bedrock Unit	Approximate Axial UCS (MPa)	Approximate Diametral UCS (MPa)
BH14-4	16.3 / 66.2	Whitby Shale	82	3
BH14-5	18.3 / 64.4	Whitby Shale	61	2
BH14-10	16.5 / 65.6	Whitby Shale	114	2

Photos of the Point Load Test breakages are provided in Appendix C, and indicate that the rock is weak in the bedding direction, based on ISRM convention.

In situ horizontal stresses in the bedrock were not measured for this report, but based on reported values for nearby projects and literature for similar sedimentary rock deposits, major principal stress is expected to be in the range of 9 to 11 MPa (expected orientation: east-northeast) and minor principal stress may be in the order of 4 to 6 MPa. Confirmatory tests should be considered, subject to detailed design requirements for tunnel linings.

#### 4.2.2 SHALE AND SILTSTONE

Beds of very fine-grained darkish grey brown non-calcareous shale interbedded with grey fossiliferous siltstone were encountered below the shale stratum at all borehole locations. The siltstone may form a harder more competent layer. The top of the shale and siltstone stratum was encountered at elevations between 62.5 mASL to 63.8 mASL, and this unit was 2.7 m to over 3.1 m thick. The proposed tunnel alignment in the Highway crossing will generally cut through the interface of this unit and the shale above. The shale and siltstone is interpreted to belong to the Blue Mountain Formation (Lower Whitby Formation).

The shale and siltstone unit is horizontally bedded and sparsely fossiliferous, whereas the calcareous laminae interbeds are fossiliferous. Laminae represent approximately 20 % of the core, and are generally about 25 mm to 50 mm in thickness. Core samples can be scratched easily by pointed steel indicating a relative hardness of 5 or less on Mohs Scale.



Rock Quality Designations (RQD's) were determined during coring, and were subsequently confirmed by a professional geoscientist in the laboratory. RQD values the shale and siltstone vary from 8 to over 90 percent, and range from 27 to over 90 percent (poor to excellent quality) proximal to the tunnel horizon. As noted in the previous section RQD's may tend to underestimate in situ quality in these laminated rock formations.

Strength and in situ stress properties for this unit are expected to be generally similar to the thicker shale unit above.

#### 4.2.3 SHALEY LIMESTONE

Boreholes BH14-4 and BH14-10 were terminated in medium to dark-grey shaley limestone below the tunnel invert. The top of the shaley limestone stratum was interpreted at elevation 58.9 mASL at BH14-4 and 61.0 mASL at BH14-10 (see logs). This unit is interpreted to belong to the Lindsay / Cobourg Formation and contains horizontal beds that are strongly bioturbated and fossiliferous. Core samples are scratched easily by pointed steel indicating a relative hardness of 5 or less on Mohs Scale.

Rock Quality Designations (RQD's) were determined during drilling, and were subsequently confirmed by a professional geoscientist in the laboratory. RQD values range from 95 to 100 proximal to the tunnel alignment and are indicative of excellent quality rock.

### 4.3 GROUNDWATER

Groundwater was observed in the open boreholes upon completion of drilling, and was also noted as seepage from granular layers. Groundwater seepage observations are summarized in Table 4-6, below.

Groundwater monitoring wells were installed at all borehole locations, and screened in bedrock at the approximate tunnel horizon. Measurements taken from the groundwater monitoring wells are summarized in Table 4-6, below, as well as indicated on the corresponding borehole logs in Appendix A.

**Table 4-6: Summary of Groundwater Monitoring Well Locations and Data**

Borehole Identification and Groundwater Monitoring Well Identification	Approximate Ground Surface Elevation (mASL)	Shallow Groundwater Seepage (mBGL) <sup>1</sup>	Measured Depth of Groundwater Level (Oct. 2, 2014; mBGL) <sup>2</sup>	Measured Depth of Groundwater Level (May 25, 2015; mBGL) <sup>2</sup>	Measured Depth of Groundwater Level (June 11, 2015; mBGL) <sup>2</sup>	Approximate Elevation of Groundwater (mASL)	Approximate Elevation of Proposed Trunk Sewer Invert (mASL)
BH14-4	82.0	Dry	Not drilled at this time	2.94	3.0	79.1	62.5
BH14-5	83.0	1.9	6.4	n/a	15.6	67.4	62.0
BH14-10	82.0	Dry	Not drilled at this time	1.4	1.3	80.7	61.6

<sup>1</sup> Groundwater seepage is observed at the time of drilling.

<sup>2</sup> Groundwater levels are measured from wells after stabilization.

<sup>3</sup> Presumed that water levels had not recharged since testing on May 25, 2015.

Groundwater measurements from the monitoring wells are indicative of head pressures within the bedrock at the approximate tunnel horizon. It can be seen that groundwater pressures range up to approximately 19 m above the trunk sanitary sewer invert within the MTO and CNR corridors. The groundwater measurements are summarized visually on the subsurface profile drawings. Groundwater levels are subject to seasonal fluctuations and the quality/longevity of monitoring well installations (including screen performance with respect to plugging).

It should be noted that drilling activities produced dark shale flour resembling oil, as well as remobilized oil entrapped in the shale bedrock. The oil entrapped within the shale pores is essentially hydrophobic, and presumably hampers water movement within the shale. Slug tests performed on the monitoring wells



indicate that recharge levels in the bedrock are low. Slug tests are discussed further in the West Whitby Trunk Sanitary Sewer Hydrogeological Investigation (WSP, 2015). Encountering and remobilizing oil within the shale bedrock will need to be considered in terms of disposal and safety (see Section 8).

## 5 PROJECT OVERVIEW

### 5.1 GENERAL DESCRIPTION OF THE PROJECT

Plan and profile design drawings for the proposed 900 mm / 1200 mm diameter trunk sanitary sewer are included as Figures 2 through 10 of this report. It is understood that the trunk sanitary sewer will be installed beneath the Highway 401 (and CNR / Go Transit) corridor, between Project Stations 1+280 to 1+780, using trenchless methods through the bedrock. The proposed trunk sanitary sewer pipe invert is approximately between elevations 59 mASL to 64.2 mASL across the full length of the project. Within the Highway 401 corridor the tunnel invert is close to el. 62 mASL, or approximately 20 mBGL.

The project will require the excavation of vertical shafts and installation of manholes, including Manholes No. 2 at Station 1+280 and No. 3 at Station 1+780. The horizontal and vertical alignments of the proposed trunk sanitary sewer shall be designed in consideration of the following:

- Located within the Region's 20 m wide permanent easement as much as possible;
- Minimize necessary expansion of easement limits;
- Avoid existing utilities; and
- Installation below the inferred 1.4 metre frost depth (OPSD 3090.101).

### 5.2 CONNECTIONS

The West Whitby Trunk Sanitary Sewer will require two (2) connection points:

- Connection to proposed trunk sewer construction at north extent of the project limits, located approximately at the intersection of Dundas Road and Coronation Road (Station 2+315), with presumed construction at a later date.
- Connection to the proposed Jeffery Street sewage pumping station at southern project extent of this investigation, located on Jeffery Street (Station 0+000), with presumed construction to commence subsequently.

Further to the scope of this report, the tunnel will connect at Shaft 3, discussed in Section 5.4, and continue northward to the intersection of Dundas Road and Coronation Road after leaving the north extents of the MTO corridor. Shaft 4 (Manhole No. 3), located at Station 1+780, is the most proximal to the MTO corridor from the north.

### 5.3 UNDERCROSSINGS

The proposed 900 mm diameter trunk sanitary sewer pipe shall cross beneath Highway 401 as well as the adjacent Canadian National Railroad (CNR / Go Transit) corridor to the south.

### 5.4 SHAFTS AND MANHOLES

The locations and invert elevations of the shafts are summarized in Table 5-1. The final dimensions and shape of the shafts are to be decided by the Contractor.

**Table 5-1: Summary of Main Shaft Locations (Full Limits)**

Shaft (Associated Manhole)	Approximate Chainage (m)	Nearest Borehole	Approximate Invert Elevation (mASL)	Trunk Sanitary Sewer Diameter
1 (JSPS)	0+000	BH-JSPS1	58	900 mm
2 (No. 1)	0+450	BH14-8	59.5	900 mm
3 (No. 2)	1+280	BH14-5	61.5	900 mm
4 (No. 3)	1+780	BH14-3	63.4	900 mm
5 (No. 4)	2+360	BH14-11	81.0 to north 76.0 to south	900 mm

The MTO Encroachment Area, which is the subject of the report, is located between Shafts 3 and 4 as shown on Figure 7.

## 5.5 TRAFFIC CONTROL

No traffic control is expected to be required to undertake the installation of the trunk sanitary sewer within the MTO and CNR corridor.

Construction of the settlement monitoring plan, discussed in Section 11, will require a Road Occupancy Permit (ROP) and Traffic Control Services in accordance with Book 7 of the Ontario Traffic Manual. Work is not expected to require road closure.

# 6 TUNNEL DESIGN AND CONSTRUCTION

## 6.1 ANTICIPATED GEOTECHNICAL CONDITIONS

The proposed invert elevations of the trunk sanitary sewer fall within the existing shale and siltstone bedrock formations (i.e. Whitby Formation) as described in Section 4. Proposed alignments are not expected to penetrate the shaley limestone beds (Lindsay/Cobourg Formation).

Rock quality designation (RQD) values for the bedrock at the proposed alignment elevations range from fair to good, and relevant values are plotted on the Figure 6 and 7 borehole logs. The entirety of the tunnel alignment is below the observed piezometric groundwater level as noted.

Specific excavation requirements must be evaluated in terms of the expected RQD and groundwater seepage conditions. Care should also be taken at shaft/pit excavations to control seepage, sloughing and to prevent basal heave.

## 6.2 ANTICIPATED GROUND BEHAVIOUR

The geotechnical investigation indicates that the proposed trunk sanitary sewer tunnel will be advanced through fair to good quality shale and siltstone beds, with depths of bedrock overlying the pipe invert ranging from approximately 5 to 10 metres in thickness, and competent soil overburden forming the balance. The available depth and type of cover is considered sufficient to minimize risk of surficial settlement effects during the construction period.

A tunnel of the proposed diameter excavated through the shale and siltstone is viable using a tunnel boring machine (TBM), where full and immediate support is provided behind the excavation face. Tunnel design and construction should consider the potential for high horizontal rock stresses and related squeeze effects following excavation, groundwater seepage and potential for combustible and/or poisonous gases. The



observed shale beds have sub-horizontal bedding planes and fractures, and Contractors shall be advised of the potential for delamination and breakage effects as the face is advanced. Adequate support and worker protection is required according to OHSA. While the rock quality is expected to be fairly good overall, the tunnel may encounter soft clay seams that may require adjustments to the tunneling equipment to prevent clogging.

Groundwater seepage should be anticipated and up-sloping drives should be used to drain water back to the launch shaft for sump pumping. In heavily fractured shale with seepage, localized grouting may be required.

The shale formations in the site area are reported to contain methane and combustible gas mixtures that may be explosive in air. The following Non-Standard Special Provision (NSSP) is presented to address this condition:

NSSP 1: Ventilation and monitoring must be a stringent requirement for all excavations and tunnelling work, in accordance with OHSA requirements. The Contractor shall be warned of explosive gas potential in the project specifications. Active pressure ventilation systems shall be used in lieu of passive systems to remove tunnel gas.

### 6.3 TUNNELLING METHODS

Tunnelling should be undertaken in accordance with OPSS 415 and 416 as appropriate as well as any associated and/or applicable Regional standards.

The diameter of pipe (900 mm), length of drive (500 m) and anticipated subsurface conditions (Shale Rock) limit the range of trenchless installation techniques that would be economically and technically viable for this project. There are two possible tunneling methods that could be utilized to construct this sewer. Those being via Tunnel Boring Machine (TBM) or a Micro Tunnel Boring Machine (MTBM).

The TBM option would include the tunneling being excavated with a primary liner installed (i.e. rib and lagging or rock bolts/mesh), then following this the concrete pressure pipe (CPP) would be placed inside the tunnel and the annular space between the outside of the sewer pipe and the primary liner would be grouted (200 mm thick minimum). The CPP trunk sewer pipe would be manufactured with sulphate resistant cement (Type HS) in order to mitigate corrosive effects of any internal and external gases.

The MTBM option would involve the tunnel being excavated with a slurry microtunnelling technique and reinforced concrete jacking pipe. This would be a single pass tunneling installation. The reinforced concrete jacking pipe (RCJP) would be manufactured with sulphate resistant cement (Type HS) in order to mitigate corrosive effects of any internal and external gases. There would be an overcut by the MTBM that would create a small gap between the exterior of the pipe and the excavated tunnel wall. This small gap/annulus would be filled with a compressible grout.

The following Table 6-1 tabulates a tunneling method comparison that was used to evaluate tunneling alternatives.

**Table 6-1: Tunneling Method Comparison Table**

Tunnelling Method – Trunk Sewer	Advantages	Disadvantages	Costs Ranking	Risks / Consequences
Jack and Bore / Pipe Ramming	- Least expensive alternative	- Tunnel Face is not fully supported. - Not suitable for drive lengths greater than 100 meters	1	High Risk of over-mining in flowing ground conditions. Not considered further.
Tunneling using TBM	- Minimal ground disturbance - Higher advance rates	- High equipment capital cost	3	n/a



<b>Micro-Tunnelling</b>	<ul style="list-style-type: none"> <li>- Can be applied to wide range of soils</li> <li>- High Precision, Laser guided accuracy</li> </ul>	<ul style="list-style-type: none"> <li>- High equipment capital cost</li> </ul>	4	Excavation can be hindered by large boulders
<b>Horizontal Directional Drilling</b>	<ul style="list-style-type: none"> <li>- Has maximum drive length</li> </ul>	<ul style="list-style-type: none"> <li>- Not as accurate for vertical grades</li> </ul>	2	<p>Cannot provide the required slopes of 0.3%.</p> <p>Surface launching is not practical with deep sewer depths.</p> <p>Not considered further.</p>

The Jack and Bore/Pipe Ramming has not been considered further as an alternative due to the risk of settlement and the length of drive required. Similarly, Horizontal Directional Drilling has not been considered further due to the lack of vertical grade accuracy within the pipe alignment. In addition, HDD pipes are launched at the surface and require the installed pipes to flex prior to reaching its intended grade.

TBM and MTBM methods can both construct the required tunnel size for the 900 mm diameter sanitary sewer whilst maintaining accurate vertical grade control and ground stability. The TBM will utilize a double-pass installation whereas the MTBM method would utilize a single pass installation. Since MTBM's may experience difficulty cutting through large boulders and rock, the TBM method is considered the most suitable trenchless technology for the construction of the West Whitby Trunk Sanitary Sewer underneath Hwy 401.

Tunnel boring machine (TBM) techniques involve assembling a rotating cutter head at the tunnel elevation, which is advanced by hydraulic jacking or "thrust cylinders". Excavated rock is recovered through the cutterhead and transferred through the rear conveyor to haulage equipment. The TBM operator and automated systems keep the rate of rock removal equal to the rate of machine advance, maintaining a stable environment within the excavated tunnel.

The Contractor should have the provision for powering the cutterhead within the body of the TBM. The TBM should be of new or newly refurbished construction, including new cutting tools and hard facing on the cutterhead. The TBM should be designed in consideration of the expected shale and siltstone rock conditions, with thin bedding and inherent fissility, occasional soft clayey seams, and some variability between weaker and stronger rock layers with strengths ranging from a diametral UCS of 2 MPa up to an axial UCS of about 114 MPa as noted. The Contractor shall have the capability to replace worn tooling, including gage cutters from within the TBM. It is recommended that slurries, rail cars or conveyor systems be used for the transport of muck from the tunnel face to the access shafts. Auger based systems, other than between the plenum chamber and the TBM, should not be used.

TBM's may be self-propelled or propelled by a jacking frame located in the launching shaft. If a TBM propelled by a jacking frame is used, the contract documents should require the Contractor to estimate the minimum overcut, given the tendency of the shale to swell and undergo time-dependent deformation. The minimum overcut should be selected such that the mined tunnel will not converge onto the jacked pipe during construction.

## 6.4 TEMPORARY AND FINAL SUPPORT

The geotechnical investigation indicates that the trunk sanitary sewer tunnel will be advanced under approximately 20 m of soil overburden and bedrock as noted. A tunnel of the proposed diameter excavated through the Blue Mountain Formation is expected to be stable when made by tunnel boring machine excavation, and where full support is immediately provided at and behind the excavation face.

Preferential weakness along the horizontal plane of the shales will result in fracturing during mining of the shales, which may allow increased water migration along the alignment. The annulus between the tunnel liner and the bedrock should be grouted using a compressible material as tunnelling progresses to mitigate the migration of water along the alignment at the time of drilling and in the future. Design of the liner and

the compressible annulus material will need to consider the swelling nature of the shale bedrock, which may take several months to reach a relaxed state.

## 6.5 ANTICIPATED GROUND DEFORMATION

Shale bedrock with anticipated high horizontal stress is expected to swell and squeeze causing time-dependent tunnel convergence, similar to behavior observed in other Paleozoic shale formations in the Region. Specific tests have not been completed for this report, but the typical magnitude of time-dependent tunnel convergence in these types of rocks is expected to be in the order of 0.05 % of the tunnel diameter per log cycle of time.

Although the bedrock is expected to remain intact, provided support is installed immediately, the overburden soils are anticipated to respond to construction vibrations. Localized liquefaction and settling may occur, and maximum settlement at the tunnel centreline may be calculated as follows:

$$w_{\max} = 0.125 \times V_L \times (\frac{1}{2}D_o)^2$$

where,  $w_{\max}$  = the maximum surface settlement at the centre of the tunnel (m)

$V_L$  = estimated volume loss (%)

$D_o$  = tunnel outside diameter (m)

Refer to the HMM peer review calculations in Appendix E. The depth from ground surface to the tunnel springline ranges from approximately 18.5 m to 19.5 m within the MTO and CNR corridor. Of this, approximately 10 m is bedrock as noted. Vibrations conducted upward into the soil overburden from the bedrock create a settlement potential. Provided good workmanship is used, estimated settlement is expected to be less than 9 mm.

# 7 MANHOLES AND SHAFTS

Shaft locations and depths are indicated on the plan and profile drawings (Figures 2 through 10), and were discussed in Section 5.4. For each of the proposed shaft excavation, overburden soils above the groundwater table may be cut back to a stable inclination if space restrictions permit. OSHA safe slopes for open cut excavations shall be provided.

Where shaft excavations cannot be sloped, or where open cuts are not economical, they may be supported through the overburden using a shored excavation designed by a professional engineer. Localized rock bolting should be installed to support the tunnel portals since the thin bedded/laminated shale bedrock may delaminate otherwise. Shafts and manholes shall be kept stable, dry, and watertight during the work.

Shoring may be considered as a seepage control alternative. No excavation shall extend below the foundations of any existing structures without adequate alternative support being provided.

## 7.1 SHAFT STABILITY AND DEWATERING

Basal instability may occur when a high hydraulic gradient creates seepage pressure through the base of an excavation, or where a more pervious deposits containing water under high hydrostatic head underlie the base of the shaft at a shallow depth.

The shaft at Station 1+280 will penetrate approximately 13.8 metres of soil overburden, including the Shale-Till complex deposits, before penetrating another 8 metres into the bedrock. The base of the shaft could be as much as 15 m below the potentiometric groundwater surface. Although the shaft will be founded in shale and siltstone, the potentiometric surface is above the soil/bedrock interface. As such, it should be assumed that soils above the bedrock are wet. For safety, it will be necessary to depressurize the water-bearing strata (granular materials) using an eductor well system, and the potentiometric head must be



brought down to at least 1 m below the base of soil and bedrock interface. Positive dewatering is therefore required to maintain a stable excavation for the shafts.

The till soils and shale-till complex materials above the bedrock are very dense and drainage from dewatering is not expected to cause settlement effects on nearby structures. Existing structures are well separated from the proposed work area. Moist, dense soils comprising the balance of the overburden soils shall be shored to prevent ground destabilization and localized settlement effects (see Sections 7.2 and 7.3).

It is recommended that a PTTW be obtained for wellpoint/eductor dewatering and to pump and depressurize the underlying granular materials below the shaft locations. A liberal quantity of water should be considered in the PTTW application to cover sidewall seepage handling in each shaft location. The quantity of seepage expected must be reviewed at a later time, when construction methods and details are known. Depressurization volumes for trunk sewer shafts will likely exceed 50,000 L/day, and owing to the expected duration of dewatering a Category 3 Permit to Take Water (PTTW) from the Ministry of Environment and Climate Change (MOECC) will be required. Additional hydrogeological investigations including installation of monitoring wells in granular layers and hydraulic conductivity analysis will be required to support a permit application.

A professional dewatering contractor should be consulted to review the subsurface conditions and to design a site specific dewatering system. It is the dewatering contractor's responsibility to make an assessment of the factual data and to provide recommendations on dewatering system requirements, including water treatment requirements and control of discharge. As mentioned in Section 4.3, pore space in the shale was observed to contain an oil component. Water quality sampling will be required to assess discharge options for dewatering systems.

Following depressurization, a dry excavation must be properly maintained by pumping from a conventional sump pump arrangement. Exposed soil should be protected by a skim coat of lean concrete, where necessary.

## 7.2 EARTH PRESSURE DISTRIBUTION

The anticipated excavations will be advanced surficial layers of silt, silt and sand, and sandy clayey silt, before being further advanced through Blue Mountain Formation shale and shale and siltstone.

The appropriate geotechnical parameters for use in design of shoring systems and liners at this site are tabulated as follows:

**Table 7-1: Earth Pressure Parameters (unfactored)**

Stratum	$\Phi$ (Friction angle, deg.)	$\gamma$ (bulk unit weight, kN/m <sup>3</sup> )	$K_a$ (active earth pressure)	$K_o$ (at-rest earth pressure)	$K_p$ (passive earth pressure)
Silty Clay	28	19	0.36	0.53	2.77
Silty Sand Till	34	21	0.28	0.44	3.54
Very dense sand, gravel, shale-till mixtures	36	22	0.26	0.41	3.85

The above earth pressure parameters pertain to a horizontal grade condition behind the retaining structure or shoring wall. Values of earth pressure parameters for an inclined retaining grade condition will vary.

Walls subject to lateral earth pressures (P) must be designed to resist a pressure that can be calculated based on the following equation:

$$P = K[\gamma(h - h_w) + \gamma' h_w + q] + \gamma_w h_w$$

where,	$P$	=	the horizontal pressure at depth, $h$ (m)
	$K$	=	the earth pressure coefficient
	$h_w$	=	the depth below the groundwater level (m)
	$\gamma$	=	the bulk unit weight of soil, (kN/m <sup>3</sup> )
	$\gamma'$	=	the submerged unit weight of the exterior soil, (kN/m <sup>3</sup> )
	$\gamma_w$	=	the unit weight of water (9.8 kN/m <sup>3</sup> )
	$q$	=	the complete surcharge loading (kPa)

Where the soil behind a vertical support structure is granular material and well drained effectively to eliminate hydrostatic pressures that would otherwise act in conjunction with earth pressure, a trapezoidal earth pressure distribution is applicable and the above equation is reduced to:

$$P = K[\gamma h + q]$$

Soldier pile toe support could be considered given dense to very dense mixed till deposits. The horizontal resistance of the soldier pile toes will be developed by embedment below the base of excavation, where resistance is developed from passive earth pressure in the shale. Saturated material above the bedrock may be wet and susceptible to sloughing, such that augered holes for soldier piles may become unstable. In these cases, it will be necessary to advance temporarily cased holes to prevent excess caving during the soldier pile installations.

### 7.3 SHORING SUPPORT

Shoring configurations for shaft applications typically involve the entire perimeter of a circular or square shaft being shored. Internal ring beams, whalers, or corner bracing are typically used to support shored shaft walls, especially where space restrictions will not allow a tie-back rig to enter the shaft. For this type of shoring support it is usually preferred to use tie-backs or earth anchors in shafts. Internal bracing such as rakers will not be feasible for small shaft applications.

If anchor support is necessary and determined to be feasible, the shoring system should be supported by pre-stressed soil anchors extending beneath adjacent lands. Pre-stressed anchors are installed and stressed in advance of excavation and this limits movement of the shoring system as much as is practically possible. The use of anchors on adjacent properties requires the consent of the adjacent land owners, and shall be expressed in encroachment agreements.

Multi-level supported shoring utilizing pre-tensioned anchors or internal bracing, and drained soil conditions behind the shoring, can be designed in cohesionless soils for a trapezoidal earth pressure distribution with a maximum pressure defined by:

$$P = 0.65K[\gamma h + q]$$

Shafts that are constructed using internal ring beam arrangement, as discussed above, are over-designed against active earth pressures. Ground deformations adjacent to this type of shaft, at surface and along the shoring wall, are considered to be negligible. If other methods of shoring support are used, these must be reviewed for deformation prior to being constructed adjacent to the travelled lanes of Highway 401.



## 8 MATERIAL MANAGEMENT

It is assumed that excavated soil and bedrock from the project will be disposed at licensed waste handling facilities. There is no existing evidence of significant contaminants in the overburden, which largely comprises silty sand glacial till material with anticipated gravel, cobble and boulder content. The soil to bedrock transition zone is also expected to contain cobbles and large slabs of broken bedrock mixed with wet sandy to clayey soils. Tunnel spoil and wet muck may contain petroliferous and organic constituents as noted in the report. Contract specifications should therefore allow for appropriate environmental testing to be completed, under the supervision of the Engineer, to confirm acceptable quality and for proper handling, transport and disposal of these materials according to Provincial Regulations.

Pumped groundwater from the excavation may contain oily residues as noted in the report and should also be analysed and treated if required to meet the quality standards of the receiving body. Water quality from the tunnel may change significantly as the bedrock is mined and pulverized. Monitoring and mitigation methods for construction dewatering shall be conditions of the PTTW for the project and pumped groundwater may require treatment for sediments and organic parameters if it is to be discharged to storm water systems in the site area.

## 9 SEISMIC SITE CLASS

Based on the current investigation findings for material within the tunnel alignment, seismic site class "C" is considered to be appropriate for design, according to the OBC 2012. Any higher classification would require shear wave velocity testing to be conducted.

## 10 CORROSIVITY

Corrosion testing was not done for this current investigation. However, based on previous studies for the local deposits, the soil is not expected to be highly corrosive to steel and concrete, under the AWWA and CSA criteria respectively. The proposed trunk sanitary sewer comprises a precast concrete pipe (primary liner used for construction) surrounded by a 200 mm thick grout secondary liner. The design has been used in similar conditions in the area and has sufficient resistance to corrosion. The proposed concrete sewer pipes in this project can be exposed to hydrocarbons and other organic gases through the surrounding soil as well as the wastewater sewage flowing within the pipes. In order to mitigate these corrosive effects, the concrete pipes shall only be produced using sulphate resistant cement (Type HS). This material specification will be noted in the Contract Documents.

## 11 SETTLEMENT MONITORING

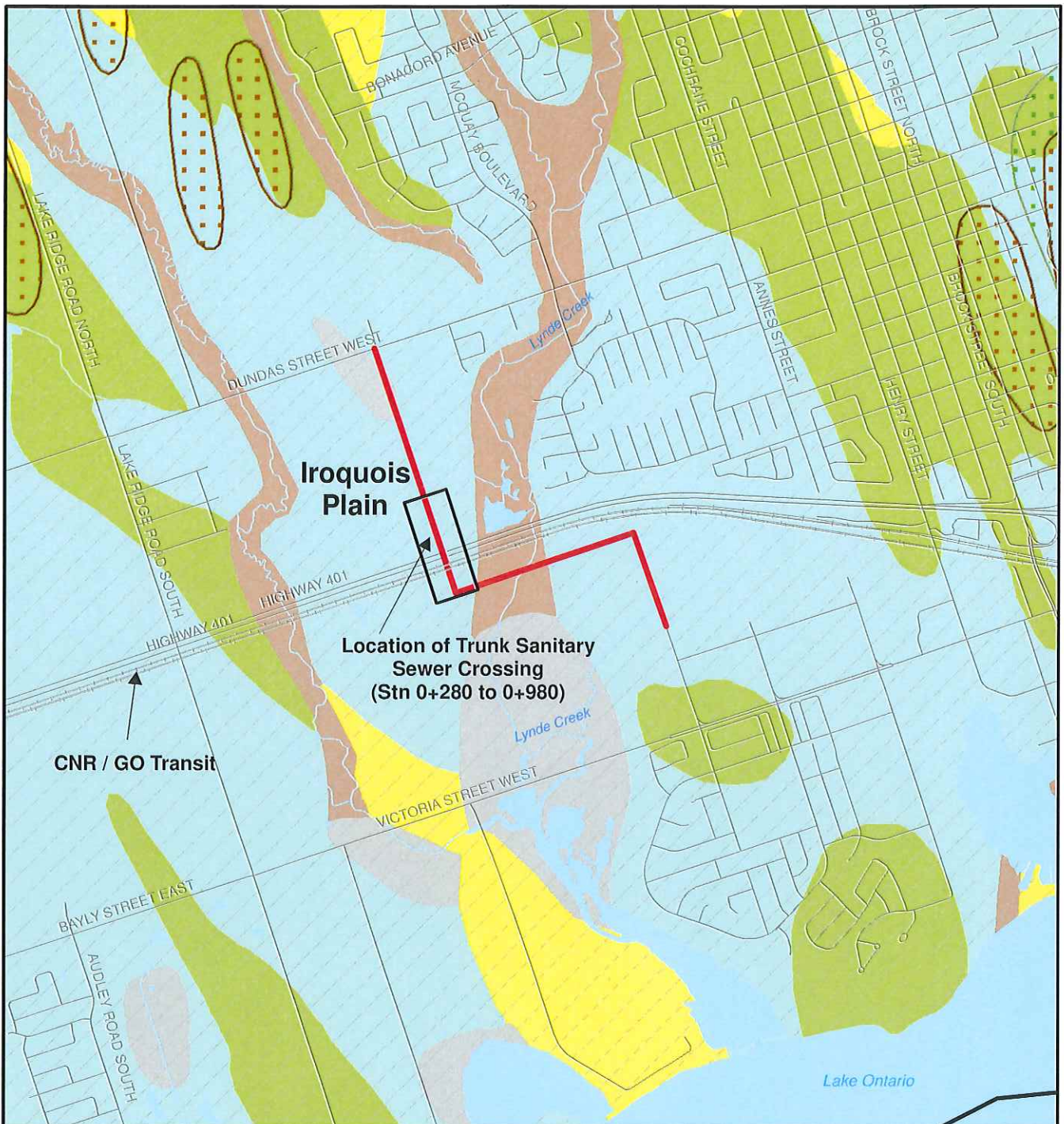
A qualified Geotechnical Consultant shall supervise the installation of settlement points to monitor potential settlements induced along the corridor by the proposed tunneling. Settlement monitoring points, including locations on the Highway pavement, are summarized on Figure 11. Review and Alert Level settlement tolerances and actions are summarized in Notes 5 to 8 of Figure 11. The CN railway authority shall be consulted regarding settlement monitoring requirements for their corridor.

It is recommended that extensometers be considered to measure convergence inside the tunnel as soon as it is excavated, and at intervals thereafter, to confirm time-dependent strain behavior. In the unlikely event that unacceptable movements do occur, methods and ground support should be modified immediately.

A condition survey for the Highway pavement shall be carried out prior to commencement of construction, and documented for the purpose of restoration requirements. The condition survey shall document visible surface distress manifestations such as cracks, distortions and deviations, heaves, and depressions. This

# Figures





#### LEGEND

- PROPOSED TRUNK SEWER
- DIAMICTON - NEWMARKET TILL (GLACIAL DEPOSITS)
- SILT - GLACIAL LAKE DEPOSITS
- SAND - RIVER DEPOSITS
- MODERN ALLUVIAL DEPOSITS
- ORGANIC DEPOSITS
- IROQUOIS BEACH PHYSIOGRAPHIC REGION
- CLAY PLAINS
- DRUMLINS
- TILL PLAINS (DRUMLINIZED)

Data Source: Ministry of Natural Resources, Ontario Base Mapping, March 2014, Chapman, L.J. and Pulnam, D.F. 2007, Physiography of southern Ontario; Ontario Geological Survey, Miscellaneous Release—Data 228, Surficial Geology of Southern Ontario, MRD 128-REV, Ontario Geological Survey, Ministry of Northern Development Mines and Forestry.



250 125 0 250 Metres

## SITE LOCATION AND SURFICIAL PHYSIOGRAPHY

GEOTECHNICAL INVESTIGATION  
WEST WHITBY TRUNK SANITARY SEWER  
Whitby, Ontario  
For The Regional Municipality of Durham

DATE: DECEMBER 2015

SCALE: 1:25000

PROJECT: 141-15350-00

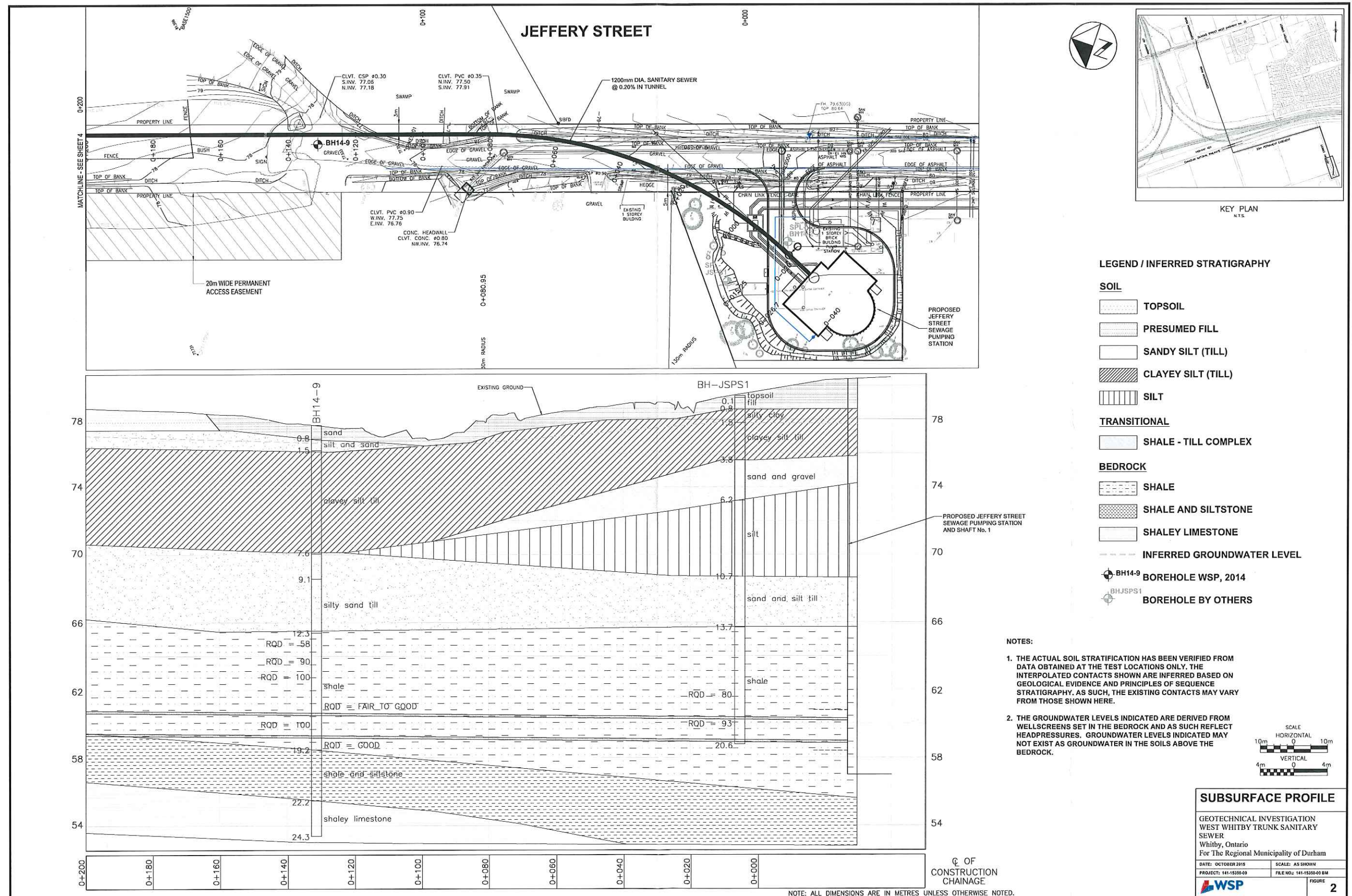
FILE. NO.:141-15350-00 F1



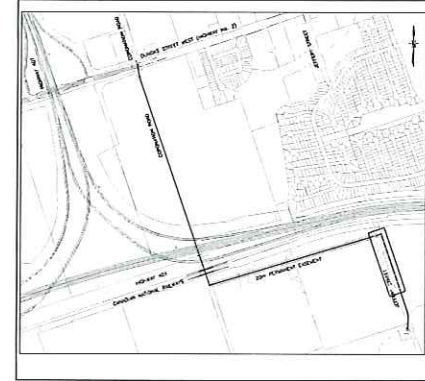
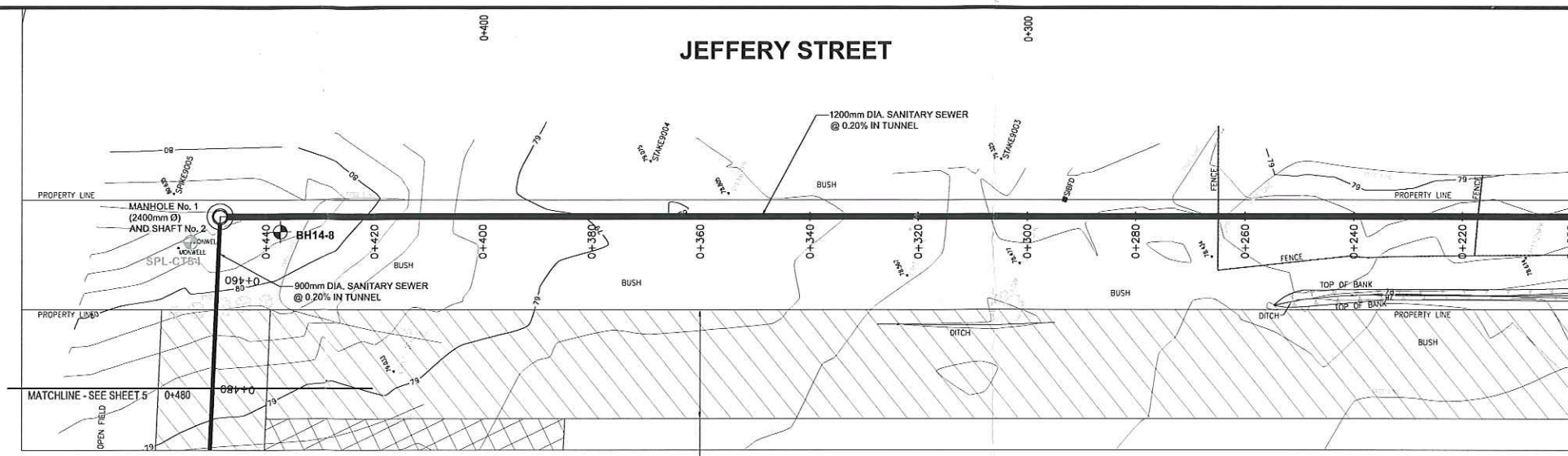
FIGURE

1





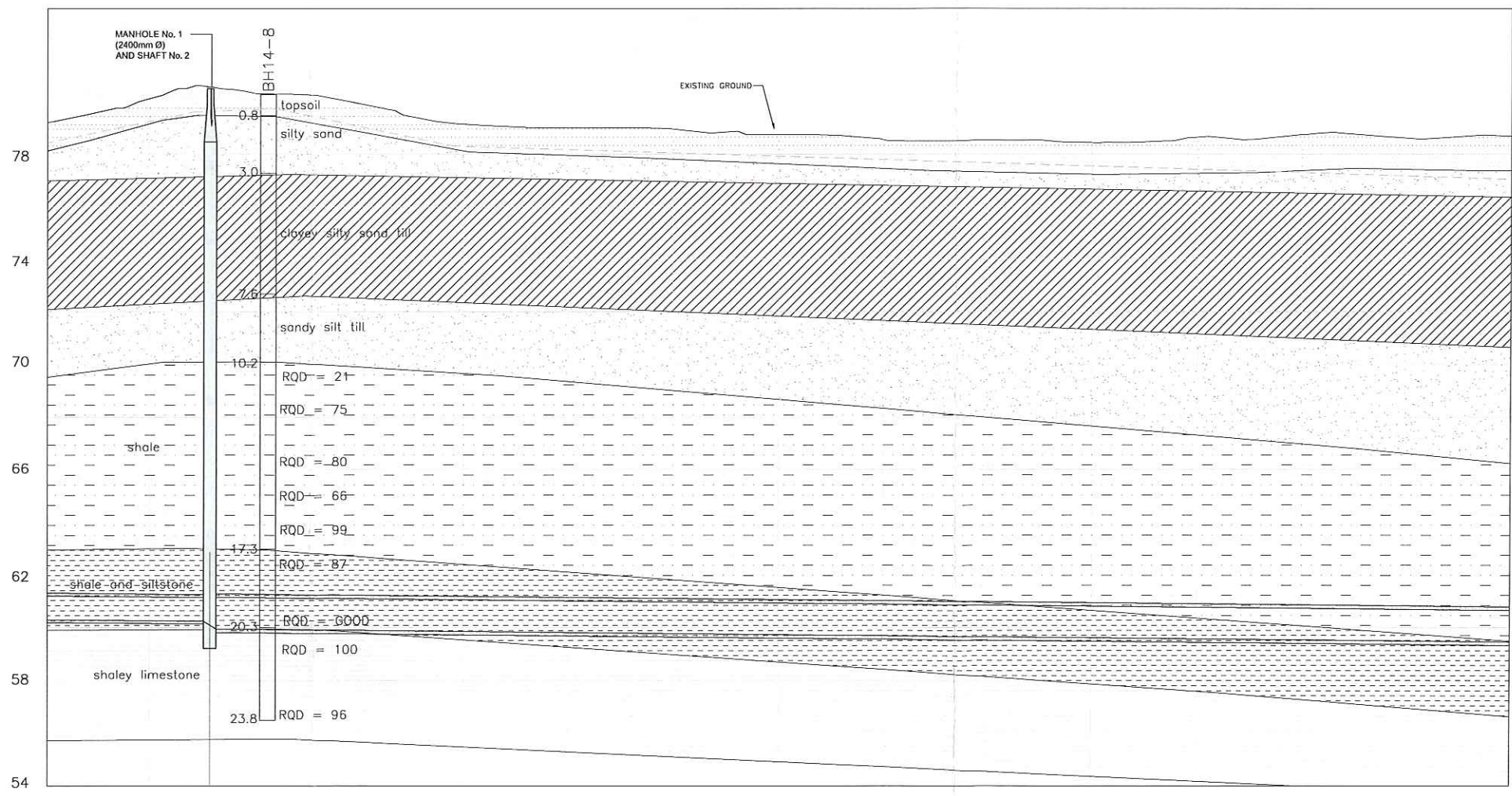




KEY PLAN  
N.T.S.

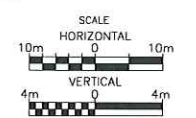
LEGEND / INFERRED STRATIGRAPHY

- SOIL**
- TOPSOIL
  - PRESUMED FILL
  - SANDY SILT (TILL)
  - CLAYEY SILT (TILL)
  - SILT
- TRANSITIONAL**
- SHALE - TILL COMPLEX
- BEDROCK**
- SHALE
  - SHALE AND SILTSTONE
  - SHALEY LIMESTONE
  - INFERRED GROUNDWATER LEVEL
  - BH14-9 BOREHOLE WSP, 2014
  - BHJSPS1 BOREHOLE BY OTHERS



NOTES:

1. THE ACTUAL SOIL STRATIFICATION HAS BEEN VERIFIED FROM DATA OBTAINED AT THE TEST LOCATIONS ONLY. THE INTERPOLATED CONTACTS SHOWN ARE INFERRED BASED ON GEOLOGICAL EVIDENCE AND PRINCIPLES OF SEQUENCE STRATIGRAPHY. AS SUCH, THE EXISTING CONTACTS MAY VARY FROM THOSE SHOWN HERE.
2. THE GROUNDWATER LEVELS INDICATED ARE DERIVED FROM WELLSCREENS SET IN THE BEDROCK AND AS SUCH REFLECT HEADPRESSURES. GROUNDWATER LEVELS INDICATED MAY NOT EXIST AS GROUNDWATER IN THE SOILS ABOVE THE BEDROCK.



SUBSURFACE PROFILE

GEOTECHNICAL INVESTIGATION  
WEST WHITBY TRUNK SANITARY  
SEWER  
Whitby, Ontario  
For The Regional Municipality of Durham

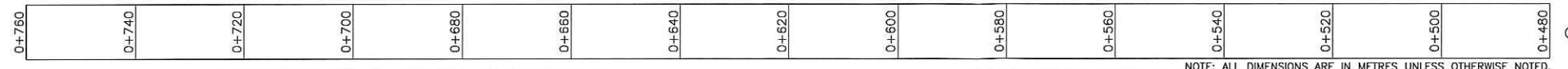
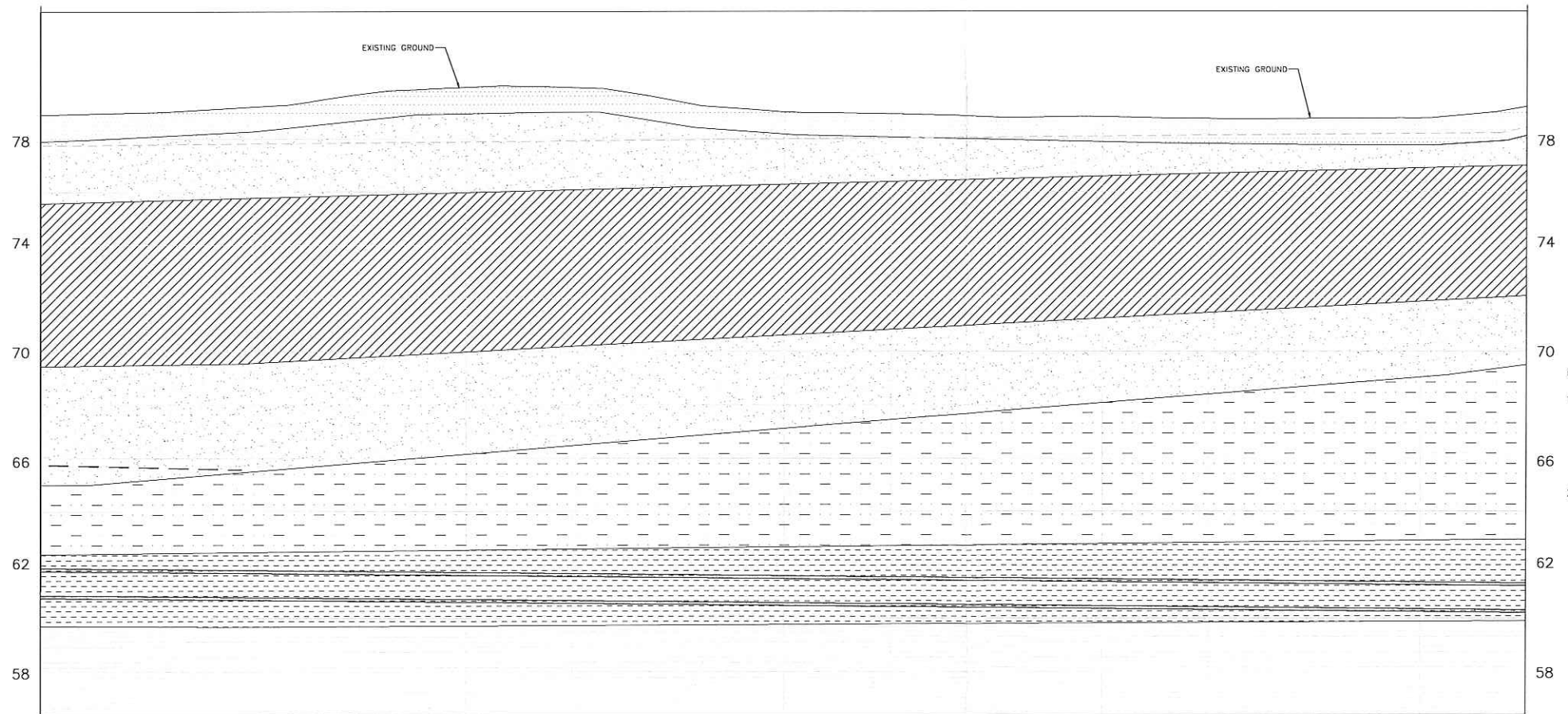
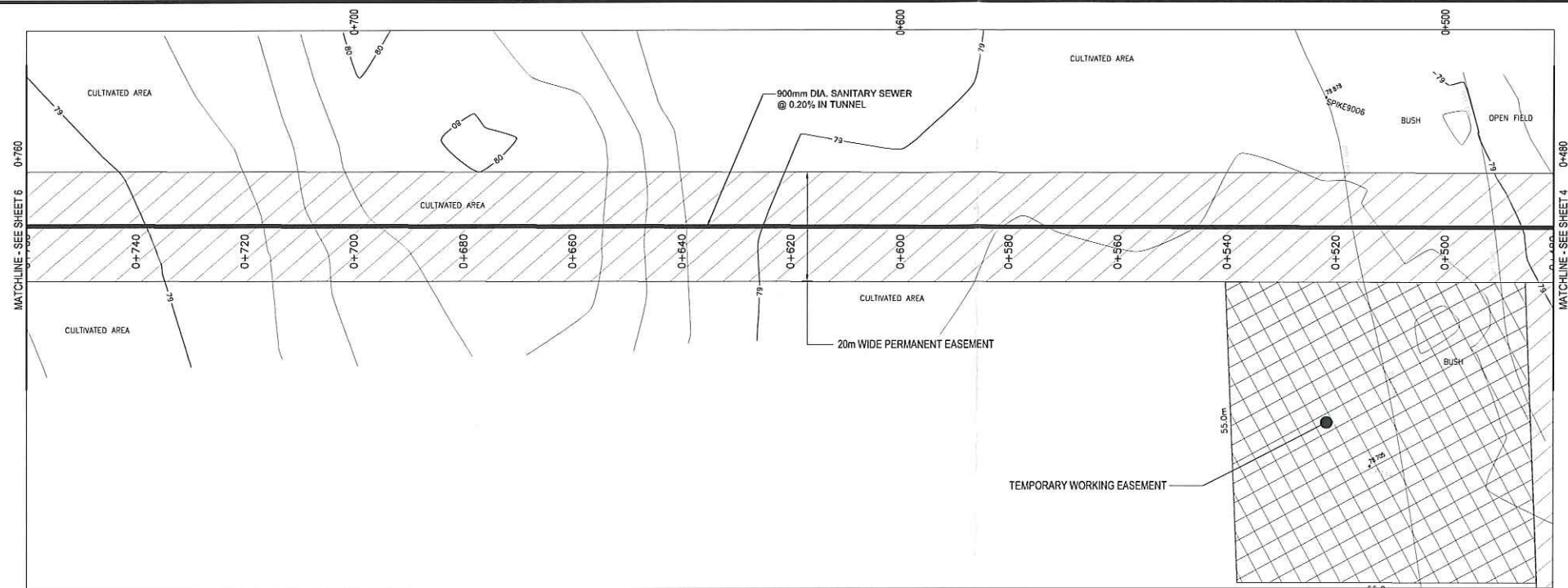
DATE: OCTOBER 2015  
PROJECT: 141-15359-00  
SCALE: AS SHOWN  
FILE NO.: 141-15359-00-BM

FIGURE 3

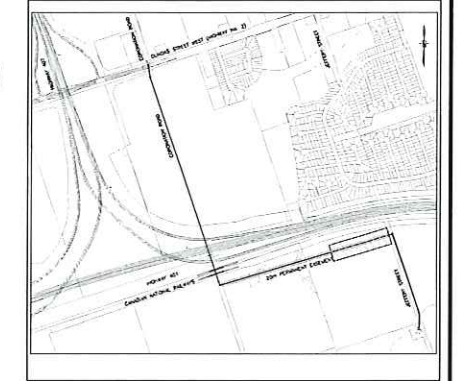
Q OF  
CONSTRUCTION  
CHAINAGE

NOTE: ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.





NOTE: ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.



KEY PLAN  
N.T.S.

LEGEND / INFERRED STRATIGRAPHY

SOIL

- TOPSOIL
- PRESUMED FILL
- SANDY SILT (TILL)
- CLAYEY SILT (TILL)
- SILT

TRANSITIONAL

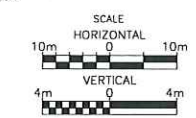
- SHALE - TILL COMPLEX

BEDROCK

- SHALE
- SHALE AND SILTSTONE
- SHALEY LIMESTONE
- INFERRED GROUNDWATER LEVEL
- BOREHOLE WSP, 2014
- BOREHOLE BY OTHERS

NOTES:

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SUBSURFACE PROFILE

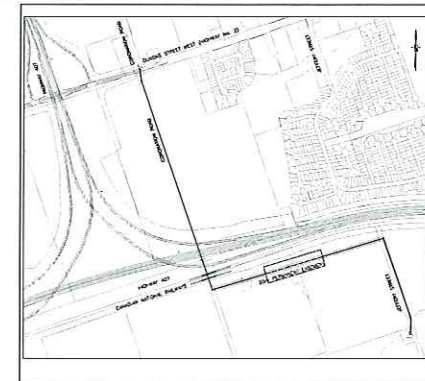
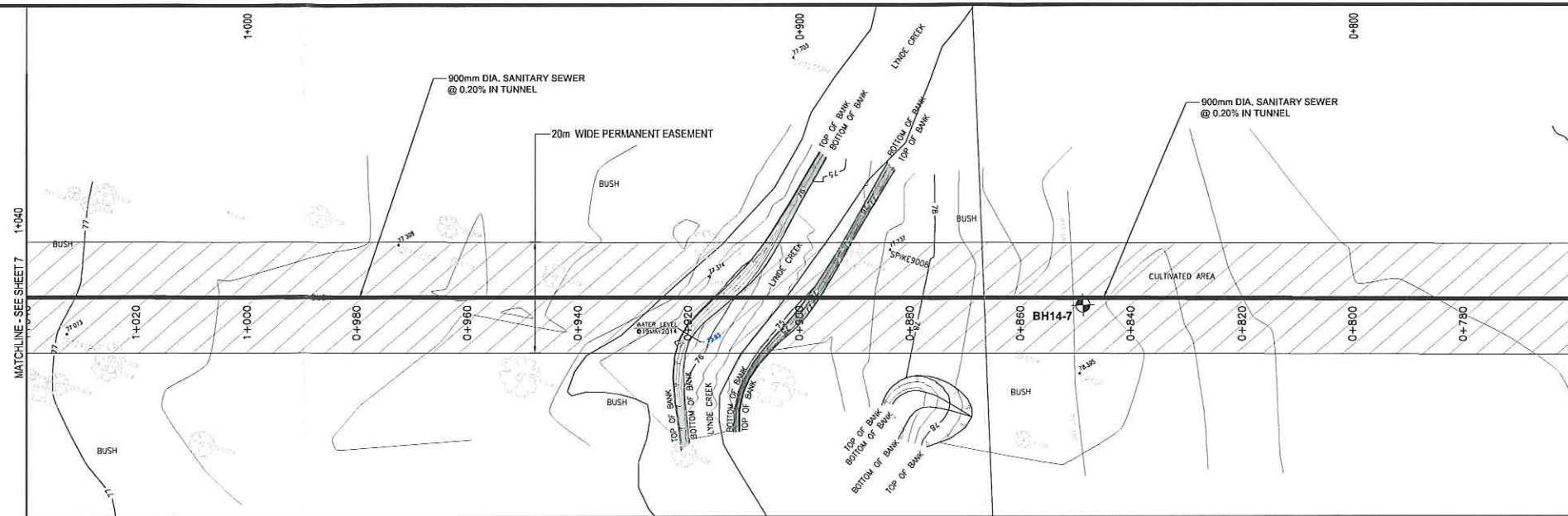
GEOTECHNICAL INVESTIGATION  
WEST WHITBY TRUNK SANITARY  
SEWER  
Whitby, Ontario  
For The Regional Municipality of Durham

DATE: OCTOBER 2015  
PROJECT: 141-15359-00  
SCALE: AS SHOWN  
FILE NO.: 141-15359-00 R1M

WSP

© OF  
CONSTRUCTION  
CHAINAGE





KEY PLAN  
N.T.S.

LEGEND / INFERRED STRATIGRAPHY

SOIL

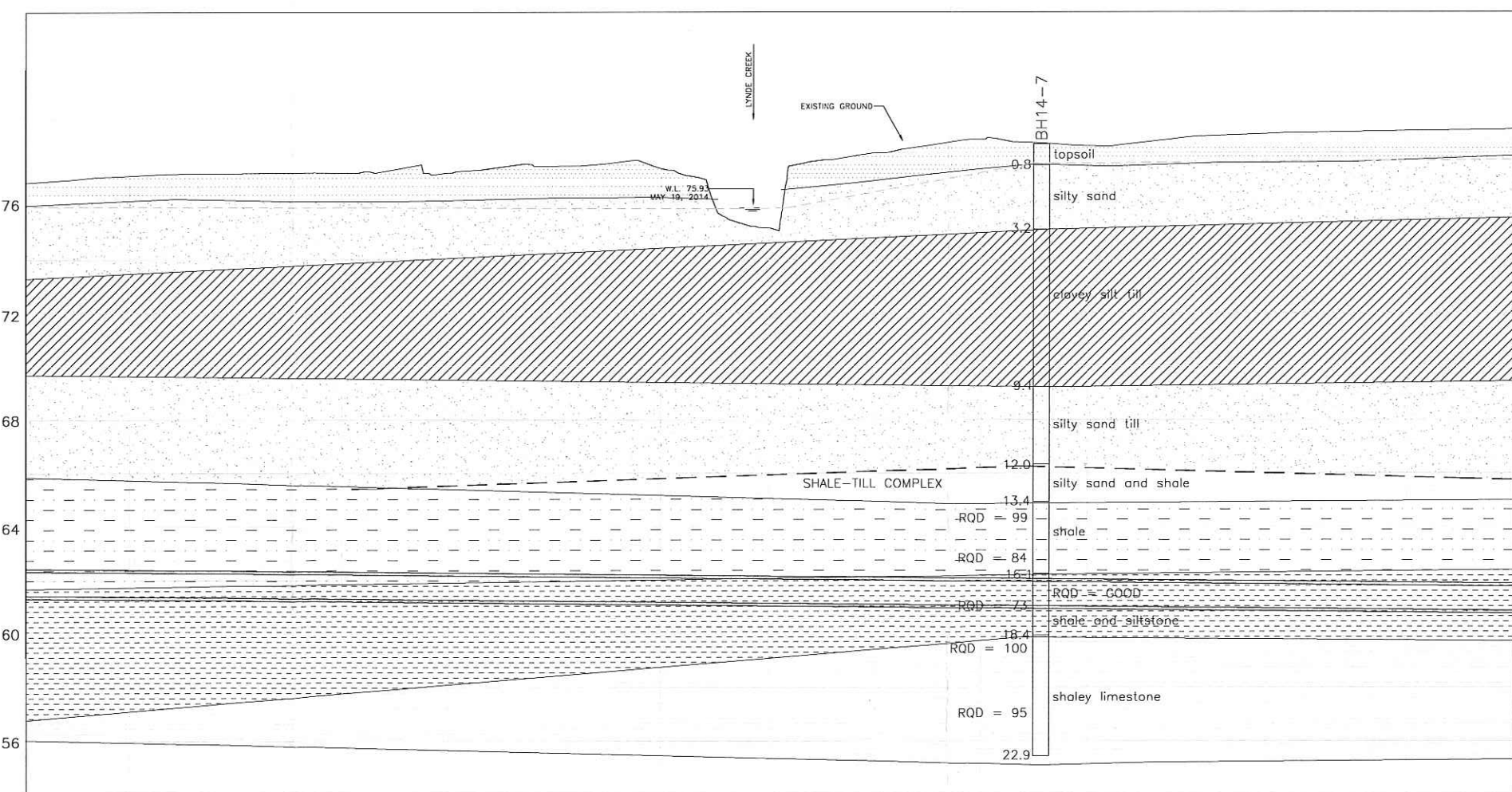
- TOPSOIL
- PRESUMED FILL
- SANDY SILT (TILL)
- CLAYEY SILT (TILL)
- SILT

TRANSITIONAL

- SHALE - TILL COMPLEX

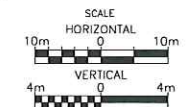
BEDROCK

- SHALE
- SHALE AND SILTSTONE
- SHALEY LIMESTONE
- INFERRED GROUNDWATER LEVEL
- BOREHOLE WSP, 2014
- BOREHOLE BY OTHERS



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SUBSURFACE PROFILE

GEOTECHNICAL INVESTIGATION  
WEST WHITBY TRUNK SANITARY  
SEWER  
Whitby, Ontario  
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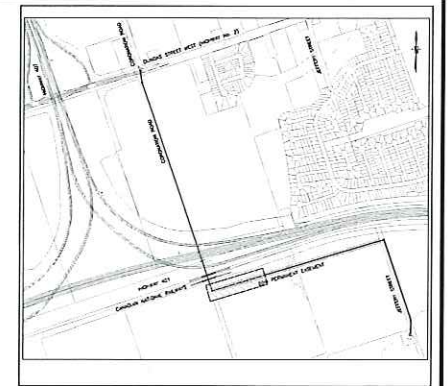
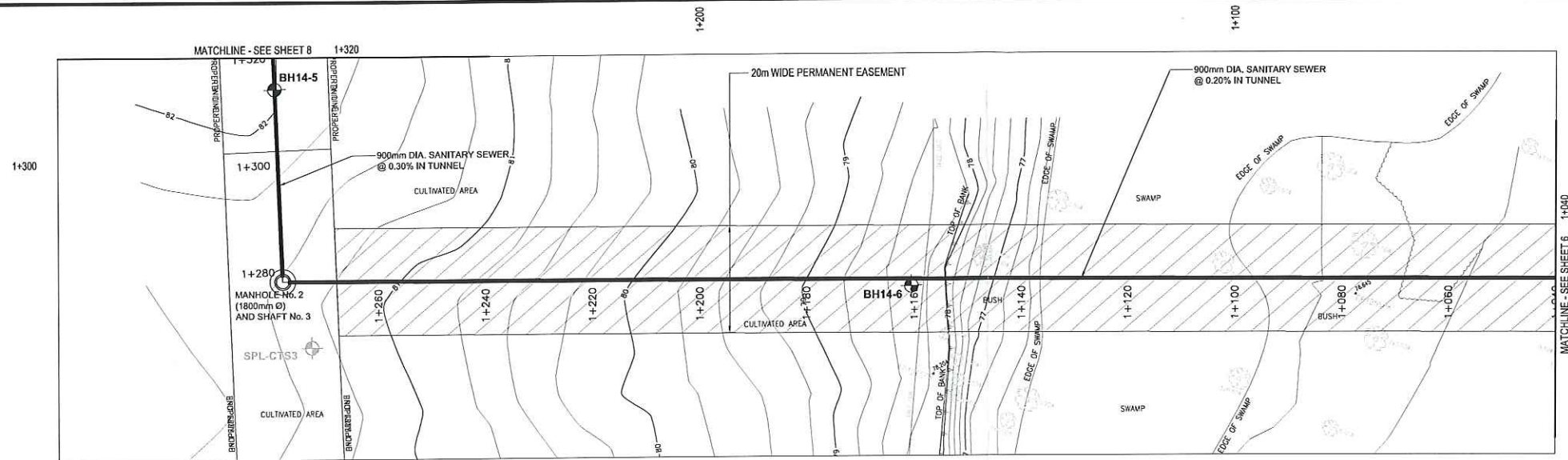
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PROJECT: 141-15350-00 FILE NO.: 141-15350-00 BM

WSP

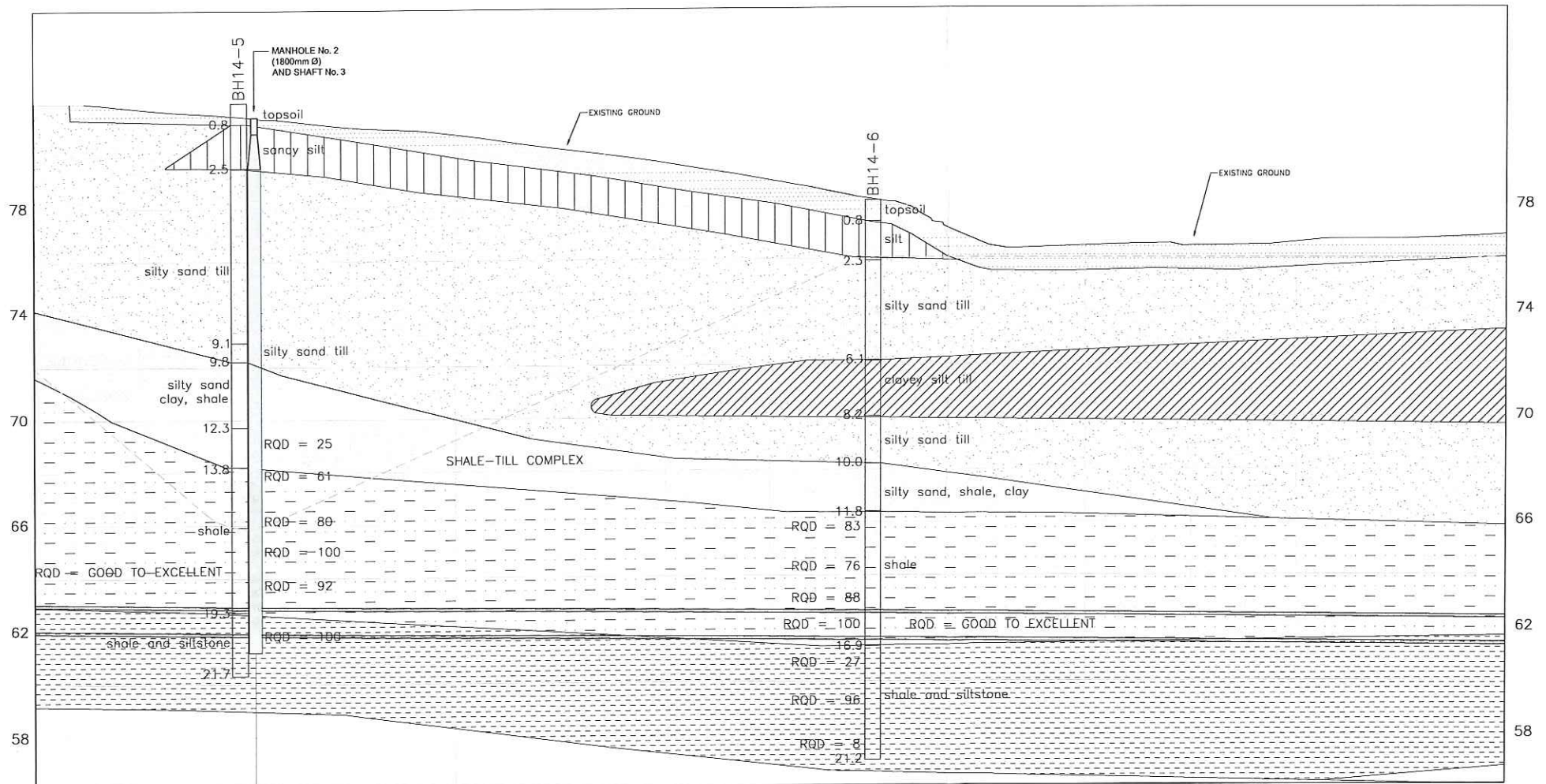
Q OF  
CONSTRUCTION  
CHAINAGE

NOTE: ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.

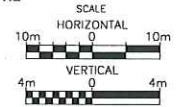




- LEGEND / INFERRED STRATIGRAPHY**
- SOIL**
- TOPSOIL
  - PRESUMED FILL
  - SANDY SILT (TILL)
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- SHALE
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- INFERRED GROUNDWATER LEVEL
- BH14-9 BOREHOLE WSP, 2014
- BHJSPS1 BOREHOLE BY OTHERS



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**SUBSURFACE PROFILE**

GEOTECHNICAL INVESTIGATION  
WEST WHITBY TRUNK SANITARY  
SEWER  
Whitby, Ontario  
For The Regional Municipality of Durham

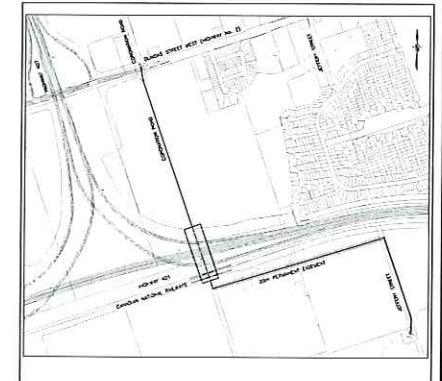
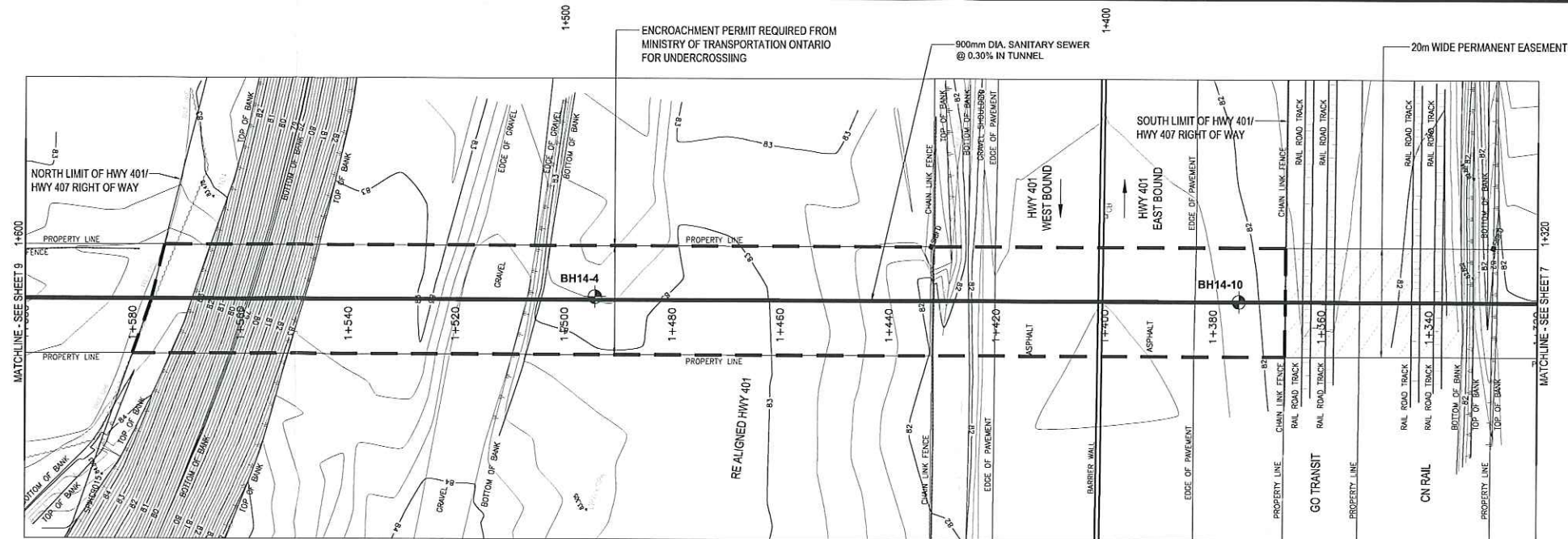
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FILE NO: 141-15355-09 B10

OF  
CONSTRUCTION  
CHAINAGE

NOTE: ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.

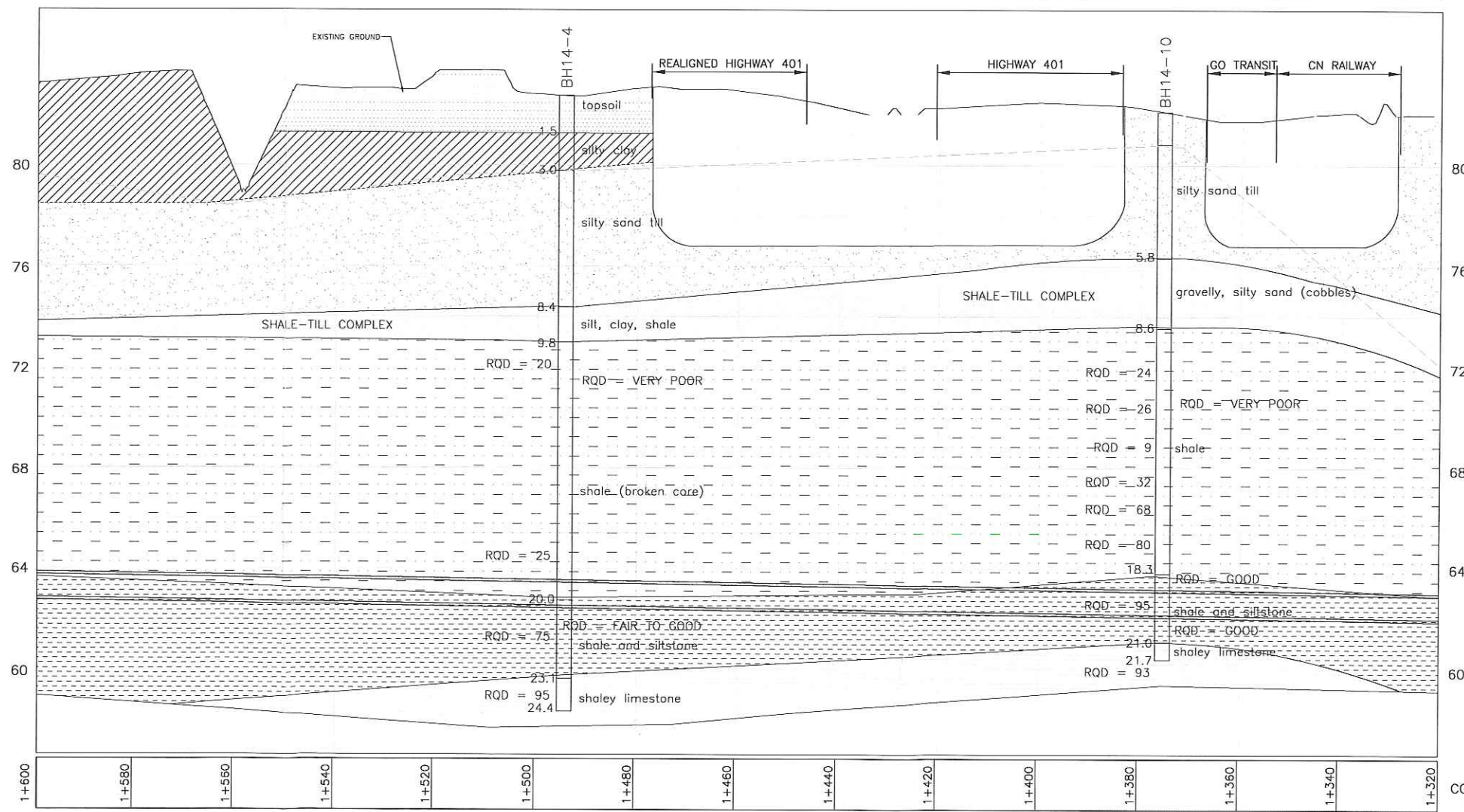




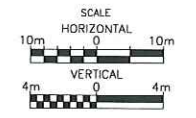


KEY PLAN  
N.T.S.

- LEGEND / INFERRED STRATIGRAPHY**
- SOIL**
- TOPSOIL
  - PRESUMED FILL
  - SANDY SILT (TILL)
  - CLAYEY SILT (TILL)
  - SILT
- TRANSITIONAL**
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- SHALE
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- BH14-9 BOREHOLE WSP, 2014
- BHJSPS1 BOREHOLE BY OTHERS



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**SUBSURFACE PROFILE**

GEOTECHNICAL INVESTIGATION  
WEST WHITBY TRUNK SANITARY  
SEWER  
Whitby, Ontario  
For The Regional Municipality of Durham

DATE: OCTOBER 2015  
PROJECT: 141-1510-00  
SCALE: AS SHOWN  
FILE NO.: 141-1510-00-BM

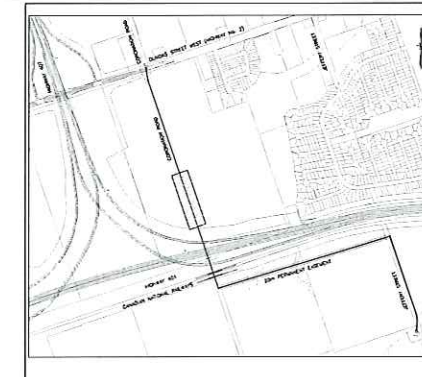
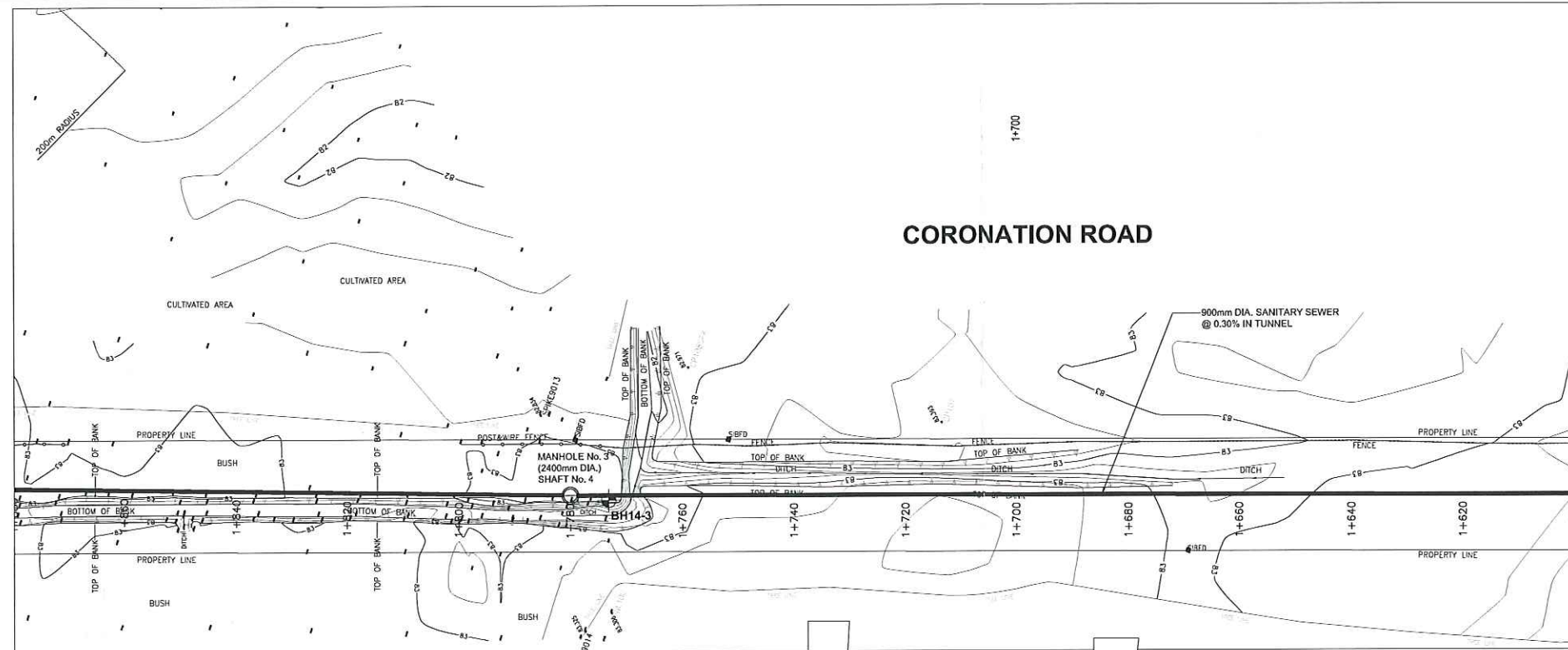
**WSP**

FIGURE 7

NOTE: ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.

OF  
CONSTRUCTION  
CHAINAGE





KEY PLAN  
N.T.S.

#### LEGEND / INFERRED STRATIGRAPHY

##### SOIL

- TOPSOIL
- PRESUMED FILL
- SANDY SILT (TILL)
- CLAYEY SILT (TILL)
- SILT

##### TRANSITIONAL

- SHALE - TILL COMPLEX

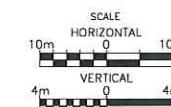
##### BEDROCK

- SHALE
- SHALE AND SILTSTONE
- SHALEY LIMESTONE
- INFERRED GROUNDWATER LEVEL

- BOREHOLE WSP, 2014
- BOREHOLE BY OTHERS

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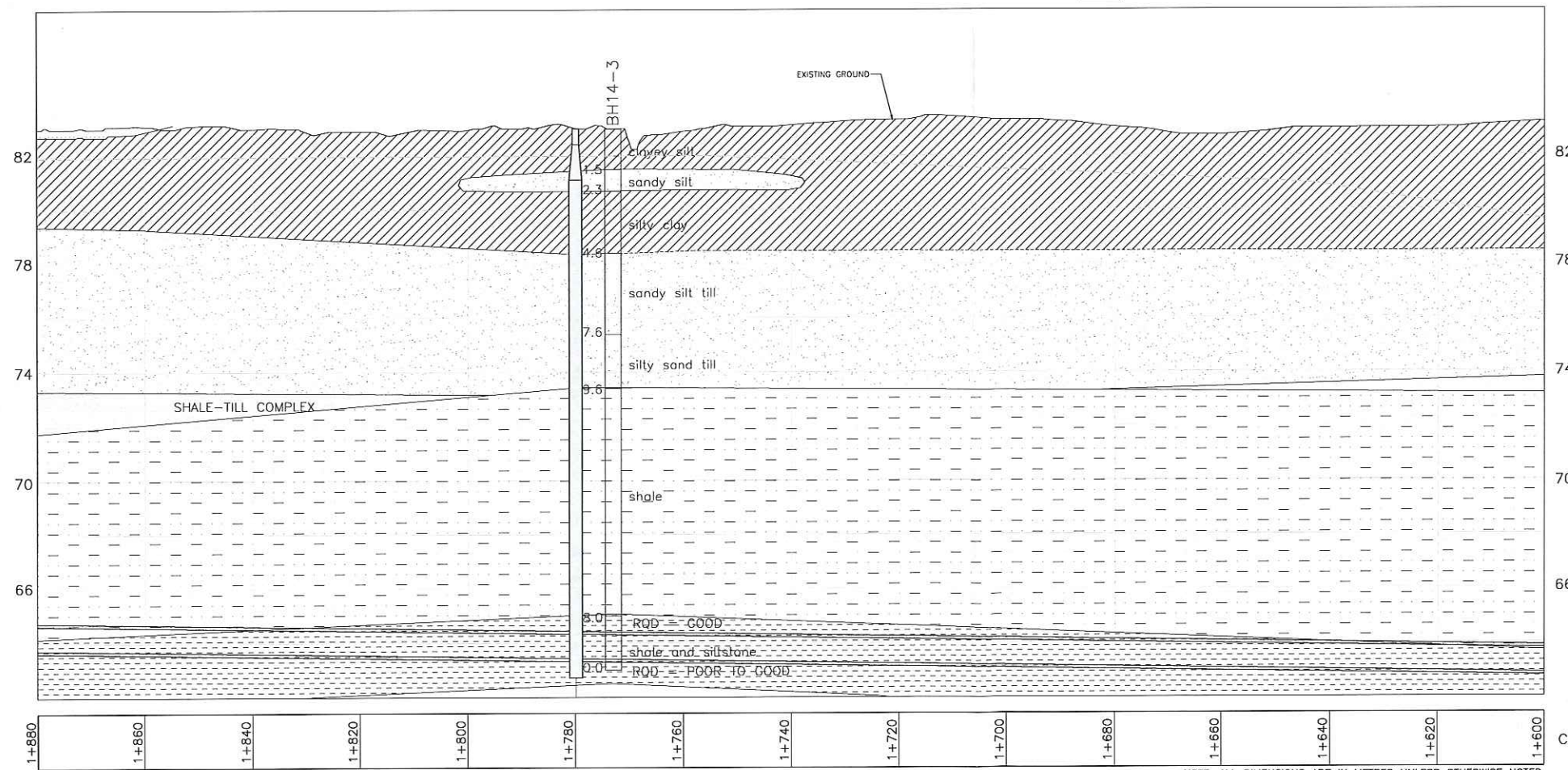
#### SUBSURFACE PROFILE

GEOTECHNICAL INVESTIGATION  
WEST WHITBY TRUNK SANITARY  
SEWER  
Whitby, Ontario  
For The Regional Municipality of Durham

DATE: OCTOBER 2015 SCALE: AS SHOWN  
PROJECT: 141-15359-00 FILE NO.: 141-15359-00 R10

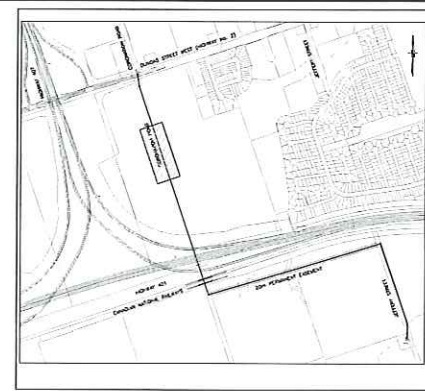
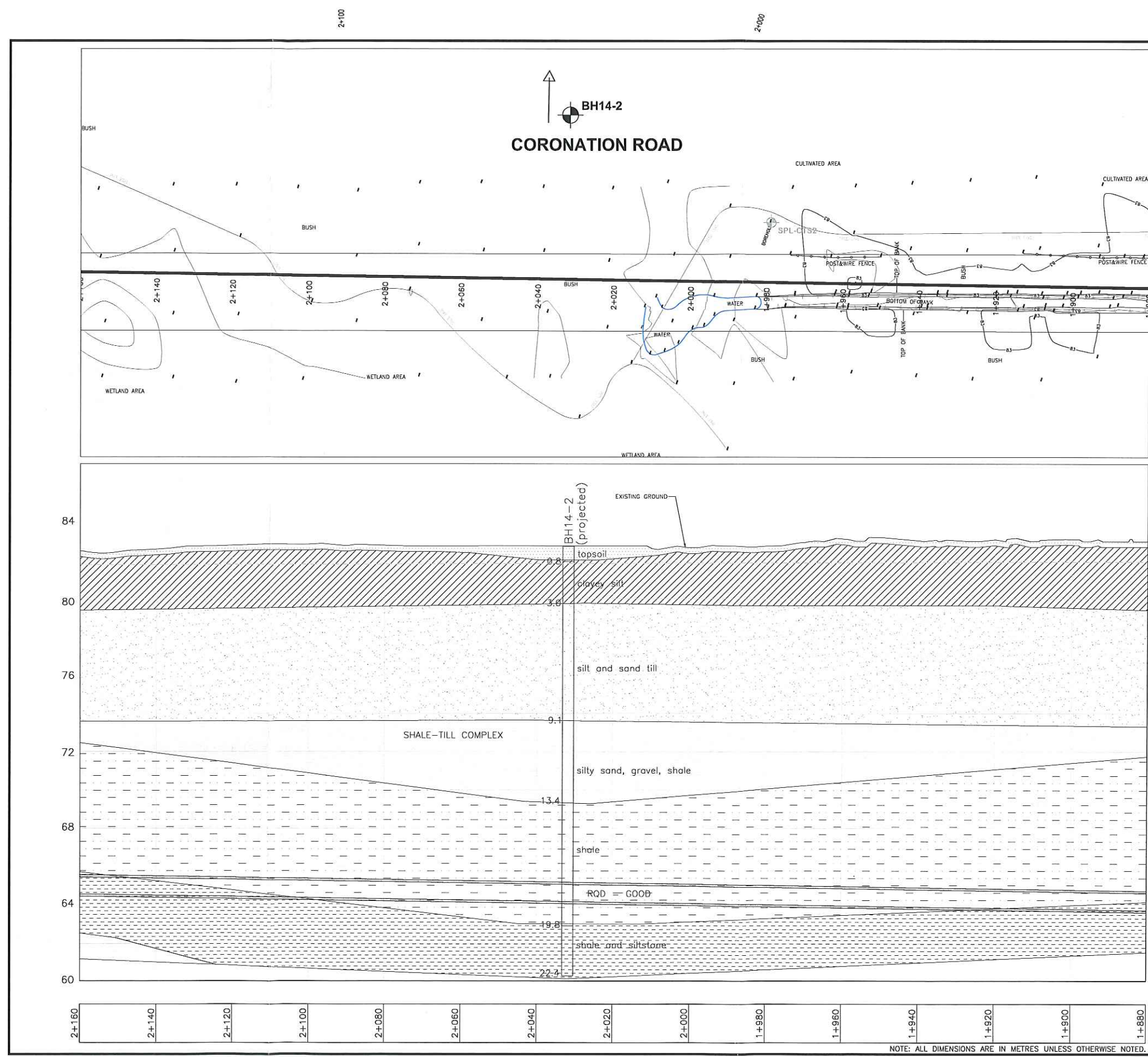
WSP

FIGURE 8



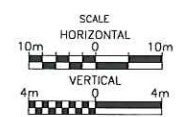
Q OF  
CONSTRUCTION  
CHAINAGE





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- BH14-9
- BOREHOLE BY OTHERS**
- BHJSPS1

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**SUBSURFACE PROFILE**

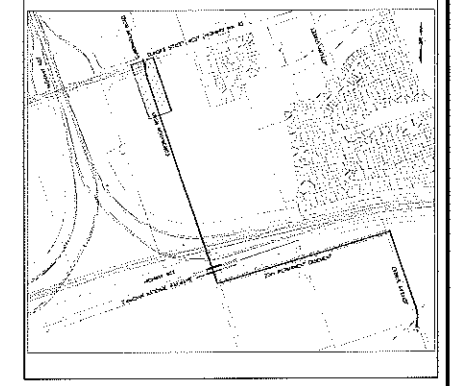
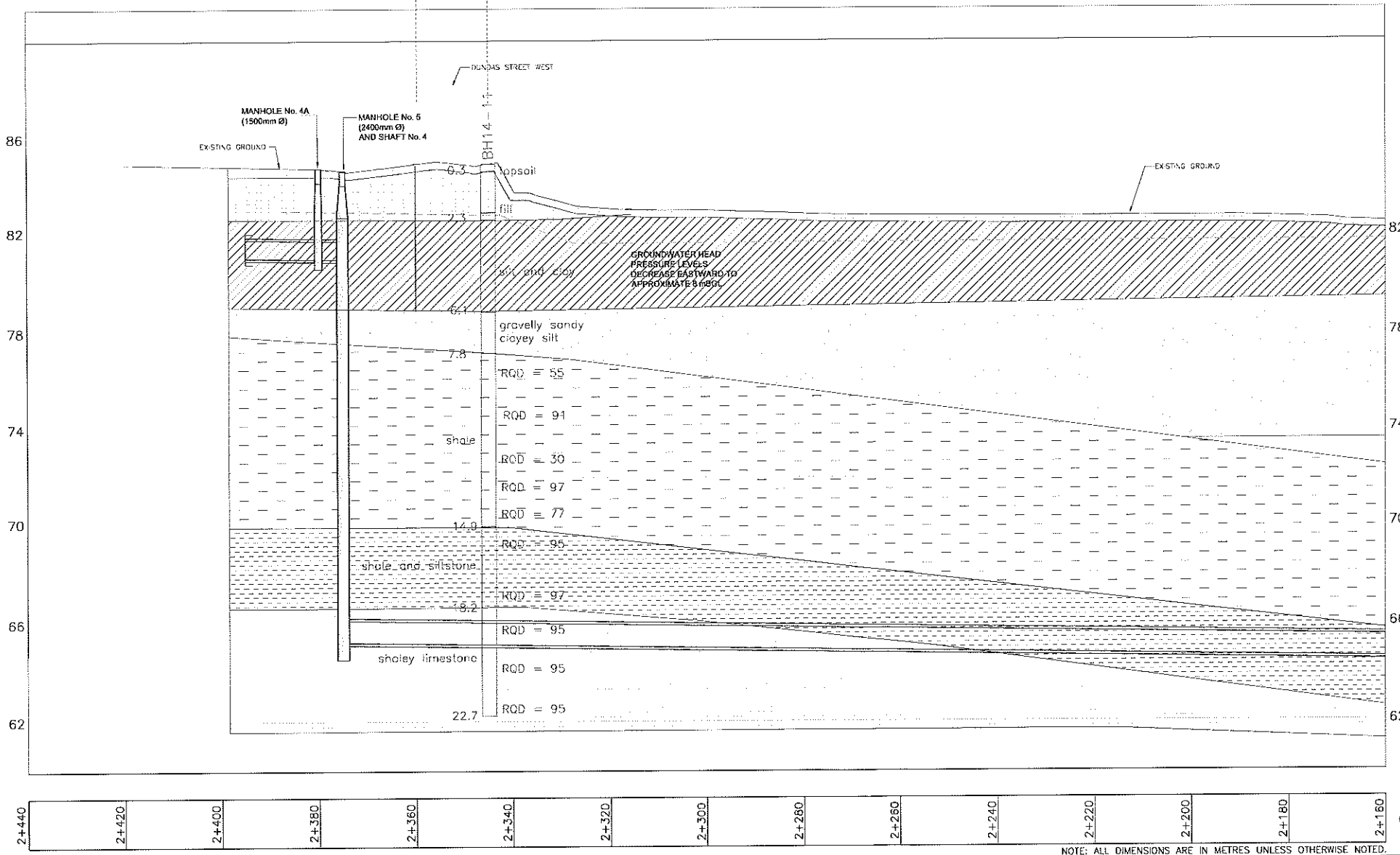
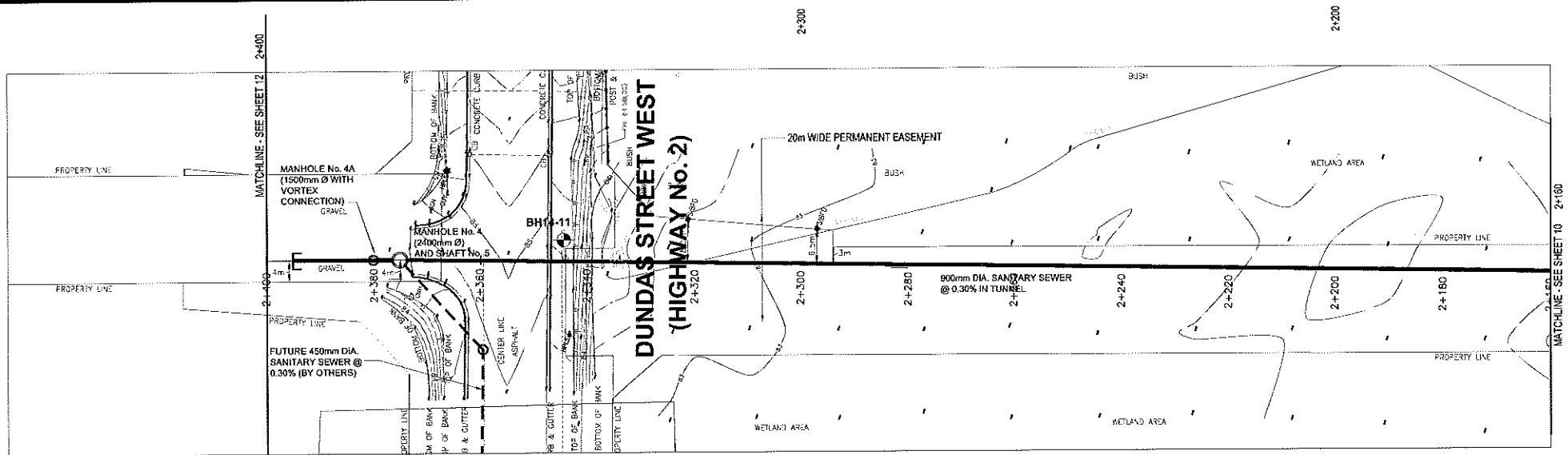
GEOTECHNICAL INVESTIGATION  
WEST WHITBY TRUNK SANITARY  
SEWER  
Whitby, Ontario  
For The Regional Municipality of Durham

DATE: OCTOBER 2015  
PROJECT: 141-15350-00  
SCALE: AS SHOWN  
FILE NO: 141-15350-00 BM  
FIGURE 9

**WSP**

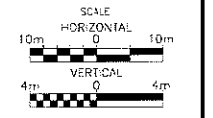
NOTE: ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.

OF  
CONSTRUCTION  
CHAINAGE



- LEGEND / INFERRED STRATIGRAPHY**
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**SUBSURFACE PROFILE**

GEOTECHNICAL INVESTIGATION  
WEST WHITBY TRUNK SANITARY SEWER  
Whitby, Ontario  
For The Regional Municipality of Durham

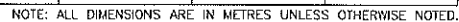
DATE: OCTOBER 2015  
PROJECT: 141-15330-00  
SCALE: AS SHOWN  
FILE NO.: 141-15330-00-00

**WSP**

FIGURE **10**

NOTE: ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.





# Appendix A

**BOREHOLE EXPLANATION FORMS, BOREHOLE LOGS**



# BOREHOLE LOG EXPLANATION FORM

This explanatory section provides the background to assist in the use of the borehole logs. Each of the headings used on the borehole log, is briefly explained.

## DEPTH

This column gives the depth of interpreted geologic contacts in metres below ground surface.

## STRATIGRAPHIC DESCRIPTION

This column gives a description of the soil based on a tactile examination of the samples and/or laboratory test results. Each stratum is described according to the following classification and terminology.

<u>Soil Classification *</u>		<u>Terminology</u>	<u>Proportion</u>
Clay	<0.002 mm		
Silt	0.002 to 0.06 mm	"trace" (eg. trace sand)	<10%
Sand	0.06 to 2 mm	"some" (eg. some sand)	10% - 20%
Gravel	2 to 60 mm	adjective (eg. sandy)	20% - 35%
Cobbles	60 to 200 mm	"and" (eg. and sand)	35% - 50%
Boulders	>200 mm	noun (eg. sand)	>50%

\* Extension of MIT Classification system unless otherwise noted.

The use of the geologic term "till" implies that both disseminated coarser grained (sand, gravel, cobbles or boulders) particles and finer grained (silt and clay) particles may occur within the described matrix.

The compactness of cohesionless soils and the consistency of cohesive soils are defined by the following:

<u>COHESIONLESS SOIL</u>		<u>COHESIVE SOIL</u>	
Compactness	Standard Penetration Resistance "N", Blows / 0.3 m	Consistency	Standard Penetration Resistance "N", Blows / 0.3 m
Very Loose	0 to 4	Very Soft	0 to 2
Loose	4 to 10	Soft	2 to 4
Compact	10 to 30	Firm	4 to 8
Dense	30 to 50	Stiff	8 to 15
Very Dense	Over 50	Very Stiff	15 to 30
		Hard	Over 30

The moisture conditions of cohesionless and cohesive soils are defined as follows.

### COHESIONLESS SOILS

Dry  
Moist  
Wet  
Saturated

### COHESIVE SOILS









DTPL - Drier Than Plastic Limit  
APL - About Plastic Limit  
WTPL - Wetter Than Plastic Limit  
MWTP - Much Wetter Than Plastic Limit

## STRATIGRAPHY

Symbols may be used to pictorially identify the interpreted stratigraphy of the soil and rock strata.

## MONITOR DETAILS

This column shows the position and designation of standpipe and/or piezometer ground water monitors installed in the borehole. Also the water level may be shown for the date indicated.

	Standpipe and Designation		Cement Seal
	Piezometer and Designation		Granular Pack
	Gas Monitor and Designation		Granular Backfill
	Borehole Seal (Peltonite, Bentonite or Hole Plug)		Native Soil Backfill/Cave

Where monitors are placed in separate boreholes, these are shown individually in the "Monitor Details" column. Otherwise, monitors are in the same borehole. For further data regarding seals, screens, etc., the reader is referred to the summary of monitor details table.

## SAMPLE

These columns describe the sample type and number, the "N" value, the water content, the percentage recovery, and Rock Quality Designation (RQD), of each sample obtained from the borehole where applicable. The information is recorded at the approximate depth at which the sample was obtained. The legend for sample type is explained below.

SS = Split Spoon	GS = Grab Sample
ST = Thin Walled Shelby Tube	CS = Channel Sample
AS = Auger Flight Sample	WS = Wash Sample
CC = Continuous Core	RC = Rock Core

$$\% \text{ Recovery} = \frac{\text{Length of Core Recovered Per Run}}{\text{Total Length of Run}} \times 100$$

Where rock drilling was carried out, the term RQD (Rock Quality Designation) is used. The RQD is an indirect measure of the number of fractures and soundness of the rock mass. It is obtained from the rock cores by summing the length of core recovered, counting only those pieces of sound core that are 100 mm or more in length. The RQD value is expressed as a percentage and is the ratio of the summed core lengths to the total length of core run. The classification based on the RQD value is given below.



### ROD Classification

### ROD (%)

Very poor quality	< 25
Poor quality	25 - 50
Fair quality	50 - 75
Good quality	75 - 90
Excellent quality	90 - 100

## TEST DATA

The central section of the log provides graphs which are used to plot selected field and laboratory test results at the depth at which they were carried out. The plotting scales are shown at the head of the column.

**Dynamic Penetration Resistance** - The number of blows required to advance a 51 mm diameter, 60° steel cone fitted to the end of 45 mm OD drill rods, 0.3 m into the subsoil. The cone is driven with a 63.5 kg hammer over a fall of 750 mm.

**Standard Penetration Resistance - Standard Penetration Test (SPT) "N" Value** - The number of blows required to advance a 51 mm diameter standard split-spoon sampler 300 mm into the subsoil, driven by means of a 63.5 kg hammer falling freely a distance of 750 mm. In cases where the split spoon does not penetrate 300 mm, the number of blows over the distance of actual penetration in millimetres is shown as  $\frac{x \text{ Blows}}{\text{mm}}$

**Water Content** - The ratio of the mass of water to the mass of oven-dry solids in the soil expressed as a percentage.

**W<sub>P</sub>** - Plastic Limit of a fine-grained soil expressed as a percentage as determined from the Atterberg Limit Test.

**W<sub>L</sub>** - Liquid Limit of a fine-grained soil expressed as a percentage as determined from the Atterberg Limit Test.

## REMARKS

The last column describes pertinent drilling details, field observations and/or provides an indication of other field or laboratory tests that were performed.

## METRIC

ORIGINATED BY RBG

COMPILED BY RDJ

CHECKED BY JSA

ONTARIO MOT WHITESEWERTRUNK MTO (2).GPJ ONTARIO MOT.GDT 10/5/15

+ 3, × 3: Numbers refer to Sensitivity      ○ 3% STRAIN AT FAILURE



**METRIC**

CHECKED BY JSA

[illegible]

+ 3, × 3: Numbers refer to Sensitivity      ○ 3% STRAIN AT FAILURE

## METRIC

ORIGINATED BY    DAO

COMPILED BY RDJ

CHECKED BY JSA

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT		PLASTIC LIMIT w <sub>p</sub>	NATURAL MOISTURE CONTENT w	LIQUID LIMIT w <sub>L</sub>	UNIT WEIGHT γ kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL				
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa							WATER CONTENT (%)			
								○ UNCONFINED    + FIELD VANE ● QUICK TRIAXIAL    × LAB VANE										
83.0 0.0	BROWN VERY FINE SILTY SAND TOPSOIL, TRACE GRAVEL, VERY LOOSE, MOIST		1	SS	7													
82.2 0.8	LIGHT BROWN SANDY SILT, SOME CLAY, TRACE GRAVEL, COMPACT, MOIST (GLACIAL TILL)		2	SS	11		82											
			3	SS	11		81							9 31 36 24				
80.5 2.5	BROWN SILTY SAND, SOME CLAY, SOME GRAVEL, COMPACT TO VERY DENSE, MOIST (GLACIAL TILL)		4	SS	22		80											
			5	SS	34													
			6	SS	72		79											
			7	SS	>100		78											
			8	SS	47		77							Groundwater measured at 6.4 mBGL on Oct. 2, 2014.				
	-SOME SHALE FRAGMENTS AND GRAVEL, HARD, MOIST		9	SS	>100		76							14 32 39 15				
73.9 9.1	GREYISH BROWN SILTY SAND, SOME SHALE FRAGMENTS AND GRAVEL, TRACE CLAY, VERY DENSE, MOIST (GLACIAL TILL)		10	SS	>100		75							14 39 LL 11				
73.3 9.8	BROWN VERY FINE SANDY CLAYEY SILT, SOME SHALE FRAGMENTS AND GRAVEL, HARD, APL MATRIX (SHALE-TILL COMPLEX)		11	SS	>100		74											
	(INFERRED TRANSITION ZONE TO BEDROCK)		12	RC			73											
70.7 12.3	DARK GREY CLAYEY SILT AND SHALE FRAGMENTS, VERY DENSE, MOIST (SHALE-TILL COMPLEX) VERTICAL FRACTURING OBSERVED FROM 13.0 TO 13.1 m		13	RC			72							Very Poor Rock Quality				
69.3 13.6	VERTICAL FRACTURING OBSERVED FROM 13.5 TO 13.6 m						71											
							70											
							69											

+ 3, × 3: Numbers refer to Sensitivity      ○ 3% STRAIN AT FAILURE



## METRIC

ORIGINATED BY    DAO

COMPILED BY RDJ

CHECKED BY                      JSA

[illegible]

ONTARIO MOT WHITBYSEWERTRUNK MTO (2).GPJ ONTARIO MOT.GDT 10/5/15

+ 3, × 3: Numbers refer to Sensitivity      ○ 3% STRAIN AT FAILURE

RECORD OF BOREHOLE No BH14-101 OF 2METRIC

LOCATIONWEST WHITBY SEWER TRUNK - N4858872m, E663288m

ORIGINATED BYRBG

BOREHOLE TYPECONTINUOUS FLIGHT HOLLOW STEM AUGERS WITH SPT SAMPLING

COMPILED BYRDJ

DATUMGEODETIC UTM ZONE 17T DATE1.16.15 - 1.19.15

CHECKED BYJSA

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT	PLASTIC LIMIT w <sub>p</sub>	NATURAL MOISTURE CONTENT w	LIQUID LIMIT w <sub>L</sub>	UNIT WEIGHT γ	REMARKS & GRAIN SIZE DISTRIBUTION (%)
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES								
82.0 0.0	BROWN SILTY SAND, SOME GRAVEL, TRACE TO SOME CLAY, OCCASIONAL COBBLES, MOIST, DENSE (GLACIAL TILL)		1	SS	24		81						Groundwater measured at 1.4 mBGL on May 25, 2015.
			2	SS	34		80						
			3	SS	24		79						
			4	SS	24		78						
			5	SS	31		77						
76.2 5.8	DARK GREY GRAVELLY SILTY SAND (CORED DENSE DIAMICTON), ROUNDED COBBLES UP TO 50 mm IN SIZE, 250 mm GNEISSIC BOULDER AT 5.9 m (SHALE-TILL COMPLEX)		6	RC			76						Saprolitic Character at Bedrock/Soil Interface
			7	RC			75						
							74						
							73						
							72						
73.4 8.6	DARK GREY TO BLACK NON-CALCAREOUS SHALE, VERY FINE GRAINED, CLASTIC TEXTURE, HORIZONTAL BEDDING, MODERATELY STRONG, SAPROLITIC AND VERY POOR TO FAIR RQD FROM 8.6 m TO 10.0 m, FAIR RQD 10.0 m TO 18.3 m (WHITBY FORMATION)		8	RC			71						
			9	RC			70						
			10	RC			69						
			11	RC			68						

Continued Next Page

+ 3, × 3: Numbers refer to Sensitivity

○ 3% STRAIN AT FAILURE



RECORD OF BOREHOLE No BH14-10										2 OF 2		METRIC					
LOCATION WEST WHITBY SEWER TRUNK - N4858872m, E663288m										ORIGINATED BY RBG							
BOREHOLE TYPE CONTINUOUS FLIGHT HOLLOW STEM AUGERS WITH SPT SAMPLING										COMPILED BY RDJ							
DATUM GEODETIC UTM ZONE 17T DATE 1.16.15 - 1.19.15										CHECKED BY JSA							
SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					PLASTIC LIMIT w <sub>p</sub>	NATURAL MOISTURE CONTENT w	LIQUID LIMIT w <sub>L</sub>	UNIT WEIGHT γ	REMARKS & GRAIN SIZE DISTRIBUTION (%)
ELEV. DEPTH	DESCRIPTION	STRAT. PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa									
								20	40	60	80	100					
	(continued) DARK GREY TO BLACK NON-CALCAREOUS SHALE, VERY FINE GRAINED, CLASTIC TEXTURE, HORIZONTAL BEDDING, MODERATELY STRONG, SAPROLITIC AND VERY POOR TO FAIR RQD FROM 8.6 m TO 10.0 m, FAIR RQD 10.0 m TO 18.3 m (WHITBY FORMATION)		12	RC													
			13	RC													
			14	RC													
63.7																	
18.3	DARK GREYISH BROWN NON-CALCAREOUS SHALE INTERBEDDED WITH DARK GREY NON-CALCAREOUS SHALE AND FOSSILIFEROUS CALCAREOUS LIMESTONE, MODERATELY STRONG, GOOD RQD (WHITBY FORMATION)		15	RC													
61.0																	
21.0	MEDIUM TO DARK GREY FOSSILIFEROUS SHALEY LIMESTONE, NODULAR BIOTURBATED CHEMOCLASTIC TEXTURE, MODERATELY STRONG TO STRONG, GOOD TO EXCELLENT RQD (LINDSAY/COBOURG FORMATION)		16	RC													
60.3																	
21.7	BOREHOLE TERMINATED AT 21.7 mBGS IN SHALEY LIMESTONE																

ONTARIO MOT WHITBYSEWERTRUNK.MTO (2).GPJ ONTARIO MOT.GDT 10/5/15

# Appendix B

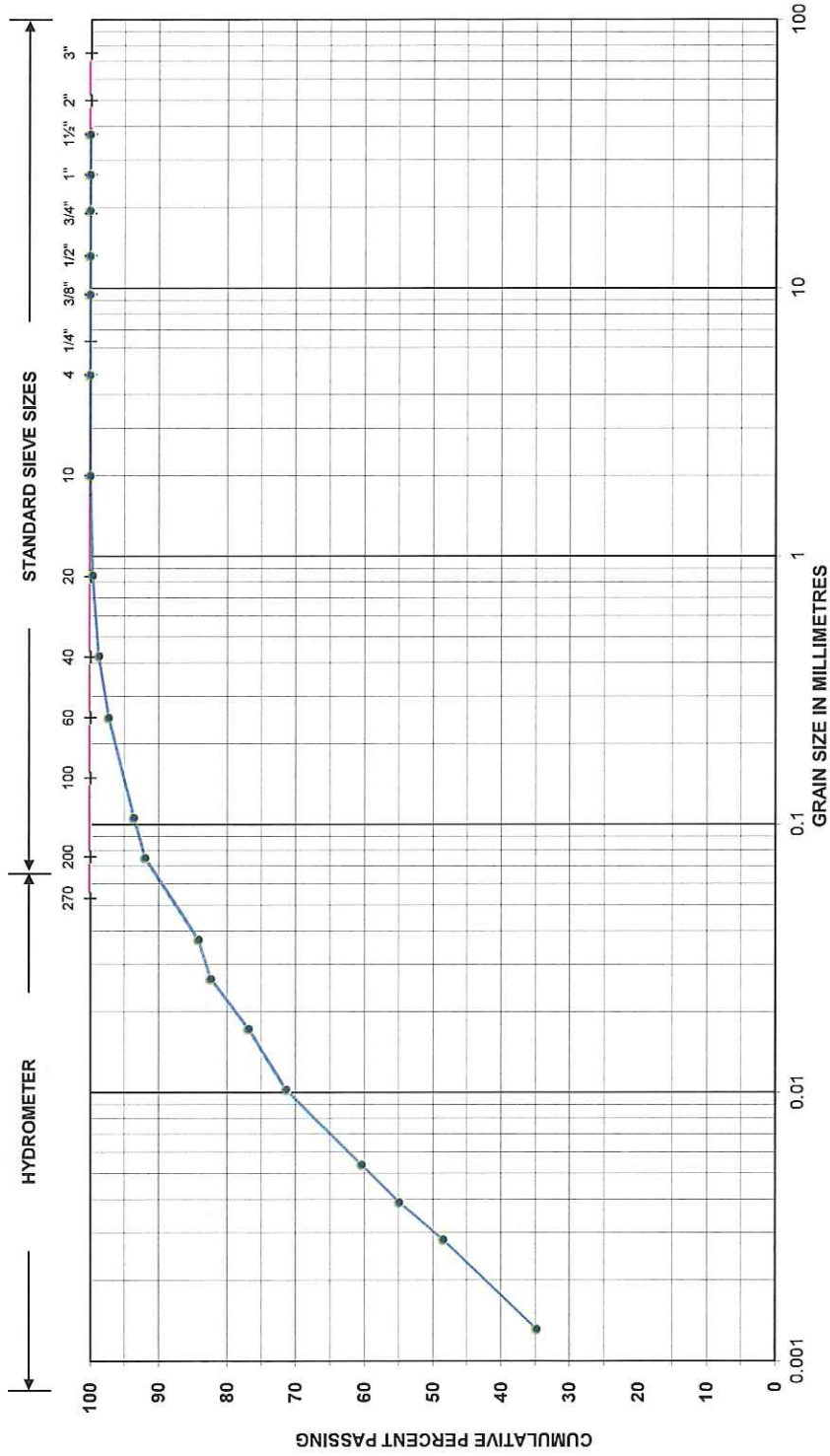
PARTICLE SIZE DISTRIBUTION AND ATTERBERG LIMITS RESULTS





# PARTICLE SIZE DISTRIBUTION

ASTM D422



Project Name: West Whitby Sanitary Sewer Trunk

Project No.: 141-15350-00

Location ID.: BH14-4

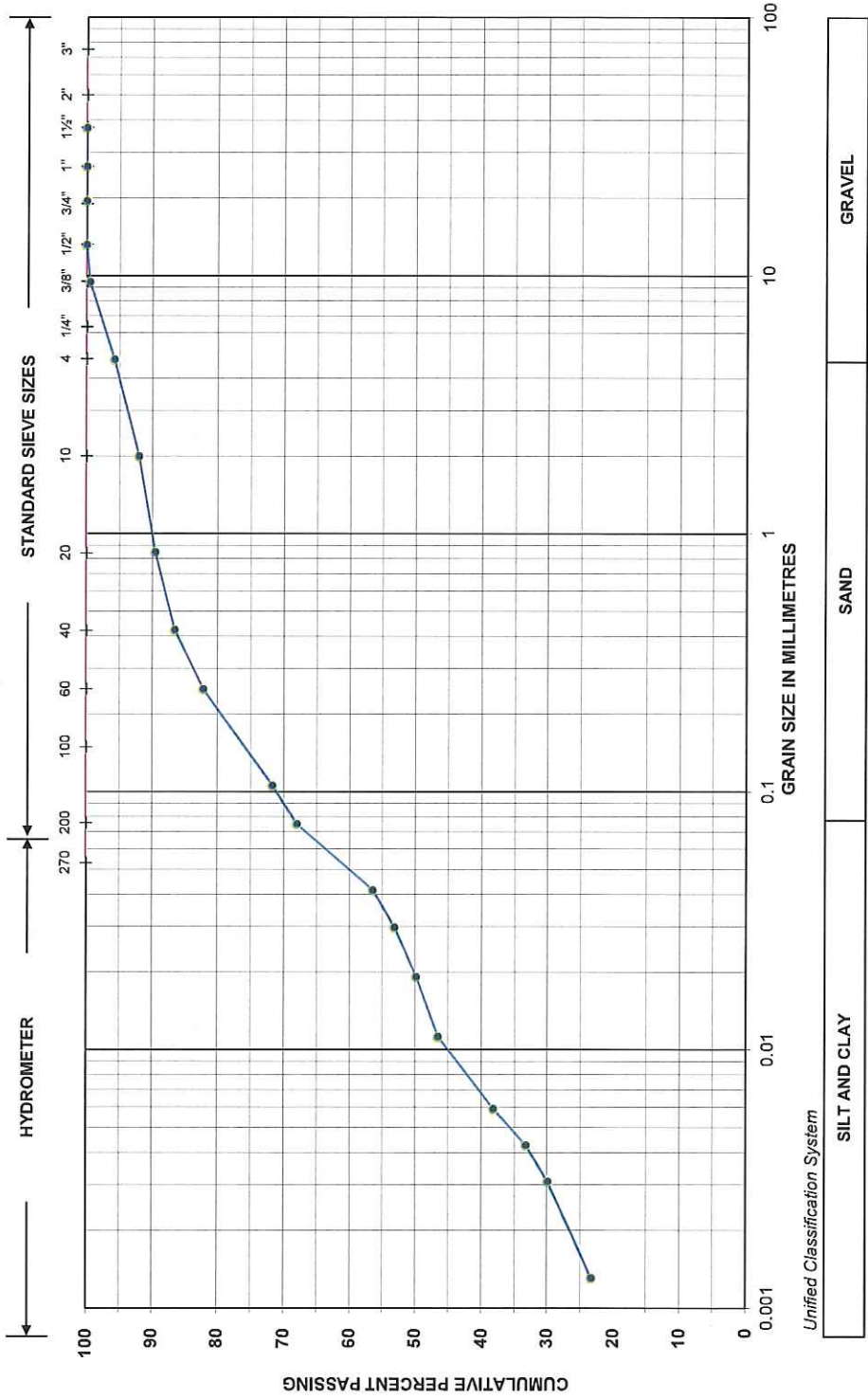
Sample No./Depth: SS2 / 1.5-2.0m

Sieve Size	% Passing Coarse	Sieve Size	% Passing Fine	Hydrometer (mm)	% Passing
26.5 mm	100.0	0.850 mm	99.6	0.037	84.1
13.2 mm	100.0	0.425 mm	98.7	0.017	76.8
9.50 mm	100.0	0.250 mm	97.2	0.005	60.3
4.75 mm	100.0	0.106 mm	93.5	0.003	48.4
2.00 mm	100.0	0.075 mm	91.8	0.001	34.7



# PARTICLE SIZE DISTRIBUTION

ASTM D422



Project Name:	West Whitby Sanitary Sewer Trunk	Project No.:	141-15350-00
Location ID.:	BH14-4	Sample No./Depth:	SS4 / 3.0-3.5m

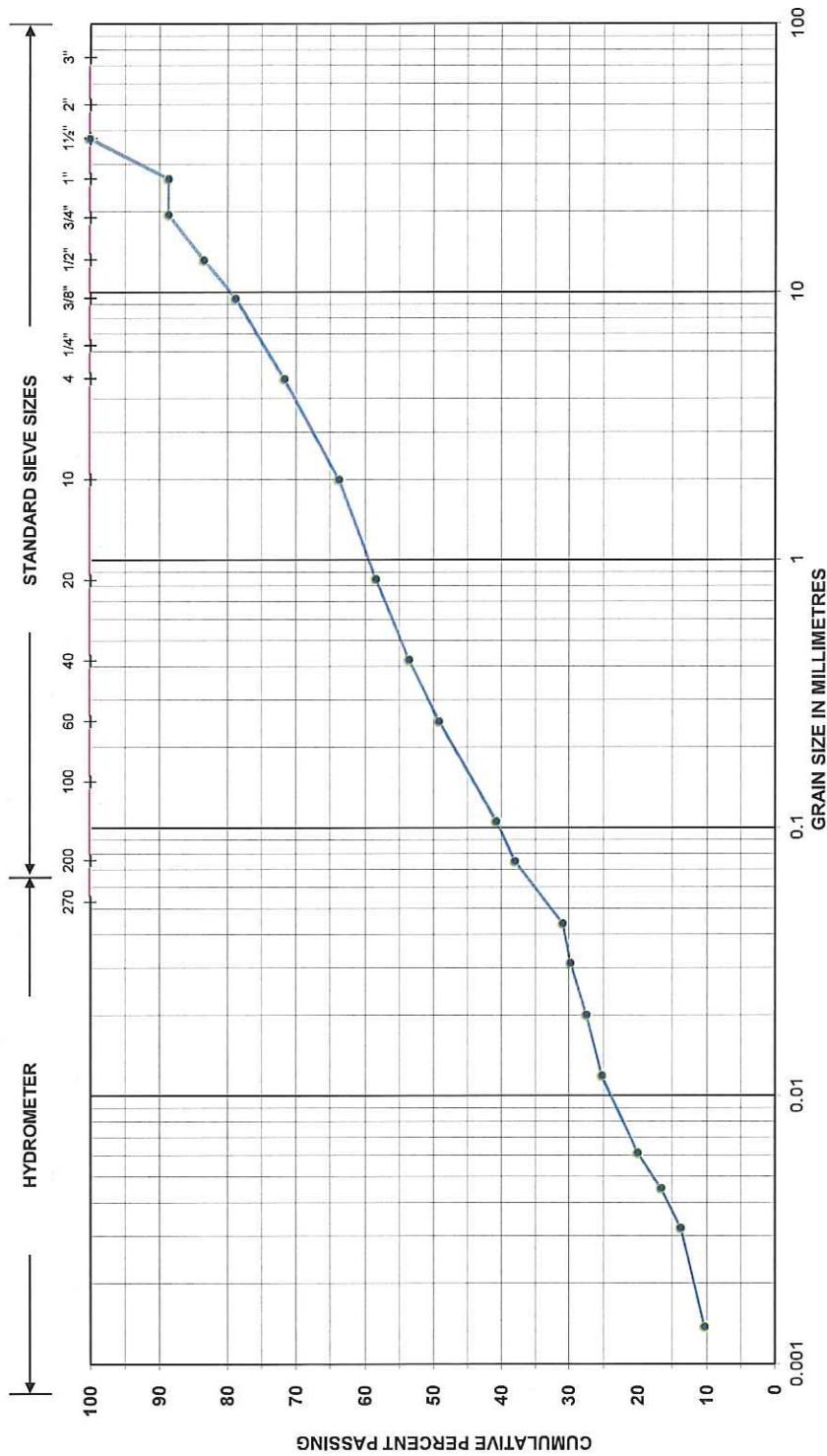
Sieve Size	% Passing Coarse	Sieve Size	% Passing Fine	Hydrometer (mm)	% Passing
26.5 mm	100.0	0.850 mm	89.5	0.042	56.4
13.2 mm	100.0	0.425 mm	86.5	0.019	49.8
9.50 mm	99.5	0.250 mm	82.1	0.006	38.2
4.75 mm	95.8	0.106 mm	71.7	0.003	29.9
2.00 mm	92.0	0.075 mm	68.0	0.001	23.2





PARTICLE SIZE DISTRIBUTION

ASTM D422



SILT AND CLAY		SAND		GRAVEL	
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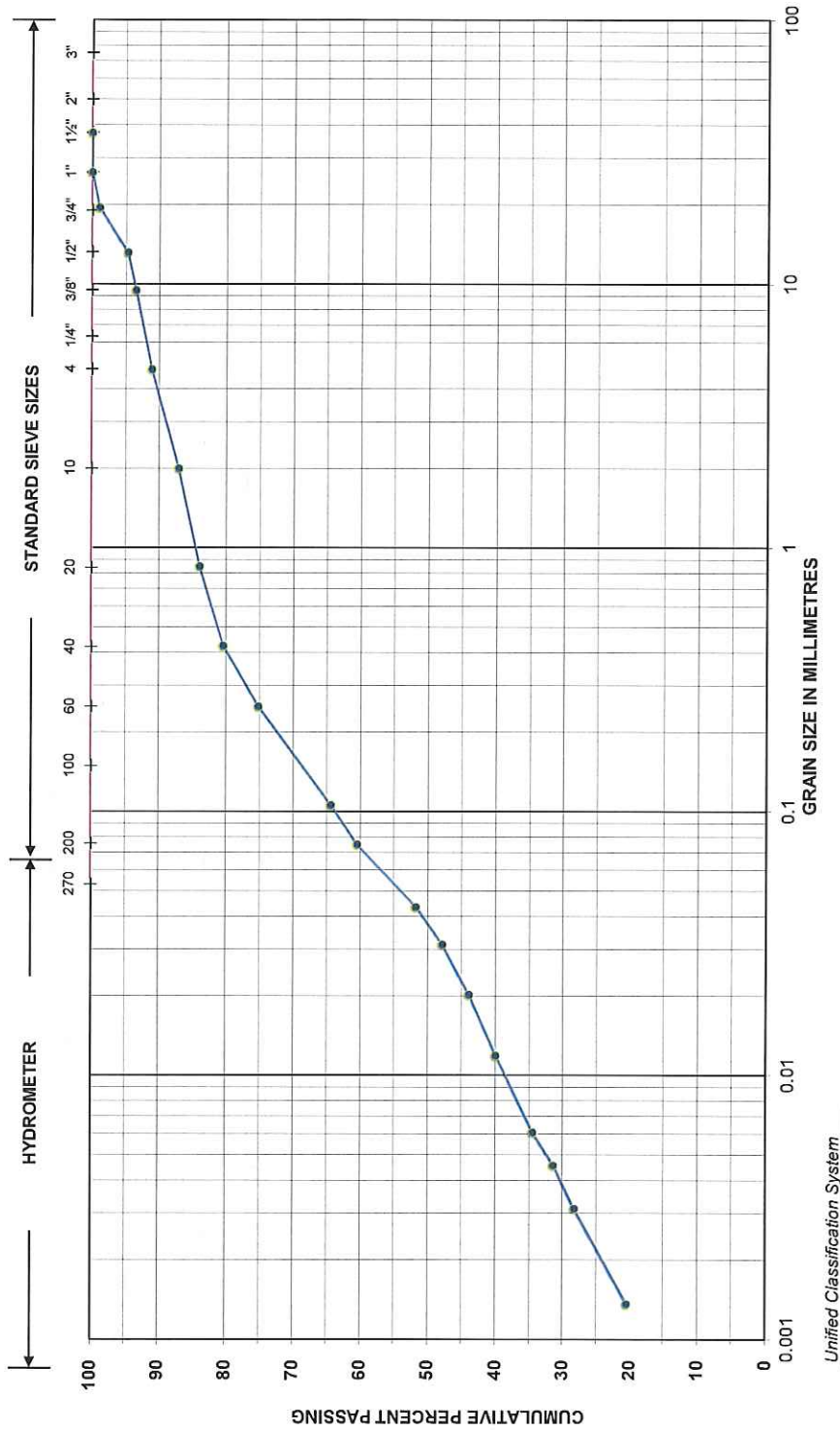
Project Name:	West Whitby Sanitary Sewer Trunk	Project No.:	141-15350-00
Location ID.:	BH14-4	Sample No./Depth:	SS5 / 4.6-5.0m

Sieve Size	% Passing Coarse	Sieve Size	% Passing Fine	Hydrometer (mm)	% Passing
26.5 mm	88.6	0.850 mm	58.4	0.044	30.9
13.2 mm	83.4	0.425 mm	53.5	0.020	27.4
9.50 mm	78.8	0.250 mm	49.1	0.006	20.0
4.75 mm	71.6	0.106 mm	40.7	0.003	13.7
2.00 mm	63.7	0.075 mm	37.9	0.001	10.3



# PARTICLE SIZE DISTRIBUTION

ASTM D422



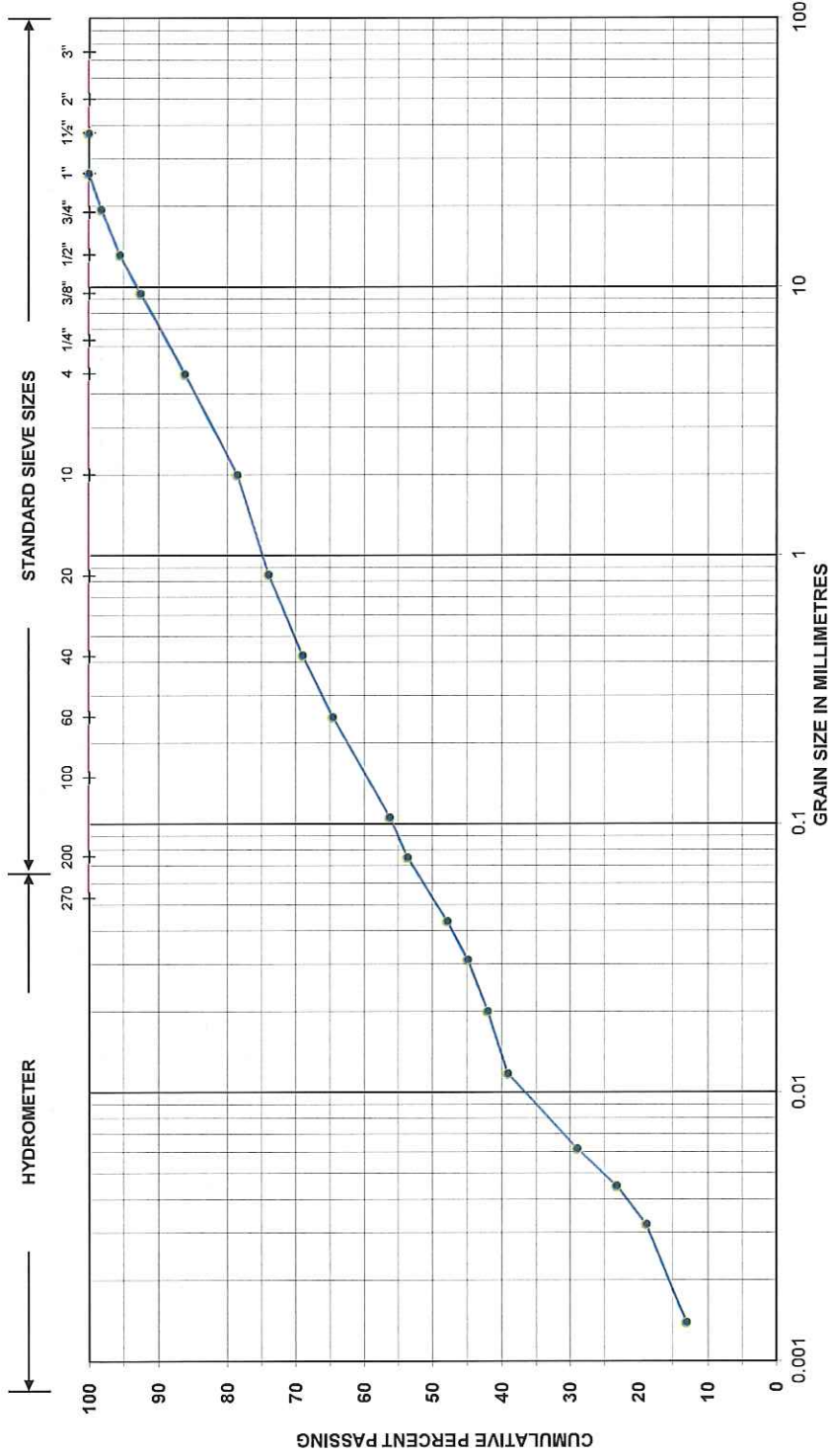
Project Name: West Whitby Sanitary Sewer Trunk		Project No.: 141-15350-00	
Location ID.: BH14-5		Sample No./Depth: SS3 / 1.5-2.2m	
Sieve Size	% Passing Coarse	Sieve Size	% Passing
26.5 mm	100.0	0.043	51.7
13.2 mm	94.7	0.020	43.9
9.50 mm	93.5	0.006	34.5
4.75 mm	91.1	0.003	28.2
2.00 mm	87.0	0.001	20.4





# PARTICLE SIZE DISTRIBUTION

ASTM D422



Unified Classification System

SILT AND CLAY	SAND	GRAVEL
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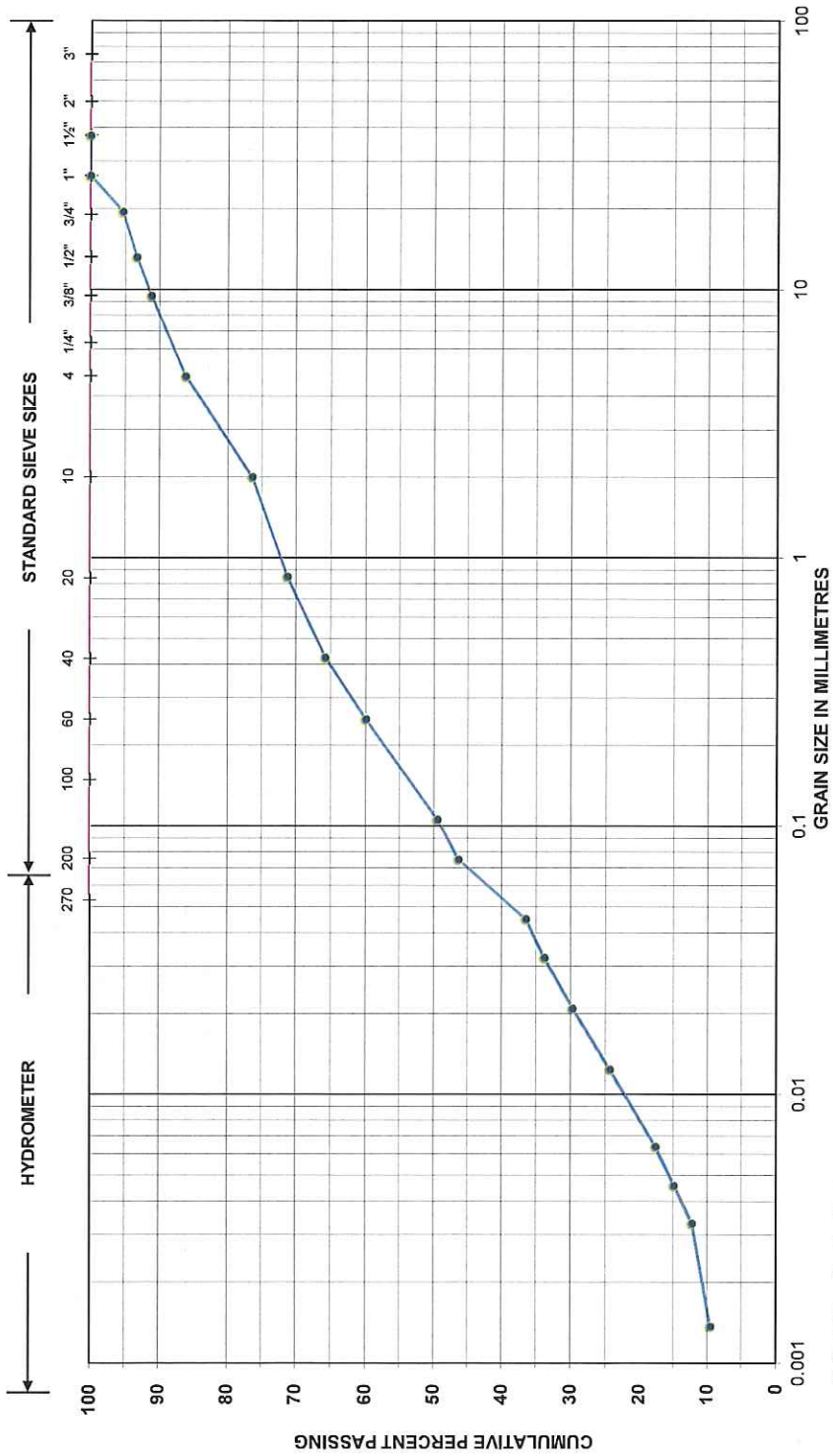
Project Name:	West Whitby Sanitary Sewer Trunk	Project No.:	141-15350-00
Location ID.:	BH14-5	Sample No./Depth:	SS8 / 7.6-8.3m

Sieve Size	% Passing Coarse	Sieve Size	% Passing Fine	Hydrometer (mm)	% Passing
26.5 mm	100.0	0.850 mm	73.9	0.043	47.8
13.2 mm	95.5	0.425 mm	68.9	0.020	42.0
9.50 mm	92.5	0.250 mm	64.6	0.006	29.0
4.75 mm	86.1	0.106 mm	56.2	0.003	18.8
2.00 mm	78.5	0.075 mm	53.6	0.001	13.0



# PARTICLE SIZE DISTRIBUTION

ASTM D422



SILT AND CLAY		SAND		GRAVEL	
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Project Name:	West Whitby Sanitary Sewer Trunk	Project No.:	141-15350-00
Location ID.:	BH14-5	Sample No./Depth:	SS9 / 9.1-9.8m

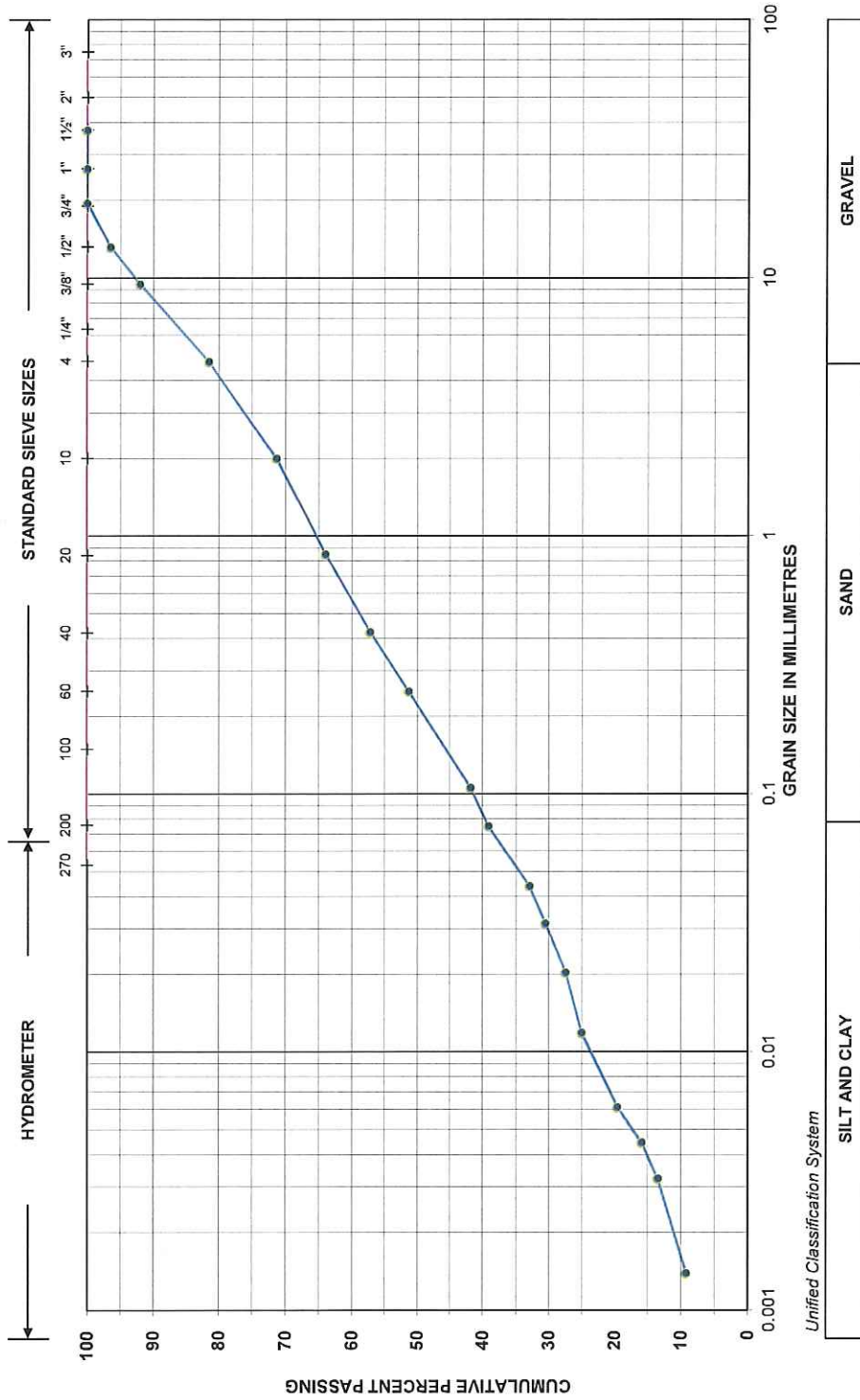
Sieve Size	% Passing Coarse	Sieve Size	% Passing Fine	Hydrometer (mm)	% Passing
26.5 mm	100.0	0.850 mm	71.2	0.045	36.4
13.2 mm	93.3	0.425 mm	65.7	0.021	29.6
9.50 mm	91.1	0.250 mm	59.9	0.006	17.5
4.75 mm	86.1	0.106 mm	49.4	0.003	12.1
2.00 mm	76.3	0.075 mm	46.2	0.001	9.4





# PARTICLE SIZE DISTRIBUTION

ASTM D422



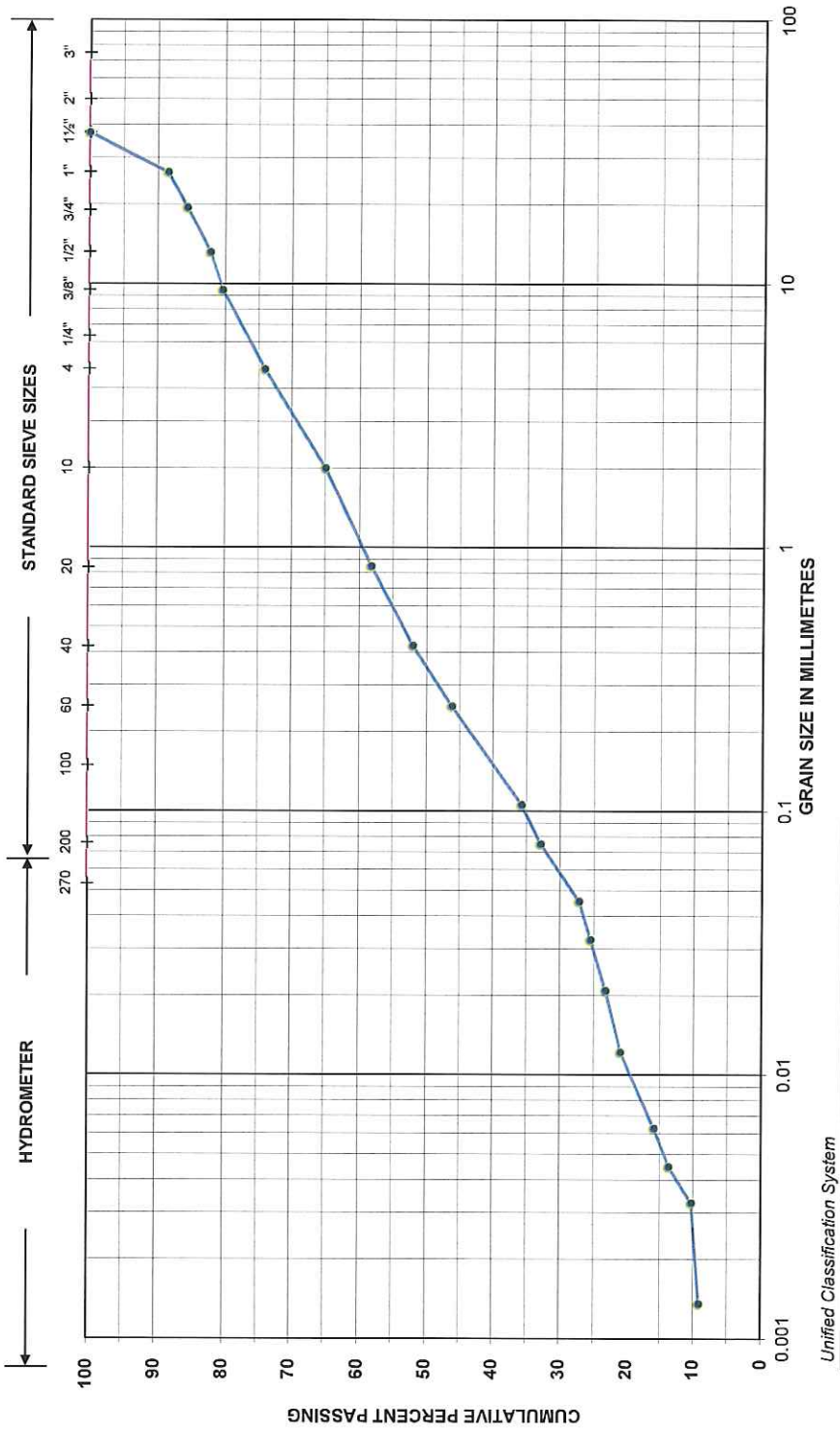
Project Name:	West Whitby Sanitary Sewer Trunk	Project No.:	141-15350-00
Location ID.:	BH14-10	Sample No./Depth:	SS4 / 3.0-3.5m

Sieve Size	% Passing Coarse	Sieve Size	% Passing Fine	Hydrometer (mm)	% Passing
26.5 mm	100.0	0.850 mm	63.9	0.044	32.9
13.2 mm	96.5	0.425 mm	57.2	0.020	27.4
9.50 mm	92.0	0.250 mm	51.2	0.006	19.5
4.75 mm	81.5	0.106 mm	41.8	0.003	13.4
2.00 mm	71.3	0.075 mm	39.0	0.001	9.1



# PARTICLE SIZE DISTRIBUTION

ASTM D422



SILT AND CLAY	SAND	GRAVEL
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Project Name:	West Whitby Sanitary Sewer Trunk	Project No.:	141-15350-00
Location ID.:	BH14-10	Sample No./Depth:	SS5 / 4.6-5.0m

Sieve Size	% Passing Coarse	Sieve Size	% Passing Fine	Hydrometer (mm)	% Passing
26.5 mm	88.4	0.850 mm	58.1	0.045	27.1
13.2 mm	82.2	0.425 mm	51.9	0.021	23.1
9.50 mm	80.3	0.250 mm	46.1	0.006	15.8
4.75 mm	74.0	0.106 mm	35.6	0.003	10.2
2.00 mm	64.8	0.075 mm	32.8	0.001	9.0





## ATTERBERG LIMITS

ASTM D4318

Date:	20-Jul-15	Job No.:	141-15350-00
Project Name:	West Whitby Sanitary Sewer Trunk	Tech.:	KLC
Borehole/Sample No.:	BH14-4 / SS2 / 1.5-2.0m		

### Liquid Limit Test

Number of Shocks	35	25	15
Tin No.			
Tin + Wet soil	32.6	38.4	31.2
Tin + Dry soil	29.4	35.5	27.7
Wt. of Water	3.2	2.9	3.5
Wt. of Tin	21.5	28.5	19.6
Wt. of Dry Soil	7.9	7.0	8.1
Water Content	40	41	43

### Plastic Limit Test

Tin No.		
Tin + Wet soil	27.6	28.5
Tin + Dry soil	26.5	27.2
Wt. of Water	1.1	1.3
Wt. of Tin	21.4	21.4
Wt. of Dry Soil	5.1	5.8
Water Content	22	22

### Natural Water Content

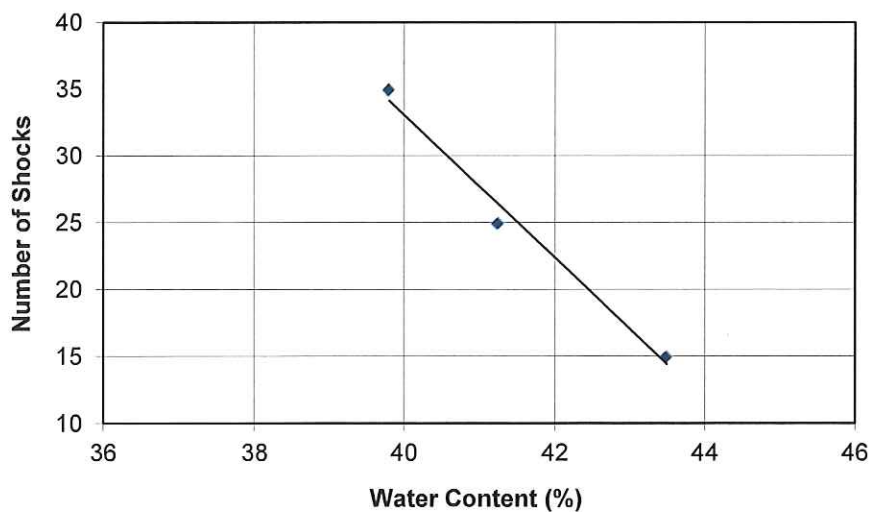
	41.4
	37.5
	3.9
	21.3
	16.2
	24.0

Liquid Limit, ( $W_L$ )	41
Plastic Limit, ( $W_P$ )	22
Plasticity Index ( $I_p = W_L - W_P$ )	19
Natural Water Content, $W$	24
Liquidity Index ( $I_L = W - W_P / W_L - W_P$ )	0.1

### Control Results

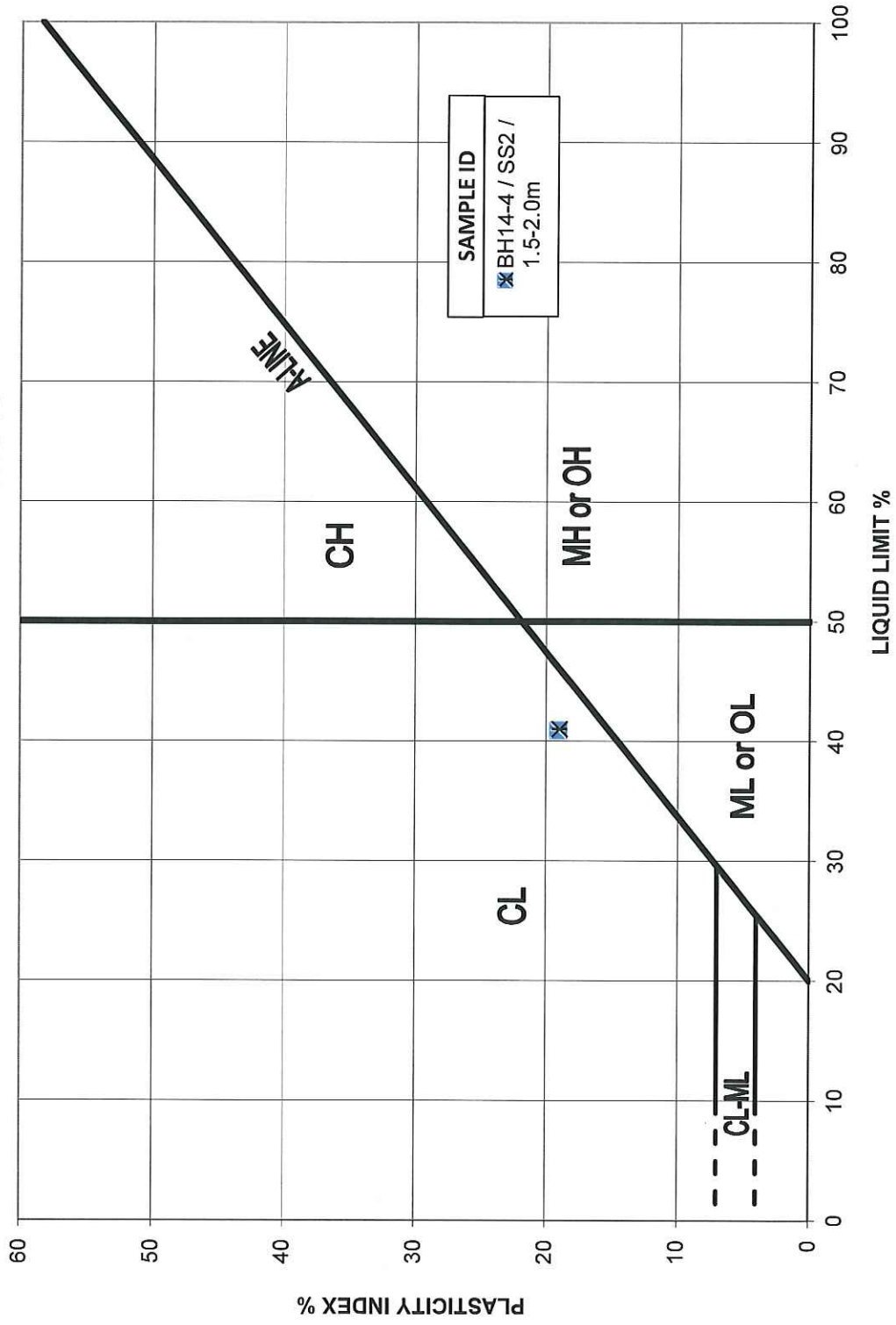
Liquid Limit, ( $W_L$ )	30
Plastic Limit, ( $W_P$ )	19
Plasticity Index ( $I_p = W_L - W_P$ )	11

### Liquid Limit





Atterberg Limits Plasticity Chart  
West Whitby Sanitary Sewer Trunk  
141-15350-00







## ATTERBERG LIMITS

ASTM D4318

Date:	20-Jul-15	Job No.:	141-15350-00
Project Name:	West Whitby Sanitary Sewer Trunk	Tech.:	KLC
Borehole/Sample No.:	B14-4 / SS3 / 2.3-2.7m		

### Liquid Limit Test

Number of Shocks	27	16	22
Tin No.			
Tin + Wet soil	33.3	23.5	32.8
Tin + Dry soil	30.7	21.6	30.6
Wt. of Water	2.6	2.0	2.3
Wt. of Tin	19.7	14.1	21.4
Wt. of Dry Soil	11.0	7.5	9.1
Water Content	24	26	25

### Plastic Limit Test

Tin No.		
Tin + Wet soil	37.2	30.0
Tin + Dry soil	36.1	28.9
Wt. of Water	1.1	1.1
Wt. of Tin	28.3	21.3
Wt. of Dry Soil	7.8	7.6
Water Content	15	15

### Natural Water Content

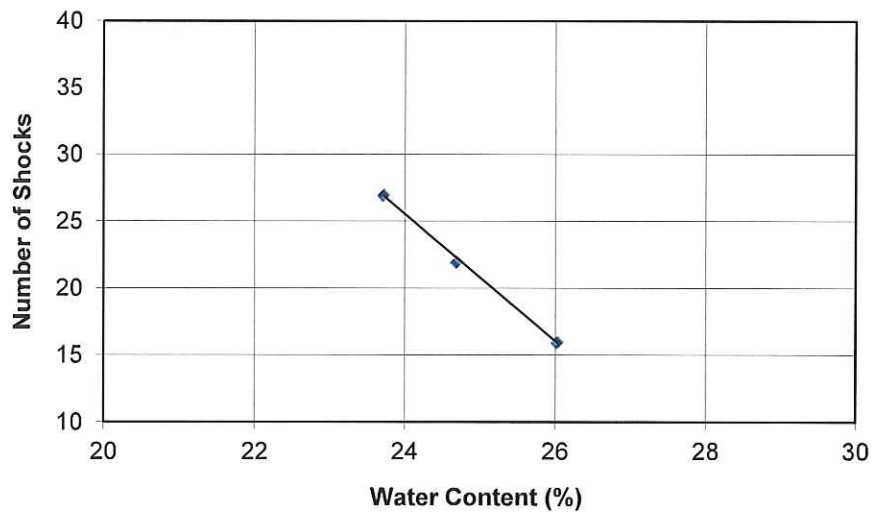
	49.4
	46.7
	2.7
	28.4
	18.2
	14.7

### Control Results

Liquid Limit, ( $W_L$ )	24
Plastic Limit, ( $W_P$ )	15
Plasticity Index ( $I_P = W_L - W_P$ )	9
Natural Water Content, $W$	15
Liquidity Index ( $I_L = W - W_P / W_L - W_P$ )	0.02

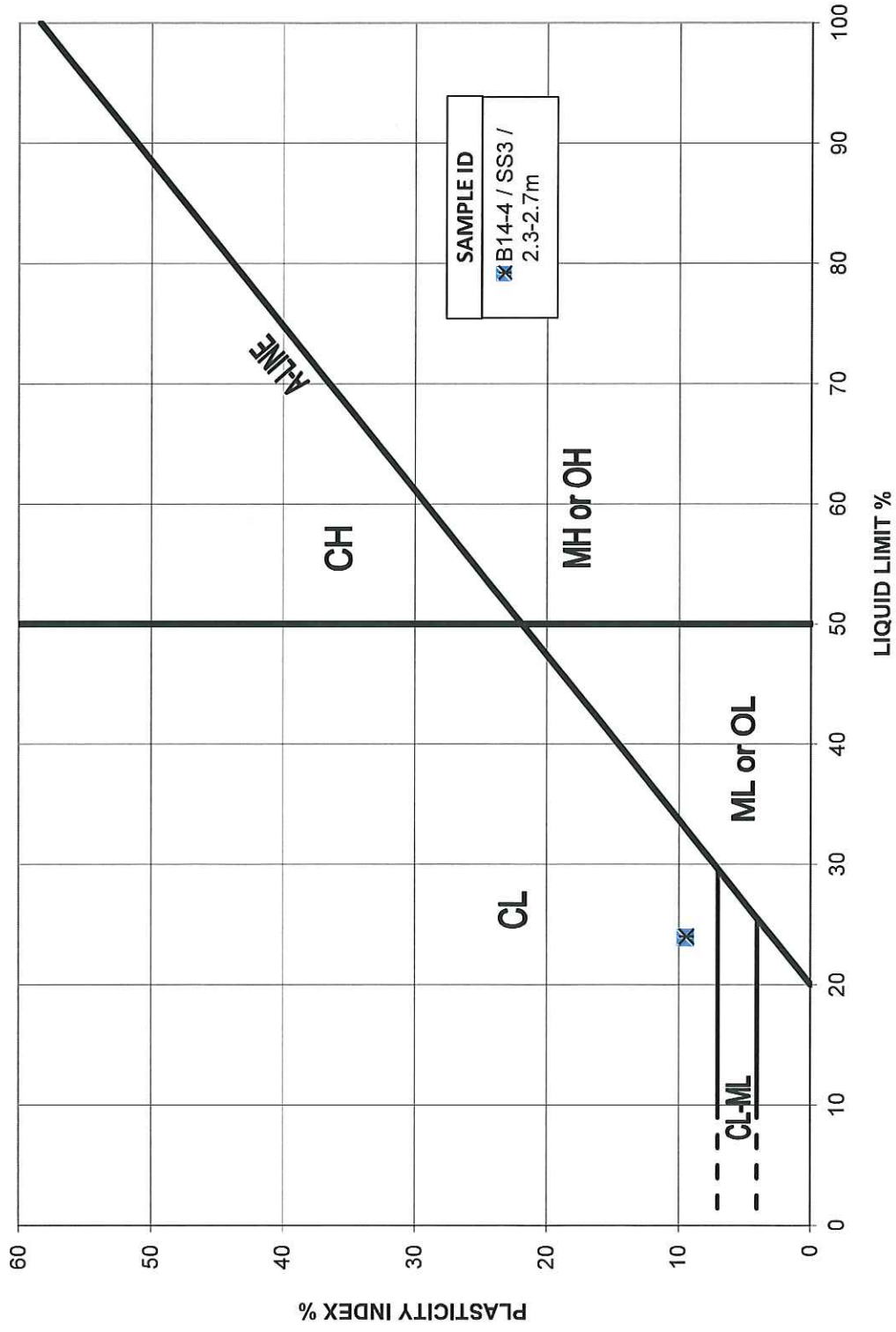
Liquid Limit, ( $W_L$ )	30
Plastic Limit, ( $W_P$ )	19
Plasticity Index ( $I_P = W_L - W_P$ )	11

### Liquid Limit





Atterberg Limits Plasticity Chart  
West Whitby Sanitary Sewer Trunk  
141-15350-00





# WSP LABORATORY - ATTERBERG LIMITS

Date:	22-Jan-15	Job No.:	141-15350-00
Project Name:	West Whitby Sanitary Sewer Trunk	Tech.:	KLK
Borehole/Sample No.:	BH14-5 / SS3 / 1.5-2.1m		

## Liquid Limit Test

Number of Shocks	29	23	15
Tin No.			
Tin + Wet soil	40.36	33.13	32.51
Tin + Dry soil	38.3	31.1	30.42
Wt. of Water	2.06	2.03	2.09
Wt. of Tin	28.23	21.27	20.96
Wt. of Dry Soil	10.07	9.83	9.46
Water Content	20	21	22

## Plastic Limit Test

Tin No.		
Tin + Wet soil	30.82	30.04
Tin + Dry soil	29.75	29.06
Wt. of Water	1.07	0.98
Wt. of Tin	21.33	21.22
Wt. of Dry Soil	8.42	7.84
Water Content	13	13

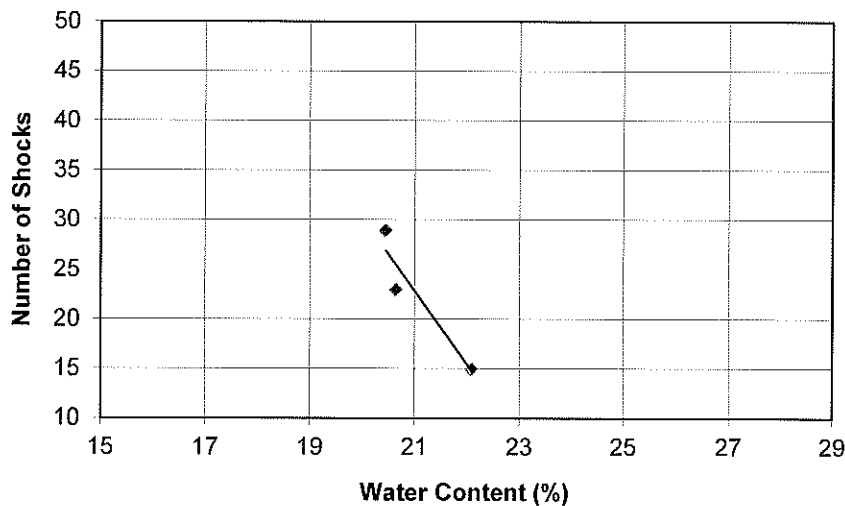
## Natural Water Content

	129.8
	118.2
	11.6
	27.6
	90.6
	12.8

Liquid Limit, ( $W_L$ )	21
Plastic Limit, ( $W_P$ )	13
Plasticity Index ( $I_P = W_L - W_P$ )	8
Natural Water Content, $W$	13
Liquidity Index ( $I_L = W - W_P / W_L - W_P$ )	0.02

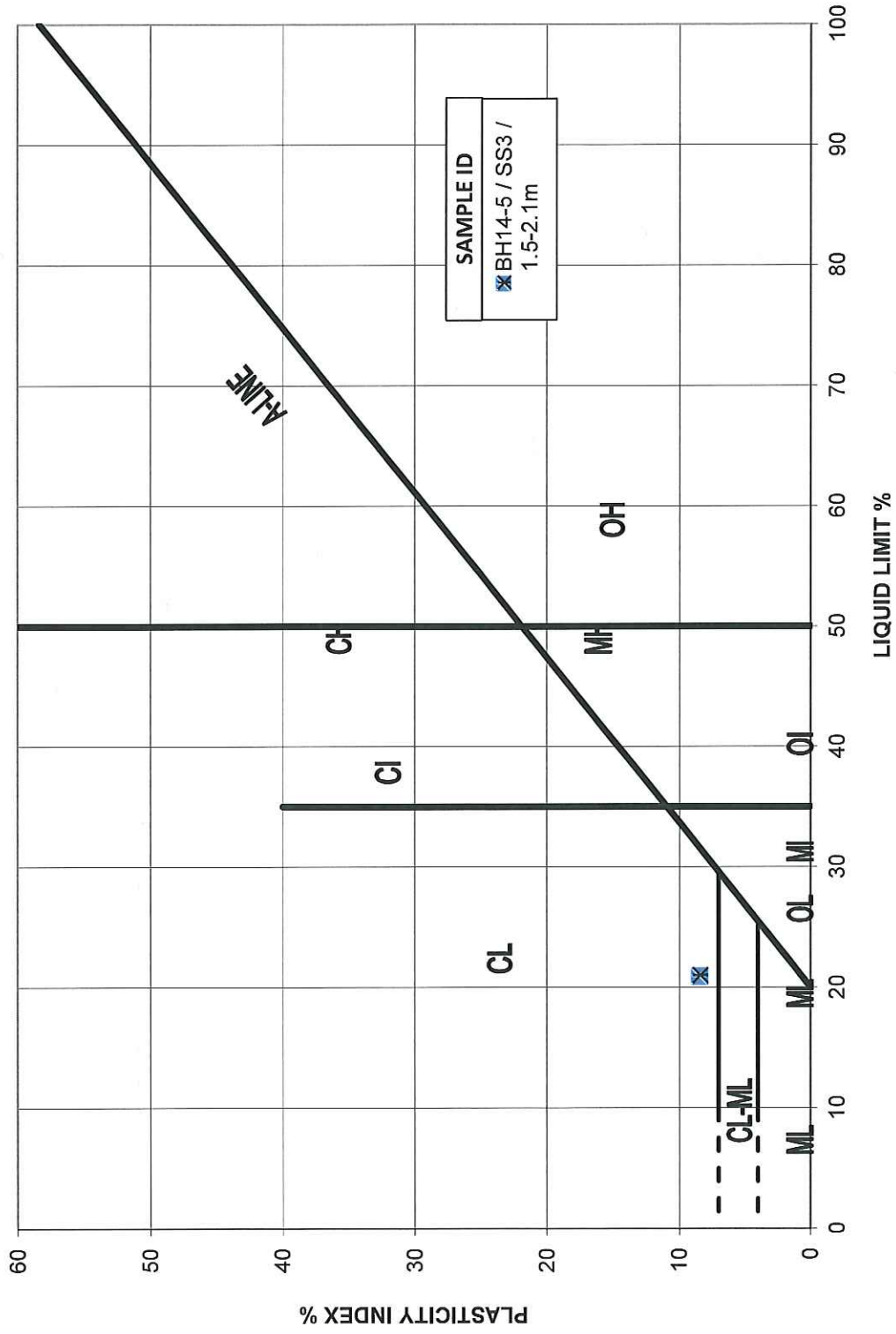
<b>Control Results</b>	
Liquid Limit, ( $W_L$ )	33
Plastic Limit, ( $W_P$ )	18
Plasticity Index ( $I_P = W_L - W_P$ )	15

## Liquid Limit





Atterberg Limits Plasticity Chart  
West Whitby Sanitary Sewer Trunk  
141-15350-00





# **WSP** **LABORATORY - ATTERBERG LIMITS**

Date:	22-Jan-15	Job No.:	141-15350-00
Project Name:	West Whitby Sanitary Sewer Trunk	Tech.:	KLC
Borehole/Sample No.:	BH14-5 / SS8 / 7.6-8.2m		

## Liquid Limit Test

Number of Shocks	16	23	31
Tin No.			
Tin + Wet soil	33.6	32.24	33.11
Tin + Dry soil	31.39	30.37	31.11
Wt. of Water	2.21	1.87	2
Wt. of Tin	21.39	21.3	21.26
Wt. of Dry Soil	10	9.07	9.85
Water Content	22	21	20

## Plastic Limit Test

Tin No.		
Tin + Wet soil	34.14	35.41
Tin + Dry soil	32.46	33.51
Wt. of Water	1.68	1.9
Wt. of Tin	21.03	21.35
Wt. of Dry Soil	11.43	12.16
Water Content	15	16

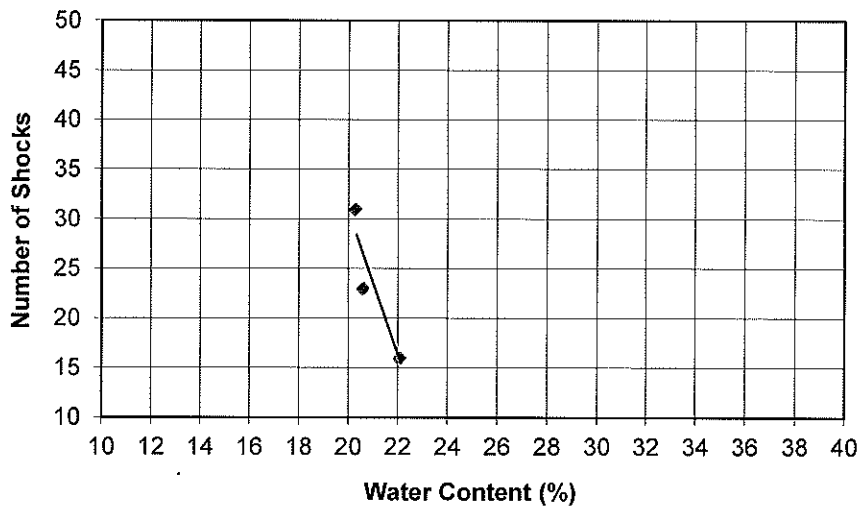
## Natural Water Content

	100.8
	97.5
	3.3
	28.8
	68.7
	4.8

## Control Results

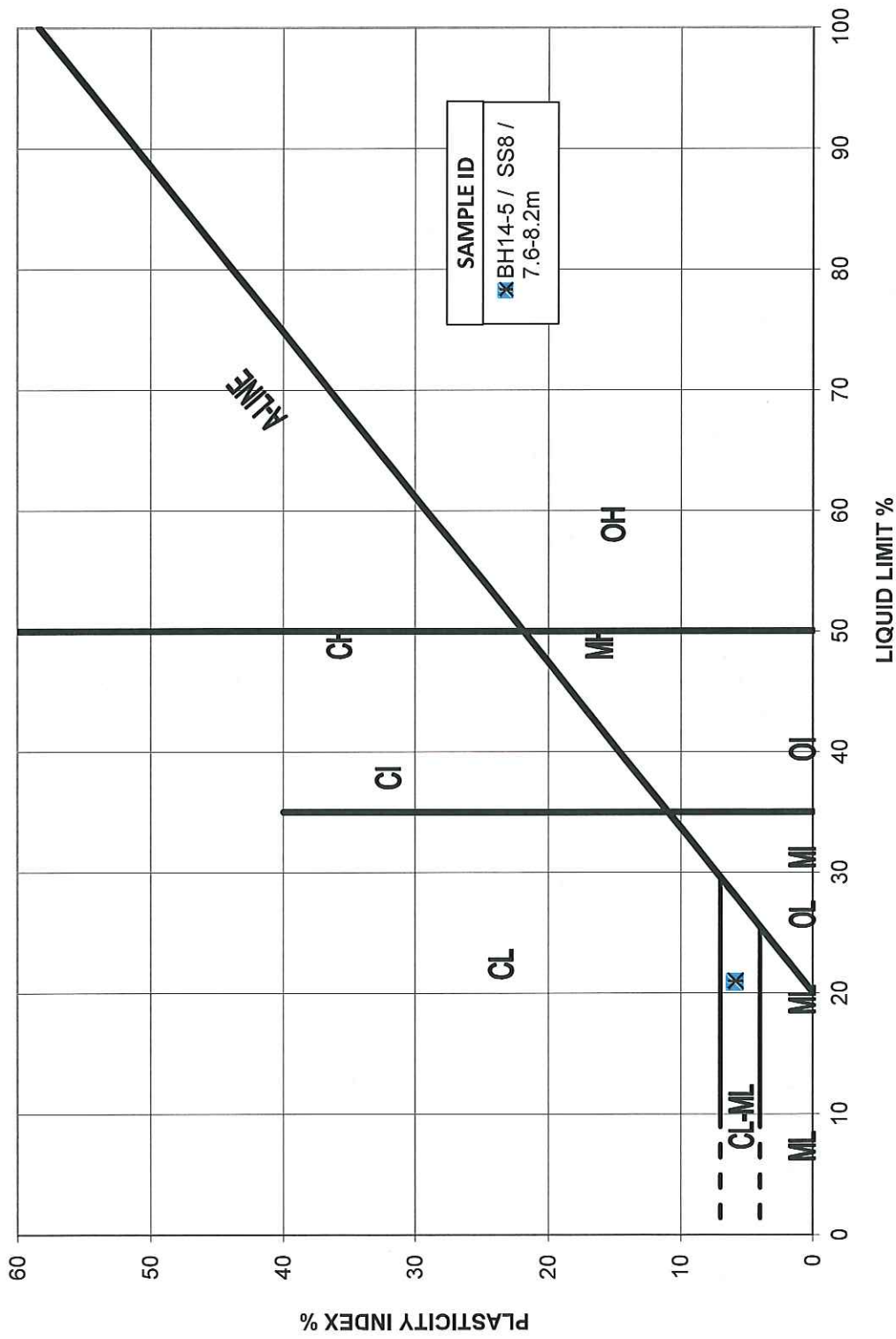
Liquid Limit, ( $W_L$ )	21	Liquid Limit, ( $W_L$ )	33
Plastic Limit, ( $W_P$ )	15	Plastic Limit, ( $W_P$ )	18
Plasticity Index ( $I_P=W_L-W_P$ )	6	Plasticity Index ( $I_P=W_L-W_P$ )	15
Natural Water Content, $W$	5		
Liquidity Index ( $I_L=W-W_P/W_L-W_P$ )	-1.8		

## Liquid Limit





Atterberg Limits Plasticity Chart  
West Whitby Sanitary Sewer Trunk  
141-15350-00





## MOISTURE CONTENTS

**Project Location:** West Whitby Sanitary Sewer Trunk  
**File No.:** 141-15350-00

**Tech:** MLM  
**Date:** 14-Jan-15

TIN NO.	AR36	AR44	LA69	TR1	AR10
BOREHOLE NO.	BH14-1	BH14-1	BH14-1	BH14-1	BH14-1
SAMPLE & DEPTH	SS1 / 0-0.6m	SS2 / 0.8-1.2m	SS3 / 1.5-2.0m	SS4 / 2.3-2.7m	SS5 / 3.0-3.5m
WT of TIN & WET SOIL (g)	97.8	103.5	136.0	110.4	111.2
WT of TIN & DRY SOIL (g)	86.1	96.2	125.6	105.6	106.2
WT of WATER (g)	11.7	7.3	10.4	4.8	5.0
TARE WT (g)	28.8	28.0	27.8	28.0	27.7
WT of DRY SOIL (g)	57.3	68.2	97.7	77.7	78.5
MOISTURE CONTENT	20.5%	10.7%	10.7%	6.1%	6.4%
TIN NO.	AR2	BN11	RD3	RD17	AR35
BOREHOLE NO.	BH14-1	BH14-1	BH14-1	BH14-1	BH14-1
SAMPLE & DEPTH	SS6 / 4.6-5.0m	SS7 / 6.1-6.7m	SS8 / 9.1-9.8m	SS9 / 10.7-11.2m	SS10 / 12.2-12.8m
WT of TIN & WET SOIL (g)	90.4	103.4	85.8	52.7	75.5
WT of TIN & DRY SOIL (g)	88.0	100.3	80.9	51.9	73.7
WT of WATER (g)	2.3	3.1	4.9	0.7	1.8
TARE WT (g)	27.4	27.8	28.1	27.8	27.9
WT of DRY SOIL (g)	60.6	72.6	52.8	24.2	45.8
MOISTURE CONTENT	3.9%	4.2%	9.2%	2.9%	4.0%
TIN NO.	BN4	BW7	RD4	BN12	RD28
BOREHOLE NO.	BH14-1	BH14-2	BH14-2	BH14-2	BH14-2
SAMPLE & DEPTH	SS11 / 13.7-14.3m	SS1 / 0-0.6m	SS2 / 0.8-1.4m	SS3 / 1.5-2.1m	SS4 / 2.3-2.9m
WT of TIN & WET SOIL (g)	70.4	89.7	90.0	107.7	117.6
WT of TIN & DRY SOIL (g)	65.8	80.1	78.4	95.7	107.6
WT of WATER (g)	4.7	9.6	11.6	12.1	10.0
TARE WT (g)	28.0	27.4	28.0	27.6	27.7
WT of DRY SOIL (g)	37.7	52.7	50.5	68.1	79.9
MOISTURE CONTENT	12.4%	18.1%	22.9%	17.7%	12.5%
TIN NO.	BN27	BN21	LA67	RD32	AR23
BOREHOLE NO.	BH14-2	BH14-2	BH14-2	BH14-2	BH14-5
SAMPLE & DEPTH	SS5 / 3.0-3.7m	SS6 / 4.6-5.2m	SS8 / 9.1-9.8m	SS9 / 10.7-11.2m	SS1 / 0-0.6m
WT of TIN & WET SOIL (g)	120.5	110.3	106.3	119.7	93.0
WT of TIN & DRY SOIL (g)	114.0	105.5	101.8	109.8	80.2
WT of WATER (g)	6.5	4.8	4.5	9.9	12.8
TARE WT (g)	27.9	27.6	27.4	28.7	28.7
WT of DRY SOIL (g)	86.1	77.9	74.4	81.1	51.5
MOISTURE CONTENT	7.6%	6.2%	6.0%	12.2%	24.9%
TIN NO.	AR7	AR9	AR21	AR19	AR43
BOREHOLE NO.	BH14-5	BH14-5	BH14-5	BH14-5	BH14-5
SAMPLE & DEPTH	SS2 / 0.8-1.4mm	SS3 / 1.5-2.1m	SS4 / 2.3-2.9m	SS5 / 3.0-3.7m	7.6-8.2m
WT of TIN & WET SOIL (g)	111.1	129.8	99.8	103.4	100.8
WT of TIN & DRY SOIL (g)	99.0	118.2	94.9	99.9	97.5
WT of WATER (g)	12.1	11.6	4.8	3.6	3.3
TARE WT (g)	27.8	27.6	27.6	27.7	28.8
WT of DRY SOIL (g)	71.2	90.5	67.3	72.1	68.7
MOISTURE CONTENT	16.9%	12.8%	7.2%	4.9%	4.7%





## MOISTURE CONTENTS

**Project Location:** West Whitby Sanitary Sewer Trunk  
**File No.:** 141-15350-00  
**Tech:** MLM  
**Date:** 14-Jan-15

TIN NO.	AR29	AR11	AR41	RD26	RD5
BOREHOLE NO.	BH14-5	BH14-5	BH14-5	BH14-6	BH14-6
SAMPLE & DEPTH	9.1-9.8m	10.7-11.2m	12.2-12.8m	SS1 / 0-0.6m	SS2 / 0.8-1.4m
WT of TIN & WET SOIL (g)	94.0	86.7	91.6	79.5	84.0
WT of TIN & DRY SOIL (g)	91.3	84.1	85.0	73.1	70.3
WT of WATER (g)	2.7	2.6	6.6	6.3	13.7
TARE WT (g)	28.0	27.7	27.9	27.8	28.0
WT of DRY SOIL (g)	63.3	56.4	57.1	45.3	42.3
MOISTURE CONTENT	4.2%	4.6%	11.6%	14.0%	32.4%

TIN NO.	BN18	RD11	RD1	RD21	LA20
BOREHOLE NO.	BH14-6	BH14-6	BH14-6	BH14-6	BH14-6
SAMPLE & DEPTH	SS3 / 1.5-2.0m	SS4 / 2.3-2.9m	SS5 / 3.0-3.7m	SS6 / 4.6-5.2m	SS7 / 6.1-6.7m
WT of TIN & WET SOIL (g)	94.2	116.0	108.4	93.0	81.2
WT of TIN & DRY SOIL (g)	85.2	107.7	102.3	89.8	78.3
WT of WATER (g)	9.0	8.2	6.1	3.3	2.8
TARE WT (g)	28.9	27.8	27.8	27.3	28.0
WT of DRY SOIL (g)	56.3	79.9	74.5	62.5	50.3
MOISTURE CONTENT	16.0%	10.3%	8.2%	5.2%	5.7%

TIN NO.	TR7	BN15	RD6	RD18	LA52
BOREHOLE NO.	BH14-6	BH14-6	BH14-6	BH14-6	BH14-7
SAMPLE & DEPTH	SS8 / 7.6-8.2m	SS9 / 9.1-9.8m	SS10 / 10.7-11.3m	SS11 / 11.7m	SS1A / 0-0.6m
WT of TIN & WET SOIL (g)	98.2	120.5	87.2	71.4	92.6
WT of TIN & DRY SOIL (g)	95.2	115.5	81.8	67.4	84.7
WT of WATER (g)	3.0	5.0	5.4	4.0	7.9
TARE WT (g)	28.1	27.7	27.8	28.8	27.6
WT of DRY SOIL (g)	67.2	87.8	54.0	38.6	57.1
MOISTURE CONTENT	4.4%	5.7%	10.0%	10.3%	13.8%

TIN NO.	LA55	LA71	LA23	LA65	LA5
BOREHOLE NO.	BH14-7	BH14-7	BH14-7	BH14-7	BH14-7
SAMPLE & DEPTH	SS1B / 0-0.6m	SS2 / 0.8-1.4m	SS3 / 1.5-2.1m	SS4 / 2.3-2.9m	SS5 / 3.0-3.7m
WT of TIN & WET SOIL (g)	69.7	92.2	90.5	101.2	90.1
WT of TIN & DRY SOIL (g)	64.8	84.7	79.6	85.3	77.6
WT of WATER (g)	4.9	7.6	10.9	15.9	12.5
TARE WT (g)	27.4	27.0	28.6	27.9	28.4
WT of DRY SOIL (g)	37.4	57.7	51.0	57.5	49.2
MOISTURE CONTENT	13.1%	13.1%	21.4%	27.6%	25.5%

TIN NO.	RD10	LA66	LA6	LA45	LA35
BOREHOLE NO.	BH14-7	BH14-7	BH14-7	BH14-7	BH14-7
SAMPLE & DEPTH	SS6 / 4.6-5.2m	SS7 / 6.1-6.7m	SS8A / 9.1-9.8m	SS8B / 9.1-9.8m	SS9A / 10.7-11.2m
WT of TIN & WET SOIL (g)	104.4	130.8	84.6	78.2	136.0
WT of TIN & DRY SOIL (g)	82.0	117.0	77.8	73.7	124.2
WT of WATER (g)	22.5	13.9	6.8	4.6	11.8
TARE WT (g)	27.6	28.0	27.8	27.4	27.8
WT of DRY SOIL (g)	54.3	88.9	50.0	46.3	96.4
MOISTURE CONTENT	41.3%	15.6%	13.6%	9.8%	12.2%



## MOISTURE CONTENTS

**Project Location:** West Whitby Sanitary Sewer Trunk  
**File No.:** 141-15350-00

**Tech:** MLM  
**Date:** 14-Jan-15

TIN NO.	BN6	LA24	RD15	RD24	LA19
BOREHOLE NO.	BH14-7	BH14-7	BH14-8	BH14-8	BH14-8
SAMPLE & DEPTH	SS9B / 10.7-11.2m	SS10 / 12.2-12.9m	SS1A / 0-0.6m	SS1B / 0-0.6m	SS2 / 0.8-1.4m
WT of TIN & WET SOIL (g)	86.8	59.8	86.4	75.1	114.8
WT of TIN & DRY SOIL (g)	84.2	57.4	73.4	68.3	102.0
WT of WATER (g)	2.6	2.4	13.0	6.8	12.8
TARE WT (g)	27.8	27.5	27.6	28.0	27.4
WT of DRY SOIL (g)	56.4	29.9	45.9	40.3	74.6
MOISTURE CONTENT	4.6%	7.9%	28.2%	16.8%	17.1%

TIN NO.	RD27	LA38	LA47	RD22	LA63
BOREHOLE NO.	BH14-8	BH14-8	BH14-8	BH14-8	BH14-8
SAMPLE & DEPTH	SS3 / 1.5-2.1m	SS4 / 2.3-2.9m	SS5 / 3.0-3.7m	SS6 / 4.6-5.2m	SS7 / 6.1-6.7m
WT of TIN & WET SOIL (g)	76.7	100.5	89.9	97.9	123.1
WT of TIN & DRY SOIL (g)	67.6	87.1	76.4	75.5	108.2
WT of WATER (g)	9.1	13.4	13.5	22.4	14.9
TARE WT (g)	28.4	28.1	28.1	28.3	27.8
WT of DRY SOIL (g)	39.2	59.0	48.3	47.2	80.5
MOISTURE CONTENT	23.2%	22.7%	28.0%	47.4%	18.5%

TIN NO.	TR9	TR8	LA10	BN3	RD2
BOREHOLE NO.	BH14-8	BH14-8	BH14-9	BH14-9	BH14-9
SAMPLE & DEPTH	SS8 / 7.6-8.2m	SS9 / 9.1-9.8m	SS1 / 0-0.6m	SS2 / 0.8-1.4m	SS3 / 1.5-2.1m
WT of TIN & WET SOIL (g)	124.8	76.7	86.9	129.2	97.0
WT of TIN & DRY SOIL (g)	115.6	75.2	79.8	112.9	83.5
WT of WATER (g)	9.2	1.5	7.1	16.3	13.5
TARE WT (g)	27.4	28.1	28.8	28.8	27.7
WT of DRY SOIL (g)	88.2	47.1	51.1	84.1	55.8
MOISTURE CONTENT	10.4%	3.1%	13.9%	19.4%	24.1%

TIN NO.	RD7	LA70	RD12	RD29	RD25
BOREHOLE NO.	BH14-9	BH14-9	BH14-9	BH14-9	BH14-9
SAMPLE & DEPTH	SS4 / 2.3-2.9m	SS5 / 3.0-3.7m	SS6 / 4.6-5.2m	SS7 / 6.1-6.7m	SS8 / 7.6-8.2m
WT of TIN & WET SOIL (g)	99.9	104.8	123.5	159.6	152.2
WT of TIN & DRY SOIL (g)	81.0	79.3	97.1	141.8	143.0
WT of WATER (g)	18.9	25.5	26.3	17.8	9.2
TARE WT (g)	28.5	27.9	28.2	28.5	27.8
WT of DRY SOIL (g)	52.6	51.4	68.9	113.3	115.2
MOISTURE CONTENT	35.9%	49.7%	38.2%	15.7%	8.0%

TIN NO.	TR4	TR6	BN5		
BOREHOLE NO.	BH14-9	BH14-9	BH14-9		
SAMPLE & DEPTH	SS9 / 9.1-9.8m	SS10 / 10.7-11.2m	SS11A / 12.2-12.8m		
WT of TIN & WET SOIL (g)	141.9	109.0	82.2		
WT of TIN & DRY SOIL (g)	133.3	103.1	78.1		
WT of WATER (g)	8.6	5.9	4.0		
TARE WT (g)	28.0	27.4	28.1		
WT of DRY SOIL (g)	105.3	75.7	50.1		
MOISTURE CONTENT	8.2%	7.8%	8.1%		





## MOISTURE CONTENTS

**Project Location:** West Whitby Sanitary Sewer Trunk  
**File No.:** 141-15350-00

**Tech:** MLM  
**Date:** 22-Jan-15

TIN NO.	K8	AT6-2	TR27	LN25	AT51
BOREHOLE NO.	BH14-3	BH14-3	BH14-3	BH14-3	BH14-3
SAMPLE & DEPTH	SS1/0.8-1.2	SS2/1.5-2.0	SS3/2.3-2.7	SS5/4.6-5.0	SS6/6.1-6.6
WT of TIN & WET SOIL (g)	83.8	70.4	72.5	74.9	74.4
WT of TIN & DRY SOIL (g)	67.4	58.3	57.2	72.2	70.9
WT of WATER (g)	16.4	12.1	15.4	2.7	3.6
TARE WT (g)	15.1	14.5	14.9	15.0	14.6
WT of DRY SOIL (g)	52.4	43.8	42.3	57.2	56.3
MOISTURE CONTENT	31.3%	27.6%	36.3%	4.8%	6.4%

TIN NO.	CS19	A67	RJ19	SA13B	JB1
BOREHOLE NO.	BH14-3	BH14-4	BH14-4	BH14-4	BH14-4
SAMPLE & DEPTH	SS7/7.6-8.1	SS1/0.8-1.2	SS2/1.5-2.0	SS3/2.3-2.7	SS4/3.0-3.5
WT of TIN & WET SOIL (g)	84.8	61.1	81.4	81.1	75.2
WT of TIN & DRY SOIL (g)	80.0	53.0	66.1	72.1	68.9
WT of WATER (g)	4.8	8.2	15.4	8.9	6.3
TARE WT (g)	14.9	14.6	15.1	14.8	15.3
WT of DRY SOIL (g)	65.1	38.3	51.0	57.4	53.6
MOISTURE CONTENT	7.4%	21.3%	30.1%	15.6%	11.8%

TIN NO.	BE31	LG12	MX6	IL-16	B3
BOREHOLE NO.	BH14-4	BH14-4	BH14-4	BH14-10	BH14-10
SAMPLE & DEPTH	SS5/4.6-5.0	SS6/6.1-6.6	SS7/7.6-8.1	SS1/0.8-1.2	SS2/1.5-2.0
WT of TIN & WET SOIL (g)	73.6	77.1	75.1	71.7	88.8
WT of TIN & DRY SOIL (g)	69.7	74.5	71.2	67.5	85.8
WT of WATER (g)	3.8	2.7	3.9	4.1	3.0
TARE WT (g)	14.6	15.2	14.6	15.2	14.7
WT of DRY SOIL (g)	55.1	59.3	56.6	52.3	71.1
MOISTURE CONTENT	7.0%	4.5%	6.9%	7.9%	4.2%

TIN NO.	WRT19	ACC75	JB17		
BOREHOLE NO.	BH14-10	BH14-10	BH14-10		
SAMPLE & DEPTH	SS3/2.3-2.7	SS4/3.0-3.5	SS5/4.6-5.0		
WT of TIN & WET SOIL (g)	78.8	73.1	70.8		
WT of TIN & DRY SOIL (g)	74.3	69.8	66.4		
WT of WATER (g)	4.4	3.3	4.3		
TARE WT (g)	14.6	15.1	15.1		
WT of DRY SOIL (g)	59.8	54.8	51.3		
MOISTURE CONTENT	7.4%	5.9%	8.4%		

TIN NO.					
BOREHOLE NO.					
SAMPLE & DEPTH					
WT of TIN & WET SOIL (g)					
WT of TIN & DRY SOIL (g)					
WT of WATER (g)					
TARE WT (g)					
WT of DRY SOIL (g)					
MOISTURE CONTENT					



# Appendix C

POINT LOAD TEST RESULTS AND PHOTOGRAPHS

# Point Load Test Data ASTM D5731-08

Project: West Whitby Sewer Trunk  
Tested By: LEK/KC  
Test Device: RocTest PIL-7  
Date: 1/29/2015

Project No.: 141-15350-00  
A<sub>s</sub> of piston m<sup>2</sup>: 0.000948  
Calibrated: 7/16/2014



Sample Details: Air Dried - tested in Laboratory

Sample ID				Data			Calculation						
Borehole Number	BH Depth Start (m)	BH Depth End (m)	Test Type (See Note)	Core Length, (mm)	Diameter (D' at failure) (mm)	Max Pressure (kPa)	Load (P) (kN)	D <sub>s</sub> <sup>2</sup> (m <sup>2</sup> )	D <sub>s</sub> (mm)	I <sub>s</sub> (MPa)	F= (D <sub>s</sub> /0.05) <sup>0.45</sup>	I <sub>s(50)</sub> (MPa)	Approximate UCS (MPa) Table 1
BH14-1	18.67	1.93	a	47	23.5	2880	2.73	1406.29	37.50	1.94	0.879	1.71	36
BH14-2	18.05	18.08	a	47	34	6320	5.99	2034.64	45.11	2.94	0.955	2.81	59
BH14-2	17.17	17.20	a	47	29	1860	1.76	1735.43	41.66	1.02	0.921	0.94	20
BH14-3	15.52	15.54	a	62	26	10840	10.28	2052.46	45.30	5.01	0.957	4.79	117
BH14-14	15.27	15.29	a	62	9	520	0.49	710.47	26.65	0.69	0.753	0.52	13
BH14-5	18.29	18.36	a	47	18	3980	3.77	1077.16	32.82	3.50	0.827	2.90	61
BH14-6	18.49	18.52	a	47	18.5	320	0.30	1107.08	33.27	0.27	0.833	0.23	5
BH14-7	17.91	17.93	a	47	31.5	700	0.66	1885.03	43.42	0.35	0.938	0.33	7
BH14-8	19.18	19.20	a	47	22	10000	9.48	1316.53	36.28	7.20	0.866	6.23	131
BH14-9	18.42	18.44	a	47	26	6060	5.74	1555.90	39.44	3.69	0.899	3.32	70

Notes:  
d= diametral  
a= axial  
b= block  
i= irregular

Statistics  
Mean I<sub>s(50)</sub>/Axial 2.38

Axial, Block, Irregular samples D<sub>s</sub><sup>2</sup>=4(WD)/3.14

# Point Load Test Data ASTM D5731-08

Project: West Whitby Sewer Trunk  
Tested By: LEK/KC  
Test Device: RocTest PIL-7  
Date: 1/29/2015

Project No.: 141-15350-00  
A<sub>p</sub> of piston m<sup>2</sup>: 0.000948  
Calibrated: 7/16/2014



Sample Details: Air Dried - tested in Laboratory

Sample ID				Data			Calculation						
Borehole Number	BH Depth Start (m)	BH Depth End (m)	Test Type (See Note)	Core Length, (mm)	Diameter (D' at failure) (mm)	Max Pressure (kPa)	Load (P) (kN)	D <sub>s</sub> <sup>2</sup> (m <sup>2</sup> )	D <sub>s</sub> (mm)	I <sub>s</sub> (MPa)	F = (D <sub>s</sub> /0.05) <sup>0.45</sup>	I <sub>s(50)</sub> (MPa)	Approximate UCS (MPa) Table 1
BH14-1	18.69	18.76	d	66.91	42	2440	2.313	1.76	42	1.31	0.925	1.21	25
BH14-2	18.05	18.08	d	184	43	180	0.171	1.85	43	0.09	0.934	0.09	2
BH14-2	17.04	17.20	d	150	42.5	360	0.341	1.81	42.5	0.19	0.929	0.18	4
BH14-3	15.52	15.74	d	218	58.5	6700	6.352	3.42	58.5	1.86	1.073	1.99	49
BH14-14	15.27	15.34	d	invalid	invalid	invalid							
BH14-5	18.29	18.36	d	81.88	43.5	200	0.190	1.89	43.5	0.10	0.939	0.09	2
BH14-6	18.49	18.67	d	173	43	500	0.474	1.85	43	0.26	0.934	0.24	5
BH14-7	17.91	18.07	d	167	42.5	820	0.777	1.81	42.5	0.43	0.929	0.40	8
BH14-8	19.18	19.28	d	102.47	44	2440	2.313	1.94	44	1.19	0.944	1.13	24
BH14-9	18.42	18.59	d	175	43	360	0.341	1.85	43	0.18	0.934	0.17	4

Notes:  
d= diametral  
a= axial  
b= block  
i= irregular

Statistics	
Mean I <sub>s(50)</sub> Diametral	0.61



# Point Load Test Data ASTM D5731-08



Project:  
Tested By:  
Test Device: RocTest PIL-7  
Date:

Project No.:  
  
A<sub>p</sub> of piston m<sup>2</sup> 0.000948  
Calibrated: 7/16/2014

Sample Details: Air Dried - tested in Laboratory

Sample ID				Data			Calculation						
Borehole Number	BH Depth Start (m)	BH Depth End (m)	Test Type (See Note)	Core Length, (mm)	Diameter (D' at failure) (mm)	Max Pressure (kPa)	Load (P) (kN)	D <sub>a</sub> <sup>2</sup> (m <sup>2</sup> )	D <sub>a</sub> (mm)	I <sub>s</sub> (MPa)	F= (D <sub>a</sub> /0.05) <sup>0.45</sup>	I <sub>s(50)</sub> (MPa)	Approximate UCS (MPa) Table 1
BH14-3	16.54	16.61	d	89	59	1640	1.555	3.48	59	0.45	1.077	0.48	12
BH14-4	16.33	0.00	d	120	59	440	0.417	3.48	59	0.12	1.077	0.13	3
BH14-10	16.46	0.00	d	112	59	260	0.246	3.48	59	0.07	1.077	0.08	2

Notes:  
d= diametral  
a= axial  
b= block  
i= irregular

Statistics	
Mean I <sub>s(50)</sub> Diametral	0.23

# Point Load Test Data ASTM D5731-08



Project: West Whitby Sewer Trunk  
Tested By: LEK  
Test Device: RocTest PIL-7  
Date: 2/6/2015

Project No.: 141-15350-00  
A<sub>p</sub> of piston m<sup>2</sup>: 0.000948  
Calibrated: 7/16/2014

Sample Details: Air Dried - tested in Laboratory

Sample ID				Data			Calculation						
Borehole Number	BH Depth Start (m)	BH Depth End (m)	Test Type (See Note)	Core Length (mm)	Diameter (D' at failure) (mm)	Max Pressure (kPa)	Load (P) (kN)	D <sub>s</sub> <sup>2</sup> (m <sup>2</sup> )	D <sub>s</sub> (mm)	I <sub>s</sub> (MPa)	F = (D <sub>s</sub> /0.05) <sup>0.45</sup>	I <sub>s(50)</sub> (MPa)	Approximate UCS (MPa) Table 1
BH14-3	16.54	0.00	a	62	20	7200	6.83	1578.82	39.73	4.32	0.902	3.90	96
BH14-4	16.33	0.00	a	62	23	6900	6.54	1815.64	42.61	3.60	0.931	3.35	82
BH14-10	16.46	0.00	a	62	26.5	10660	10.11	2091.93	45.74	4.83	0.961	4.64	114

Notes:  
d= diametral  
a= axial  
b= block  
i= irregular

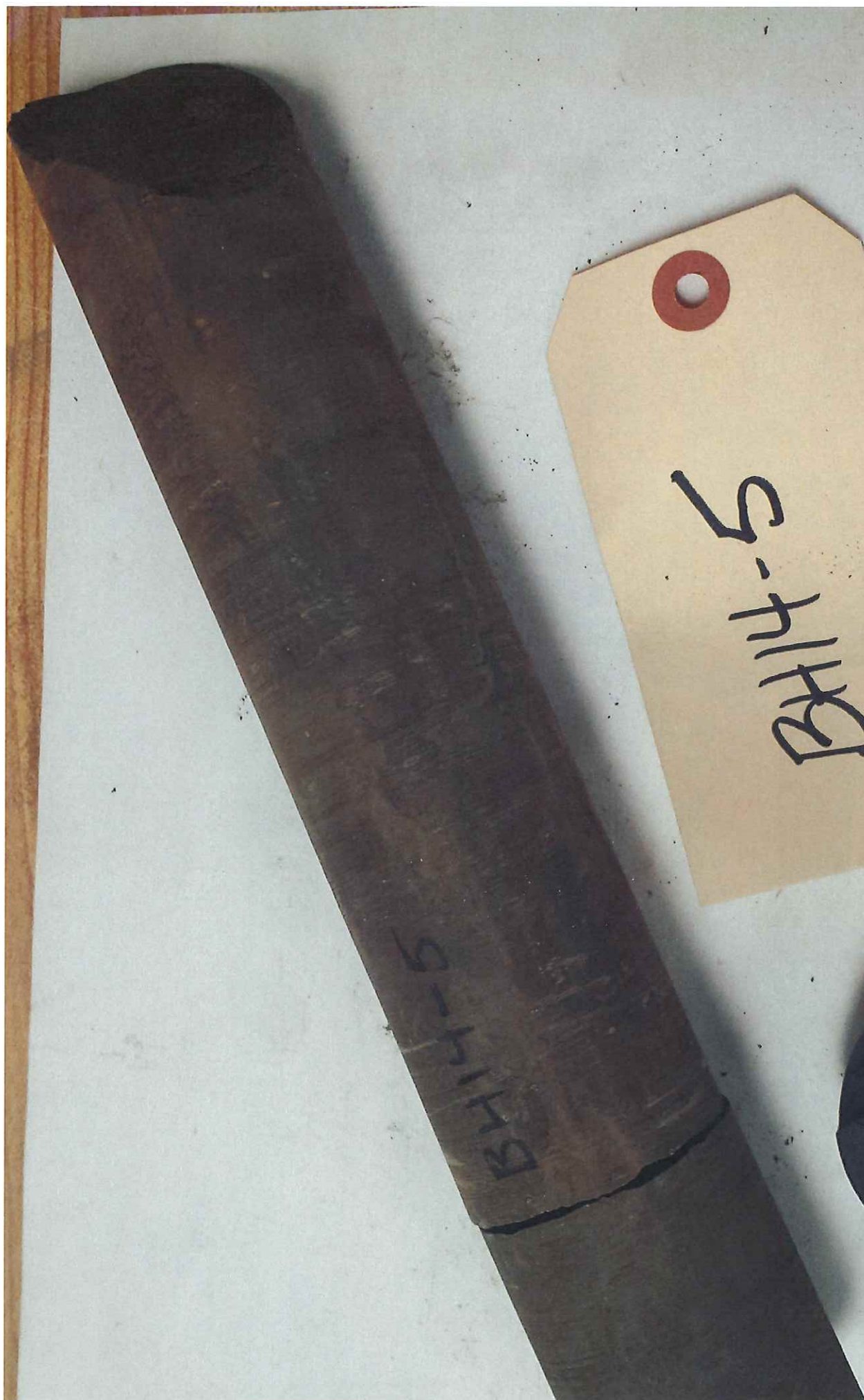
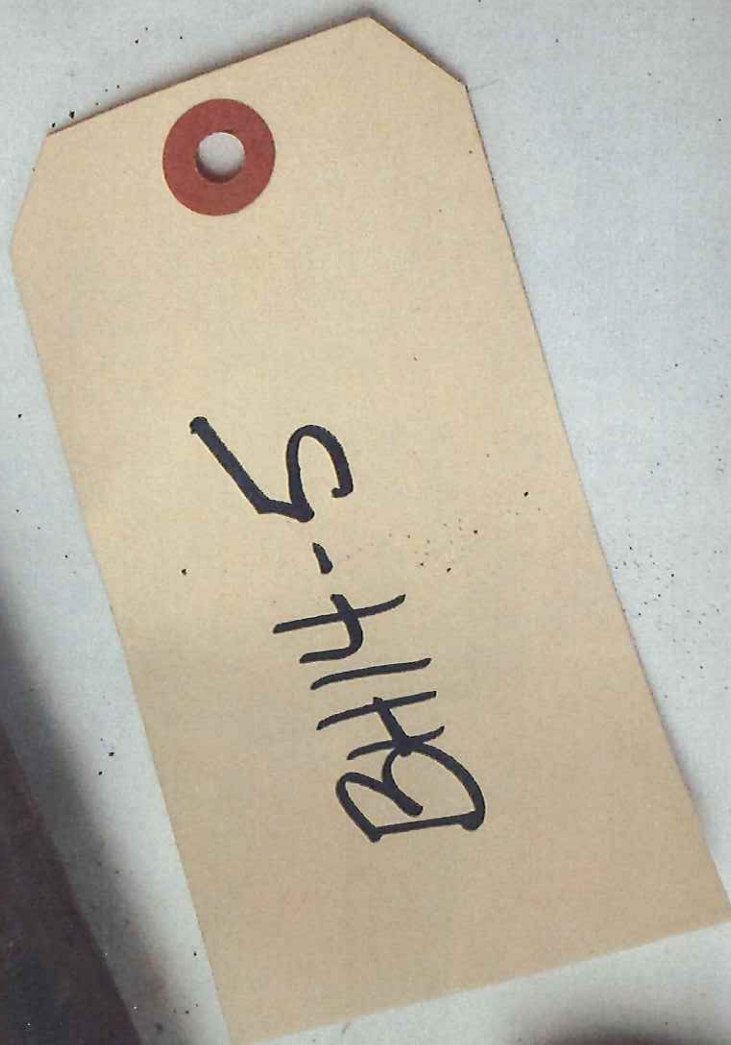
Statistics	
Mean Is(50) Axial	3.96

Axial, Block, Irregular samples D<sub>s</sub><sup>2</sup>=4(WD)/3.14

BH14-4







# Appendix D

CORE PHOTOS



Foundation Investigation and Design Report for Tunneling  
West Whitby Sanitary Sewer – Durham Region, Ontario  
CORE PHOTOS



Photograph 1: Core Samples BH14-4 (43 – 52 ft depth).



Photograph 2: Core Samples BH14-5 (55 – 70 ft depth).



# Appendix E

**HMM PEER REVIEW OF PROPOSED TRUNK SANITARY SEWER  
CROSSING OF HIGHWAY 401 WHITBY, ONTARIO**

**WSP Canada Inc.  
High-Complexity Tunneling Review  
(RAQS Review Report)**

**Review of Proposed West Whitby Trunk Sanitary Sewer - Durham  
Region, Ontario**

Issue and Revision Record					
Rev	Date	Originator (Print) (Signature)	Checker (Print) (Signature)	Approver (Print) (Signature)	Description
0	2015-09-25	C. Cosby	R. Shobayry M. Gelinas	G. Kramer	Issue for Use
1	2015-12-22	C. Cosby	R. Shobayry	G. Kramer	Issued with Two Seals
	<b>Signatures:</b>				



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### APPENDICES:

Appendix A - Project Drawings

Appendix B - Crossing Design Calculations



## **1. Introduction**

### **1.1 Project Overview**

The Regional Municipality of Durham (Region) proposes to undertake the construction of the West Whitby Trunk Sanitary Sewer in Whitby, Ontario. The trunk sanitary sewer construction, which will be completed largely by tunnelling, will include a crossing of Highway 401 east of Lake Ridge Road South. The trunk sanitary sewer will be a gravity-flow sewer and will be 900mm in diameter at the crossing location. The crossing will be completed as part of an approximately 1080 metre-long tunnel drive, out of which approximately 210 metres will be beneath the Highway 401 right-of-way.

WSP Canada Inc. will prepare the contract documents for this project and have prepared a Foundation Investigation and Design Report (WSP, 2015) summarizing geotechnical investigations completed for the crossing as well as their recommendations regarding tunnel construction. Hatch Mott MacDonald (HMM), as a qualified consultant under Ministry of Transportation Ontario (MTO) Registry Appraisal and Qualification System (RAQS) for High Complexity Tunneling has been retained by WSP Canada Inc. to complete the following tasks:

1. Review geotechnical investigations completed for the planned crossing.
2. Confirm adequacy of geotechnical investigations for MTO RAQS requirements.
3. Review recommendations for tunnelling and support systems.
4. Estimate settlement associated with proposed tunnelling and shaft construction methods.
5. Assess potential impacts due to these settlements.
6. Provide recommendations for tunnelling methods and construction monitoring to be built into contract documents.
7. Prepare and seal this RAQS review report, which is to accompany the final WSP Foundation Investigation and Design Report for submission to MTO.
8. Review completed contract documents for compliance with the recommendations provided in this report.

Documents provided by WSP for HMM review include the following:

- Foundation Investigation and Design Report (FIDR), prepared by WSP and dated August, 2015.

### **1.2 Purpose**

The purpose of this report is to provide a review and assessment of the FIDR (WSP, 2015) prepared for the Proposed Trunk Sanitary Sewer Crossing for adequacy against MTO requirements for High Complexity Tunneling (tasks 1 through 3 outlined above).



This report also provides evaluations and recommendations, which in HMMs opinion as reviewers, must be incorporated into the FIDR (WSP, 2015) and/or contract documents (tasks 4 through 6 outlined above).

### **1.3 Project Constraints and Assumptions**

The evaluations contained in this report are based, in part, on the following project constraints and assumptions:

1. Closure of any portion of Highway 401 will not be permitted. As such, only trenchless construction methods will be considered for the Trunk Sanitary Sewer Crossing.

## **2. Review of Foundation Investigation Report**

Details of the geotechnical investigation and encountered geotechnical and groundwater conditions for the proposed crossing of Highway 401 are provided in Sections 3 and 4 of the FIDR (WSP, 2015), as summarized below.

### **2.1 Introduction Section**

In the introduction section of FIDR, the length of crossing under the Highway 401 and CNR corridors is identified as extending from project chainage 1+280 to 1+500 or approximately 220 m. While not explicitly detailed in the FIDR, it is understood that the crossing will be completed as part of an approximately 1080 metre-long tunnel drive.

### **2.2 Field Investigation**

The geotechnical investigation in the vicinity of the crossing consisted of three (3) boreholes drilled through the soil overburden and into bedrock. The borehole location plan and subsurface section from the FIDR (WSP 2015) is included as Appendix A.

The first borehole (BH14-4) is located 76 m north of Highway 401 edge of pavement. This borehole is located on the proposed tunnel alignment. This boring encountered bedrock at 9.8 m below ground level (mBGL) and was advanced to a depth of 24.4 mBGL. The Proposed Sewer invert is approximately 18.2 mBGL at this location.

The second borehole (BH14-10) is located 9 m south of Highway 401 edge of pavement and 12 m north of GO Transit rail road tracks. This borehole is located on the proposed tunnel alignment. This boring encountered bedrock at 8.6 mBGL and was advanced to a depth of 21.7 mBGL. The Proposed Sewer invert is approximately 18.3 mBGL at this location.

The final borehole (BH14-5) is located 71 m south of Highway 401 edge of pavement and 24 m south of CN Rail tracks. This borehole is located on the proposed tunnel alignment. This boring encountered bedrock at 13.7 mBGL and was advanced to a depth of 21.7 mBGL. The Proposed Sewer invert is approximately 18.9 mBGL at this location.

It is also noted that selected core samples of the shale bedrock from the above borings were noted to release a petroliferous odor.





Boreholes BH14-4, BH14-5, and BH14-10, as detailed above, are the borings most relevant to crossing under MTO right-of-way. However it is noted that additional borings, most notably boreholes BH14-3 and BH14-11 were completed as part of the investigation for those portions of the tunnel drive that extend outside of the MTO right-of-way. While not included in the FIDR, it is recommended that logs of borings BH14-3 and BH14-11 to be provided to bidding contractors as part of the contract documents.

The three borings detailed above (Borings BH14-4, BH14-5, and BH14-10) were completed relative to approximately 220 m of tunnelled crossing, which equates to an average borehole spacing of approximately 110 m. MTO requirements dictate that borehole spacing shall not exceed 50 m. However, as a result of consistent rock stratigraphy and ground conditions at the approximate tunnel elevation, it is felt that the number of borings completed is adequate, as additional boreholes would cause significant traffic disruptions.

## 2.3 Sampling and Laboratory Testing

Within the overburden, sampling consisting of Standard Penetration Tests (SPTs) was completed at 0.75 m to 1.5 m intervals. While MTO guidelines dictate that sampling and testing (SPT and field vane where appropriate) must be completed at 0.75 m intervals in overburden, given that the crossing will be well below the bedrock contact, the overburden sampling completed by WSP is considered adequate.

Laboratory testing was completed on selected overburden samples. The overburden laboratory testing consisted of 'Routine Test' as defined in Guidelines For Foundation Engineering - Tunnelling Specialty For Corridor Encroachment. This test includes natural water content, Atterberg limits and grain size distribution.

Within bedrock, sampling consisted of continuous coring which is consistent with MTO requirements. The FIDR (WSP, 2015) provides a quantitative and qualitative description of the bedrock conditions at the borehole locations, including RQD, axial UCS values, and diametral UCS values. RQD values are shown on the subsurface profiles (Figure 2 and 3) of the FIDR (WSP, 2015). A basic description and the point load test results is also given in the FIDR (WSP, 2015).

It is understood that the borehole logs provided in the FIDR are presented in the format prescribed by MTO. This format is limited in the amount of data (specifically rock classification and index data) presented. HMM is advised that additional data is available and presented on the non-MTO format logs, which form part of the Geotechnical Data Report (GDR) which will be provided to bidding contractors.

HMM notes that sufficient geotechnical data should be supplied to the contractor in the GDR to enable the tunnel support designs. Ideally the additional information should include some or all of the items listed below:

- Descriptions of joint sets, if any, including joint directions, spacing and smoothness
- Uniaxial compressive strength of rock



- Rock Mass Rating (RMR) for each rock unit encountered
- Identification or recommendations for range of in-situ horizontal stresses at the elevation of the proposed Trunk Sanitary Sewer
- Recommendation on modulus of elasticity of intact rock or rock mass
- Pictures of recovered rock cores

### **3. Trenchless Construction Methods**

The FIDR (WSP, 2015), notes that the method of tunnelling should be the responsibility of the Contractor. However, the FIDR goes on to note that due to the diameter of the product pipe (900 mm) and the length of the installation (extending north of the 401 right-of-way), it is recommended that the trunk sanitary sewer be constructed using a Tunnel Boring Machine (TBM). WSP does not provide any further definition regarding the type of TBM or method of tunnel support.

HMM understands that the specification of TBM tunnelling for the MTO crossing was made in the context of the larger project, which will be completed predominantly by this method. However, HMM notes that the term "TBM tunnelling" can refer to many different forms of tunnelling, some of which may be appropriate in the context of the approximately 200 m long MTO crossing, but not in the context of the approximately 1,080 m long tunnel drive within which the crossing occurs. For this reason, it is felt that appropriate methods of tunnelling should be further specified with additional definition given regarding the type of tunnel boring machine(s) that can be used.

For example in HMM's opinion, the length of the tunnel drive precludes the use of methods such as traditional auger bore and jack tunnelling, and modified auger bore and jack tunnelling (e.g., the use of a Robbins Small Boring Unit or similar attachments). Pipe jacking methods such as microtunnelling, while technically possible, would involve significant risk for diameters smaller than 1.5 m, especially if attempted as a single-pass installation (i.e., direct installation of the 900 mm trunk sewer). TBM selection should also consider the need for rock-specific tooling on the cutterhead (disc cutters) as well as the potential for encountering gas, which will require ventilation of the tunnel.

HMM recommends that the contract documents should limit the type of TBM used by the contractor to those which:

1. Have provision for powering the cutterhead within the body of the TBM.
2. Be of new or newly refurbished construction, including new cutting tools and hard-facing on the cutterhead.
3. Be designed for excavation in bedrock similar to that encountered in the crossing borings.



4. Have the capability to replace worn tooling, including gage cutters, from within the TBM.
5. Use either slurry, rail cars or conveyor systems for the transport of muck from the tunnel face to the launch shaft. Auger-based systems (other than between the plenum chamber and the body of the TBM) should not be permitted.

TBMs may be self-propelled, or propelled by a jacking frame located in the launch shaft. If a TBM propelled by a jacking frame is used, the contract documents should require the contractor to estimate the minimum overcut, given the tendency for shale bedrock to swell and undergo time-dependent deformations during mining. The minimum overcut should be selected such that the mined tunnel will not converge onto the jacked pipe during installation.

## **4. Trunk Sanitary Sewer**

### **4.1 Trunk Sewer Alignment Geotechnical Conditions**

The Proposed Trunk Sewer alignment will be entirely within the shale and siltstone bedrock formations as reported in the FIDR (WSP 2015).

It is reiterated that the descriptions of geotechnical conditions currently provided in the FIDR are too limited for meaningful analysis, and recommends that additional data, that understood to be available but not shown in FDIR, to be provided in the contract documents. Specifically, given that the tunnel will be mined solely in shale and siltstone bedrock, HMM believes data and descriptions provided in the logs of borings, as well as the narrative provided in the FIDR (WAP, 2015) regarding crossing bedrock conditions should be more detailed.

### **4.2 Launch and Reception Shafts**

As stated above, the crossing will be completed as part of an approximately 1,080 m long tunnel drive. Based on discussions with WSP, launch and reception shafts for this tunnel drive are understood to be sufficiently offset from the MTO right-of-way that construction of the shafts should not impact MTO facilities.

For clarity, it is recommended that the location of the complete tunnel alignment, including shafts, be provided in the FIDR.

### **4.3 Loading Conditions**

It is understood that WSP intends to leave the design of the Trunk Sanitary Sewer Tunnel initial and final support to the Contractor. Section 9.4 - Temporary and Final Support of the FIDR (WSP 2015) states that a tunnel excavated through the bedrock formation will be stable provided that full support is immediately installed at and behind the excavation face. It is also stated that there is a preferential weakness in the horizontal orientation that will facilitate fracturing and allow groundwater migration along the alignment. The FIDR recommends that the annulus between the liner and the bedrock should be grouted using a compressible material. The FIDR also suggests that the design of the liner consider the swelling of the shale bedrock.

Section 7.2 - Earth Pressure Distribution of the Tunnelling Method of the FIDR (WSP 2015) has provided vertical ground stress and suggested use of all-round pressure equal to vertical ground stress for the design of initial and permanent support. In HMM's opinion in-situ





horizontal stresses should also be presented for the case where segmental lining is selected as the support system.

#### **4.4 Impacts Due to Tunnelling**

The primary impacts anticipated for the proposed crossing of Highway 401 include the potential for ground loss and settlement-related damage to the highway surface. HMM used methodology from 'Ground movements resulting from urban tunnelling: predictions and effects' (Rankin, 1988) to estimate potential settlement due to tunnelling, which are presented in Appendix B.

It is assumed that the bedrock will remain intact, though for the purposes of these calculations it will be treated as a stiff soil to achieve a conservative estimate for total settlement.

In the analysis presented in Appendix B, HMM assumed a mined diameter of 2.4 m that will consist of a tunnel lining with the reinforced concrete pipe inside. With good tunnel construction workmanship, HMM anticipates that settlements due to trunk sanitary sewer tunnelling, as measured above the trunk sanitary sewer, will be less than 9 mm.

### **5. Settlement Monitoring**

In the FIDR (WSP, 2015), WSP has specified the location of surface monitoring points. Although the spacing of settlement monitoring points does not meet the maximum 5.0 m spacing required by MTO guidelines, it is HMM's opinion that proposed arrangement of settlement monitoring points should provide reasonable indication of achieved settlement. The proposed frequency of readings meets the requirement of MTO guidelines.

### **6. Conclusions and Recommendations**

HMM has completed their review of the FIDR (WSP, 2015) and proposes the following modifications to the report and/or contract documents:

- The introduction section to clearly identify the total length of the planned underground crossing from station 1+280 to 2+360, not just Highway 401 and CNR corridor, as this understanding significantly impacts appropriate methods of construction.
- In addition to boreholes BH14-4, BH14-5, and BH14-10, which are within/immediately adjacent to the Highway 401 and CNR crossing, it is recommended that boreholes logs of BH14-3 and BH14-11 be provided as part of the contract documents.
- It is understood that the provided borehole logs are limited to the format as used by MTO and that additional geotechnical information is available that is not shown on the borehole logs. Any available geotechnical information not shown on the FDIR should be included in the contract documents, whether as part of a revised FDIR or as a separate Geotechnical Data Report (GDR).
- For clarity, locations of the complete tunnel alignment and shafts should be shown on the subsurface profile and drawings.





- Specify range of in-situ horizontal stresses in the identified rock formations. This information is required for design of segmental lining.
- TBM selection should consider the need for rock-specific tooling on the cutterhead (disc cutters) as well as the potential for encountering gas, which will require ventilation of the tunnel.
- HMM recommends that the contract documents should limit the type of TBM used by the contractor to those which:
  1. Have provision for powering the cutterhead within the body of the TBM.
  2. Be of new or newly refurbished construction, including new cutting tools and hard-facing on the cutter wheel.
  3. Be designed for excavation in bedrock similar to that encountered in the crossing borings.
  4. Have the capability to replace worn tooling, including gage cutters, from within the TBM.
  5. Use either slurry, rail cars or conveyor systems for the transport of muck from the tunnel face to the launch shaft. Auger-based systems (other than between the plenum chamber and the body of the TBM) should not be permitted.
- TBMs may be self-propelled, or propelled by a jacking frame located in the launch shaft.
- If a TBM propelled by a jacking frame is used, the contract documents should require the contractor to estimate the minimum overcut, given the tendency for shale bedrock to swell and undergo time-dependent deformations during mining. The minimum overcut should be selected such that the mined tunnel will not converge onto the jacked pipe during installation.



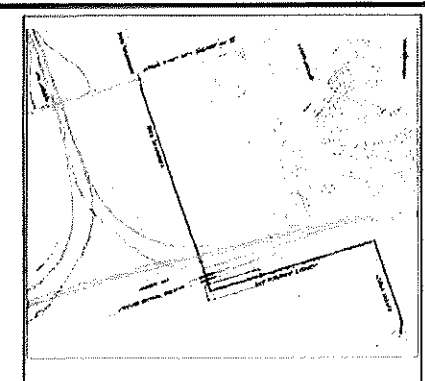
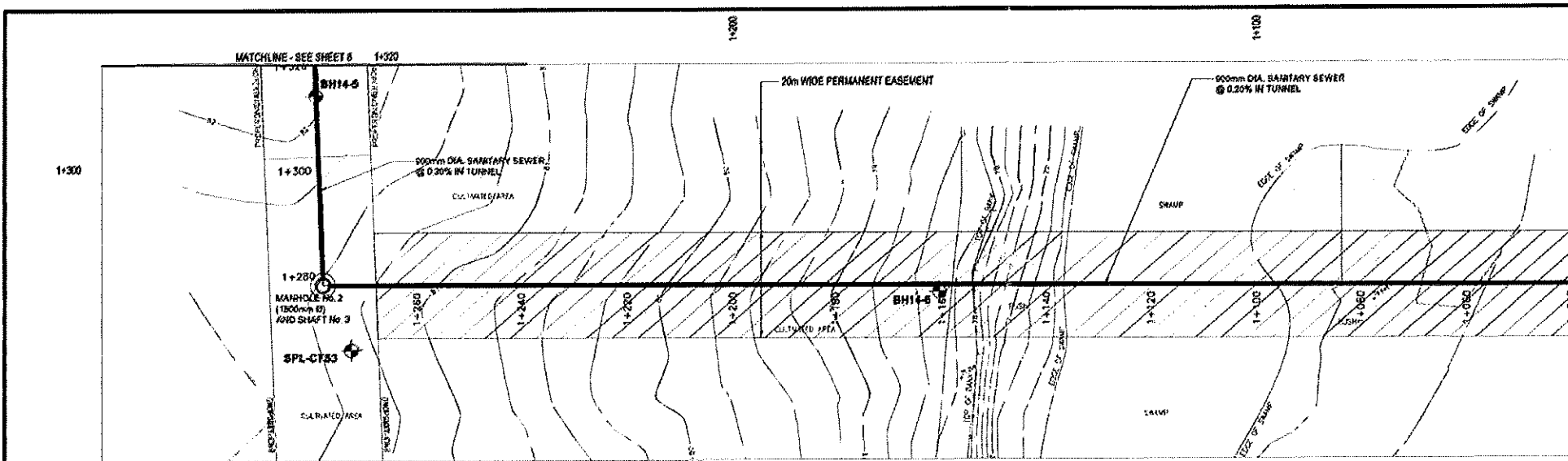
**Hatch Mott  
MacDonald**

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WSP Canada Inc. - High-Complexity Tunneling Review  
Review of Proposed West Whitby Trunk Sanitary Sewer - Durham Region, Ontario - September 25, 2015

# **Appendix A**

## **Project Drawings**

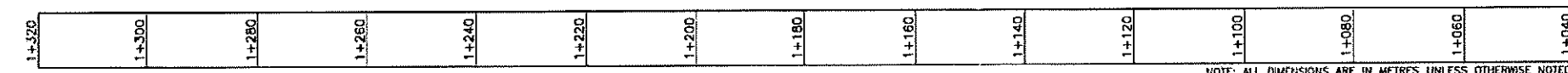
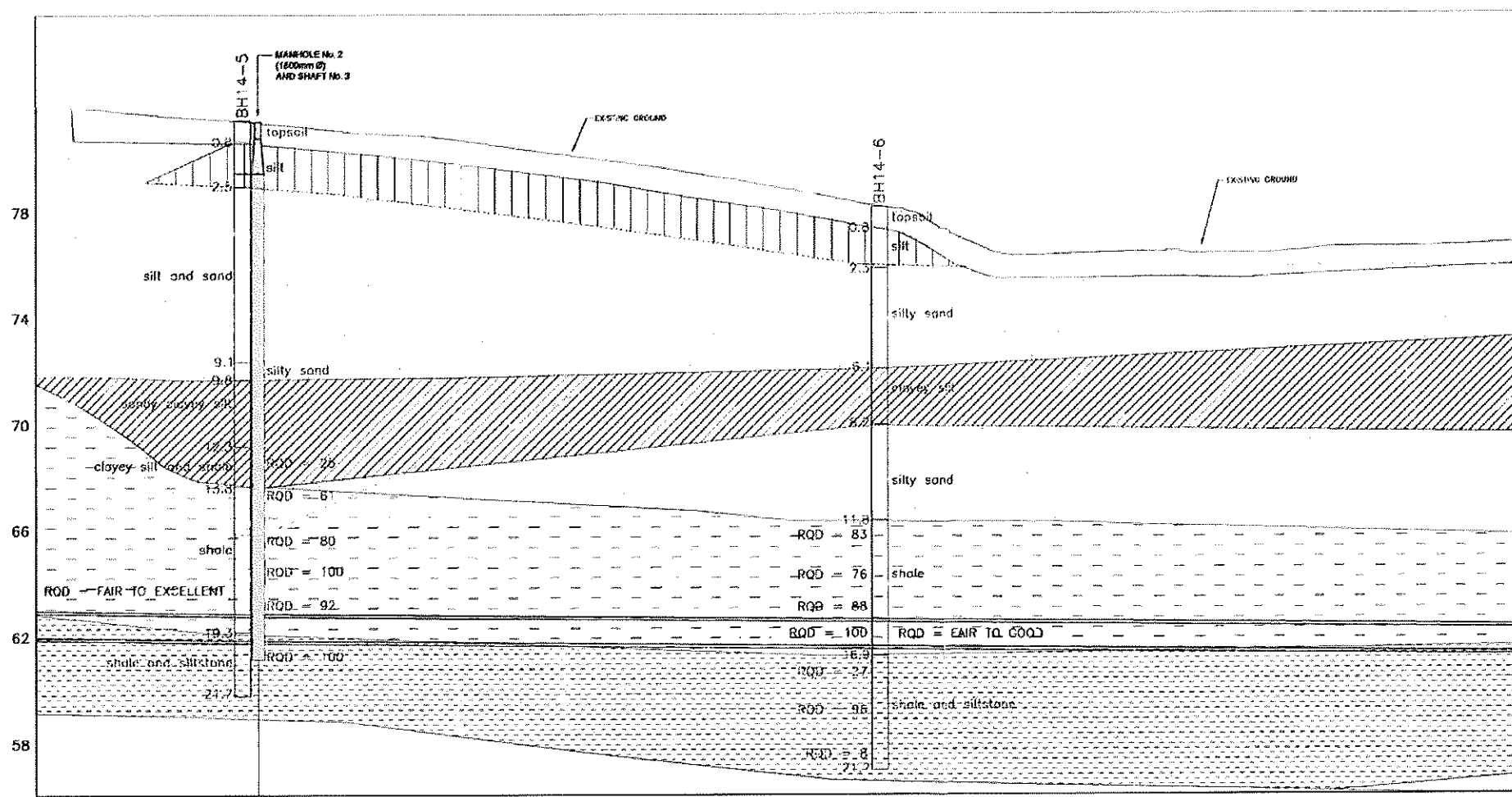
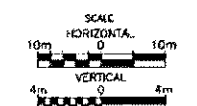


### LEGEND / INFERRED STRATIGRAPHY

- SOIL**
- TOPSOIL
  - PRESUMED FILL
  - SAND AND SILT
  - CLAY AND SILT
  - SILT
  - SAND AND GRAVEL
- ROCK**
- SHALE AND SILTSTONE
  - SHALE
  - SHALEY LIMESTONE
- INFERRED GROUNDWATER LEVEL

### NOTES:

1. THE ACTUAL SOIL STRATIFICATION HAS BEEN VERIFIED FROM DATA OBTAINED AT THE TEST LOCATIONS ONLY. THE INTERPOLATED CONTACTS SHOWN ARE INFERRED BASED ON GEOLOGICAL EVIDENCE AND PRINCIPLES OF SEQUENCE STRATIGRAPHY. AS SUCH, THE EXISTING CONTACTS MAY VARY FROM THOSE SHOWN HERE.
2. THE GROUNDWATER LEVELS INDICATED ARE DERIVED FROM WELLS SCREENS SET IN THE BEDROCK AND AS SUCH REFLECT HEADPRESSURES. GROUNDWATER LEVELS INDICATED MAY NOT EXIST AS GROUNDWATER IN THE SOILS ABOVE THE BEDROCK.



Q OF  
CONSTRUCTION  
CHAINAGE

NOTE: ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.

### SUBSURFACE PROFILE

GEOTECHNICAL INVESTIGATION  
WEST WHITBY TRUNK SANITARY  
SEWER  
Whitby, Ontario  
For The Regional Municipality of Durham

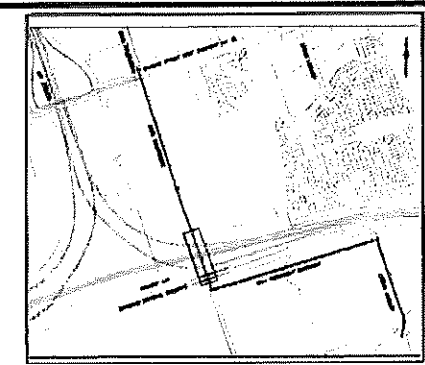
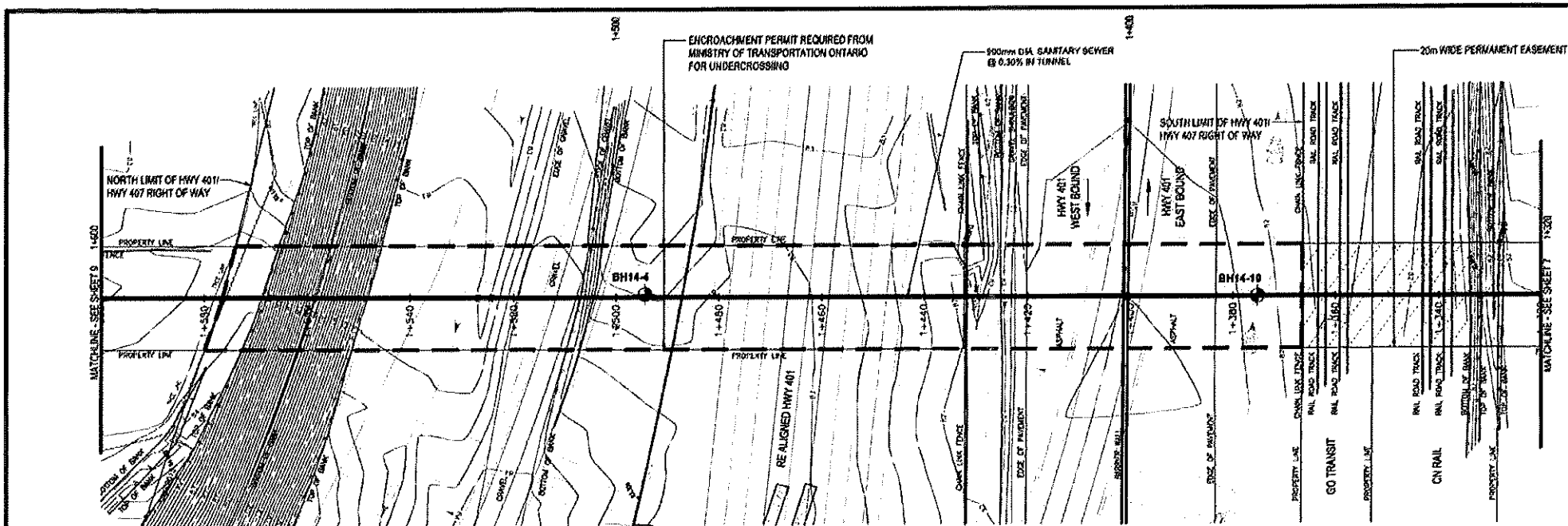
DATE: AUGUST 2011  
PROJECT: 101-1120-00  
SCALE: AS SHOWN  
FIG. NO: 101-1120-00-02

**WSP**

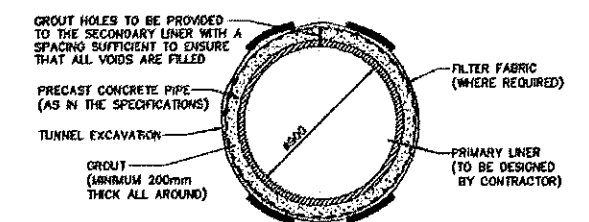




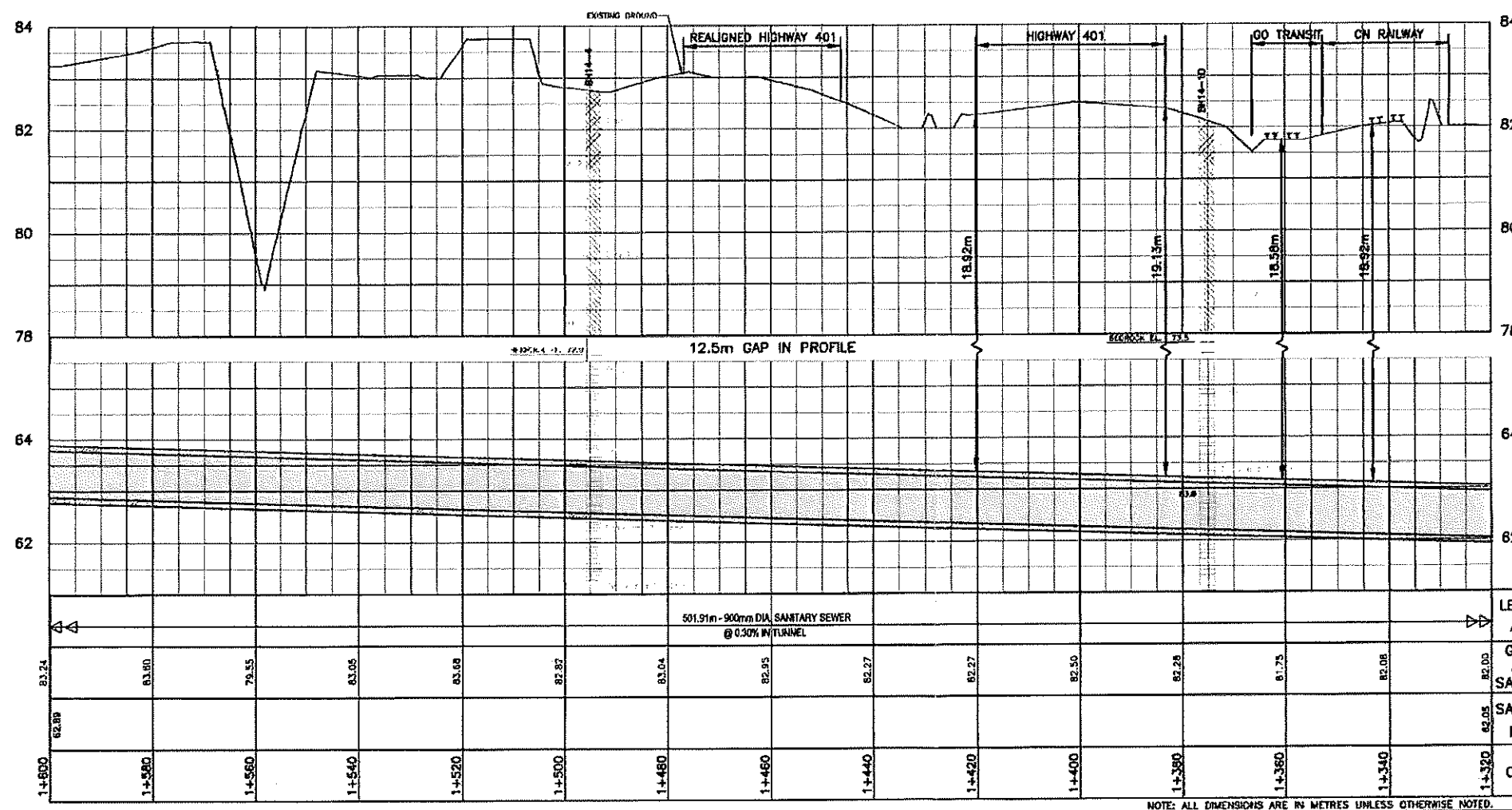
NOTE: ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED



- GENERAL NOTES:**
1. CHAINAGES ON THE DRAWINGS RELATE TO CENTRE LINE CHAINAGES OF THE SANITARY SEWER.
  2. 1200mm/900mm SANITARY SEWER SHALL BE CONCRETE PRESSURE PIPE.
  3. SANITARY SEWER AND APPURTENANCES SHALL BE IN ACCORDANCE WITH REGION OF DURHAM MATERIAL SPECIFICATIONS FOR SANITARY AND APPURTENANCES.
  4. BEDDING AND COVER MATERIAL FOR SANITARY SEWER SHALL CONFORM TO REGION OF DURHAM STANDARD.
  5. NATIVE BACKFILL MATERIAL TO BE COMPACTED TO A MINIMUM OF 95% S.P.D.
  6. ALL DISTURBED AREAS TO BE RESTORED WITH 100mm DEPTH OF TOPSOIL AND HYDRO-SEEDED.



**PRE-CAST TUNNEL SECTION DETAIL**  
N.T.S.



NOTE: ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.

1		14 11 10	CGS	ISSUED FOR CLIENT REVIEW
NO.	DATE	NAME	REVISIONS	
LOCATION APPROVAL				
MUNICIPALITY OF WHITBY			XXXX XX XX	
UTILITIES VERIFIED				
CABLE T.V. BELL CANADA ENBRIDGE				
CONTRACTOR TO BE RESPONSIBLE FOR LOCATION OF ALL EXISTING U/G & OVERHEAD UTILITIES. VARIOUS UTILITIES REQUIRE ADVANCE NOTICE PRIOR TO DIGGING, FOR STAKE OUT. THE REGION ASSUMES NO RESPONSIBILITY FOR THE ACCURACY OF THE LOCATION OF EXISTING UTILITIES AS INDICATED ON THIS DRAWING.				
		SURVEY DATA DATE 2014 06 01		
		SCALE HORIZONTAL 10m VERTICAL 1m		
DRAWN: A.V. DESIGNED: CGS CHECKED: J.L. APPROVED: CGS	DATE: 2014 11 DATE: 2014 11 DATE: 2014 11 DATE: 2014 11			
<b>THE REGIONAL MUNICIPALITY OF DURHAM</b> WORKS DEPARTMENT WHITBY ONTARIO				
<b>WEST WHITBY TRUNK SANITARY SEWER</b> <b>PLAN AND PROFILE</b> <b>FROM ST. 1+320 TO ST. 1+800</b>				
CONCESSION	REG. NO.	AREA MUNICIPALITY		FIGURE
—	—	WHITBY		4
DRAWING NUMBER		CONTRACT NUMBER		
X-XX-SW-006		XXXX-XX		



Hatch Mott  
MacDonald

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WSP Canada Inc. - High-Complexity Tunneling Review  
Review of Proposed West Whitby Trunk Sanitary Sewer - Durham Region, Ontario - September 25, 2015

## **Appendix B**

### **Closing Design Calculation**



# CALCULATION SHEET

SHEET NO.

DESCRIPTION

**High Complexity Tunnelling RAQ  
Settlement Estimate - Sewer**

PROJECT NO.

**358397**

MADE BY

**CC**

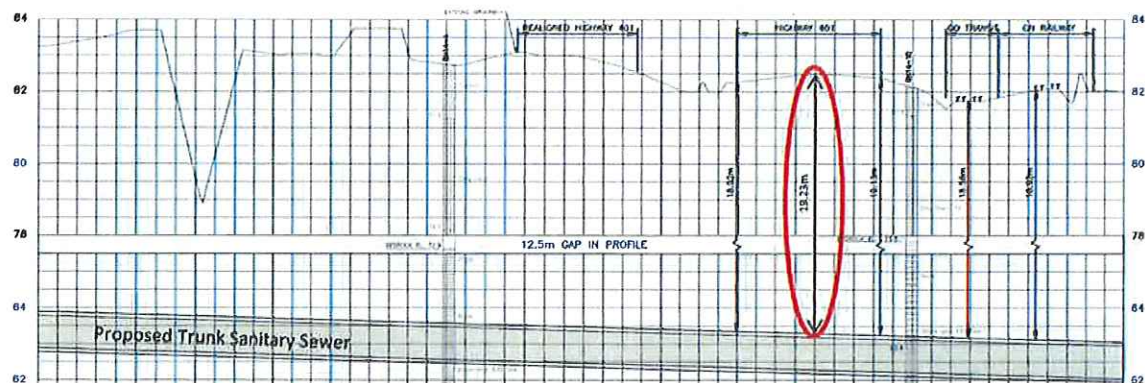
DATE 11-Sep-2015

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## 1.0 Calculation Purpose

The purpose of this calculation sheet is to estimate the ground surface settlement due to the proposed 900 mm Trunk Sewer tunnel crossing Ontario Highway 401. The critical location for settlement is estimated to be at the centre of the highway.



## 2.0 Engineering Assumptions and Tunnel Parameters

Description	Symbol	Value	Units	Notes
Tunnel Springline Depth	$z_0$	20.7	m	19.23m cover + diameter + 150mm liner
Tunnel Outside Diameter	$D_0$	2.40	m	2.4 m tunnel diameter for 900mm sewer
Ground Characterization, min	$K_{min}$	0.40		WSP Foundation Investigation
Ground Characterization, max	$K_{max}$	0.60		O'Reilly, New (1982), Glacial Deposits
Volume Loss, min	$V_{Lmin}$	1.00	%	WSP Foundation Investigation
Volume Loss, max	$V_{Lmax}$	4.00	%	O'Reilly, New (1982), Glacial Deposits

## 3.0 Equations

Trough Width Parameter:  $i_y = K \times z_0$

Maximum Settlement:  $w_{max} = \frac{0.125 \times V_L \times [D_0/2]^4}{i_y}$

Vertical Settlement Profile:  $w = w_{max} \times \exp\left(-\frac{y^2}{2i_y^2}\right)$

## 4.0 Trough Width Parameter

Settlement and ground movements associated with a single tunnel appear as a Gaussian curve shaped trough at the ground surface centred above the tunnel centreline. The shape of the settlement trough depends on the trough width parameter.

Case 1 and 3:  $K_{min}$ 

$$K = 0.40$$

$$i_y = 8.29$$

Case 2 and 4:  $K_{min}$ 

$$K = 0.60$$

$$i_y = 12.44$$

# CALCULATION SHEET

SHEET NO.

DESCRIPTION

**High Complexity Tunnelling RAQ  
Settlement Estimate - Sewer**

PROJECT NO.

**358397**

MADE BY

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DATE 11-Sep-2015

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DATE

## 5.0 Estimated Settlement

Maximum vertical displacements:

where  $V_L$  = Volume Loss  
 $K$  = Ground characterization  
 $D_0$  = Tunnel Springline Depth  
 $i_y$  = Trough width parameter ( $K \times z_0$ )  
 $w_{max}$  = maximum settlement

**Case 1:  $K_{min}$ ,  $V_{min}$** 
 $K = 0.40$   
 $V_L = 1.00$   
 $i_y = 8.29$ 
 $w_{max} = 2.2 \text{ mm}$ 
**Case 2:  $K_{max}$ ,  $V_{min}$** 
 $K = 0.60$   
 $V_L = 1.00$   
 $i_y = 12.44$ 
 $w_{max} = 1.4 \text{ mm}$ 
**Case 3:  $K_{min}$ ,  $V_{max}$** 
 $K = 0.40$   
 $V_L = 4.00$   
 $i_y = 8.29$ 
 $w_{max} = 8.7 \text{ mm}$ 
**Case 4:  $K_{max}$ ,  $V_{max}$** 
 $K = 0.60$   
 $V_L = 4.00$   
 $i_y = 12.44$ 
 $w_{max} = 5.8 \text{ mm}$ 

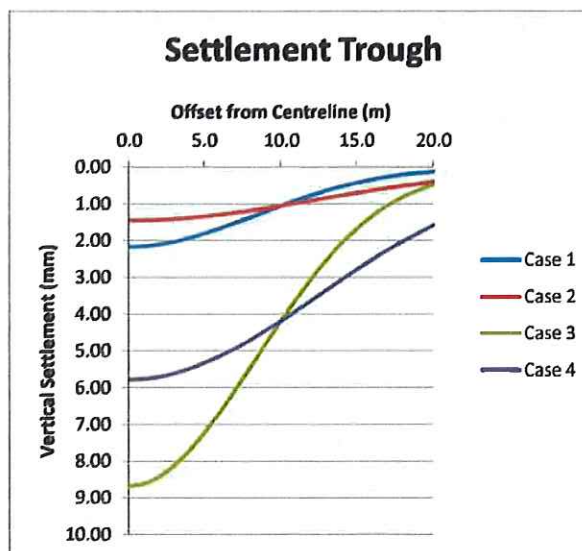
## 6.0 Settlement Trough

The profile of the vertical settlement can be predicted using the following equation:

Vertical Settlement Profile:  $w = w_{max} \times \exp\left(-\frac{y^2}{2i_y^2}\right)$ 

where  $w_{max}$  = maximum settlement  
 $y$  = Horizontal Offset perpendicular to alignment  
 $i_y$  = Trough width parameter ( $K \times z_0$ )

Offset (m)	Case 1	Case 2	Case 3	Case 4
0.0	2.17	1.45	8.68	5.79
1.0	2.16	1.44	8.62	5.77
2.0	2.11	1.43	8.43	5.71
3.0	2.03	1.41	8.13	5.62
4.0	1.93	1.37	7.73	5.50
5.0	1.81	1.33	7.24	5.34
6.0	1.67	1.29	6.68	5.15
7.0	1.52	1.24	6.08	4.94
8.0	1.36	1.18	5.45	4.71
9.0	1.20	1.11	4.82	4.46
10.0	1.05	1.05	4.20	4.19
11.0	0.90	0.98	3.60	3.92
12.0	0.76	0.91	3.05	3.63
13.0	0.64	0.84	2.54	3.35
14.0	0.52	0.77	2.09	3.07
15.0	0.42	0.70	1.69	2.80
16.0	0.34	0.63	1.35	2.53
17.0	0.27	0.57	1.06	2.27
18.0	0.21	0.51	0.82	2.03
19.0	0.16	0.45	0.63	1.80
20.0	0.12	0.40	0.47	1.59



# CALCULATION SHEET

SHEET NO.

DESCRIPTION

**High Complexity Tunnelling RAQ  
Settlement Estimate - Sewer**

PROJECT NO.

**358397**

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DATE 11-Sep-2015

CHECKED BY

DATE

## 7.0 Damage Assessment

The impact to Ontario Highway 401 is assessed based on the maximum ground surface settlement over the centreline of the tunnel.

Maximum allowable ground surface settlement: 15 mm

Based on WSP Technical Memo 'Non-Standard Special Provision, Settlement Instrumentation and Monitoring' at ground surface movement of 10mm or greater triggers 'Alert Level'.

			Maximum Settlement (mm)	Percent Allowable	Damage Assessment
<b>Case 1</b>	$K_{min}$	$V_{Lmin}$	2.2	14%	Acceptable II
<b>Case 2</b>	$K_{max}$	$V_{Lmin}$	1.4	10%	Acceptable I
<b>Case 3</b>	$K_{min}$	$V_{Lmax}$	8.7	58%	Acceptable III
<b>Case 4</b>	$K_{max}$	$V_{Lmax}$	5.8	39%	Acceptable II

Potential Impact Categories	
Acceptable I	<10%
Acceptable II	10-50%
Acceptable III	50-100%
Not Acceptable A	100-150%
Not Acceptable B	>150%

## 8.0 References

1. Lake L.M., Rankin W.J. and Hawley J. "Prediction and Effects of Ground Movements Caused by Tunnelling in Soft Ground Beneath Urban Areas" (CIRIA Funders Report/CP/5, September 1992).
2. O'Reilly, M.P. and New, B.M. (1982). "Settlements above tunnels in the United Kingdom-their magnitude and prediction", Tunnelling, pp173-181. London: IMM.