WATERFORD SAND & GRAVEL LTD.

LAW QUARRY EXTENSION

LEVEL 1 AND 2 WATER STUDY REPORT

March 2022

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WATERFORD SAND & GRAVEL LTD.

WSP PROJECT NO.: 111-53023-06
DATE: MARCH 2022

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Subject: **Law Quarry Extension**
Level 1 and 2 Water Study Report
WSP Project No. 111-53023-06

Dear Mr. Lamb:

We are pleased to provide the Level 1 and 2 Water Study Report in support of the Waterford Sand & Gravel Ltd. (Waterford) Law Quarry Extension.

The existing quarry, which has operated since the 1920s, has not resulted in any unacceptable impacts to local groundwater and surface water features. Although a measurable drawdown cone in the groundwater regime is predicted within the deeper bedrock aquifer; the results of this investigation suggest that much like the existing quarry, effects can be readily mitigated where there is potential for interference with private drinking water wells and the predicted drawdown will also not negatively impact surface water features within the study area.

The report provides background information on the Site and physical setting, details of the hydrogeologic work program completed, and an interpretation of the monitoring data collected at the site since 2004. Recommendations for the hydrogeologic monitoring program during the operation of the quarry extension are also included in the report.

We trust that this report satisfies your requirements.

Yours truly,
WSP Canada Inc.

Kevin Fitzpatrick

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EXECUTIVE SUMMARY

The Law Quarry is located approximately 3 kilometers west of the City of Port Colborne in parts of Lots 3, 4, 5 and 6, Concession 2, Wainfleet Township, Regional Municipality of Niagara, and owned and operated by Waterford. Lands located immediately to the west of the existing quarry have been acquired by Waterford for the proposed quarry extension (Site). Like the existing quarry, the Site will be developed below the natural groundwater table and will be dewatered to maintain dry working conditions. Waterford is required to obtain a Category 2 Class "A" below-water Quarry licence for the Site under the Aggregate Resources Act (ARA) and to apply for amendments to the Niagara Region Official Plan, Township of Wainfleet Official Plan and the Township Zoning By-Law. This Level 1 and 2 Water Study report has been completed to support the proposed quarry extension licence application.

The work program included:

- A review of published studies and available monitoring data to assess the local geology and hydrogeology and to identify gaps in the conceptual understanding of the Site.
- Additional drilling programs were conducted to improve the understanding of the local geology, as well as to establish a suitable groundwater monitoring network for predicting impacts within the identified subsurface units.
- An extensive hydraulic testing program was undertaken during borehole advancement and after the completion of the monitoring network installation using a variety of field methods.
- A surface water monitoring program was completed to characterize baseline water quality.
- A residential water well survey was also completed for the parcels situated within 1 km of the Site to identify local water well users.

Hydrogeology

The regional groundwater flow pattern in the study area is influenced by the buried Onondaga Escarpment, a bedrock scarp striking roughly parallel to Lake Erie, which was formed by differential erosion of the harder dolostone of the Bertie Formation and the softer underlying Salina Formation. The Erigan Channel, a buried ancestral bedrock valley that is inferred to link Lake Erie and Lake Ontario, is situated to the west of the Site near the community of Lowbanks. The buried bedrock valley is suspected to influence regional groundwater flow patterns within weathered Salina Formation bedrock. Enhanced hydraulic conductivities have been observed along buried bedrock valleys due to the creation and enhancement of porosity through solution-enhancement of fractures and bedding planes located within the bedrock walls.

Two aquifer systems have been identified from the groundwater levels at the Site. A shallow, unconfined system (i.e., the shallow bedrock aquifer) was identified within the Bois Blanc and Upper Bertie Formations. Some upper Bertie Formation members, particularly the Scajaquada member, likely act as an aquitard, confining the deeper bedrock units of the Bertie Formation forming a deep aquifer.

Groundwater elevations within the shallow bedrock aquifer and deeper bedrock units fluctuate seasonally, typically between 1 m and 2 m. The deeper Bertie Formation bedrock units seem to respond very rapidly to precipitation events, with equally rapid dissipation. Generally, the shallow bedrock wells show remarkably muted response to dewatering at the existing Law Quarry property, while the data from the deeper bedrock wells suggest that the effects of quarry dewatering are more pronounced in the lower units.

Locally, vertical hydraulic gradients are typically downward between the shallow bedrock aquifer and deeper bedrock units. Stronger gradients are observed at more distant nests from the existing quarry, inferred to be outside of the existing quarry dewatering radius of influence.

In general, the results of the hydraulic testing suggest that the Salina Formation bedrock, located below the quarry extraction depth, is the most conductive unit in the vicinity of the Site, likely as a result of enhanced weathering in this unit. The results also indicate that the shallow bedrock aquifer is also quite conductive. The observed radius of influence from the 72-hour pumping test completed in early 2019 was relatively small. Drawdown was observed only at the closest deep bedrock wells within about 400 m of the pumping well, while no drawdown was observed in the shallow bedrock aquifer. These results are consistent with the previous 72-hour pumping test completed as part of the Law Quarry east extension license application in 2005. In fact, in 2005 no drawdown at any monitoring well was observed as a result of the pumping tests, although unlike the current program, it is noted that there were no deep bedrock wells in the quarry monitoring network. The result is that although the Law Quarry reports significant volumes of pumped water on an annual basis, there are no users or natural features associated with this deep Salina groundwater system located below the quarry floor. This has limited any groundwater interference effects since extraction activities began at the site.

Surface Water

There are no significant surface water features within the Site boundary. According to topographic mapping, a surface water drainage divide bisects the Site. Surface runoff in the northern portion drains north to the Biederman Drain. The Biederman Drain also receives runoff from the Wainfleet Bog north and east of the Site and ultimately flows to the Welland Canal north of the City of Port Colborne. Surface runoff in the southeastern portion of the site domain drains to the Eagle Marsh Drain which flows south to Lake Erie southwest of the City of Port Colborne. A small area in the southwestern portion of the Site drains to Mill Race Creek which flows north to the Welland River. When the Site is developed, all of the runoff within the proposed limit of extraction will be directed via an internal drainage network to the sump within the existing quarry footprint where water is discharged to the Eagle Marsh Drain.

The Wainfleet Bog situated north of the Site contains a surficial water table which is perched above the bedrock water table due to a thick layer of clayey sediment underlying the organic bog deposits. Previous studies by others have concluded that there is no hydraulic connection between the existing quarry sump and the bog deposits.

There is one existing quarry licence and two unlicensed former quarries in close proximity to the Site. Reeb Quarry is a 70-hectare property situated southeast of the Site that has been licensed for bedrock resource extraction under the Aggregate Resources Act but currently sits undeveloped. The former Canadian Cement Company quarry (Quarry Lakes) situated 1 km south of the Site (within the Wainfleet Wetlands Conservation Area) is maintained in a partially dewatered state by the NPCA to depress stage elevation in the ponds. At the Cement Plant Ponds (Horseshoe Lakes) a former quarry situated 800 m southeast of the existing quarry, the stage elevation is allowed to fluctuate naturally with seasonal changes in precipitation and groundwater discharge. Both of the former quarries are inferred to be completed within the shallow bedrock aquifer, while the Reeb Quarry excavation is licensed to be completed to the base of the Falkirk member of the Bertie Formation, similar to the existing Law Quarry.

Groundwater Use

A residential water well survey was completed for sixty-two (62) parcels situated within a 1 km radius of the Site. Many of the surveyed property owners use a cistern for their primary water supply, or in addition to a well for their water supply. Of the surveyed property owners, 3 wells were used for domestic purposes, 1 well was used for lawn and / or garden watering / irrigation, 2 wells were used for livestock and gardening, and 6 wells were not in use. One (1) surveyed property owner used a spring associated with the former quarries as their sole water supply, and 8 property owners used a cistern as their sole water supply.

A search of the MECP PTTW database indicates that there are three (3) permitted groundwater users within the study area, including (i) the existing Law Quarry dewatering sump, (ii) the Reeb Quarry dewatering sump and aggregate washing plant to be located southeast of the Site (these are not yet in operation), and (iii) the Scholfield Avenue pumping station operated by the City of Port Colborne in the west end of the city (east of the Site) which operates to limit groundwater infiltration to the municipal sewer system. The Townline Tunnel dewatering sump is an unpermitted dewatering system operated by the St. Lawrence Seaway Management Corporation along the Welland Canal approximately 8 km northeast of the Site and is known to have a significant impact on the regional groundwater flow directions within the weathered Salina Formation bedrock.

Impact Assessment for Full Quarry Development

A steady-state numerical groundwater flow model was constructed to simulate baseline hydrogeological conditions at the Site, calibrated to observed baseline conditions. The calibrated baseline model was then modified to predict the effects of quarry dewatering on local groundwater users and surface water features at both full quarry development and at final rehabilitation. Known permitted groundwater users are included in the models in order to assess the cumulative impacts from existing permitted groundwater users and the future Law Quarry. The estimated annual demand from other non-permitted groundwater users within the model domain is less than 1 mm/year over the study area.

The modeling suggests minimal impact to the shallow bedrock aquifer at full development of the proposed quarry extension, while a drawdown of up to approximately 4 m relative to baseline water levels in the deeper bedrock units is predicted for a small number of parcels adjacent to the southwest of the proposed extension lands. The radius of influence in the deeper bedrock units extends to the west and south by approximately 1,000 m and 800 m, respectively.

Based on a review of the MECP water well records within the predicted radius of influence, the wells are completed to an average depth of 17 m into bedrock. Site borehole data indicates that the depth to the Salina Formation contact ranges between 19 m to 26 m below the top of bedrock. Therefore, where they exist and are still in use, most private water wells present within the study area are inferred to be hydraulically connected to the deeper bedrock units, although as open holes, they would also be open to the shallow bedrock aquifer. Using the static water levels provided on the well records, these wells have an average of approximately 11 m of available drawdown. Since the predicted drawdown from the proposed quarry extension at full development is only up to 4 m below baseline conditions, local water well interference is not expected.

At full development of the quarry, discharge from the Scholfield Avenue pumping station is predicted to decrease by 16% compared to baseline (i.e., no quarry) conditions; however, the majority of this decrease is due to the previously licensed portions of the existing quarry.

Dewatering operations at the Townline Tunnel are not predicted to be impacted by a substantial amount under full development conditions.

As noted previously, earlier studies by others suggest no hydraulic connection between the existing quarry sump and the Wainfleet Bog perched water table. The results of the predictive modeling completed for this study are consistent with the previous findings, and no negative impacts to the bog are anticipated under full development conditions.

The Biederman Drain, located north of the site, receives only minimal groundwater flux. This is not unexpected given the thick, low permeability underlying clay soils associated with the bog. Groundwater discharge as baseflow to the Biederman Drain north of the Site is predicted to be marginally reduced under full development conditions. The ecological function of the Biederman Drain is not anticipated to be impacted at full development of the proposed quarry extension.

Surface runoff and groundwater discharge to the existing quarry collects in the sump and is discharged to the Eagle Marsh Drain. At full development of the proposed quarry extension, the quarry discharge to the Eagle Marsh Drain is predicted to increase by 35% over baseline conditions and is predicted to reach up to 10,800 m^3/day during peak spring conditions. An evaluation of the flow capacity of the Eagle Marsh Drain completed as part of the Reeb Quarry licence application estimated that the conveyance capacity of the drain is approximately 2.1 m^3/s (180,000 m^3/day) at its limiting point. The predicted full development spring conditions of discharge from the proposed extension represents only 6% of the drain capacity.

Baseline surface water sampling suggests that there will be no negative impacts on the ecological function of Eagle Marsh Drain as a result of the increased discharge amounts. Discharge water quality is not expected to change from the current and long-standing conditions. The ecological function of the drain has developed over nearly 100 years of receiving groundwater and accumulated precipitation as discharge from the site.

At full development of the proposed quarry extension, the stage elevation in the Quarry Lakes ponds is predicted to be reduced by approximately 0.3 m relative to baseline conditions, with 33% of the decrease due to the previously licensed portions of the existing quarry. Discharge from the Quarry Lakes dewatering sump operated by the NPCA is also predicted to decrease. No impacts from the proposed quarry extension are predicted at the Cement Plant Ponds.

Impact Assessment for Final Rehabilitation

The proposed end use of the quarry is a lake, which will fill naturally with precipitation and groundwater discharge once the dewatering sump is decommissioned. A steady-state autumn average stage elevation of approximately 174.4 masl is predicted for the final quarry lake. This is similar to the stage elevation of ± 175 masl shown in the east extension Rehabilitation Plan and to the elevation of the water level in Lake Erie. Since the lowest natural ground surface elevation around the perimeter of the existing quarry has an elevation of approximately 178 masl, it is predicted that there will be no discharge from the future quarry lake to surface water drainage features under natural climatic conditions.

After the steady-state stage lake elevation is reached, net groundwater flow will be outwards to the surrounding aquifer, similar to baseline conditions. However, the rate of outward groundwater flow doubles relative to baseline conditions. It is expected that once final rehabilitation is achieved, the operation of private wells in the vicinity of the Site will return to similar to or greater than baseline conditions (where the existing quarry sump was in operation).

Upon final rehabilitation of the quarry to a lake, the steady-state autumn discharge from the Scholfield Avenue pumping station is predicted to increase by about 40% compared to baseline conditions. Similar to full development conditions, the Townline Tunnel dewatering system is not predicted to be substantially impacted in this scenario.

The very limited discharge from the Wainfleet Bog deposits to the deep groundwater system decreases by approximately 38% below baseline conditions as the pressure differential decreases due to the cessation of quarry sump pumping. Predicted groundwater discharge as baseflow to Biederman Drain, which is currently low, remains reduced at final rehabilitation. At the watershed scale, this represents a reduction of 2 mm/year.

At final rehabilitation, the steady-state autumn average stage elevation in the Quarry Lakes ponds is predicted to increase by 0.2 m relative to baseline conditions, and discharge from the sump is predicted to average approximately 2,350 m^3/day (0.9 Mm^3/year). Ending pumping at the quarries in the far future results in a notable increase from the average discharge rate under baseline conditions, estimated as 80 m^3/day.

The autumn average stage elevation in the Cement Plant Ponds south pond is predicted to increase by 1.4 m relative to baseline conditions.

Cumulative Impacts from Reeb Quarry

An additional future scenario model was created to simulate the impacts of both the proposed quarry extension and the Reeb Quarry at full development and final rehabilitation. According to hydrogeological studies completed previously by others, the Reeb Quarry will be developed in 2 phases. Phase 1 is west of Bessey Road, and phase 2 is east of Bessey Road. Once phase 1 extraction has been completed, the water management plan for the site allows discharge water collected in phase 2 to accumulate in phase 1, with a stage elevation to be maintained at 174 masl. The purpose of the phase 1 pond is to mitigate potential groundwater impacts to the west of the quarry. It is expected that impact from both quarries would be greatest when the Law Quarry extension is fully completed and the Reeb Quarry phase 1 excavation is completed and not yet inundated. For the final rehabilitation cumulative assessment, it is assumed that both phases of the Reeb Quarry are excavated and inundated to form final quarry lakes. An outlet to the Eagle Marsh Drain would be situated on the east side of the phase 2 pond with a control elevation at 175.5 masl.

In the cumulative full development scenario, a predicted drawdown of up to 3 m occurs in the shallow bedrock aquifer to the south of Reeb phase 1. The radius of influence extends to Golf Club Road in the west, Cement Road in the east and south to the Lake Erie shoreline. It is inferred that the drawdown within the shallow bedrock aquifer is the result of dewatering of the Reeb Quarry, as the full development model for the proposed extension showed no drawdown in this unit. In the deeper bedrock units, a drawdown of up to 10 m relative to baseline water levels is predicted immediately adjacent to Reeb phase 1.

It is predicted that the average annual dewatering rate for the fully developed Law Quarry will decrease by approximately 70% relative to the scenario without considering Reeb phase 1 cumulative effects. Earlier studies by others, which did not consider the extension of the Law Quarry, predicted that the excavation of Reeb phase 1 would reduce the Law Quarry dewatering rate by approximately 30%. Based on either of these predictions, the discharge to Eagle Marsh Drain from the Law Quarry would be substantially reduced when the Reeb Quarry is developed.

The drawdown within the shallow bedrock aquifer predicted in the cumulative full development scenario suggests that Quarry Lakes pond could be subject to a decrease of up to 3 m for autumn average conditions, while the Cement Plant Ponds could be subject to a decrease of up to 0.6 m compared to baseline conditions. Earlier studies by others predicted no impacts to water levels in either of these features.

When cumulative effects of the proposed quarry extension and Reeb phase 1 are considered, the average Autumn sump discharge from the Scholfield Avenue pumping station and Townline Tunnel dewatering sump will decrease by approximately 45% relative to baseline conditions. Since the pumping station is in place to reduce groundwater infiltration to the City of Port Colborne sewer system and local basement sumps, neither the proposed Law Quarry extension nor Reeb phase 1 will negatively impact its operation. Both the proposed Law Quarry extension and Reeb phase 1 appear to have minimal impact on pumping at the Townline Tunnel.

In the cumulative final rehabilitation scenario, a steady-state autumn average stage elevation of 174.1 masl is predicted for the future lake in Law Quarry with the presence of the Reeb Quarry final lakes to the south, a decrease of 0.3 m in comparison to the rehabilitated conditions model simulating only the Law Quarry. The predicted steady-state autumn average stage elevation in the Reeb Quarry final lakes is predicted to be approximately 173.5 masl. This estimate is 2.5 m to 3.5 m lower than predictions in earlier studies by others. At this lower elevation, flow from the Reeb Quarry final lakes to Eagle Marsh Drain would not occur in the autumn under normal climatic conditions.

The cumulative impact assessment for the Biederman Drain subwatershed water balance for rehabilitated conditions is not substantially different compared when only the Law Quarry rehabilitated conditions are simulated.

The steady-state autumn average stage elevation in the Quarry Lakes ponds is predicted to increase by 0.1 m relative to the rehabilitated scenario where only the Law Quarry is simulated, while the steady-state average autumn discharge from the sump is predicted to increase by nearly 20% relative to rehabilitated conditions considering the Law Quarry only. The autumn average stage elevation in the Cement Plant Ponds is predicted to decrease by 0.2 m when the cumulative effects of Law Quarry and Reeb Quarry final lakes are considered. The steady-state autumn discharge from the Scholfield Avenue pumping station is also predicted to decrease slightly in this scenario.

Recommendations

To mitigate the impacts of the proposed quarry extension, the following recommendations should be implemented upon licence approval:

- ➔ The proposed long-term monitoring program outlined in **Table 1** and shown in **Figure 18**, to be completed during the quarry extension operational and rehabilitation phases, until stable conditions are observed after quarry decommissioning;
- ➔ A well interference mitigation plan; and
- ➔ A Spills Contingency Program in compliance with the prescribed conditions for a Class A Category 2 licence under the ARA.

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1 INTRODUCTION

1.1 BACKGROUND

The existing Law Quarry is located in parts of Lots 3, 4, 5 and 6, Concession 2, Wainfleet Township, Regional Municipality of Niagara, and owned and operated by Waterford. The existing quarry is located approximately 3 kilometers west of the City of Port Colborne, as shown in **Figure 1** (Site Location Map). A Site Plan showing the existing area of extraction, sump location and monitoring well network is provided in **Figure 2**.

Excavation within the existing quarry began prior to 1934 and currently covers an area of approximately 144 hectares. **Figure 1-1** below shows the approximate extent of the quarry footprint since 1934. Extents were determined using aerial imagery available on the Brock University Niagara Air Photo Index GIS portal.

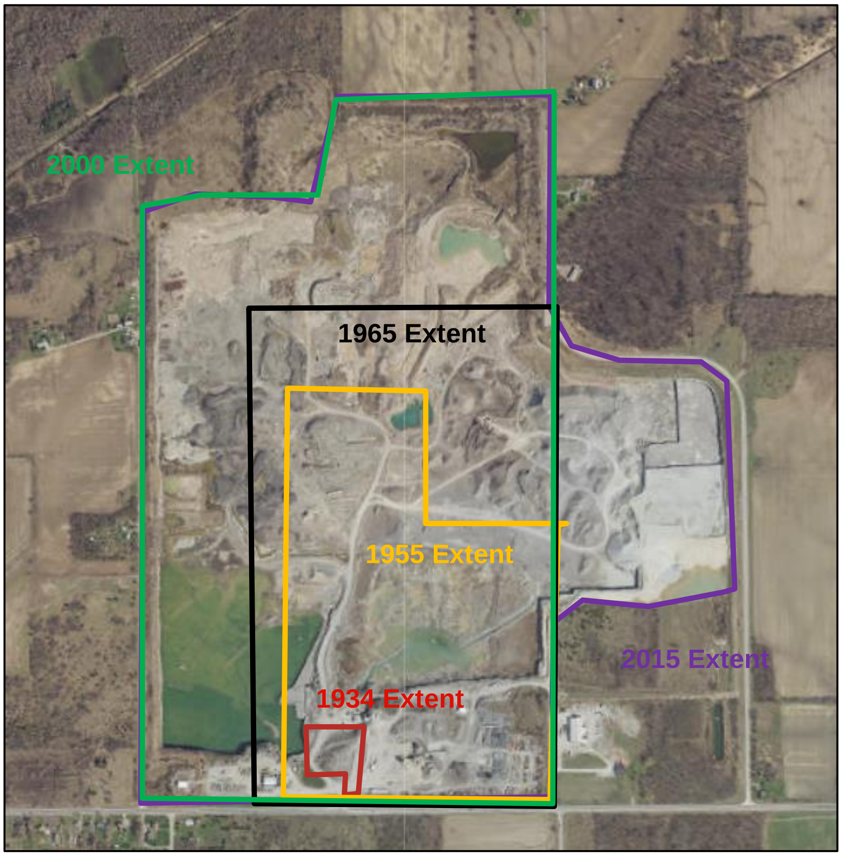

Figure 1-1: Law Quarry excavation boundaries since 1934 (Brock University Niagara Air Photo Index)

Additional lands to the west of the existing quarry have been acquired by Waterford over time for the proposed quarry extension (Site). Like the existing quarry, the Site will be developed below the natural groundwater table and will be dewatered to maintain dry working conditions. Therefore, Waterford is required to obtain a Category 2 Class “A” below-water Quarry licence for the Site under the Aggregate

Resources Act (ARA) and to apply for amendments to the Niagara Region Official Plan, Township of Wainfleet Official Plan and the Township Zoning By-Law.

WSP Canada Inc. (WSP) was retained by Waterford to provide hydrogeologic services, including the completion of this Level 1 and 2 Water Study in support of the Site licence application.

1.2 DESCRIPTION OF PROPOSED QUARRY

The Site boundary and proposed limit of extraction is shown in **Figure 2**. The extension lands are bounded by Biederman Road to the east, Graybiel Road to the west, Highway 3 to the south and the Wainfleet Bog to the north.

Excavation will proceed to a maximum depth of up to 20 m below ground surface, corresponding to the base of the Bertie Formation, Falkirk member dolostone, similar to the existing quarry. The high-quality dolomite will provide many decades of aggregate reserves for building projects in the Niagara Peninsula.

The extraction limit for the proposed quarry extension assumes removal of Biederman Road north of Highway 3 to connect to the existing quarry. Graybiel Road will be extended to the north and east of the Site to allow access for the remaining resident north of the Site. As an alternative, Biederman Road may be kept as-is, and the proposed extension would be separate from the existing quarry. The analysis completed as part of this study conservatively assumes removal of Biederman Road, and is therefore applicable in either case.

1.3 EVALUATION REQUIREMENTS

In the Aggregate Resources of Ontario Provincial Standards (Ministry of Natural Resources and Forestry (MNRF), August 2020), Part 2.5 outlines the following requirements for a Water Report to meet the study requirements for a Category 2 Class A quarry below groundwater:

> *Water Report Level 1:*
> *Determine the potential for impacts to ground water and surface water resources and their uses (e.g. water wells, ground water aquifers, surface water courses and bodies, springs, discharge areas) and identify if the proposed site is in a Wellhead Protection Area for Quantity (WHPA-Q) set out in an applicable source water protection plan under the Clean Water Act. If so, identify applicable source water protection policies and mitigation measures that will be implemented at the site.*
>
> *Water Report Level 2:*
> *Where the results of Level 1 have identified a potential for impacts from the aggregate site on ground water and/or surface water resources and their uses, an impact assessment is required. The assessment is to determine the significance of the effect and the potential for mitigation.*
>
> *The assessment must address the potential effects of the operation on any ground water and surface water features located within the zone of influence, including but not limited to:*
>
> > *a) water wells (includes all types e.g. municipal, private, industrial, commercial, geothermal and agricultural)*
> >
> > *b) springs (e.g., place where ground water flows out of the ground)*

c) ground water aquifers;

d) surface water courses and bodies (e.g., lakes, rivers, brooks)

e) wetlands

The assessment must include but not be limited to the following:

f) a description of the physical setting including local geology, hydrogeology, and surface water systems;

g) proposed water diversion, discharge, storage and drainage facilities;

h) water budget (e.g. how water is managed on-site);

i) the possible positive or negative impacts that the proposed site may have on the water regime;

The Level 2 water report must also contain:

j) monitoring plan(s); and

k) technical support data in the form of tables, graphs and figures, usually appended to the report.

This report addresses the Level 1 and Level 2 Water Report requirements for the hydrogeological evaluation of the Site. In addition, the study included herein may also be used in support of Permit-to-Take-Water (PTTW) application for the Site dewatering as well as the Environmental Compliance Approval (ECA) for Industrial Sewage Works application for the sump discharge to the environment.

Additional requirements considered in the preparation of this study include the Township of Wainfleet Official Plan (January 2016), the consolidated Niagara Region Official Plan (2014), the Provincial Policy Statement (2020) and the Clean Water Act (2006).

1.4 OBJECTIVES AND SCOPE

The principal objectives of this Level 1 and 2 Water Study are as follows:

- Characterize the baseline groundwater and surface water conditions and uses;
- Establish a baseline water budget for the Site and local study area;
- Provide input to the proposed quarry extension design and end use, particularly related to water management at the Site;
- Predict potential effects of the proposed quarry extension on local groundwater users and surface water features by constructing a steady-state numerical groundwater flow model and simulating baseline hydrogeological conditions, quarry extension effects on the baseline conditions, and potential mitigation or contingency measures; and
- Implement an environmental monitoring program to assess the predicted effects of the proposed quarry extension on the groundwater and surface water features to ensure compliance with the Site Plan and other permits.

1.5 STATEMENT OF QUALIFICATIONS

This Level 1 and 2 Water Study was completed by a project team at WSP Canada Inc. The Project and Technical Manager was Kevin Fitzpatrick, P.Eng., and the Technical Project Co-ordinator was Rebecca Warrack, P.Eng. Numerical groundwater modeling was completed by Leigh Davis, M.A.Sc., P.Eng. A team of internal technical support staff assisted with the field work, data collection and analyses. Curriculum vitae are provided in **Appendix A**.

1.6 STUDY METHODOLOGY

The objective of the study was to develop a conceptual understanding of the hydrogeological conditions in the vicinity of the Site in order to predict the potential effects of the proposed quarry extension on local groundwater users and surface water features. The work program began with a review of previous studies and existing monitoring data to assess the local geology and hydrogeology and identify gaps in our conceptual understanding of the Site. Previous studies include:

- Gartner Lee Limited (2005). Hydrogeological Assessment for Below Water Extraction Law Quarry Eastern Extension, Township of Wainfleet, Region of Niagara. Prepared for Hard Rock Paving Company, March 2005.
- Azimuth Environmental Consulting and Earthfx Incorporated (2005). Reeb Quarry Level 2 Hydrogeological Assessment. Prepared for M.A.Q. Aggregates Inc., January 2005
- Azimuth Environmental Consulting (2008). Addendum Hydrogeological Assessment / Numerical Modelling Report, Reeb Quarry. Prepared for M.A.Q. Aggregates Inc., January 2008.
- WSP (2019) Law Quarry 2015 - 2018 Annual Permit to Take Water Monitoring Reports, PTTW No. 7112-98MS6F/1541-B2DLQF.

Based on our review of the previous studies undertaken at the Site, additional drilling programs were required to improve our understanding of the local geology, as well as to establish a suitable monitoring well network. A hydraulic testing program was undertaken both during borehole advancement as well as after the completion of the monitoring network using a variety of field methods.

1.6.1 WATER WELL SURVEY

To establish an initial database of local groundwater users, a search of the MECP Water Well Record database was undertaken to identify wells located within 1 km of the Site. A water well survey of all residences within a 1 km radius of the Site was conducted by WSP staff in the summer of 2018 in accordance with the MECP technical guidance (MECP, 2008).

The results of the well record database search and water well survey are included in **Appendix B**, with further discussion provided in **Section 2.4.4**.

1.6.2 DRILLING PROGRAMS

Boreholes were advanced during two separate drilling programs at the Site. The locations of all boreholes and shallow drivepoints are shown in the Site Plan, **Figure 2**. Available borehole logs, rock core photos and monitor construction details are included in **Appendix C**.

Prior to the current study, in 2004, Gartner Lee Limited (GLL) advanced ten (10) boreholes as part of the east quarry extension license application. In each borehole, 51 mm diameter PVC monitors were installed in the more hydraulically conductive zones based on the results of packer testing in the bedrock (previous packer testing is provided in **Appendix D**). The details of the drilling program are included in the Hydrogeological Assessment for Below Water Extraction, Law Quarry Eastern Extension, Township of Wainfleet, Region of Niagara report (GLL, 2005). Boreholes installed during the 2004 drilling program are described as GLL-1 to GLL-10 in this report. It is noted that the two (2) monitoring wells at GLL-11 were installed in 2005 after the initial drilling program and GLL-2 was abandoned in 2013 as the quarry face advanced east.

The 2004 GLL wells were completed in various hydraulically conductive zones identified through packer testing as follows:

- ➔ GLL-1 was screened across the Bois Blanc Formation, the Springvale member of the Bois Blanc Formation, and the Akron member of the Bertie Formation.
- ➔ GLL-3 was screened across the Williamsville, Scajaquada and Falkirk members of the Bertie Formation.
- ➔ GLL-4 was screened within the Bois Blanc Formation.
- ➔ GLL-5 was screened across the Falkirk and Oatka members of the Bertie Formation.
- ➔ GLL-6 was screened across the Williamsville, Scajaquada and Falkirk members of the Bertie Formation.
- ➔ GLL-7 was screened across the Akron, Williamsville and Scajaquada members of the Bertie Formation.
- ➔ GLL-8 was screened across the Falkirk and Oatka members of the Bertie Formation.
- ➔ GLL-9 was screened across the Bois Blanc Formation, the Springvale member of the Bois Blanc Formation and the Akron and Williamsville members of the Bertie Formation.
- ➔ GLL-10 was installed across the Springvale member of the Bois Blanc Formation and the Akron, Williamsville and Scajaquada members of the Bertie Formation.

Borehole logs for GLL-11 were not available; as such, field-measured depths were used to interpret the stratigraphy screened.

A 150 mm diameter pumping well, referred to as PW, was installed on November 28, 2004 to a depth of 32.8 m BGS by licensed water well driller Field Well Drilling of Vineland, ON. The well tag is A018302, and the Ministry of the Environment, Conservation and Parks (MECP) water well record number is 6604836. This pumping well was originally tested as part of the east extension license application in 2005. In early 2019, pumping well PW was rehabilitated for an additional 72-hour pumping test completed as part of the current study to observe the effects of pumping on the deeper bedrock units in the newly installed monitoring wells. Further discussion of the 2019 pumping test is provided below.

In the autumn of 2017 and summer of 2018, WSP completed a drilling program at the Site in order to establish a more suitable groundwater monitoring network for predicting impacts within the deeper bedrock units. A total of fourteen (14) monitoring wells were installed at seven (7) existing well nests (GLL-1, GLL-4, GLL-5, GLL-6, GLL-9, GLL-10 and GLL-11). An additional two (2) monitoring wells were installed at well nest MW12 located south of GLL-8 adjacent to Highway 3. Typically, each well nest consists of two to three wells screened within the following intervals (from deepest to shallowest):

- Monitoring well designation ‘I’ corresponds to well screens installed 4.6 – 6.1 metres into the Salina Formation, referenced as deep Salina Formation wells. These wells correspond to depths below the proposed quarry floor.
- Monitoring well designation ‘II’ corresponds well screens installed at the contact between the Oatka Member of the Bertie Formation and the Salina Formation. It is noted that MW11-1 was also installed across the Oatka and Salina contact.
- Monitoring well designation ‘III’ corresponds to the Falkirk member of the Bertie Formation. The base of the Falkirk member is equivalent to the proposed final quarry floor depth (excavation will not occur into the underlying Oatka member as the rock quality is not acceptable for construction aggregate).

Both the initial and supplemental drilling programs undertaken as part of the current study were completed by Noll Drilling of Breslau, Ontario. Boreholes advanced through the overburden were completed with hollow-stem augers (108 mm inner diameter) to allow measurement of in-situ geotechnical parameters and detailed soil logging. Bedrock coring was completed with an HQ (64 mm diameter) diamond drill bit. The deepest boreholes in each well nest were continuously cored from the bedrock surface to the final depth of the borehole, typically into the Salina Formation. Rock core was placed into core boxes and stored at the Site for review by a senior geological engineer. Descriptions included stratigraphy, percent recovery and rock quality designation (RQD).

Monitoring wells were constructed of 51 mm diameter PVC riser pipe and a slot 10 well screen of varying lengths depending on the interval screened. The borehole annulus around the screen was filled with number 2 silica sand to a nominal height above the screen to provide a filter pack. The remainder of the borehole annulus was sealed with bentonite pellets and / or grout. A lockable protective steel casing was cemented in place at the surface to provide a surface seal. Dedicated inertial lift sampling equipment (Waterra) was installed and the wells were developed to set the filter pack. Cluster MECP well records were submitted for the separate drilling programs.

All of the available wells included in the current monitoring network were surveyed by WSP to establish ground surface and top of pipe elevations to a geodetic datum and UTM location coordinates. The elevation data is provided in **Table C-1, Appendix C**.

1.6.3 HYDRAULIC TESTING PROGRAM

Various methods were used to perform the hydraulic conductivity testing at the Site, as summarized below. A complete description of the testing and results is provided in **Appendix D**.

Packer testing was completed during borehole advancement at selected ‘I’ series wells to assess relative hydraulic conductivity of discreet bedrock intervals, undertaken between July 4, 2018 and July 30, 2018. After the completion of the borehole drilling, ~3 m (10’) test intervals were sealed off from the remaining borehole annulus by inflatable packers. Similar to a falling head slug test, water was injected into the packer interval to a reference elevation, and the decrease in the head was monitored over time as the excess water dissipated into the bedrock interval fracture network. The results of the packer testing were used to assess the relative hydraulic conductivities of zones within the bedrock with depth to enhance the conceptual understanding of the hydrostratigraphy at the Site.

A 72-hour pumping test was completed at pumping well PW between February 6 – 9, 2019, to estimate bulk transmissivity of the bedrock and to simulate dewatering of the proposed quarry extension. Prior to the long-term test, a stepped-rate test was completed on February 6, 2019 to assess the pumping well efficiency as well as to determine an appropriate pumping rate for the long-term test. Both the long-term and stepped-rate tests were completed by licensed water well driller Country Water Systems of Thornton Ontario, with the supervision of WSP field staff in accordance with Permit-to-Take-Water (PTTW) No. 5816-B5FPUV, issued by the MECP on October 15, 2018. Discharge from the pumping well was directed away from the well area to the drainage ditch along Highway 3 to limit the potential for re-infiltration of water.

During the tests, groundwater elevations were monitored at pumping well PW and available Site monitoring wells. Water levels were recorded using electronic dataloggers augmented with periodic manual measurements. Field measurements for pH, conductivity and temperature was collected during each day of pumping. A sample of the pumping well discharge was collected 6 hours after the start of the pumping test. The discharge flow rate from the pumping well was continuously monitored using a flow meter and confirmed with period manual flow rate measurements.

During the constant rate test, groundwater levels in Salina Formation wells MW10-I and MW10-II and shallow aquifer (Falkirk member) well MW10-III located closest to the pumping well (28 metres to the west) were observed to lower in response to pumping at PW. Salina Formation well MW12-II located 365 metres to the east of the pumping well was observed to lower in response to pumping at PW.

Finally, in November 2019, rising head slug tests were completed to determine local in-situ hydraulic conductivity for selected monitoring wells. The Hvorslev analytical method was used to analyze the slug test data, using AquiferTest software.

1.6.4 GROUNDWATER MONITORING

The baseline groundwater monitoring program completed for this study consisted of the following:

- Continuous groundwater level monitoring using dataloggers installed at six (6) shallow bedrock aquifer wells, nine (9) Falkirk member wells, eight (8) Oatka / Salina contact wells, and three (3) deep Salina wells included in the monitoring network. Loggers were programmed to collect data every four (4) hours. One barologger was installed at nest MW4 to correct for atmospheric pressure changes over time.
- Continuous groundwater level monitoring using dataloggers installed at two (2) off-Site private supply wells included in the monitoring program for the existing quarry. Loggers were programmed to collect data concurrently with the Site monitoring well loggers.
- Periodic manual water level measurements at each location were made over the course of the baseline monitoring period, generally occurring on a quarterly basis. The manual measurements were used to confirm the datalogger water levels. The manual water levels were measured with an electric contact gauge (Water Level Tape). The datalogger and manual water level measurements are depicted in the hydrographs included in **Appendix E**. Water level data notably affected by hydraulic testing over the short test period are presented separately for clarity.

As noted previously, during this study, a sample of the pumping well discharge was collected during the pumping test on February 6, 2019. A sample was also collected from the private well located at 20808

Graybiel Road during the pumping test at the request of the property owner. These samples were submitted to Eurofins Environmental Testing Inc. for analysis.

Several rounds of groundwater sampling were completed between 2004 and 2007 by others as part of the Reeb Quarry Level 2 Hydrogeological Investigation and Hydrogeological Investigation Addendum (Azimuth Environmental Consulting and Earthfx Inc., 2005 and 2008). As shown in **Figure 2**, Reeb Quarry nest OW6 is located approximately 200 m east of the proposed extension lands.

These groundwater chemical results are provided in **Appendix F**.

1.6.5 SURFACE WATER MONITORING

The baseline surface water monitoring program completed for this study consisted of the following:

- Continuous sump stage elevation monitoring using a datalogger programmed to collect hourly data. Periodic manual water level measurements were made over the course of the baseline monitoring period, generally occurring on a quarterly basis. The manual measurements were used to confirm the datalogger water levels. The manual water levels were measured with an electric contact gauge. The datalogger and manual water level measurements are depicted in the hydrographs included in **Appendix E**.
- A quarterly surface water sampling program was implemented at the site in early 2018, to obtain baseline data which will be used to support an application for an Environmental Compliance Approval (ECA) under Section 53 of the Ontario Water Resources Act. The quarterly samples were collected in January, April, July and October of 2018 and 2019. Samples were collected from the quarry sump discharge channel (SW2), and upstream (SW1) and downstream (SW3) locations in the Eagle Marsh Drain. The surface water sampling stations are shown in **Figure 3A**. Grab samples were collected from downstream to upstream locations using a decontaminated bottle, decanted into laboratory prepared bottles and submitted under standard chain-of-custody procedures to Eurofins Environmental Testing Inc. for analysis of general parameters, major ions, nutrients and organic indicators, and total metals. Field measurement of pH, conductivity, temperature and dissolved oxygen was also completed prior to sampling. The surface water chemical results are included in **Appendix G**.

1.6.6 NUMERICAL GROUNDWATER FLOW MODEL

A steady-state numerical groundwater flow model was constructed to simulate baseline hydrogeological conditions at the Site. The model was calibrated using the available baseline groundwater elevation data, as well as the results of the various hydraulic tests completed to estimate the hydrogeological properties of the bedrock units. The calibrated baseline model was then used to predict the effects of future quarry dewatering on local groundwater users and surface water features. MODFLOW-USG (Panday et al, 2017) was used as the numerical simulation code for the groundwater model. MODFLOW-USG (**U**n-**S**tructured **G**rid) is similar to the more traditional MODFLOW (USGS 1988-2005) code; however, it allows for additional flexibility with the model grid, for instance, for easier grid refinement in areas of increased interest.

MODFLOW-USG is capable of simulating steady-state three-dimensional groundwater flow in unconfined, semi-confined and confined aquifers in any physical setting. Companion programs, such as ZoneBudget (Harbaugh, 1990 and updates) and mod-PATH3DU (Muffels et al, 2018) were used during the construction and calibration process to assess mass balance and flow directions within the model.

Groundwater Vistas version 7 was used as the pre- and post-processor for the model construction and calibration process. The parameter estimation software PEST (Doherty, 2019) was also used during the calibration and model prediction process.

The detailed numerical groundwater model documentation is included as **Appendix H**.

2 PHYSICAL SETTING

2.1 PHYSIOGRAPHY, TOPOGRAPHY AND LAND USES

The Site is situated within the Haldimand Clay Plain physiographic region, extending from the Niagara Escarpment in the north to Lake Erie in the South (Chapman and Putnam, 1984). This physiographic region is characterized by low topographic relief and poorly drained soils. During the last glaciation, the area was inundated by glacial Lake Warren and resulted in the deposition of up to several tens of metres of massive stratified clay and silt deposited on the underlying Silurian and Devonian age dolostone. The Wainfleet Bog is a significant low-lying peat bog composed of organic material and peat deposits located to the north of the Site.

The buried Onondaga Escarpment is a prominent physiographic feature located near the northern Site boundary. The Onondaga Escarpment is characterized by the differential erosion of the harder Bertie Formation dolostone and the softer underlying Salina Formation dolomitic and gypsiferous shales. The Onondaga Escarpment caprock is exposed at ground surface in portions of the study area but local deposits of glacial sediment drift can range up to a few metres in thickness. Overburden thickness generally increases from north to south on the Site, where glacial sediments have infilled below the crest of the Onondaga Escarpment. Overburden thickness ranges between 3 to 15 metres near the Lake Erie shoreline (Chapman and Putnam, 1984).

Of note, there are two unlicensed former quarries within the study area which currently fill naturally with runoff and groundwater discharge. Both of these former quarries are included in the numerical groundwater flow model (refer to **Appendix H**).

The former Canadian Cement Company quarry (Quarry Lakes) is situated 1 km south of the Site. This former quarry was excavated into the Onondaga and Bois Blanc Formation limestone and operated from the late 19th Century to the 1960s. The lands on which the Quarry Lakes are situated have since been purchased by the Niagara Peninsula Conservation Authority (NPCA) to form the present-day Wainfleet Wetlands Conservation Area. The stage elevation in the Quarry Lakes are controlled by a dewatering sump operated by the NPCA. Originally, the operation of the sump required a Permit-to-Take-Water (PTTW), which required the operator to record elevation and flow data. However, the operation was exempted a number of years ago. Nonetheless, the NPCA has continued to periodically monitor elevation and flow data for the dewatering sump. For the baseline period, a representative sump elevation of 172.7 masl was estimated from the available data, with a dewatering flow rate of approximately 80 m^3/day.

The Cement Plant Ponds (sometimes referred to as the Horseshoe Lakes ponds) are situated approximately 800 m southeast of the existing quarry licence. The excavation depth for this former quarry is not well documented; however, it is assumed that resource extraction was completed to the base of the Bois Blanc Formation, similar to the Quarry Lakes for use in the production of cement powder. The stage elevation within the Cement Plant Ponds is not actively controlled and is understood to fluctuate due to seasonal changes in precipitation and groundwater discharge. A representative stage elevation of 173.8 masl was estimated for the south quarry pond based on data obtained through an MECP Freedom of Information (FOI) request.

The majority of land uses within the local vicinity of the Site include agricultural and rural residential. To the southeast, the unopened Reeb Quarry has been licensed for extraction of bedrock resources under the Aggregate Resources Act under the Ministry of Natural Resources and Forestry (MNRF). Reeb Quarry is a 70-hectare property located on Part Lot 2, 3, 4 and 5, Concession 1, in the township of Wainfleet, Ontario.

2.2 DRAINAGE

The closest predominant surface water feature is the Wainfleet Bog situated immediately north of the Site. It is typically composed of between 2 m and 4 m of organic material (peat) and pond deposits (Feenstra, 1981) and contains a surficial water table which is perched above the bedrock water table. Clayey sediment underlying the bog can be up to 24 m thick (Crowe et al, 2002). The bog developed north of the Onondaga Escarpment since the last glaciation where surface drainage south to Lake Erie is naturally poor.

Environment Canada completed a study of the Wainfleet Bog (Crowe et al., 2002), which involved the installation of several water table monitors and piezometers within the bog. The study concluded that a water table is perched within the bog and there is no hydraulic connection between the Law Quarry sump and the bog deposits. This study was used for the development of the baseline numerical groundwater flow model (refer to **Appendix H**).

There are no significant surface water features within the Site boundary. According to topographic mapping shown in **Figure 3**, a surface water drainage divide bisects the Site. Surface runoff in the northern portion drains north to the Biederman Drain. The Biederman Drain also receives runoff from the Wainfleet Bog north and east of the Site and ultimately flows to the Welland Canal north of the City of Port Colborne. Surface runoff in the southeastern portion drains to the Eagle Marsh Drain which flows south to Lake Erie southwest of the City of Port Colborne. A small area in the southwestern portion of the Site drains to Mill Race Creek which flows north to the Welland River. When the Site is developed, the runoff within the proposed limit of extraction will be directed via an internal drainage network to the sump within the existing quarry footprint where it discharges to Eagle Marsh Drain.

2.3 GEOLOGY

Geology at the Site is based on recent data acquired during the baseline monitoring program completed by WSP, augmented with data obtained during previous investigations completed for other sites within the study area, including:

- Law Quarry PTTW Annual Monitoring Report (WSP, March 2019);
- Hydrogeological Assessment for Below Water Extraction, Law Quarry (Gartner Lee Limited, 2005);
- Reeb Quarry (Azimuth Environmental Consulting and Earthfx Inc., 2005 and 2008) southeast of the Site.

Additional information was also obtained from:

- *Updated Assessment Report, Niagara Peninsula Source Protection Area* (NPCA, November 2013);
- *Buried Ancestral Drainage Between Lakes Erie and Ontario* (Flint and Lolcoma, 1985).
- *The Physiography of Southern Ontario, Third Edition* (Chapman and Putnam, 1984).

- *Map P3811, Paleozoic Geology, Welland-Fort Erie Area, Southern Ontario* (Ontario Geological Survey, 2017);
- The Subsurface Paleozoic Stratigraphy of Southern Ontario (Armstrong and Carter, 2010); and
- Aggregate Resources Inventory Paper (ARIP) 115 (Wainfleet) (OGS, 1985).

2.3.1 OVERBURDEN

Low permeability glaciolacustrine clay and silt overburden, typical of much of the southern portion of the Niagara Peninsula, is generally less than 3 m thick at the site. A prominent northeast / southwest trending ridge of Bois Blanc bedrock at surface within the extension lands (visible in aerial photographs) demarks a significant area of no overburden.

The overburden thickness increases at the northern edge of the existing quarry, where a northeast / southwest trending re-entrant channel exists in the Onondaga cuesta. Here a very dense, stony, reddish till with a sand-silt matrix exists up to 5 m in thickness (possibly the “lower till” of Feenstra, 1981). Excavation of this material is quite difficult and requires the use of a toothed bucket excavator, suggesting that it may have a lodgement-type depositional origin. The till is more easily eroded by surface water than the local clayey overburden due to the sandy matrix, and small washouts of sand are common where it is exposed in the existing quarry excavation.

Study area overburden geology and thickness maps (depth to bedrock in metres) are provided on **Figures 4 and 5**, respectively.

2.3.2 BEDROCK GEOLOGY

2.3.2.1 REGIONAL SETTING

Regionally, the area is underlain by Silurian and Devonian age limestone, dolostone, gypsum, shale and sandstone. The Onondaga Escarpment is the dominant physiographic feature in the area. The buried Onondaga Escarpment, a bedrock scarp roughly parallel to Lake Erie, was formed by differential erosion of the harder dolostone of the Bertie Formation and the softer underlying Salina Formation (GLL, 2005). Local bedrock units dip to the southeast at about 0.5% to less than 1.0%. The naming convention for bedrock stratigraphic units in this report are defined from youngest to oldest below.

Formation (Age)	**Member**	**Description**
Onondaga Formation (Middle Devonian Age)	**Edgecliffe Member**	Cherty, thin to medium bedded, semi-nodular to tabular bedded, fossiliferous, biostromal limestone. Chert is typically dark grey to black and occurs in a variety of fine, including stratoform lenses, lobate to highly irregular nodules and tube-like forms (possibly after burrows). Fossils are abundant and varied and include tabulate corals, solitary and colonial rugose corals, crinoids, brachiopods and trilobites. The Quarry Lakes excavation, part of the Wainfleet Wetlands Conservation Area, exposes approximately 5.6 m of Lithofacies 1 in the north face of the old quarry. Lithofacies 3, consisting of dark green, very argillaceous, fossiliferous limestone with sparse chert, is reported to be limited to the basal part of the Edgecliff Member in the Port Colborne area. Approximately 1.2 m of

Formation (Age)	**Member**	**Description**
		this shaley lithofacies may be seen at the base of the Onondaga Formation in the south wall of the existing Law Quarry. A thin shale seam at the top of the section appears to mark the contact at the Law Quarry.
Bois Blanc Formation (Lower Devonian Age)		Medium- to light-grey fine-textured, thin to medium-bedded, cherty limestone with shaley partings and minor, inter-bedded dolostones. It is very diverse in texture and composition (Derry et al., 1989). Fossils and bioturbation are common, and the chert can be light grey or brown in colour and occurs as thin beds or nodules. Fossils include rugose corals, tabulate corals, amphipora and brachiopods. Within the existing quarry, the Bois Blanc Formation thins northward due to the erosion surface and is absent at the north end of the quarry. It reaches a typical maximum thickness of about 5.4 metres within the south wall of the existing quarry (Gartner Lee Ltd., 2005).
	Springvale Member	Discontinuous basal portion of the Bois Blanc Formation. It consists of a medium to coarse grained, green to grey, glauconitic sandstone with some interbeds of limestone, dolostone and brown chert (Derry et al., 1989). Where it exists, the Springvale Sandstone is observed within the existing quarry to be approximately 0.5 metres thick (Gartner Lee Ltd., 2005).
Bertie Formation (Upper Silurian age)		Composed predominantly of resistant dolostones that are exposed in the Onondaga Escarpment (Derry et al., 1989). The lower contact of the Bertie Formation with the Salina Formation, below the existing quarry floor, is gradational, and its upper contact with Devonian-age rocks is a distinct erosional surface representing a major disconformity.
	Akron Member	Dominated by grey, fine grained dolostone, thin to massive bedded, trace shale partings and calcite nodules and distinctly mottled in appearance.
	Williamsville Member	Medium grey, fine to medium grained, shaley dolostones with interbedded dolomitic shales.
	Scajaquada Member	Interbedded shale, dolomitic shale and shaley dolostone. Locally, the basal part of the Scajaquada Member contains a thin, conglomeratic bed with clasts of the underlying Falkirk Member.
	Falkirk Member	Very hard, laminated, medium to dark brown, massive bedded crystalline to medium grained dolostone. Vugs often containing calcite, gypsum or celestite and trace shaley laminations are common in the Falkirk Member. This unit has excellent aggregate properties and represents the deepest mined bedrock at the site
	Oatka Member	Fine crystalline, grey to dark grey dolostone interbedded with dark grey to more rarely greenish shale. In proximity to the Onondaga Escarpment, a high porosity, “paleokarst” rubble zone has been identified at some

Formation (Age)	**Member**	**Description**
		locations within the portions of the Oatka Formation generally near the Salina contact. The Oatka is not utilized as a source of construction aggregate in Ontario.
Salina Formation (Upper Silurian Age)		Argillaceous dolostone and shale with abundant gypsum nodules to lenses. Hydrogen sulphide gas, which originates from the Salina Formation has been observed as bubbles through the floor of the existing quarry, often resulting in white precipitate in standing water. The Salina Formation is mined for gypsum elsewhere in southern Ontario but is not suitable for aggregate production and generally not considered a drinking water source rock due to water quality and quantity issues.

Figure 6 illustrates the Paleozoic bedrock mapping with the interpolated subcrops of the various bedrock units described above.

The bedrock surface has been interpolated using GIS software and the available data from the Site and other studies noted above, including the MECP water well database. The interpolated bedrock topography is shown in **Figure 7**. It is noted that the interpolated bedrock topography shown in **Figure 7** is consistent with the bedrock topography mapping completed as part of the NPCA Source Protection report.

The Erigan Channel, a buried ancestral bedrock valley that is inferred to link Lake Erie and Lake Ontario, is situated to the west of the Site near the community of Lowbanks. The bedrock elevation of the Erigan Channel at Lowbanks is approximately 123 metres above sea level, well below the water elevation of Lake Erie (~174 m above sea level (masl)). The buried bedrock valley is suspected to influence regional groundwater flow patterns within weathered Salina Formation bedrock. Enhanced hydraulic conductivities have been observed along buried bedrock valleys due to the creation and solution-enhancement of fractures and bedding planes located within the bedrock walls.

Recent unpublished quaternary sediment mapping by the Ontario Geological Survey (OGS) and geophysical mapping by the Geological Survey of Canada (GSC) identified the presence of buried bedrock channels in many locations along the Lake Erie shoreline where a curvature towards the north is observed (A. Burt, Personal Comm., **Figure 2-1** below).

Regional north-south and east-west oriented cross sections through the Site centroid are shown in **Figures 8 and 9**, respectively. The regional sections illustrate the topography, overburden thickness and bedrock type across the study area. The cross sections are based on boreholes completed as part of this study and other studies listed at the outset of this section. The inferred bedrock stratigraphic contacts were developed based on the discussion provided below. A discussion of the regional groundwater flow is included in **Section 2.4.1**.

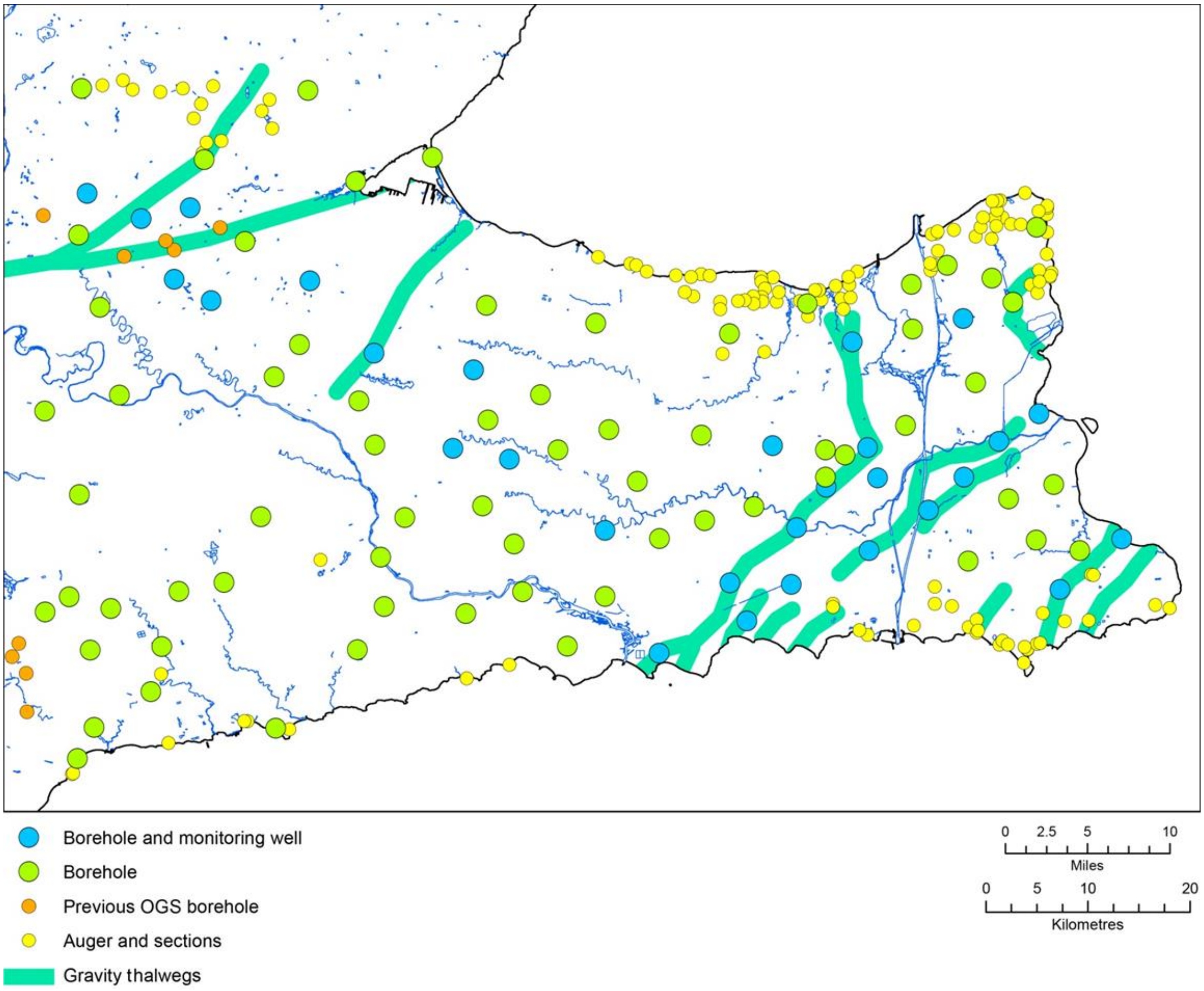

Figure 2-1: Location of buried bedrock channels in the Niagara Peninsula (A. Burt, Personal Comm.)

2.3.2.2 LOCAL SETTING

Photo 1 (below) is a photograph taken from the existing quarry south face exposing the Bois Blanc and Bertie Formations in the deepest part of the quarry.

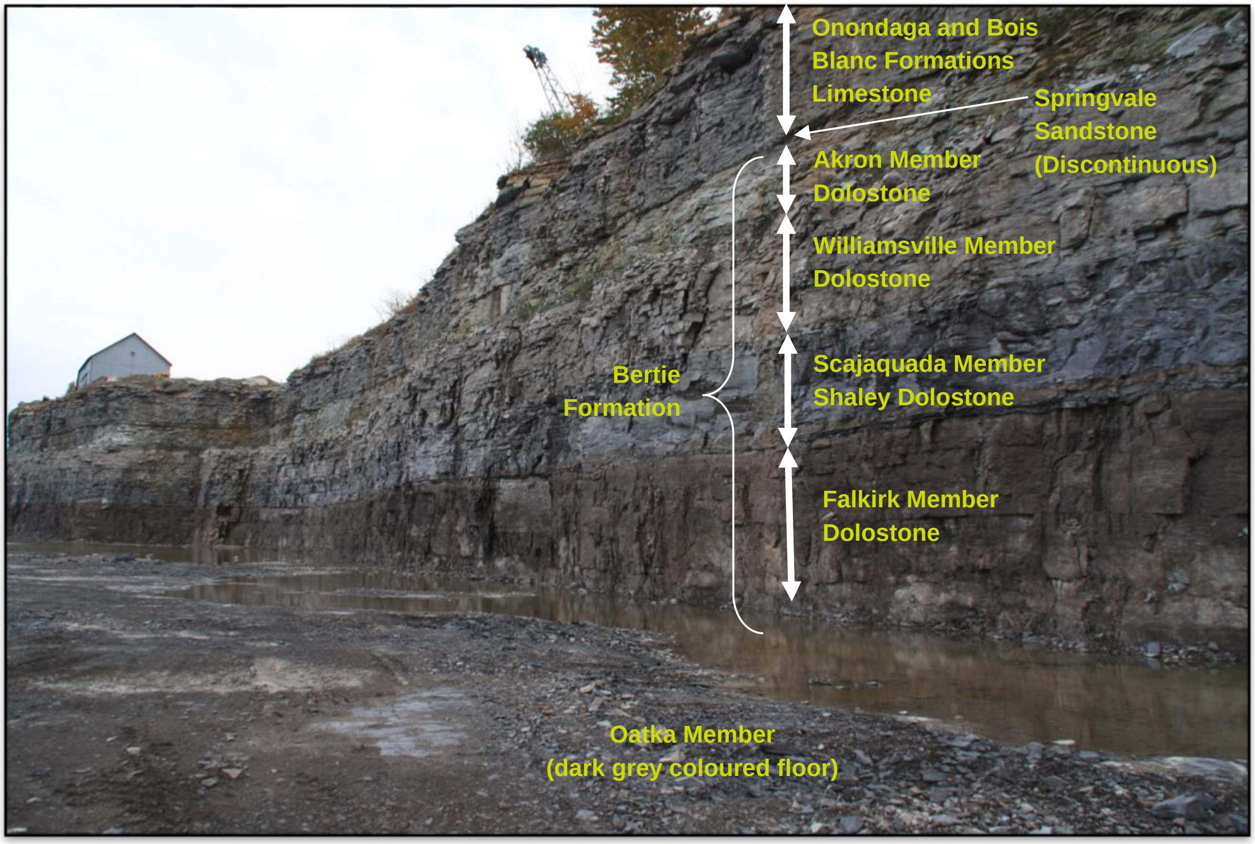

Photo 1: Existing Quarry South Face

Bedrock was contacted at each deep borehole location completed during the drilling programs completed as part of this study. A summary of the stratigraphic contact information for each borehole is provided in **Table C-2, Appendix C**. Rock core photos are also provided in **Appendix C**. The Site-scale bedrock topography is shown in **Figure 10**, and the local topography, overburden thickness and bedrock strata are shown in cross sections A-A’ and B-B’, included as **Figures 11 and 12**, respectively. The cross-section locations are shown in the Site Plan, **Figure 2**.

The bedrock strata encountered in the boreholes are described from youngest (Bois Blanc Formation) to oldest (Salina Formation) below.

Bois Blanc Formation

The Bois Blanc Formation consists of a hard, weathered, light grey to grey, fine to medium grained dolostone with trace to some chert. It is medium bedded, highly fossiliferous and bioturbated with wavy laminations observed in some core. Calcite nodules and pyrite mineralization was observed in some core. The RQD ranges from very poor to excellent.

Bois Blanc Formation, Springvale Member

The lower contact between the un-subdivided Bois Blanc Formation and the Springvale member of the Bois Blanc Formation is typically distinct owing to the sharp colour and lithology change. The Springvale member of the Bois Blanc Formation consists of a green to grey, medium grained, glauconitic sandstone with trace to some chert nodules and occasional calcite nodules. The RQD is typically fair to good.

The Springvale member contact ranges in depth from 1.3 m below ground surface (mbgs) at MW6 to 7.9 mbgs at MW4. The stratigraphic contact data from the Site boreholes suggest that the contact of the Springvale member also dips to the southeast, ranging in elevation from 181.8 masl at MW9 in the northwest to 171.7 masl at MW1 in the southeast. The Springvale member of the Bois Blanc Formation does not subcrop at MW5 near the Onondaga Escarpment.

The thickness of the Springvale member is relatively consistent across the Site, ranging from 1.8 m at MW10 in the southeast to 0.5 m at MW6 in the northeast.

Bertie Formation, Akron Member

The lower contact between the Springvale member of the Bois Blanc Formation and the Akron member of the Bertie Formation is typically distinct owing to the sharp colour and lithology change. The Akron member of the Bertie Formation consists of grey, crystalline to fine grained dolostone. The Akron member is thinly bedded with trace shale partings and calcite nodules. The RQD is typically fair to excellent, except at MW6 where the RQD is very poor to fair.

The Akron member contact ranges in depth from 1.8 mbgs at MW6 to 7.9 mbgs at MW4 and MW12. The stratigraphic contact data from the Site boreholes suggest that the contact of the Akron member dips to the east, ranging in elevation from 181.1 masl at MW6 in the southwest to 171.1 masl at MW1 in the southeast. The Akron member of the Bertie Formation does not subcrop at MW5 near the Onondaga Escarpment.

The thickness of the Akron member ranges from from 4.8 m at MW6 in the northeast to 2.0 m at MW10 in the southeast.

Bertie Formation, Williamsville Member

The lower contact between the Akron member and the Williamsville member of the Bertie Formation is gradational. The Williamsville member of the Bertie Formation consists of medium grey, fine to medium grained dolostone with trace shale partings. The RQD is typically good to excellent.

The Williamsville member contact ranges in depth from 6.6 mbgs at MW6 to 12.9 mbgs at MW12. The stratigraphic contact data from the Site boreholes suggest that the contact of the Williamsville member dips to the east, ranging in elevation from 176.3 masl at MW6 in the southwest to 168.5 masl at MW1 in the southeast. The Williamsville member of the Bertie Formation does not subcrop at MW5 near the Onondaga Escarpment.

The thickness of the Williamsville member ranges from 2.8 m at MW9 in the west to 0.8 m at MW4 and MW12 in the south.

Bertie Formation, Scajaquada Member

The lower contact between the Williamsville member and Scajaquada member of the Bertie Formation is gradational. The Scajaquada member of the Bertie Formation consists of medium to dark grey, fine grained dolostone. The Scajaquada member is thinly bedded with shaly laminations increasing with depth. The RQD is typically fair to excellent.

The Scajaquada member contact ranges in depth from 8.1 mbgs at MW6 to 13.4 mbgs at MW4. The stratigraphic contact data from the Site boreholes suggest that the contact of the Scajaquada member dips to the east, ranging in elevation from 174.8 masl at MW6 in the southwest to 165.9 masl at MW1 in the southeast. The Scajaquada member of the Bertie Formation does not subcrop at MW5 near the Onondaga Escarpment.

The thickness of the Scajaquada member ranges from 3.1 m at MW10 in the southwest to 0.8 m at MW12 in the south.

Bertie Formation, Falkirk Member

The lower contact between the Scajaquada member and Falkirk Member of the Bertie Formation is typically distinct owing to the sharp colour change and the transition from thin to medium bedding. The Falkirk member of the Bertie Formation consists of brown to grey, fine to medium grained, medium bedded, weathered argillaceous dolostone with trace to some shaly laminations increasing with depth. In some boreholes, the Oatka member makes a 1 m to 4 m appearance before transitioning back to the Falkirk member near the lower contact of the Falkirk member and the Oatka member. The RQD is typically fair to excellent.

The Falkirk member contact ranges in depth from 4.6 mbgs at MW5 to 17.0 mbgs at MW12. The stratigraphic contact data from the Site boreholes suggest that the contact of the Falkirk dips to the east, ranging in elevation from 172.5 masl at MW6 in the southwest to 163.6 masl at MW1 in the southeast.

The thickness of the Falkirk ranges from 7.4 m at MW4 in the south to 3.9 m at MW5 in the north.

Bertie Formation, Oatka Member

The lower contact between the Falkirk member and Oatka Member of the Bertie Formation is typically distinct owing to the sharp colour and textural change. The Oatka member of the Bertie Formation consists of fine grained, smooth, grey dolostone. The RQD ranges from very poor to excellent. The RQD is poor where the Oatka member appears as ‘karst rubble’ near the crest of the Onondaga Escarpment at MW5 with void spaces up to several metres encountered during drilling.

The Oatka member contact ranges in depth from 8.6 mbgs at MW5 and MW9 to 23.2 mbgs at MW4. The stratigraphic contact data from the Site boreholes suggest that the contact of the Falkirk dips to the south, ranging in elevation from 169.3 masl at MW5 in the north to 161.4 masl at MW11 in the southeast.

The thickness of the Oatka member ranges from 2.1 m at MW4 in the south to 10.6 m at MW9 in the north.

Salina Formation

The lower contact between the Oatka member of the Bertie Formation and the underlying Salina Formation is distinct, characterised by the presence of abundant gypsum and shale interbeds. The Salina Formation consists of a grey, fine crystalline dolomitic shale with interbedded to interlaminated gypsum beds and nodules. The Salina Formation is locally vuggy and fractured. The RQD is typically good to excellent, except at MW5 in the ‘karst rubble zone’ at the crest of the Onondaga Escarpment.

The Salina Formation contact ranges in depth from 18.4 mbgs at MW6 to 26.1 mbgs at MW12. The stratigraphic contact data from the Site boreholes suggest that the contact of the Salina Formation also dips to the south, ranging in elevation from 164.5 masl at MW6 in the northwest to 153.8 masl at MW1 in the southeast.

Stratigraphic Interpolation

Planar bedrock contacts were interpolated for the various units encountered. Additional details of the interpolation may be found in **Appendix H**.

2.4 HYDROGEOLOGY

2.4.1 REGIONAL GROUNDWATER SETTING

Regionally, a groundwater divide is inferred to roughly coincide with the surface water divide between Lake Erie and the Welland River drainage basin (Gartner Lee Ltd, 1987). Groundwater is inferred to flow to the north and south on either side of the divide. Two aquifer systems have been identified from the water levels at the Site (GLL, 2005). A shallow, unconfined system (i.e., the shallow bedrock aquifer) was identified within the Bois Blanc and Upper Bertie Formations. The upper Bertie Formation members, particularly the Scajaquada member, likely act as an aquitard, confining the deeper bedrock units of the Bertie Formation forming a deep aquifer. Nonetheless, based on recent observations from the Site dataloggers, the deeper Bertie Formation bedrock units have been observed to respond rapidly to precipitation events, with equally rapid dissipation.

Significant groundwater inflow from the Oatka member of the Bertie Formation through the floor of the existing quarry is observed as open ice-free ponds throughout the winter. These may be associated with observations of bubbling hydrogen sulphide gas.

Typically, groundwater quality in the area is poor with high hardness, iron and sulphur (hydrogen sulphide and sulphates) in the water, which likely accounts for the number of residents who use cisterns for their water supply. Shallow groundwater is often of better quality and highly productive, relatively shallow bedrock supply wells are known to exist south and east of the Site.

2.4.2 LOCAL GROUNDWATER SETTING

The bedrock units relevant to this study have been divided into four hydrostratigraphic units as outlined in the sections below, based on the regional groundwater setting interpretation above. Water level hydrographs are included in **Figures E-1 through E-15**, **Appendix E**. Water level data from the GLL-series of wells is available starting 2004 and the wells installed as part of this study have data starting 2018. As noted in **Section 1.5.3**, various methods were used to perform the hydraulic conductivity testing at the Site. A complete description of the testing and results is provided in **Appendix D**. Hydraulic conductivity ranges and important observations from the hydraulic testing program are discussed below.

2.4.2.1 SHALLOW BEDROCK AQUIFER

The shallow bedrock aquifer consists of the Bois Blanc Formation and upper Bertie Formation bedrock. There are seven wells which are inferred to be completed into this hydrostratigraphic unit at the Site, as listed in **Table C-1, Appendix C**.

Groundwater Elevations

Based on electronic water level monitoring, there appears to be a muted response to precipitation events within the shallow bedrock aquifer, on the order of a maximum of 0.5 m. Minor seasonal fluctuations are observed in the shallow bedrock aquifer wells. In general, the water levels increase in the spring following snow melt and several large precipitation events. Typically, the lowest water levels observed in the shallow bedrock aquifer are in the late summer / early autumn. Most of the wells exhibit seasonal variation on the order of 1 m to 2 m between the spring and late summer.

Generally, the shallow bedrock wells show remarkably little response to dewatering at the existing Law Quarry property. Nearby shallow supply wells, such as those along Young’s Road, show no evidence of quarry dewatering interference. A slight decline in water levels since 2008 at GLL-3 is observed, which is likely due to the progression of the east quarry extension.

There are downward vertical hydraulic gradients present at the nested wells screened in the shallow bedrock aquifer. Stronger downward vertical hydraulic gradients are observed west of the Site at MW9 and MW10, and east of the Site at MW11, as these wells are located farther from the existing dewatered quarry. Weaker downward vertical hydraulic gradients are observed at MW1, which is located within the inferred cone of depression from the existing quarry.

The average shallow bedrock aquifer water table elevation in April 2019 is shown in **Figure 13**. The water level from GLL-4 has not been included in the figure, as the groundwater elevations have historically been the highest on the Site. According to the borehole log for GLL-4, this well is screened entirely in the Bois Blanc Formation limestone, whereas the other shallow bedrock aquifer wells are screened between the Bois Blanc Formation limestone, the Springvale Sandstone and the Akron / Williamsville members of the Bertie Formation bedrock. Groundwater flow in the shallow bedrock aquifer is generally eastward to southeast in the vicinity of the Site. Historically, a groundwater divide existed approximately 200 metres to the east of the excavation. The available data suggests a relatively small cone of depression in the shallow aquifer due to existing quarry dewatering.

Hydraulic Properties

The packer test results completed during the advancement of selected deep boreholes suggest that the shallow bedrock aquifer has a relatively high hydraulic conductivity but is perhaps not as conductive as the deeper bedrock units. This is generally consistent with the packer testing completed as part of the east quarry extension (GLL, 2005) and the Reeb Quarry license application (Azimuth Consulting Engineers and Earthfx Inc., 2005 and 2008).

Slug tests were completed at the majority of the shallow bedrock aquifer wells to assess the horizontal hydraulic conductivity in this unit, ranging between $2x10^{-6}$ cm/s to $3x10^{-3}$ cm/s, with a geometric mean of $5x10^{-5}$ cm/s. These test results are generally consistent with the range of published values for sound limestone and dolostone bedrock.

During the long-term constant rate pumping test in early 2019, drawdown was not observed at any of the shallow bedrock monitoring wells. This is consistent with observations from a long-term constant rate pumping test completed on the pumping well as part of the east quarry extension licence application (GLL, 2005). These observations support the interpretation of the upper Bertie Formation acting as a confining layer. Although the pumping well is completed as an open hole across the Bois Blanc, Bertie and Salina Formations, drawdown from the pumping test was only observed in the deeper bedrock units.

2.4.2.2 FALKIRK MEMBER

The Falkirk member hydrostratigraphic unit consists of the Falkirk member dolostone of the Berite Formation. There are nine wells which are completed into this hydrostratigraphic unit at the Site, as listed in **Table C-1, Appendix C**.

Groundwater Elevations

Although confined by the shaley Scajaquada member, the wells screened in the Falkirk member appear to respond rapidly to precipitation events. This suggests that in some localized areas, the vertical anisotropy of the confining unit may be high. Increasing water levels are generally observed during the spring and decreasing water levels are observed in the late summer and autumn. Most of the wells exhibit seasonal variation on the order of 1 m to 2 m between the spring and late summer. A slight decline in water levels since 2008 at GLL-11-I is observed, which is likely due to the progression of the excavation to the east of the existing quarry.

The average Falkirk member potentiometric surface elevation in April 2019 is shown in **Figure 14**. The contours show that drawdown effects from the existing quarry dewatering are more pronounced to the west. This observation is also shown in the geological cross-sections in **Figure 11**. The water level at GLL-8 (west of the existing quarry) is 4 m lower than the level at GLL-3 (east of the easting quarry), attributed to anisotropy in the bedrock fracture network.

Vertical hydraulic gradients between the Falkirk member and Oatka / Salina contact interval are typically weak at the nested wells located farthest from the existing quarry. Closer to the quarry, upward gradients are observed at MW1-II/III, and Reeb Quarry nest OW6, due to the drawdown effects of the existing quarry dewatering within the Falkirk member unit. At nest MW5 near the Onondaga Escarpment, there are essentially no vertical gradients between these units, inferred to be the result of enhanced weathering along the buried escarpment face.

Hydraulic Properties

The packer test results completed during the advancement of selected deep boreholes suggest that the Falkirk member is among the most hydraulically conductive hydrostratigraphic units at the Site.

Single well response tests (Slug tests) were completed at the majority of the Falkirk member wells to assess the horizontal hydraulic conductivity in this unit, ranging between $5x10^{-6}$ cm/s to $1x10^{-3}$ cm/s, with a geometric mean of $7x10^{-5}$ cm/s. These test results are generally consistent with the range of published values for sound limestone and dolostone bedrock. A slug test was not completed at GLL-8 as the water level was not able to be drawn down by a significant amount. This is an indication of a significantly high hydraulic conductivity. It is also noted that the highest hydraulic conductivity within this unit was observed at GLL-5 near the Onondaga Escarpment.

During the long-term constant rate pumping test in early 2019, drawdown was observed at Falkirk wells MW10-III (28 m west of pumping well), MW9-III (230 m north of pumping well) and MW12-III (365 m east of pumping well). It is noted that there were no wells screened in the deeper bedrock units during the previous long-term test completed by others in 2005. However, in the Reeb Quarry Addendum Hydrogeological Investigation (Azimuth Environmental Consulting and Earthfx Inc., 2008), it is noted that drawdown of up to 0.3 m was observed within the deeper bedrock units at several monitoring wells situated closest to the pumping well.

A number of different analyses were completed on the pumping test results, as described in **Appendix D**. The estimated transmissivity of the bulk aquifer is between 4 m^2/day to 41 m^2/day, which is similar to the range of values estimated from the 2005 results, and similar to the published range of transmissivity in sound limestone and dolostone bedrock. Based on a saturated thickness of approximately 23.4 m, the estimated hydraulic conductivity range from the pumping test is similar to the geometric mean slug test results for the Falkirk and Oatka members. The aquifer storativity is estimated to be approximately $8x10^{-5}$ based on the results of the observation well distance-drawdown analysis, which is within the expected range of values for sound bedrock.

2.4.2.3 OATKA / SALINA CONTACT

The Oatka / Salina contact hydrostratigraphic unit consists of the Oatka member of the Bertie Formation and the upper Salina Formation bedrock. There are eight wells which are completed into this hydrostratigraphic unit at the Site, as listed in **Table C-1, Appendix C**.

<u>Groundwater Elevations</u>

The potentiometric surface in Oatka / Salina contact unit wells MW1-II and MW4-II, located in close proximity to the existing quarry, is generally steady and fluctuates gradually over the long term, which suggests that these wells are influenced by the existing quarry dewatering. At the remaining Oatka / Salina contact wells, seasonal fluctuations on the order of 3 m are typically observed, while responses to precipitation events can be observed, typically on the order of 1 m. At nest MW6 (**Figure E-5**) and MW12 (**Figure E-11**), more significant responses to precipitation events are observed in the Oatka / Salina contact wells compared to the Falkirk Member wells.

Average groundwater levels in the Oatka / Salina Contact wells in April 2019 are included on **Figure 14**; however, the contours shown on **Figure 14** are drawn using the Falkirk Member wells. The interpreted groundwater flow direction within the Oatka / Salina contact wells is similar to the Falkirk Member wells and a drawdown effect from the existing quarry dewatering is observed.

Vertical hydraulic gradients between the Oatka / Salina contact and Deep Salina units are weak at the nested well locations.

<u>Hydraulic Properties</u>

The packer test results completed during the advancement of selected deep boreholes suggest that the Oatka / Salina contact interval has a similar hydraulic conductivity compared to the Falkirk member.

Slug tests were completed at the majority of the Oatka / Salina contact wells. The horizontal hydraulic conductivity is highly variable for this unit, ranging between $4x10^{-9}$ cm/s and $1x10^{-4}$ cm/s, with a geometric mean of $1x10^{-6}$ cm/s. These test results are generally consistent with the range of published values for sound limestone and dolostone bedrock. It is noted that at MW1-II and MW4-II south of the existing quarry, the water level did not return to pre-test static conditions even after a significant period of time, which suggests that these wells may not have been developed sufficiently following drilling, and / or the surrounding bedrock has a particularly low hydraulic conductivity. Conversely, at MW5-II near the Onondaga Escarpment, a slug test could not be completed as the water level could not be drawn down by a significant amount. This suggests a particularly high hydraulic conductivity at this location.

During the long-term constant rate pumping test in early 2019, drawdown was observed at Oatka / Salina contact wells MW10-II (28 m west of pumping well), MW9-II (230 m north of pumping well) and MW12-II (365 m east of pumping well).

2.4.2.4 DEEP SALINA

There are three wells completed into the deep Salina hydrostratigraphic unit at the Site as listed in **Table C-1, Appendix C.**

<u>Groundwater Elevations</u>

At deep Salina well MW1-I, located southeast of the existing quarry, groundwater levels show similar fluctuations as the shallower Falkirk Member well; although weak downward gradients are observed between the bedrock units at this location. The Falkirk Member and Oatka / Salina contact bedrock at this location is interpreted to be influenced by the existing quarry dewatering.

At deep Salina wells MW5-I and MW10-I, groundwater level elevations mirror those at the shallower bedrock units (Falkirk Member and Oatka / Salina contact).

Hydraulic Properties

The packer test results completed during the advancement of selected deep boreholes suggest that the deep Salina has among the highest hydraulic conductivities at the Site.

Slug tests were completed at two of the three deep Salina wells. The horizontal hydraulic conductivity ranges between $5x10^{-5}$ cm/s and $5x10^{-4}$ cm/s, with a geometric mean of $2x10^{-4}$ cm/s. These test results are notably above the range of published values for shale bedrock, likely as a result of enhanced weathering in this unit. Once again, a slug test could not be completed at MW5-I near the Onondaga Escarpment as significant drawdown could not be achieved.

During the long-term constant rate pumping test in early 2019, drawdown was only observed at the closest deep Salina well MW10-I (28 m west of pumping well).

2.4.3 NIAGARA REGION SOURCE PROTECTION PLAN

As part of the enactment of the Ontario Clean Water Act (2006), Source Protection Plans (SPPs) were developed to protect municipal drinking water sources for each region in southern Ontario. The results of the technical studies undertaken as part of the SPP for Niagara Region are outlined in the *Updated Assessment Report* (NPCA, 2013). In Niagara Region, there are no municipal drinking water sources which are reliant on groundwater supply wells, and therefore, no Wellhead Protection Areas (WHPAs). Instead, surface water sources are used for municipal supply. Intake Protection Zones (IPZs) have been delineated for each drinking water source in the region to identify vulnerable areas, and potential drinking water threats within each IPZ have been identified.

The closest municipal water treatment plant (WTP) to the Site is the Port Colborne WTP, with the intake drawing water from the Welland Canal just downstream of the Bridge Street East crossing. Per Figure 8.2 of the *Updated Assessment Report* (NPCA, 2013), the associated IPZ covers portions of the City of Port Colborne east of Steele Street and the mouth of the Welland Canal on Lake Erie. Both the proposed quarry extension and the Eagle Marsh Drain (i.e., the proposed receiving watercourse for dewatering discharge) are well outside of the Port Colborne WTP IPZ. Therefore, the proposed quarry extension does not represent a potential threat to the municipal drinking water supply.

Highly vulnerable aquifers (HVAs) are designated for areas where an aquifer is relatively shallow and there is minimal protection from the overburden. Per Figure 4.9 of the *Updated Assessment Report* (NPCA, 2013), both the existing quarry and proposed extension are situated within an area designated as an HVA. Aggregate operations are also considered a high vulnerability transport pathway which impacts the HVA designation. As noted previously, there are no municipal groundwater supplies within Niagara Region, but the proposed quarry does represent a potential drinking water threat to local groundwater users. The recommendations in **Section 4** of this report are specifically designed to mitigate potential threats to private well drinking water quantity or quality, and include a comprehensive monitoring program, a well interference complaint mechanism and Spills Contingency Program. Further discussion is provided below.

Significant groundwater recharge areas (SGRAs) are also considered vulnerable to drinking water threats, and have been mapped for the region. Per Figure 4.12 of the *Updated Assessment Report* (NPCA, 2013), both the existing quarry and proposed extension are not situated within an SGRA.

2.4.4 GROUNDWATER USE

2.4.4.1 MECP WATER WELL RECORD SEARCH

A search of the MECP Water Well Record database was undertaken to identify well records located within 1 km of the site. The results of the search are shown on **Figure 15** and summarized in **Table B-1**, **Appendix B**.

A total of twenty-one (21) water well records plot within the search area. Of these well records, seventeen (17) are reported as domestic supply, three (3) are reported as commercial supply and one (1) is reported as public supply. Land parcels which are not associated with a well record may use cisterns or dug wells for supply or have a drilled well with no record. Based on a detailed review of each water well record, including the drillers sketch included on the original well log, there are no water well records that were interpreted to be plotted incorrectly.

The identified public well is mapped within the Site boundary (Lot 7, Concession 2) and the record (record no. 6602174) indicates that the well was drilled in 1963 for the Ontario Department of Highways for a proposed patrol yard. This property is currently vacant and there are no available records which indicate that a patrol yard was ever constructed on the property. The status of this well is unknown. It is noted that there are no municipal groundwater supply systems servicing Niagara Region; all of the municipally serviced areas obtain drinking water from Lake Ontario or Lake Erie.

Of the twenty-one (21) wells which plot within the search area, twenty (20) wells are reportedly installed in the bedrock and one (1) well was terminated in the overburden. The overburden well (record no. 6604076) is located near the western limit of the search area, near the Onondaga Escarpment. Fresh water was reported in twelve (12) wells, sulphur water was reported in eight (8) wells and mineralized water was reported in one (1) well. Where recommended pumping rates are provided on the records, which range between 2 Imperial gallons per minute (Igpm) and 10 Igpm, with a median value of 3.5 Igpm (16 L/min).

2.4.4.2 WATER WELL SURVEY

A water well survey was undertaken in 2018 / 2019 in accordance with MECP technical guidance (MECP, 2008). The survey responses are summarized in **Table B-2, Appendix B**, and depicted graphically in **Figure 15**. The survey results are summarized below:

- ➔ Attempts were made to deliver surveys to a total of the 62 parcels that were identified within a 1 km buffer area of the Site. This total does not include other lands owned by the proponent, Waterford. Six of the parcels either did not have a mailbox, were inaccessible, or vacant; as such, these parcels were not surveyed.
- ➔ Of the 56 remaining properties, a total of 15 surveys were either filled out in person during the door-to-door survey or were completed by the homeowner and mailed to WSP at a later date.
- ➔ The initial door-to-door surveys were conducted in June 2018. At least two attempts at contact were made: once during daytime hours, and a follow-up attempt during evening hours, where no response

was received during the first attempt. In most cases, a third attempt was made during evening hours when no response was received during the first and second attempts.

- ➔ Many of the surveyed property owners use a cistern for their primary water supply, or in addition to a well for their water supply. Of the surveyed property owners, 3 wells were used for domestic purposes, 1 well was used for lawn and / or garden watering / irrigation, 2 wells were used for livestock and gardening, and 6 wells were not in use. One (1) surveyed property owner used a spring associated with the former quarries as their sole water supply, and 8 property owners used a cistern as their sole water supply.

2.4.4.3 PERMITS-TO-TAKE-WATER

A search of the MECP Permit-to-Take-Water (PTTW) database was undertaken as part of the current study to identify permitted groundwater users within the study area.

A total of five (5) active PTTWs are mapped within a 2 km radius of the Site, summarized as follows:

Groundwater Takings

PTTW no. 1541-B2DLQF (Law Quarry, Waterford Sand & Gravel Ltd.) authorizes groundwater takings for construction dewatering up to a maximum rate of 20,190,000 litres/day (approximately 234 L/s).

PTTW no. 3156-BH9L8H (Reeb Quarry, QBJR Aggregates Inc.) authorizes groundwater takings up to a maximum rate of 10,080,000 litres/day (approximately 117 L/s) for construction dewatering and 5,400,000 litres/day (62.5 L/s) for aggregate washing.

PTTW no. 7885-8JSLJM (Scholfield Avenue pumping station, The Corporation of the City of Port Colborne) authorizes groundwater takings for dewatering purposes up to a maximum rate of 8,176,492 litres/day (95 L/s). The dewatering system is in place to limit groundwater infiltration to the City of Port Colborne sewer system. An FOI request was submitted to the MECP for all data submitted to the Water Taking Reporting System (WTRS) for the active and previous PTTW for the pumping station. A representative autumn flow volume of approximately 1,950 m^3/day was estimated for baseline conditions. A sump elevation of 171.7 masl was assumed.

Surface Water and Groundwater Takings

PTTW no. 3541-AHPSYC (Port Colborne Golf Club Inc.) authorizes groundwater takings for golf course irrigation up to a maximum rate of 982,000 litres/day (11 L/s), and surface water takings from Lake Erie of 943,000 litres/day (11 L/s).

Surface Water Takings

PTTW no. 2351-BBXM8S (Port Colborne Water Treatment Plant, The Regional Municipality of Niagara) authorizes surface water takings for municipal water supply purposes from the Welland Canal up to a maximum rate of 45,460,000 litres/day (526 L/s).

Of note, the Townline Tunnel dewatering sump, situated on the Welland Canal approximately 8 km northeast of the Site, is operated by the St. Lawrence Seaway Management Corporation (SLSMC), a federal agency. No PTTW is in place for its operation. Based on previous studies (Farvolden and Nunan, 1970 and Frind, 1970), this dewatering is known to have a significant impact on the regional groundwater flow directions within the weathered Salina Formation bedrock. An inquiry was made by WSP to the local SLSMC in St. Catharines for any monitoring data that may have been recorded over its operational history as part of this study. Flow rates and groundwater elevations at a number of monitoring wells localized around the dewatering sump are reportedly recorded. However, recent flow data were not provided, and only limited elevation data were provided for the sump monitoring wells. A “county wide” water well monitoring program is reportedly also undertaken at selected private domestic supply wells; however, these data were not provided.

The SLSMC did provide a number of historical engineering reports indicating a sump elevation of approximately 152.6 masl, with groundwater flow to the dewatering sump averaging between 930 US gallons per minute (gpm) to 1,020 US gpm (5,000 m^3/day to 5,600 m^3/day). This dewatering was included in the numerical groundwater modeling analysis (refer to **Appendix H**).

2.5 WATER QUALITY

This section summarizes the baseline water quality for the Site. Original laboratory certificates of analysis are not included in this report, but have been kept on file and are available electronically upon request.

2.5.1 GROUNDWATER

Available groundwater chemical results from samples collected from pumping well PW during the 2019 pumping test and by others during the Reeb Quarry Hydrogeological Investigation between 2004 and 2007 are presented in **Table F-1, Appendix F**. In addition to the results provided in **Table F-1**, BTEX volatile organic compounds (VOCs) were analyzed in the 2019 sample collected from the PW and the results were below the laboratory detection limit for each parameter. The groundwater relative ion ratios from the available results are plotted on the trilinear diagram included as **Figure 16**.

The results of the baseline monitoring program at the Site indicate that the groundwater within each hydrostratigraphic unit is typically hard with a neutral pH. Mineralization of the groundwater generally increases with depth, as evidenced by the elevated concentrations of total dissolved solids (TDS), major ions and conductivity in the Salina Formation relative to the Bertie Formation bedrock.

Exceedances of the Ontario Drinking Water Quality Standards (ODWQS) are shown in **Table F-1**, **Appendix F**. Groundwater quality in the pumping well PW discharge generally met the ODWQS, with the exception of aesthetic objective exceedances of sulphide and sulphate. The discharge from the pumping well during the pumping test was observed to be clear and colourless. A sulphur odour was noted during the sample collection. The baseline groundwater quality results at Reeb Quarry nest OW6 indicate that non-health related ODWQS exceedances of hardness and iron commonly occur within the Bertie Formation, while concentrations of turbidity, chloride, manganese and sulphate occasionally exceed the ODWQS. In addition, there were two (2) ODWQS exceedances of health-related parameters in the Bertie Formation bedrock wells: (i) the fluoride concentration marginally exceeded the ODWQS on one occasion in the Falkirk member, and (ii) the lead concentration exceeded the ODWQS on one occasion in the Falkirk member. Similar exceedances occurred within the Reeb Quarry Salina Formation well OW6-IV. The ODWQS exceedances are inferred to be related to ambient conditions within the deeper bedrock units, or the result of existing anthropogenic sources (i.e., agricultural activity, septic systems, etc.).

The baseline groundwater relative ion ratio ranges are illustrated on the trilinear diagram, **Figure 16**. The anion chemical results are plotted on the lower right triangular graph, while the cation chemical results are plotted on the lower left triangular graph. The anion and cation results are combined on the diamond shaped graph in the centre. Water with similar chemical signatures will plot together on the trilinear diagram.

The trilinear diagram presents the results of the 2004 to 2007 groundwater samples collected from Reeb Quarry nest OW6 as ranges. The shallow bedrock aquifer range generally has no dominate anion or cation, or is chloride-enriched. The deeper bedrock units are typically calcium and sulphate-enriched. As shown on the diamond shaped graph in the centre, groundwater quality from the deeper bedrock units plots higher than the shallow bedrock aquifer, indicating that the shallow bedrock aquifer is fresher and less mineralized and the deeper bedrock groundwater has a distinct sulphate influence.

2.5.2 PRIVATE SUPPLY WELLS

A groundwater quality sample of one (1) private supply well was collected during the 2019 pumping test. The private well is located at 20808 Graybiel Road, adjacent to the west of the Site. The groundwater chemical results for the private well sample are included in **Table F-1**, **Appendix F**.

The chemical results for 20808 Graybiel Road were similar to the results at Reeb Quarry nest OW6 and the pumping well PW discharge. Concentrations of TOC, turbidity, iron, manganese, sulphide and sulphate exceeded the ODWQS. The property owner indicated that this well is currently used for livestock and gardening.

2.5.3 SURFACE WATER

Surface water chemical results from samples collected as part of the surface water monitoring program between 2018 and 2019 are presented in **Table G-1, Appendix G**. The surface water relative ion ratios from October 2019 are plotted on the trilinear diagram included as **Figure 16**.

On-going monitoring of ambient surface water quality in the Eagle Marsh Drain subwatershed has been completed by the NPCA. Results from the surface water quality stations operated by the NPCA suggest surface water conditions display anthropogenic impacts. The main contaminants of concern are total phosphorus, E.coli, suspended solids and chloride, originating from sources including agricultural and rural run-off and mineralized quarry dewatering.

The results of the surface water monitoring program at the Site indicate that the baseline ambient surface water quality is generally in poor condition either as a result of natural conditions or other anthropogenic sources unrelated to the existing quarry, consistent with the characterization of the regional surface water conditions included in the NPCA Source Protection report.

Provincial Water Quality Objectives (PWQO) exceedances are shown in **Table G-1, Appendix G**. At the Site, concentrations of total phosphorus and iron typically exceed the PWQO at all stations. Boron typically exceeds the PWQO at SW2 and SW3, as a result of the existing quarry discharge to Eagle Marsh Drain. It is noted, however, that both the existing quarry discharge and downstream boron concentrations are below the long-term Canadian Environmental Quality Guideline (CEQG) for protection of aquatic life (1.5 mg/L). Un-dissociated hydrogen sulphide regularly exceeds the PWQO. In the case of un-dissociated hydrogen sulphide, total phosphorus and iron, the existing quarry discharge reduces the concentrations of these parameters in the downstream surface water quality, meeting the PWQO Policy 2 objective.

As shown in **Figure 16**, the ion ratio for the background surface water at the Site appears to be a mixture of meteoric and shallow bedrock-influenced waters and is slightly calcium-enriched with no dominant anion. The ion ratio for the sample collected from the existing quarry sump is calcium and sulphate enriched and plots within the range of the deep bedrock (Salina Member) on the combined graph. This suggests that most of the groundwater entering the existing quarry sump originates from within the deeper bedrock units, which is consistent with field observations.

2.6 WATER BUDGET

To estimate the water budget, temperature and precipitation data from the Port Colborne climatological station operated by Environment Canada were used. The 30-year climate normal and yearly water budget data for 2011 through 2019 are included in **Appendix I**.

As shown in **Table I-1**, **Appendix I**, the 30-year climate normal (1981-2010) for total annual precipitation for the study area is 984 mm. Using the Thornthwaite Mather methodology, the estimated annual evapotranspiration is 680 mm, yielding an average water surplus of 427 mm/year available for surface water runoff and recharge to the groundwater system. As shown in **Tables I-2 through I-10**, **Appendix I**, the average annual precipitation averaged 887 mm between 2011 and 2019, below the 30-year climate normal. Notable dry years include 2012 (780 mm), 2014 (784 mm), 2015 (762 mm) and 2016 (529 mm), while 2013 (1,178 mm) was notably wetter than normal.

3 IMPACT ASSESSMENT

The numerical groundwater modeling results completed for this study (included in **Appendix H**) were used as a basis for quantifying the effects of the proposed quarry extension on local groundwater users and surface water features.

The study area baseline conditions were simulated using a steady-state numerical groundwater flow model calibrated to observed conditions from the baseline monitoring program. The simulated groundwater flow conditions in the calibrated baseline model are a reasonable representation of observed conditions, and the model is considered sufficiently robust such that predictive model simulations for full quarry development and final rehabilitation can be interpreted with confidence.

The calibrated baseline model is the most representative simulation of the existing conditions within the study area using the data currently available. In the future, the model could be modified to better represent observed conditions as new information becomes available.

The impact assessment outlined below considers the effects of the proposed quarry under full development conditions as well as final rehabilitation to a lake with islands. Cumulative impacts including the licenced Reeb Quarry are also considered.

3.1 FULL DEVELOPMENT CONDITIONS

3.1.1 GROUNDWATER CONDITIONS

3.1.1.1 PREDICTED RADIUS OF INFLUENCE

As noted previously, numerical groundwater modeling was completed to simulate the drawdown within the shallow bedrock aquifer and deeper bedrock units as a result of the proposed quarry extension dewatering. For full details of the modeling, refer to **Appendix H**. The modeling suggests minimal impact to the shallow bedrock aquifer; as such, only the contours for the deeper bedrock units are shown in **Figure 17**. A drawdown of less than 1 m is generally not distinguishable from seasonal fluctuations in the potentiometric surfaces; therefore, a minimum drawdown of 1 m was used to produce the contours.

A drawdown of up to approximately 4 m relative to baseline water levels in the deeper bedrock units is predicted for a small number of parcels adjacent to the southwest of the proposed extension lands. The radius of influence (i.e., 1 m drawdown contour) in the deeper bedrock units extends to the west and south by approximately 1,000 m and 800 m, respectively.

At full quarry development, the stage elevation in the Quarry Lakes ponds is predicted to be reduced by approximately 0.6 m relative to baseline conditions, with 13% of the decrease due to the previously licensed portions of the existing quarry. Discharge from the Quarry Lakes sump is also predicted to decrease. At the Cement Plant Ponds, no impacts from the proposed quarry extension are predicted. Finally, discharge from the Scholfield Avenue pumping station is predicted to decrease by 16% compared to baseline conditions; however, the majority of the decrease is again due to the previously licensed portions of the existing quarry. These impacts are relatively small and will likely be obscured by short-term seasonal and longer-term climatic fluctuations in the ambient groundwater system conditions. Dewatering operations at the Townline Tunnel are not predicted to be impacted by a substantial amount.

An analysis of the water balance under full development conditions for both the Site and Biederman Drain subwatershed is provided in **Section H.7.2**, **Appendix H**. In summary, the full development Site water balance indicates that the predicted annual dewatering rate at full development of the Site is approximately 1,467 m^3/day for the proposed quarry extension, in addition to 4,400 m^3/day for the existing licensed portion of the quarry. In total, the predicted quarry sump discharge under average autumn climatic conditions is approximately 2.1 Mm^3/year, which represents a 35% increase over baseline simulated conditions. The total inflow from recharge also increases due to the removal of the overburden within the proposed limit of extraction. However, the increase in total inflow from recharge exceeds the total outflow due to dewatering. As a result, the net lateral groundwater flow switches from marginally net outward flow under baseline conditions to a net inward flow at full quarry development, and accounts for approximately 74% of the predicted annual dewatering rate.

It is noted that all water that collects within the proposed extension footprint will be directed to the existing quarry sump via an internal drainage network. The sump discharge will continue to be directed to Eagle Marsh Drain; therefore, the Biederman Drain subwatershed area will decrease slightly to approximately 17.6 km^2. The water balance was completed for the reconfigured subwatershed area. At the subwatershed scale, there is a net increase of approximately 6% in the lateral groundwater outflow compared to baseline conditions. However, groundwater / surface water interaction within the Wainfleet Bog largely remains the same as baseline conditions. Finally, groundwater discharge as baseflow to the Biederman Drain is predicted to be reduced by approximately 2 mm/year (averaged over the subwatershed area). However, it is noted that even under baseline conditions, groundwater flux to the Biederman Drain is minimal, which is not unexpected given the thick low permeability underlying clay soils. As such, the ecological function of the Biederman Drain is not anticipated to be impacted at full development of the proposed quarry extension.

3.1.1.2 GROUNDWATER QUALITY

No adverse groundwater quality impacts are predicted as a result of the proposed quarry extension. Chemicals or nutrients are not used during normal quarry operations. Limited quantities of fuel and petroleum products will be used on Site as part of the resource extraction. A spill action plan for these substances is included in the mitigation plan, further discussion is provided below.

3.1.1.3 GROUNDWATER USE

The predicted radius of influence extends over most of the area included in the water well survey. However, drawdown is only predicted for the deeper bedrock units; minimal drawdown is predicted for the shallow bedrock aquifer. Based on a review of the 21 MECP water well records within the search area (included in **Appendix B**), the wells are completed to an average depth of 17 m into bedrock. At well nests MW6 (northwest of Site), MW10 (southwest of Site) and MW12 (south of Site), the depth to the Salina Formation contact ranges between 19 m to 26 m below the top of bedrock. Therefore, where they exist and are still in use, most private water wells present within the study area are inferred to be hydraulically connected to the deeper bedrock units, although as open holes, they would also be open to the shallow bedrock aquifer.

Using the static water levels provided on the well records, these wells have an average of approximately 11 m of available drawdown. Since the predicted drawdown from the proposed quarry is a maximum of

4 m below baseline conditions with decreasing impacts with increasing distance, local water well interference is not expected. Nonetheless, a well interference mitigation plan has been recommended, further details are provided in **Section 4.2** below.

3.1.2 SURFACE WATER CONDITIONS

3.1.2.1 SURFACE WATER FLOW

As noted previously, there is a predicted marginal decrease of groundwater discharge as baseflow to the Biederman Drain; however, under baseline conditions, groundwater flux to the drain is minimal.

The quarry discharge to the Eagle Marsh Drain is predicted to increase by 35% over baseline conditions. During autumn conditions, discharge is predicted to average approximately 5,700 m^3/day (2.1 Mm^3/year). This annual value is notably higher than other local quarries of similar size. This higher rate is attributed to the inflow of deep bedrock groundwater. Baseline sump discharge data since 2012 indicates that discharge during spring conditions is nearly double the rate of autumn conditions, estimated to be approximately 8,000 m^3/day. A 35% increase in the baseline spring conditions discharge rate is calculated as 10,800 m^3/day.

During previous license applications, the NPCA has expressed concern over the increase in flow in the Eagle Marsh Drain from quarry dewatering discharge. An evaluation of the flow capacity of the Eagle Marsh Drain was completed as part of the Reeb Quarry licence application (CCTA, 2008). The conveyance capacity of the drain was determined to be approximately 2.1 m^3/s (180,000 m^3/day) at its limiting point. The predicted full development spring conditions discharge from the future Law Quarry represents approximately 6% of the drain capacity.

3.1.2.2 SURFACE WATER QUALITY

As noted in **Section 2.5.3**, concentrations of total phosphorus and iron consistently exceed the PWQO in the background Eagle Marsh Drain surface water under baseline conditions. Concentrations of un-dissociated hydrogen sulphide also occasionally exceed the PWQO at background station SW1. As such, Eagle Marsh Drain is considered a Policy 2 receiver for these parameters under the PWQO, where

> *"Water quality which presently does not meet the Provincial Water Quality Objectives shall not be degraded further and all practical measures shall be taken to upgrade the water quality to the Objectives."*

Runoff and groundwater infiltration collecting in the proposed quarry extension will be directed to the existing quarry sump where it is discharged to Eagle Marsh Drain. Samples collected from station SW2 indicate that, in addition to the Policy 2 parameters noted above, boron concentrations also regularly exceed the PWQO in the existing quarry discharge.

A comparison of the baseline background and downstream surface water quality in Eagle Marsh Drain and the existing quarry sump discharge for selected parameters noted above and field measured temperature is provided in the table below.

On average, the temperature of the existing quarry discharge is about 1°C warmer than the temperature of the background surface water within Eagle Marsh Drain. As a result, the downstream surface water temperature increases by an average of less than 0.5°C. This effect is considered marginal and is not predicted to negatively impact the ecological function of Eagle Marsh Drain.

Parameter	PWQO	Baseline Median Concentrations		
		Existing Quarry Discharge (Station SW2)	Eagle Marsh Drain	
			Background (Station SW1)	Downstream (Station SW3)
Temperature (°C)	**--**	10.9	9.8	10.2
Un-dissociated Hydrogen Sulphide	**0.002**	0.0008	0.002	0.0009
Total Phosphorus	**0.03**	0.01	0.30	0.039
Boron	**0.2**	0.57	0.03	0.50
Iron	**0.3**	0.20	0.96	0.325

Notes: *Concentrations in mg/L unless otherwise noted*
PWQO – Provincial Water Quality Objectives (MECP 1994 and updates)
Shaded values exceed the PWQO.

As noted previously, in the case of un-dissociated hydrogen sulphide, total phosphorus and iron, the existing quarry discharge reduces the concentrations of these parameters in the downstream surface water quality, meeting the PWQO Policy 2 objective. The baseline median concentration of boron in the existing quarry discharge and at downstream station SW3 is greater than the median background concentration in Eagle Marsh Drain and the PWQO. However, it is noted that both the quarry discharge and downstream boron concentrations are below the long-term Canadian Environmental Quality Guideline (CEQG) for protection of aquatic life (1.5 mg/L). Based on these observations, there are no negative impacts predicted for the ecological function of Eagle Marsh Drain. In most cases, the existing quarry discharge improves the surface water quality in the drain. This effect is predicted to continue with the development of the proposed quarry extension.

Discharge water quality is not expected to change from the current and long-standing conditions. The ecological function of the drain has developed over nearly 100 years of receiving groundwater and accumulated precipitation as discharge from the site.

3.1.2.3 SURFACE WATER USE

A search of all current permitted surface water users in the study area has been completed, as outlined in **Section 2.4.4.3**. None of the active surface water PTTWs in the study area utilize the Eagle Marsh Drain for their source of takings and there are no other known users of the surface water in the drain. Therefore, impacts to surface water users are not expected.

3.2 FINAL REHABILITATION CONDITIONS

Once the quarry excavation is complete, the dewatering will cease, and the excavation will be allowed to fill naturally with precipitation and groundwater discharge. As such, the proposed end use of the quarry is a lake with islands.

Numerical groundwater modeling was completed to predict the long-term steady-state effects of the proposed end use. The full development model was adapted to simulate the final rehabilitation of the Site to a lake. The internal islands were not included in the simulation as they will not have an impact outside of the lake.

A steady-state autumn average stage elevation of approximately 174.4 masl is predicted for the final quarry lake. This is similar to the stage elevation of ± 175 masl shown in the east extension Rehabilitation Plan (Law Quarry Extension, Figure 3 of 4, Licence No. 607541, MHBC Planning, Revised June 2006).

The lowest natural ground surface elevation around the perimeter of the existing quarry is situated within the southeastern portion of the east extension lands, with an elevation of approximately 178 masl. As such, it is predicted that there will be no discharge from the future quarry lake to surface water drainage features under natural climatic conditions. This is consistent with the Site Plans for both the original quarry and east extension which indicated no discharge points.

At final rehabilitation, the steady-state autumn average stage elevation in the Quarry Lakes ponds is predicted to increase by 0.2 m relative to baseline conditions, and discharge from the sump is predicted to average approximately 2,350 m^3/day (0.9 Mm^3/year). This is a notable increase from the average discharge rate under baseline conditions, estimated as 80 m^3/day. The autumn average stage elevation in the Cement Plant Ponds south pond is predicted to increase by 1 m relative to baseline conditions. Finally, the steady-state autumn discharge from the Scholfield Avenue pumping station is predicted to average approximately 2,750 m^3/day (1.0 Mm^3/year), which represents an increase of about 40% compared to baseline conditions. Similar to full development conditions, the Townline Tunnel dewatering system is not predicted to be substantially impacted upon final rehabilitation of the quarry to a lake.

3.2.1 GROUNDWATER CONDITIONS

At final rehabilitation, about 75% of the total inflow to the Site originates as recharge. After the steady-state stage lake elevation is reached, net groundwater flow will be outwards to the surrounding aquifer, similar to baseline conditions. However, the rate of outward groundwater flow doubles relative to baseline conditions. It is expected that once final rehabilitation is achieved, the operation of private wells in the vicinity of the Site will return to similar to or higher than baseline conditions (where the existing quarry sump was in operation).

Similar to full development conditions, no adverse groundwater quality impacts are predicted under final rehabilitation conditions.

3.2.2 SURFACE WATER CONDITIONS

After rehabilitation to the final lake, the total inflow from recharge in the Biederman Drain subwatershed decreases by approximately 22% due to the permanent removal of bedrock outcrops (i.e., a high groundwater recharge area) within the proposed quarry extension footprint. Much of the remaining subwatershed area is underlain by low permeability glaciolacustrine clays, which results in a lower average groundwater recharge estimated for rehabilitation conditions. However, this is not predicted to have a substantial impact on the ecological function of Biederman Drain since there is little groundwater influx to the drain. The very limited recharge from the Wainfleet Bog deposits to the deep groundwater system notably decreases by approximately 38% below baseline conditions as the pressure differential decreases due to the cessation of the quarry sump pumping. Predicted groundwater discharge as baseflow to Biederman Drain, which is currently low, remains reduced at final rehabilitation, although at the watershed scale, this represents a reduction of 2 mm/year.

3.3 CUMULATIVE ASSESSMENT

As noted in **Appendix H**, known permitted groundwater users are included in the calibrated baseline, full development and final rehabilitation models to assess the cumulative impacts from the proposed quarry extension and existing permitted groundwater users.

Non-permitted groundwater users of significance include private domestic well users, and wells used for livestock watering or crop irrigation. In other parts of Niagara Region, the estimated annual demand from these non-permitted groundwater users is less than 1 mm/year. As such, the cumulative impact from these additional takings is interpreted to be negligible.

The Reeb Quarry, situated southeast of the proposed quarry extension, is licensed for extraction; however, excavation has not yet commenced. As part of this study, an additional future scenario model was created to simulate the impacts of both the proposed quarry extension and the Reeb Quarry at full development and final rehabilitation.

In the Addendum Hydrogeological Assessment (Azimuth Environmental Consulting and Earthfx Inc., 2008), it is noted that the Reeb Quarry will be developed in 2 phases. Phase 1 is west of Bessey Road, and phase 2 is east of Bessey Road. Once phase 1 extraction has been completed, the water management plan for the site allows discharge water collected in phase 2 to accumulate in phase 1, with a stage elevation to be maintained at 174 masl. The purpose of the phase 1 pond is to mitigate potential groundwater impacts to the west of the quarry. It is expected that impact from both quarries would be greatest when the Law Quarry extension is fully completed and the Reeb Quarry phase 1 excavation is completed and not yet inundated. Therefore, this scenario was chosen to provide a conservative estimate for the cumulative impact assessment including the effects of Reeb Quarry under full development conditions.

For the final rehabilitation cumulative assessment, it is assumed that both phases of the Reeb Quarry are excavated and inundated to form final quarry lakes. In the Addendum Hydrogeological Assessment (Azimuth Environmental Consulting and Earthfx, 2008), it is noted that an outlet to the Eagle Marsh Drain would be situated on the east side of the phase 2 pond with a control elevation at 175.5 masl.

3.3.1 FULL QUARRY DEVELOPMENT

In the shallow bedrock aquifer, predicted drawdown of up to 3 m occurs to the south of Reeb phase 1 covering mostly vacant conservation lands. The 2 m drawdown contour covers the western portion of the community of Camelot Beach on the Lake Erie north shore. The radius of influence (i.e., 1 m drawdown contour) extends to Golf Club Road in the west, Cement Road in the east and south to the Lake Erie shoreline. It is inferred that the drawdown within the shallow bedrock aquifer is the result of dewatering of the Reeb Quarry, as the full development model for the proposed Law Quarry extension showed no drawdown in this unit. The drawdown contours also suggest that the Quarry Lakes pond could be subject to a decrease of up to 3 m for autumn average conditions, while the Cement Plant Ponds could be subject to a decrease of up to 0.6 m compared to baseline conditions. In the Reeb Quarry Addendum Hydrogeological investigation report (Azimuth Environmental Consulting and Earthfx Inc., 2008), it was stated that development of Reeb phase 1 would cause no impacts to water levels in either of these features.

In the deeper bedrock units, a drawdown of up to 10 m relative to baseline water levels is predicted immediately adjacent to Reeb phase 1. The 1 m drawdown cone covers roughly the same extent as that of the shallow bedrock aquifer, with the addition of the drawdown to the west of the proposed extension.

In this scenario, it is predicted that the average annual dewatering rate for Reeb phase 1 is approximately 2.7 Mm^3/year (7,400 m^3/day) under autumn conditions. It is expected that the daily dewatering rate will be higher during the spring freshet. In the Reeb Quarry Addendum Hydrogeological investigation report (Azimuth Environmental Consulting and Earthfx Inc., 2008), the full development dewatering rate for Reeb phase 1 was simulated as approximately 1.1 Mm^3/year (3,000 m^3/day).

It is also predicted that the average annual dewatering rate for the fully developed Law Quarry will decrease by nearly 80% relative to the scenario without considering Reeb phase 1 cumulative effects. When Reeb phase 1 is fully developed, an average annual dewatering rate of approximately 0.5 Mm^3/year (1,250 m^3/day) at Law Quarry could be expected for autumn conditions. It was acknowledged in the Reeb Quarry Addendum Hydrogeological investigation that because the Reeb Quarry is situated down dip relative to Law Quarry, the drawdown was expected to be of increased magnitude. However, it was predicted that the excavation of Reeb phase 1 would only reduce the Law Quarry dewatering rate by approximately 30%. Based on these observations, the discharge to Eagle Marsh Drain from the Law Quarry would be substantially reduced when the Reeb Quarry is developed.

Finally, when cumulative effects of the proposed quarry extension and Reeb phase 1 are considered, the average autumn sump discharge from the Scholfield Avenue pumping station and Townline Tunnel dewatering sump will decrease by approximately 45% and 2%, respectively, relative to baseline conditions. Both the proposed quarry extension and Reeb phase 1 appear to have minimal impact on pumping at the Townline Tunnel; however, the reduction in pumping at the Scholfield Avenue pumping station is predicted to be significant. Since the pumping station is in place to reduce groundwater infiltration to the City of Port Colborne sewer system and local basement sumps, neither the proposed quarry extension nor Reeb phase 1 will negatively impact its operation.

The cumulative assessment water balance for Biederman Drain subwatershed indicates that when both the proposed quarry extension and Reeb phase 1 are fully developed, the water balance components remain similar to the scenario with full development only at the proposed Law Quarry extension.

3.3.2 FINAL REHABILITATION

At Law Quarry, the cumulative rehabilitated conditions model predicts a steady-state autumn average stage elevation of 174.1 masl with the presence of the Reeb Quarry final lakes to the south. This is a decrease of 0.3 m in comparison to the rehabilitated conditions model simulating only the Law Quarry. The predicted steady-state autumn average stage elevation in the Reeb Quarry final lakes is predicted to be approximately 173.5 masl. This estimate is 2.5 m to 3.5 m lower than the predictions from the Addendum Hydrogeological Assessment. At this lower elevation, flow from the lakes to Eagle Marsh Drain would not occur in the autumn under normal climatic conditions.

In the cumulative scenario for rehabilitated conditions, the steady-state autumn average stage elevation in the Quarry Lakes ponds is predicted to increase by less than 0.1 m relative to the rehabilitated scenario where only Law Quarry is simulated. Likewise, the steady-state average autumn discharge from the sump is predicted to increase to 2,800 m^3/day (1.0 Mm^3/year), a nearly 20% increase relative to rehabilitation conditions considering Law Quarry only. The autumn average stage elevation in the Cement Plant Ponds south pond is predicted to decrease by 0.2 m, and steady-state autumn discharge from the Scholfield Avenue pumping station is predicted to decrease slightly to 2,600 m^3/day (0.95 Mm^3/year).

The cumulative assessment Biederman Drain subwatershed water balance for rehabilitated conditions is not substantially different from when only the Law Quarry rehabilitated conditions are simulated.

4 MITIGATION

To mitigate the impacts of the proposed quarry extension, the following measures are proposed:

- Maintain the current well network and continue the monitoring program to confirm predicted effects of the proposed quarry extension dewatering on the groundwater system and on surface water features;
- Implement a water management plan to manage groundwater discharge and runoff within the proposed quarry extension;
- Implement a well interference mitigation plan for local groundwater users in the event that wells are impacted by the proposed quarry extension dewatering;
- Once operations have begun, implement a spill action plan at the Site; and
- Provide the local community with contact information for reporting any water well interference complaints to Waterford / MECP.

4.1 PROPOSED MONITORING PROGRAM

The purpose of the proposed monitoring program is to:

- Monitor groundwater and surface water resources during the operational phase of the proposed quarry and compare to baseline conditions;
- Maintain a record of daily water takings from the proposed quarry sump;
- Resolve potential water well interference claims with local groundwater users; and
- Provide documentation of the monitoring and assessment results, and provide recommendations for operational or monitoring improvements if necessary.

The proposed monitoring program is summarized on **Table 1**. The monitoring locations are shown on **Figure 18**. It is noted that well nest MW4 and monitoring wells GLL-7 and GLL-8 are within the proposed quarry extension limit of extraction. These monitoring locations have been included in the proposed monitoring program, but will eventually need to be decommissioned as the quarry excavation proceeds. Also, monitoring wells located around the perimeter of the Site may need to be retrofitted with extended riser pipes as the perimeter berms are constructed.

Additional private supply wells may be incorporated to the monitoring program over time. PTTW applications / renewals typically require an updated water well survey to be completed. It is expected that over time, additional water well users within the study area may opt in to the ongoing residential well monitoring program. This will be encouraged by Waterford.

As a condition of the Site’s PTTW, an annual monitoring report, summarizing all monitoring activities, an interpretation of the monitoring results and any recommendations, will be produced for each calendar year during the operational phase of the quarry until the license is surrendered after final rehabilitation is achieved.

4.2 PROPOSED WATER MANAGEMENT PLAN

Since the proposed quarry extension will be developed below the natural groundwater table, the quarry will be dewatered in order to maintain dry working conditions. Water that collects on the quarry floor from either direct precipitation or groundwater discharge will flow along an internal ditch network to the existing quarry sump and be discharged to Eagle Marsh Drain. Overland surface water flow from outside the quarry footprint will be managed by perimeter ditches (where required). The water management plan for both quarry dewatering discharge and surface water flow outlined below will be implemented to address stormwater management for the Site.

4.2.1 QUARRY DEWATERING MANAGEMENT

Dewatering of the proposed quarry will maintain groundwater levels within the quarry excavation at lower elevation than the surrounding groundwater levels within the bedrock. This will induce the movement of groundwater toward the quarry and discharge at the quarry face. Perimeter berms and ditches will prevent the flow of off-site surface water into the quarry; however, direct precipitation will also continue to fall on the quarry floor.

Within the quarry excavation footprint, a network of internal ditches will be constructed in the quarry floor to direct water to the existing sump. Water accumulating in the sump and quarry floor ponds will be subject to increased evaporative losses, estimated to be approximately 800 mm/year (Map 17 – Mean Annual Lake Evaporation, Hydrogeologic Atlas of Canada, 1975). Additional losses of water for dust suppression and wash plant operations will also occur. Previous studies completed by others indicate that water losses of up to 5% of the annual tonnage can be expected. The losses due to increased evaporation have been accounted for in the predictive models.

Submersible pumps will continue to be used to discharge water from the sump to the Eagle Marsh Drain. The quarry discharge is directed to a sediment forebay to prevent erosion and minimize sedimentation downstream of the discharge point.

During an anticipated precipitation event of 25 mm or more, the quarry sump pump will be deactivated, and the quarry will not discharge to the watercourse until the excess water has dissipated. This will prevent quarry-induced flooding along the Eagle Marsh Drain downstream (south) of the Site. As noted previously, the predicted full development spring conditions discharge from the future Law Quarry represents approximately 6% of the drain capacity.

The proposed monitoring program included in **Section 4.1** includes daily discharge volume measurement and monthly sampling of the discharge for water quality analysis.

The proposed quarry extension dewatering involves the collection, transmission, treatment and discharge of water extracted from the quarry as well as process water. The existing quarry is dewatered under PTTW No. 1541-B2DLWF which would remain sufficient for the initial stages of quarrying within the extension lands. An amendment to the existing PTTW may be required in the future if pumping volumes approach the currently approved maximums. In addition, discharge of the sump to the natural environment is considered an industrial sewage works under the broad definition included in Section 53 of the Ontario Water Resources Act (OWRA); therefore, Waterford will be required to obtain an Environmental Compliance Approval for Industrial Sewage Works (ECA (Sewage)). Waterford is currently in the process of applying for an ECA (Sewage) for the existing quarry. It is expected that the findings of this report would be used as support for both future permit applications.

In addition to reporting requirements, a monitoring program and surface water management plan is typically included as part of the conditions for both the PTTW and ECA (Sewage). It is anticipated that the monitoring and reporting requirements for these permits would be substantially met by the proposed monitoring program included above.

4.2.2 SURFACE WATER MANAGEMENT

Berms will be progressively constructed around the perimeter of the Site during the initial site preparation phase. As shown on **Figure 3**, a portion of the headwaters for three watercourses originate at the Site (Eagle Marsh Drain, Biederman Creek and the Feeder Canal). Construction of the perimeter berm will marginally truncate these tributaries but otherwise will have little impact on flow relative to baseline conditions. Where necessary, shallow perimeter ditches / swales will be constructed outside of the perimeter berm to direct overland flow to the existing watercourses.

During anticipated severe precipitation events, offsite runoff would continue to contribute to these watercourses similar to baseline conditions. Quarry discharge to Eagle Marsh Drain would be temporarily deactivated to prevent downstream quarry-induced flooding.

4.3 WELL INTERFERENCE MITIGATION PLAN

Local land owners surrounding the Site rely on a mix of groundwater wells and / or cisterns for domestic supply, commercial, agricultural (including livestock watering and irrigation) and garden watering as identified in the 2018 / 2019 residential water well survey results presented in **Section 2.4.4.2** above. Because the proposed quarry extension dewatering will induce drawdown in the bedrock in the vicinity of the Site, a well interference mitigation plan is proposed to protect local groundwater users in the unlikely event that the operation of their well is impaired.

4.3.1 WATER WELL INTERFERENCE MITIGATION PLAN

The proposed monitoring program is comprehensive and will be able to assess any potential impact to a well and allow proactive mitigation in advance of a well being adversely impacted. In the event a well interference claim is received, the licensee will be required to implement the following mitigation plan to protect the local groundwater users.

Water Well Interference Mitigation Plan

A) If a water well interference claim is received by the licensee the following actions will be taken:
  - The licensee will immediately notify MNRF and MECP of the complaint.
  - The licensee will contact a well contractor in the event of a well malfunction and residents will be provided a temporary water supply within 24 hours, if the issue cannot be easily determined and rectified.

B) The well contractor will contact the resident with the supply issue to rectify the problem as expediently as possible, provided landowner authorization of the work.

C) If the issue raised by the landowner is related to loss of water supply, the licensee will have a consultant / contractor determine the likely causes of the loss of water supply, which can result from a number of factors, including pump failure (owner's expense), extended overuse of the well (owner's expense), lack of well maintenance / well cleaning (owner’s expense) or lowering of the water level in the well from the quarry development (licensee expense). This assessment process would be carried out at the expense of the licensee and the results provided to the homeowner.

D) If it has been determined that the quarry caused the water supply interference (i.e., lowering of the water level), the quarry shall continue to supply water at the licensee's expense until the problem is rectified. The following mitigation measures shall be considered and the appropriate measure(s) implemented at the expense of the licensee:

  - adjust pump pressure;
  - lowering of the pump to take advantage of existing water storage within the well;
  - deepening of the well to increase the available water column, if the well deepening changes the water quality a water treatment shall be provided;
  - widening of the well to increase the available storage of water;
  - relocation of the well to another area on the property;
  - drilling multiple wells; or
  - install a cistern.

E) If the issue raised by the landowner is related to water quality, the licensee will have a consultant / contractor determine the likely causes of the change in water quality, and review monitoring results at the quarry and background monitoring results from the baseline well survey to determine if there is any potential correlation with the quarry. If it has been determined that the quarry caused a water quality issue, the quarry shall continue to supply water at the licensee's expense until the problem is rectified. The licensee shall be responsible for restoring the water supply by replacing the well or providing a water treatment system. The licensee is responsible for the expense to restore the water quality.

4.4 SPILLS CONTINGENCY PROGRAM

Waterford has a detailed Spills Contingency Program for all its sites in accordance with the prescribed conditions for a Class A Category 2 licence under the ARA. Fuel and petroleum products are managed according to the Gasoline Handling Act. No impact to surface or groundwater resources is anticipated from petroleum handling as a result of the proposed quarry extension.

5 SUMMARY OF FINDINGS AND RECOMMENDATIONS

The following is a summary of the key findings of the Level 1 and 2 Water Study undertaken in support of the Law Quarry proposed extension Category 2 Class A quarry license application.

1. A Level 1 and 2 Water Study has been completed for the Law Quarry proposed extension situated within Wainfleet Township. A conceptual understanding of the hydrogeological conditions within the study area was developed to predict the potential effects of the proposed quarry extension on local groundwater users and surface water features.
2. A steady-state numerical groundwater flow model was constructed to simulate baseline hydrogeological conditions at the Site, calibrated to observed baseline conditions. The calibrated baseline model was then modified to predict the effects of quarry extension dewatering on local groundwater users and surface water features at both full quarry development and at final rehabilitation. Known permitted groundwater users are included in the models to assess the cumulative impacts from the proposed quarry extension and existing permitted groundwater users. The estimated annual demand from non-permitted groundwater users within the study area is less than 1 mm/year and was not included in the models. The cumulative assessment also included the licensed Reeb Quarry southeast of the Site.
3. Two aquifer systems have been identified from the water levels at the Site. A shallow, unconfined system (i.e., the shallow bedrock aquifer) was identified within the Bois Blanc and Upper Bertie Formations. The upper Bertie Formation members, particularly the Scajaquada member, likely act as an aquitard, confining the deeper bedrock units of the Bertie Formation forming a deep aquifer. The modeling suggests minimal impact to the shallow bedrock aquifer at full development of the proposed quarry extension, while a drawdown of up to approximately 4 m relative to baseline water levels in the deeper bedrock units is predicted for a small number of parcels adjacent to the southwest of the proposed extension lands. The radius of influence in the deeper bedrock units extends to the west and south by approximately 1,000 m and 800 m, respectively.
4. Based on a review of the MECP water well records within the predicted radius of influence, the wells are completed to an average depth of 17 m into bedrock. Site borehole data indicates that the depth to the Salina Formation contact ranges between 19 m to 26 m below the top of bedrock. Therefore, where they exist and are still in use, most private water wells present within the study area are inferred to be hydraulically connected to the deeper bedrock units, although as open holes, they would also be open to the shallow bedrock aquifer. Using the static water levels provided on the well records, these wells have an average of approximately 11 m of available drawdown. Since the predicted drawdown from the proposed quarry extension at full development is only up to 4 m below baseline conditions, local water well interference is not expected.
5. The impacts on other known groundwater users within the study area were also assessed under full development conditions. Scholfield Avenue pumping station is a permitted dewatering system operated by the City of Port Colborne in the west end of the city (east of the Site) to lower groundwater infiltration to the sewer system. At full development of the quarry, discharge from the

Scholfield Avenue pumping station is predicted to decrease by 16% compared to baseline conditions; however, the majority of the decrease is due to the previously licensed portions of the existing quarry. The Townline Tunnel dewatering sump is an unpermitted dewatering system operated by the St. Lawrence Seaway Management Corporation along the Welland Canal approximately 8 km northeast of the Site and is known to have a significant impact on the regional groundwater flow directions within the weathered Salina Formation bedrock. Dewatering operations at the Townline Tunnel are not predicted to be impacted by a substantial amount under full development conditions.

6. The Wainfleet Bog situated north of the Site contains a surficial water table which is perched above the bedrock water table due to a thick layer of clayey sediment underlying the organic bog deposits. Previous studies by others have concluded that there is no hydraulic connection between the existing quarry sump and the bog deposits. The results of the predictive modeling completed for this study are consistent with the previous findings, and no negative impacts to the bog are anticipated under full development conditions.

7. Groundwater discharge as baseflow to the Biederman Drain north of the Site is predicted to be marginally reduced under full development conditions. However, it is noted that even under baseline conditions, groundwater flux to the Biederman Drain is minimal, which is not unexpected given the thick low permeability underlying clay soils. As such, the ecological function of the Biederman Drain is not anticipated to be impacted at full development of the proposed quarry extension.

8. Runoff and groundwater discharge to the existing quarry collects in the sump and is discharged to the Eagle Marsh Drain. At full development of the proposed quarry extension, the quarry discharge to the Eagle Marsh Drain is predicted to increase by 35% over baseline conditions and is predicted to reach up to 10,800 m^3/day during peak spring conditions. An evaluation of the flow capacity of the Eagle Marsh Drain completed as part of the Reeb Quarry licence application estimated that the conveyance capacity of the drain is approximately 2.1 m^3/s (180,000 m^3/day) at its limiting point. The predicted full development spring conditions discharge represents approximately 6% of the drain capacity. Therefore, the increased quarry discharge is not predicted to overwhelm the capacity of the Eagle Marsh Drain.

9. Baseline surface water sampling suggests that there will be no negative impacts on the ecological function of Eagle Marsh Drain as a result of the increased discharge amounts. In most cases, the existing quarry discharge improves the surface water quality in the drain. This effect is predicted to continue with the development of the proposed quarry extension.

10. Two inundated former quarries within the study area were included in the numerical models to assess potential impacts under full development conditions. The Quarry Lakes ponds situated 1 km south of the Site are currently dewatered by the NPCA to maintain the stage elevation. At full development of the proposed quarry extension, the stage elevation in the Quarry Lakes ponds is predicted to be reduced by approximately 0.6 m relative to baseline conditions, with 13% of the decrease due to the previously licensed portions of the existing quarry. Discharge from the Quarry Lakes dewatering sump operated by the NPCA is also predicted to decrease. At the Cement Plant Ponds former quarry situated 800 m southeast of the existing quarry, the stage elevation is allowed to fluctuate naturally with seasonal changes in precipitation and groundwater discharge. No impacts from the proposed quarry extension are predicted at the Cement Plant Ponds.

11. The proposed end use of the quarry is a lake, which will fill naturally with precipitation and groundwater discharge once the dewatering sump is decommissioned. A steady-state autumn average stage elevation of approximately 174.4 masl is predicted for the final quarry lake. This is similar to the stage elevation of ± 175 masl shown in the east extension Rehabilitation Plan. Since the lowest natural ground surface elevation around the perimeter of the existing quarry has an elevation of approximately 178 masl, it is predicted that there will be no discharge from the future quarry lake to surface water drainage features under natural climatic conditions.

12. After the steady-state stage lake elevation is reached, net groundwater flow will be outwards to the surrounding aquifer, similar to baseline conditions. However, the rate of outward groundwater flow doubles relative to baseline conditions. It is expected that once final rehabilitation is achieved, the operation of private wells in the vicinity of the Site will return to similar to or better than baseline conditions (where the existing quarry sump was in operation).

13. Upon final rehabilitation of the quarry to a lake, the steady-state autumn discharge from the Scholfield Avenue pumping station is predicted to increase by about 40% compared to baseline conditions. Similar to full development conditions, the Townline Tunnel dewatering system is not predicted to be substantially impacted in this scenario.

14. Recharge from the Wainfleet Bog deposits to the deep groundwater system notably decreases by approximately 38% below baseline conditions due to the cessation of the quarry sump pumping. Groundwater discharge as baseflow to Biederman Drain remains reduced at final rehabilitation, although at the watershed scale, this represents a reduction of 2 mm/year.

15. At final rehabilitation, the steady-state autumn average stage elevation in the Quarry Lakes ponds is predicted to increase by 0.2 m relative to baseline conditions, and discharge from the sump is predicted to average approximately 2,350 m^3/day (0.9 Mm^3/year). This is a significant increase from the average discharge rate under baseline conditions, estimated as 80 m^3/day. The autumn average stage elevation in the Cement Plant Ponds south pond is predicted to increase by 1 m relative to baseline conditions.

16. An additional future scenario model was created to simulate the cumulative impacts of both the proposed quarry extension and the Reeb Quarry at full development and final rehabilitation.

To mitigate the impacts of the proposed quarry extension, the following recommendations should be implemented upon licence approval:

- The proposed long-term monitoring program outlined in **Table 1** and shown in **Figure 18**, to be completed during the quarry extension operational and rehabilitation phases, until stable conditions are observed after quarry decommissioning;
- A well interference mitigation plan; and
- A Spills Contingency Program in compliance with the prescribed conditions for a Class A Category 2 licence under the ARA.

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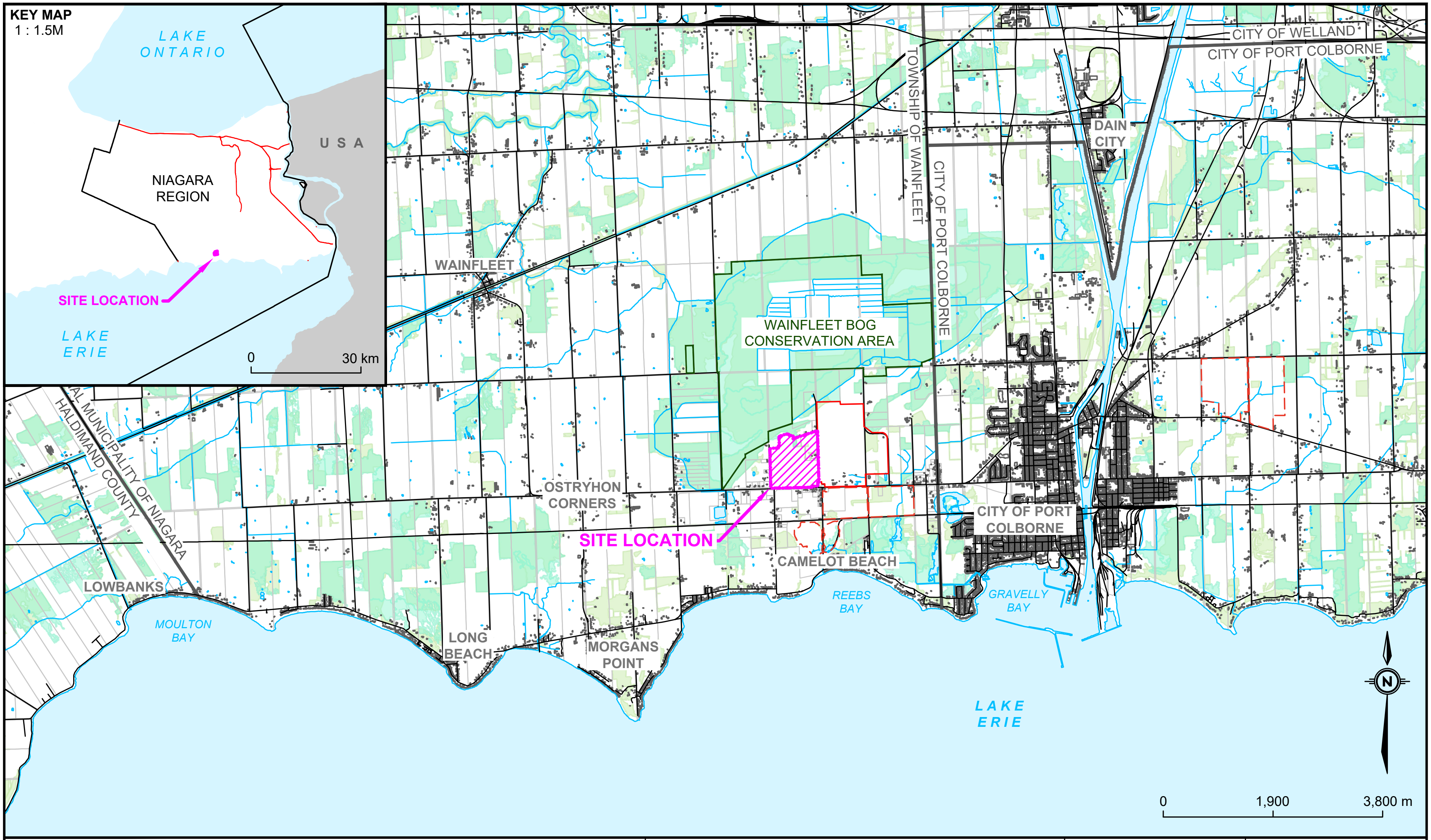
TABLES

Table 1 Proposed Monitoring Program

Activity	Location and Geologic Unit	Frequency	Analysis / Measurement
Groundwater Monitoring			
Groundwater Level Monitoring	**Shallow Bedrock Aquifer (7):** GLL-1, GLL-3, GLL-4, GLL-7, GLL-9, GLL-10, GLL-11-II **Falkirk Member (9):** MW1-III, MW4-III, GLL-5, GLL-6, GLL-8, MW9-III, MW10-III, GLL-11-I, MW12-III **Oatka / Salina Contact (8):** MW1-II, MW4-II, MW5-II, MW6-II, MW9-II, MW10-II, MW11-I, MW12-II **Deep Salina (3):** MW1-I, MW5-I, MW10-I **Quarry Sump (1):** Sump **Residential Wells (2):** 20246 Youngs Road, 722 Highway 3	Semi-Annually	Water level measurement and logger download. Check logger condition.
Well Inspection	**All Monitoring Wells (27)**	Semi-Annually	Visual inspection for well integrity.
Surface Water Monitoring			
Surface Water Sampling	**Quarry Sump Discharge (1):** SW2 **Eagle Marsh Drain (2):** SW1, SW3	Quarterly	**<u>Surface Water List</u>** **Field measurements:** pH, conductivity, temperature, dissolved oxygen **General Parameters:** TSS, turbidity, sulphide, un-dissociated hydrogen sulphide (calculated) **Major Ions:** alkalinity, chloride, sulphate, calcium, magnesium, sodium, potassium **Nutrients/Organic Indicators:** nitrate, nitrite, TKN, ammonia, un-ionized ammonia (calculated), TOC, total phosphorus **Total Metals:** aluminum, arsenic, barium, boron, total chromium, cobalt, copper, iron, lead, manganese, molybdenum, nickel, strontium, uranium, vanadium, zinc **Organics:** Total Oil & Grease

FIGURES



SITE LOCATION MAP

LEVEL 2 WATER STUDY REPORT
LAW QUARRY EXTENSION
WAINFLEET, ON
For Waterford Sand & Gravel Ltd.

DATE: DECEMBER 2021
PROJECT: 111-53023-06
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SCALE: 1 : 95,000
FIGURE No: 1

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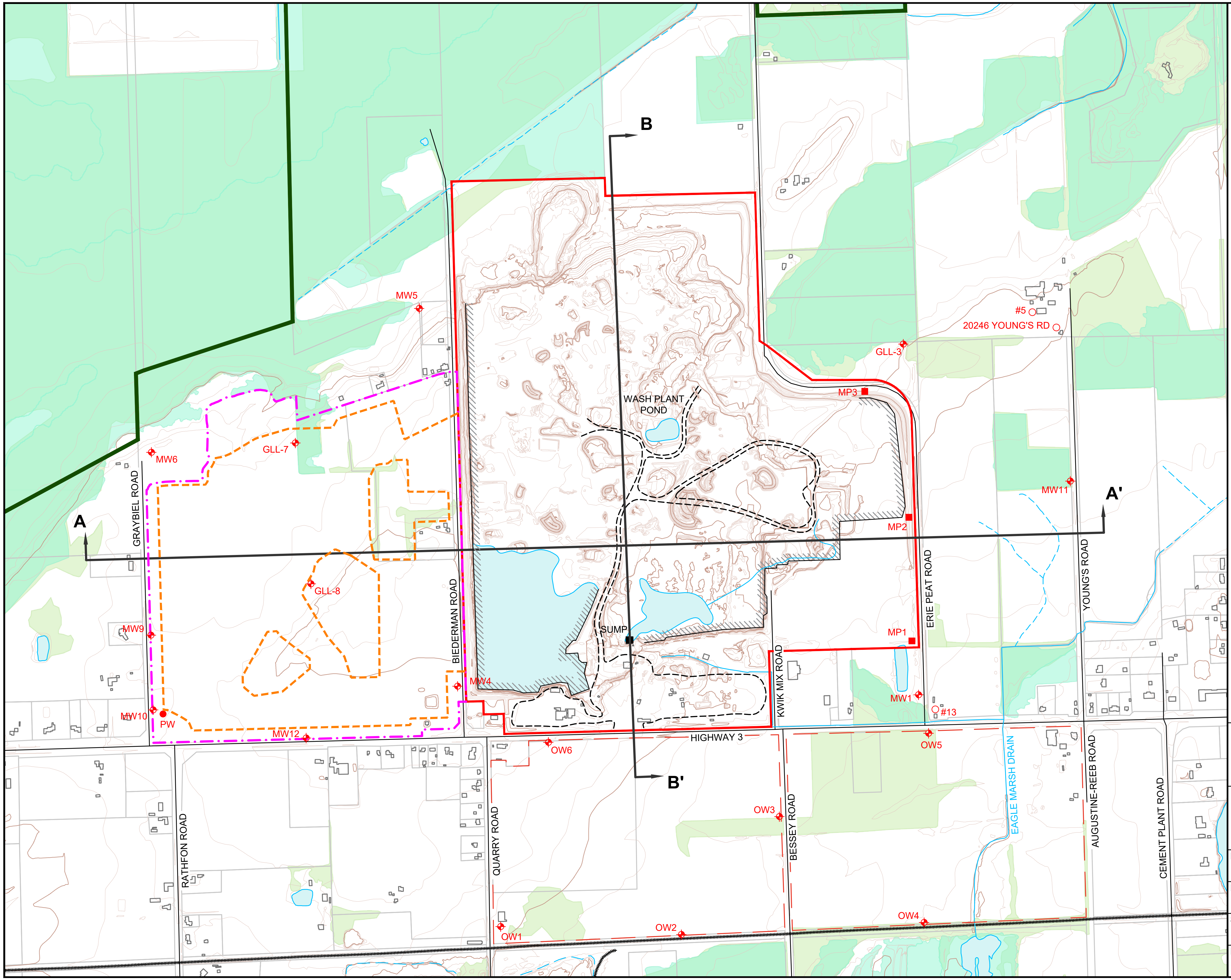

LEGEND

- PROPOSED WEST EXTENSION
- PROPOSED LIMIT OF EXTRACTION
- EXISTING QUARRY LICENCE
- APPROXIMATE LAND PARCEL
- REEB QUARRY LICENCE
- WAINFLEET BOG CONSERVATION AREA
- 🟩 WOODLOT
- 🟩 WETLAND
- PERMANENT STREAM
- INTERMITTENT STREAM
- GROUND SURFACE CONTOUR, 5 m INTERVAL
- GROUND SURFACE CONTOUR, 1 m INTERVAL
- GLL-3 ✦ MONITORING WELL NEST LOCATION AND DESIGNATION
- MP2 ■ MINI-PIEZOMETER LOCATION AND DESIGNATION
- PW ● PUMPING WELL
- ○ PRIVATE WATER WELL
- ▨ APPROXIMATE WORKING FACE
- A CROSS SECTION LOCATION

SITE PLAN

LEVEL 2 WATER STUDY REPORT
LAW QUARRY EXTENSION
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For Waterford Sand & Gravel Ltd.

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FIGURE No: 2

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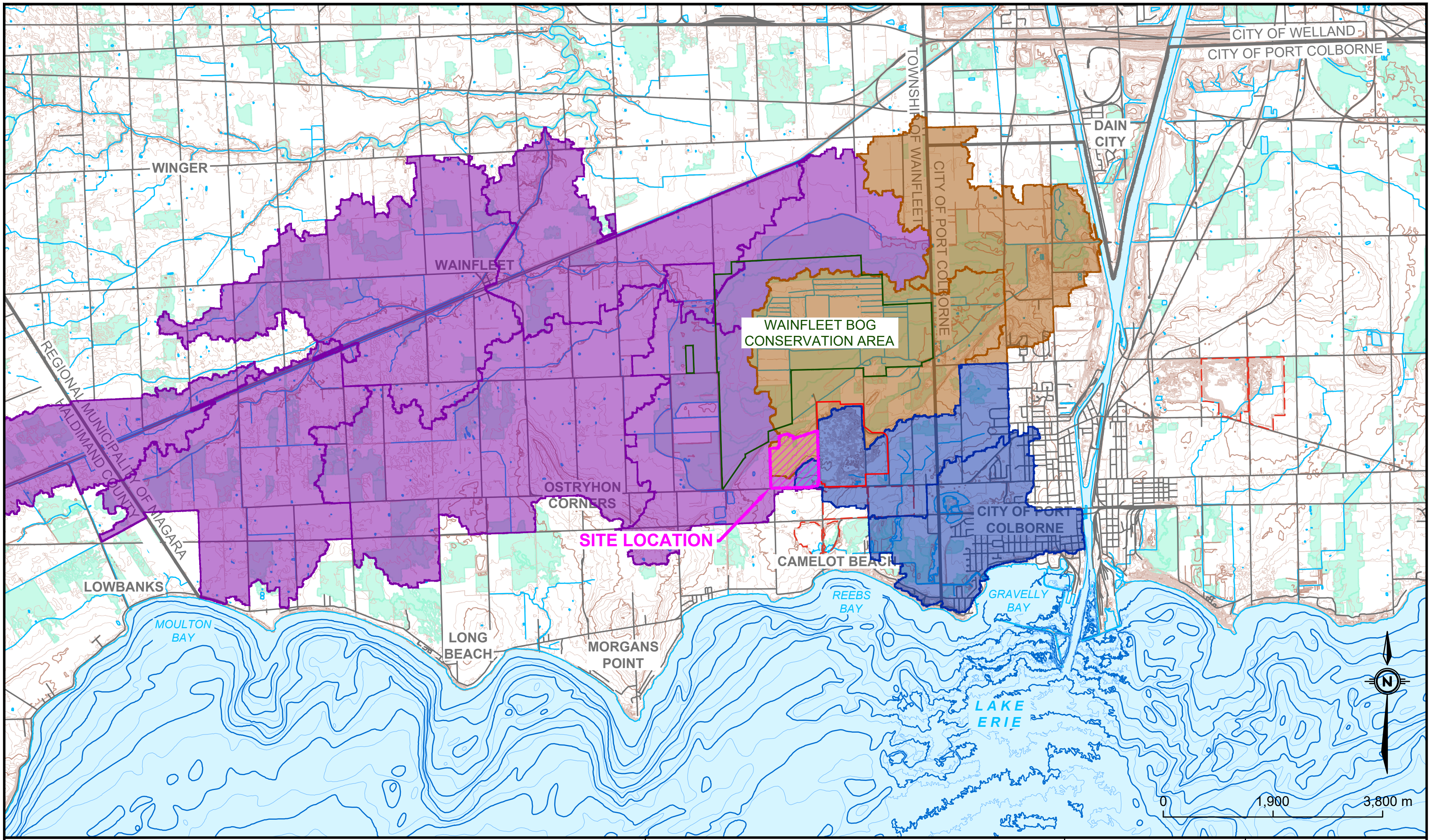

LEGEND

🟩 WETLAND

SUBWATERSHEDS (NPCA, 2013)

— EAGLE MARSH DRAIN

— BIEDERMAN DRAIN

— FEEDER CANAL

STUDY AREA SURFACE TOPOGRAPHY AND DRAINAGE

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DATE: DECEMBER 2021

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FIGURE No: 3

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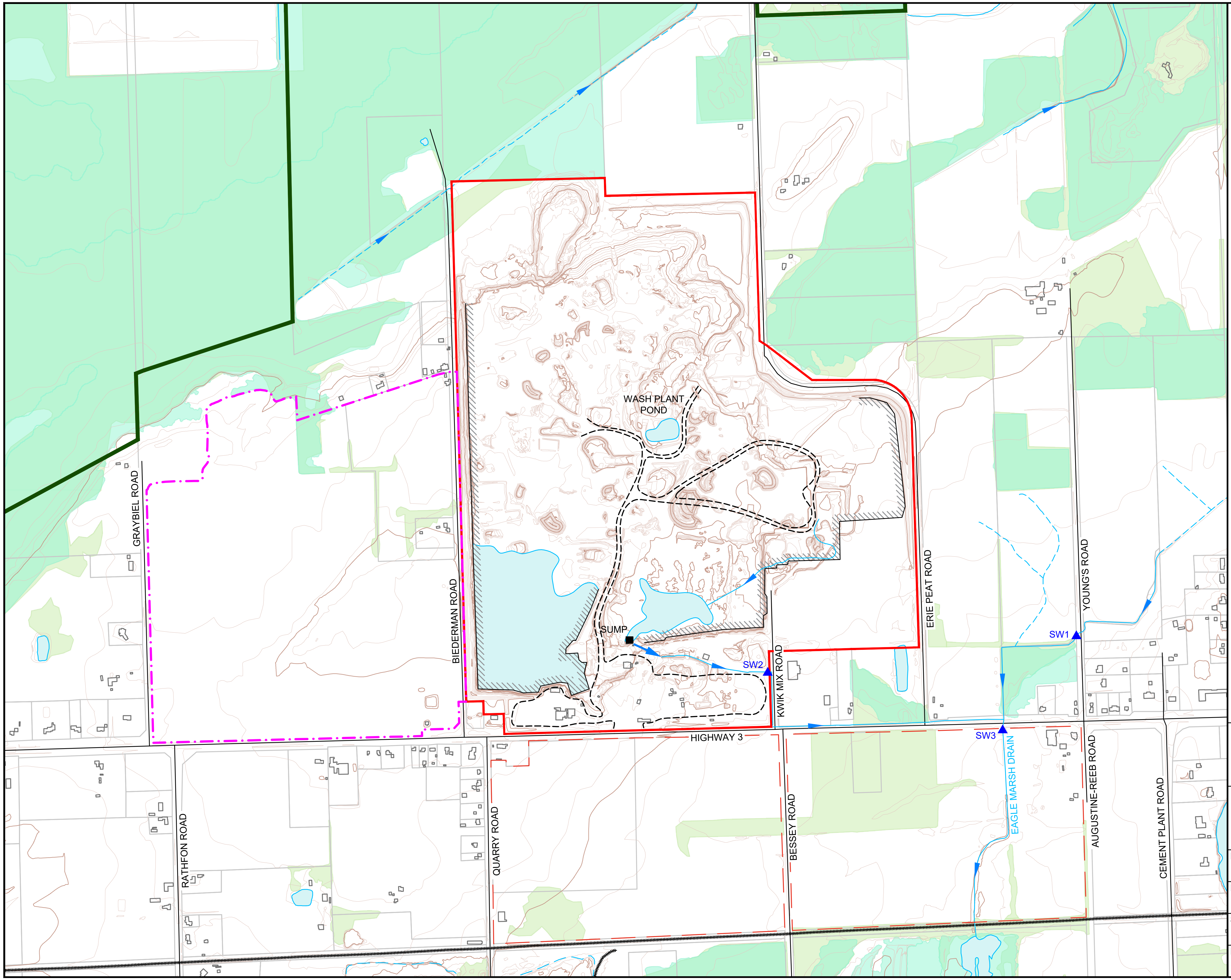

LEGEND

-·-·-	PROPOSED WEST EXTENSION
──	EXISTING QUARRY LICENCE
──	APPROXIMATE LAND PARCEL
- - -	REEB QUARRY LICENCE
──	WAINFLEET BOG CONSERVATION AREA
🟩	WOODLOT
▨	WETLAND
─►	PERMANENT STREAM AND FLOW DIRECTION
- - -	INTERMITTENT STREAM
──	GROUND SURFACE CONTOUR, 5 m INTERVAL
──	GROUND SURFACE CONTOUR, 1 m INTERVAL
SW1 ▲	SURFACE WATER STATION LOCATION AND DESIGNATION
//////	APPROXIMATE WORKING FACE

N

0 200 400 m

SITE SCALE SURFACE TOPOGRAPHY AND DRAINAGE

LEVEL 2 WATER STUDY REPORT
LAW QUARRY EXTENSION
WAINFLEET, ON
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PROJECT: 111-53023-06
SCALE: 1 : 10,000
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FIGURE No: 3A

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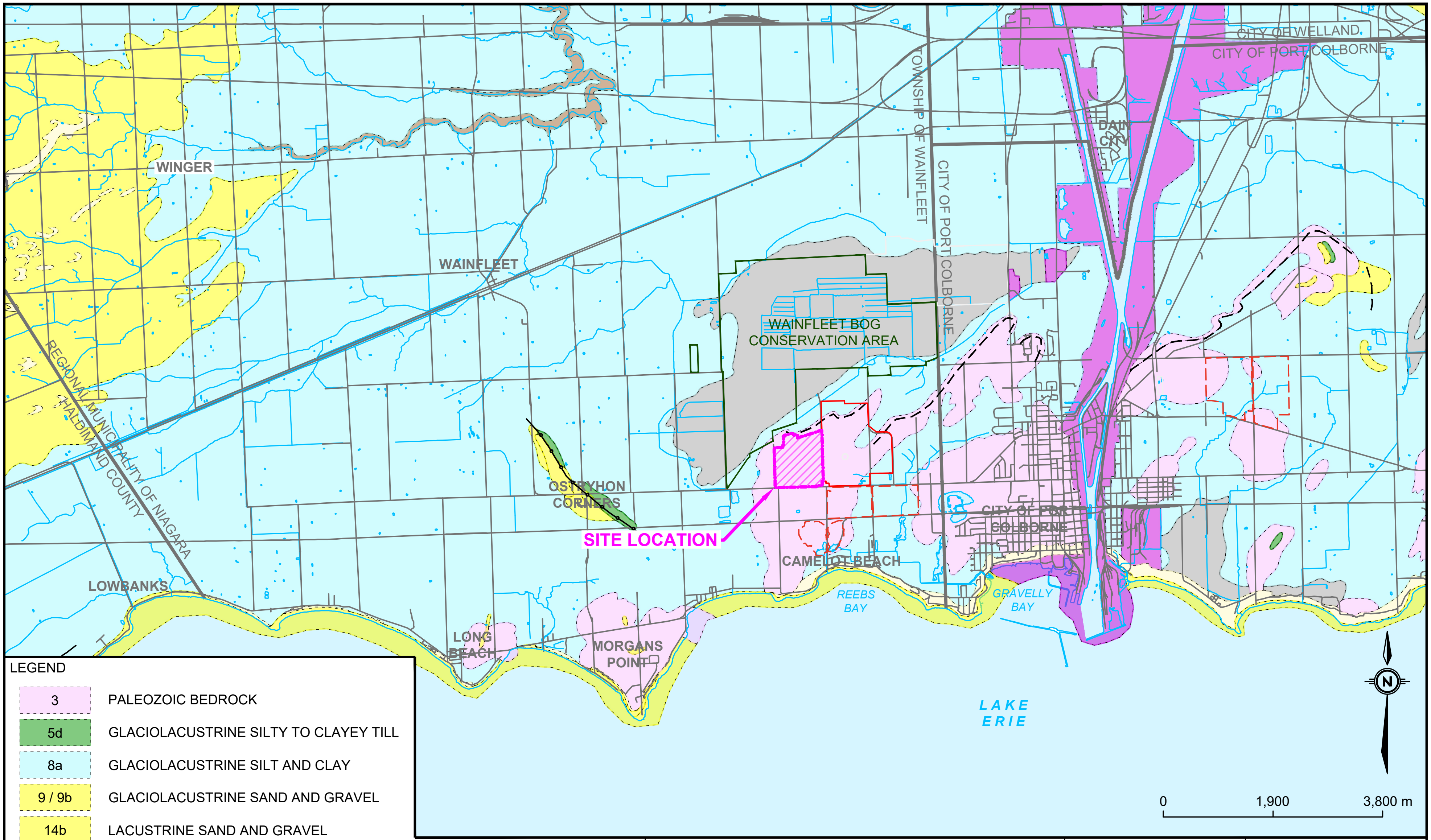

LEGEND

3	PALEOZOIC BEDROCK
5d	GLACIOLACUSTRINE SILTY TO CLAYEY TILL
8a	GLACIOLACUSTRINE SILT AND CLAY
9 / 9b	GLACIOLACUSTRINE SAND AND GRAVEL
14b	LACUSTRINE SAND AND GRAVEL
17	EOLIAN DEPOSITS
19	MODERN ALLUVIAL
20	ORGANIC DEPOSITS
21	MAN-MADE DEPOSITS
— — —	ESCARPMENT
•—•—•	MORAINE

SOURCE: THE ONTARIO GEOLOGICAL SURVEY. 2003.
SURFICIAL GEOLOGY OF SOUTHERN ONTARIO.

SURFICIAL GEOLOGY

LEVEL 2 WATER STUDY REPORT
LAW QUARRY EXTENSION
WAINFLEET, ON
For Waterford Sand & Gravel Ltd.

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PROJECT: 111-53023-06
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SCALE: 1 : 95,000
FIGURE No: 4

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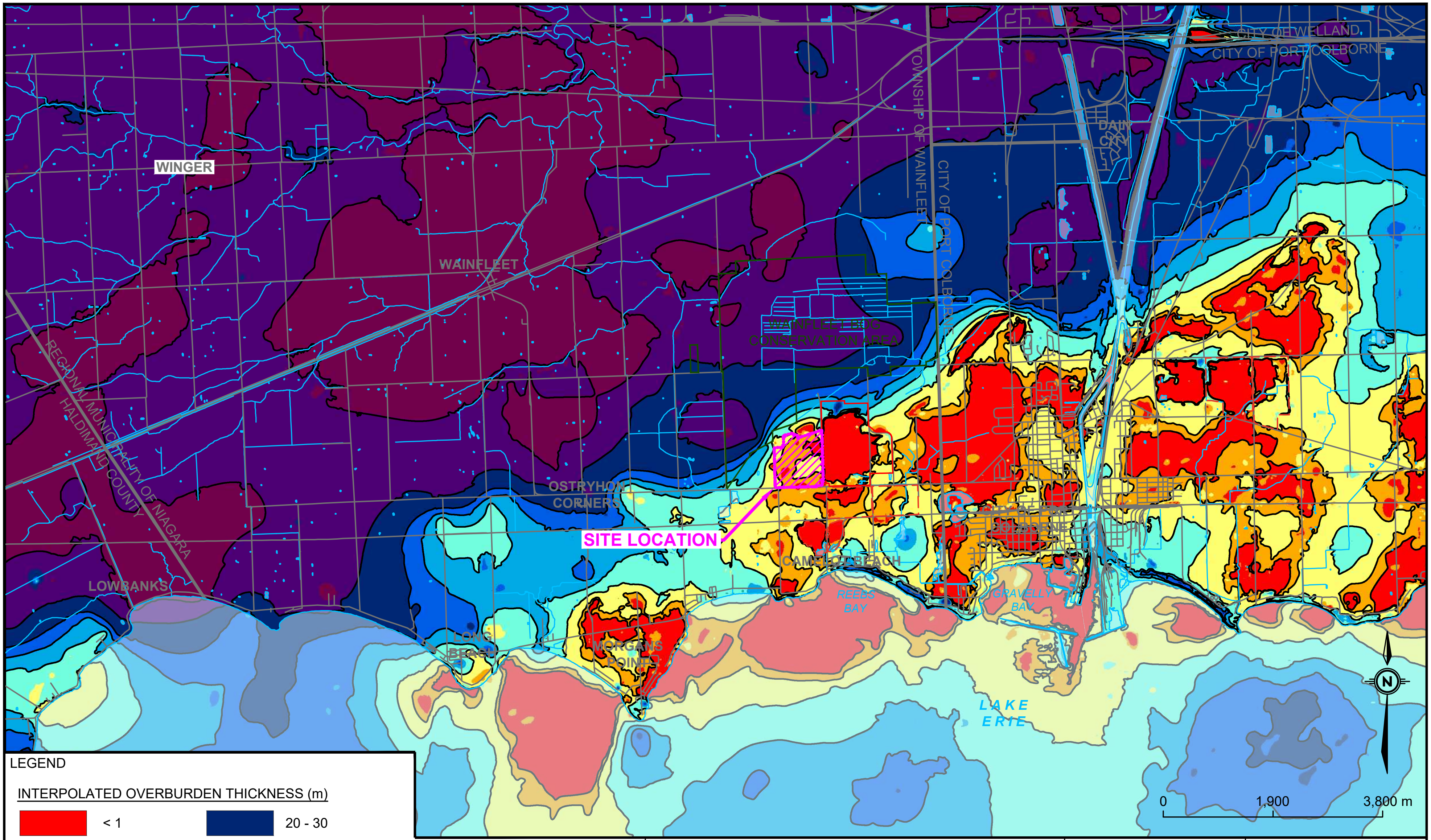

INTERPOLATED OVERBURDEN THICKNESS

LEVEL 2 WATER STUDY REPORT
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FIGURE No: 5

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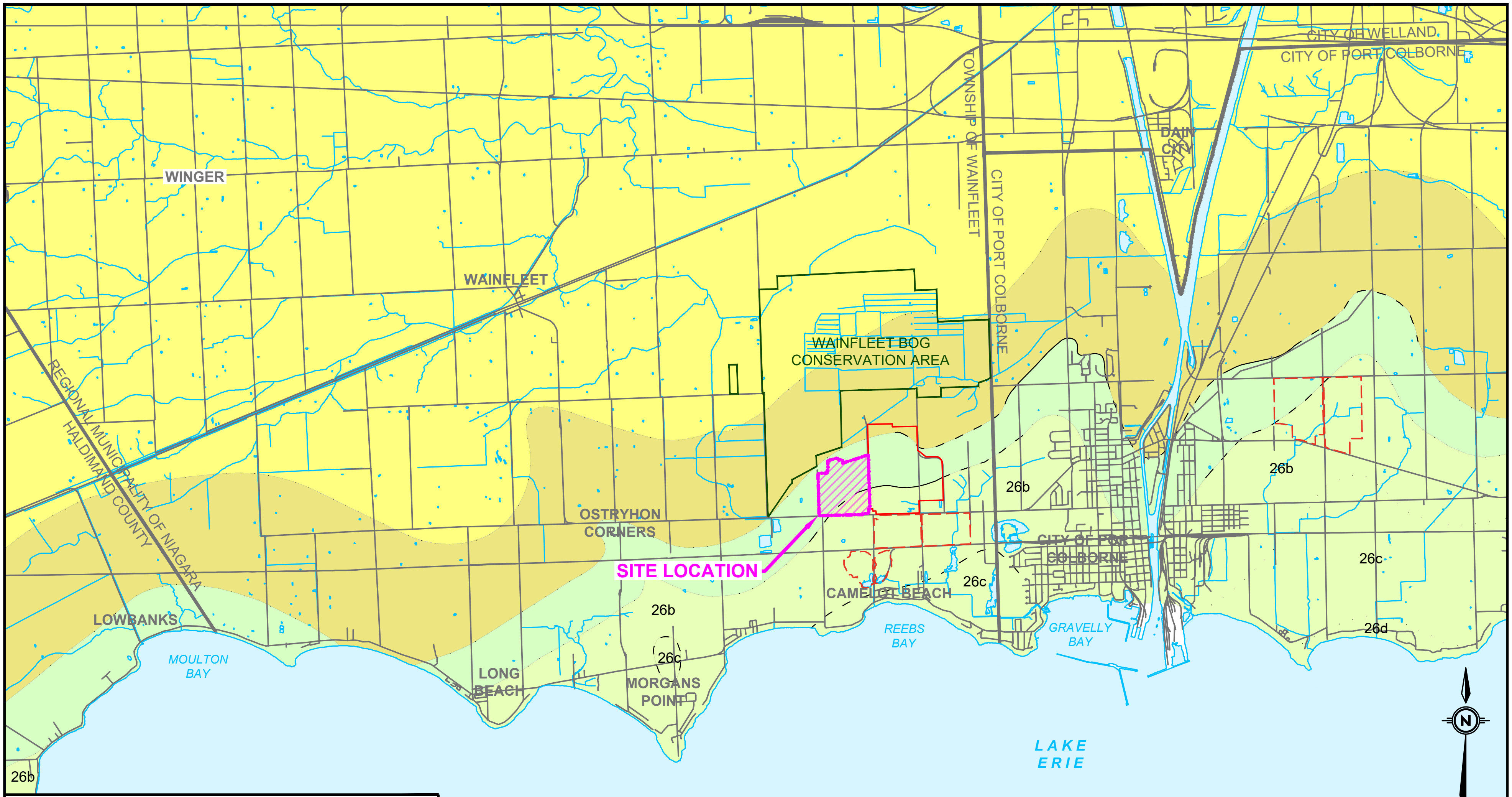

LEGEND

21	SALINA FORMATION DOLOSTONE, SHALE AND EVAPORITES
22	BERTIE FORMATION DOLOSTONE
25	BOIS BLANC LIMESTONE
26	ONONDAGA FORMATION LIMESTONE: b - EDGECLIFFE MEMBER c - CLARENCE MEMBER d - MOOREHOUSE MEMBER

SOURCE: THE ONTARIO GEOLOGICAL SURVEY. 1975.
PALEOZOIC GEOLOGY OF NIAGARA, MAP 2344.

CONTACT TYPE

- - - - - -	APPROXIMATE
· · · · · ·	INTERPRETED
———	OBSERVED

PALEOZOIC BEDROCK GEOLOGY

LEVEL 2 WATER STUDY REPORT
LAW QUARRY EXTENSION
WAINFLEET, ON
For Waterford Sand & Gravel Ltd.

DATE: DECEMBER 2021

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FIGURE No: 6

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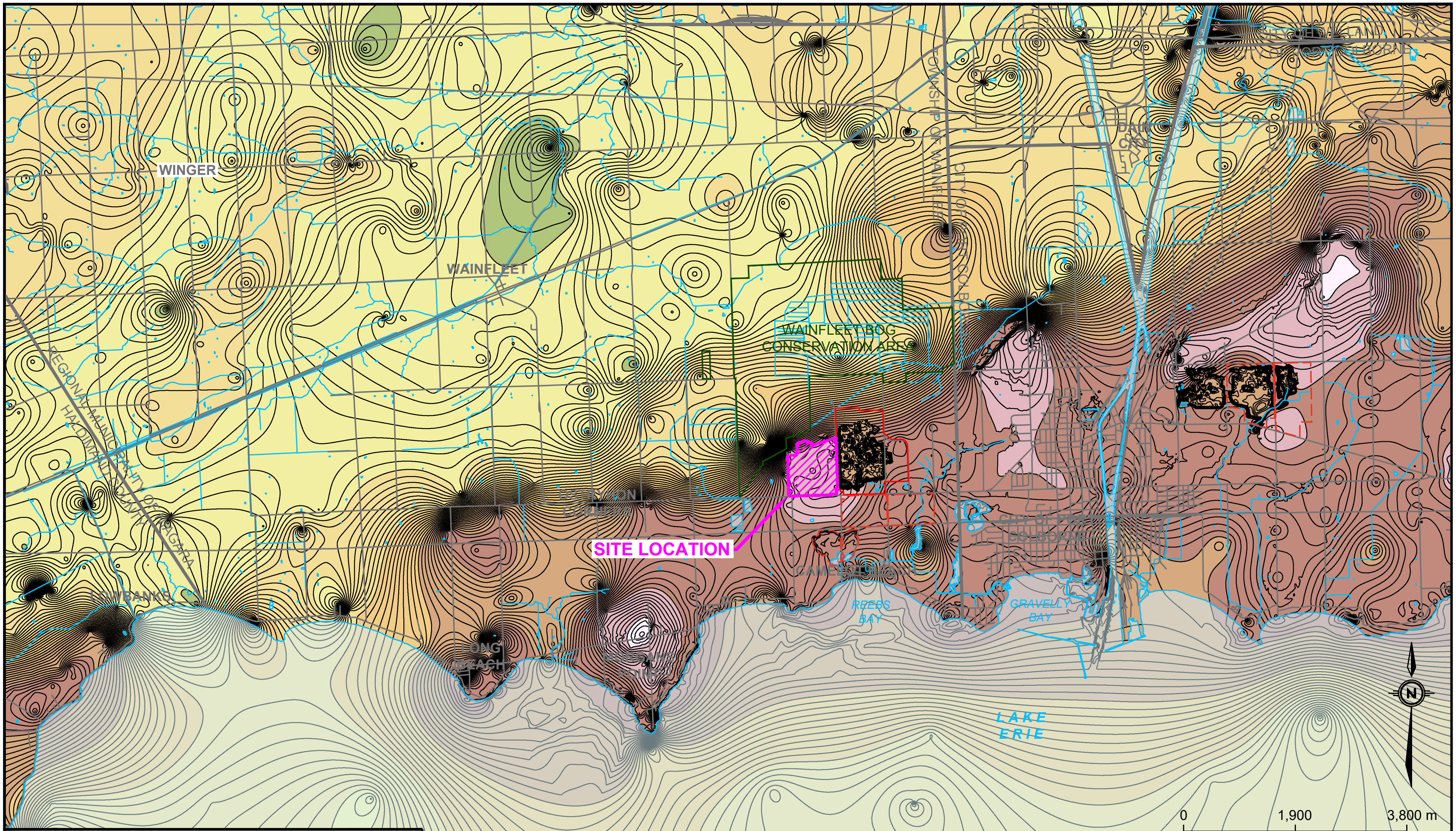

LEGEND

BEDROCK TOPOGRAPHIC CONTOUR, 1m INTERVALS

INTERPOLATED TOP OF BEDROCK (masl)

🟩 110 - 120
🟩 120 - 130
🟨 130 - 140
🟨 140 - 150
🟧 150 - 160
🟫 160 - 170
🟫 170 - 180
🟪 180 - 190
⬜ 190 - 200

INTERPOLATED BEDROCK TOPOGRAPHY

LEVEL 2 WATER STUDY REPORT
LAW QUARRY EXTENSION
WAINFLEET, ON
For Waterford Sand & Gravel Ltd.

DATE: DECEMBER 2021
PROJECT: 111-53023-06
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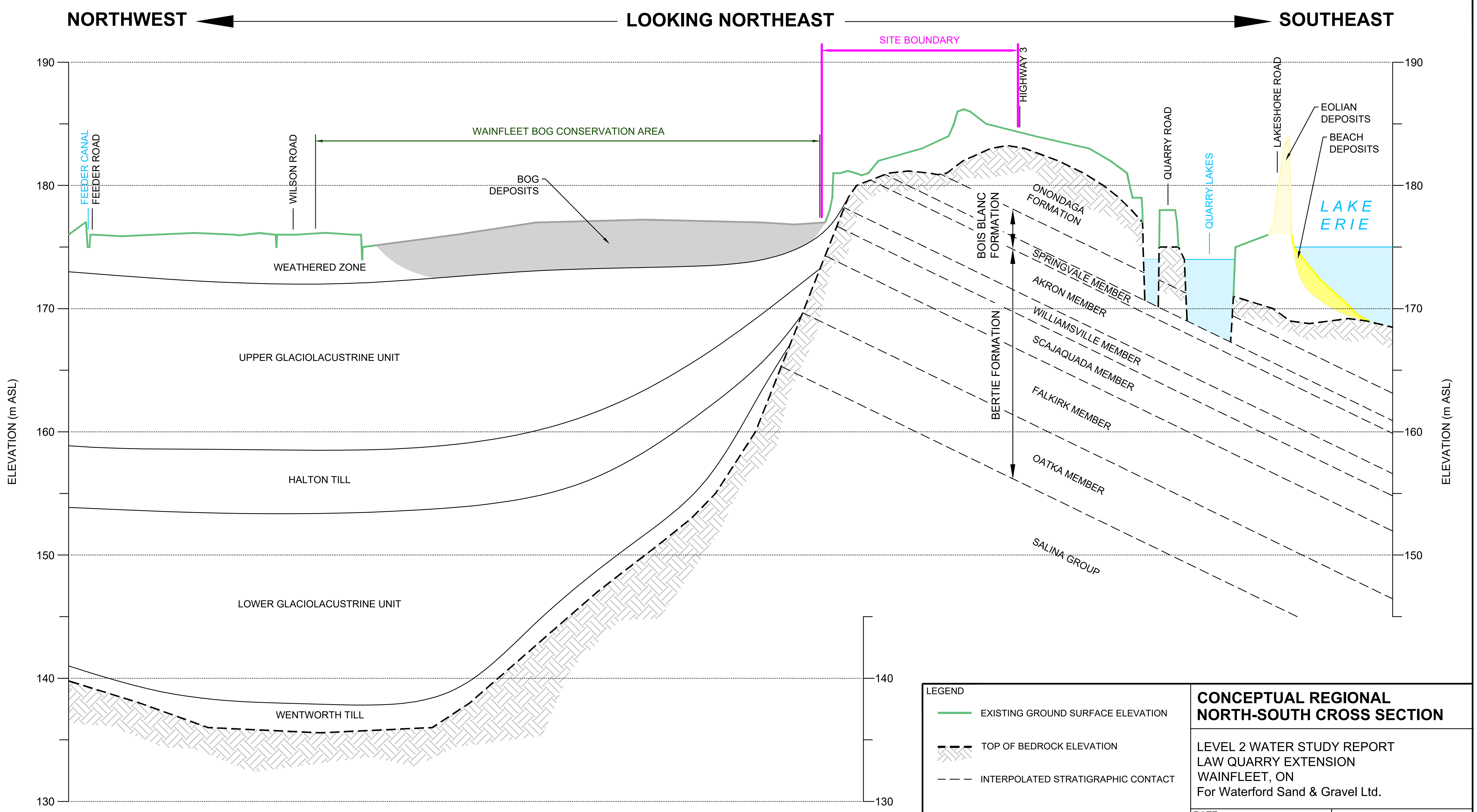
SCALE: 1 : 95,000
FIGURE No: 7



CONCEPTUAL REGIONAL NORTH-SOUTH CROSS SECTION

LEVEL 2 WATER STUDY REPORT
LAW QUARRY EXTENSION
WAINFLEET, ON
For Waterford Sand & Gravel Ltd.

DATE:	DECEMBER 2021
PROJECT:	111-53023-06
HORIZONTAL SCALE:	1 : 21,000
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FIGURE No: 8

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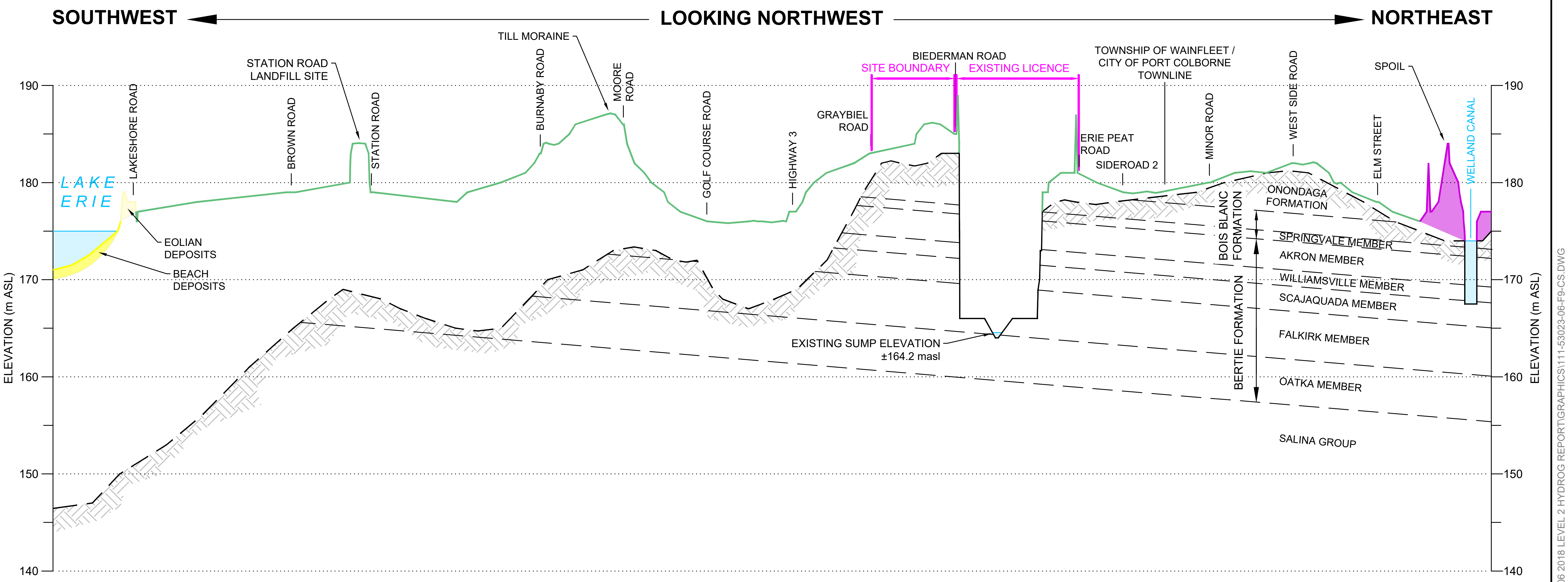

LEGEND

- EXISTING GROUND SURFACE ELEVATION
- TOP OF BEDROCK ELEVATION
- INTERPOLATED STRATIGRAPHIC CONTACT

HORIZONTAL SCALE:
0 800 1,600 m

NOTE: 100X VERTICAL EXAGGERATION

CONCEPTUAL REGIONAL EAST-WEST CROSS SECTION

LEVEL 2 WATER STUDY REPORT
LAW QUARRY EXTENSION
WAINFLEET, ON
For Waterford Sand & Gravel Ltd.

DATE: DECEMBER 2021
PROJECT: 111-53023-06
HORIZONTAL SCALE: 1 : 40,000
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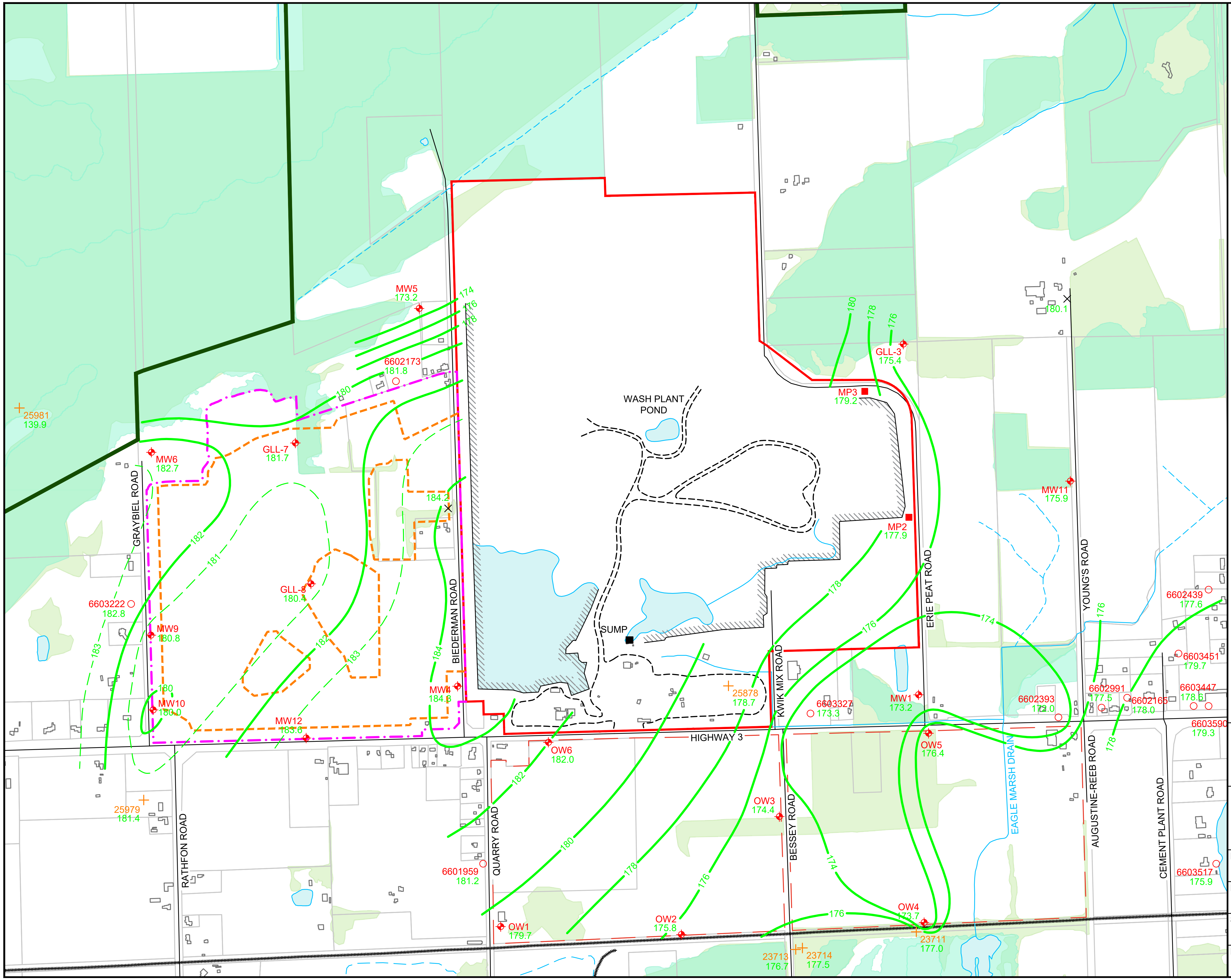
FIGURE No: 9

\\CASCR1DAT01\VOL1\PROJECTS\2011\111-53023 LAW QUARRY\06 2018 LEVEL 2 HYDROG REPORT\GRAPHICS\111-53023-06-F9-CS.DWG



LEGEND

▬ · ▬	PROPOSED WEST EXTENSION
- - -	PROPOSED LIMIT OF EXTRACTION
▬	EXISTING QUARRY LICENCE
▬	APPROXIMATE LAND PARCEL
— — —	REEB QUARRY LICENCE
▬	WAINFLEET BOG CONSERVATION AREA
🟩	WOODLOT
🟩	WETLAND
～	PERMANENT STREAM
- - -	INTERMITTENT STREAM
▨	APPROXIMATE WORKING FACE
GLL-3 ⊕	MONITORING WELL NEST LOCATION AND DESIGNATION
MP2 ■	MINI-PIEZOMETER LOCATION AND DESIGNATION
25878 +	OIL & GAS WELL RECORD
6603222 ○	MECP WATER WELL RECORD
×	BEDROCK OUTCROP
175.9	BEDROCK CONTACT ELEVATION (mASL)
—180—	INTERPOLATED BEDROCK TOPOGRAPHY CONTOUR, 2m INTERVALS (mASL)
—181—	INTERPOLATED BEDROCK TOPOGRAPHY CONTOUR, 1m INTERVALS (mASL)

SITE SCALE INTERPOLATED BEDROCK TOPOGRAPHY

LEVEL 2 WATER STUDY REPORT
LAW QUARRY EXTENSION
WAINFLEET, ON
For Waterford Sand & Gravel Ltd.

DATE: DECEMBER 2021	
PROJECT: 111-53023-06	
SCALE: 1 : 10,000	
DRAWN BY: JLD	FIGURE No: 10

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55 KING STREET, SUITE 700
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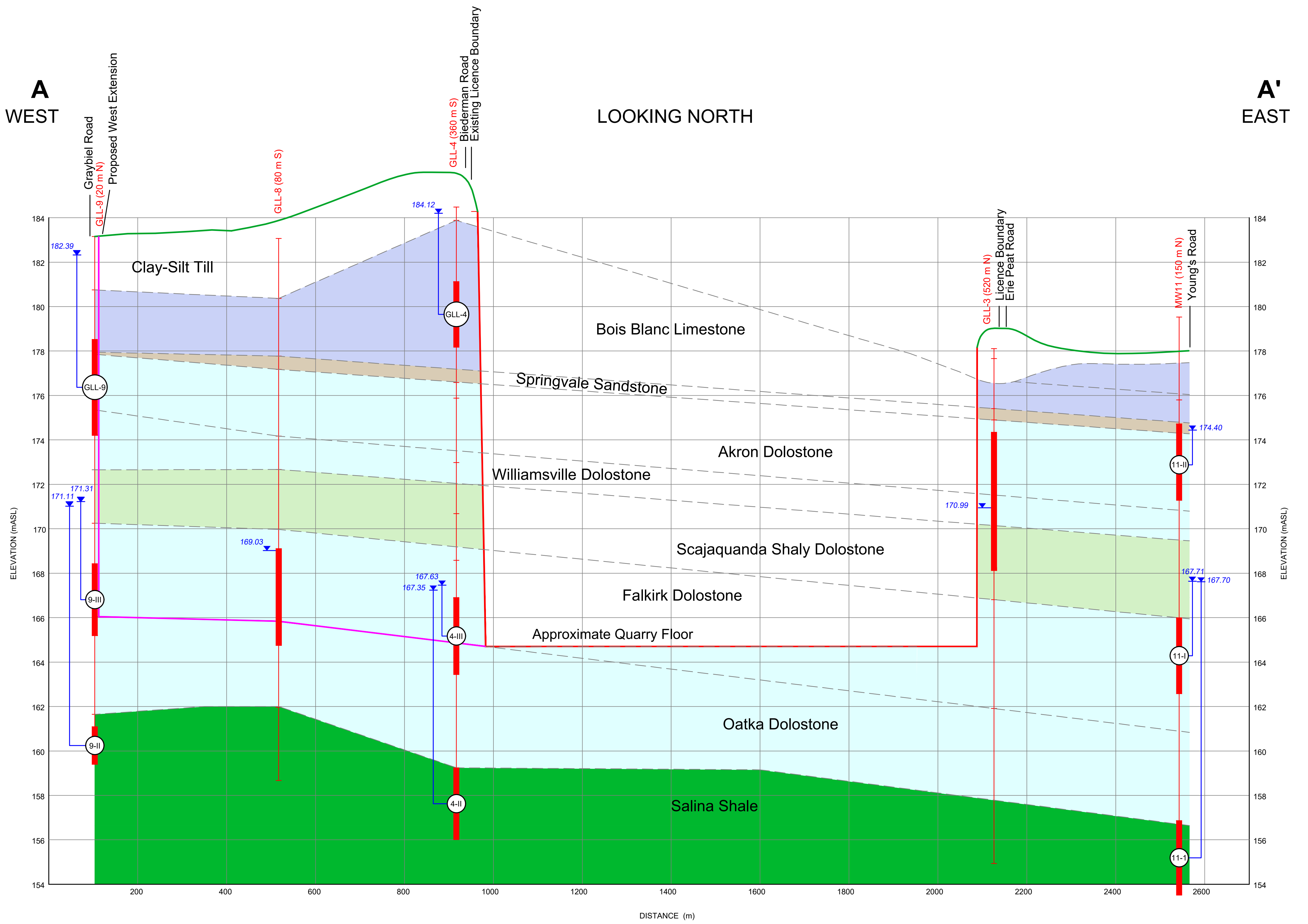
\\CASCR1DAT01\VOL1\PROJECTS\2011\111-53023 LAW QUARRY\06 2018 LEVEL 2 HYDROG REPORT\GRAPHICS\111-53023-06-F10-BR.DWG



LEGEND

GLL-2 BOREHOLE LOCATION AND DESIGNATION
SURFACE
▼ WATER LEVEL (FEBRUARY 4, 2019)
CHANGE IN STRATIGRAPHY
▮ SCREENED INTERVAL
END OF HOLE

🟦 LIMESTONE
▢ DOLOSTONE
🟩 SHALY DOLOSTONE
🟩 SHALE
🟫 SANDSTONE

REFERENCE: GARTNER LEE LTD. (2005).

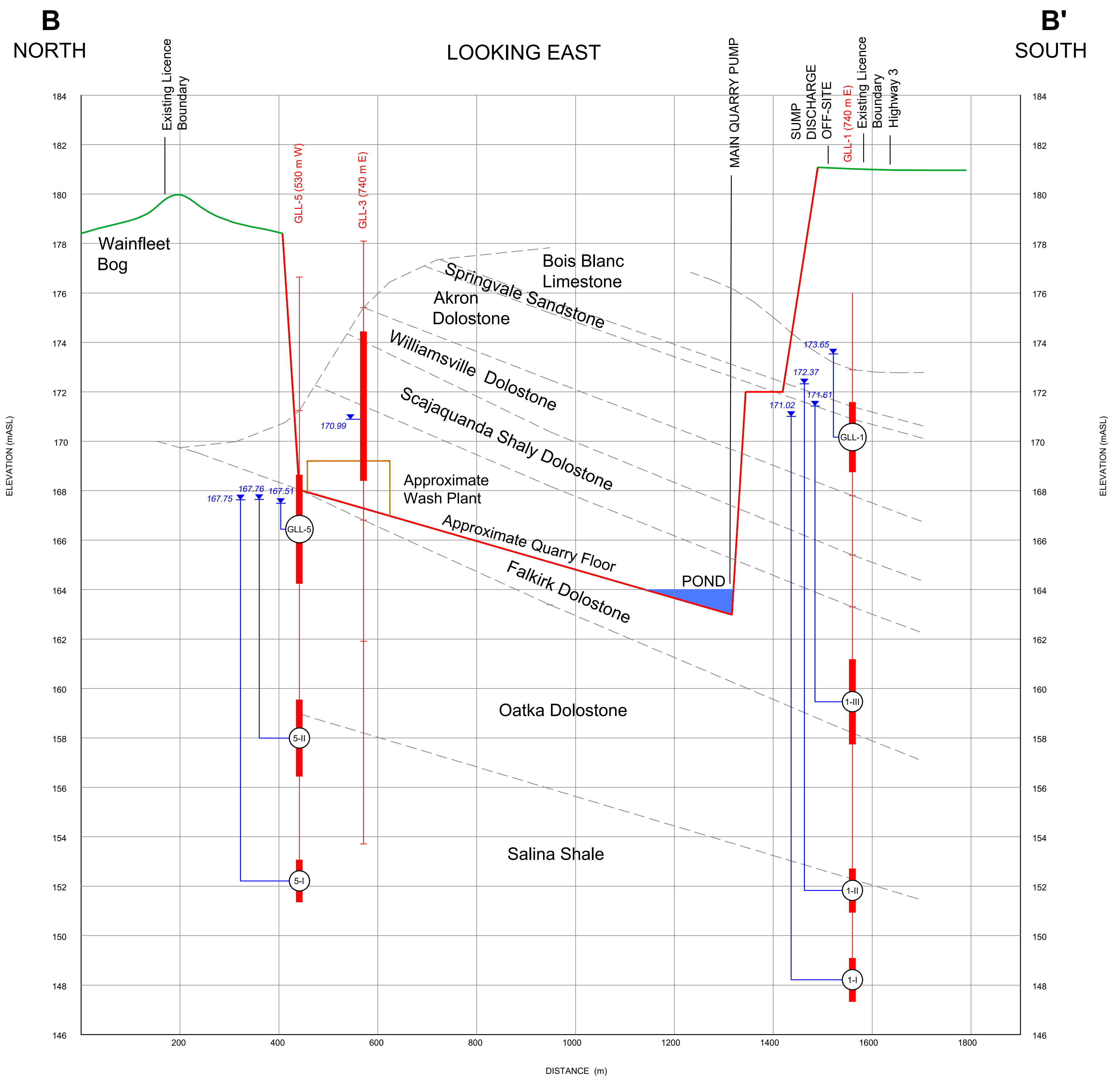
CROSS SECTION A-A'

LEVEL 2 WATER STUDY REPORT
LAW QUARRY EXTENSION
WAINFLEET, ON
For Waterford Sand & Gravel Ltd.

DATE:	DECEMBER 2021
PROJECT:	111-53023-06
SCALE:	AS SHOWN
DRAWN BY:	JLD
FIGURE No:	11

55 KING STREET, SUITE 700
ST. CATHARINES, ON L2R 3H5
T 905-687-1771 | F 905-687-1773 | www.wsp.com

\\CASCR1DAT01\VOL1\PROJECTS\2011\111-53023 LAW QUARRY\06 2018 LEVEL 2 HYDROG REPORT\GRAPHICS\111-53023-06-F11-CS.DWG



LEGEND

GLL-3 BOREHOLE LOCATION AND DESIGNATION
SURFACE
WATER LEVEL (FEBRUARY 4, 2019)
CHANGE IN STRATIGRAPHY
SCREENED INTERVAL
END OF HOLE

LIMESTONE
DOLOSTONE
SHALY DOLOSTONE
SHALE
SANDSTONE

CROSS SECTION B-B'

LEVEL 2 WATER STUDY REPORT
LAW QUARRY EXTENSION
WAINFLEET, ON
For Waterford Sand & Gravel Ltd.

DATE: DECEMBER 2021
PROJECT: 111-53023-06
SCALE: AS SHOWN
DRAWN BY: JLD

55 KING STREET, SUITE 700
ST. CATHARINES, ON L2R 3H5
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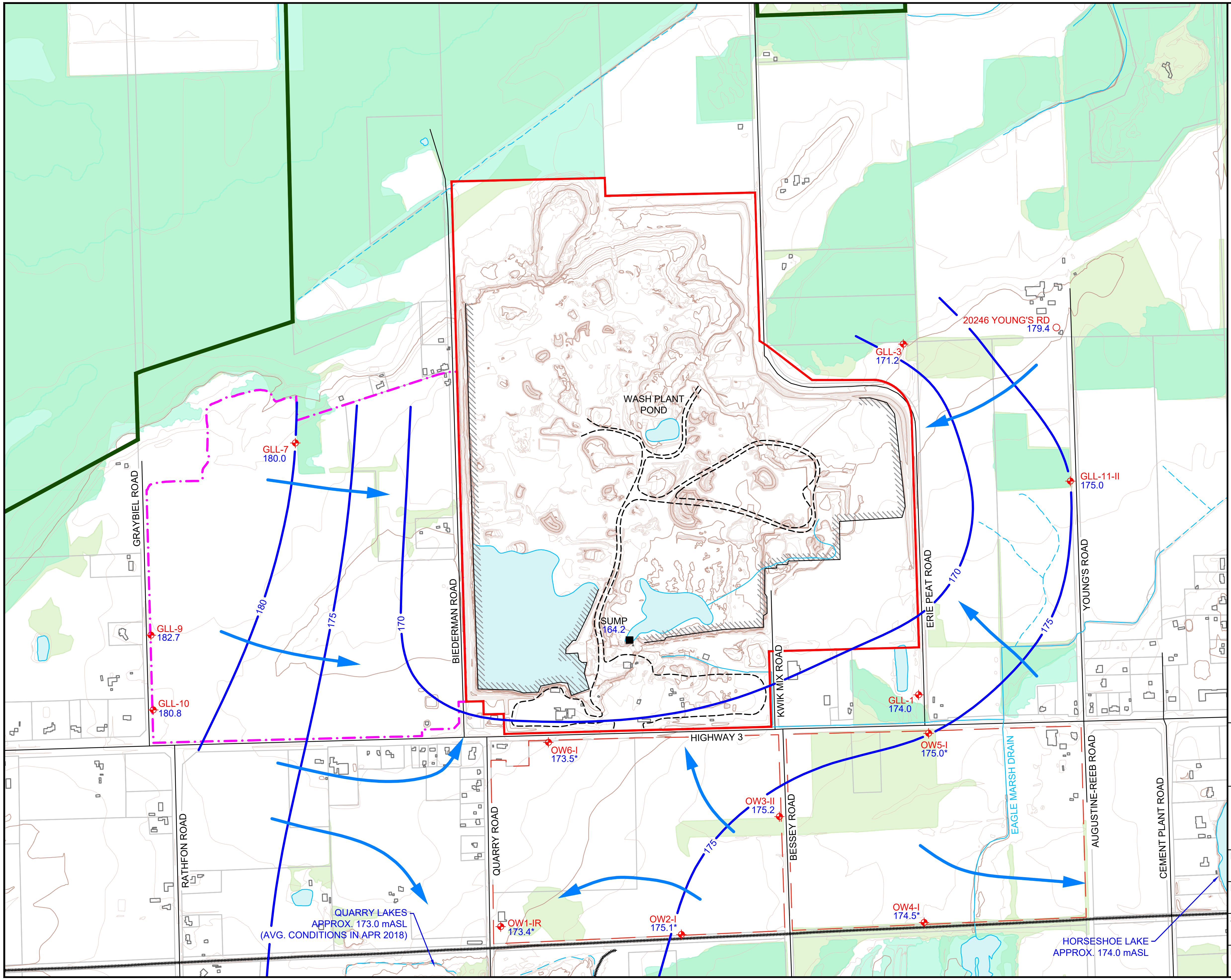
FIGURE No: 12

\\CASCR1DAT01\VOL1\PROJECTS\2011\111-53023 LAW QUARRY\06 2018 LEVEL 2 HYDROG REPORT\GRAPHICS\111-53023-06-F12-CS.DWG



LEGEND

— · —	PROPOSED WEST EXTENSION
——	EXISTING QUARRY LICENCE
——	APPROXIMATE LAND PARCEL
— — —	REEB QUARRY LICENCE
——	WAINFLEET BOG CONSERVATION AREA
🟩	WOODLOT
🟩	WETLAND
——	PERMANENT STREAM
- - -	INTERMITTENT STREAM
——	GROUND SURFACE CONTOUR, 5 m INTERVAL
——	GROUND SURFACE CONTOUR, 1 m INTERVAL
▨	APPROXIMATE WORKING FACE
GLL-3 ⌖	MONITORING WELL LOCATION AND DESIGNATION
○	PRIVATE WATER WELL
175.0	SHALLOW BEDROCK GROUNDWATER ELEVATION, AVERAGE APRIL 2019 CONDITIONS (mASL)
*	AVERAGE APRIL CONDITIONS BETWEEN 2005 - 2007
—175—	INTERPRETED SHALLOW BEDROCK AQUIFER WATER TABLE CONTOUR (mASL)
→	INFERRED SHALLOW BEDROCK AQUIFER GROUNDWATER FLOW DIRECTION

INTERPRETED WATER TABLE CONTOURS - SHALLOW BEDROCK AQUIFER

LEVEL 2 WATER STUDY REPORT
LAW QUARRY EXTENSION
WAINFLEET, ON
For Waterford Sand & Gravel Ltd.

DATE: DECEMBER 2021
PROJECT: 111-53023-06
SCALE: 1 : 10,000
DRAWN BY: JLD

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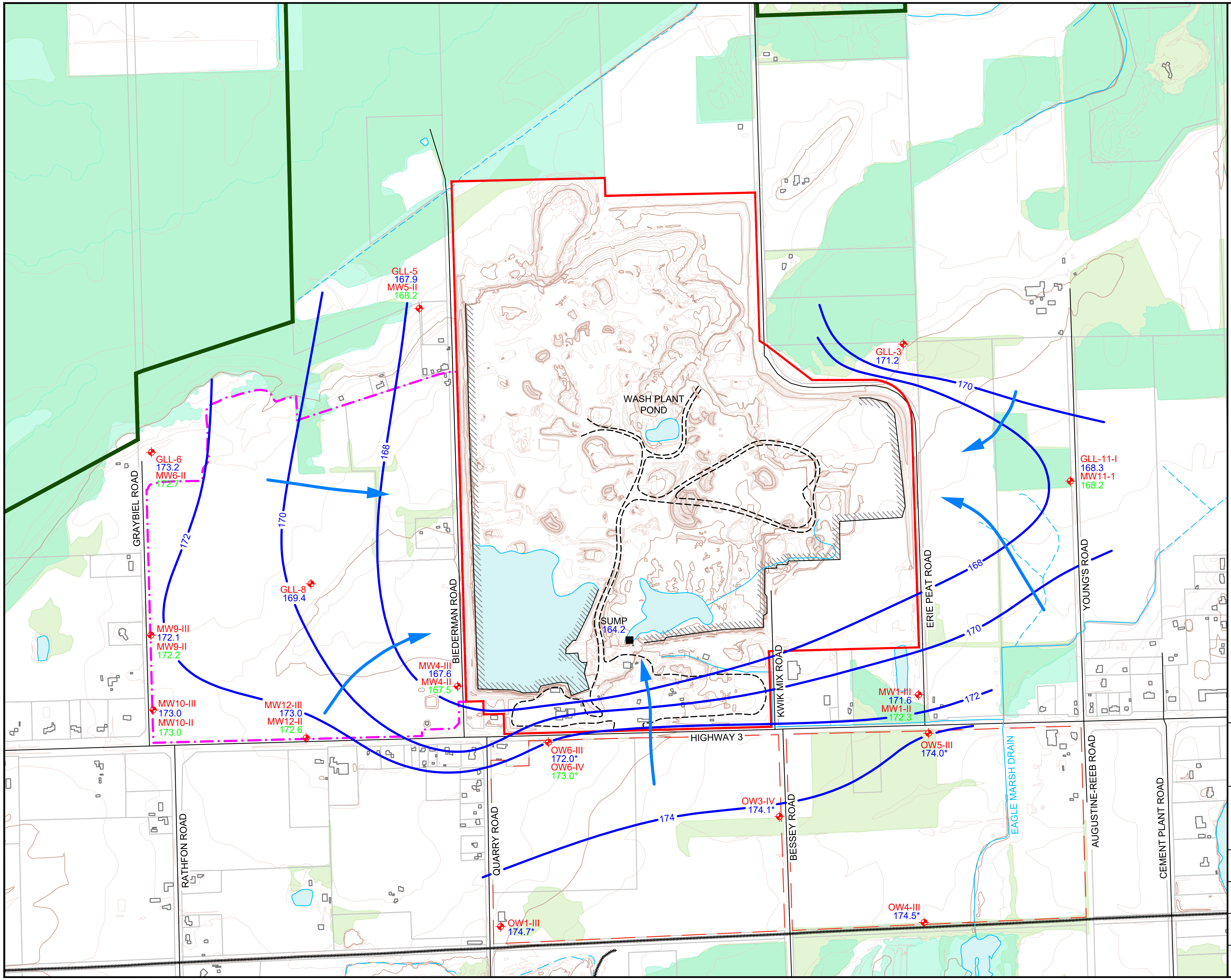
FIGURE No: 13

\\CASCR1DAT01\VOL1\PROJECTS\2011\111-53023 LAW QUARRY\06 2018 LEVEL 2 HYDROG REPORT\GRAPHICS\111-53023-06-F13-GW.DWG



LEGEND

━ · ━	PROPOSED WEST EXTENSION
━━	EXISTING QUARRY LICENCE
──	APPROXIMATE LAND PARCEL
─ ─	REEB QUARRY LICENCE
━━	WAINFLEET BOG CONSERVATION AREA
🟩	WOODLOT
🟩	WETLAND
──	PERMANENT STREAM
- - -	INTERMITTENT STREAM
──	GROUND SURFACE CONTOUR, 5 m INTERVAL
──	GROUND SURFACE CONTOUR, 1 m INTERVAL
▨	APPROXIMATE WORKING FACE
GLL-3 ⌖	MONITORING WELL LOCATION AND DESIGNATION
175.0	DEEP BEDROCK (FALKIRK MEMBER) GROUNDWATER ELEVATION, AVERAGE APRIL 2019 CONDITIONS (mASL)
175.0	DEEP BEDROCK (OATKA MEMBER) GROUNDWATER ELEVATION, AVERAGE OF APRIL 2019 CONDITIONS (mASL)
*	AVERAGE APRIL CONDITIONS BETWEEN 2005 - 2007
—175—	INTERPRETED DEEP BEDROCK AQUIFER POTENTIOMETRIC CONTOUR (mASL)
→	INFERRED DEEP BEDROCK AQUIFER GROUNDWATER FLOW DIRECTION

N

0 200 400 m

INTERPRETED POTENTIOMETRIC CONTOURS - DEEPER BEDROCK UNITS

LEVEL 2 WATER STUDY REPORT
LAW QUARRY EXTENSION
WAINFLEET, ON
For Waterford Sand & Gravel Ltd.

DATE: DECEMBER 2021
PROJECT: 111-53023-06
SCALE: 1 : 10,000
DRAWN BY: JLD

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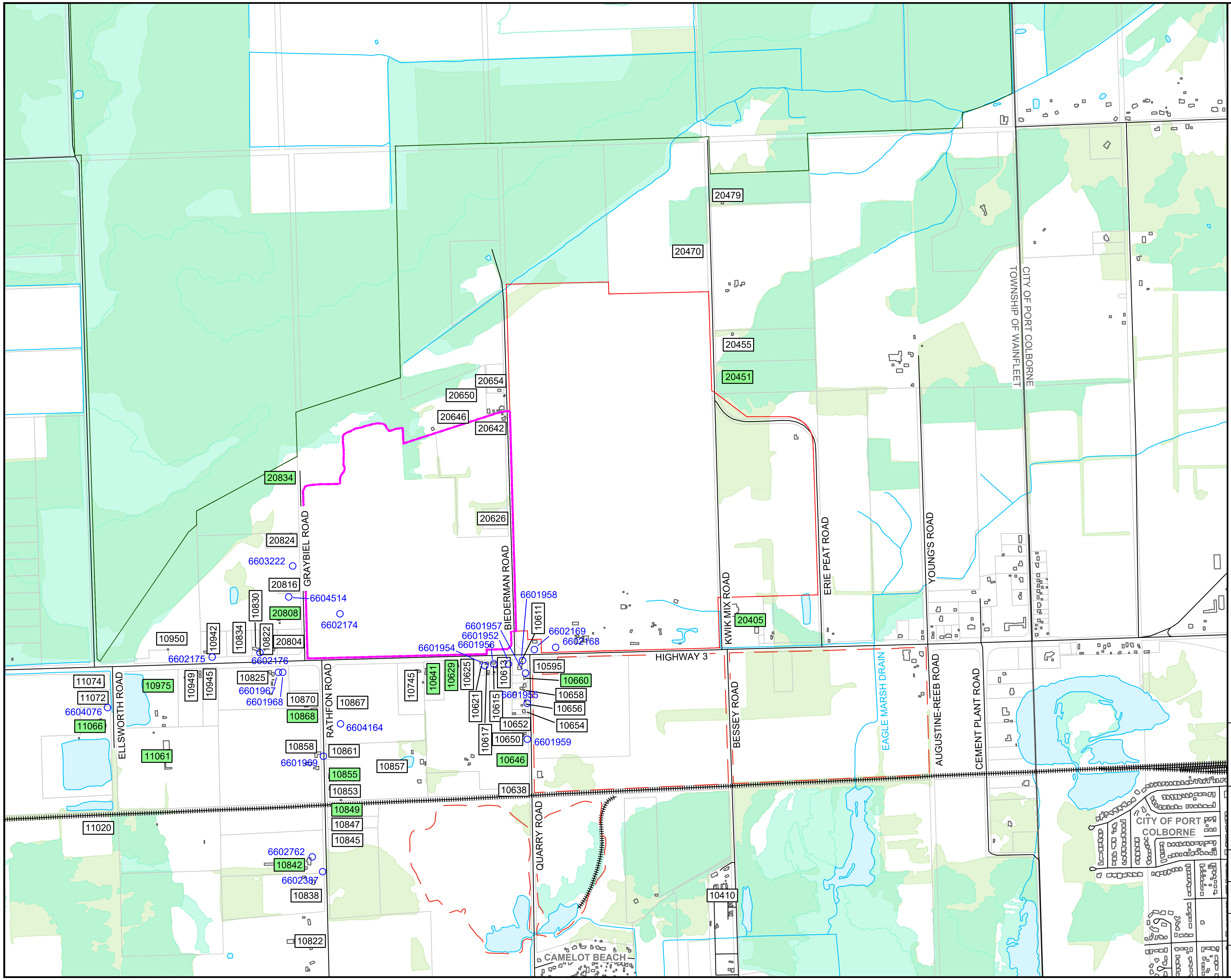
FIGURE No: 14

\\CASCR1DAT01\VOL1\PROJECTS\2011\111-53023 LAW QUARRY\06 2018 LEVEL 2 HYDROG REPORT\GRAPHICS\111-53023-06-F14-GW.DWG



LEGEND

- ▬ PROPOSED WEST EXTENSION
- ▬ EXISTING QUARRY LICENCE
- ▬ APPROXIMATE LAND PARCEL
- ‒ ‒ REEB QUARRY LICENCE
- ▬ WAINFLEET BOG CONSERVATION AREA
- 🟩 WOODLOT
- 🟩 WETLAND
- ∼ PERMANENT STREAM
- ∼ INTERMITTENT STREAM
- 5584 STREET ADDRESS (GREEN INDICATES SURVEY RETURNED)
- 7194083○ MECP WATER WELL RECORD LOCATION AND DESIGNATION

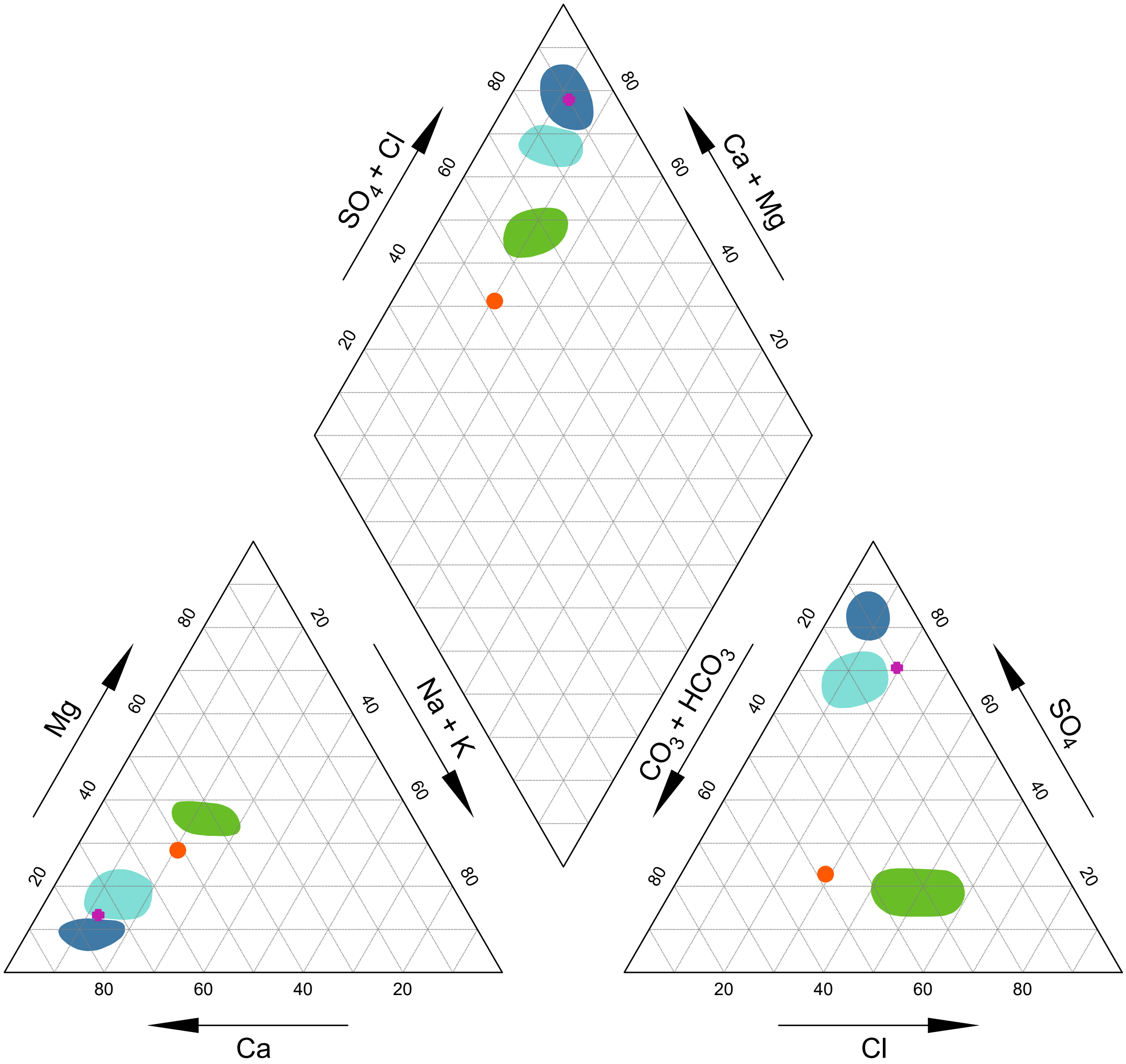
0 300 600 m

WATER WELL SURVEY

LEVEL 2 WATER STUDY REPORT
LAW QUARRY EXTENSION
WAINFLEET, ON
For Waterford Sand & Gravel Ltd.

DATE: DECEMBER 2021	
PROJECT: 111-53023-06	
SCALE: 1 : 15,000	55 KING STREET, SUITE 700 ST. CATHARINES, ON L2R 3H5 T 905-687-1771 | F 905-687-1773 | www.wsp.com
DRAWN BY: JLD	FIGURE No: 15

\\CASCR1DAT01\VOL1\PROJECTS\2011\111-53023 LAW QUARRY\06 2018 LEVEL 2 HYDROG REPORT\GRAPHICS\111-53023-06-F15-SP.DWG



LEGEND

BASELINE RANGES (AZIMUTH, 2008)

🟩 SHALLOW BEDROCK AQUIFER

🟦 DEEP BEDROCK (OATKA MEMBER)

🟦 DEEP BEDROCK (SALINA MEMBER)

✚ LAW QUARRY SUMP (SW2)

● BACKGROUND SURFACE WATER (SW1)

TRILINEAR DIAGRAM - OCTOBER 2019

LEVEL 2 WATER STUDY REPORT
LAW QUARRY EXTENSION
WAINFLEET, ON
For Waterford Sand & Gravel Ltd.

SCALE: AS SHOWN

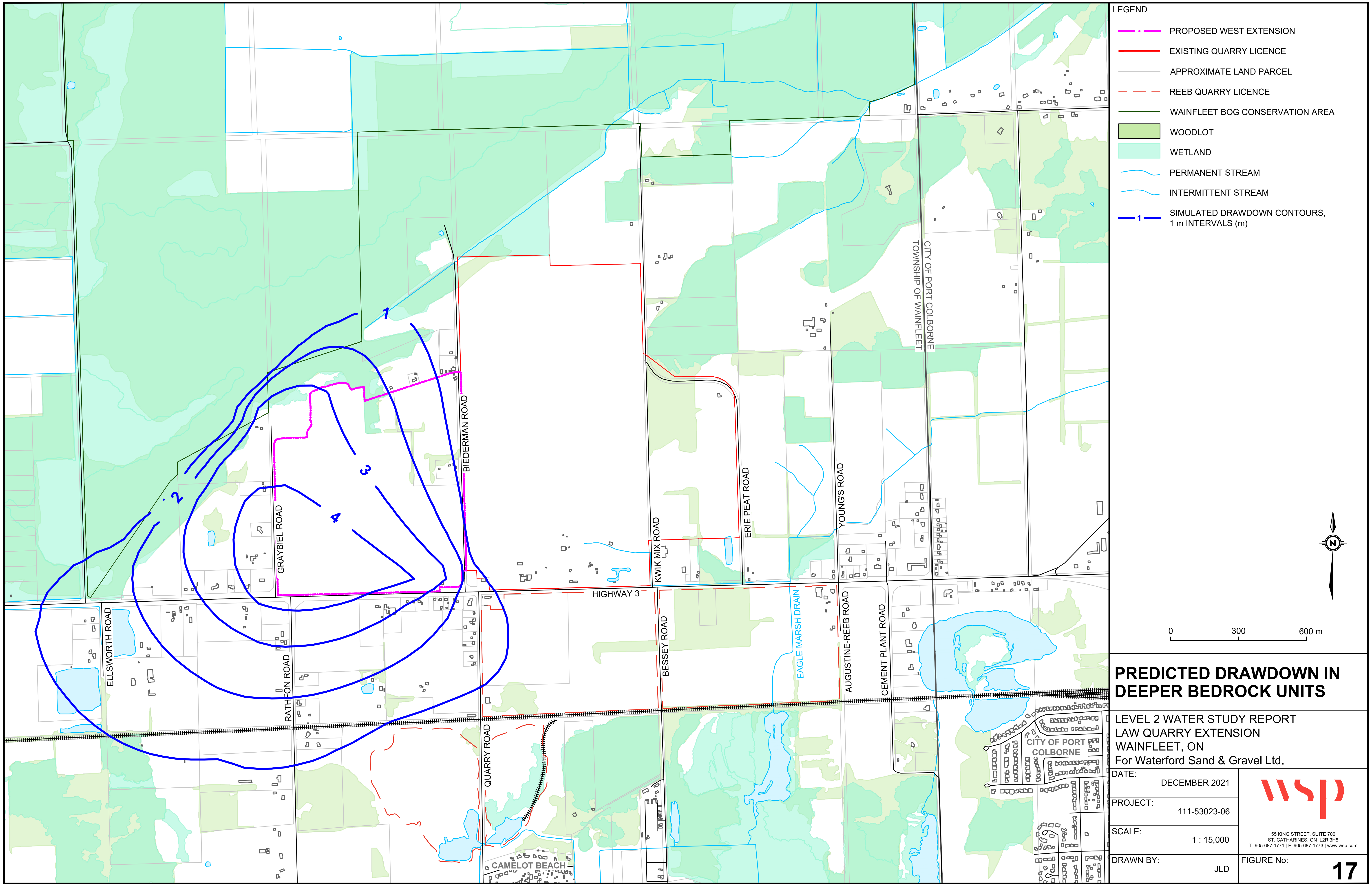
DRAWN BY: JLD

DATE: DECEMBER 2021

PROJECT: 111-53023-06

FIGURE No: 16

\\CASCR1DAT01\VOL1\PROJECTS\2011\111-53023\111-53023-06\2018 LEVEL 2 HYDROG REPORT\GRAPHICS\111-53023-06-F16-TL.DWG



LEGEND

	PROPOSED WEST EXTENSION
	EXISTING QUARRY LICENCE
	APPROXIMATE LAND PARCEL
	REEB QUARRY LICENCE
	WAINFLEET BOG CONSERVATION AREA
🟩	WOODLOT
🟩	WETLAND
	PERMANENT STREAM
	INTERMITTENT STREAM
1	SIMULATED DRAWDOWN CONTOURS, 1 m INTERVALS (m)

PREDICTED DRAWDOWN IN DEEPER BEDROCK UNITS

LEVEL 2 WATER STUDY REPORT
LAW QUARRY EXTENSION
WAINFLEET, ON
For Waterford Sand & Gravel Ltd.

DATE: DECEMBER 2021

PROJECT: 111-53023-06

SCALE: 1 : 15,000

DRAWN BY: JLD

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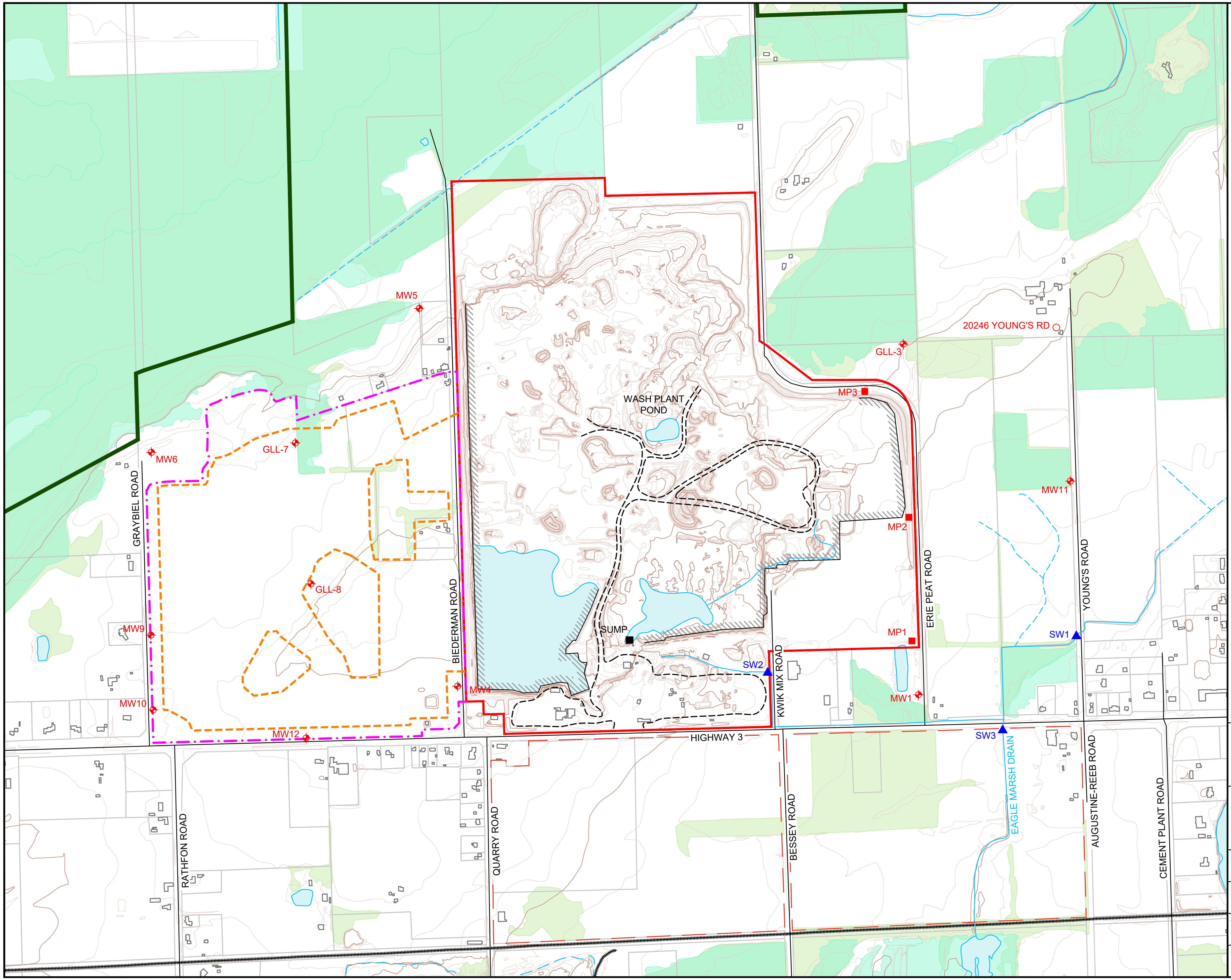
FIGURE No: 17

\\CASCR1DAT01\VOL1\PROJECTS\2011\111-53023 LAW QUARRY\06 2018 LEVEL 2 HYDROG REPORT\GRAPHICS\111-53023-06-F17-GW.DWG



LEGEND

- PROPOSED WEST EXTENSION
- PROPOSED LIMIT OF EXTRACTION
- EXISTING QUARRY LICENCE
- APPROXIMATE LAND PARCEL
- REEB QUARRY LICENCE
- WAINFLEET BOG CONSERVATION AREA
- 🟩 WOODLOT
- 🟦 WETLAND
- PERMANENT STREAM
- INTERMITTENT STREAM
- GROUND SURFACE CONTOUR, 5 m INTERVAL
- GROUND SURFACE CONTOUR, 1 m INTERVAL
- ▨ APPROXIMATE WORKING FACE
- GLL-3 ⌖ MONITORING WELL NEST LOCATION AND DESIGNATION
- MP2 ■ MINI-PIEZOMETER LOCATION AND DESIGNATION
- SW1 ▲ SURFACE WATER STATION LOCATION AND DESIGNATION
- ○ PRIVATE WATER WELL

N

0 200 400 m

PROPOSED ENVIRONMENTAL MONITORING PROGRAM

LEVEL 2 WATER STUDY REPORT
LAW QUARRY EXTENSION
WAINFLEET, ON
For Waterford Sand & Gravel Ltd.

DATE: DECEMBER 2021
PROJECT: 111-53023-06
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DRAWN BY: JLD

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FIGURE No: 18

\\CASCR1DAT01\VOL1\PROJECTS\2011\111-53023 LAW QUARRY\06 2018 LEVEL 2 HYDROG REPORT\GRAPHICS\111-53023-06-F18-SP.DWG

APPENDIX

A CURRICULUM VITAE

KEVIN J. FITZPATRICK, P.Eng.

Senior Project Engineer, Environment

AREAS OF PRACTICE

Hydrogeology

Aggregate Resources

Geology & Geotechnical Engineering

Environmental Assessments & Remediation

Waste Management

PROFILE

Mr. Kevin Fitzpatrick, P. Eng. (Geological) is a Senior Project Engineer with more than 20 years of experience in geology, hydrogeology, geotechnical engineering, and water resources. His work experience encompasses project management, field investigations, analysis, interpretation, and peer review for numerous projects requiring his earth science expertise.

Mr. Fitzpatrick has developed his technical and project management expertise through his management of geological, hydrogeologic and geotechnical investigations related to groundwater quality and quantity compliance issues, aggregate resources, waste management, environmental remediation, dewatering, and civil construction. He has been a guest lecturer for geotechnical engineering course at Niagara College since 2012.

EDUCATION

B.A.Sc. Geological Engineering, University of Waterloo, ON	1993

PROFESSIONAL DEVELOPMENT

WHMIS	2013
Critical Thinking in Aquifer Test Interpretation, Christopher Neville, S.S. Papadopulos & Associates	2009
40-hour Health & Safety Training Course for Hazardous Waste Operations, OSHA, and update courses, Surface Miner Common Core Training	2005
Waterloo In-situ Groundwater Remediation Course, Toronto, ON	2000

PROFESSIONAL ASSOCIATIONS

Professional Engineers Ontario	1996
Ontario Stone, Sand and Gravel Association, Rehabilitation Committee	OSSGA
Aggregate Resource Prospecting and Evaluation Specialty, Ontario Ministry of Transportation, Registry Appraisal and Qualifications System	RAQS
Niagara College Programs Advisory Committee for Construction/ Civil Engineering Programs	2013

CAREER

Senior Project Engineer, Environment, WSP	2014 - Present
Senior Project Engineer, Environment, GENIVAR (now named WSP)	2009 - 2013
Project Engineer, Jagger Hims Limited (GENIVAR Acquisition)	1993 - 2009

PROFESSIONAL EXPERIENCE

Hydrogeology

- Assessments, Permit to Take Water Applications and Hydrogeologic Monitoring Reports (ongoing): Completed numerous studies as project manager in support of OWRA applications and Certificate of Approval for Discharge studies throughout Ontario, including in Lincoln, Waterford, Mosport, Thorold, Hamilton, Niagara Falls, Coboconk, Markham, Port Colborne, Port Dover, Wainfleet and Hagersville. The studies supported quarry applications, civil construction dewatering and industrial applications. Client: Various.
- Dewatering Assessment, Fort Erie, ON (2012): Hydrogeologic study for a pumping station within a productive, corrosive bedrock aquifer. Client: Region of Niagara.
- Hydrogeologic Assessment, Flamborough, ON (2011): Hydrogeologic assessment for a large food processing facility. Work included geotechnical design and wastewater compliance issues. Client: Earthfresh Foods Inc.
- Water Well Interference, Niagara-on-the-Lake, ON (2011): Completed a salt water intrusion contaminant assessment as part of a Ministry of Environment director’s order. Design of a sulphate-resistant decommissioning program to prevent future cross-contamination. Client: Aviva Canada.
- Groundwater Interference Study, Dunnville, ON (2010): Intermittent issues at residential wells located adjacent to a dolostone and limestone quarry were evaluated for quality and quantity. The hydrogeology was complicated by the high transmissivities of the aquifer and the proximity of the Grand River and Lake Erie. Client: Dunnville Rock Products.
- Lookout Point Golf Club, Pelham, ON (2008-ongoing): Conducted a multi-year groundwater and surface water investigation that led to construction of a high capacity deep well in the Fonthill Kame for golf course irrigation. Other consultants had installed deep wells at the site; however, yields were very poor. High hydrogen sulphide concentrations and a cold-water fishery were also a concern. A thorough re-evaluation of the local hydrogeology was completed and detailed long-term pump tests were performed to satisfy Niagara Escarpment Commission and MOE concerns. Monitoring of the various system components was designed to improve data quality and lower operating costs. Client: Lookout Point Golf and Country Club.
- Groundwater Salt Impact Assessment, Lincoln, ON (ongoing): Hydrogeologic monitoring at a winter sand storage facility. The facility is located above the Niagara Escarpment on fractured bedrock upgradient of several groundwater springs. A best management plan was produced for the facility. Client: Town of Lincoln.
- Hydrogeologic Study, Port Colborne, ON (2009): Hydrogeologic study to support residential development plan. A developer needed to assess a productive shallow bedrock aquifer as part of a plan of subdivision. Client: Lester Shoaltz Limited.
- Hydrogeologic Monitoring, Caledonia, ON (2009): Hydrogeologic monitoring at a golf course in support of a Permit to Take Water. Electronic groundwater monitoring was installed to provide high quality data. Client: Numbered Ontario Company.
- Niagara Tunnel Project, Niagara Falls, ON (2008): Completed detailed core logging on deep groundwater monitors. Cores represented a complete section of Niagara Escarpment bedrock from the Guelph Formation to the Queenston Formation. Client: Strabag.
- Alternative Irrigation Sources, St. Catharines, ON (2007): Conducted hydrogeologic evaluation of a groundwater irrigation source for a golf course. The site was utilizing

a municipal supply for irrigation. Multiple low-yielding wells of poor quality complicated the assessment. Client: Urban & Environmental Management.

- Hydrogeologic Assessment, Massey, ON (2006): Hydrogeologic assessment of proposed Greenfield quarry. The site is a traprock escarpment and is located at a watershed divide. Impact assessments, a monitoring program and a closure plan were completed. Client: Pioneer Construction.

Aggregate Resources

- Completed detailed resource assessments, approvals and licensing for many major aggregate producers including Ontario Ministry of Transportation, CBM Canada, Dufferin Aggregates, Lafarge Canada, Walker Industries, Capital Materials Inc., Chefero Sand, Pioneer Construction, Waterford Sand and Gravel, Nelson Aggregates, Dimension Stone Ltd. and for several private clients.
- Conducted geologic studies in unconsolidated deposits. These sites include the Oak Ridges Moraine, Paris and Galt Moraines, and sites in Ayr, Caledon, Cambridge, London, Stratford, Brantford, North Dumfries, Orangeville, Norwood, Ommemee, and more than 60 sites in Northern Ontario.
- Conducted numerous detailed bedrock resource evaluations (dolostone, limestone, shale, granite, traprock) and licenses at sites throughout Ontario, including the Niagara Escarpment, Lake Erie shoreline, Guelph, Shelburne, Hamilton, Georgian Bay, Carden, Hudson Bay lowlands, Manitoulin Island, and Northern Ontario. Northern Ontario aggregate experience has included work within the Grenville, Southern and Superior Province locations.
- Proposed Shale Quarry Assessment, Brampton, ON (2010): Completed a resource assessment of a property zoned for a shale quarry in support of redevelopment. Client: Osmington Inc.
- Proposed Dolostone Quarry, Wainfleet, ON (2009): Peer review and witness statements at a proposed quarry for an Ontario municipal board hearing. Client: Sullivan Mahoney LLP.
- Clay Borrow Pit, Thorold, ON (2007): Completed aggregate wayside pit permit for clay borrow for 400-series highway embankments. Client: Hardrock Group.

Geology and Geotechnical Engineering

- Slope Stability Studies, Excavations and Retaining Wall Inspections (ongoing): Conducted over 60 studies in support of development approval for private clients, public agencies and consultants.
- Rock Mechanics Work (ongoing): Conducted rock wall stability assessments in Lincoln, Woodstock, Orillia, Ottawa, and Quebec for various clients in support of open excavations.
- Post-construction Investigations (ongoing): Conducted forensic examinations of failed structures and roadways related to subsurface conditions in Burlington, Niagara-on-the-Lake and Lake Simcoe for various private and professional clients.
- Foundation Inspections (ongoing): Inspections of footings for bridges, buildings, marine facilities and retaining walls for public, private and institutional clients.
- Road Construction Investigations (ongoing): Geotechnical studies completed in support of road reconstruction for municipal government agencies including project management for material inspections (concrete, asphalt and compaction testing).

- Septic System Investigations and Sewage Lagoon Assessments, various locations in Niagara Region (ongoing): Conducted geotechnical investigations for new municipal sewage lagoons, and investigations for large septic systems. Client: Niagara Region.
- Dewatering Investigation, Hamilton (2019): Dewatering investigation for earth retaining structure at a proposed waste water treatment plant. Client: Canada Centre for Inland Waters.
- Pipeline Work, Geotechnical Investigations for pipeline works across CN Rail/Welland Canal/Niagara Escarpment. (2018): Client: Walker Industries.
- Retaining Pond Design, North Dumfries ON (2017): Geotechnical work for liner installation. Client: Preston Sand and Gravel; Walker Industries
- Jerseyville Road Facility, Jerseyville, ON (2017): Water supply, geotechnical investigation and wastewater servicing peer review and project management. Client: The Green Organic Dutchman.
- Boat Ramp Investigation, Fort Erie, ON (2017): Below water geotechnical investigation within the Niagara River. Client: Niagara Parks Commission.
- Binbrook Dam Safety Review, Binbrook, ON (2016): Earth dam testing and inspection. Client: Niagara Peninsula Conservation Authority.
- East Rail Maintenance Yard, Whitby, ON (2016): Construction dewatering issues for a rail siding. Client: Bird/Kiewit Joint Venture.
- Glanbrook Landfill Collector System Evaluation, Hamilton, ON (2015): Subsurface geotechnical assessment of a failed sewer. CCTV work. Client: City of Hamilton.
- Hydrogeologic Study, Flamborough, ON (2011): Proposed Earthfresh potato processing facility hydrogeologic study. Client: Earthfresh.
- Facility Relocation and reservoir installation, Dunnville, ON (2011). Client: Intercounty Concrete.
- VivaNext, Highway 7, Markham, ON (2011): Permit to take Water for three concrete box culvert stream crossings. Client: Brennan Paving and Construction.
- Hotel Dieu Hospital, St. Catharines, ON (2004, 2010): Conducted a preliminary geotechnical investigation for a proposed general hospital on an existing site; and subsequently, geotechnical considerations for site after use. Client: Niagara Health System.
- Rail Siding Hopper, Niagara Falls, ON (2012): Conducted a geotechnical investigation for an unloading facility. Client: Redpath Sugar.
- Niagara Health System
  - Hotel Dieu Hospital, St. Catharines, ON (2004, 2010): Conducted a preliminary geotechnical investigation for a proposed general hospital on an existing site; and subsequently, geotechnical considerations for site after use. Clients: Niagara Health System and Mountainview Homes.
  - Port Colborne General Hospital (2006): Geotechnical investigation at the Port Colborne Hospital Site.
  - St. Catharines General Hospital (2005): Preliminary geotechnical investigation on a proposed greenfield general hospital site.
- Commercial Construction of an Automobile Dealership, St. Catharines, ON (2008): Geotechnical studies for construction of an automobile dealership on thick fill soils. Client: Confidential.

- Hamilton Public Housing, Stone Church Road, Burlington, ON (2005): Geotechnical Drilling Program at failed former public housing building. Client: Morrison Hershfield.
- Rolling Meadows Subdivision, St. Catharines, ON (2005): Geotechnical investigation and report at a large proposed subdivision. Client: Numbered Ontario Company.
- Arcelor Mittal, East Chicago Steel Works, Gary, IN, USA (2002): Slag granulation dewatering assessment. Provided expert testimony for a construction dewatering investigation around a sheet pile wall cofferdam. This work was in support of a dispute before the American Arbitration Association. Client: Lafarge Canada Inc.
- Caisson and Pile Inspections, St. Catharines/Thorold, ON (2002, 1999): Supervised and inspected caisson installations. Geotechnical investigation of a pile-supported outbuilding at a hospital. Clients: Walker Industries Holdings Limited; Polymax Construction.

Environmental Assessment and Remediation

- Environmental Reporting (ongoing): Numerous soil, groundwater and surface water environmental reports completed for private and public clients. Reviewed and authored numerous Phase I and Phase II Environmental Site Assessments.
- Former Public Works Yard, Lincoln, ON (ongoing): Design, operation and optimization of a pump and treat groundwater remediation system in a fractured bedrock environment. The system has operated successfully for over 15 years. Client: Town of Lincoln.
- Truck Marshalling Yard, Burlington, ON (2011): Conducted a hydrogeologic investigation at a DNALP-impacted site. Client: DML Environmental.
- Former Dry Cleaning Site, Hamilton, ON (2009): Conducted a DNAPL investigation in shallow fractured bedrock, complicated by the presence of shale. This work corrected a previous consultant’s study. Client: Confidential.
- Reported PCB-impacted Automobile Dealership Property, St. Catharines, ON (2009): Groundwater assessment program at a commercial property as part of a dispute resolution. Client: Confidential.
- Pesticide-Impacted Farm Building, St. Catharines, ON (2008): Soil assessment and remediation due to pesticide and fuel oil impacts at a former farm. Client: Confidential.
- Commercial Property Assessment, Canarctic Drive, North York, ON (2005): Soil and groundwater assessment at a former manufacturing facility prior to purchase. Client: Confidential.
- Flint Road Phase II ESA, Downsview ON (2004): The absence of groundwater and soil contamination was confirmed prior to sale of a commercial property. Client: Torkin Manes Cohen Arbus LLP.
- Fuel-impacted Soil and Groundwater, Orwell Road, Mississauga, ON (2004): Conducted a soil remediation program at a leaky underground storage tank site. Work included installation of a dewatering and treatment system for soil excavation below the water table. Client: Confidential.
- Fuel Oil Tank at a Housing Complex, Dunnville, ON (2002): Underground storage tank soil and groundwater investigation. Construction activities uncovered a UST. The tank had leaked into soil and sewer utilities. Sampling was completed and remedial options presented. Client: Hydro Vac Inc.

- Vineland Quarry Asphalt Plant, Lincoln, ON (2002): Conducted an analysis of scrubber sediment for disposal options. Client: Rankin Construction.
- Former Plating Facility, Mississauga, Ontario (2001): Environmental Assessment and remediation of soil, groundwater and installation of a remedial pumping system at a chrome and copper plating facility. Client: Chambers of Canada.
- Former General Abrasives Site, Niagara Falls, ON (2001): Extensive soil and groundwater sampling and contaminant delineation program at a large (40 ha) former industrial facility. Client: R. Ste. Pierre Excavation.
- Effluent-impacted Water Course, Beamsville, ON (2000): Investigation of a complaint led to an MOE order being rescinded regarding a leaking surface water underground storage tank. Client: Desousa Wines.

Waste Management

- Involved in numerous hydrogeologic monitoring programs at private and public landfills throughout Southern Ontario, including Niagara, Hamilton, Region of Waterloo, Simcoe County, City of North Bay, Region of Halton and in Lambton County.
- Unlicensed Landfill, Grimsby, ON (2008-ongoing): Preliminary and ongoing monitoring of a 30,000 tonne unlicensed landfill within a former quarry. Work includes a hydrogeological evaluation of the site, waste delineation and impact analysis; calculations of contaminating lifespan of the waste and financial assurance. The project involves extensive liaison with the Ministry of Environment on behalf of the client. Client: Confidential.
- Park Road Landfill, Grimsby, ON (2009, 2011): Bedrock core logging for new open-hole groundwater monitors. Interpretation of downhole geophysical logs to further define bedrock stratigraphy and fractures/flow zones. Client: Niagara Region.
- Bridge Street Landfill, Fort Erie, ON (2004, 2007, 2010): Geotechnical studies in support of L.C.S. construction. Analysis of instability of waste slopes for regarding purposes. Bedrock core logging for groundwater monitors installed through the Onondaga Escarpment. Completed leachate seep analysis and review of remedial measures, and toe drain installation. Client: Niagara Region.
- Line 5 Landfill, Niagara-on-the-Lake, ON (1994, 2004): Conducted geotechnical evaluation of base of new landfill cell to support landfill operations. Hazardous material sampling and analysis of sealed drums left at landfill site. Client: Niagara Region, Town of Niagara-on-the-Lake.
- West Quarry Landfill, Leachate Management Program, Thorold, ON (1999, 2003): Field supervision of installation of large-diameter caisson wells for controlling leachate in waste. Consultations for construction of residential compost facility on waste. Client: Niagara Waste Systems Limited.
- Glanbrook Landfill Site, Artesian Conditions Assessment, Glanbrook, ON (2000): Conducted an evaluation of deep groundwater upwellings associated with a former gas well on the landfill site. Client: Regional Municipality of Hamilton Wentworth.
- Centre Street Landfill, Pelham, ON (1998): Landfill compliance monitoring reporting as part of the site’s Certificate of Approval. This landfill is located above deep unsaturated sands. Client: Town of Pelham.

PUBLICATIONS AND PRESENTATIONS

Publications

- Fitzpatrick, K and Campbell, J. 2012. Lake Erie to Lake Ontario, Spills, Mills and Landfills and GW/GS Glacial Geology; International Association of Hydrogeologists, 39th IAH Congress, September 16-21, 2012, Niagara Falls, ON, unpublished technical tour book.

REBECCA L. WARRACK, P.Eng.

PROJECT ENGINEER

AREAS OF PRACTICE

Waste Management

Environmental Site Assessments & Site Remediation

Groundwater Resources

Aggregate Resources

Geotechnical Engineering

PROFILE

Ms. Rebecca Warrack is a graduate of the Co-op Environmental Engineering Program at the University of Guelph. Her university training included groundwater and storm water management, air and water quality treatment, waste management and urban water systems designs. Since joining our firm in 2009, Ms. Warrack has expanded her practical experience through extensive field work, technical analysis, data interpretation and report preparation for numerous projects in waste management, environmental site assessments, aggregate resources and geotechnical engineering.

EDUCATION

B.Eng, Environmental Engineering, Co-op, University of Guelph	2009

PROFESSIONAL ASSOCIATIONS

Professional Engineers Ontario	PEO

CAREER

Project Engineer, WSP	2014 – Present
Project Manager, GENIVAR (now named WSP)	2009 – 2013
Student Engineering Technician, Jagger Hims Limited (GENIVAR Acquisition)	2008

PROFESSIONAL EXPERIENCE

Waste Management

- Regional Municipality of Niagara
  - Niagara Road 12 Landfill Site, Monitoring Program, Grimsby, ON (2009-2015, 2018-ongoing): Completed the project management role for the annual monitoring program at this active landfill site located in a bedrock setting. Tasks include managing field staff to complete required groundwater, surface water and leachate collection system sampling events, collating and analyzing data and preparing annual monitoring reports. Project management tasks also include managing the project budget, invoicing and client communication.
  - Glenridge Quarry Naturalization Site, Monitoring Program, St. Catharines, ON (2018-ongoing): Completed the project management role for the annual monitoring program at this site located along the Niagara Escarpment. This closed landfill was constructed in a former rock quarry. Tasks include managing field staff to complete required groundwater, surface water and leachate collection system sampling events and combustible gas monitoring events, collating and analyzing data and preparing annual monitoring reports. Project management tasks also include managing the project budget, invoicing and client communication. Currently completing an Environmental Monitoring Program Optimization Program to propose revisions to the monitoring program, including the implantation of revised trigger locations and criteria.
  - Centre Street Landfill, Monitoring Program, Pelham, ON (2012-ongoing): Completed the project management role for the annual monitoring program at this closed landfill site located in the Fonthill Kame. Managed field staff to

complete required groundwater sampling events, collated and analyzed data and prepared annual monitoring report. Additional tasks have included coordination of supplemental environmental isotope sampling events and prepared technical responses to MECP review comments. Project management tasks also include managing the project budget, invoicing and client communication.

  - Park Road Landfill, Monitoring Program, Grimsby, ON (2009-2015, 2018-ongoing): Tasks completed for this landfill in a bedrock setting have included groundwater and surface water sampling, coordination of field activities, data collation and preparation of annual monitoring reports. Completed the project management role for the annual monitoring program since 2018, including managing the project budget, invoicing and client communication.
  - Station Road Landfill, Monitoring Program, Wainfleet, ON (2009-2015, 2018-ongoing): Tasks completed for this landfill in a bedrock setting have included groundwater and surface water sampling, monitoring well drilling and decommissioning, in-situ hydraulic conductivity testing, data collation and preparation of annual monitoring reports. Completed the project management role for the 2014 and 2018 (and ongoing) annual monitoring program, including managing the project budget, invoicing and client communication.
  - Elm Street Landfill, Monitoring Program, Port Colborne, ON (2018-ongoing): Tasks completed for this landfill in a bedrock setting have coordination of field staff to complete groundwater, surface water and leachate collection system sampling, data collation and preparation of annual monitoring reports. Completed the project management role for the annual monitoring program since 2018, including managing the project budget, invoicing and client communication.
  - Winger Road Landfill, Monitoring Program, Fort Erie, ON (2014-2015): Completed the project management role for the annual monitoring program at this closed landfill site located in an overburden setting. Managed field staff to complete required groundwater sampling events, collated and analyzed data and prepared annual monitoring report.
  - Caistor Road Landfill, Monitoring Program, West Lincoln, ON (2012-2015): Completed the project management role for the annual monitoring program at this closed landfill site located in an overburden setting. Managed field staff and assisted to complete required surface water and groundwater sampling events, collated and analyzed data and prepared annual monitoring report. Also coordinated an overburden well installation program.

- Rotary Park Landfill, Monitoring Program, St. Catharines, ON (2009-ongoing): Field tasks for this closed landfill have included surface water, leachate and groundwater sampling and monitoring, as well as combustible gas monitoring. Office duties included data collation and analysis, as well as the preparation of the annual monitoring reports and project management. Client: The City of St. Catharines.
- East and South Landfill Sites, Thorold, ON (2013-ongoing): Assisted in data management, analysis and annual monitoring report preparation for two active landfill sites in Thorold, ON. Client: Walker Environmental Group.

Environmental Site Assessments and Site Remediation

- Phase One and Phase Two Environmental Site Assessments, St. Catharines, ON (2014-2015): Completed a Phase One Environmental Site Assessment at a City of St. Catharines parks and recreations yard, which contained garage and office buildings, underground fuel storage tanks, fill and debris storage and equipment/vehicle storage. The Phase One Environmental Site Assessment recommended further investigation and a Phase Two Environmental Site Assessment was completed which involved installing ten monitoring wells and advancing several boreholes at the Site and submitting soil and groundwater samples to investigate the areas of potential environmental concern identified in the Phase One Environmental Site Assessment. The work was completed in compliance with the Ontario Regulation 153/04 as amended, to support the future filing of a Record of Site Condition. Client: City of St. Catharines

- Phase One and Phase Two Environmental Site Assessments, New Hamburg, ON (2016-2017): Completed a Phase One Environmental Site Assessment at a felt manufacturing factory located in New Hamburg. The Phase One Environmental Site Assessment recommended further investigation and a Phase Two Environmental Site Assessment was completed which involved installing four monitoring wells at the Site and submitting soil and groundwater samples to investigation the areas of potential environmental concern identified in the Phase One Environmental Site Assessment. Client: Confidential.
- Groundwater Investigation, Niagara Region, ON (2018): Completed a groundwater investigation to delineate and provide recommendations regarding a potential contamination of groundwater at an asphalt plant property located in the Niagara Region. The asphalt plant is located within a licenced quarry property and the contamination has been identified within the groundwater in the bedrock. The project involved the installation of several bedrock monitoring wells and the collection of representative samples using low-flow sampling techniques. The well installation, sample collection and sample results were presented in a report, which provided recommendations for remediation and future work. Client: Confidential.

Groundwater Resources

- Proposed Greenhouse, Ancaster, ON (2017-ongoing): A hydrogeological investigation was conducted for a proposed greenhouse facility which will utilize a private bedrock groundwater well for irrigation water supply. An application for an Environmental Compliance Approval (ECA) from the Ministry of the Environment, Conservation and Parks was prepared for discharge of reverse-osmosis system effluent into a surface water receiver. The ECA application included the collection of several background groundwater and surface water samples and using the data to prepare an assimilative capacity study for the proposed discharge. Additional tasks for this project has included coordination and client communication regarding various engineering-related studies/designs (traffic, noise, dust, odour, sewage system, etc.). Client: The Green Organic Dutchman Ltd.
- Permit-To-Take-Water Monitoring and Environmental Compliance Approval Reporting, Niagara Region, ON (2009-ongoing): Annual compliance reporting is conducted for several quarries in the Niagara Region, for submission to the Ministry of the Environment and Climate Change. Reports typically include the compilation of daily pumping records and water level data for the previous calendar year, for compliance with the Site's Permit-To-Take-Water and Environmental Compliance Approvals. Maintenance and installation of automated flowmeters and loggers is also conducted. Clients: Port Colborne Quarries & the Waterford Group.
- Permit-To-Take-Water Monitoring and Reporting, Fonthill, ON (2009-ongoing): Environmental monitoring and reporting is conducted for a golf course located on the Fonthill Kame geologic feature. The golf course has a Permit-to-Take-Water which allows it to draw groundwater from a deep bedrock pumping well, store the water in a lined-pond and use the water from the pond for irrigation. Specific tasks have involved preparation of the hydrogeological study to support the Permit-to-Take-Water application and renewal applications, install groundwater monitoring wells and multi-level piezometers, instrument monitors and surface water stations with automated monitoring equipment, download and interpret surface water and

hydrogeological data and prepare annual monitoring reports in compliance with the Permit-to-Take-Water.

Aggregate Resources

- Sault Ste. Marie, Quarry & Pit Licensing, Sault Ste. Marie, ON (2009-ongoing): Surface water and groundwater monitoring is being conducted for land adjacent to an existing quarry for future expansion purposes. Site activities included recording groundwater levels, the installation of two stilling wells and leveloggers in a creek, measuring manual surface water flow rates and completing a seep inspection. Compiled, analyzed and presented the collected data in a letter progress report to the client. Client: Pioneer Construction.
- Aggregate Licensing Applications, North Bay, ON (2008-2013): Aggregate licensing applications were prepared for the Bourassa Pit & Quarry, March Pit & Quarry, Stanley Pit and Bomarc Pit which included completing the license application forms, obtaining zoning and ownership information for the properties and preparing full detailed site plans. The approvals were granted in 2013. Client: Pioneer Construction.

Geotechnical Engineering

- Port Colborne Water Tower, Port Colborne, ON (2014-2015): Coordinated and supervised geotechnical drilling and bedrock coring along Elm Street and side streets for geotechnical design of a new watermain. Coordinated with several subcontractors, including utility locating, drilling and traffic control contractors. Advanced a total of 42 geotechnical boreholes and selected soil samples for laboratory testing. Two monitoring wells were also installed to measure groundwater levels. Prepared borehole logs and assisted with preparation of the geotechnical design report. Client: Regional Municipality of Niagara.

J. LEIGH DAVIS, M.A.Sc., P.Eng.

Project Engineer, Environment

Areas of practice

Waste Management

Groundwater Modelling

Aggregate Resources

Geotechnical Engineering

PROFILE

Mr. Leigh Davis is a licensed Project Engineer with WSP, specializing in hydrogeology. His eleven years of experience in the environmental consulting industry include project management, preparation of hydrogeological study and annual monitoring reports, coordination and analysis of in-situ testing, field sampling (including low-flow methods), GIS/CAD figure preparation and numerical groundwater model construction and calibration, including simulation of contaminant transport in the subsurface.

Leigh holds a Bachelor of Applied Science in Environmental Engineering, as well as a Master of Applied Science in Civil Engineering, covering topics including hydrology, hydrogeology, contaminant transport mechanisms, groundwater modelling and landfill design. Leigh's Master's thesis was *Investigation of Seismic Excitation as a Method for Flow Enhancement in Porous Media.* He has a working knowledge of relevant software including ArcGIS, Microsoft Office (including Access), AutoCAD, USGS MODFLOW (including various pre/post processing software) and HELP 3.

EDUCATION

Master of Applied Science, Honours Civil Engineering, University of Waterloo	2008
Bachelor of Applied Science, Honours Environmental Engineering (Co-op), University of Waterloo	2006

PROFESSIONAL DEVELOPMENT

8-Hour Health & Safety Refresher Training Course (HAZWOPER)	2014 – Present
MODFLOW Solvers, Speed, Convergence and Robustness	2018
Introduction to Fortran Programming for MODFLOW Modelers	2018
Calibration and Uncertainty Analysis for Environmental Models	2017
Surface Miner Common Core Training	2013
Estimating Rates of Groundwater Recharge, International Association of Hydrogeologists (IAH)	2012
Reactive Transport Modelling with PHT3D, International Groundwater Modeling Centre (IGWMC)	2011
The New MODFlow Course: Theory and Hands-On Applications, NGWA	2009
Critical Thinking in Aquifer Test Interpretation, S.S.Papadopulos & Associates Inc.	2009
24-Hour Occupational Health & Safety Training Course (HAZWOPER)	2009

PROFESSIONAL ASSOCIATIONS

Professional Engineers Ontario	PEO
Halton Region Environmental and Ecological Advisory Committee (Volunteer, 2011 – 2014)	EEAC

CAREER

Project Engineer, Environment, WSP	2014 – Present
Project Manager, Environment, GENIVAR (now named WSP)	2009 – 2013
Project Manager, Jagger Hims Limited (GENIVAR Acquisition)	2008 – 2009
Technical Project Assistant, Jagger Hims Limited	2005 – 2006
Engineer Assistant, St. Michael's Hospital, Toronto, ON	2004

PROFESSIONAL EXPERIENCE

Aggregate Resources

- Haliburton, ON (2019): Level 2 Hydrogeological Study in support of below water quarry application. Pumping test analysis and hydrogeological conceptual model development. Client: Confidential.
- Wainfleet, ON (2017-ongoing): Level 2 Hydrogeologicay Study in support of below water quarry extension of existing quarry. Field support, pumping test coordination and analysis, report and figure preparation and liaison with regulatory agencies. Construction and calibration of a numerical groundwater flow model to predict impacts of quarry extension on local groundwater users and sensitive features. Client: MHBC Planning.
- Thorold, ON (2016-ongoing): Level 2 Hydrogeological Study in support of below water quarry application at a greenfield site. Field support, pumping test coordination and analysis, report and figure preparation and liaison with regulatory agencies. Construction and calibration of a numerical groundwater flow model to predict impacts of quarry development on local groundwater users and sensitive features. Client: MHBC Planning.
- Walker Aggregates Inc.
  - Walker Brothers Quarry, Niagara Falls, ON (2012-ongoing): Preparation of annual compliance monitoring report for an active quarry located adjacent to one active and two closed landfill sites. Data management and QA/QC using a custom Access database. Monitoring data from all four sites are considered when characterizing and assessing the hydrogeologic setting.
  - Vineland Quarry, Interference Complaint Study, Vineland, ON (2011): Evaluation of sub-watershed hydrologic data and outflow characteristics of quarry pond to determine the cause of downstream channel erosion.
  - Duntroon Quarry Expansion, Collingwood, ON (2009): Numerical groundwater model development for a proposed quarry expansion near the Niagara Escarpment, and GIS figure preparation.
- Pioneer City Pit, Sault Ste. Marie, ON (2016-2017): Level 2 Hydrogeological Study in support of pit / quarry licence extension for below water table extraction. Data collation, report and figure preparation and liaison with regulatory agencies. Client: Pioneer Construction Ltd.
- Palmer Pit, Sault Ste. Marie, ON (2015-2016): Level 2 Hydrogeological Study in support of pit / quarry licence extension for below water table extraction. Field support, data collation, report and figure preparation and liaison with regulatory agencies. Client: Pioneer Construction Ltd.

- Erin Pit, Erin, ON (2015-2017): Level 1 Hydrogeological Study in support of pit licence extension for above water table extraction. Field support, pumping test coordination and analysis, data collation, report and figure preparation and liaison with regulatory agencies. Client: Halton Crushed Stone Inc. / MHBC Planning.
- Identify Potential New Sand and Gravel Pit, Haldimand and Norfolk Counties, ON (2015): GIS and ARIP mapping used to assess potential new sand and gravel pit locations. Client: Confidential.
- Jigs Hollow Pit, Waterloo, ON (2014-ongoing): Level 2 Hydrogeological Study in support of pit licence application. Field support, pumping test coordination and analysis, data collation, report and figure preparation and liaison with regulatory agencies. Client: Preston Sand and Gravel / IBI Group.
- Vinemount Quarry, Stoney Creek, ON (2013-2018): Level 2 Hydrogeolgical Study in support of quarry licence extension. Field support, data collation, report and figure preparation and liaison with regulatory agencies. Client: Waterford Sand and Gravel Limited / IBI Group.
- Aggregate Resource Assessment, Windsor, ON (2012): Review of borehole information and local geology to quantify remaining high-quality aggregates at two quarries near Windsor. Client: Confidential.
- Melancthon Hydrogeologic Study, Township of Melancthon, ON (2009-2010): Calibration of numerical groundwater flow model for existing site conditions and quarry scenario assessment. Client: The Highland Companies.
- Aggregate Resource Assessment, Greater Toronto Area, ON (2008): Development of aggregate resource database and GIS figure preparation to determine high quality aggregate resources in the Greater Toronto Area. Client: Confidential.

Groundwater Modelling

- Peer Review of Proposed Cumberland Quarry, County of Simcoe, ON (2018): Peer review of a Level 1 & Level 2 Hydrogeological Study report and numerical groundwater model in support of a below-water quarry application for a greenfield site. Client: Walker Aggregates Inc.
- Peer Review of Crane Mountain Landfill Groundwater Flow Model, NB (2018): Peer review of a numerical groundwater flow model used to predict landfill impacts on a drinking water aquifer in a complex bedrock setting. Client: Fundy Regional Service Commission, NB.
- Wellhead Protection Area Delineation, Pugwash, NS (2017): Construct and calibrate a numerical groundwater flow model to delineate the wellhead protection area for a municipal supply system. Client: Municipality of the County of Cumberland, NS.
- Hydrogeological Investigation/Numerical Groundwater Flow and Transport Modelling for Phosphate Mine, Kapuskasing, ON (2009-2014): Field work including drilling supervision, monitoring well installation, in-situ hydraulic conductivity tests / analysis and groundwater sampling (including low-flow sampling). Review of existing site data to construct and calibrate a groundwater flow model to be used for simulation of tailings pond leachate transport in the sub-surface in support of the mine closure plan. Hydrogeological report and figure preparation in support of a revised mine closure plan. Client: Agrium Inc.
- Groundwater Capacity Assessment, Omemee, ON (2014): Use of an existing regional numerical groundwater model to identify potential groundwater supply well locations within the community as part of a Class EA. Client: City of Kawartha Lakes.

- Detailed Water Budget Analysis, South Lake Scugog Watershed, Durham Region, ON (2011): Use of an existing regional numerical groundwater model to calculate the groundwater components of the water budget. Client: Kawartha Lakes Conservation Authority.
- Contaminant Transport Modelling for a Thermal In-Situ Heavy Oil Processing Facility, near Cold Lake, AB (2010): Review of site data to construct and calibrate a groundwater flow model to simulate chloride transport from a process water retention pond, and evaluate remediation alternatives. Client: Canadian Natural Resources Limited.
- Numerical Groundwater Modelling, Legault Subdivision Water Supply, St. Albert, ON (2010): Construct and calibrate a numerical groundwater flow model to predict the steady-state drawdown due to proposed subdivision private water supply wells, and assess the impact on nearby existing private wells. Client: The Thomson Rosemount Group, Inc.
- Wilmot Creek Watershed Tier 2 Water Budget Analysis, Durham Region, ON (2010): Calibration of an existing regional groundwater flow model within the watershed of interest to determine the water budget components. Client: Ganaraska Region Conservation Authority.
- Contaminant Transport Modelling for a Former Oil Battery Site, Calmar, AB (2009): Review of site data to construct and calibrate a groundwater flow model to simulate chloride transport and fate in the sub-surface. Client: Canadian Natural Resources Limited / Wiebe Environmental Services.
- Thermal Plume Migration Analysis, Mill Creek Aggregate Pit, Guelph, ON (2009): Use a recalibrated groundwater flow model to determine heat transfer into groundwater system from proposed final pit lake configuration, as well as assess impact on nearby cold water fish habitat. Client: Dufferin Aggregates.
- Groundwater Vulnerability Assessment, City of Kawartha Lakes, ON (2007-2009): Regional groundwater model development; capture zone modelling; GIS figure preparation; technical memo/report preparation to develop a groundwater threat inventory database for 15 municipal well systems. Client: The City of Kawartha Lakes / Trent Conservation Coalition.

Groundwater Resources

- Hydrogeological Study, St. Anns, ON (2019): Development of a hydrogeological conceptual model and water supply assessment for proposed site re-development. Client: Silverdale Gun Club / IBI Group.
- Open Space Design Development, Nova Scotia (2012-2014): Analysis of step test and pumping test data to estimate private supply well capacity as part of subdivision development applications at various sites throughout Nova Scotia. Client: Confidential.
- Earthfresh Potato Processing Facility, Hydrogeological Study, Flamborough, ON (2011): Design of drilling program and analysis of in-situ testing data. Client: Earthfresh Inc. / IBI Group.
- Viva Next H3 Project, Construction Dewatering PTTW Application, Markham, ON (2011): Hydrogeological analysis and report preparation for construction dewatering Permit to Take Water application. Client: Kiewit-EllisDon / The Miller Group.
- 3091 Appleby Line, Hydrogeological Study, Burlington, ON (2011): Design of drilling program, field groundwater sampling, data analysis, figure and report preparation for a hydrogeological study of a dense non-aqueous phase liquid (DNAPL) contaminated site. Client: 1345059 Ontario Ltd.

- Greenwich Street Sewage Pumping Station, Construction Dewatering PTTW Application, Brantford, ON (2011): Hydrogeological analysis and report preparation for construction dewatering Permit to Take Water application. Client: City of Brantford.
- Dominion Road Sewage Pumping Station, Construction Dewatering PTTW Application, Fort Erie, ON (2011): In-situ testing, hydrogeological analysis and report preparation for construction dewatering Permit to Take Water application. Client: R.V. Anderson & Associates / Niagara Region.
- Microbial Contaminant Control Plan, Halton Region, Peel Region, ON (2005, 2006): Threat inventory preparation; CAD figure preparation; field reconnaissance for development of microbial contaminant control plans for groundwater supply systems. Client: Regional Municipality of Halton, Peel Region.
- Garden City Municipal Golf Club, Evaluation of Alternative Irrigation Sources, St. Catharines, ON (2006): Report preparation, CAD figure preparation to assess the ability of a local pond to supply irrigation water requirements. Client: Urban & Environmental Management Inc.

Waste Management

- Regional Municipality of Niagara
  - Bridge Street and Quarry Road Landfill Sites and Quarry Road Constructed Wetland, Annual Monitoring Programs (2013/2014 and 2018-ongoing): Project Manager for annual compliance monitoring programs at landfills in complex fractured bedrock settings. Responsibilities include: manage field staff; liaise with client, subcontractors and laboratories; cost/budget control, collate, QA/QC, analyze and interpret technical data for leachate, groundwater, surface water and sediment samples. Evaluate and assess the condition of the monitoring well network at the Site, develop a work/cost program and implement maintenance and repair program. Performance evaluation of containment systems and perimeter leachate collection systems. Provide routine status updates to client and prepare annual report for submission to the MECP.
  - Line 5 Landfill, Niagara-on-the-Lake, ON (2013-ongoing): Project manager for annual compliance monitoring program at a closed landfill in an overburden setting. Management of field staff; liaisons with client and laboratories; cost/budget control, collation, QA/QC, analysis and interpretation of technical data for leachate, groundwater, and surface water samples; routine status updates to client; and preparation of annual compliance monitoring report. Preparation of a revised environmental monitoring program, which included assessment of site conceptual model, potential contaminant pathways and sensitive receptors.
  - Landfill Monitoring Programs, Niagara Falls, Grimsby, Pelham, Niagara-on-the-Lake, Fort Erie, ON (2005-2014): Field sampling for groundwater and surface water as part of annual monitoring programs at Mountain Road, Park Road, Niagara Road 12, Line 5, Station Road, Centre Street, Quarry Road and Bridge Street Landfills.
  - Nitrate Isotope Sampling and Assessment, Fonthill, ON (2017): Analysis of groundwater general chemistry and isotope results to determine the source of elevated nitrate concentrations at Centre Street Landfill Site.
  - Stormwater Management Pond Trigger Mechanism Plans, Line 5 Landfill and Perry Road Landfill (2014-2015): Statistical analysis of historic chemical results to determine appropriate trigger parameters and levels for operation of the stormwater management pond. Preparation of report, tables and figures.

  - Chloride Isotope Sampling and Assessment, Caistor Centre, ON (2014): Analysis of groundwater general chemistry and isotope results to determine the source of elevated chloride concentrations at Caistor Road Landfill Site.
  - Paleo-karst Investigation, Fort Erie, ON (2013): Low-flow groundwater sampling to complete a hydrogeological investigation to characterize an inferred paleo-karst zone at Bridge Street Landfill. Preparation of report and figures summarizing results, including an analysis of paleo-karst geochemistry.
  - Chloride Isotope Sampling and Assessment, Wainfleet, Fort Erie, ON (2011): Analysis of groundwater general chemistry and isotope results to determine the source of elevated chloride concentrations at Station Road and Bridge Street landfills; technical memo and figure preparation.
  - Tritium, Oxygen and Hydrogen Isotope Sampling and Assessment, Wainfleet, Fort Erie, ON (2010): Analysis of groundwater general chemistry and isotope results to determine the source of elevated chloride concentrations at Station Road and Bridge Street landfills; technical memo and figure preparation.
  - Mountain Road In-situ Hydraulic Conductivity Tests, Niagara Falls, ON (2005): In-situ hydraulic conductivity tests; slug test analysis; report preparation.
- East, South, and West Landfill Sites, City of Niagara Falls, ON (2012-ongoing): Preparation of annual compliance monitoring reports for one operating and two closed landfill sites located within one continuous footprint. Data management and QA/QC using a custom Access database. An adjacent active quarry is also monitored and monitoring data from all four sites are considered when characterizing and assessing the hydrogeologic setting. Client: Walker Environmental Group
- County of Oxford
  - Landfill Monitoring Programs, Norwich, Salford, ON (2012-2014): Preparation of annual monitoring report data tables, figures and text at Holbrook (closed) and Oxford County (operational) landfills.
  - Well Network Assessment, Norwich, ON (2013): Completion of a well network assessment at Holbrook (closed) landfill to identify monitoring program deficiencies and recommend remedial measures.
- Mohawk Street Landfill, Brantford, ON (2009-2018): Field sampling for groundwater and surface water at a large operating landfill. Data collation, technical analysis, and reporting as part of the annual monitoring program. Client: City of Brantford.
- Private Landfill Monitoring Programs, Kapuskasing, ON (2012-2013): Preparation of annual monitoring report data tables, figures and text for two private landfill sites. Client: Tembec Kapuskasing Operations.
- Potential Landfill Constraint Mapping, Eastern Ontario (2006): Constraint mapping for potential landfill sites; GIS figure preparation. Client: Confidential.

Geotechnical Engineering

- OPG Pump Generating Station Dyke Monitoring Program, Niagara Falls, ON (2012-2013): Field and technical support for the abandonment of 111 pressure relief wells and piezometers and 4 additional tunnel well nests around the PGS Dyke, including 3 Waterloo System multi-level wells. Wells were located adjacent to the Niagara Escarpment and the Buried St. Davids Gorge. Additional work included rehabilitation of 48 wells; and preparation of documentation and figures. Client: Ontario Power Generation Inc.

- Sir Adam Beck Tunnel 3, Groundwater Monitoring Program, Niagara Falls, ON (2010-2013): Installation and operation of double-valve pumps (DVPs) for low-flow groundwater sampling to monitor the effect of dewatering for tunnel construction on local groundwater resources. Client: Strabag.
- Abitibi Thorold Mill, Cogeneration Plant, Geotechnical Drilling Program, Thorold, ON (2006): Drill rig supervision; borehole logging and soil sampling as part of a geotechnical investigation of soils for a planned co-generation plant. Client: Abitibi-Consolidated.
- Whirlpool Rapids Bridge Monitoring Program, Niagara Falls, ON (2005): Groundwater sampling and erosion monitoring at a contaminated site within the Niagara River Gorge. Client: Niagara Falls Bridge Commission.

Environmental Site Assessments and Site Remediation

- Designated Substance Survey, Brantford, ON (2013): Development of an Access database for survey results and automated reporting of asbestos material location and condition. Client: City of Brantford.

APPENDIX

B

MECP WATER WELL RECORDS AND WATER WELL SURVEY

Table B-1: MECP WWIS Report

MECP WWR No.	EASTING	NORTHING	ACCURACY	Date Completed	Contractor	COUNTY	TWP	Final Status	1^{st} Use	2^{nd} Use	Drilling Method
1. **6601952**	638308	4750103	unknown UTM	13-Jul-49	Arthur W. Eaton	NIAGARA (WELLAND)	WAINFLEET TOWNSHIP	Water Supply	Domestic		Cable Tool
2. **6601954**	638214	4750097	unknown UTM	6-Aug-49	Arthur W. Eaton	NIAGARA (WELLAND)	WAINFLEET TOWNSHIP	Water Supply	Domestic		Cable Tool
3. **6601955**	638383	4749946	unknown UTM	19-Oct-50	Arthur W. Eaton	NIAGARA (WELLAND)	WAINFLEET TOWNSHIP	Water Supply	Domestic		Cable Tool
4. **6601956**	638250	4750104	unknown UTM	4-Nov-50	Arthur W. Eaton	NIAGARA (WELLAND)	WAINFLEET TOWNSHIP	Water Supply	Domestic		Cable Tool
5. **6601957**	638377	4750067	unknown UTM	12-May-51	Arthur W. Eaton	NIAGARA (WELLAND)	WAINFLEET TOWNSHIP	Water Supply	Domestic		Cable Tool
6. **6601958**	638365	4750117	unknown UTM	8-Apr-52	Caughill Brothers	NIAGARA (WELLAND)	WAINFLEET TOWNSHIP	Water Supply	Commerical		Cable Tool
7. **6601959**	638384	4749803	100 m - 300 m	26-Jul-60	Raymond L. Schooley	NIAGARA (WELLAND)	WAINFLEET TOWNSHIP	Water Supply	Domestic		Cable Tool
8. **6601967**	637390	4750070	unknown UTM	24-May-54	Raymond L. Schooley	NIAGARA (WELLAND)	WAINFLEET TOWNSHIP	Water Supply	Domestic		Cable Tool
9. **6601968**	637407	4750070	unknown UTM	22-Jun-54	Raymond L. Schooley	NIAGARA (WELLAND)	WAINFLEET TOWNSHIP	Water Supply	Domestic		Cable Tool
10. **6601969**	637570	4749735	unknown UTM	18-Nov-55	Raymond L. Schooley	NIAGARA (WELLAND)	WAINFLEET TOWNSHIP	Water Supply	Domestic		Cable Tool
11. **6602168**	638497	4750170	unknown UTM	11-Aug-48	Arthur W. Eaton	NIAGARA (WELLAND)	WAINFLEET TOWNSHIP	Water Supply	Commerical		Cable Tool
12. **6602169**	638412	4750161	unknown UTM	23-Dec-52	LeRoy Kramer	NIAGARA (WELLAND)	WAINFLEET TOWNSHIP	Water Supply	Commerical		Cable Tool
13. **6602174**	637636	4750304	100 m - 300 m	30-Sep-63	Wesley Packham	NIAGARA (WELLAND)	WAINFLEET TOWNSHIP	Water Supply	Public		Cable Tool
14. **6602175**	637126	4750131	unknown UTM	10-Jul-48	Arthur W. Eaton	NIAGARA (WELLAND)	WAINFLEET TOWNSHIP	Water Supply	Domestic		Cable Tool
15. **6602176**	637316	4750149	unknown UTM	8-Sep-54	Knoll & Hollborg	NIAGARA (WELLAND)	WAINFLEET TOWNSHIP	Water Supply	Domestic		Cable Tool
16. **6602387**	637565	4749273	100 m - 300 m	2-Nov-68	Raymond L. Schooley	NIAGARA (WELLAND)	WAINFLEET TOWNSHIP	Water Supply	Domestic		Cable Tool
17. **6602762**	637525	4749333	30 m - 100 m	18-Jul-73	Donald Merritt	NIAGARA (WELLAND)	WAINFLEET TOWNSHIP	Water Supply	Domestic		Cable Tool
18. **6603222**	637447	4750495	30 m - 100 m	10-Sep-75	Donald Merritt	NIAGARA (WELLAND)	WAINFLEET TOWNSHIP	Water Supply	Domestic		Cable Tool
19. **6604076**	636708	4749929		14-Jul-92	Johnson & Baetz Well Boring	NIAGARA (WELLAND)	WAINFLEET TOWNSHIP	Water Supply	Domestic		Boring

Table B-1: MECP WWIS Report

MECP WWR No.	Screen Depth (m BGS)				Water Depth (m)		Pumping Test Data					Formation Depth (m BGS)						
	Top	Bottom	Type	Dia (in)	Depth	TYPE	Static WL (m)	Final WL (m)	Duration	Rate (GPM)	Recommended Rate (GPM)	Layer	Top	Bottom	Description			
1. **6601952**	0.0	1.8	Steel	6	24.4	Fresh	9.1		0 : 30	10		1	0.0	1.5		CLAY		
	1.8	24.4	Open hole	6								2	1.5	24.4	GREY	LIMESTONE		
2. **6601954**	0.0	2.1	Steel	6	20.1	Sulphur	7.6		0 : 30	10		1	0.0	1.5		CLAY		
	2.1	20.1	Open hole	6								2	1.5	20.1	GREY	LIMESTONE		
3. **6601955**	0.0	1.5	Steel	6	20.4	Mineral	8.5					1	0.0	0.9		CLAY		
	1.5	20.4	Open hole	6								2	0.9	20.4	GREY	LIMESTONE		
4. **6601956**	0.0	1.8	Steel	6	20.1	Fresh	8.5					1	0.0	1.8		CLAY		
	1.8	20.1	Open hole	6								2	1.8	20.1	GREY	LIMESTONE		
5. **6601957**	0.0	1.2	Steel	6	20.1	Fresh	7.6					1	0.0	0.3		TOPSOIL		
	1.2	20.1	Open hole	6								2	0.3	20.1	GREY	LIMESTONE		
6. **6601958**	0.0	1.8	Steel	6	22.6	Fresh	9.8	10.7	0 : 30	17		1	0.0	0.6		CLAY		
	1.8	23.5	Open hole	6								2	0.6	23.5		LIMESTONE		
7. **6601959**	0.0	2.4	Steel	6	19.8	Sulphur	5.8	5.8	1 : 30	10	10	1	0.0	1.2		TOPSOIL	CLAY	
	2.4	19.8	Open hole	6								2	1.2	19.8		LIMESTONE		
8. **6601967**	0.0	1.8	Steel	6	20.7	Sulphur	11.3	20.7	0 : 30	4		1	0.0	1.8	RED	CLAY		
	1.8	20.7	Open hole	6								2	1.8	2.1		SHALE		
												3	2.1	20.7		LIMESTONE		
9. **6601968**	0.0	2.1	Steel	6	17.4	Fresh	13.4	17.4	0 : 30	4		1	0.0	2.1	RED	CLAY		
	2.1	17.4	Open hole	6								2	2.1	17.4		LIMESTONE		
10. **6601969**	0.0	2.1	Steel	6	8.2	Fresh	5.2	8.2	0 : 30	4		1	0.0	0.9		CLAY		
	2.1	8.2	Open hole	6								2	0.9	2.1		SHALE		
												3	2.1	8.2		LIMESTONE		
11. **6602168**	0.0	1.2	Steel	6	24.4	Fresh	6.1					1	0.0	24.4	GREY	LIMESTONE		
	1.2	24.4	Open hole	6														
12. **6602169**	0.0	0.9	Steel	6	13.1	Sulphur	13.1			5		1	0.0	0.9		MEDIUM SAND	CLAY	STONES
	0.9	19.5	Open hole	6								2	0.9	19.5	GREY	SHALE	LIMESTONE	
13. **6602174**	0.0	2.1	Steel	6	17.4	Sulphur	8.8	10.7	3 : 00	4	4	1	0.0	1.5		CLAY		
	2.1	18.0	Open hole	6								2	1.5	18.0		LIMESTONE		
14. **6602175**	0.0	1.5	Steel	6	19.8	Fresh	7.6					1	0.0	1.2		CLAY		
	1.5	19.8	Open hole	6								2	1.2	19.8	GREY	LIMESTONE		
15. **6602176**	0.0	1.2	Steel	5	5.5	Fresh	9.1	15.2	0 : 30	15		1	0.0	0.6		MEDIUM SAND		
	1.2	17.1	Open hole	5	16.5	Sulphur						2	0.6	1.2		CLAY		
												3	1.2	7.6		LIMESTONE		
												4	7.6	17.1	BROWN	LIMESTONE		
16. **6602387**	0.0	3.0	Steel	6	9.8	Fresh	1.8	4.3	14 : 00	15	2	1	0.0	1.2		CLAY		
	3.0	9.8	Open hole	6								2	1.2	9.8	GREY	LIMESTONE		
17. **6602762**	0.0	3.0	Steel	6	13.1	Sulphur	6.4	13.7	1 : 00	4	4	1	0.0	2.1	BROWN	CLAY		
	3.0	13.7	Open hole	6								2	2.1	13.7	GREY	LIMESTONE		
18. **6603222**	0.0	3.4	Steel	6	15.2	Sulphur	9.1	19.8	1 : 15	2	2	1	0.0	1.2	BROWN	CLAY		
	3.4	21.3	Open hole	6								2	1.2	21.3	GREY	LIMESTONE		
19. **6604076**	0.0	10.7	Concrete	36	0.9	Fresh	2.4				3	1	0.0	0.3		TOPSOIL		
					2.4	Fresh						2	0.3	0.6	BROWN	CLAY		
					8.5	Fresh						3	0.6	1.2	BROWN	SAND		
												4	1.2	2.4	BROWN	CLAY		
												5	2.4	6.7	BLUE	CLAY		
												6	6.7	8.5	BLUE	CLAY	SAND	LAYERED
												7	8.5	9.8	RED	CLAY	SANDY	
												8	9.8	10.1	RED	SAND		
												9	10.1	10.7	RED	CLAY	STONES	

Table B-1: MECP WWIS Report

MECP WWR No.	EASTING	NORTHING	ACCURACY	Date Completed	Contractor	COUNTY	TWP	Final Status	1st Use	2nd Use	Drilling Method
20. **6604164**	637638	4749864		17-Mar-94	Ken Schooley	NIAGARA (WELLAND)	WAINFLEET TOWNSHIP	Water Supply	Domestic		Cable Tool
21. **6604514**	637431	4750371		2-Dec-00	Ken Schooley	NIAGARA (WELLAND)	WAINFLEET TOWNSHIP	Water Supply	Domestic		Cable Tool

Table B-1: MECP WWIS Report

MECP WWR No.	Screen Depth (m BGS)				Water Depth (m)		Pumping Test Data					Formation Depth (m BGS)						
	Top	Bottom	Type	Dia (in)	Depth	TYPE	Static WL (m)	Final WL (m)	Duration	Rate (GPM)	Recommended Rate (GPM)	Layer	Top	Bottom	Description			
20. **6604164**	0.0	6.1	Steel	5	21.3	Fresh	8.5	18.9	1 : 45	4	5	1	0.0	1.2	BROWN	CLAY	PACKED	
	6.1	21.6	Open hole	5								2	1.2	1.5	BROWN	CLAY	FINE GRAVEL	PACKED
												3	1.5	11.0	GREY	SHALE	LAYERED	
												4	11.0	21.6	GREY	LIMESTONE	LAYERED	
21. **6604514**			Steel	5	25.6	Sulphur	13.4	24.4	1 : 45	12		1	0.0	2.7	BROWN	CLAY	PACKED	
			Open hole	5								2	2.7	14.6	GREY	LIMESTONE	LAYERED	
												3	14.6	18.9	BLUE	LIMESTONE	LAYERED	
												4	18.9	26.2	GREY	LIMESTONE	LAYERED	

Table B-2: 2018 / 2019 Water Well Survey Results

Address	Water Well Plots on Property	Building on Property	Comments	Source	Responded to Survey	Owner Name	Supply	Use
1. 10410 Bessey Road	No	Yes	residence and trailer park	Door-to-Door Survey	(no mailbox)			
2. 20626 Biederman Road	No	Yes		Door-to-Door Survey	(no mailbox)			
3. 20642 Biederman Road	No	Yes	residence	Door-to-Door Survey	No			
4. 20646 Biederman Road	No	Yes	residence	Door-to-Door Survey	No			
5. 20650 Beiderman Road	Yes	No	Owned by 20646 Biederman Road, shop property	Door-to-Door Survey	No			
6. 20654 Biederman Road	No	No	No building or P.O. number on property	Door-to-Door Survey	(no mailbox)			
7. 11020 Ellsworth Road	No	Yes	residence	Door-to-Door Survey	No			
8. 11061 Ellsworth Road	No	Yes	Horseplay Niagara, 20-110 people using well daily	Door-to-Door Survey	Yes	Buttigieg	Well	Domestic / Livestock / Garden
9. 11066 Ellsworth Road	Yes	Yes	residence	Door-to-Door Survey	Yes	Spence	Well	Domestic / Livestock / Garden
10. 11072 Ellsworth Road	No	Yes	residence	Door-to-Door Survey	No			
11. 11074 Ellsworth Road	No	Yes	residence	Door-to-Door Survey	No			
12. 20451 Erie Peat Road	No	Yes	residence	Door-to-Door Survey	Yes	Nasato	Cistern	Domestic
13. 20455 Erie Peat Road	No	Yes	residence	Door-to-Door Survey	No			
14. 20470 Erie Peat Road	Yes	Yes	residence	Door-to-Door Survey	No			
15. 20479 Erie Peat Road	No	Yes	residence	Door-to-Door Survey	No			
16. 20804 Graybiel Road	No	Yes	residence	Door-to-Door Survey	No			
17. 20808 Graybiel Road	Multiple	Yes	Two wells used for livestock and gardening	Door-to-Door Survey	Yes	Collins	Cistern	Domestic
18. 20816 Graybiel Road	No	Yes	residence	Door-to-Door Survey	No			
19. 20824 Graybiel Road	No	Yes	residence	Door-to-Door Survey	No			
20. 20834 Graybiel Road	No	Yes	One well on property, not in use	Door-to-Door Survey	Yes	Labbe	Cistern	Domestic
21. 10595 Highway 3	No	No	Abandoned building on property, no mailbox	Door-to-Door Survey	(no mailbox)			
22. 10611 Highway 3	Multiple	Yes	Wainfleet Congregational Christian Church	Door-to-Door Survey	(no mailbox)			
23. 10613 Highway 3	Yes	Yes	residence	Door-to-Door Survey	No			
24. 10615 Highway 3	Yes	Yes	residence	Door-to-Door Survey	No			
25. 10617 Highway 3	Yes	Yes	residence	Door-to-Door Survey	No			
26. 10621 Highway 3	No	Yes	residence	Door-to-Door Survey	No			
27. 10625 Highway 3	No	Yes	residence	Door-to-Door Survey	No			
28. 10629 Highway 3	No	Yes	One well on property, used for gardening	Door-to-Door Survey	Yes	Carver	Cistern	Domestic
29 10641 Highway 3	No	Yes	Two wells on property not in use	Door-to-Door Survey	Yes	Port Colborne BIC Church	Cistern	Domestic / Garden
30. 10745 Highway 3	No	Yes	residence	Door-to-Door Survey	No			
31. 10822 Highway 3	No	Yes	residence	Door-to-Door Survey	No			
32. 10825 Highway 3	Multiple	Yes	residence	Door-to-Door Survey	No			

Table B-2: 2018 / 2019 Water Well Survey Results

Address	Water Well Plots on Property	Building on Property	Comments	Source	Responded to Survey	Owner Name	Supply	Use
33. 10830 Highway 3	No	Yes	residence	Door-to-Door Survey	No			
34. 10834 Highway 3	No	Yes	residence	Door-to-Door Survey	No			
35. 10942 Highway 3	Yes	Yes	residence	Door-to-Door Survey	No			
36. 10945 Highway 3	No	Yes	residence	Door-to-Door Survey	No			
37. 10949 Highway 3	No	Yes	residence	Door-to-Door Survey	No			
38. 10950 Highway 3	No	Yes	residence	Door-to-Door Survey	No			
39. 10975 Highway 3	No	Yes	Spring discharging to pond main water supply	Door-to-Door Survey	Yes	Black	Spring	Domestic
40. 20405 Kwik Mix Road	Yes	Yes	Well not in use, not potable water	Door-to-Door Survey	Yes	Kwik-Mix Materials Limited	Unknown	
41. 10638 Quarry Road	No	Yes	residence	Door-to-Door Survey	No			
42. 10646 Quarry Road	Yes	Yes	residence	Door-to-Door Survey	Yes	McAdam	Cistern	Livestock / Garden
43. 10650 Quarry Road	No	Yes	residence	Door-to-Door Survey	No			
44. 10652 Quarry Road	No	Yes	residence	Door-to-Door Survey	No			
45. 10654 Quarry Road	No	Yes	residence	Door-to-Door Survey	No			
46. 10656 Quarry Road	Yes	Yes	residence	Door-to-Door Survey	No			
47. 10658 Quarry Road	No	Yes	residence	Door-to-Door Survey	No			
48. 10660 Quarry Road	No	Yes	residence	Door-to-Door Survey	Yes	Brinda	Cistern	Domestic
49. 10822 Rathfon Road	No	Yes	residence	Door-to-Door Survey	No			
50. 10838 Rathfon Road	Yes	Yes	residence	Door-to-Door Survey	No			
51. 10842 Rathfon Road	Multiple	Yes	Two wells not used due to sulphur and hardness	Door-to-Door Survey	Yes	Kramer	Cistern	Domestic
52. 10845 Rathfon Road	No	Yes	Jericho House spirituality centre	Door-to-Door Survey	No			
53. 10847 Rathfon Road	No	Yes	residence, junkyard	Door-to-Door Survey	No			
54. 10849 Rathfon Road	No	Yes	residence	Door-to-Door Survey	Yes	Moore	Well	Domestic
55. 10853 Rathfon Road	No	Yes	residence	Door-to-Door Survey	No			
56. 10855 Rathfon Road	No	Yes	residence	Door-to-Door Survey	Yes	Harriettha	Cistern	Domestic
57. 10857 Rathfon Road	No	Yes	G & R Deschamps	Door-to-Door Survey	No			
58. 10858 Rathfon Road	Yes	Yes	residence	Door-to-Door Survey	No			
59. 10861 Rathfon Road	No	Yes	residence	Door-to-Door Survey	No			
60. 10867 Rathfon Road	Yes	No	No building or mailbox, vacant, community garden	Door-to-Door Survey	No			
61. 10868 Rathfon Road	No	Yes	residence	Door-to-Door Survey	Yes	Stouth	Cistern	Domestic / Garden
62. 10870 Rathfon Road	No	Yes	residence	Door-to-Door Survey	No			

APPENDIX

C

BOREHOLE LOGS AND WELL CONSTRUCTION DETAILS

Table C-1 Monitoring Well Details

Well ID	Monitor Installation Date	Well Pipe Diameter mm	Ground Elevation	Top of Pipe Elevation	Screened Interval	Filter Pack	Seal	Surface Seal	Hydrostratigraphic Unit
					m below ground surface				
1. GLL-1	2004	51	176.00	176.95	4.3 - 7.3	3.7 - 7.6	0.0 - 3.7		Shallow Bedrock
2. MW1-I	2018	51	177.17	177.99	28.2 - 29.8	27.4 - 29.8	1.0 - 27.4	0.0 - 1.0	Deep Salina Formation
3. MW1-II	2018	51	177.20	177.95	24.6 - 26.3	22.6 - 26.3	1.0 - 22.6	0.0 - 1.0	Oatka / Salina Contact
4. MW1-III	2018	51	177.19	177.98	16.1 - 19.4	15.4 - 19.4	1.0 - 15.4	0.0 - 1.0	Falkirk Member
5. GLL-3	2004	51	178.11	178.96	3.9 - 10.0	3.4 - 10.5	0.0 - 3.4		Shallow Bedrock
6. GLL-4	2004	51	184.48	185.18	3.4 - 6.4	1.5 - 7.1	0.0 - 1.5		Shallow Bedrock
7. MW4-II	2017	51	184.68	185.65	25.4 - 28.7	25.2 - 28.9	0.7 - 25.2	0.0 - 0.7	Oatka / Salina Contact
8. MW4-III	2017	51	184.69	185.73	17.9 - 21.2	17.4 - 21.3	0.7 - 17.4	0.0 - 0.7	Falkirk Member
9. GLL-5	2004	51	176.64	177.36	8.0 - 12.4	7.0 - 13.1	0.0 - 7.0		Falkirk Member
10. MW5-I	2018	51	176.83	177.75	24.0 - 25.6	23.3 - 25.6	1.0 - 23.3	0.0 - 1.0	Deep Salina Formation
11. MW5-II	2017	51	176.97	177.77	17.4 - 20.7	15.4 - 20.7	0.7 - 15.4	0.0 - 0.7	Oatka / Salina Contact
12. GLL-6	2004	51	182.72	183.54	8.0 - 12.4	7.1 - 12.9	0.0 - 7.1		Falkirk Member
13. MW6-II	2017	51	182.93	183.88	17.1 - 20.3	16.4 - 20.3	0.7 - 16.4	0.0 - 0.7	Oatka / Salina Contact
14. GLL-7	2004	51	182.27	183.28	4.7 - 8.0	2.8 - 8.6	0.0 - 2.8		Shallow Bedrock
15. GLL-8	2004	51	183.07	183.91	14.0 - 18.4	13.2 - 19.1	0.0 - 13.2		Falkirk Member
16. GLL-9	2004	51	183.15	183.95	4.7 - 9.0	3.5 - 9.7	0.0 - 3.5		Shallow Bedrock
17. MW9-II	2018	51	183.21	184.08	22.1 - 23.7	21.3 - 23.7	1.0 - 21.3	0.0 - 1.0	Oatka / Salina Contact
18. MW9-III	2018	51	183.13	184.02	14.8 - 18.0	14.1 - 18.0	1.0 - 14.1	0.0 - 1.0	Falkirk Member
19. GLL-10	2004	51	182.55	183.39	4.7 - 11.0	4.0 - 11.4	0.0 - 4.0		Shallow Bedrock
20. MW10-I	2018	51	182.64	183.51	27.2 - 30.5	26.6 - 30.5	1.0 - 26.6	0.0 - 1.0	Deep Salina Formation
21. MW10-II	2017	51	182.58	183.54	22.0 - 25.3	21.2 - 25.3	0.7 - 21.2	0.0 - 0.7	Oatka / Salina Contact
22. MW10-III	2017	51	182.63	183.54	13.4 - 16.8	13.2 - 16.8	0.3 - 13.2	0.0 - 0.3	Falkirk Member
23. GLL-11-I	2005	51	177.78	178.69	11.8 - 15.3				Falkirk Member
24. GLL-11-II	2005	51	177.94	178.85	3.2 - 6.6				Shallow Bedrock
25. MW11-1	2018	51	178.18	179.05	21.2 - 24.5	20.6 - 24.7	0.5 - 20.6	0.0 - 0.5	Oatka / Salina Contact

Notes:
- Elevations provided in metres above sea level (mASL)
- Survey for ground surface / top of pipe elevations completed in 2018.
- Blank indicates that data is not available

Table C-1 Monitoring Well Details

Well ID	Monitor Installation Date	Well Pipe Diameter	Ground Elevation	Top of Pipe Elevation	Screened Interval	Filter Pack	Seal	Surface Seal	Hydrostratigraphic Unit
		mm			m below ground surface				
26. MW12-II	2018	51	184.36	185.20	27.3 - 28.9	26.6 - 28.9	1.0 - 26.6	0.0 - 1.0	Oatka / Salina Contact
27. MW12-III	2018	51	184.40	185.32	19.0 - 22.3	18.4 - 22.3	1.0 - 18.4	0.0 - 1.0	Falkirk Member
28. PW	2004	152.4	182.50	183.10	6.6 - 32.9		0.0 - 6.6		(open hole)

Notes:
- Elevations provided in metres above sea level (mASL)
- Survey for ground surface / top of pipe elevations completed in 2018.
- Blank indicates that data is not available

Table C-1 Monitoring Well Details

Residential Well Address	Alias	Installation Date	Well Pipe Diameter mm	Ground Elevation	Top of Pipe Elevation	Screened Interval m bgs	MECP WWR
1. 20246 Youngs Road				179.72	179.96		
2. 722 Highway 3				179.46	179.71	- 8.4	

Notes:
- Elevations provided in metres above sea level (mASL)
- Survey for ground surface / top of pipe elevations completed in 2018.
- Blank indicates that data is not available

Table C-2 Site Well Stratigraphic Summary

Well Nest	Ground Elevation	Bedrock Elevation	Bedrock Subcrop	Stratigraphic Contact Depth / Elevation															
				Bois Blanc Formation				Bertie Formation										Salina Formation	
						Springvale Mb		Akron Mb		Williamsville Mb		Scajaquada Mb		Falkirk Mb		Oatka Mb			
	masl			mbgs	masl	mbgs	masl	mbgs	masl	mbgs	masl	mbgs	masl	mbgs	masl	mbgs	masl	mbgs	masl
MW1	177.2	173.2	Bois Blanc Formation	4.0	173.2	5.5	171.7	6.1	171.1	8.7	168.5	11.3	165.9	13.6	163.6	18.2	159.0	23.4	153.8
GLL-3	178.1	175.4	Bertie Formation, Williamsville Mb	-		-		-		2.7	175.4	4.1	174.0	6.6	171.5	11.3	166.8	16.2	161.9
MW4	184.7	184.3	Bois Blanc Formation	0.4	184.3	7.9	176.8	9.2	175.5	12.6	172.1	13.4	171.3	15.8	168.9	23.2	161.5	25.3	159.4
MW5	177.8	173.2	Bertie Formation, Falkirk Mb	-		-		-		-		-		4.6	173.2	8.6	169.2	18.9	158.9
MW6	182.9	182.7	Bois Blanc Formation	0.2	182.7	1.3	181.6	1.8	181.1	6.6	176.3	8.1	174.8	10.4	172.5	16.2	166.7	18.4	164.5
GLL-7	182.3	181.7	Bois Blanc Formation	0.6	181.7	1.4	180.9	1.9	180.4	5.1	177.2	7.4	174.9	9.6	172.7	14.9	167.4	19.4	162.9
GLL-8	183.1	180.4	Bois Blanc Formation	2.7	180.4	5.3	177.8	5.9	177.2	8.9	174.2	10.4	172.7	13.1	170.0	17.5	165.6	21.1	162.0
MW9	183.2	180.8	Bois Blanc Formation	2.4	180.8	4.2	179.0	5.1	178.1	7.6	175.6	10.4	172.8	13.0	170.2	17.0	166.2	21.4	161.8
MW10	182.6	180.0	Bois Blanc Formation	2.6	180.0	5.1	177.5	6.9	175.7	8.9	173.7	10.0	172.6	13.1	169.5	17.1	165.5	21.9	160.7
MW11	178.2	175.9	Bois Blanc Formation	2.3	175.9	4.8	173.4	5.3	172.9	8.0	170.2	9.4	168.8	11.7	166.5	16.8	161.4	21.4	156.8
MW12	184.4	183.6	Bois Blanc Formation	0.8	183.6	7.5	176.9	9.2	175.2	12.9	171.5	13.7	170.7	17.0	167.4	21.1	163.3	26.1	158.3

Notes:
- Elevations provided in metres above sea level (masl)
- Depths provided in metres below ground surface (mbgs)

GRAPHICS, SYMBOLS AND ABBREVIATIONS ON LOGS

SAMPLE TYPES and TESTS

▨	**SS**	Split Spoon Sample	
▨	**SN**	Non-Standard Split Spoon Sample	
I	**ST**	Shelby Tube Sample : (unconfined compression or unconsolidated undrained test)	- ◆
I	**DS**	Denision Type Sample	
▯	**PS**	Piston Type Sample	
I	**CS**	Continuous Sample	
I	**GS**	Grab Sample	
▨	**WS**	Wash Sample	
▨	**BQ**	BQ Core Sample	
▨	**HQ**	HQ Core Sample	
▨	**NQ**	NQ Core Sample	
I	**DT**	Dynamic Penetration Test	
█	**VT**	Field Vane Test (undisturbed)	- ⊙
█	**VT**	Field Vane Test (remoulded)	- ⊕

PENETRATION RESISTANCES

Standard Penetration Resistance(N Value)

The number of blows by a 63.6 kg (140 lb) hammer dropped 760 mm (30 in.) required to drive a 50 mm (2 in.) Split Spoon Sampler for a distance of 300 mm (12 in.).

ABBREVIATIONS

DTPL: Drier Than Plastic Limit
APL: About Plastic Limit
WTPL: Wetter Than Plasic Limit
K: Hydraulic Conductivity (m/s)
C_u: Undrained Shear Strength (kPa)
% REC : Percentage of Sample Recovered
% RQD : Indirect Measure of the Number of Fractures and Soundness of Rock Mass
▼ Approximate Water Table

GRAIN SIZE CLASSIFICATION

	%
trace, "eg. trace sand"	1 - 10
some, "eg. some sand"	10 - 20
adjective, "eg. sandy"	20 - 35
and, "eg. and sand"	35 - 50
noun, "eg. sand"	>50

Note: Classification Divisions Based on Modified M.I.T. Grain Size Scale

SOIL DESCRIPTIONS

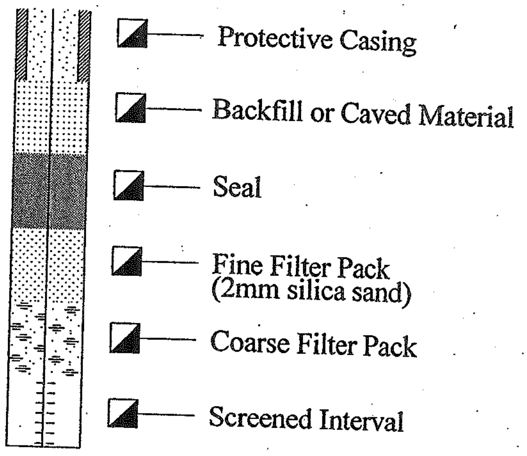
Cohesionless Soils

Relative Density	N Value
Very loose	0 to 4
Loose	4 to 10
Compact	10 to 30
Dense	30 to 50
Very Dense	over 50

Cohesive Soils

Consistency	C_u(kPa)	N Value
Very soft	0 to 12	0 to 2
Soft	12 to 25	2 to 4
Firm	25 to 50	4 to 8
Stiff	50 to 100	8 to 15
Very Stiff	100 to 200	15 to 30
Hard	over 200	over 30

MONITOR DETAILS



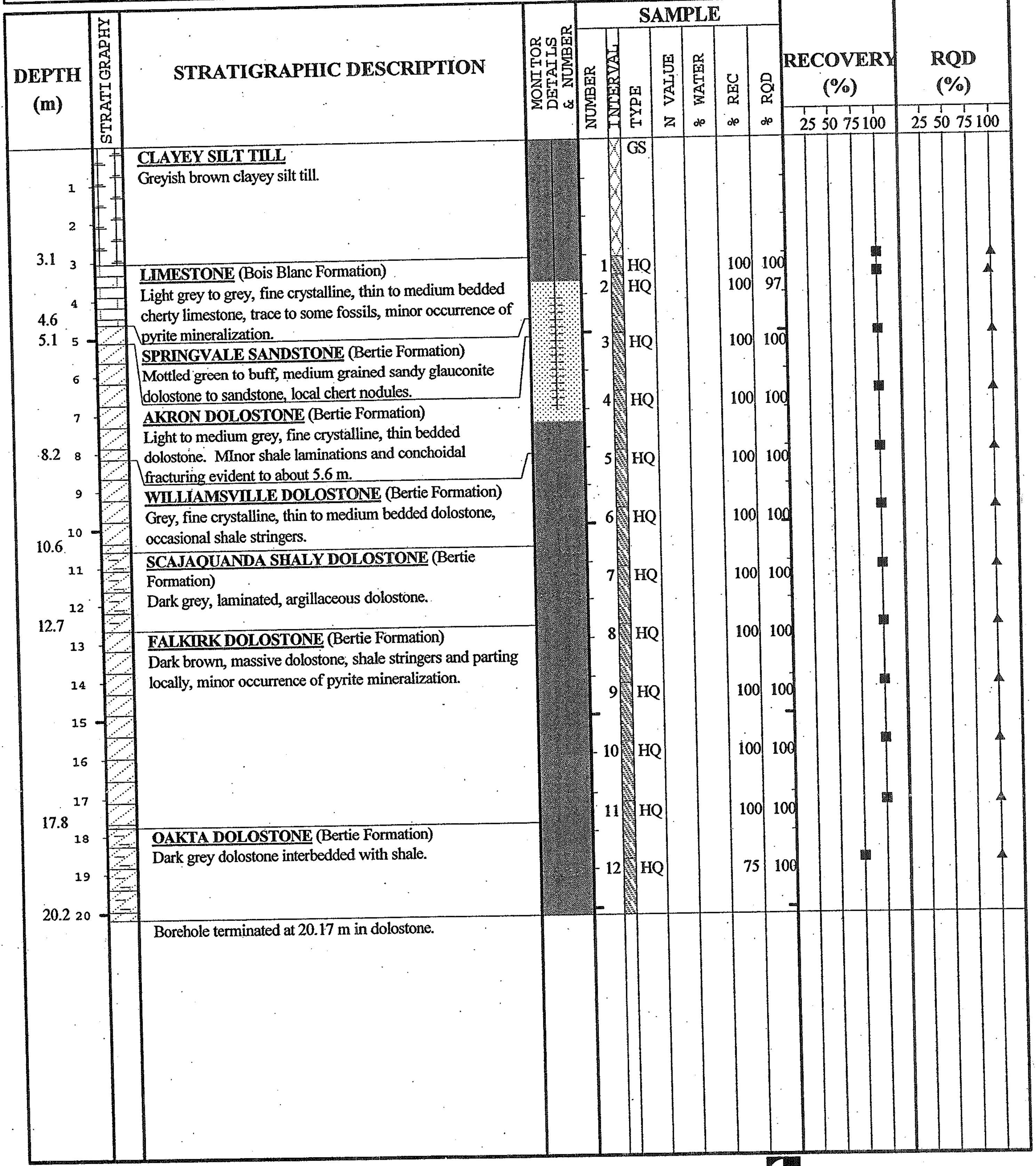
BOREHOLE LOG

PROJECT: 40-403

BOREHOLE: GLL-1 1 of 1

Hydrogeological-Geological Investigation
Law Quarry, Port Colborne
FOR: Hard Rock Paving

DATE: 07 July 2004
LOGGED BY DL/MT
GROUND ELEV 176.00 m ASL



DEPTH (m)	STRATIGRAPHIC DESCRIPTION
	CLAYEY SILT TILL Greyish brown clayey silt till.
3.1	**LIMESTONE** (Bois Blanc Formation) Light grey to grey, fine crystalline, thin to medium bedded cherty limestone, trace to some fossils, minor occurrence of pyrite mineralization.
4.6	**SPRINGVALE SANDSTONE** (Bertie Formation) Mottled green to buff, medium grained sandy glauconite dolostone to sandstone, local chert nodules.
5.1	**AKRON DOLOSTONE** (Bertie Formation) Light to medium grey, fine crystalline, thin bedded dolostone. MInor shale laminations and conchoidal fracturing evident to about 5.6 m.
8.2	**WILLIAMSVILLE DOLOSTONE** (Bertie Formation) Grey, fine crystalline, thin to medium bedded dolostone, occasional shale stringers.
10.6	**SCAJAQUANDA SHALY DOLOSTONE** (Bertie Formation) Dark grey, laminated, argillaceous dolostone.
12.7	**FALKIRK DOLOSTONE** (Bertie Formation) Dark brown, massive dolostone, shale stringers and parting locally, minor occurrence of pyrite mineralization.
17.8	**OAKTA DOLOSTONE** (Bertie Formation) Dark grey dolostone interbedded with shale.
20.2	Borehole terminated at 20.17 m in dolostone.

NUMBER	TYPE	N VALUE	% WATER	% REC	% RQD
	GS				
1	HQ			100	100
2	HQ			100	97
3	HQ			100	100
4	HQ			100	100
5	HQ			100	100
6	HQ			100	100
7	HQ			100	100
8	HQ			100	100
9	HQ			100	100
10	HQ			100	100
11	HQ			100	100
12	HQ			75	100

Printed: 16 Mar 05
File Location:N:\Projects\2004\40403\2004\WorkInProgress\BoreholeLogs\

Gartner Lee Limited

BOREHOLE LOG

PROJECT: 40-403

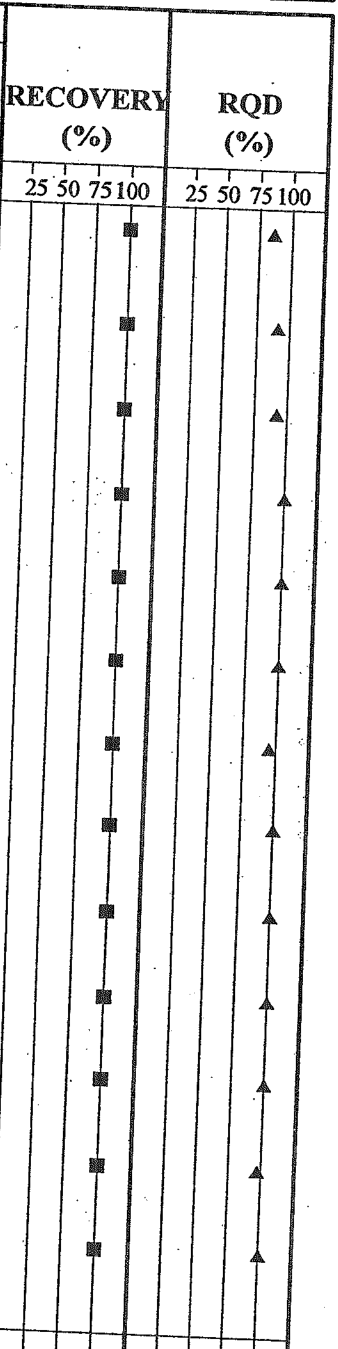
BOREHOLE: GLL-2 1 of 1

Hydrogeological-Geological Investigation
Law Quarry, Port Colborne
FOR: Hard Rock Paving

DATE: 15 July 2004
LOGGED BY MT
GROUND ELEV 178.59 m ASL

DEPTH (m)	STRATIGRAPHIC DESCRIPTION
0.4	**CLAYEY SILT TILL** Greyish brown clayey silt till.
	LIMESTONE (Bois Blanc Formation) Buff to grey (mottled), fine crystalline, medium bedded cherty limestone, fossiliferous.
2.9 3.4	**SPRINGVALE SANDSTONE** (Bertie Formation) Greenish grey, medium grained glauconitic sandstone, local chert nodules.
	AKRON DOLOSTONE (Bertie Formation) Light to medium grey, fine crystalline, thin to medium bedded dolostone.
6.1	**WILLIAMSVILLE DOLOSTONE** (Bertie Formation) Grey, fine crystalline, thin to medium bedded dolostone.
8.2	**SCAJAQUANDA SHALY DOLOSTONE** (Bertie Formation) Dark grey, laminated, argillaceous dolostone.
10.4	**FALKIRK DOLOSTONE** (Bertie Formation) Brown to grey, medium bedded dolostone, shale stringers and parting locally.
15.2	**OAKTA DOLOSTONE** (Bertie Formation) Dark grey dolostone interbedded with shale.
20.4	Borehole terminated at 20.39 m in dolostone.

NUMBER	TYPE	N VALUE	% WATER	% REC	% RQD
	GS				
1	HQ			100	86
2	HQ			100	91
3	HQ			100	92
4	HQ			100	100
5	HQ			100	100
6	HQ			100	100
7	HQ			100	95
8	HQ			100	100
9	HQ			100	100
10	HQ			100	100
11	HQ			100	100
12	HQ			100	97
13	HQ			100	100



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File Location:N:\Projects\2004\40403\2004\WorkInProgress\BoreholeLogs\

Gartner Lee Limited

BOREHOLE LOG

PROJECT: 40-403

BOREHOLE: GLL-3 1 of 1

Hydrogeological-Geological Investigation
Law Quarry, Port Colborne
FOR: Hard Rock Paving

DATE: 20 July 2004
LOGGED BY MT
GROUND ELEV 178.11 m ASL

DEPTH (m)	STRATIGRAPHIC DESCRIPTION
	CLAYEY SILT TILL Greyish brown clayey silt till.
2.7	**WILLIAMSVILLE DOLOSTONE** (Bertie Formation) Light grey, fine crystalline, medium bedded dolostone.
4.1	**SCAJAQUANDA SHALY DOLOSTONE** (Bertie Formation) Dark grey, laminated, argillaceous dolostone.
6.6	**FALKIRK DOLOSTONE** (Bertie Formation) Brown to grey, medium bedded dolostone, shale stringers and parting locally, minor occurrence of pyrite mineralization.
11.3	**OAKTA DOLOSTONE** (Bertie Formation) Dark grey dolostone interbedded with shale.
16.2	**SHALE** (Salina Formation) Grey dolomitic shale to shale interbedded to interlaminated with gypsum.
24.4	Borehole terminated at 24.38 m in shale.

SAMPLE

NUMBER	TYPE	N VALUE	% WATER	% REC	% RQD	RECOVERY (%)	RQD (%)
	GS						
1	HQ			100	100	100	100
2	HQ			100	100	100	100
3	HQ			100	100	100	100
4	HQ			100	100	100	100
5	HQ			100	100	100	100
6	HQ			100	100	100	100
7	HQ			100	100	100	100
8	HQ			100	100	100	100
9	HQ			100	100	100	100
10	HQ			100	100	100	100
11	HQ			100	100	100	100
12	HQ			100	100	100	100
13	HQ			100	100	100	100
14	HQ			100	100	100	100
15	HQ			100	100	100	100

Printed: 16 Mar 05
File Location:N:\Projects\2004\40403\2004\WorkInProgress\BoreholeLogs\

Gartner Lee Limited

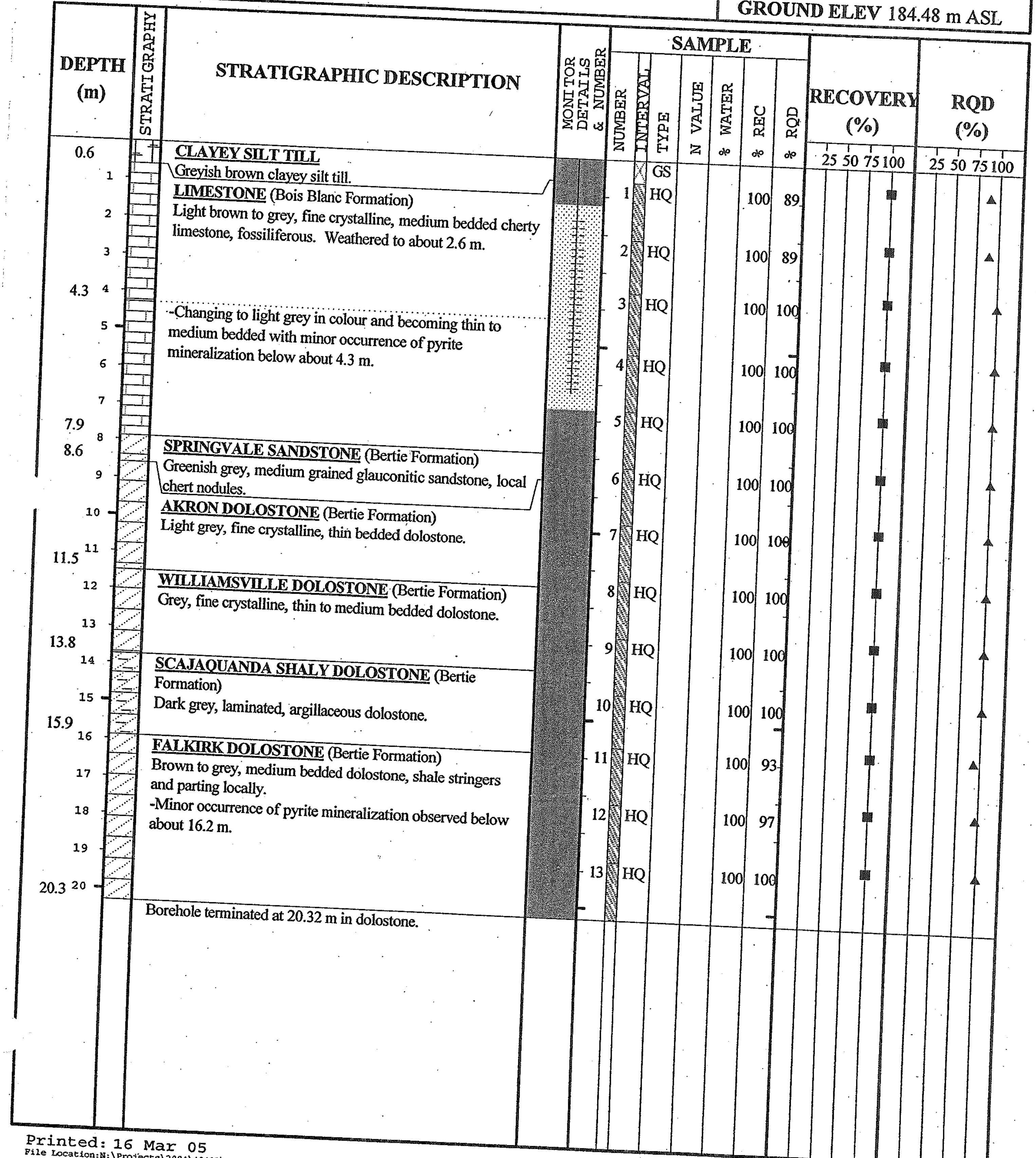
BOREHOLE LOG

PROJECT: 40-403

BOREHOLE: GLL-4 1 of 1

Hydrogeological-Geological Investigation
Law Quarry, Port Colborne
FOR: Hard Rock Paving

DATE: 23 July 2004
LOGGED BY MT/PJAM
GROUND ELEV 184.48 m ASL



DEPTH (m)	STRATIGRAPHIC DESCRIPTION
0.6	**CLAYEY SILT TILL** Greyish brown clayey silt till.
	LIMESTONE (Bois Blanc Formation) Light brown to grey, fine crystalline, medium bedded cherty limestone, fossiliferous. Weathered to about 2.6 m.
4.3	-Changing to light grey in colour and becoming thin to medium bedded with minor occurrence of pyrite mineralization below about 4.3 m.
7.9	**SPRINGVALE SANDSTONE** (Bertie Formation) Greenish grey, medium grained glauconitic sandstone, local chert nodules.
8.6	**AKRON DOLOSTONE** (Bertie Formation) Light grey, fine crystalline, thin bedded dolostone.
11.5	**WILLIAMSVILLE DOLOSTONE** (Bertie Formation) Grey, fine crystalline, thin to medium bedded dolostone.
13.8	**SCAJAQUANDA SHALY DOLOSTONE** (Bertie Formation) Dark grey, laminated, argillaceous dolostone.
15.9	**FALKIRK DOLOSTONE** (Bertie Formation) Brown to grey, medium bedded dolostone, shale stringers and parting locally. -Minor occurrence of pyrite mineralization observed below about 16.2 m.
20.3	Borehole terminated at 20.32 m in dolostone.

NUMBER	TYPE	N VALUE	% WATER	% REC	% RQD
	GS				
1	HQ			100	89
2	HQ			100	89
3	HQ			100	100
4	HQ			100	100
5	HQ			100	100
6	HQ			100	100
7	HQ			100	100
8	HQ			100	100
9	HQ			100	100
10	HQ			100	100
11	HQ			100	93
12	HQ			100	97
13	HQ			100	100

Printed: 16 Mar 05
File Location:N:\Projects\2004\40403\2004\WorkInProgress\BoreholeLogs\

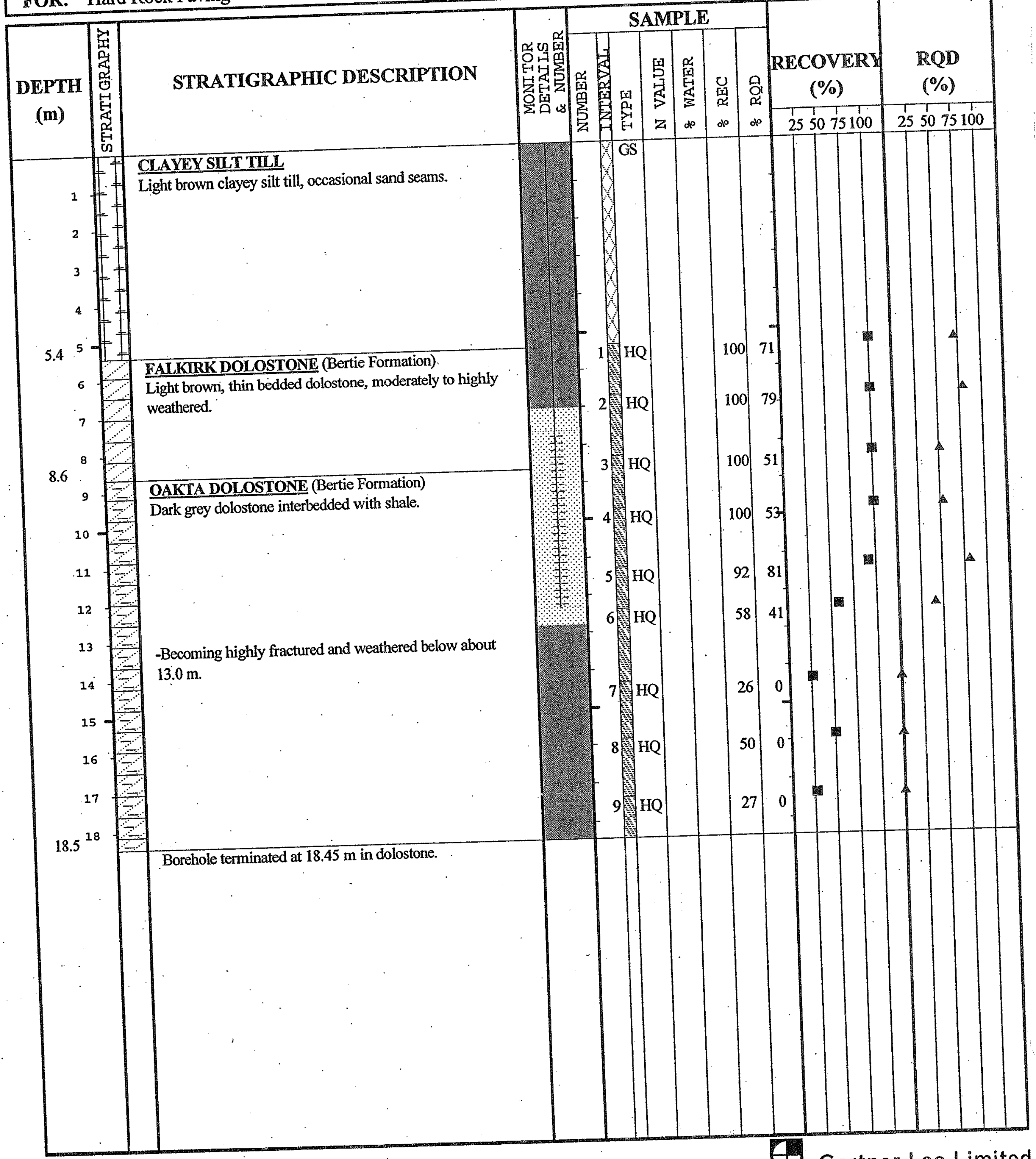
BOREHOLE LOG

PROJECT: 40-403

BOREHOLE: GLL-5 1 of 1

Hydrogeological-Geological Investigation
Law Quarry, Port Colborne
FOR: Hard Rock Paving

DATE: 28 July 2004
LOGGED BY MT
GROUND ELEV 176.64 m ASL



CLAYEY SILT TILL
Light brown clayey silt till, occasional sand seams.

FALKIRK DOLOSTONE (Bertie Formation)
Light brown, thin bedded dolostone, moderately to highly weathered.

OAKTA DOLOSTONE (Bertie Formation)
Dark grey dolostone interbedded with shale.

-Becoming highly fractured and weathered below about 13.0 m.

Borehole terminated at 18.45 m in dolostone.

NUMBER	TYPE	N VALUE	% WATER	% REC	% RQD
	GS				
1	HQ			100	71
2	HQ			100	79
3	HQ			100	51
4	HQ			100	53
5	HQ			92	81
6	HQ			58	41
7	HQ			26	0
8	HQ			50	0
9	HQ			27	0

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Gartner Lee Limited

BOREHOLE LOG

PROJECT: 40-403

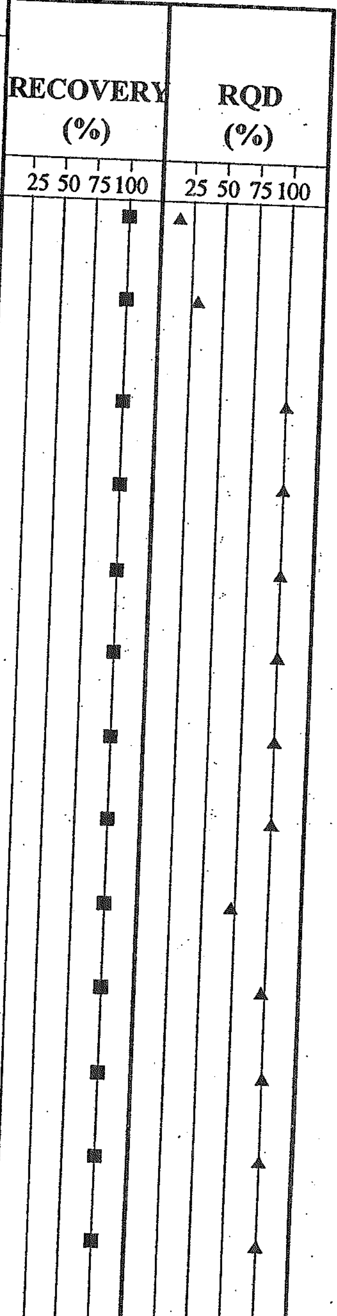
BOREHOLE: GLL-6 1 of 1

Hydrogeological-Geological Investigation
Law Quarry, Port Colborne
FOR: Hard Rock Paving

DATE: 03 August 2004
LOGGED BY MT
GROUND ELEV 182.72 m ASL

DEPTH (m)	STRATIGRAPHIC DESCRIPTION
0.3	**TOPSOIL** Medium brown silty clay topsoil, trace to some gravel.
1.5	**LIMESTONE** (Bois Blanc Formation) Buff to grey, fine crystalline, medium bedded cherty limestone. Weathered and fractured to about 1.4 m.
1.9	**SPRINGVALE SANDSTONE** (Bertie Formation) Greenish grey, fine to medium grained glauconitic sandstone, local chert nodules.
5.2	**AKRON DOLOSTONE** (Bertie Formation) Light to medium grey, fine crystalline, thin to medium bedded dolostone, occasional shale stringers.
8.2	**WILLIAMSVILLE DOLOSTONE** (Bertie Formation) Grey, fine crystalline, thin to medium bedded dolostone. Mottled appearance to about 6.7 m.
9.6	**SCAJAQUANDA SHALY DOLOSTONE** (Bertie Formation) Dark grey, laminated, argillaceous dolostone.
14.9	**FALKIRK DOLOSTONE** (Bertie Formation) Brown to grey, medium bedded dolostone, shale stringers and parting locally. Weathered zone at upper contact. -Becoming interbedded with shaly dolostone below about 14.3 m.
18.8	**OAKTA DOLOSTONE** (Bertie Formation) Dark grey dolostone interbedded with shale.
20.4	**SHALE** (Salina Formation) Grey dolomitic shale to shale interbedded to interlaminated with gypsum.
	Borehole terminated at 20.43 m in dolomitic shale to shaly dolostone.

NUMBER	TYPE	N VALUE	% WATER	% REC	% RQD
1	GS HQ			100	14
2	HQ			100	30
3	HQ			100	100
4	HQ			100	100
5	HQ			100	100
6	HQ			100	100
7	HQ			100	100
8	HQ			100	100
9	HQ			100	72
10	HQ			100	97
11	HQ			100	100
12	HQ			100	100
13	HQ			100	100



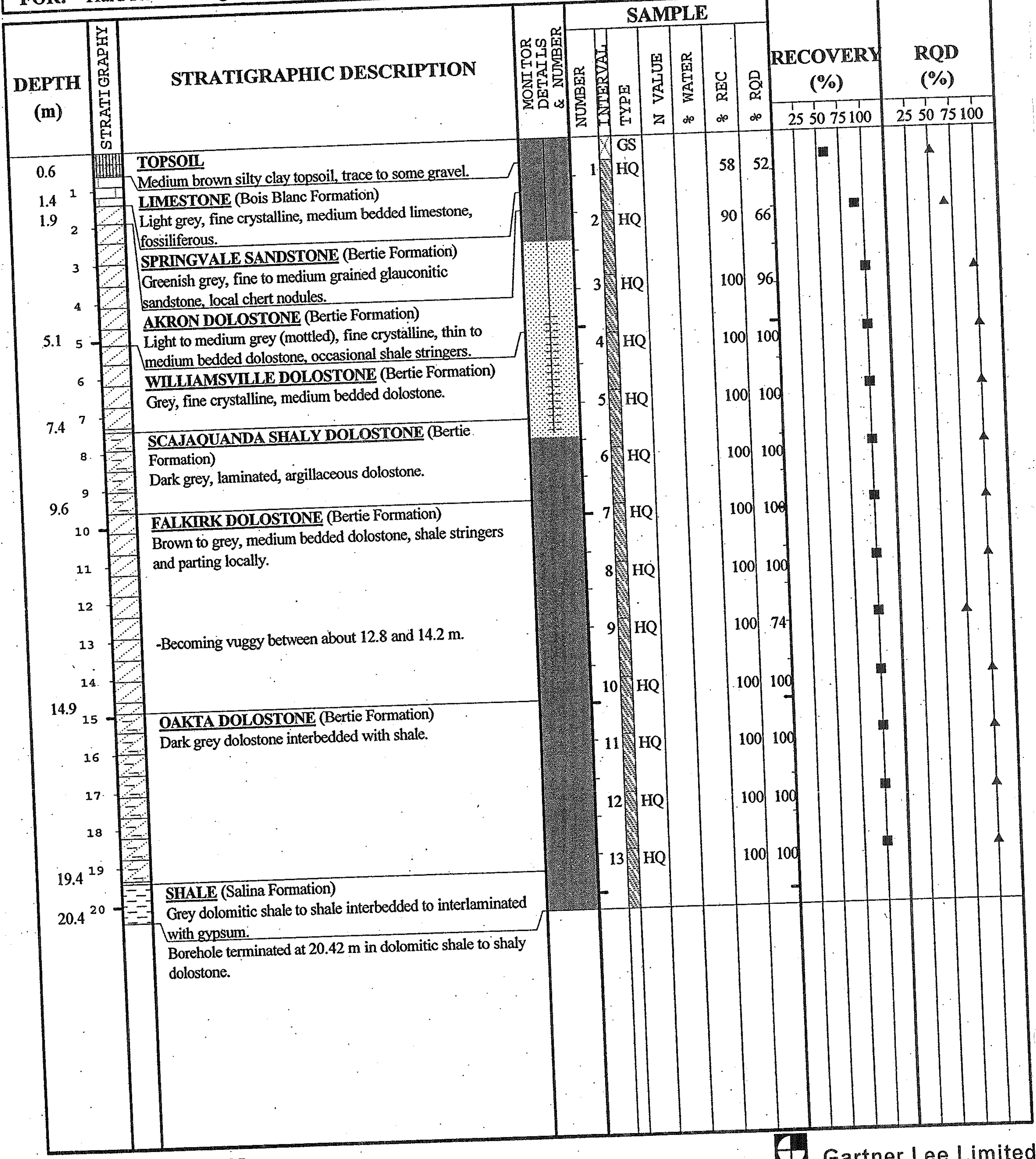
Printed: 16 Mar 05
File Location:N:\Projects\2004\40403\2004\WorkInProgress\BoreholeLogs\

Gartner Lee Limited

BOREHOLE LOG | **PROJECT:** 40-403 | **BOREHOLE:** GLL-7 1 of 1

Hydrogeological-Geological Investigation
Law Quarry, Port Colborne
FOR: Hard Rock Paving

DATE: 05 August 2004
LOGGED BY MT
GROUND ELEV 182.27 m ASL



DEPTH (m)	STRATIGRAPHIC DESCRIPTION
0.6	**TOPSOIL** Medium brown silty clay topsoil, trace to some gravel.
1.4	**LIMESTONE** (Bois Blanc Formation) Light grey, fine crystalline, medium bedded limestone, fossiliferous.
1.9	**SPRINGVALE SANDSTONE** (Bertie Formation) Greenish grey, fine to medium grained glauconitic sandstone, local chert nodules.
	AKRON DOLOSTONE (Bertie Formation) Light to medium grey (mottled), fine crystalline, thin to medium bedded dolostone, occasional shale stringers.
5.1	**WILLIAMSVILLE DOLOSTONE** (Bertie Formation) Grey, fine crystalline, medium bedded dolostone.
7.4	**SCAJAQUANDA SHALY DOLOSTONE** (Bertie Formation) Dark grey, laminated, argillaceous dolostone.
9.6	**FALKIRK DOLOSTONE** (Bertie Formation) Brown to grey, medium bedded dolostone, shale stringers and parting locally. -Becoming vuggy between about 12.8 and 14.2 m.
14.9	**OAKTA DOLOSTONE** (Bertie Formation) Dark grey dolostone interbedded with shale.
19.4	**SHALE** (Salina Formation) Grey dolomitic shale to shale interbedded to interlaminated with gypsum.
20.4	Borehole terminated at 20.42 m in dolomitic shale to shaly dolostone.

NUMBER	TYPE	N VALUE	% WATER	% REC	% RQD
	GS				
1	HQ			58	52
2	HQ			90	66
3	HQ			100	96
4	HQ			100	100
5	HQ			100	100
6	HQ			100	100
7	HQ			100	100
8	HQ			100	100
9	HQ			100	74
10	HQ			100	100
11	HQ			100	100
12	HQ			100	100
13	HQ			100	100

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Gartner Lee Limited

BOREHOLE LOG

PROJECT: 40-403

BOREHOLE: GLL-8 1 of 1

Hydrogeological-Geological Investigation
Law Quarry, Port Colborne
FOR: Hard Rock Paving

DATE: 09 August 2004
LOGGED BY MT/DL
GROUND ELEV 183.07 m ASL

DEPTH (m)	STRATIGRAPHIC DESCRIPTION
	SILTY SAND Light brown silty sand.
2.7	**LIMESTONE** (Bois Blanc Formation) Light grey, fine crystalline, medium bedded limestone, minor occurrence of pyrite mineralization.
5.3	
5.9	**SPRINGVALE SANDSTONE** (Bertie Formation) Greenish grey, fine to medium grained glauconitic sandstone, local chert nodules.
	AKRON DOLOSTONE (Bertie Formation) Light to medium grey (mottled), fine crystalline, thin bedded dolostone, occasional shale stringers.
8.9	**WILLIAMSVILLE DOLOSTONE** (Bertie Formation) Grey, fine crystalline, medium bedded dolostone.
10.4	**SCAJAQUANDA SHALY DOLOSTONE** (Bertie Formation) Dark grey, laminated, argillaceous dolostone.
13.1	**FALKIRK DOLOSTONE** (Bertie Formation) Brown to grey, medium bedded dolostone, shale stringers and parting locally. -Occasional vugs with pyrite and calcite infilling from about 16.2 to 16.4 m.
17.5	**OAKTA DOLOSTONE** (Bertie Formation) Dark grey dolostone interbedded with shale.
21.1	**SHALE** (Salina Formation) Grey dolomitic shale to shale interbedded to interlaminated with gypsum.
24.4	Borehole terminated at 24.38 m in dolomitic shale to shaly dolostone.

SAMPLE

NUMBER	TYPE	N VALUE	% WATER	% REC	% RQD
	GS				
1	HQ			100	100
2	HQ			100	100
3	HQ			100	100
4	HQ			100	100
5	HQ			100	100
6	HQ			100	99
7	HQ			100	100
8	HQ			100	100
9	HQ			100	100
10	HQ			100	88
11	HQ			100	100
12	HQ			100	100
13	HQ			100	100
14	HQ			100	100
15	HQ			100	100

RECOVERY (%) 25 50 75 100

RQD (%) 25 50 75 100

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Gartner Lee Limited

BOREHOLE LOG

PROJECT: 40-403

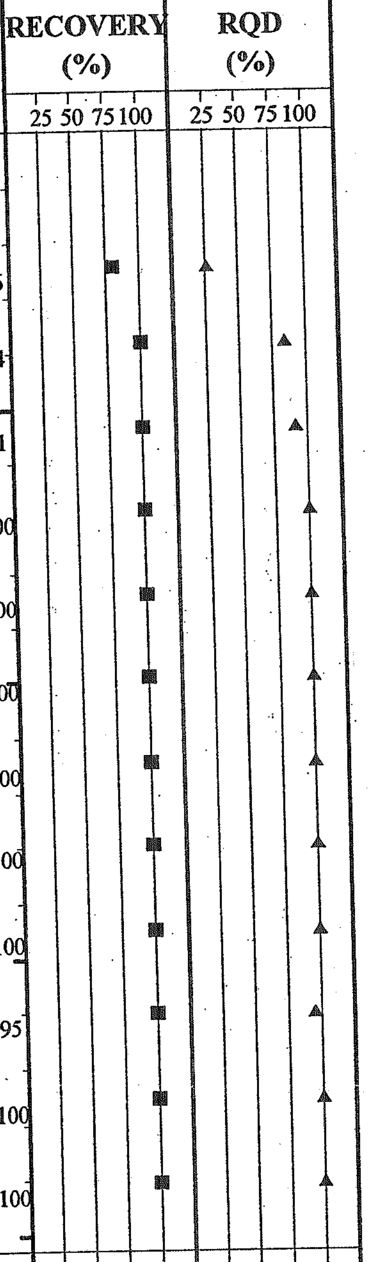
BOREHOLE: GLL-9 1 of 1

Hydrogeological-Geological Investigation
Law Quarry, Port Colborne
FOR: Hard Rock Paving

DATE: 10 August 2004
LOGGED BY MT
GROUND ELEV 183.15 m ASL

DEPTH (m)	STRATIGRAPHIC DESCRIPTION
	CLAYEY SILT TILL Greyish brown clayey silt till, some gravel and cobbles.
2.4	**LIMESTONE** (Bois Blanc Formation) Light brown to grey, fine crystalline, thin bedded cherty limestone, fossiliferous.
5.2	**SPRINGVALE SANDSTONE** (Bertie Formation) Greenish grey, medium grained glauconitic sandstone, local chert nodules.
5.3	**AKRON DOLOSTONE** (Bertie Formation) Light grey, fine crystalline, thin bedded dolostone.
7.8	**WILLIAMSVILLE DOLOSTONE** (Bertie Formation) Grey, fine crystalline, thin to medium bedded dolostone.
10.5	**SCAJAQUANDA SHALY DOLOSTONE** (Bertie Formation) Dark grey, laminated, argillaceous dolostone.
12.9	**FALKIRK DOLOSTONE** (Bertie Formation) Brown to grey, thin bedded dolostone, shale stringers and parting locally. Minor occurrence of vugs infilled with calcite and pyrite.
17.1	**OAKTA DOLOSTONE** (Bertie Formation) Dark grey dolostone interbedded with shale.
20.3	Borehole terminated at 20.27 m in dolostone.

SAMPLE NUMBER	TYPE	N VALUE	% WATER	% REC	% RQD
	GS				
1	HQ			80	26
2	HQ			100	84
3	HQ			100	91
4	HQ			100	100
5	HQ			100	100
6	HQ			100	100
7	HQ			100	100
8	HQ			100	100
9	HQ			100	100
10	HQ			100	95
11	HQ			100	100
12	HQ			100	100



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Gartner Lee Limited

BOREHOLE LOG

PROJECT: 40-403

BOREHOLE: GLL-10 1 of 1

Hydrogeological-Geological Investigation
Law Quarry, Port Colborne
FOR: Hard Rock Paving

DATE: 11 August 2004
LOGGED BY MT
GROUND ELEV 182.55 m ASL

DEPTH (m)	STRATIGRAPHIC DESCRIPTION
0 – 1.7	**SILTY SAND** Light brown silty sand.
1.7 – 4.4	**LIMESTONE** (Bois Blanc Formation) Light grey, fine crystalline, medium bedded limestone, fossiliferous.
4.4 – 5.5	**SPRINGVALE SANDSTONE** (Bertie Formation) Greenish grey, fine to medium grained glauconitic sandstone, local chert nodules.
5.5 – 8.3	**AKRON DOLOSTONE** (Bertie Formation) Light grey, fine crystalline, thin bedded dolostone, occasional shale stringers.
8.3 – 10.2	**WILLIAMSVILLE DOLOSTONE** (Bertie Formation) Grey, fine crystalline, medium bedded dolostone.
10.2 – 13.1	**SCAJAQUANDA SHALY DOLOSTONE** (Bertie Formation) Dark grey, laminated, argillaceous dolostone.
13.1 – 17.8	**FALKIRK DOLOSTONE** (Bertie Formation) Brown to grey, medium bedded dolostone, shale stringers and parting locally. Minor occurrence of small vugs to about 14.5 m. -Weathered between about 15.9 and 16.5 m.
17.8 – 22.1	**OAKTA DOLOSTONE** (Bertie Formation) Dark grey dolostone interbedded with shale.
22.1 – 24.4	**SHALE** (Salina Formation) Grey dolomitic shale to shale interbedded to interlaminated with gypsum.
24.4	Borehole terminated at 24.38 m in dolomitic shale to shaly dolostone.

SAMPLE

NUMBER	TYPE	N VALUE	% WATER	% REC	% RQD
	GS				
1	HQ			82	86
2	HQ			100	91
3	HQ				
4	HQ			100	76
5	HQ			100	100
6	HQ			100	100
7	HQ			100	100
8	HQ			100	100
9	HQ			100	100
10	HQ			100	100
11	HQ			100	64
12	HQ			100	100
13	HQ			100	100
14	HQ			100	100
15	HQ			100	100
16	HQ			100	100

RECOVERY (%) 25 50 75 100
RQD (%) 25 50 75 100

Printed: 16 Mar 05
File Location:N:\Projects\2004\40403\2004\WorkInProgress\BoreholeLogs\

Gartner Lee Limited

LOG OF BOREHOLE MW1-I

project | Law Quarry Extension
project no. | 111-53023-06
client | Waterford Sand & Gravel Ltd.
rig type | CME 75, track-mounted
date started | 2018/06/28
location | Wainfleet, ON
method | Rock coring
supervisor | SCL/CS
position | E: 639543 N: 4750253 (17T, Geodetic)
coring | HQ core, OD=96mm, ID=64mm
reviewer | KJF

Elev Depth (m)	STRATIGRAPHY	Number	Type	SPT N-Value Core Recovery	Lab Data and Comments
177.2	**GROUND SURFACE**				
	CLAYEY SILT: Grey brown, trace rounded gravel, WTPL, firm.	1	GS		
173.2 4.0	**BOIS BLANC FORMATION** Dolostone, light grey to brown grey, weathered, fine grained, medium bedded, hard, trace to some chert, fossiliferous, bioturbated, some wavy laminations.		C		
			R2	TCR = **100%** RQD = **98%**	
	...calcite nodules and pyrite mineralization at 5.13 m, some small vugs (<1 mm in diameter)				← Bentonite grout
171.7 171.7 5.5	**BOIS BLANC FORMATION, SPRINGVALE MEMBER** Glauconitic Sandstone, green to grey, medium grained, trace to some chert and calcite.		C		
171.1 6.1	**BERTIE FORMATION, AKRON MEMBER** Dolostone, grey, fine grained to fine crystalline, thinly bedded, trace shale partings, trace chert nodules, glauconic sandstone partings present at 7.14 m, chonchoidal fracturing.		R3	TCR = **100%** RQD = **89%**	
170.1	...Trace green sandstone partings at 7.14 m.		C		
			R4	TCR = **92%** RQD = **92%**	
168.5 168.5 8.7	**BERTIE FORMATION, WILLIAMSVILLE MEMBER** Dolostone, medium grey, fine to medium grained, trace shale partings.		C		
			R5	TCR = **105%** RQD = **85%**	
167.0					

Penetration Test Values (Blows / 0.3m)
× Dynamic Cone 10 20 30 40
Undrained Shear Strength (kPa)
○ Unconfined ✚ Field Vane
● Pocket Penetrometer ■ Lab Vane
40 80 120 160

Water Content (%) & Plasticity
PL MC LL
10 20 30
Water level on completion

PID Readings

Well Details

GRAIN SIZE DISTRIBUTION (%) (MIT)
GR SA SI CL

(continued next page)

LOG OF BOREHOLE MW1-I

project | Law Quarry Extension
project no. | 111-53023-06
client | Waterford Sand & Gravel Ltd.
rig type | CME 75, track-mounted
date started | 2018/06/28
location | Wainfleet, ON
method | Rock coring
supervisor | SCL/CS
position | E: 639543 N: 4750253 (17T, Geodetic)
coring | HQ core, OD=96mm, ID=64mm
reviewer | KJF

Penetration Test Values (Blows / 0.3m): × Dynamic Cone 10 20 30 40
Undrained Shear Strength (kPa): ○ Unconfined + Field Vane ● Pocket Penetrometer ■ Lab Vane 40 80 120 160
Water Content (%) & Plasticity: PL MC LL 10 20 30; Water level on completion
PID Readings | Well Details | Lab Data and Comments: GRAIN SIZE DISTRIBUTION (%) (MIT) GR SA SI CL

Depth Scale (m)	Elev Depth (m)	STRATIGRAPHY *(continued)*	Number	Type	SPT N-Value / Core Recovery	Elevation Scale (mASL)	Lab Data and Comments
10	167.0	**BERTIE FORMATION, WILLIAMSVILLE MEMBER** Dolostone, medium grey, fine to medium grained, trace shale partings. *(continued)*		R5		167	
				C			
				R6	TCR = **104%** RQD = **100%**		
11	165.9 11.3	**BERTIE FORMATION, SCAJAQUADA MEMBER** Argillaceous dolostone, medium to dark grey, fine grained, thinly bedded, laminated, some shaly laminations increasing with depth.		C		166	
12				R7	TCR = **98%** RQD = **98%**	165	
	164.4			C			
13	163.6 13.6	**BERTIE FORMATION, FALKIRK MEMBER** Dolostone, brown to grey, medium grained, medium bedded, weathered, trace shaly laminations, becomes bioturbated at 13.61 m, locally vuggy (1 mm diameter).		R8	TCR = **102%** RQD = **97%**	164	
14	162.8			C		163	
15				R9	TCR = **100%** RQD = **100%**	162	← Bentonite grout
16	161.4			C		161	
				R10	TCR = **105%** RQD = **78%**		
17	160.4			C		160	
				R11	TCR = **100%** RQD = **100%**		
18	159.0 18.2 158.8	**BERTIE FORMATION, OATKA MEMBER** Dolostone, grey to dark grey, very smooth, fine grained to fine crystalline, some shale interbeds, trace pyrite mineralization.		R12 C	TCR = **128%** RQD = **101%**	159	
19				C		158	
	156.8			R13	TCR = **98%** RQD = **94%**		

(continued next page)

LOG OF BOREHOLE MW1-I

project |	Law Quarry Extension			**project no. |**	111-53023-06
client |	Waterford Sand & Gravel Ltd.	**rig type |**	CME 75, track-mounted	**date started |**	2018/06/28
location |	Wainfleet, ON	**method |**	Rock coring	**supervisor |**	SCL/CS
position |	E: 639543 N: 4750253 (17T, Geodetic)	**coring |**	HQ core, OD=96mm, ID=64mm	**reviewer |**	KJF

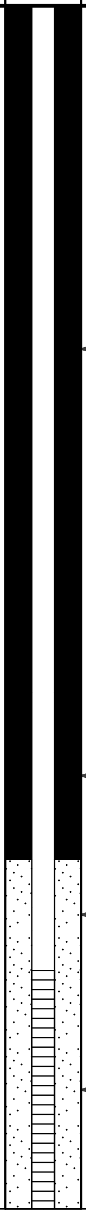
SUBSURFACE PROFILE | SAMPLE

Depth Scale (m) | Elev Depth (m) | STRATIGRAPHY | Graphic Plot | Number | Type | SPT N-Value / Core Recovery | Elevation Scale (mASL) | Penetration Test Values (Blows / 0.3m) × Dynamic Cone 10 20 30 40; Undrained Shear Strength (kPa) ○ Unconfined + Field Vane ● Pocket Penetrometer ■ Lab Vane 40 80 120 160 | Water Content (%) & Plasticity PL MC LL 10 20 30 | Water level on completion | PID Readings | Well Details | Lab Data and Comments GRAIN SIZE DISTRIBUTION (%) (MIT) GR SA SI CL

(continued)

Elev / Depth (m)	STRATIGRAPHY
156.8	**BERTIE FORMATION, OATKA MEMBER** Dolostone, grey to dark grey, very smooth, fine grained to fine crystalline, some shale interbeds, trace pyrite mineralization. *(continued)*
155.3	
153.8 23.5	**SALINA FORMATION** Dolomitic Shale with interbedded to interlaminated gypsum beds and nodules, grey, locally vuggy (<1 to 2 cm in diameter), fine crystalline matrix.
152.2	
150.5	
149.5 27.7	

Type	Core Recovery
R13	TCR = **98%** RQD = **94%**
C	
R14	TCR = **100%** RQD = **75%**
C	
R15	TCR = **100%** RQD = **100%**
C	
R16	TCR = **95%** RQD = **95%**
C	
R17	TCR = **95%** RQD = **94%**
C	
R18	TCR = **100%** RQD = **73%**



END OF BOREHOLE

Unstabilized water level at 3.4 m below ground surface; borehole was open upon completion.

50 mm monitoring well installed.
No. 10 screen installed.

WATER LEVEL MONITORING

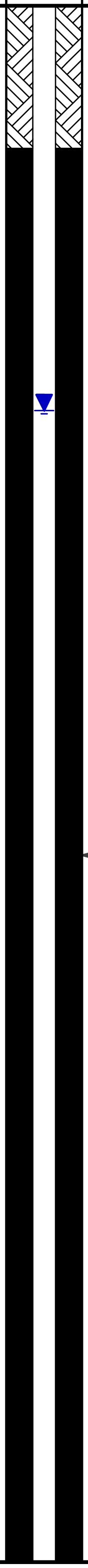
Date	Depth (m)	Elevation (m)
Jul 9, 2018	6.5	170.6

LOG OF BOREHOLE MW1-II

project | Law Quarry Extension
project no. | 111-53023-06
client | Waterford Sand & Gravel Ltd.
rig type | CME 75, track-mounted
date started | 2018/07/04
location | Wainfleet, ON
method | Rock coring
supervisor | CS
position | E: 639543 N: 4750255 (17T, Geodetic)
coring | HQ core, OD=96mm, ID=64mm
reviewer | KJF

Penetration Test Values (Blows / 0.3m): × Dynamic Cone; 10, 20, 30, 40
Undrained Shear Strength (kPa): ○ Unconfined; + Field Vane; ● Pocket Penetrometer; ■ Lab Vane; 40, 80, 120, 160
Water Content (%) & Plasticity: PL, MC, LL; 10, 20, 30
PID Readings
Well Details
Lab Data and Comments: GRAIN SIZE DISTRIBUTION (%) (MIT) GR SA SI CL

Depth Scale (m)	Elev Depth (m)	STRATIGRAPHY	Number	Type	SPT N-Value / Core Recovery	Elevation Scale (mASL)
0	177.2	**GROUND SURFACE**				
0–4		**CLAYEY SILT:** Grey brown, trace rounded gravel, WTPL, firm.				177, 176, 175, 174
4	173.2 4.0	**BOIS BLANC FORMATION** Dolostone, light grey to brown grey, weathered, fine grained, medium bedded, hard, trace to some chert, fossiliferous, bioturbated, some wavy laminations.		C		173
				R2	TCR = **100%** RQD = **98%**	
5		...Calcite nodules and pyrite mineralization at 5.13 m, some small vugs (<1 mm in diameter)				172
	171.7 171.7 5.5	**BOIS BLANC FORMATION, SPRINGVALE MEMBER** Glauconitic Sandstone, green to grey, medium grained, trace to some chert and calcite.		C		
6	171.1 6.1	**BERTIE FORMATION, AKRON MEMBER** Dolostone, grey, fine grained to fine crystalline, thinly bedded, trace shale partings, trace chert nodules, glauconic sandstone partings present at 7.14 m, chonchoidal fracturing.		R3	TCR = **100%** RQD = **89%**	171
7	170.1	...Trace green sandstone partings at 7.14 m.		C		170
8				R4	TCR = **92%** RQD = **92%**	169
	168.5 168.5 8.7	**BERTIE FORMATION, WILLIAMSVILLE MEMBER** Dolostone, medium grey, fine to medium grained, trace shale partings.		C		
9				R5	TCR = **105%** RQD = **85%**	168
	167.0					



← Bentonite grout

(continued next page)

LOG OF BOREHOLE MW1-II

project	Law Quarry Extension			**project no.**	111-53023-06
client	Waterford Sand & Gravel Ltd.	**rig type**	CME 75, track-mounted	**date started**	2018/07/04
location	Wainfleet, ON	**method**	Rock coring	**supervisor**	CS
position	E: 639543 N: 4750255 (17T, Geodetic)	**coring**	HQ core, OD=96mm, ID=64mm	**reviewer**	KJF

Depth Scale (m) | SUBSURFACE PROFILE: Elev Depth (m), STRATIGRAPHY *(continued)*, Graphic Plot | SAMPLE: Number, Type, SPT N-Value / Core Recovery | Elevation Scale (mASL) | Penetration Test Values (Blows / 0.3m): × Dynamic Cone 10 20 30 40; Undrained Shear Strength (kPa): ○ Unconfined, + Field Vane, ● Pocket Penetrometer, ■ Lab Vane 40 80 120 160 | Water Content (%) & Plasticity: PL MC LL 10 20 30 | PID Readings | Well Details | Lab Data and Comments: GRAIN SIZE DISTRIBUTION (%) (MIT) GR SA SI CL

Elev / Depth (m)	Stratigraphy
167.0	**BERTIE FORMATION, WILLIAMSVILLE MEMBER** Dolostone, medium grey, fine to medium grained, trace shale partings. *(continued)*
165.9 11.3	**BERTIE FORMATION, SCAJAQUADA MEMBER** Argillaceous dolostone, medium to dark grey, fine grained, thinly bedded, laminated, some shaly laminations increasing with depth.
164.4	
163.6 13.6	**BERTIE FORMATION, FALKIRK MEMBER** Dolostone, brown to grey, medium grained, medium bedded, weathered, trace shaly laminations, becomes bioturbated at 13.61 m, locally vuggy (1 mm diameter).
162.8	
161.4	
160.4	
159.0 18.2	**BERTIE FORMATION, OATKA MEMBER** Dolostone, grey to dark grey, very smooth, fine grained to fine crystalline, some shale interbeds, trace pyrite mineralization.
158.8	
156.8	

Number	Type	Core Recovery
R5		
R6	C	TCR = **104%** RQD = **100%**
R7	C	TCR = **98%** RQD = **98%**
R8	C	TCR = **102%** RQD = **97%**
R9	C	TCR = **100%** RQD = **100%**
R10	C	TCR = **105%** RQD = **78%**
R11	C	TCR = **100%** RQD = **100%**
R12	C	TCR = **128%** RQD = **101%**
R13	C	TCR = **98%** RQD = **94%**

Depth Scale (m): 10, 11, 12, 13, 14, 15, 16, 17, 18, 19

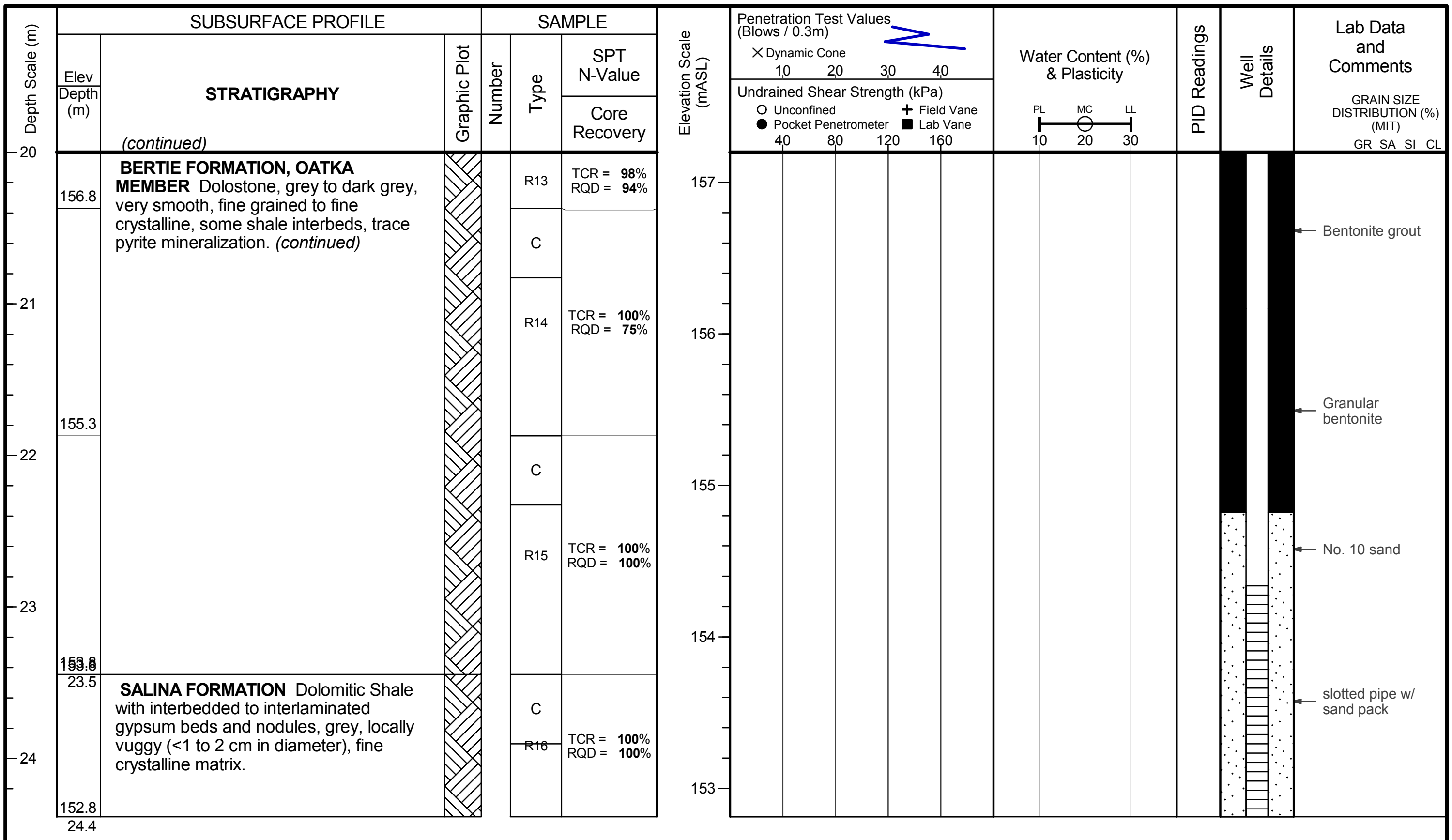
Elevation Scale (mASL): 167, 166, 165, 164, 163, 162, 161, 160, 159, 158

Lab Data and Comments: ← Bentonite grout

(continued next page)

LOG OF BOREHOLE MW1-II

project |	Law Quarry Extension					**project no. |**	111-53023-06
client |	Waterford Sand & Gravel Ltd.		**rig type |**	CME 75, track-mounted		**date started |**	2018/07/04
location |	Wainfleet, ON		**method |**	Rock coring		**supervisor |**	CS
position |	E: 639543 N: 4750255 (17T, Geodetic)		**coring |**	HQ core, OD=96mm, ID=64mm		**reviewer |**	KJF



BERTIE FORMATION, OATKA MEMBER Dolostone, grey to dark grey, very smooth, fine grained to fine crystalline, some shale interbeds, trace pyrite mineralization. *(continued)*

SALINA FORMATION Dolomitic Shale with interbedded to interlaminated gypsum beds and nodules, grey, locally vuggy (<1 to 2 cm in diameter), fine crystalline matrix.

END OF BOREHOLE

Borehole was open upon completion. Water level was not measured upon completion.

50 mm monitoring well installed.
No. 10 screen installed.

WATER LEVEL MONITORING

Date	Depth (m)	Elevation (m)
Jul 9, 2018	2.6	174.6

LOG OF BOREHOLE MW1-III

project | Law Quarry Extension
project no. | 111-53023-06
client | Waterford Sand & Gravel Ltd.
rig type | CME 75, track-mounted
date started | 2018/07/05
location | Wainfleet, ON
method | Rock coring
supervisor | CS
position | E: 639543 N: 4750257 (17T, Geodetic)
coring | HQ core, OD=96mm, ID=64mm
reviewer | KJF

Elev Depth (m)	STRATIGRAPHY	Number	Type	SPT N-Value / Core Recovery	Lab Data and Comments
177.2	**GROUND SURFACE**				
	CLAYEY SILT: grey brown, trace rounded gravel, WTPL, firm.				
173.2 4.0	**BOIS BLANC FORMATION** Dolostone, light grey to brown grey, weathered, fine grained, medium bedded, hard, trace to some chert, fossiliferous, bioturbated, some wavy laminations.		C		
			R2	TCR = **100%** RQD = **98%**	
	...at 5.1 m, calcite nodules and pyrite mineralization at 16.84 m, some small vugs (<1 mm in diameter)				← Bentonite grout
171.7 171.7 5.5	**BOIS BLANC FORMATION, SPRINGVALE MEMBER** Glauconitic Sandstone, green to grey, medium grained, trace to some chert and calcite.		C		
171.1 6.1	**BERTIE FORMATION, AKRON MEMBER** Dolostone, grey, fine grained to fine crystalline, thinnly bedded, trace shale partings, trace chert nodules, glauconic sandstone partings present at 7.14 m, chonchoidal fracturing.		R3	TCR = **100%** RQD = **89%**	
170.1	...at 7.2 m, Trace green sandstone partings at 7.14 m.		C		
			R4	TCR = **92%** RQD = **92%**	
168.5 168.5 8.7	**BERTIE FORMATION, WILLIAMSVILLE MEMBER** Dolostone, medium grey, fine to medium grained, trace shale partings.		C		
			R5	TCR = **105%** RQD = **85%**	
167.0					

Depth Scale (m): 0, 1, 2, 3, 4, 5, 6, 7, 8, 9

Elevation Scale (mASL): 177, 176, 175, 174, 173, 172, 171, 170, 169, 168

Penetration Test Values (Blows / 0.3m)
× Dynamic Cone
10 20 30 40

Undrained Shear Strength (kPa)
○ Unconfined ✚ Field Vane
● Pocket Penetrometer ■ Lab Vane
40 80 120 160

Water Content (%) & Plasticity
PL MC LL
10 20 30

PID Readings

Well Details

GRAIN SIZE DISTRIBUTION (%) (MIT)
GR SA SI CL

(continued next page)

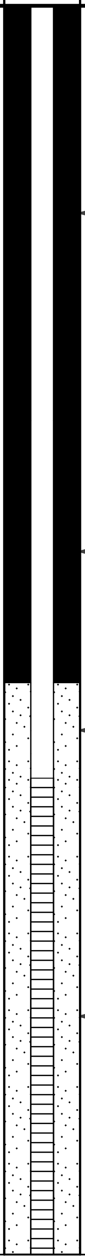
Sheet No. 1 of 2

LOG OF BOREHOLE MW1-III

project | Law Quarry Extension
project no. | 111-53023-06
client | Waterford Sand & Gravel Ltd.
rig type | CME 75, track-mounted
date started | 2018/07/05
location | Wainfleet, ON
method | Rock coring
supervisor | CS
position | E: 639543 N: 4750257 (17T, Geodetic)
coring | HQ core, OD=96mm, ID=64mm
reviewer | KJF

Elev / Depth (m)	STRATIGRAPHY *(continued)*
167.0	**BERTIE FORMATION, WILLIAMSVILLE MEMBER** Dolostone, medium grey, fine to medium grained, trace shale partings. *(continued)*
165.9 11.3	**BERTIE FORMATION, SCAJAQUADA MEMBER** Argillaceous dolostone, medium to dark grey, fine grained, thinly bedded, laminated, some shaly laminations increasing with depth.
164.4	
163.6 13.6	**BERTIE FORMATION, FALKIRK MEMBER** Dolostone, brown to grey, medium grained, medium bedded, weathered, trace shaly laminations, becomes bioturbated at 13.61 m, locally vuggy (1 mm diameter).
162.8	
161.4	
160.4	
159.2 18.0	

Number	Type	Core Recovery
R5		
R6	C	TCR = **104%** RQD = **100%**
R7	C	TCR = **98%** RQD = **98%**
R8	C	TCR = **102%** RQD = **97%**
R9	C	TCR = **100%** RQD = **100%**
R10	C	TCR = **105%** RQD = **78%**
R11	C	TCR = **100%** RQD = **100%**



Bentonite grout

Granular bentonite

No. 10 sand

slotted pipe w/ sand pack

END OF BOREHOLE

Borehole was open upon completion. Water level was not measured upon completion.

50 mm monitoring well installed.
No. 10 screen installed.

WATER LEVEL MONITORING

Date	Depth (m)	Elevation (m)
Jul 9, 2018	6.1	171.1

LOG OF BOREHOLE MW4-II

project | Law Quarry Extension
project no. | 111-53023-06
client | Waterford Sand & Gravel Ltd.
rig type | CME 75, track-mounted
date started | 2017/11/23
location | Wainfleet, ON
method | Hollow stem augers, 215 mm dia.
supervisor | SCL
position | E: 638316 N: 4750276 (17T, Geodetic)
coring | HQ core, OD=96mm, ID=64mm
reviewer | KJF

SUBSURFACE PROFILE

Elev Depth (m)	STRATIGRAPHY
184.7	**GROUND SURFACE**
184.3 0.4	**CLAYEY SILT** brown, WTPL, soft, some gravel and rootlets.
183.5	**BOIS BLANC FORMATION** Dolostone, light grey to brown grey, weathered, fine grained, medium bedded, hard, trace to some chert, fossiliferous. ...Large fossils >50 mm at 1.2 m, styolites up to 2 mm thick.
182.0	...Small fossils from 2.4 m to 3.4 m, becomes less fossiliferous at 3.4 m.
180.5	
179.0	
177.5	
176.8 7.9	
176.0	**BOIS BLANC FORMATION, SPRINGVALE MEMBER** Glauconitic sandstone, green to grey, medium grained, trace chert, some black nodules.
175.5 9.2	
174.5	**BERTIE FORMATION, AKRON MEMBER** Dolostone, light grey, fine crystalline to fine grained, thinly bedded, trace shale partings, trace calcite nodules. ...soft muddy nodules up to 10 mm at 10.4 m.
173.0	
172.1 12.6	...Weathered fracture at 12.6 m.
171.5	**BERTIE FORMATION, WILLIAMSVILLE MEMBER** Dolostone, medium grey, fine to medium grained becoming fine grained, trace shale partings.
171.3 13.4	
170.0	**BERTIE FORMATION, SCAJAQUADA MEMBER** Argillaceous dolostone, medium to dark grey, fine grained, thinly bedded, laminated, some shaly laminations increasing with depth.
168.5	

SAMPLE

Type	SPT N-Value / Core Recovery
R1	TCR = **100%** RQD = **66%**
R2	TCR = **100%** RQD = **64%**
R3	TCR = **103%** RQD = **48%**
R4	TCR = **97%** RQD = **88%**
R5	TCR = **97%** RQD = **88%**
R6	TCR = **100%** RQD = **70%**
R7	TCR = **97%** RQD = **79%**
R8	TCR = **95%** RQD = **100%**
R9	TCR = **102%** RQD = **98%**
R10	TCR = **98%** RQD = **92%**
R11	

Depth Scale (m): 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14

Elevation Scale (mASL): 184, 183, 182, 181, 180, 179, 178, 177, 176, 175, 174, 173, 172, 171, 170

Penetration Test Values (Blows / 0.3m)
X Dynamic Cone
10 20 30 40
Undrained Shear Strength (kPa)
○ Unconfined + Field Vane
● Pocket Penetrometer ■ Lab Vane
40 80 120 160

Water Content (%) & Plasticity
PL MC LL
10 20 30

PID Readings

Well Details

Lab Data and Comments
GRAIN SIZE DISTRIBUTION (%) (MIT)
GR SA SI CL

(continued next page)

Sheet No. 1 of 2

LOG OF BOREHOLE MW4-II

project |	Law Quarry Extension			**project no. |**	111-53023-06
client |	Waterford Sand & Gravel Ltd.	**rig type |**	CME 75, track-mounted	**date started |**	2017/11/23
location |	Wainfleet, ON	**method |**	Hollow stem augers, 215 mm dia.	**supervisor |**	SCL
position |	E: 638316 N: 4750276 (17T, Geodetic)	**coring |**	HQ core, OD=96mm, ID=64mm	**reviewer |**	KJF

SUBSURFACE PROFILE

Elev Depth (m)	STRATIGRAPHY *(continued)*
168.9 15.8	...Fossiliferous band at 15.7 m.
168.5	**BERTIE FORMATION, FALKIRK MEMBER** Dolostone, brown to grey, medium grained, medium bedded, trace shaly laminations. Becomes grey, smooth dolostone characteristic of the Oatka Member with large beds and trace shaley partings at 20.4 m interbedded with brown, medium grained dolostone (Falkirk member) until 22.9 m. Grey brown medium grained dolostone (Falkirk) from 22.9 m to 23.2 m. ...Becoming vuggy at 17.1 m, becoming less vuggy with depth at 17.7 m. ...Gypsum nodule at 17.8 m.
167.0	
165.4	...Shaly parting at 19.1 m.
163.9	...Pyrite mineralization at 20.2 m.
162.4	
161.5 23.2	**BERTIE FORMATION, OATKA MEMBER** Dolostone, grey to dark grey, very smooth, fine grained.
160.8	
159.4 159.4 25.4	**SALINA FORMATION** Dolomitic Shale with interbedded to interlaminated gypsum beds and nodules, grey.
157.9 26.8	**END OF BOREHOLE** Borehole was dry and open upon completion.

SAMPLE

Number	Type	SPT N-Value / Core Recovery
	R11	TCR = **95%** RQD = **100%**
	R12	TCR = **103%** RQD = **89%**
	R13	TCR = **100%** RQD = **97%**
	R14	TCR = **102%** RQD = **100%**
	R15	TCR = **95%** RQD = **96%**
	R16	TCR = **101%** RQD = **98%**
	R17	TCR = **101%** RQD = **100%**
	R18	TCR = **97%** RQD = **97%**

Depth Scale (m): 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26

Elevation Scale (mASL): 169, 168, 167, 166, 165, 164, 163, 162, 161, 160, 159, 158

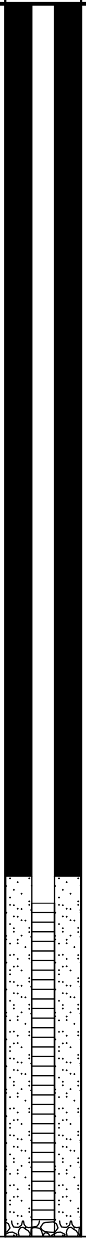
Penetration Test Values (Blows / 0.3m)
× Dynamic Cone
10 20 30 40

Undrained Shear Strength (kPa)
○ Unconfined + Field Vane
● Pocket Penetrometer ■ Lab Vane
40 80 120 160

Water Content (%) & Plasticity
PL MC LL
10 20 30

PID Readings

Well Details



Lab Data and Comments
GRAIN SIZE DISTRIBUTION (%) (MIT)
GR SA SI CL

LOG OF BOREHOLE MW4-III

wsp

project |	Law Quarry Extension			**project no. |**	111-53023-06
client |	Waterford Sand & Gravel Ltd.	**rig type |**	CME 75, track-mounted	**date started |**	2017/11/24
location |	Wainfleet, ON	**method |**	Hollow stem augers, 215 mm dia.	**supervisor |**	SCL
position |	E: 638314 N: 475026 (17T, Geodetic)	**coring |**	HQ core, OD=96mm, ID=64mm	**reviewer |**	KJF

SUBSURFACE PROFILE

Elev Depth (m)	STRATIGRAPHY
184.7	**GROUND SURFACE**
184.3 0.4	**CLAYEY SILT TOPSOIL** Brown, some gravel and rootlets, WTPL, soft.
176.8 7.9	**BOIS BLANC FORMATION** Dolostone, light grey to brown grey, weathered, fine grained, medium bedded, hard, trace to some chert, fossiliferous. ...Large fossils >50 mm at 1.2 m, styolites up to 2 mm thick. ...Small fossils from 2.4 m to 3.4 m, becomes less fossiliferous at 3.4 m.
175.5 9.2	**BOIS BLANC FORMATION, SPRINGVALE MEMBER** Glauconitic sandstone, green to grey, medium grained, trace chert, some black nodules.
172.1 12.6	**BERTIE FORMATION, AKRON MEMBER** Dolostone, light grey, fine crystalline to fine grained, thinnly bedded, trace shale partings, trace calcite nodules. ...soft muddy nodules up to 10 mm at 10.4 m. ...Weathered fracture at 12.6 m.
171.3 13.4	**BERTIE FORMATION, WILLIAMSVILLE MEMBER** Dolostone, medium grey, fine to medium grained becoming fine grained, trace shale partings.
	BERTIE FORMATION, SCAJAQUADA MEMBER Argillaceous dolostone, medium to dark grey, fine grained, thinly bedded, laminated, some shaly laminations increasing with depth.

SAMPLE

Elev	Number	Type	SPT N-Value / Core Recovery
183.5		R1	TCR = **100%** RQD = **66%**
182.0		R2	TCR = **100%** RQD = **64%**
180.5		R3	TCR = **103%** RQD = **48%**
179.0		R4	TCR = **97%** RQD = **88%**
177.5		R5	TCR = **97%** RQD = **88%**
176.0		R6	TCR = **100%** RQD = **70%**
174.5		R7	TCR = **97%** RQD = **79%**
173.0		R8	TCR = **95%** RQD = **100%**
171.5		R9	TCR = **102%** RQD = **98%**
170.0		R10	TCR = **98%** RQD = **92%**
168.5		R11	

Depth Scale (m): 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14

Elevation Scale (mASL): 184 183 182 181 180 179 178 177 176 175 174 173 172 171 170

Penetration Test Values (Blows / 0.3m)
× Dynamic Cone
10 20 30 40

Undrained Shear Strength (kPa)
○ Unconfined ✚ Field Vane
● Pocket Penetrometer ■ Lab Vane
40 80 120 160

Water Content (%) & Plasticity
PL MC LL
10 20 30

PID Readings

Well Details

Lab Data and Comments
GRAIN SIZE DISTRIBUTION (%) (MIT)
GR SA SI CL

(continued next page)

LOG OF BOREHOLE MW4-III

project | Law Quarry Extension
project no. | 111-53023-06
client | Waterford Sand & Gravel Ltd.
rig type | CME 75, track-mounted
date started | 2017/11/24
location | Wainfleet, ON
method | Hollow stem augers, 215 mm dia.
supervisor | SCL
position | E: 638314 N: 475026 (17T, Geodetic)
coring | HQ core, OD=96mm, ID=64mm
reviewer | KJF

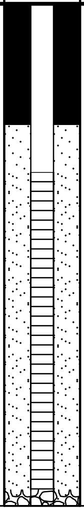
Depth Scale (m)	Elev Depth (m)	SUBSURFACE PROFILE – STRATIGRAPHY *(continued)*	SAMPLE Number	Type	SPT N-Value / Core Recovery	Elevation Scale (mASL)
15		...Fossiliferous band at 15.7 m.		R11	TCR = **95%** RQD = **100%**	169
16	168.9 15.8	**BERTIE FORMATION, FALKIRK MEMBER** Dolostone, brown to grey, medium grained, medium bedded, trace shaly laminations. Becomes grey, smooth dolostone characteristic of the Oatka Member with large beds and trace shaley partings at 20.4 m interbedded with brown, medium grained dolostone (Falkirk member) until 22.9 m. Grey brown medium grained dolostone (Falkirk) from 22.9 m to 23.2 m. ...Becoming vuggy at 17.1 m, becoming less vuggy with depth at 17.7 m. ...Gypsum nodule at 17.8 m.				
17	168.5			R12	TCR = **103%** RQD = **89%**	168
18	167.0			R13	TCR = **100%** RQD = **97%**	167
19	165.4	...Shaly parting at 19.1 m.		R14	TCR = **100%** RQD = **100%**	166
	164.9 19.8	**END OF BOREHOLE** Borehole was dry and open upon completion.				165

Penetration Test Values (Blows / 0.3m)
× Dynamic Cone
10 20 30 40
Undrained Shear Strength (kPa)
○ Unconfined + Field Vane
● Pocket Penetrometer ■ Lab Vane
40 80 120 160

Water Content (%) & Plasticity
PL MC LL
10 20 30

PID Readings

Well Details

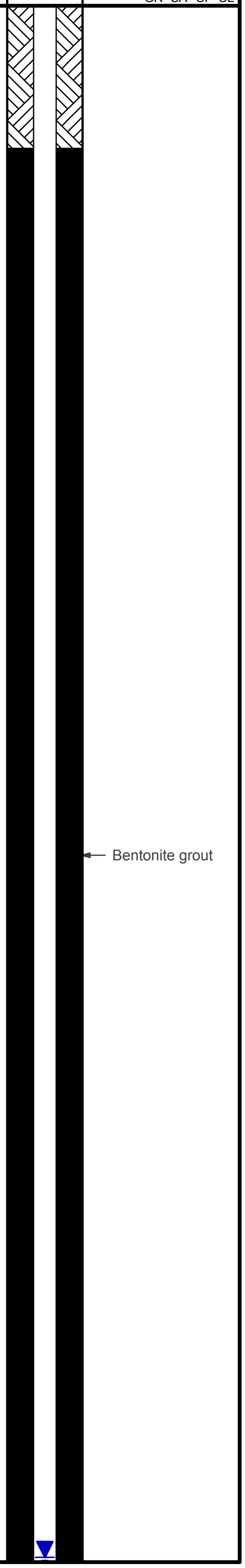


Lab Data and Comments
GRAIN SIZE DISTRIBUTION (%) (MIT)
GR SA SI CL

LOG OF BOREHOLE MW5-I

project | Law Quarry Extension
project no. | 111-53023-06
client | Waterford Sand & Gravel Ltd.
rig type | CME 75, track-mounted
date started | 2018/07/23
location | Wainfleet, ON
method | Rock coring
supervisor | CS
position | E: 638206 N: 4751279 (17T, Geodetic)
coring | HQ core, OD=96mm, ID=64mm
reviewer | KJF

Elev Depth (m)	STRATIGRAPHY
176.8	**GROUND SURFACE**
	TOPSOIL Brown, DTPL, some rootlets and gravel.
	SILTY CLAY Brown with grey mottling, becoming grey at 10', WTPL, stiff.
173.7 3.2	**CLAYEY SILT TILL** Brown with grey mottling, some coarse sand and gravel, WTPL, very stiff.
172.2 4.6	**BERTIE FORMATION, FALKIRK MEMBER** Dolostone, brown to grey, medium grained, medium bedded, weathered, trace shaly laminations, bioturbated, fossiliferous. Becomes grey dolostone at 8.2 m (Oatka Member), smooth, trace shaly partings, fine crystalline interbedded with brown to grey dolostone (Falkirk). ...Becoming vuggy at 5.8 m. ...some gypsum nodules from 7.4 m to 7.8 m. ...Clay seam from 7.8 m to 7.9 m. ...Pyrite nodules from 8.18 m to 8.23 m.
168.2 8.6	**BERTIE FORMATION, OATKA MEMBER** Dolostone, grey to dark grey, smooth, fine grained, weathered, highly fractured, vuggy (<1 mm to 2 cm in diameter). ...Clayey sand seam at 8.94 m for 3 cm. ...Chert nodules from 9.1 m to 10.1 m.



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LOG OF BOREHOLE MW5-I

project | Law Quarry Extension

project no. | 111-53023-06

client | Waterford Sand & Gravel Ltd.

rig type | CME 75, track-mounted

date started | 2018/07/23

location | Wainfleet, ON

method | Rock coring

supervisor | CS

position | E: 638206 N: 4751279 (17T, Geodetic)

coring | HQ core, OD=96mm, ID=64mm

reviewer | KJF

Depth Scale (m)	Elev Depth (m)	STRATIGRAPHY (continued)	Elevation Scale (mASL)	Lab Data and Comments
10		**BERTIE FORMATION, OATKA MEMBER** Dolostone, grey to dark grey, smooth, fine grained, weathered, highly fractured, vuggy (<1 mm to 2 cm in diameter). *(continued)* ...3-5 cm clay seam at 10.2 m, 10.26 m, 10.9 m. ...Vuggy from 10.7 m to 10.9 m.	166	
11		...Wavy bedding, possibly bioturbated from 11.58 m to 11.77 m.	165	
12		...10 cm clayey seams between 12.5 m and 13.0 m.	164	
13		...0.76 m void space encountered at 13.2 m.	163	
14		...Weathered rubble from 14.7 m to 16.9 m.	162	
15				Bentonite grout
16			161	
17			160	
18			159	
19	157.6 19.2	**SALINA FORMATION** Dolomitic Shale with interbedded to interlaminated gypsum beds and nodules, grey, locally vuggy, highly fractured, becoming less gypsumiferous at 23.6 m.	158 157	

SUBSURFACE PROFILE: Elev Depth (m); STRATIGRAPHY; Graphic Plot

SAMPLE: Number; Type; SPT N-Value; Core Recovery

Penetration Test Values (Blows / 0.3m)
× Dynamic Cone
10 20 30 40

Undrained Shear Strength (kPa)
○ Unconfined
✚ Field Vane
● Pocket Penetrometer
■ Lab Vane
40 80 120 160

Water Content (%) & Plasticity
PL MC LL
10 20 30

PID Readings

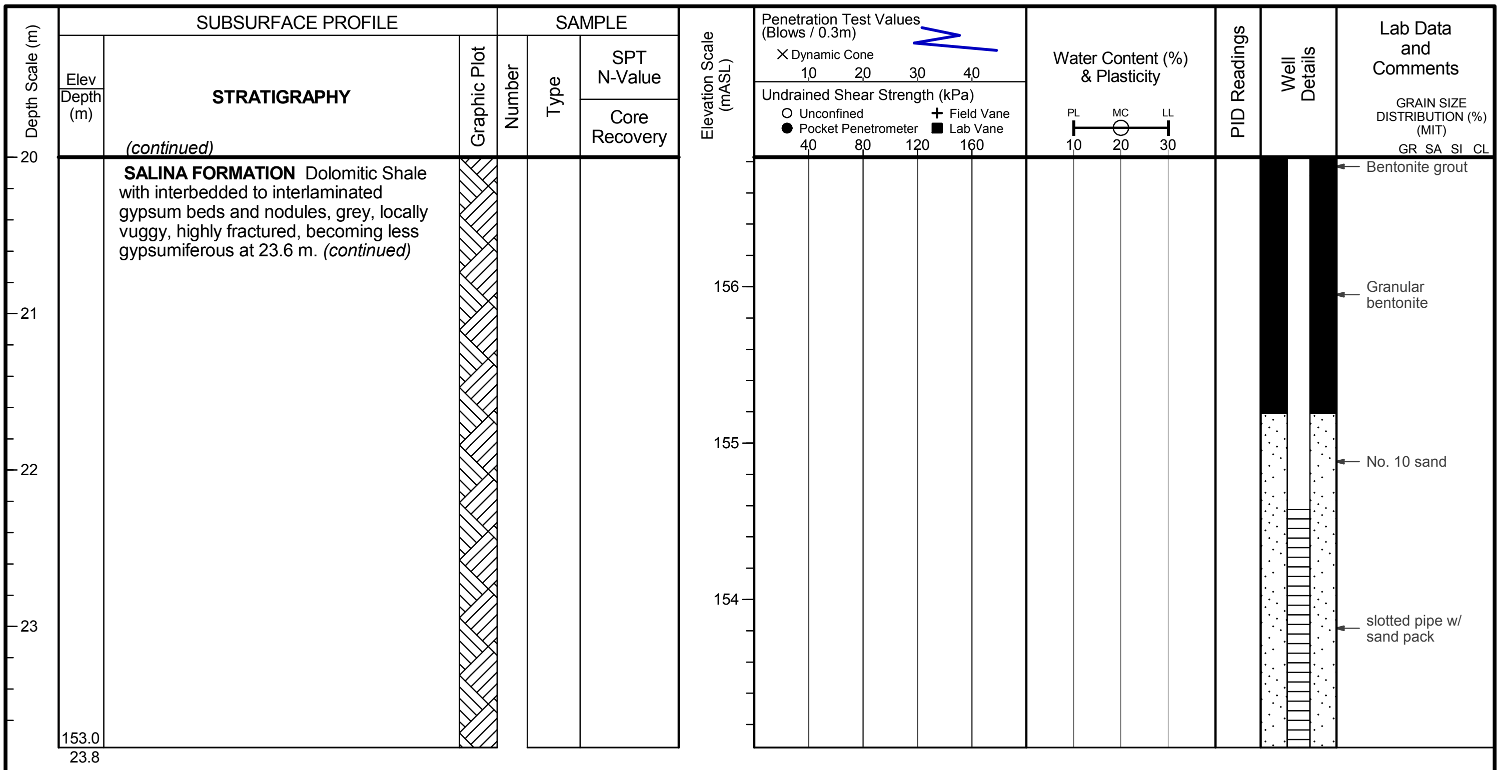
Well Details

Lab Data and Comments
GRAIN SIZE DISTRIBUTION (%) (MIT)
GR SA SI CL

(continued next page)

LOG OF BOREHOLE MW5-I

project | Law Quarry Extension
project no. | 111-53023-06
client | Waterford Sand & Gravel Ltd.
rig type | CME 75, track-mounted
date started | 2018/07/23
location | Wainfleet, ON
method | Rock coring
supervisor | CS
position | E: 638206 N: 4751279 (17T, Geodetic)
coring | HQ core, OD=96mm, ID=64mm
reviewer | KJF



(continued)

SALINA FORMATION Dolomitic Shale with interbedded to interlaminated gypsum beds and nodules, grey, locally vuggy, highly fractured, becoming less gypsumiferous at 23.6 m. *(continued)*

153.0
23.8

END OF BOREHOLE

Borehole was open upon completion.
Water level was not measured upon completion.

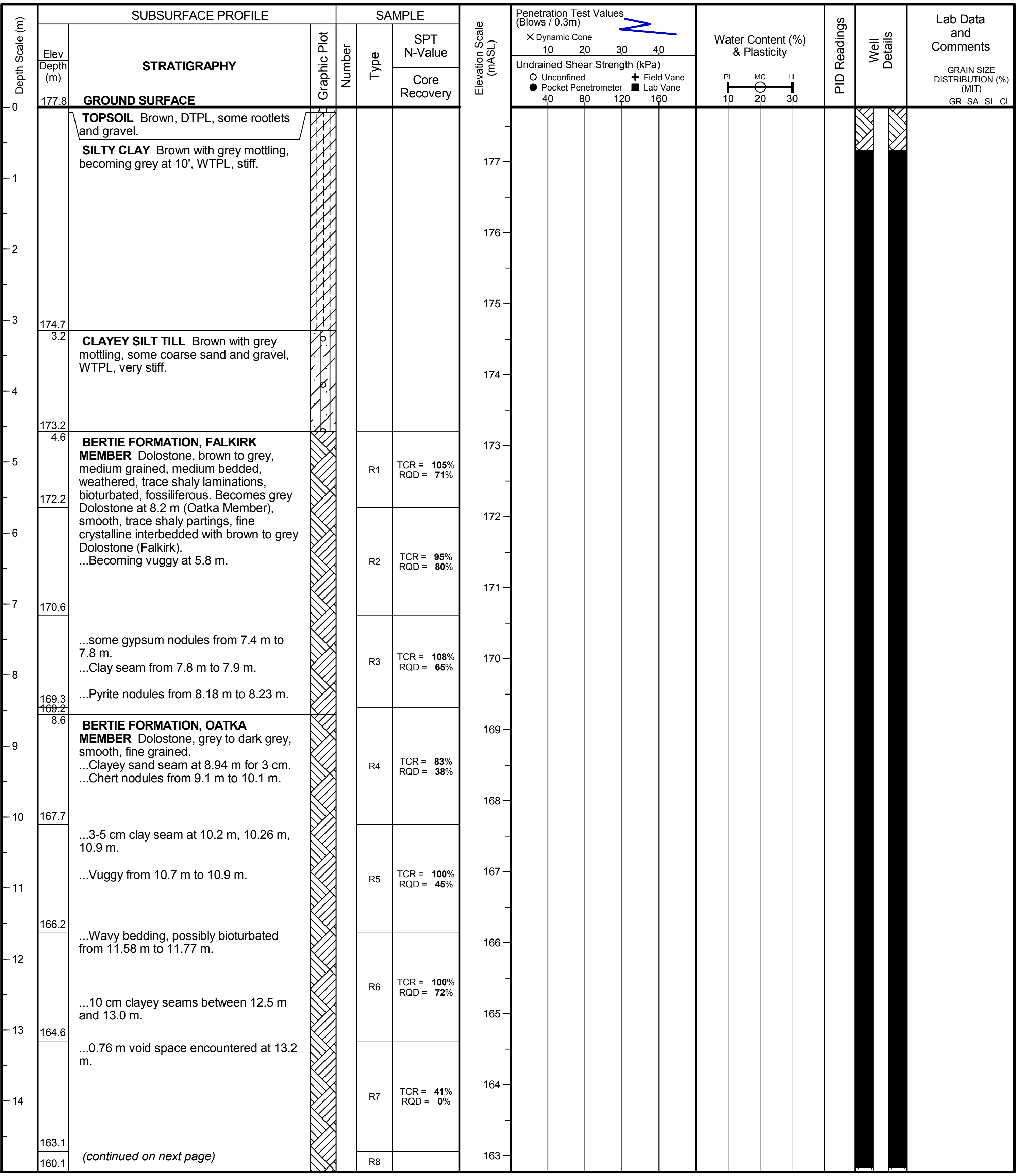
50 mm monitoring well installed.
No. 10 screen installed.

WATER LEVEL MONITORING

Date	Depth (m)	Elevation (m)
Jul 24, 2018	10.0	166.9

LOG OF BOREHOLE MW5-II

project | Law Quarry Extension
project no. | 111-53023-06
client | Waterford Sand & Gravel Ltd.
rig type | CME 75, track-mounted
date started | 2017/11/28
location | Wainfleet, ON
method | Hollow stem augers, 215 mm dia.
supervisor | CS
position | E: 638214 N: 4751282 (17T, Geodetic)
coring | HQ core, OD=96mm, ID=64mm
reviewer | KJF

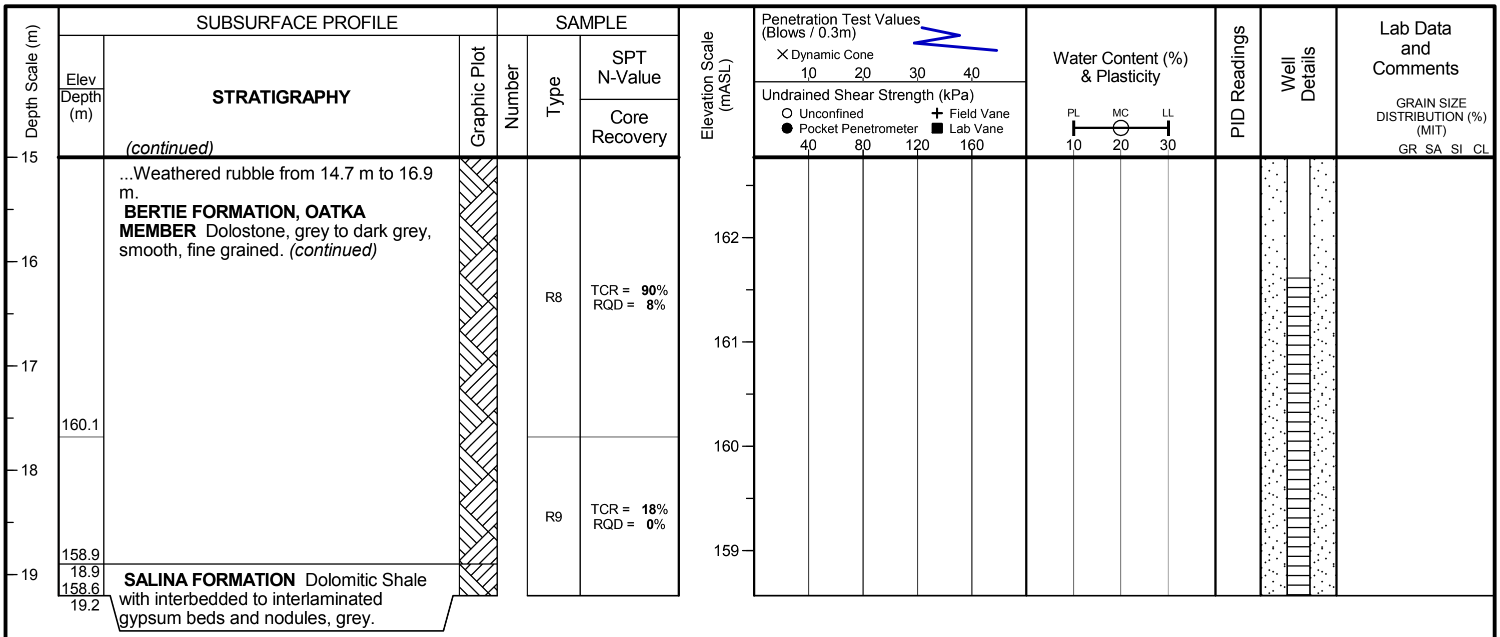


Elev Depth (m)	STRATIGRAPHY	Number	Type	SPT N-Value / Core Recovery
177.8	**GROUND SURFACE**			
	TOPSOIL Brown, DTPL, some rootlets and gravel.			
	SILTY CLAY Brown with grey mottling, becoming grey at 10', WTPL, stiff.			
174.7 3.2	**CLAYEY SILT TILL** Brown with grey mottling, some coarse sand and gravel, WTPL, very stiff.			
173.2 4.6	**BERTIE FORMATION, FALKIRK MEMBER** Dolostone, brown to grey, medium grained, medium bedded, weathered, trace shaly laminations, bioturbated, fossiliferous. Becomes grey Dolostone at 8.2 m (Oatka Member), smooth, trace shaly partings, fine crystalline interbedded with brown to grey Dolostone (Falkirk).		R1	TCR = 105% RQD = 71%
172.2	...Becoming vuggy at 5.8 m.		R2	TCR = 95% RQD = 80%
170.6	...some gypsum nodules from 7.4 m to 7.8 m. ...Clay seam from 7.8 m to 7.9 m. ...Pyrite nodules from 8.18 m to 8.23 m.		R3	TCR = 108% RQD = 65%
169.3 169.2 8.6	**BERTIE FORMATION, OATKA MEMBER** Dolostone, grey to dark grey, smooth, fine grained. ...Clayey sand seam at 8.94 m for 3 cm. ...Chert nodules from 9.1 m to 10.1 m.		R4	TCR = 83% RQD = 38%
167.7	...3-5 cm clay seam at 10.2 m, 10.26 m, 10.9 m. ...Vuggy from 10.7 m to 10.9 m.		R5	TCR = 100% RQD = 45%
166.2	...Wavy bedding, possibly bioturbated from 11.58 m to 11.77 m. ...10 cm clayey seams between 12.5 m and 13.0 m.		R6	TCR = 100% RQD = 72%
164.6	...0.76 m void space encountered at 13.2 m.		R7	TCR = 41% RQD = 0%
163.1			R8	
160.1	*(continued on next page)*			

(continued next page)

LOG OF BOREHOLE MW5-II

project | Law Quarry Extension
project no. | 111-53023-06
client | Waterford Sand & Gravel Ltd.
rig type | CME 75, track-mounted
date started | 2017/11/28
location | Wainfleet, ON
method | Hollow stem augers, 215 mm dia.
supervisor | CS
position | E: 638214 N: 4751282 (17T, Geodetic)
coring | HQ core, OD=96mm, ID=64mm
reviewer | KJF



(continued)

...Weathered rubble from 14.7 m to 16.9 m.
BERTIE FORMATION, OATKA MEMBER Dolostone, grey to dark grey, smooth, fine grained. *(continued)*

Elev / Depth (m)	Type	Core Recovery
	R8	TCR = **90%** RQD = **8%**
160.1	R9	TCR = **18%** RQD = **0%**

158.9 / 18.9 — **SALINA FORMATION** Dolomitic Shale with interbedded to interlaminated gypsum beds and nodules, grey.

158.6 / 19.2

END OF BOREHOLE

Borehole was dry and open upon completion.

LOG OF BOREHOLE MW6-II

project | Law Quarry Extension
project no. | 111-53023-06
client | Waterford Sand & Gravel Ltd.
rig type | CME 75, track-mounted
date started | 2017/11/30
location | Wainfleet, ON
method | Hollow stem augers, 215 mm dia.
supervisor | CS
position | E: 637501 N: 4750899 (17T, Geodetic)
coring | HQ core, OD=96mm, ID=64mm
reviewer | KJF

SUBSURFACE PROFILE

Elev Depth (m)	STRATIGRAPHY
182.9	**GROUND SURFACE**
182.7 0.2	**TOPSOIL** Brown.
0.2	**BOIS BLANC FORMATION** Dolostone, light grey to brown grey, weathered, highly fractured, fine crystalline, medium bedded, hard, some chert, fossiliferous, chonchoidal fracturing. ...Rubble from 0.97 m to 1.01 m.
181.6 1.3	**BOIS BLANC FORMATION, SPRINGVALE MEMBER** Glauconitic sandstone, green to grey, medium grained, trace chert.
181.1 1.8	**BERTIE FORMATION, AKRON MEMBER** Dolostone, medium to light grey, fine crystalline to fine grained, thinnly bedded, weathered, trace shale partings, trace calcite nodules. ...Glauconitic sandstone seams from 3.0 m to 3.25 m.
180.4	
178.9	
177.4	
176.3 6.6	**BERTIE FORMATION, WILLIAMSVILLE MEMBER** Dolostone, medium grey, fine grained to fine crystalline, trace shale partings.
175.8	
174.8 8.1	**BERTIE FORMATION, SCAJAQUADA MEMBER** Argillaceous dolostone, medium to dark grey, fine grained, thinly bedded, laminated, some shaly laminations increasing with depth.
174.4	
172.8	
172.5 10.4	**BERTIE FORMATION, FALKIRK MEMBER** Dolostone, brown to grey, medium grained, medium bedded, trace shaly laminations, vugs up to 2 cm in length increasing with depth. At 14.0 m becomes light grey, fine crystalline dolostone (Oatka) with thin shale partings, becoming medium grey to brown at 14.7 m with shale laminations and partings (Falkirk).
171.4	
169.8	
168.4	
166.8	

SAMPLE

Number	Type	SPT N-Value / Core Recovery
	R1	TCR = 112% RQD = 0%
	R2	TCR = 166% RQD = 0%
	R3	TCR = 40% RQD = 7%
	R4	TCR = 100% RQD = 25%
	R5	TCR = 102% RQD = 54%
	R6	TCR = 98% RQD = 87%
	R7	TCR = 85% RQD = 89%
	R8	TCR = 95% RQD = 81%
	R9	TCR = 107% RQD = 91%
	R10	TCR = 100% RQD = 92%
	R11	TCR = 83% RQD = 74%
	R12	TCR = 100% RQD =

Depth Scale (m): 0 – 14

Elevation Scale (mASL): 182 – 168

Penetration Test Values (Blows / 0.3m)
× Dynamic Cone
10 20 30 40

Undrained Shear Strength (kPa)
○ Unconfined ✚ Field Vane
● Pocket Penetrometer ■ Lab Vane
40 80 120 160

Water Content (%) & Plasticity
PL MC LL
10 20 30

PID Readings

Well Details

Lab Data and Comments
GRAIN SIZE DISTRIBUTION (%) (MIT)
GR SA SI CL

(continued next page)

Sheet No. 1 of 2

LOG OF BOREHOLE MW6-II

project | Law Quarry Extension
project no. | 111-53023-06
client | Waterford Sand & Gravel Ltd.
rig type | CME 75, track-mounted
date started | 2017/11/30
location | Wainfleet, ON
method | Hollow stem augers, 215 mm dia.
supervisor | CS
position | E: 637501 N: 4750899 (17T, Geodetic)
coring | HQ core, OD=96mm, ID=64mm
reviewer | KJF

Depth Scale (m)	Elev Depth (m)	SUBSURFACE PROFILE: STRATIGRAPHY	SAMPLE: Number	SAMPLE: Type	SAMPLE: SPT N-Value / Core Recovery	Elevation Scale (mASL)
15		*(continued)*			95%	
				R12	TCR = 100% RQD = 95%	
16	166.8					167
	166.7 16.2	**BERTIE FORMATION, OATKA MEMBER** Dolostone, grey to dark grey, smooth, fine grained to fine crystalline, some wavy laminations.		R13	TCR = 95% RQD = 95%	
17	165.4					166
18				R14	TCR = 102% RQD = 95%	165
	164.5 18.4	**SALINA FORMATION** Dolomitic Shale with interbedded to interlaminated gypsum beds and nodules up to 6 cm in diameter, medium grey.				
	163.9 19.0					164

END OF BOREHOLE

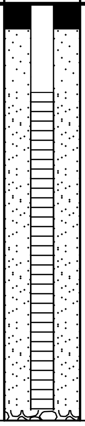
Borehole was dry and open upon completion.

Penetration Test Values (Blows / 0.3m)
× Dynamic Cone: 10, 20, 30, 40
Undrained Shear Strength (kPa)
○ Unconfined
✚ Field Vane
● Pocket Penetrometer
■ Lab Vane
40, 80, 120, 160

Water Content (%) & Plasticity
PL, MC, LL: 10, 20, 30

PID Readings

Well Details



Lab Data and Comments
GRAIN SIZE DISTRIBUTION (%) (MIT)
GR SA SI CL

LOG OF BOREHOLE MW9-II

project |	Law Quarry Extension			**project no. |**	111-53023-06
client |	Waterford Sand & Gravel Ltd.	**rig type |**	CME 75, track-mounted	**date started |**	2018/07/17
location |	Wainfleet, ON	**method |**	Rock coring	**supervisor |**	CS
position |	E: 637500 N: 4750412 (17T, Geodetic)	**coring |**	HQ core, OD=96mm, ID=64mm	**reviewer |**	KJF

Depth Scale (m)	Elev Depth (m)	SUBSURFACE PROFILE: STRATIGRAPHY	SAMPLE: Number	SAMPLE: Type	SAMPLE: SPT N-Value / Core Recovery	Elevation Scale (mASL)	Lab Data and Comments
0	183.2	**GROUND SURFACE**					
		SILT Brown, some clay, DTPL, soft.				183	
1			1	GS		182	
2	180.8					181	
	2.4	**BOIS BLANC FORMATION** Dolostone, light to medium grey, fine crystalline, thin to medium bedded, hard, some chert, fossiliferous, bioturbated.		R2	TCR = **101**% RQD = **86**%		
				C			
				C			
3				R3	TCR = **100**% RQD = **97**%	180	
4	179.0 179.0						
	4.2	**BOIS BLANC FORMATION, SPRINGVALE MEMBER** Glauconitic Sandstone, green to medium grey, mottled, medium grained, some chert nodules, some thin wavy laminations.		C		179	
5	178.1			R4	TCR = **100**% RQD = **82**%		
	5.1	**BERTIE FORMATION, AKRON MEMBER** Dolostone, grey, fine grained to fine crystalline, thinnly bedded, trace shale partings, occasional calcite nodules, chonchoidal fracturing, mottled.				178	Bentonite grout
	177.5						
6				C			
		...Vertical fracture from 6.46 m to 6.99 m. ...Springvale facies partings at 6.5 m, 6.7 m and 6.95 m. ...Calcite nodules at 6.7 m and 6.83 m.		R5	TCR = **105**% RQD = **75**%	177	
7	176.0						
				C		176	
	175.6 7.6	**BERTIE FORMATION, WILLIAMSVILLE MEMBER** Dolostone, medium grey, fine grained to fine crystalline, trace shale partings, some chert.					
8				R6	TCR = **102**% RQD = **76**%	175	
	174.5						
9				C		174	
				R7	TCR = **100**% RQD = **98**%		
	173.0						

Penetration Test Values (Blows / 0.3m)
× Dynamic Cone
10 20 30 40

Undrained Shear Strength (kPa)
○ Unconfined + Field Vane
● Pocket Penetrometer ■ Lab Vane
40 80 120 160

Water Content (%) & Plasticity
PL MC LL
10 20 30

PID Readings

Well Details

Lab Data and Comments
GRAIN SIZE DISTRIBUTION (%) (MIT)
GR SA SI CL

library: general - library.glb **report:** gen log v1 **file:** law quarry extension 2018 drilling.gpj

(continued next page)

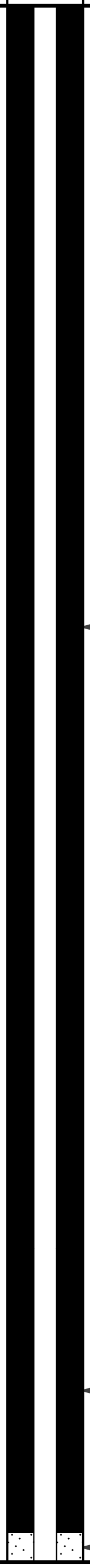
LOG OF BOREHOLE MW9-II

project |	Law Quarry Extension			**project no. |**	111-53023-06
client |	Waterford Sand & Gravel Ltd.	**rig type |**	CME 75, track-mounted	**date started |**	2018/07/17
location |	Wainfleet, ON	**method |**	Rock coring	**supervisor |**	CS
position |	E: 637500 N: 4750412 (17T, Geodetic)	**coring |**	HQ core, OD=96mm, ID=64mm	**reviewer |**	KJF

SUBSURFACE PROFILE

Depth Scale (m)	Elev Depth (m)	STRATIGRAPHY *(continued)*	Graphic Plot	Number	Type	SPT N-Value / Core Recovery	Elevation Scale (mASL)
10	173.0				R7		173
	172.8 10.4	**BERTIE FORMATION, SCAJAQUADA MEMBER** Argillaceous dolostone, medium to dark grey, fine grained, thin to medium bedded, laminated, vuggy (<1 mm in size), some to trace calcite and pyrite mineralization.			C R8	TCR = **86%** RQD = **81%**	
11							172
	171.3				C R9	TCR = **123%** RQD = **110%**	
12							171
	170.2	...Rubble for 5-10 cm at 12.8 m.					
13	170.1 13.0	**BERTIE FORMATION, FALKIRK MEMBER** Dolostone, brown to grey, medium grained, medium bedded, occasional shaly laminations, locally vuggy, some pyrite mineralization and calcite nodules.			C R10	TCR = **107%** RQD = **102%**	170
14							169
	168.7				C R11	TCR = **103%** RQD = **98%**	
15							168
16	167.2				C R12	TCR = **98%** RQD = **70%**	167
17	166.2 17.0	**BERTIE FORMATION, OATKA MEMBER** Dolostone, grey to dark grey, very smooth, fine grained to fine crystalline, some shale interbeds, some chert.					166
	165.6				C R13	TCR = **98%** RQD = **98%**	
18							165
19	164.0				C R14	TCR = **94%** RQD = **82%**	164
	162.7						

Penetration Test Values (Blows / 0.3m)	Water Content (%) & Plasticity	PID Readings	Well Details	Lab Data and Comments
× Dynamic Cone 10 20 30 40 Undrained Shear Strength (kPa) ○ Unconfined ✚ Field Vane ● Pocket Penetrometer ■ Lab Vane 40 80 120 160	PL MC LL 10 20 30			GRAIN SIZE DISTRIBUTION (%) (MIT) GR SA SI CL



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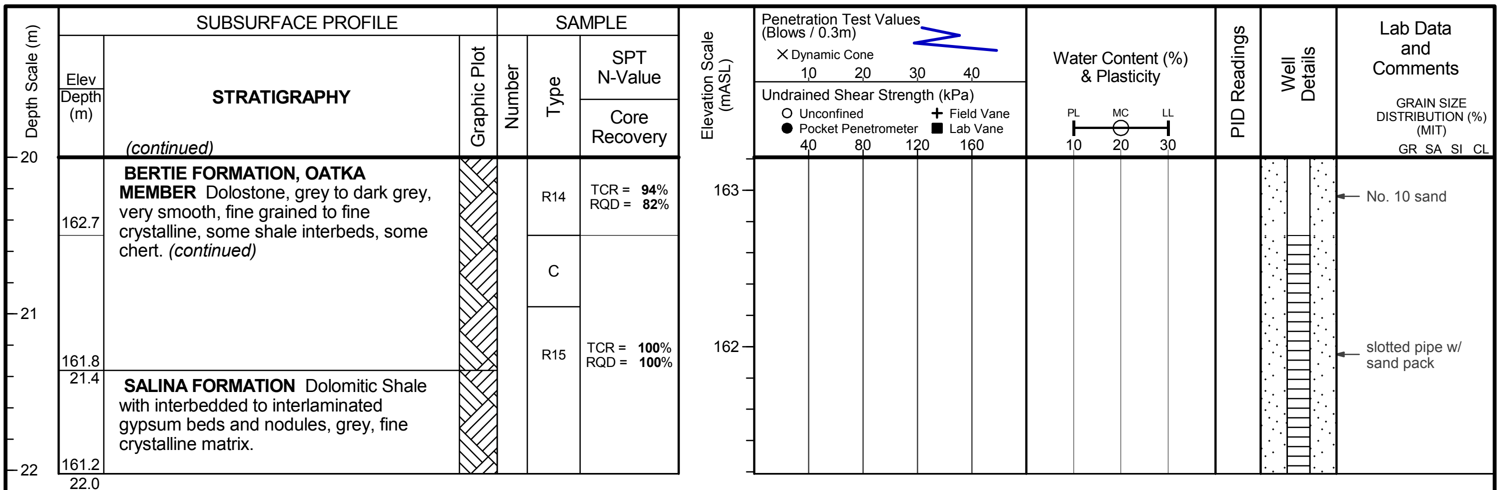
Sheet No. 2 of 3

LOG OF BOREHOLE MW9-II

project | Law Quarry Extension
project no. | 111-53023-06
client | Waterford Sand & Gravel Ltd.
rig type | CME 75, track-mounted
date started | 2018/07/17
location | Wainfleet, ON
method | Rock coring
supervisor | CS
position | E: 637500 N: 4750412 (17T, Geodetic)
coring | HQ core, OD=96mm, ID=64mm
reviewer | KJF



Elev Depth (m)	STRATIGRAPHY	Number	Type	SPT N-Value / Core Recovery
	(continued)			
162.7 161.8 21.4	**BERTIE FORMATION, OATKA MEMBER** Dolostone, grey to dark grey, very smooth, fine grained to fine crystalline, some shale interbeds, some chert. *(continued)*		R14	TCR = **94%** RQD = **82%**
			C	
			R15	TCR = **100%** RQD = **100%**
161.2 22.0	**SALINA FORMATION** Dolomitic Shale with interbedded to interlaminated gypsum beds and nodules, grey, fine crystalline matrix.			

END OF BOREHOLE

Borehole was open upon completion. Water level was not measured upon completion.

50 mm monitoring well installed. No. 10 screen installed.

WATER LEVEL MONITORING

Date	Depth (m)	Elevation (m)
Jul 24, 2018	6.9	176.3

library: general - library.glb report: gen log v1 file: law quarry extension 2018 drilling.gpj

LOG OF BOREHOLE MW9-III

project | Law Quarry Extension
project no. | 111-53023-06
client | Waterford Sand & Gravel Ltd.
rig type | CME 75, track-mounted
date started | 2018/07/19
location | Wainfleet, ON
method | Rock coring
supervisor | CS
position | E: 637500 N: 4750414 (17T, Geodetic)
coring | HQ core, OD=96mm, ID=64mm
reviewer | KJF

Penetration Test Values (Blows / 0.3m)
× Dynamic Cone
10 20 30 40
Undrained Shear Strength (kPa)
○ Unconfined ✚ Field Vane
● Pocket Penetrometer ■ Lab Vane
40 80 120 160

Water Content (%) & Plasticity
PL MC LL
10 20 30

PID Readings

Well Details

Lab Data and Comments
GRAIN SIZE DISTRIBUTION (%) (MIT)
GR SA SI CL

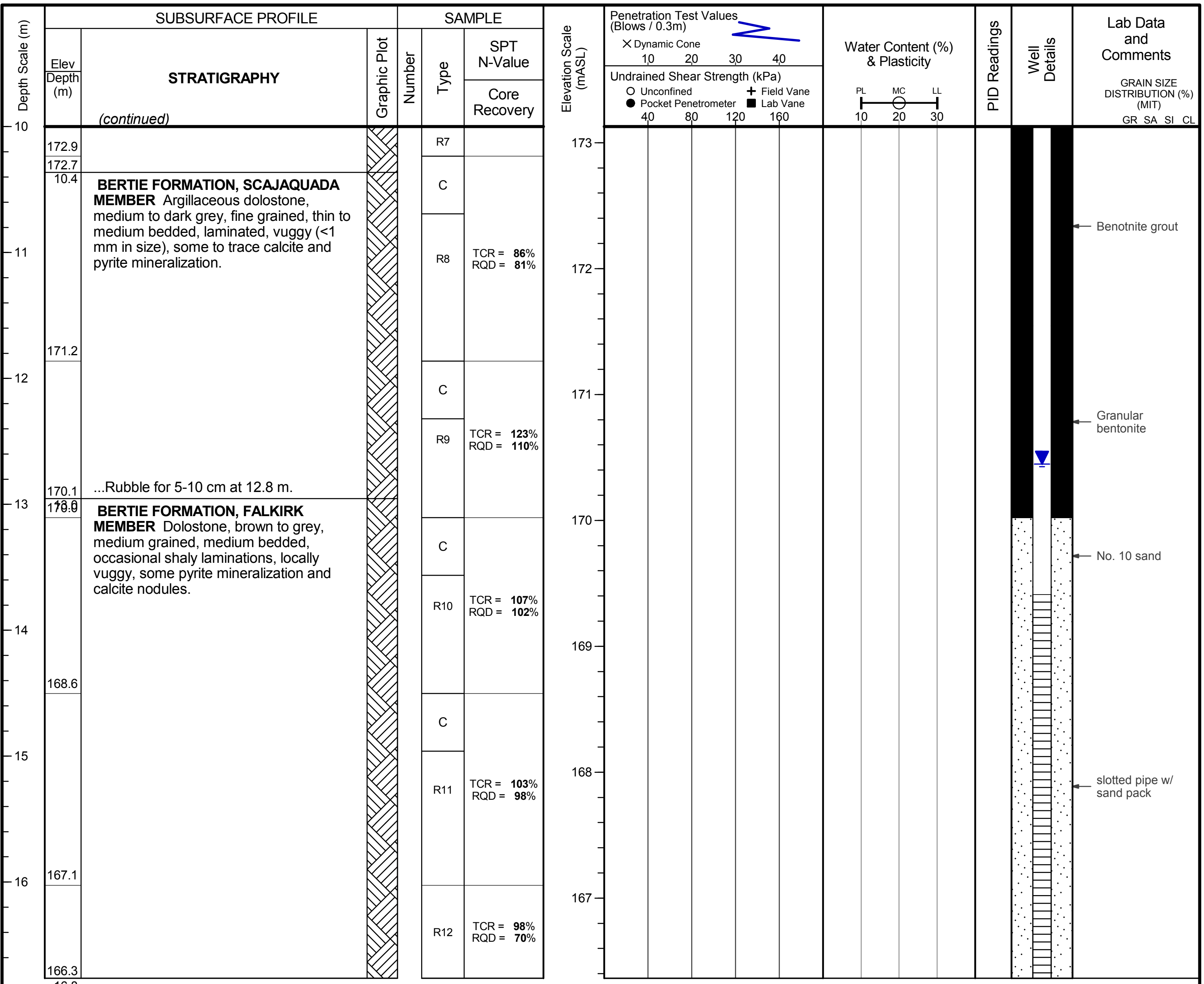
Depth Scale (m)	Elev Depth (m)	STRATIGRAPHY	Number	Type	SPT N-Value / Core Recovery	Elevation Scale (mASL)	Lab Data and Comments
0	183.1	**GROUND SURFACE**					
		SILT Brown, some clay, DTPL, soft.				183	
1						182	
2						181	
	180.7 2.4	**BOIS BLANC FORMATION** Dolostone, light to medium grey, fine crystalline, thin to medium bedded, hard, some chert, fossiliferous, bioturbated.		R2	TCR = **101%** RQD = **86%**		
				C			
				C			
3				R3	TCR = **100%** RQD = **97%**	180	
4	178.9 178.9 4.2	**BOIS BLANC FORMATION, SPRINGVALE MEMBER** Glauconitic Sandstone, green to medium grey, mottled, medium grained, some chert nodules, some thin wavy laminations.		C		179	
				R4	TCR = **100%** RQD = **82%**		
5	178.0 5.1	**BERTIE FORMATION, AKRON MEMBER** Dolostone, grey, fine grained to fine crystalline, thinly bedded, trace shale partings, occasional calcite nodules, chonchoidal fracturing, mottled.				178	← Benotnite grout
	177.4						
6				C		177	
		...Vertical fracture from 6.46 m to 6.99 m. ...Springvale facies partings at 6.5 m, 6.7 m and 6.95 m. ...Calcite nodules at 6.7 m and 6.83 m.		R5	TCR = **105%** RQD = **75%**		
7	175.9			C		176	
	175.5 7.6	**BERTIE FORMATION, WILLIAMSVILLE MEMBER** Dolostone, medium grey, fine grained to fine crystalline, trace shale partings, some chert.		R6	TCR = **102%** RQD = **76%**		
8						175	
	174.4			C			
9				R7	TCR = **100%** RQD = **98%**	174	
	172.9						

(continued next page)

Sheet No. 1 of 2

LOG OF BOREHOLE MW9-III

project |	Law Quarry Extension			**project no. |**	111-53023-06
client |	Waterford Sand & Gravel Ltd.	**rig type |**	CME 75, track-mounted	**date started |**	2018/07/19
location |	Wainfleet, ON	**method |**	Rock coring	**supervisor |**	CS
position |	E: 637500 N: 4750414 (17T, Geodetic)	**coring |**	HQ core, OD=96mm, ID=64mm	**reviewer |**	KJF



Elev / Depth (m)	STRATIGRAPHY
172.9	
172.7 10.4	**BERTIE FORMATION, SCAJAQUADA MEMBER** Argillaceous dolostone, medium to dark grey, fine grained, thin to medium bedded, laminated, vuggy (<1 mm in size), some to trace calcite and pyrite mineralization.
171.2	
170.1	...Rubble for 5-10 cm at 12.8 m.
170.0 13.0	**BERTIE FORMATION, FALKIRK MEMBER** Dolostone, brown to grey, medium grained, medium bedded, occasional shaly laminations, locally vuggy, some pyrite mineralization and calcite nodules.
168.6	
167.1	
166.3 16.8	

Type	Core Recovery
R7	
C	
R8	TCR = **86**% RQD = **81**%
C	
R9	TCR = **123**% RQD = **110**%
C	
R10	TCR = **107**% RQD = **102**%
C	
R11	TCR = **103**% RQD = **98**%
R12	TCR = **98**% RQD = **70**%

END OF BOREHOLE

Borehole was open upon completion. Water level was not measured upon completion.

50 mm monitoring well installed. No. 10 screen installed.

WATER LEVEL MONITORING

Date	**Depth (m)**	**Elevation (m)**
Jul 24, 2018	12.7	170.4

LOG OF BOREHOLE MW10-I

project | Law Quarry Extension
client | Waterford Sand & Gravel Ltd.
location | Wainfleet, ON
position | E: 637506 N: 4750213 (17T, Geodetic)

rig type | CME 75, track-mounted
method | Rock coring
coring | HQ core, OD=96mm, ID=64mm

project no. | 111-53023-06
date started | 2018/07/12
supervisor | CS
reviewer | KJF

Elev Depth (m)	SUBSURFACE PROFILE – STRATIGRAPHY	SAMPLE Number	Type	SPT N-Value / Core Recovery	Lab Data and Comments
182.6	**GROUND SURFACE**				
	CLAYEY SILT TILL Reddish brown, some gravel, DTPL, firm.				
180.9 1.7	**SILTY CLAY** Brown, trace organics, ATPL, very stiff.		R1	TCR = **100%** RQD = **66%**	
180.0 2.6	**BOIS BLANC FORMATION** Dolostone, light grey to brown grey, weathered, fine grained, medium bedded, hard, trace to some chert, fossiliferous, bioturbated, some wavy laminations.				
178.5			R2	TCR = **100%** RQD = **72%**	
177.5 5.1	**BOIS BLANC FORMATION, SPRINGVALE MEMBER** Glauconitic Sandstone, green to grey, medium grained, trace chert.				Bentonite grout
177.0			R3	TCR = **103%** RQD = **68%**	
175.7 6.9	**BERTIE FORMATION, AKRON MEMBER** Dolostone, grey, fine grained, thinly bedded, trace shale partings, trace calcite nodules, glauconic sandstone partings present to 6.9 m.				
175.5			R4	TCR = **100%** RQD = **83%**	
174.0			R5	TCR = **98%** RQD = **98%**	
173.7 8.9	**BERTIE FORMATION, WILLIAMSVILLE MEMBER** Dolostone, medium grey, fine to medium grained, trace shale partings.				
172.4 172.6					

Depth Scale (m): 0, 1, 2, 3, 4, 5, 6, 7, 8, 9

Elevation Scale (mASL): 182, 181, 180, 179, 178, 177, 176, 175, 174, 173

Penetration Test Values (Blows / 0.3m)
× Dynamic Cone
10 20 30 40

Undrained Shear Strength (kPa)
○ Unconfined ✚ Field Vane
● Pocket Penetrometer ■ Lab Vane
40 80 120 160

Water Content (%) & Plasticity
PL MC LL
10 20 30

PID Readings

Well Details

GRAIN SIZE DISTRIBUTION (%) (MIT)
GR SA SI CL

(continued next page)

LOG OF BOREHOLE MW10-I

project |	Law Quarry Extension			**project no. |**	111-53023-06
client |	Waterford Sand & Gravel Ltd.	**rig type |**	CME 75, track-mounted	**date started |**	2018/07/12
location |	Wainfleet, ON	**method |**	Rock coring	**supervisor |**	CS
position |	E: 637506 N: 4750213 (17T, Geodetic)	**coring |**	HQ core, OD=96mm, ID=64mm	**reviewer |**	KJF

SUBSURFACE PROFILE | SAMPLE | Penetration Test Values (Blows / 0.3m) × Dynamic Cone 10 20 30 40 | Undrained Shear Strength (kPa) ○ Unconfined ✚ Field Vane ● Pocket Penetrometer ■ Lab Vane 40 80 120 160 | Water Content (%) & Plasticity PL MC LL 10 20 30 | PID Readings | Well Details | Lab Data and Comments GRAIN SIZE DISTRIBUTION (%) (MIT) GR SA SI CL

Depth Scale (m)	Elev Depth (m)	STRATIGRAPHY *(continued)*	Number	Type	SPT N-Value / Core Recovery	Elevation Scale (mASL)	Well Details	Lab Data and Comments
10	10.0 172.4	**BERTIE FORMATION, SCAJAQUADA MEMBER** Argillaceous dolostone, medium to dark grey, fine grained, thinly bedded, laminated, some shaly laminations increasing with depth.		R5				
11				R6	TCR = **100%** RQD = **68%**	172	▼	
	171.0	...Vertical fracture from 11.61 m to 12.29 m.		R7	TCR = **95%** RQD = **68%**	171 170		
12 13	169.5							
	169.4 13.1	**BERTIE FORMATION, FALKIRK MEMBER** Dolostone, brown to grey, medium grained, medium bedded, weathered, trace shaly laminations.		R8	TCR = **110%** RQD = **98%**	169		
14	167.9			R9	TCR = **102%** RQD = **78%**	168 167		← Bentonite grout
15		...Vugs becoming larger in size between 15.7 m and 16.1 m. ...Rubble between 15.8 m and 16.0 m.						
16	166.4	...Larger vugs present from 16.7 m to 16.9 m.		R10	TCR = **98%** RQD = **80%**	166		
17	165.5 17.1	**BERTIE FORMATION, OATKA MEMBER** Dolostone, grey to dark grey, very smooth, fine grained.				165		
18	164.9			R11	TCR = **93%** RQD = **93%**	164		
19	163.4	...Fractures at 19.56 m and 19.60 m. Vuggy between 19.56 m and 19.66 m.		R12	TCR = **100%** RQD = **90%**	163		
	161.9							

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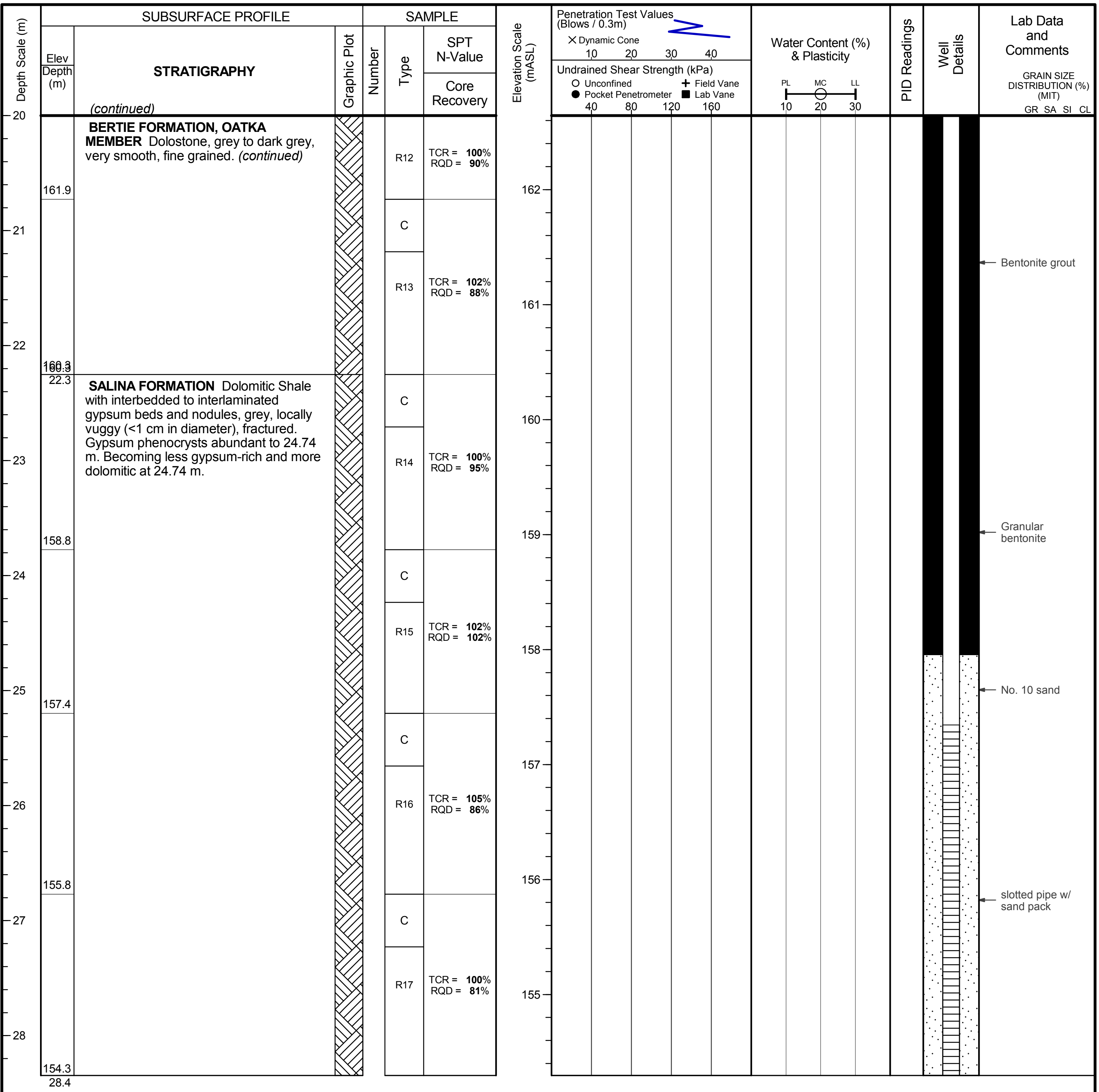
LOG OF BOREHOLE MW10-I

project | Law Quarry Extension
project no. | 111-53023-06
client | Waterford Sand & Gravel Ltd.
rig type | CME 75, track-mounted
date started | 2018/07/12
location | Wainfleet, ON
method | Rock coring
supervisor | CS
position | E: 637506 N: 4750213 (17T, Geodetic)
coring | HQ core, OD=96mm, ID=64mm
reviewer | KJF



(continued)

BERTIE FORMATION, OATKA MEMBER Dolostone, grey to dark grey, very smooth, fine grained. *(continued)*

SALINA FORMATION Dolomitic Shale with interbedded to interlaminated gypsum beds and nodules, grey, locally vuggy (<1 cm in diameter), fractured. Gypsum phenocrysts abundant to 24.74 m. Becoming less gypsum-rich and more dolomitic at 24.74 m.

Elev Depth (m)	Type	Core Recovery
	R12	TCR = **100%** RQD = **90%**
161.9	C	
	R13	TCR = **102%** RQD = **88%**
160.3 22.3	C	
	R14	TCR = **100%** RQD = **95%**
158.8	C	
	R15	TCR = **102%** RQD = **102%**
157.4	C	
	R16	TCR = **105%** RQD = **86%**
155.8	C	
	R17	TCR = **100%** RQD = **81%**
154.3 28.4		

END OF BOREHOLE

Borehole was open upon completion. Water level was not measured upon completion.

50 mm monitoring well installed. No. 10 screen installed.

WATER LEVEL MONITORING

Date	Depth (m)	Elevation (m)
Jul 18, 2018	11.4	171.2

LOG OF BOREHOLE MW10-II

wsp

project | Law Quarry Extension
project no. | 111-53023-06
client | Waterford Sand & Gravel Ltd.
rig type | CME 75, track-mounted
date started | 2017/12/01
location | Wainfleet, ON
method | Hollow stem augers, 215 mm dia.
supervisor | CS
position | E: 637506 N: 4750209 (17T, Geodetic)
coring | HQ core, OD=96mm, ID=64mm
reviewer | KJF

Depth Scale (m): 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14

Elevation Scale (mASL): 182, 181, 180, 179, 178, 177, 176, 175, 174, 173, 172, 171, 170, 169, 168

Penetration Test Values (Blows / 0.3m): × Dynamic Cone — 10, 20, 30, 40
Undrained Shear Strength (kPa): ○ Unconfined, + Field Vane, ● Pocket Penetrometer, ■ Lab Vane — 40, 80, 120, 160
Water Content (%) & Plasticity: PL, MC, LL — 10, 20, 30
PID Readings
Well Details
Lab Data and Comments: GRAIN SIZE DISTRIBUTION (%) (MIT) — GR SA SI CL

Elev Depth (m)	SUBSURFACE PROFILE — STRATIGRAPHY	SAMPLE — Number	Type	SPT N-Value / Core Recovery
182.6	**GROUND SURFACE**			
	CLAYEY SILT TILL Reddish brown, some gravel, DTPL.			
180.9 1.7	**SILTY CLAY** Brown, trace organics, ATPL, very stiff.			
180.0 2.6	**BOIS BLANC FORMATION** Dolostone, light grey to brown grey, weathered, fine grained, medium bedded, hard, trace to some chert, fossiliferous, bioturbated, some wavy laminations.		R1	TCR = **100%** RQD = **66%**
178.5			R2	TCR = **100%** RQD = **72%**
177.5 5.1	**BOIS BLANC FORMATION, SPRINGVALE MEMBER** Glauconitic Sandstone, green to grey, medium grained, trace chert.			
177.0			R3	TCR = **103%** RQD = **68%**
175.7 176.9 6.9	**BERTIE FORMATION, AKRON MEMBER** Dolostone, grey, fine grained, thinly bedded, trace shale partings, trace calcite nodules, glauconic sandstone partings present to 6.9 m.		R4	TCR = **100%** RQD = **83%**
174.0			R5	TCR = **98%** RQD = **98%**
173.7 8.9	**BERTIE FORMATION, WILLIAMSVILLE MEMBER** Dolostone, medium grey, fine to medium grained, trace shale partings.			
172.6 172.4 10.0	**BERTIE FORMATION, SCAJAQUADA MEMBER** Argillaceous dolostone, medium to dark grey, fine grained, thinly bedded, laminated, some shaly laminations increasing with depth.		R6	TCR = **100%** RQD = **68%**
171.0	...Vertical fracture from 11.61 m to 12.29 m.		R7	TCR = **95%** RQD = **68%**
169.5 169.4 13.1	**BERTIE FORMATION, FALKIRK MEMBER** Dolostone, brown to grey, medium grained, medium bedded, weathered, trace shaly laminations.		R8	TCR = **110%** RQD = **98%**
167.9			R9	
166.4				

(continued next page)

Sheet No. 1 of 2

LOG OF BOREHOLE MW10-II

project |	Law Quarry Extension			**project no. |**	111-53023-06
client |	Waterford Sand & Gravel Ltd.	**rig type |**	CME 75, track-mounted	**date started |**	2017/12/01
location |	Wainfleet, ON	**method |**	Hollow stem augers, 215 mm dia.	**supervisor |**	CS
position |	E: 637506 N: 4750209 (17T, Geodetic)	**coring |**	HQ core, OD=96mm, ID=64mm	**reviewer |**	KJF

Depth Scale (m)	Elev Depth (m)	STRATIGRAPHY *(continued)*	Number	Type	SPT N-Value / Core Recovery	Elevation Scale (mASL)
15		**BERTIE FORMATION, FALKIRK MEMBER** Dolostone, brown to grey, medium grained, medium bedded, weathered, trace shaly laminations. *(continued)*		R9	TCR = **102%** RQD = **78%**	167
16	166.4	...Vugs becoming larger in size between 15.7 m and 16.1 m. ...Rubble between 15.8 m and 16.0 m. ...Larger vugs present from 16.7 m to 16.9 m.		R10	TCR = **98%** RQD = **80%**	166
17	165.5 17.1	**BERTIE FORMATION, OATKA MEMBER** Dolostone, grey to dark grey, very smooth, fine grained.				165
	164.9			R11	TCR = **93%** RQD = **93%**	164
18–19	163.4	...Fractures at 19.56 m and 19.60 m. Vuggy between 19.56 m and 19.66 m.		R12	TCR = **100%** RQD = **90%**	163
20–21	161.9			R13	TCR = **102%** RQD = **102%**	162, 161
22	160.7 22.0	**SALINA FORMATION** Dolomitic Shale with interbedded to interlaminated gypsum beds and nodules, grey.		R14	TCR = **103%** RQD = **81%**	160
23	159.1 23.5					

Penetration Test Values (Blows / 0.3m)
× Dynamic Cone
10 20 30 40

Undrained Shear Strength (kPa)
○ Unconfined + Field Vane
● Pocket Penetrometer ■ Lab Vane
40 80 120 160

Water Content (%) & Plasticity
PL MC LL
10 20 30

PID Readings

Well Details

Lab Data and Comments
GRAIN SIZE DISTRIBUTION (%) (MIT)
GR SA SI CL

END OF BOREHOLE

Borehole was dry and open upon completion.

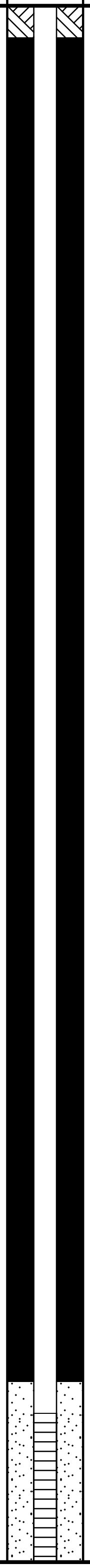
LOG OF BOREHOLE MW10-III

project | Law Quarry Extension
project no. | 111-53023-06
client | Waterford Sand & Gravel Ltd.
rig type | CME 75, track-mounted
date started | 2017/12/04
location | Wainfleet, ON
method | Hollow stem augers, 215 mm dia.
supervisor | SCL
position | E: 637506 N: 4750211 (17T, Geodetic)
coring | HQ core, OD=96mm, ID=64mm
reviewer | KJF

SUBSURFACE PROFILE | SAMPLE

Penetration Test Values (Blows / 0.3m): × Dynamic Cone 10 20 30 40
Undrained Shear Strength (kPa): ○ Unconfined ✛ Field Vane ● Pocket Penetrometer ■ Lab Vane 40 80 120 160
Water Content (%) & Plasticity: PL MC LL 10 20 30
PID Readings | Well Details | Lab Data and Comments: GRAIN SIZE DISTRIBUTION (%) (MIT) GR SA SI CL

Elev Depth (m)	STRATIGRAPHY	Number	Type	SPT N-Value / Core Recovery
182.6	**GROUND SURFACE**			
	CLAYEY SILT TILL Reddish brown, some gravel, DTPL.			
180.9 1.7	**SILTY CLAY** Brown, trace organics, ATPL, very stiff.			
180.0 2.6	**BOIS BLANC FORMATION** Dolostone, light grey to brown grey, weathered, fine grained, medium bedded, hard, trace to some chert, fossiliferous, bioturbated, some wavy laminations.		R1	TCR = **100%** RQD = **66%**
178.5			R2	TCR = **100%** RQD = **72%**
177.5 5.1	**BOIS BLANC FORMATION, SPRINGVALE MEMBER** Glauconitic Sandstone, green to grey, medium grained, trace chert.			
177.0			R3	TCR = **103%** RQD = **68%**
175.7 176.9 6.9	**BERTIE FORMATION, AKRON MEMBER** Dolostone, grey, fine grained, thinly bedded, trace shale partings, trace calcite nodules, glauconitic sandstone partings present to 6.9 m.		R4	TCR = **100%** RQD = **83%**
174.0				
173.7 8.9	**BERTIE FORMATION, WILLIAMSVILLE MEMBER** Dolostone, medium grey, fine to medium grained, trace shale partings.		R5	TCR = **98%** RQD = **98%**
172.6 172.4 10.0	**BERTIE FORMATION, SCAJAQUADA MEMBER** Argillaceous dolostone, medium to dark grey, fine grained, thinly bedded, laminated, some shaly laminations increasing with depth.		R6	TCR = **100%** RQD = **68%**
171.0	...Vertical fracture from 11.61 m to 12.29 m.		R7	TCR = **95%** RQD = **68%**
169.5 169.4 13.1	**BERTIE FORMATION, FALKIRK MEMBER** Dolostone, brown to grey, medium grained, medium bedded, weathered, trace shaly laminations.		R8	TCR = **110%** RQD = **98%**
167.9			R9	
166.4				



(continued next page)

Sheet No. 1 of 2

LOG OF BOREHOLE MW10-III

project | Law Quarry Extension
project no. | 111-53023-06
client | Waterford Sand & Gravel Ltd.
rig type | CME 75, track-mounted
date started | 2017/12/04
location | Wainfleet, ON
method | Hollow stem augers, 215 mm dia.
supervisor | SCL
position | E: 637506 N: 4750211 (17T, Geodetic)
coring | HQ core, OD=96mm, ID=64mm
reviewer | KJF

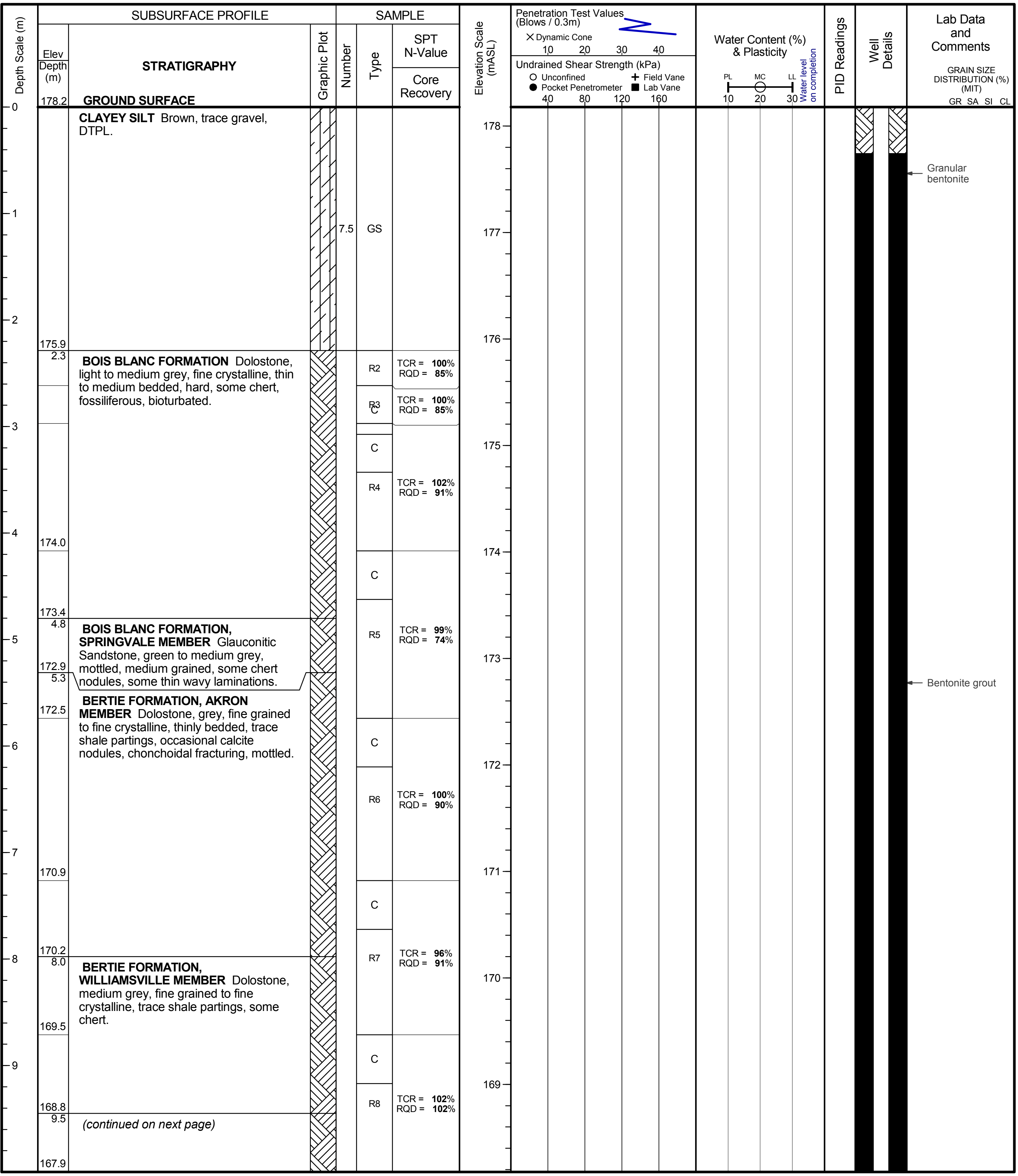
Depth Scale (m)	SUBSURFACE PROFILE Elev Depth (m)	SUBSURFACE PROFILE STRATIGRAPHY *(continued)*	Graphic Plot	SAMPLE Number	SAMPLE Type	SAMPLE SPT N-Value / Core Recovery	Elevation Scale (mASL)	Penetration Test Values (Blows / 0.3m) ✕ Dynamic Cone 10 20 30 40 Undrained Shear Strength (kPa) ○ Unconfined ✚ Field Vane ● Pocket Penetrometer ■ Lab Vane 40 80 120 160	Water Content (%) & Plasticity PL MC LL 10 20 30	PID Readings	Well Details	Lab Data and Comments GRAIN SIZE DISTRIBUTION (%) (MIT) GR SA SI CL
15		**BERTIE FORMATION, FALKIRK MEMBER** Dolostone, brown to grey, medium grained, medium bedded, weathered, trace shaly laminations. *(continued)*			R9	TCR = **102%** RQD = **78%**	167					
16	166.4	...Vugs becoming larger in size between 15.7 m and 16.1 m. ...Rubble between 15.8 m and 16.0 m.			R10	TCR = **98%** RQD = **80%**	166					
	165.8 16.8											

END OF BOREHOLE

Borehole was dry and open upon completion.

LOG OF BOREHOLE MW11-1

project | Law Quarry Extension
project no. | 111-53023-06
client | Waterford Sand & Gravel Ltd.
rig type | CME 75, track-mounted
date started | 2018/07/27
location | Wainfleet, ON
method | Rock coring
supervisor | SCL/MC
position | E: 639946 N: 4750822 (17T, Geodetic)
coring | HQ core, OD=96mm, ID=64mm
reviewer | KJF



Elev Depth (m)	STRATIGRAPHY
178.2	**GROUND SURFACE**
	CLAYEY SILT Brown, trace gravel, DTPL.
175.9 2.3	**BOIS BLANC FORMATION** Dolostone, light to medium grey, fine crystalline, thin to medium bedded, hard, some chert, fossiliferous, bioturbated.
174.0	
173.4 4.8	**BOIS BLANC FORMATION, SPRINGVALE MEMBER** Glauconitic Sandstone, green to medium grey, mottled, medium grained, some chert nodules, some thin wavy laminations.
172.9 5.3	**BERTIE FORMATION, AKRON MEMBER** Dolostone, grey, fine grained to fine crystalline, thinly bedded, trace shale partings, occasional calcite nodules, chonchoidal fracturing, mottled.
172.5	
170.9	
170.2 8.0	**BERTIE FORMATION, WILLIAMSVILLE MEMBER** Dolostone, medium grey, fine grained to fine crystalline, trace shale partings, some chert.
169.5	
168.8 9.5	*(continued on next page)*
167.9	

Number	Type	Core Recovery
7.5	GS	
	R2	TCR = **100%** RQD = **85%**
	R3 C	TCR = **100%** RQD = **85%**
	C	
	R4	TCR = **102%** RQD = **91%**
	C	
	R5	TCR = **99%** RQD = **74%**
	C	
	R6	TCR = **100%** RQD = **90%**
	C	
	R7	TCR = **96%** RQD = **91%**
	C	
	R8	TCR = **102%** RQD = **102%**

(continued next page)

LOG OF BOREHOLE MW11-1

project | Law Quarry Extension
project no. | 111-53023-06
client | Waterford Sand & Gravel Ltd.
rig type | CME 75, track-mounted
date started | 2018/07/27
location | Wainfleet, ON
method | Rock coring
supervisor | SCL/MC
position | E: 639946 N: 4750822 (17T, Geodetic)
coring | HQ core, OD=96mm, ID=64mm
reviewer | KJF

Penetration Test Values (Blows / 0.3m): × Dynamic Cone 10 20 30 40
Undrained Shear Strength (kPa): ○ Unconfined ✚ Field Vane ● Pocket Penetrometer ■ Lab Vane 40 80 120 160
Water Content (%) & Plasticity: PL MC LL 10 20 30; Water level on completion
PID Readings | Well Details | Lab Data and Comments: GRAIN SIZE DISTRIBUTION (%) (MIT) GR SA SI CL

SUBSURFACE PROFILE

Elev Depth (m)	STRATIGRAPHY
(continued)	
167.9	**BERTIE FORMATION, SCAJAQUADA MEMBER** Argillaceous dolostone, medium to dark grey, fine grained, thin to medium bedded, laminated, some to trace calcite and pyrite mineralization. *(continued)*
	...Slightly vuggy at 11.73 m.
166.5	
166.4 11.7	**BERTIE FORMATION, FALKIRK MEMBER** Dolostone, brown to grey, medium grained, medium bedded, occasional shaly laminations, locally vuggy, some pyrite mineralization and calcite nodules.
164.9	
163.4	
162.1	
161.4 16.8	**BERTIE FORMATION, OATKA MEMBER** Dolostone, grey to dark grey, very smooth, fine grained to fine crystalline, some shale interbeds, some chert.
160.5	
158.9	
157.3	

SAMPLE

Type	Core Recovery
R8	
C	
R9	TCR = **100%** RQD = **100%**
C	
R10	TCR = **100%** RQD = **95%**
C	
R11	TCR = **98%** RQD = **98%**
C	
R12	TCR = **102%** RQD = **96%**
C	
R13	TCR = **100%** RQD = **83%**
C	
R14	TCR = **98%** RQD = **77%**
C R15	TCR = **100%** RQD = **86%**

Depth Scale (m): 10, 11, 12, 13, 14, 15, 16, 17, 18, 19
Elevation Scale (mASL): 168, 167, 166, 165, 164, 163, 162, 161, 160, 159

Well details / comments:
- Bentonite grout
- Granular bentonite
- No. 10 sand
- slotted pipe w/ sand pack

(continued next page)

LOG OF BOREHOLE MW11-1

project | Law Quarry Extension
project no. | 111-53023-06
client | Waterford Sand & Gravel Ltd.
rig type | CME 75, track-mounted
date started | 2018/07/27
location | Wainfleet, ON
method | Rock coring
supervisor | SCL/MC
position | E: 639946 N: 4750822 (17T, Geodetic)
coring | HQ core, OD=96mm, ID=64mm
reviewer | KJF

Depth Scale (m)	Elev Depth (m)	STRATIGRAPHY	Number	Type	SPT N-Value Core Recovery	Elevation Scale (mASL)	Lab Data and Comments
20		*(continued)*					
		BERTIE FORMATION, OATKA MEMBER Dolostone, grey to dark grey, very smooth, fine grained to fine crystalline, some shale interbeds, some chert. *(continued)*		R15	TCR = **100%** RQD = **86%**	158	
	157.3			C			
21						157	
	156.8 21.4	**SALINA FORMATION** Dolomitic Shale with interbedded to interlaminated gypsum beds and nodules, grey, fine crystalline matrix.		R16	TCR = **100%** RQD = **95%**		slotted pipe w/ sand pack
22						156	
	155.8			C R17	TCR = **117%** RQD = **117%**		
	155.3 22.9						

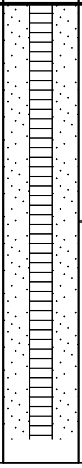
Penetration Test Values (Blows / 0.3m)
✕ Dynamic Cone
10 20 30 40

Undrained Shear Strength (kPa)
○ Unconfined ✚ Field Vane
● Pocket Penetrometer ■ Lab Vane
40 80 120 160

Water Content (%) & Plasticity
PL MC LL
10 20 30
Water level on completion

PID Readings

Well Details



GRAIN SIZE DISTRIBUTION (%) (MIT)
GR SA SI CL

END OF BOREHOLE

Unstabilized water level at 11.2 m below ground surface; borehole was open upon completion.

50 mm monitoring well installed.
No. 10 screen installed.

WATER LEVEL MONITORING

Date	Depth (m)	Elevation (m)
Jul 31, 2018	11.4	166.8

library: general - library.glb report: gen log v1 file: law quarry extension 2018 drilling.gpj

LOG OF BOREHOLE MW12-II

project | Law Quarry Extension
project no. | 111-53023-06
client | Waterford Sand & Gravel Ltd.
rig type | CME 75, track-mounted
date started | 2018/07/09
location | Wainfleet, ON
method | Rock coring
supervisor | CS
position | E: 637913 N: 4750138 (17T, Geodetic)
coring | HQ core, OD=96mm, ID=64mm
reviewer | KJF

Depth Scale (m)	Elev Depth (m)	STRATIGRAPHY	Graphic Plot	Number	Type	SPT N-Value / Core Recovery	Elevation Scale (mASL)	Well Details	Lab Data and Comments
0	184.4	**GROUND SURFACE**							
		SILTY SAND Light brown, some angular gravel, dry, loose.		1	GS		184		
1	183.6 0.8	**BOIS BLANC FORMATION** Dolostone, light grey to brown grey, weathered, fine grained to crystalline, thin to medium bedded, hard, trace to some chert, fossiliferous, bioturbated.			R2 C	TCR = **107%** RQD = **40%**			
					C		183		
2					R3	TCR = **81%** RQD = **43%**	182		
	181.8				C				
3		...Hydrocarbon odour and bitumen present from 3.45 m to 3.5 m and 5.18 m and 5.25 m.			R4	TCR = **105%** RQD = **69%**	181		
4	180.3				C		180		
5					R5	TCR = **98%** RQD = **84%**	179		Bentonite grout
	178.8	...Highly fossiliferous from 5.59 m to 5.63 m.			C				
6					R6	TCR = **100%** RQD = **81%**	178		
7	177.2				C		177		
	176.9 7.5	**BOIS BLANC FORMATION, SPRINGVALE MEMBER** Glauconitic Sandstone, green to grey, mottled, medium grained, trace to some chert nodules, some thin wavy laminations.			R7	TCR = **100%** RQD = **90%**	176		
9	175.7				C				
	175.2 9.2	**BERTIE FORMATION, AKRON MEMBER** Dolostone, grey, fine crystalline to fine grained, thin to medium bedded, occasional shale partings, some chert nodules, chonchoidal fracturing.			R8	TCR = **102%** RQD = **66%**	175		
	174.2								

Penetration Test Values (Blows / 0.3m)
× Dynamic Cone
10 20 30 40

Undrained Shear Strength (kPa)
○ Unconfined ✚ Field Vane
● Pocket Penetrometer ■ Lab Vane
40 80 120 160

Water Content (%) & Plasticity
PL MC LL
10 20 30

PID Readings

GRAIN SIZE DISTRIBUTION (%) (MIT)
GR SA SI CL

(continued next page)

Sheet No. 1 of 3

LOG OF BOREHOLE MW12-II

project | Law Quarry Extension
project no. | 111-53023-06
client | Waterford Sand & Gravel Ltd.
rig type | CME 75, track-mounted
date started | 2018/07/09
location | Wainfleet, ON
method | Rock coring
supervisor | CS
position | E: 637913 N: 4750138 (17T, Geodetic)
coring | HQ core, OD=96mm, ID=64mm
reviewer | KJF

SUBSURFACE PROFILE

Depth Scale (m)	Elev Depth (m)	STRATIGRAPHY *(continued)*
10	174.2	**BERTIE FORMATION, AKRON MEMBER** Dolostone, grey, fine crystalline to fine grained, thin to medium bedded, occasional shale partings, some chert nodules, chonchoidal fracturing. *(continued)* ...Vug with pyrite mineralization at 10.92 m.
11		
	172.7	
12		
	171.5 12.9	**BERTIE FORMATION, WILLIAMSVILLE MEMBER** Dolostone, medium grey, fine to medium grained, trace shale partings.
13	171.1	
	170.7 13.7	**BERTIE FORMATION, SCAJAQUADA MEMBER** Argillaceous dolostone, medium to dark grey, fine grained, thinly bedded, laminated, some shaly laminations increasing with depth.
14	169.7	
15		
16	168.2	
	167.4 17.0	**BERTIE FORMATION, FALKIRK MEMBER** Dolostone, brown to grey, medium grained, medium bedded, occasional shaly laminations, locally vuggy, some pyrite mineralization and calcite nodules.
17	166.7	
18		
19	165.1	
	163.6	

SAMPLE

Number	Type	SPT N-Value / Core Recovery
	R8	
	C	
	R9	TCR = **102%** RQD = **93%**
	C	
	R10	TCR = **100%** RQD = **100%**
	C	
	R11	TCR = **102%** RQD = **90%**
	C	
	R12	TCR = **102%** RQD = **96%**
	C	
	R13	TCR = **100%** RQD = **91%**
	C	
	R14	TCR = **102%** RQD = **102%**
	C R15	TCR = **98%** RQD = **98%**

Elevation Scale (mASL): 174, 173, 172, 171, 170, 169, 168, 167, 166, 165

Penetration Test Values (Blows / 0.3m)
× Dynamic Cone
10 20 30 40

Undrained Shear Strength (kPa)
○ Unconfined
✚ Field Vane
● Pocket Penetrometer
■ Lab Vane
40 80 120 160

Water Content (%) & Plasticity
PL MC LL
10 20 30

PID Readings

Well Details

▼

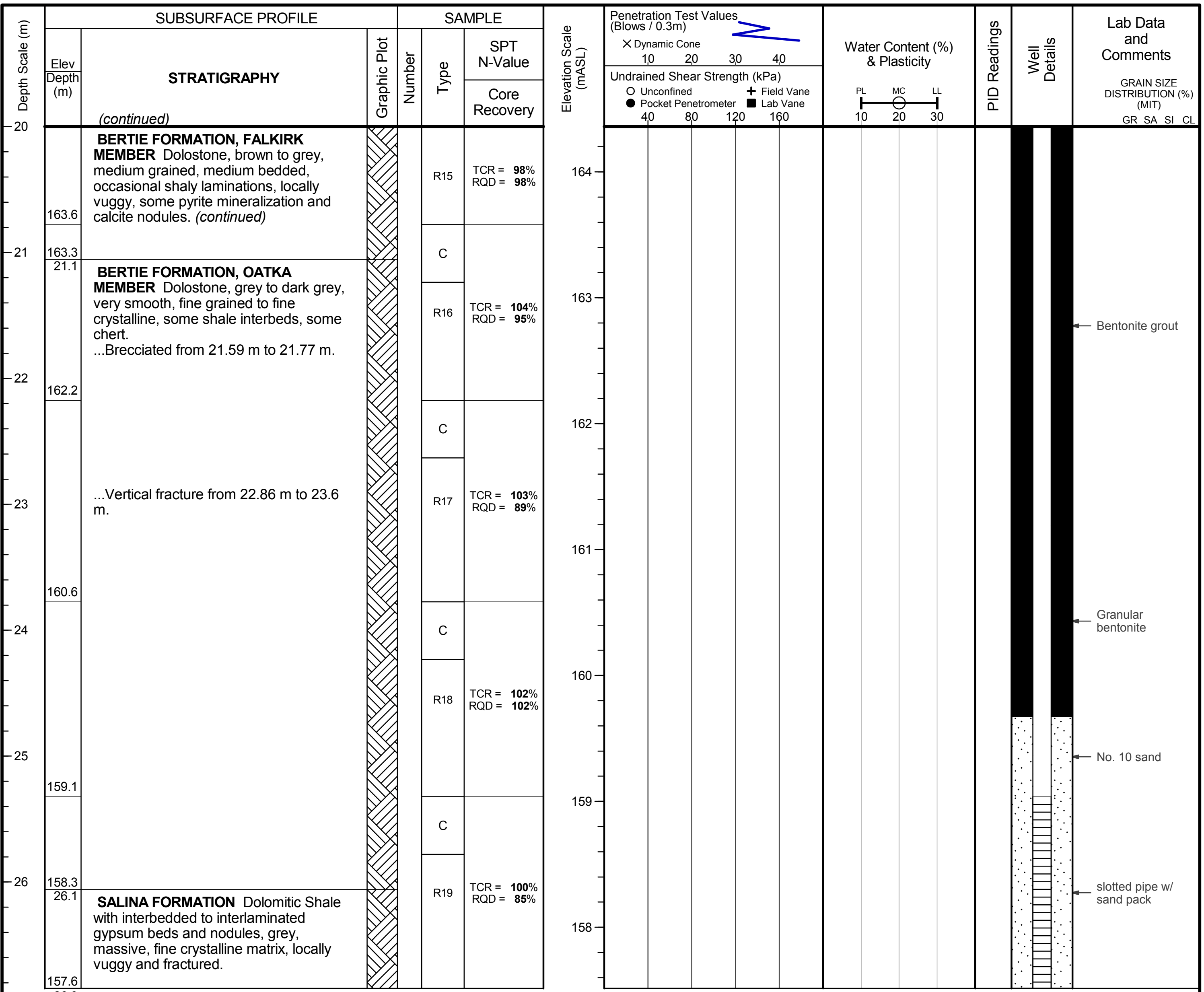
← Bentonite grout

Lab Data and Comments
GRAIN SIZE DISTRIBUTION (%) (MIT)
GR SA SI CL

(continued next page)

LOG OF BOREHOLE MW12-II

project | Law Quarry Extension
project no. | 111-53023-06
client | Waterford Sand & Gravel Ltd.
rig type | CME 75, track-mounted
date started | 2018/07/09
location | Wainfleet, ON
method | Rock coring
supervisor | CS
position | E: 637913 N: 4750138 (17T, Geodetic)
coring | HQ core, OD=96mm, ID=64mm
reviewer | KJF



(continued)

Elev / Depth (m)	STRATIGRAPHY
163.6	**BERTIE FORMATION, FALKIRK MEMBER** Dolostone, brown to grey, medium grained, medium bedded, occasional shaly laminations, locally vuggy, some pyrite mineralization and calcite nodules. *(continued)*
163.3 21.1	**BERTIE FORMATION, OATKA MEMBER** Dolostone, grey to dark grey, very smooth, fine grained to fine crystalline, some shale interbeds, some chert. ...Brecciated from 21.59 m to 21.77 m.
162.2	
	...Vertical fracture from 22.86 m to 23.6 m.
160.6	
159.1	
158.3 26.1	**SALINA FORMATION** Dolomitic Shale with interbedded to interlaminated gypsum beds and nodules, grey, massive, fine crystalline matrix, locally vuggy and fractured.
157.6 26.9	

Type	Core Recovery
R15	TCR = **98%** RQD = **98%**
C	
R16	TCR = **104%** RQD = **95%**
C	
R17	TCR = **103%** RQD = **89%**
C	
R18	TCR = **102%** RQD = **102%**
C	
R19	TCR = **100%** RQD = **85%**

END OF BOREHOLE

Borehole was open upon completion.
Water level was not measured upon completion.

50 mm monitoring well installed.
No. 10 screen installed.

WATER LEVEL MONITORING

Date	Depth (m)	Elevation (m)
Jul 12, 2018	14.8	169.6

LOG OF BOREHOLE MW12-III

project | Law Quarry Extension
project no. | 111-53023-06
client | Waterford Sand & Gravel Ltd.
rig type | CME 75, track-mounted
date started | 2018/07/11
location | Wainfleet, ON
method | Rock coring
supervisor | CS
position | E: 637914 N: 4750138 (17T, Geodetic)
coring | HQ core, OD=96mm, ID=64mm
reviewer | KJF

SUBSURFACE PROFILE

Elev Depth (m)	STRATIGRAPHY
184.4	**GROUND SURFACE**
	SILTY SAND Light brown, some angular gravel, dry, loose.
183.6 0.8	**BOIS BLANC FORMATION** Dolostone, light grey to brown grey, weathered, fine grained to crystalline, thin to medium bedded, hard, trace to some chert, fossiliferous, bioturbated.
181.8	
	...Hydrocarbon odour and bitumen present from 3.45 m to 3.5 m and 5.18 m and 5.25 m.
180.3	
178.8	...Highly fossiliferous from 5.59 m to 5.63 m.
177.2	
176.9 7.5	**BOIS BLANC FORMATION, SPRINGVALE MEMBER** Glauconitic Sandstone, green to grey, mottled, medium grained, trace to some chert nodules, some thin wavy laminations.
175.7	
175.2 9.2	**BERTIE FORMATION, AKRON MEMBER** Dolostone, grey, fine crystalline to fine grained, thin to medium bedded, occasional shale partings, some chert nodules, chonchoidal fracturing.
174.2	

SAMPLE

Number	Type	SPT N-Value / Core Recovery
	R2 C	TCR = **107%** RQD = **40%**
	C	
	R3	TCR = **81%** RQD = **43%**
	C	
	R4	TCR = **105%** RQD = **69%**
	C	
	R5	TCR = **98%** RQD = **84%**
	C	
	R6	TCR = **100%** RQD = **81%**
	C	
	R7	TCR = **100%** RQD = **90%**
	C	
	R8	TCR = **102%** RQD = **66%**

Depth Scale (m): 0, 1, 2, 3, 4, 5, 6, 7, 8, 9

Elevation Scale (mASL): 184, 183, 182, 181, 180, 179, 178, 177, 176, 175

Penetration Test Values (Blows / 0.3m)
× Dynamic Cone
10 20 30 40

Undrained Shear Strength (kPa)
○ Unconfined + Field Vane
● Pocket Penetrometer ■ Lab Vane
40 80 120 160

Water Content (%) & Plasticity
PL MC LL
10 20 30

PID Readings

Well Details

Lab Data and Comments
GRAIN SIZE DISTRIBUTION (%) (MIT)
GR SA SI CL

Bentonite grout

(continued next page)

LOG OF BOREHOLE MW12-III

project | Law Quarry Extension
project no. | 111-53023-06
client | Waterford Sand & Gravel Ltd.
rig type | CME 75, track-mounted
date started | 2018/07/11
location | Wainfleet, ON
method | Rock coring
supervisor | CS
position | E: 637914 N: 4750138 (17T, Geodetic)
coring | HQ core, OD=96mm, ID=64mm
reviewer | KJF

Depth Scale (m)	Elev Depth (m)	SUBSURFACE PROFILE – STRATIGRAPHY *(continued)*	SAMPLE Number	SAMPLE Type	SPT N-Value / Core Recovery	Elevation Scale (mASL)
10	174.2	**BERTIE FORMATION, AKRON MEMBER** Dolostone, grey, fine crystalline to fine grained, thin to medium bedded, occasional shale partings, some chert nodules, chonchoidal fracturing. *(continued)*		R8		
				C		174
11		...Vug with pyrite mineralization at 10.92 m.		R9	TCR = **102%** RQD = **93%**	173
	172.7					
12				C		
				R10	TCR = **100%** RQD = **100%**	172
	171.5					
13	12.9 171.1	**BERTIE FORMATION, WILLIAMSVILLE MEMBER** Dolostone, medium grey, fine to medium grained, trace shale partings.		C		171
	170.7 13.7	**BERTIE FORMATION, SCAJAQUADA MEMBER** Argillaceous dolostone, medium to dark grey, fine grained, thinly bedded, laminated, some shaly laminations increasing with depth.				
14				R11	TCR = **102%** RQD = **90%**	170
	169.7					
15				C		
				R12	TCR = **102%** RQD = **96%**	169
16	168.2					
				C		168
17	167.4 17.0	**BERTIE FORMATION, FALKIRK MEMBER** Dolostone, brown to grey, medium grained, medium bedded, occasional shaly laminations, locally vuggy, some pyrite mineralization and calcite nodules.		R13	TCR = **100%** RQD = **91%**	167
	166.7					
18				C		
				R14	TCR = **102%** RQD = **102%**	166
19	165.1					
				C R15	TCR = **100%** RQD = **100%**	165
	163.7					

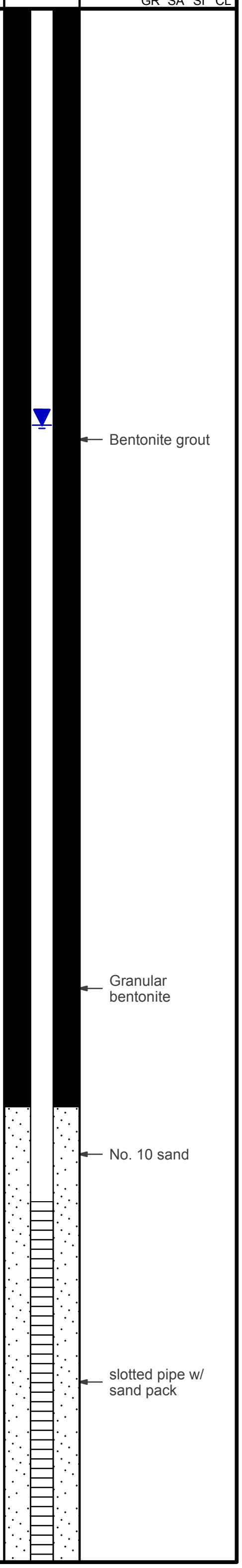
Penetration Test Values (Blows / 0.3m)
× Dynamic Cone
10 20 30 40

Undrained Shear Strength (kPa)
○ Unconfined + Field Vane
● Pocket Penetrometer ■ Lab Vane
40 80 120 160

Water Content (%) & Plasticity
PL MC LL
10 20 30

PID Readings

Well Details

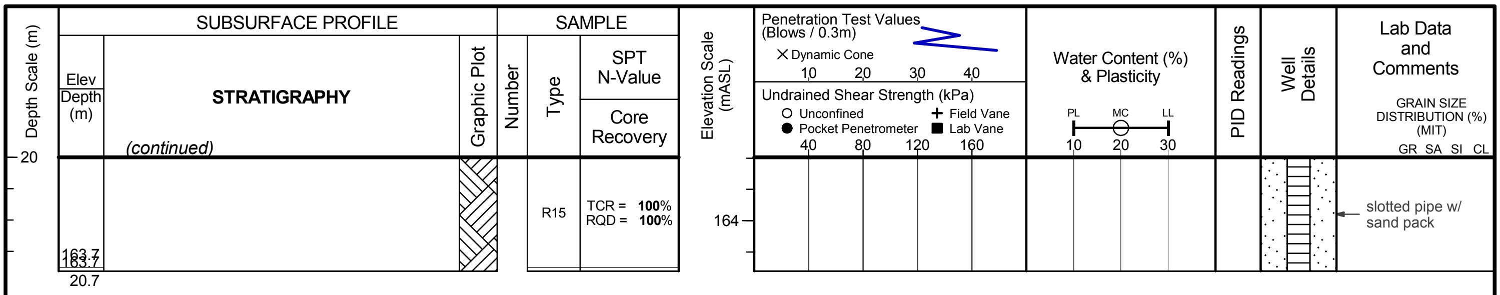


Lab Data and Comments
GRAIN SIZE DISTRIBUTION (%) (MIT)
GR SA SI CL

(continued next page)

LOG OF BOREHOLE MW12-III

project | Law Quarry Extension
project no. | 111-53023-06
client | Waterford Sand & Gravel Ltd.
rig type | CME 75, track-mounted
date started | 2018/07/11
location | Wainfleet, ON
method | Rock coring
supervisor | CS
position | E: 637914 N: 4750138 (17T, Geodetic)
coring | HQ core, OD=96mm, ID=64mm
reviewer | KJF



END OF BOREHOLE

Borehole was open upon completion.
Water level was not measured upon completion.

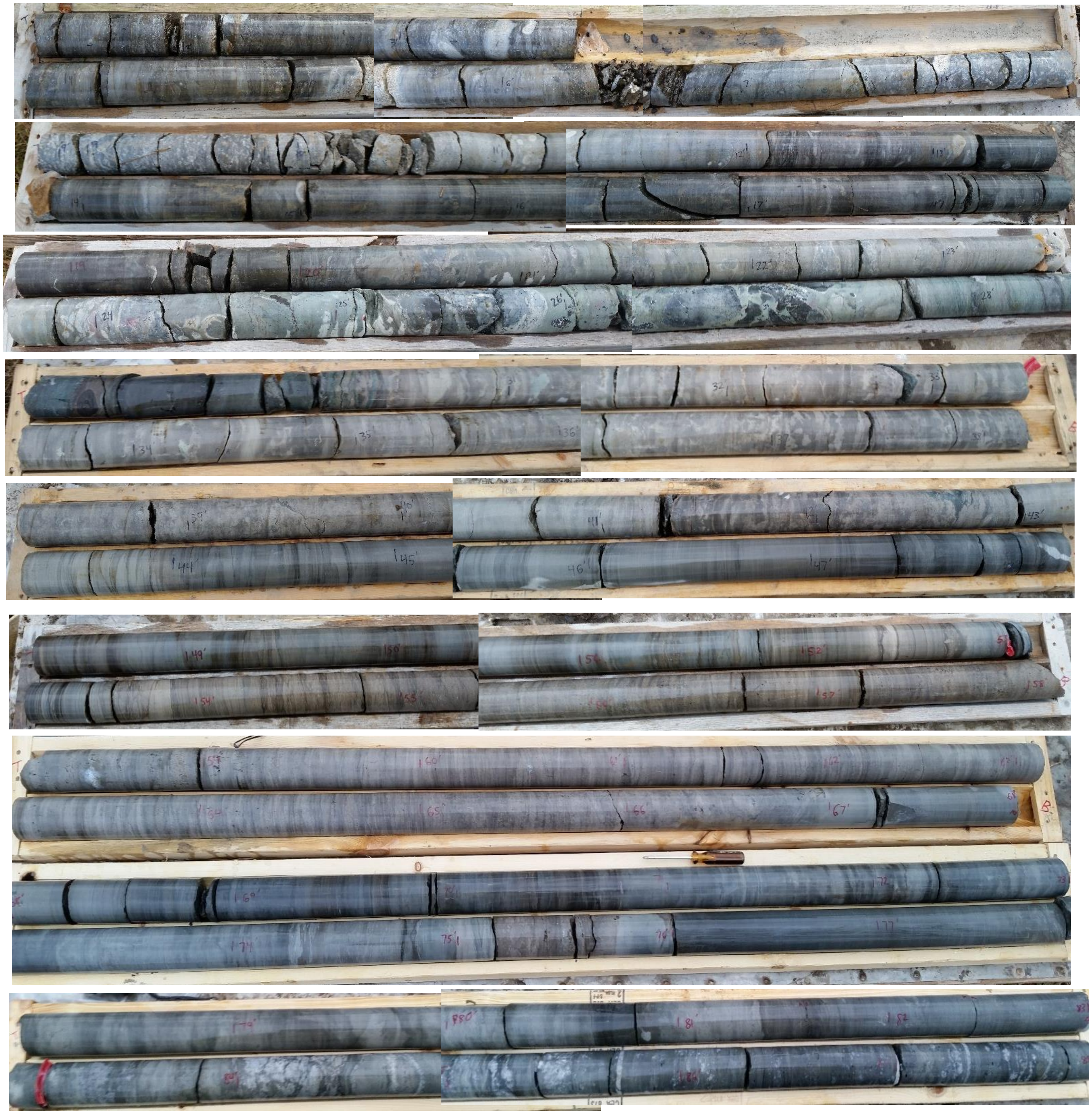
50 mm monitoring well installed.
No. 10 screen installed.

WATER LEVEL MONITORING

Date	Depth (m)	Elevation (m)
Jul 12, 2018	12.7	171.7

BH1

BH4



BH5

BH6


9
110'
11
12'
13'2"
113'
14
15'
16'
17'
18'
18'11"
19'
120'
121'
22'
23'2"
23'
125'
126'
128
131'
134
135'
136'
137'
138'
139'
140'
141'
142
143
44
45
146
147
47'10"
148
49
49'3"
52'10"
150
151
152
53
155
156
157
57'3"
158
159
160
161
62

BH9


8'
9'
10'
11'
12'
13'
14'
15'
16'
17'
18'
19'
20'
21'
23'
24'
25'
26'
28'
29'
30'
31'
32'
33'
34'
35'
36'
37'
38'
39'
40'
41'
142'
43'
44'
45'
46'
47'
48'
49'
50'
51'
52'
53'
54'
55'
56'
57'
58'
59'
60'
61'
62'
63'
64'
65'
66'
67'
68'
69'
70'
71'
72'

BH10


168'
169'
170'
171'
172'
173'
174'
175'
176'
177'
178'
179'
180'
181'
182'
183'
184'
185'
187'
188'
189'
190'
193'

BH11


8'
10'
11'
12'
13'
14'
15'
19'
20'
21'
23'
25'
26'
27'
28'
29'
30'
31'
33'
34'
36'
37'
38'
39'
42'
43'
49'
50'
51'
53'
54'
60'
64'
65'
66'
71'
72'
73'
74'

BH12


112'
113'
114'
115'
116'
17'
18'
119'
120'


121'
122'
123'
124'
25'
126'
127'
128'
29'
130'


31'
32'
133'
134'
135'
136'
137'
138'
139'


140'
141'
142'
143'
44'
145'
146'
147'
148


149'
150'
151'
152'
153
154'
155'
156'
157'
58

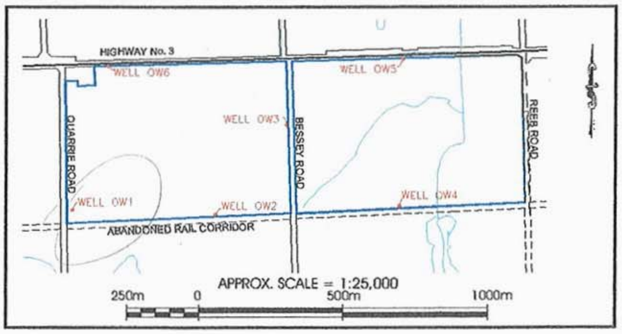

159'
160'
161
162'
163'
164'
165'
166'


167'
168'
69'
70'
171'
72'
173'
174'
75'


176'
177'
178'
179'
180'
181'
82'
183'
184'
185
186'
87
188'

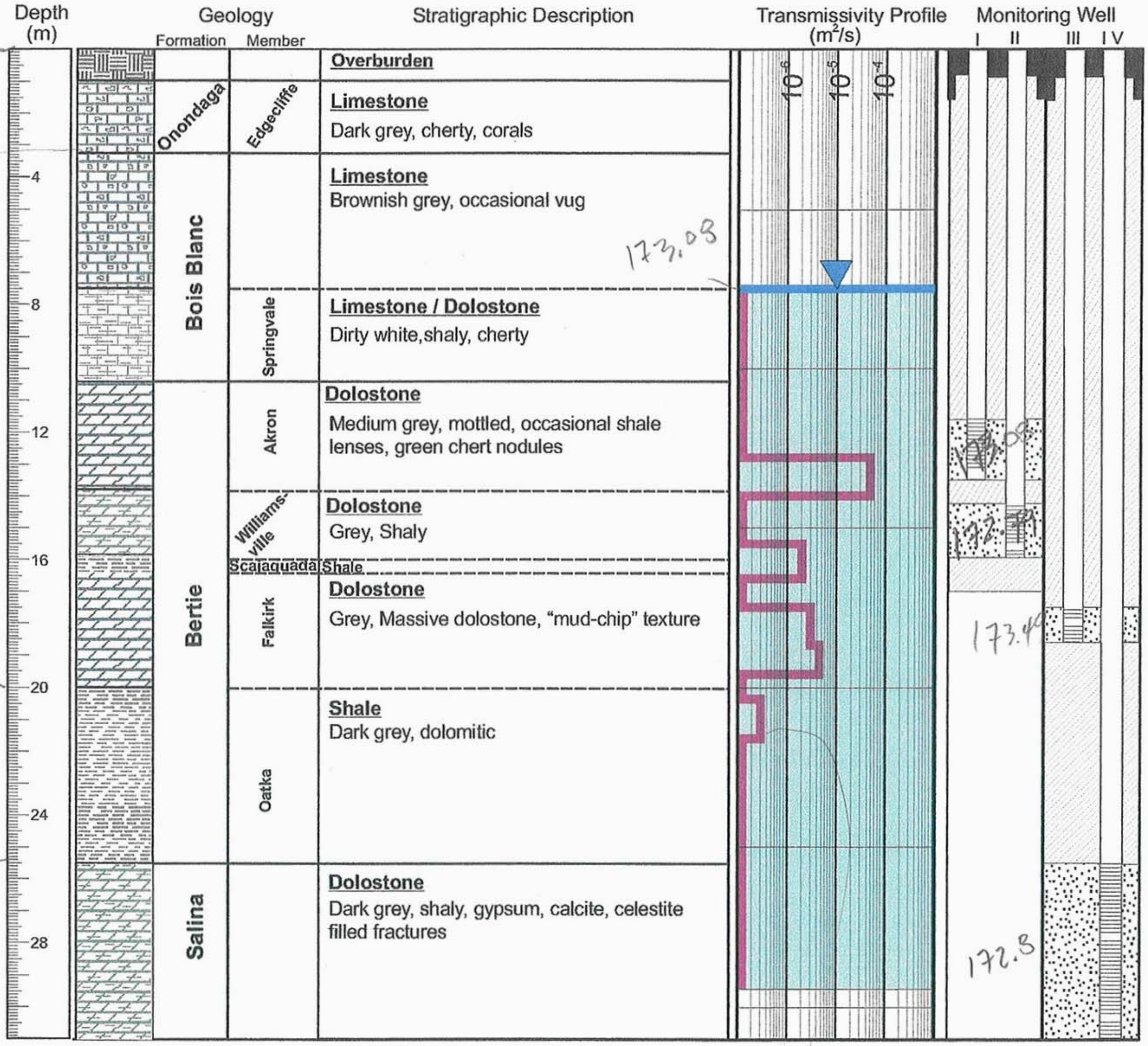
Drill Date: Feb/2004
Drilling Method: Continuous Core
Driller: Lantech Drilling
Geologist: TLW

Need Elev Data!



180.72 masl

177.52



10^{-3} cm/s

20 to 25.4m

Δ = 5.4

Elev data from Nov 15/04

2.5×10^{-5} cm/s

NOTES:
These borehole logs are not intended for detailed interpretation.
Borehole logs are provided as a summary of field data
For a detailed description of the geological units refer to Section 4.4 of the report
Information on well construction details refer to Appendix A: Methodology
Information on stratigraphic contacts refer to Appendix C: Borehole Geophysics
Information on transmissivity profiles refer to Appendix D: Packer Testing Data

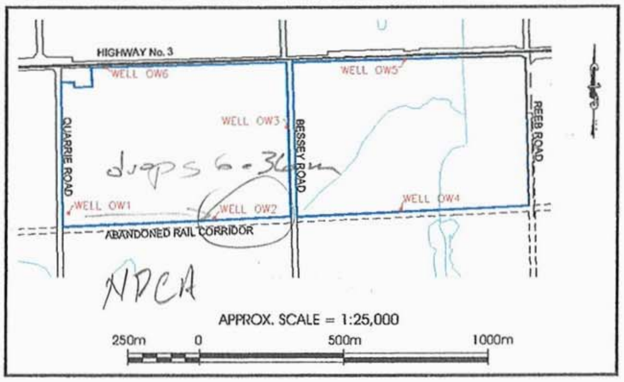
AZIMUTH ENVIRONMENTAL CONSULTING, INC.

Observation Well Nest 1

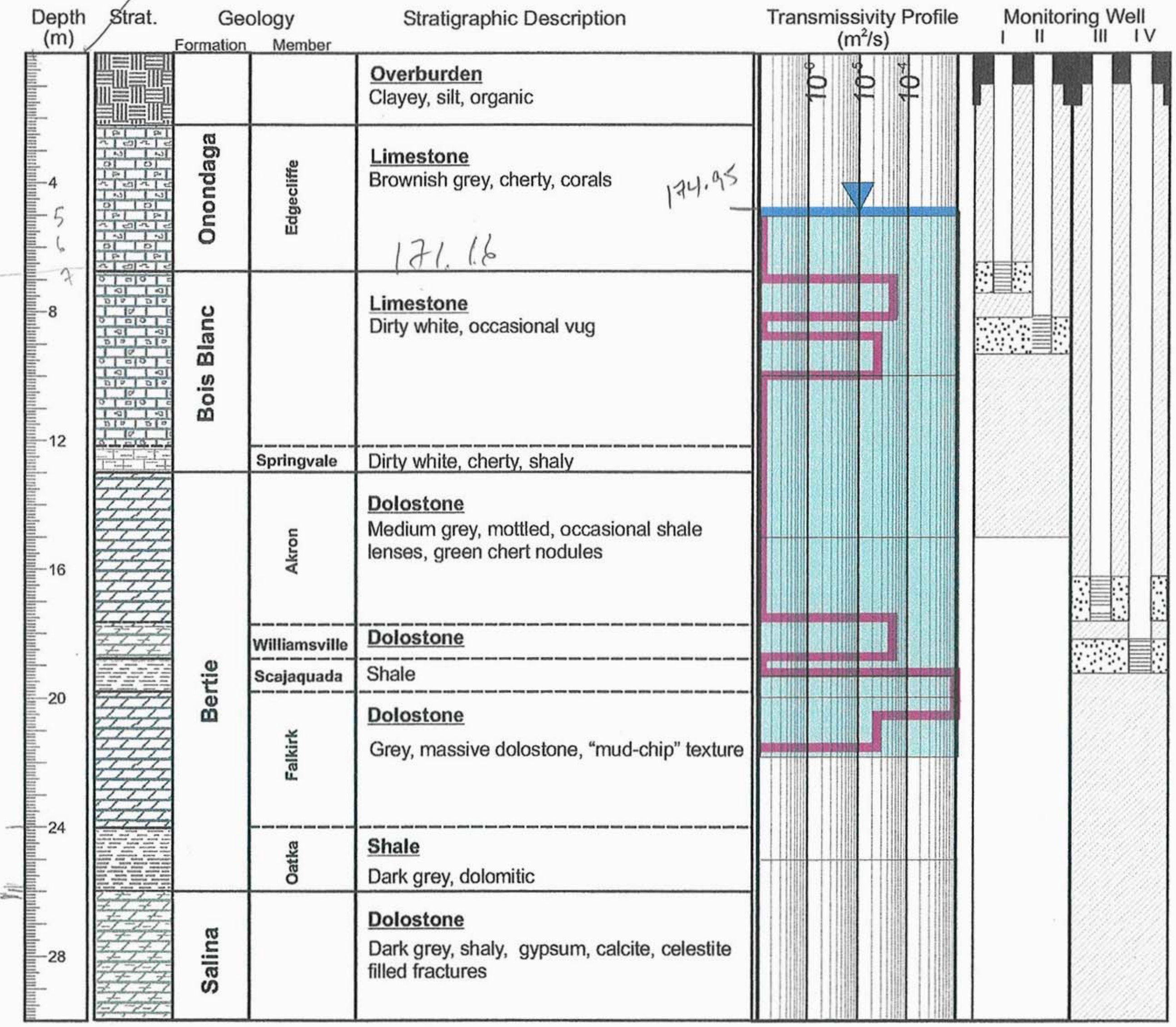
Date Issued:	Oct 29, 2004
Geologist:	TLW
Project No.	04-025
File Name:	OW1.cdr

Reeb Quarry
Hydrogeological Assessment

Drill Date: Feb/2004
Drilling Method: Continuous Core
Driller: Lantech Drilling
Geologist: TLW



177.96



Overburden
Clayey, silt, organic

Limestone
Brownish grey, cherty, corals

Limestone
Dirty white, occasional vug

Dirty white, cherty, shaly

Dolostone
Medium grey, mottled, occasional shale lenses, green chert nodules

Dolostone

Shale

Dolostone
Grey, massive dolostone, "mud-chip" texture

Shale
Dark grey, dolomitic

Dolostone
Dark grey, shaly, gypsum, calcite, celestite filled fractures

gypsum vein - See App C - borehole geophys

10⁻³ cm/s

Δ ≈ 2 m

NOTES:
These borehole logs are not intended for detailed interpretation.
Borehole logs are provided as a summary of field data
For a detailed description of the geological units refer to Section 4.4 of the report
Information on well construction details refer to Appendix A: Methodology
Information on stratigraphic contacts refer to Appendix C: Borehole Geophysics
Information on transmissivity profiles refer to Appendix D: Packer Testing Data

AZIMUTH ENVIRONMENTAL CONSULTING, INC.

Observation Well Nest 2

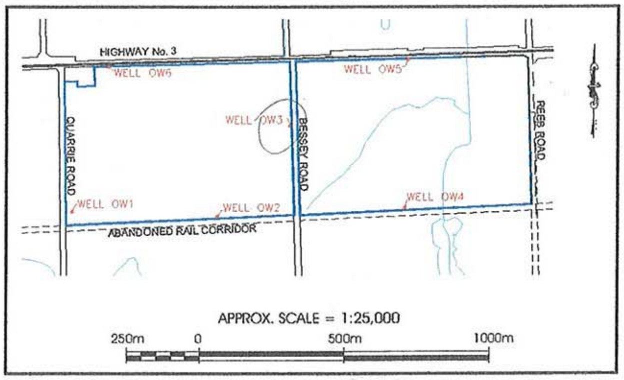
Date Issued:	Oct 29, 2004
Geologist:	TLW
Project No.	04-025
File Name:	OW2.cdr

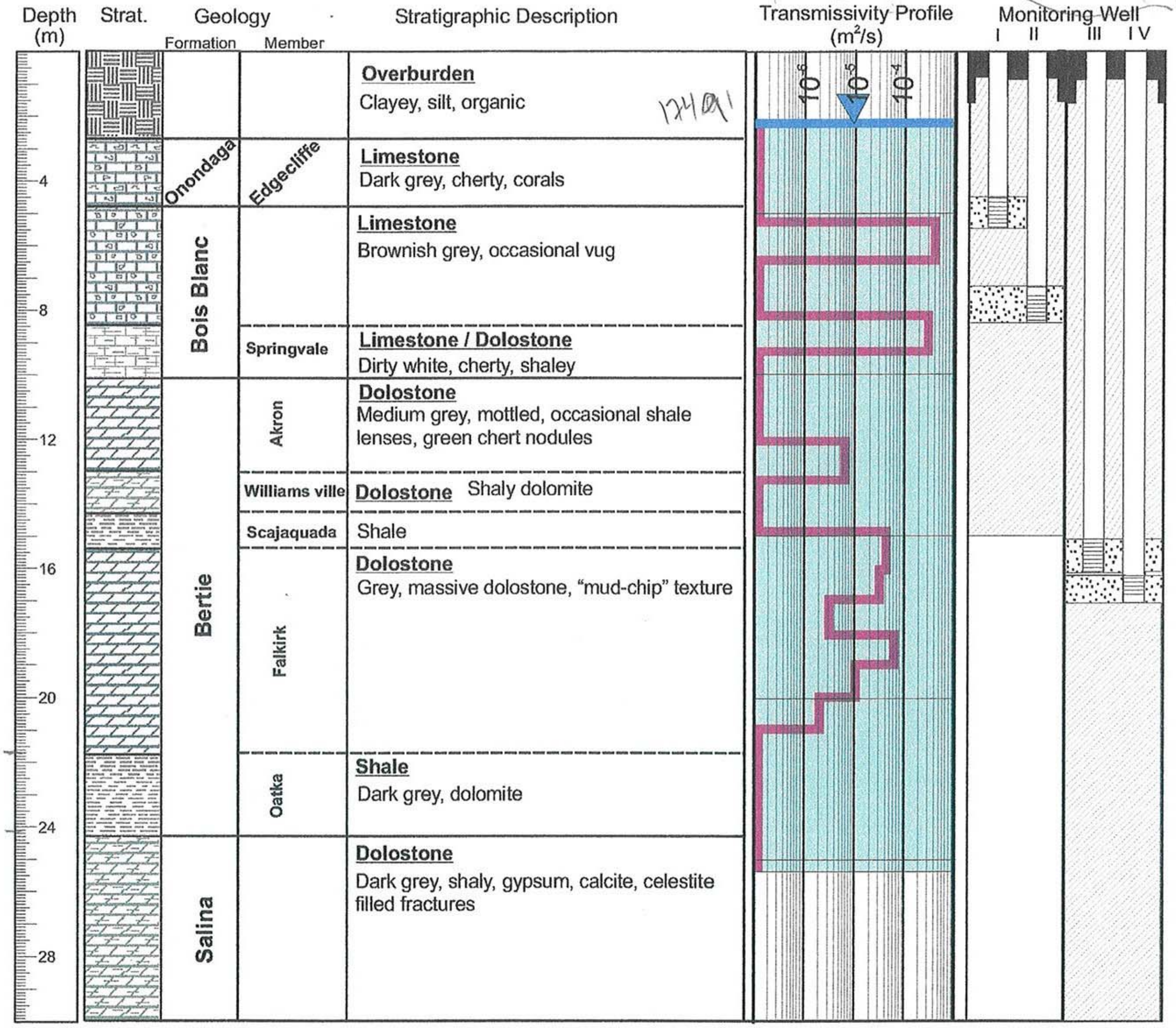
Reeb Quarry
Hydrogeological Assessment

Oatka thin - 2 m only

N/A

Drill Date: Feb/2004
Drilling Method: Continuous Core
Driller: Lantech Drilling
Geologist: TLW





174.9'

21.6

24.2

Δ=2.6

NOTES:
These borehole logs are not intended for detailed interpretation.
Borehole logs are provided as a summary of field data
For a detailed description of the geological units refer to Section 4.4 of the report
Information on well construction details refer to Appendix A: Methodology
Information on stratigraphic contacts refer to Appendix C: Borehole Geophysics
Information on transmissivity profiles refer to Appendix D: Packer Testing Data

AZIMUTH ENVIRONMENTAL CONSULTING, INC.

Observation Well Nest 3

Date Issued:	Oct 29, 2004
Geologist:	TLW
Project No.	04-025
File Name:	Ow3.cdr

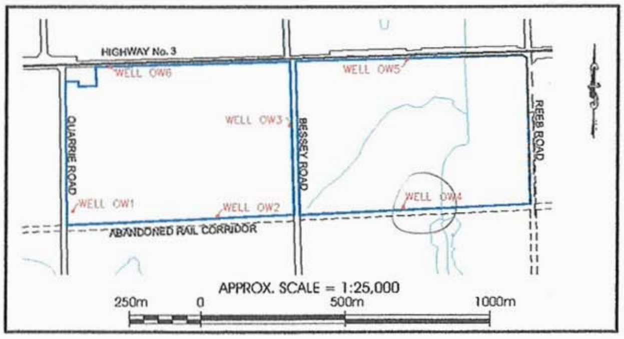
Reeb Quarry
Hydrogeological Assessment

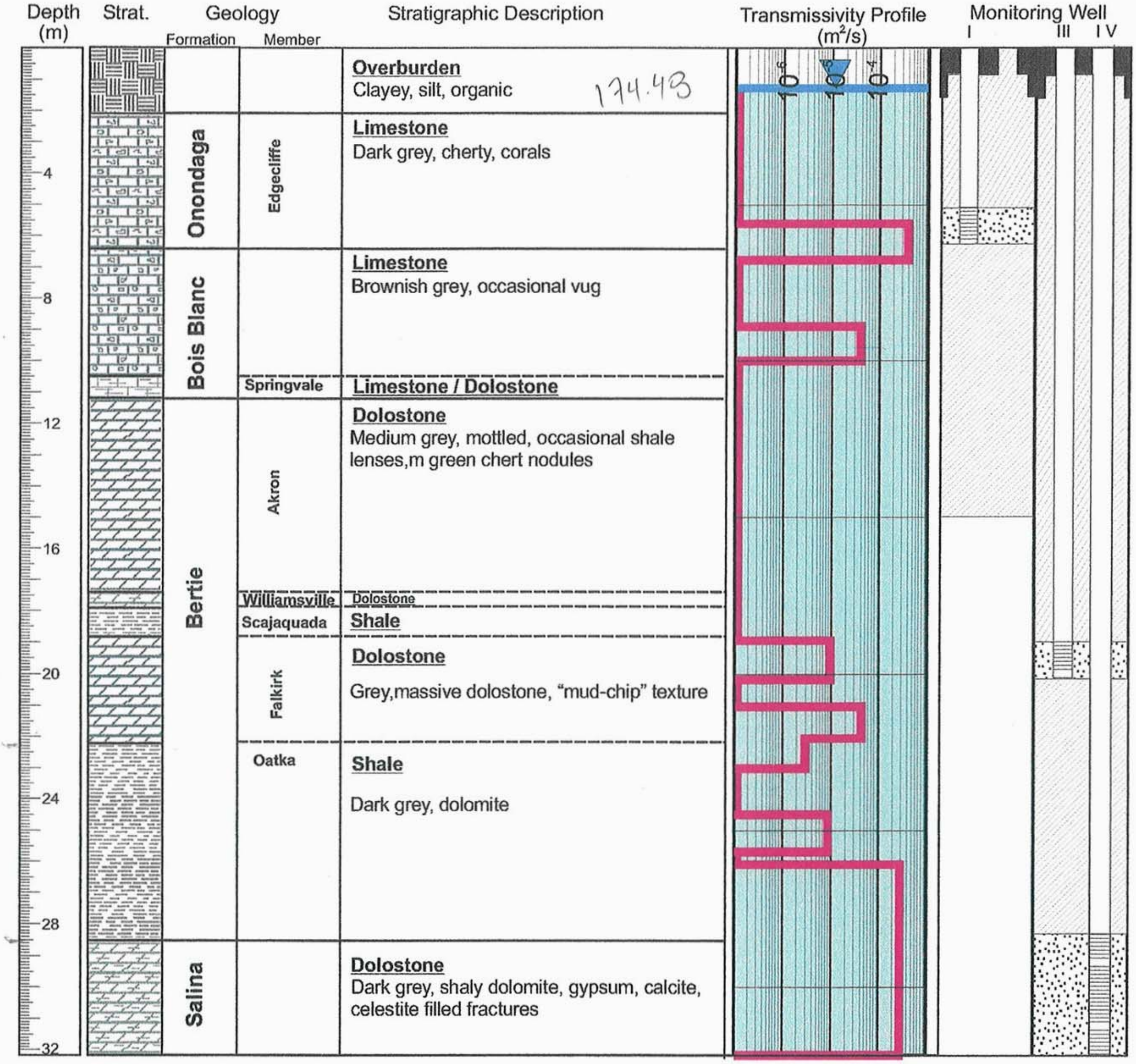
24.2
21.6
2.6

Oatka is thin 2.6 m

1×10⁻⁷ m²/s

Drill Date: Feb/2004
Drilling Method: Continuous Core
Driller: Lantech Drilling
Geologist: TLW





NOTES:
These borehole logs are not intended for detailed interpretation.
Borehole logs are provided as a summary of field data
For a detailed description of the geological units refer to Section 4.4 of the report
Information on well construction details refer to Appendix A: Methodology
Information on stratigraphic contacts refer to Appendix C: Borehole Geophysics
Information on transmissivity profiles refer to Appendix D: Packer Testing Data

Appendix D

AZIMUTH ENVIRONMENTAL CONSULTING, INC.

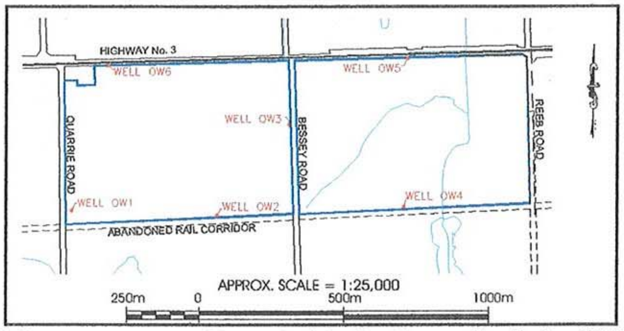
Observation Well Nest 4

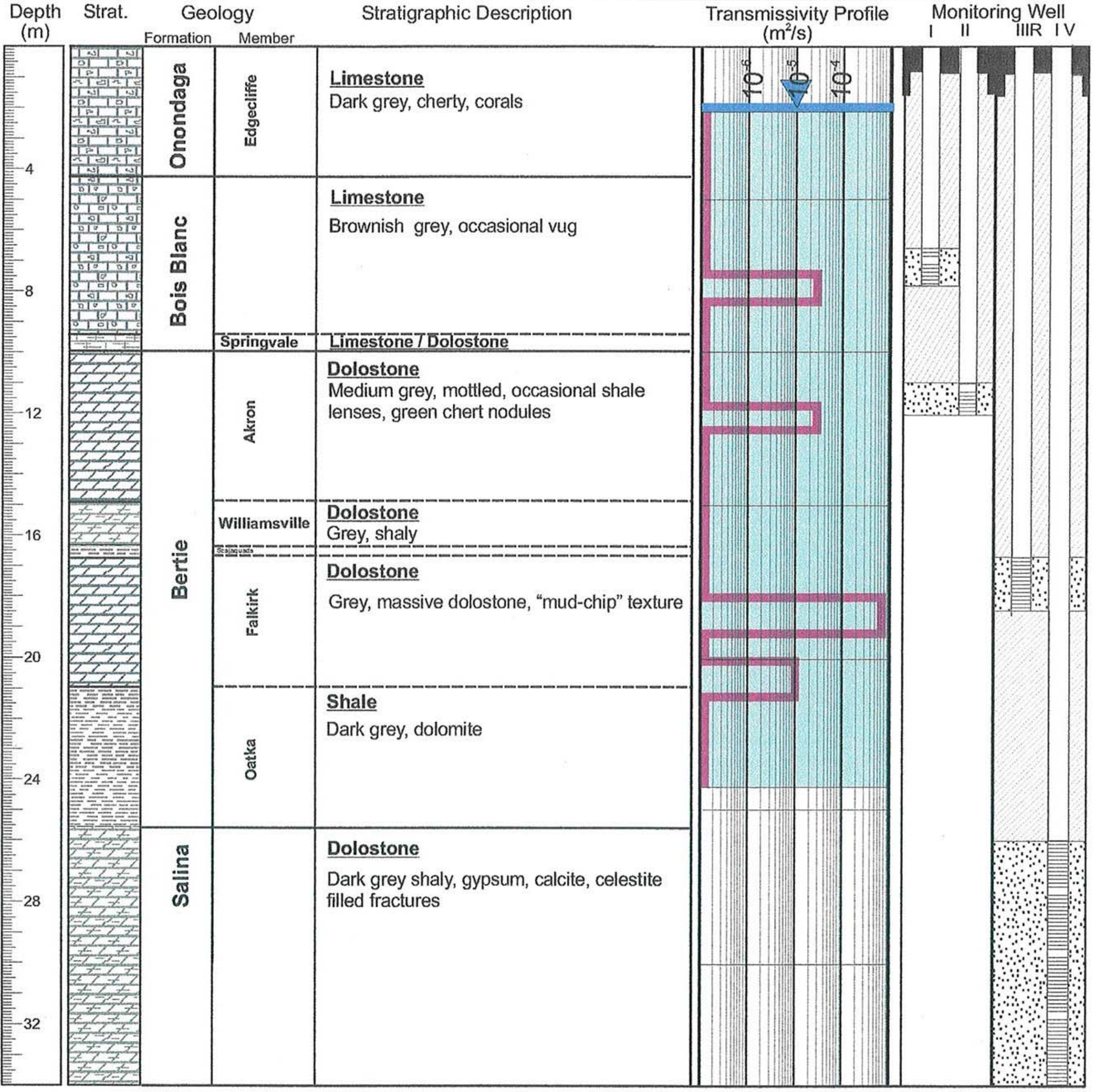
Date Issued:	Oct 29, 2004
Geologist:	TLW
Project No.	04-025
File Name:	OW4.cdr

Reeb Quarry
Hydrogeological Assessment

pg 19
High K zones Oatka = 2.1×10^{-3} cm/sec / 2.1×10^{-3} to 1×10^{-6} m²/s
2.5×10^{-2} cm/sec / 2.5×10^{-2} to 8.3×10^{-5} cm/s

Drill Date: Feb/2004
Drilling Method: Continuous Core
Driller: Lantech Drilling
Geologist: TLW





Formation	Member	Stratigraphic Description
Onondaga	Edgecliffe	**Limestone** Dark grey, cherty, corals
Bois Blanc		**Limestone** Brownish grey, occasional vug
	Springvale	**Limestone / Dolostone**
Bertie	Akron	**Dolostone** Medium grey, mottled, occasional shale lenses, green chert nodules
	Williamsville	**Dolostone** Grey, shaly
	Scajaquada	
	Falkirk	**Dolostone** Grey, massive dolostone, "mud-chip" texture
	Oatka	**Shale** Dark grey, dolomite
Salina		**Dolostone** Dark grey shaly, gypsum, calcite, celestite filled fractures

20.9

25.5

25.5
20.9
4.6

NOTES:
These borehole logs are not intended for detailed interpretation.
Borehole logs are provided as a summary of field data
For a detailed description of the geological units refer to Section 4.4 of the report
Information on well construction details refer to Appendix A: Methodology
Information on stratigraphic contacts refer to Appendix C: Borehole Geophysics
Information on transmissivity profiles refer to Appendix D: Packer Testing Data

AZIMUTH ENVIRONMENTAL CONSULTING, INC.

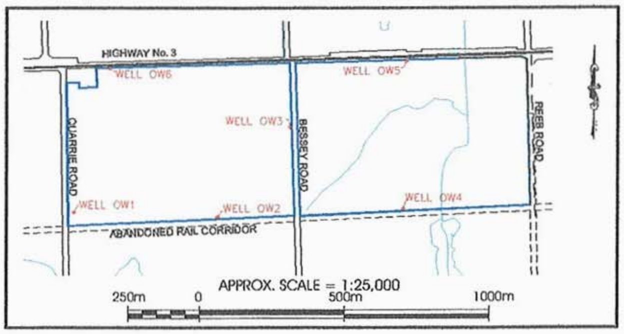
Observation Well Nest 5

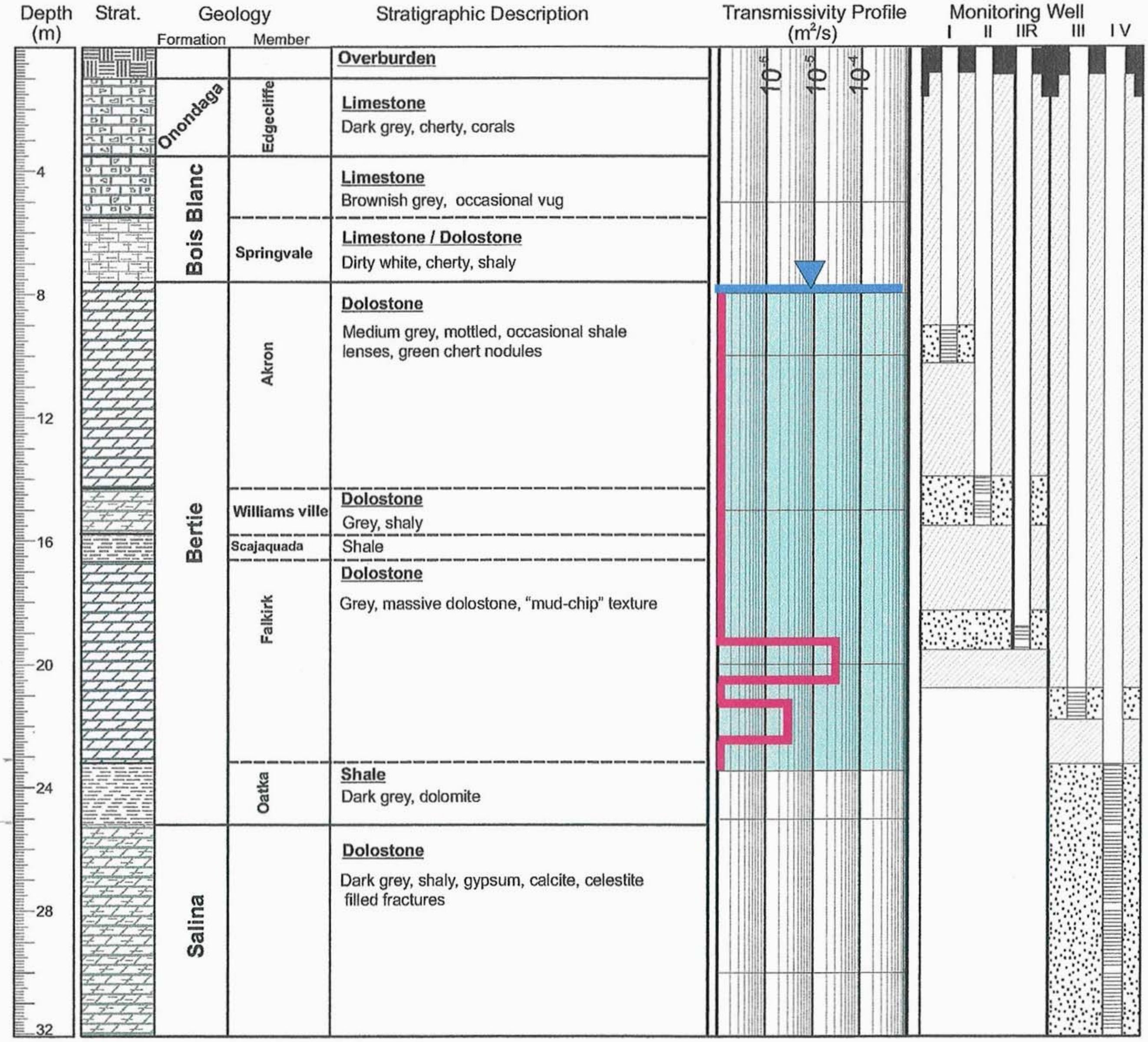
Date Issued:	Oct 29, 2004
Geologist:	TLW
Project No.	04-025
File Name:	Ow5.cdr

Reeb Quarry
Hydrogeological Assessment

Oatka Packer
~ 1x10^{-7} m²/s

Drill Date: Feb/2004
Drilling Method: Continuous Core
Driller: Lantech Drilling
Geologist: TLW





23

25.1

2.1

NOTES:
These borehole logs are not intended for detailed interpretation.
Borehole logs are provided as a summary of field data
For a detailed description of the geological units refer to Section 4.4 of the report
Information on well construction details refer to Appendix A: Methodology
Information on stratigraphic contacts refer to Appendix C: Borehole Geophysics
Information on transmissivity profiles refer to Appendix D: Packer Testing Data

Azimuth Environmental Consulting, Inc.

Observation Well Nest 6

Date Issued:	Oct 29, 2004
Geologist:	TLW
Project No.	04-103
File Name:	OW1-page 1.cdr

Reeb Quarry
Hydrogeological Assessment

Oatka is thin ≈ 2,1 m
see Borehole geophys gypsum vein (~ 0.4 m thick)
between 24.~~4~~ & 24.3 in Oatka!

Oatka Packer = N/A

OW 1-39, 23, 11

CLIENT MacLaren Engineers Inc. FILE NO 670-901
PROJECT Elm St. Landfill LOCATION Port Colborne
GEOLOGIST/ENGINEER T.A.B. DATE COMPLETED SEPTEMBER 5 1990

STRATIGRAPHIC DESCRIPTION

Ground Elevations (m a s l) OW1-11-174 1, OW1-23-174 ? OW1-39-174 7

TOPSOIL: Silty with roots, loose, low cohesion, dark brown, damp, 60 mm layer of light brown silt and 90 mm layer of black organic rich silt

CLAYEY SILT hard, mottled-brown grey, damp becoming moist with depth, laminated with individual laminae 1-2 mm thick, blocky with closely spaced weathering fractures that are oriented in all directions, and whose walls have been altered to a grey colour

SILTY CLAY: Trace fine angular gravel, occasional small (3 mm diameter) pockets of grey sandy silt, very stiff in upper 2.5m of unit, becoming firm to stiff with depth, very cohesive, medium brown coloured with occasional alternating (laminated) red and grey layers, wet to saturated

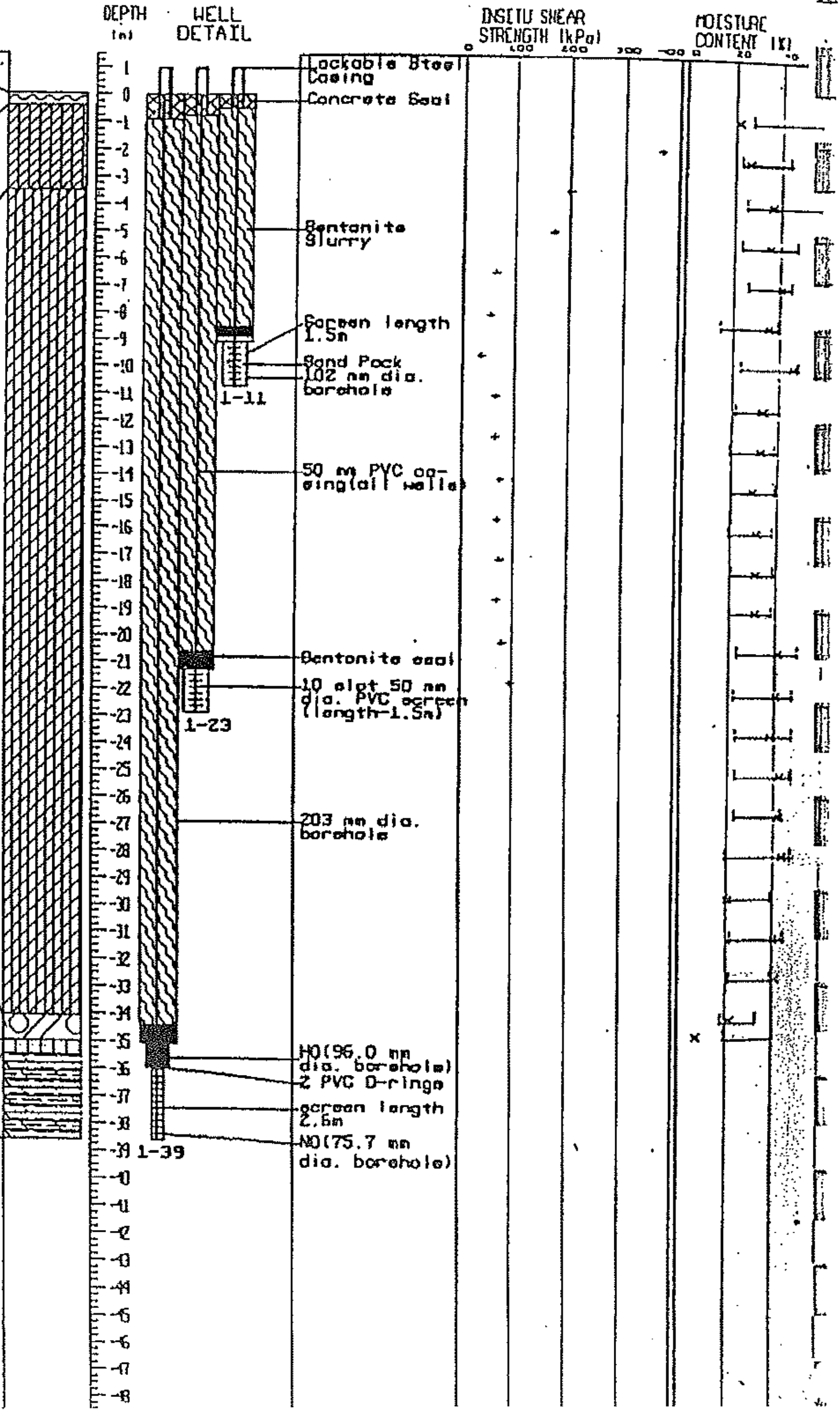
Occasional 0.5-1.0 mm grey silt seams (sometimes fractured) at 0 3 to 1.5m intervals below 27m

GRAVELLY CLAY (Till): with trace silt, sand and cobbles, gravel and cobbles are mostly limestone pieces that are subrounded to angular, some gypsum crystallization noted in soil, stiff to very stiff, brown, moist to wet.

SANDY SILT (Till): with angular to subrounded limestone gravel sizes and trace clay, dense to very dense, dark reddish brown, moist

SHALEY DOLOSTONE very fine-grained, with gypsum; dark grey-brown
CORE RECOVERY-67%

End of hole - 39.6 m b g.l



OW 2-47, 27, 14

CLIENT MacLaren Engineers Inc. FILE NO 670-901
PROJECT Elm St. Landfill LOCATION Port Colborne
GEOLOGIST/ENGINEER I A B DATE COMPLETED SEPTEMBER 13 1990

STRATIGRAPHIC DESCRIPTION

Ground Elevations (m a s l) OW2-14-176 2, OW2-27-176 0, OW2-47-175 9

FILL peat with minor sandy silt, clay, angular to rounded gravel roots and wood fragments, trace metal, loose, dark brown to black, damp to moist

FILL clayey silt with abundant roots, stems and wood fragments, cohesive, brownish-grey, moist

PEAT loose, dark brown, moist to wet

CLAYEY SILT with abundant roots and stems, slightly friable, somewhat cohesive, very soft, greyish-brown, wet to saturated

SILTY CLAY trace fine angular to subangular gravel, occasional small (<3 mm diameter) pockets of grey sandy silt, soft to stiff with depth, very cohesive, grey-brown to medium brown with depth, with occasional sections of alternating (laminated) red and grey layers, wet to saturated

Occasional grey silt seams (approx 1mm thick, and relatively dry) below 30 m

CLAYEY SILT (Till) with sand, trace medium-grained angular to subrounded gravel increasing in abundance with depth, firm to stiff with depth, very cohesive, medium brown, moist to wet

GRAVELLY SILT (Till), with sand, some clay (though clay content decreases to trace quantities with depth) and traces of white powdered gypsum, gravel size ranges from fine to 80 mm diameter; compact to very dense, slightly cohesive, medium to dark red-brown, moist with fine uneven horizontal fractures <10 mm long.
Fine to med. grained sand seams (35.6-~35.9m and 36.0-36.3 m) separated by a layer of laminated clay with silt

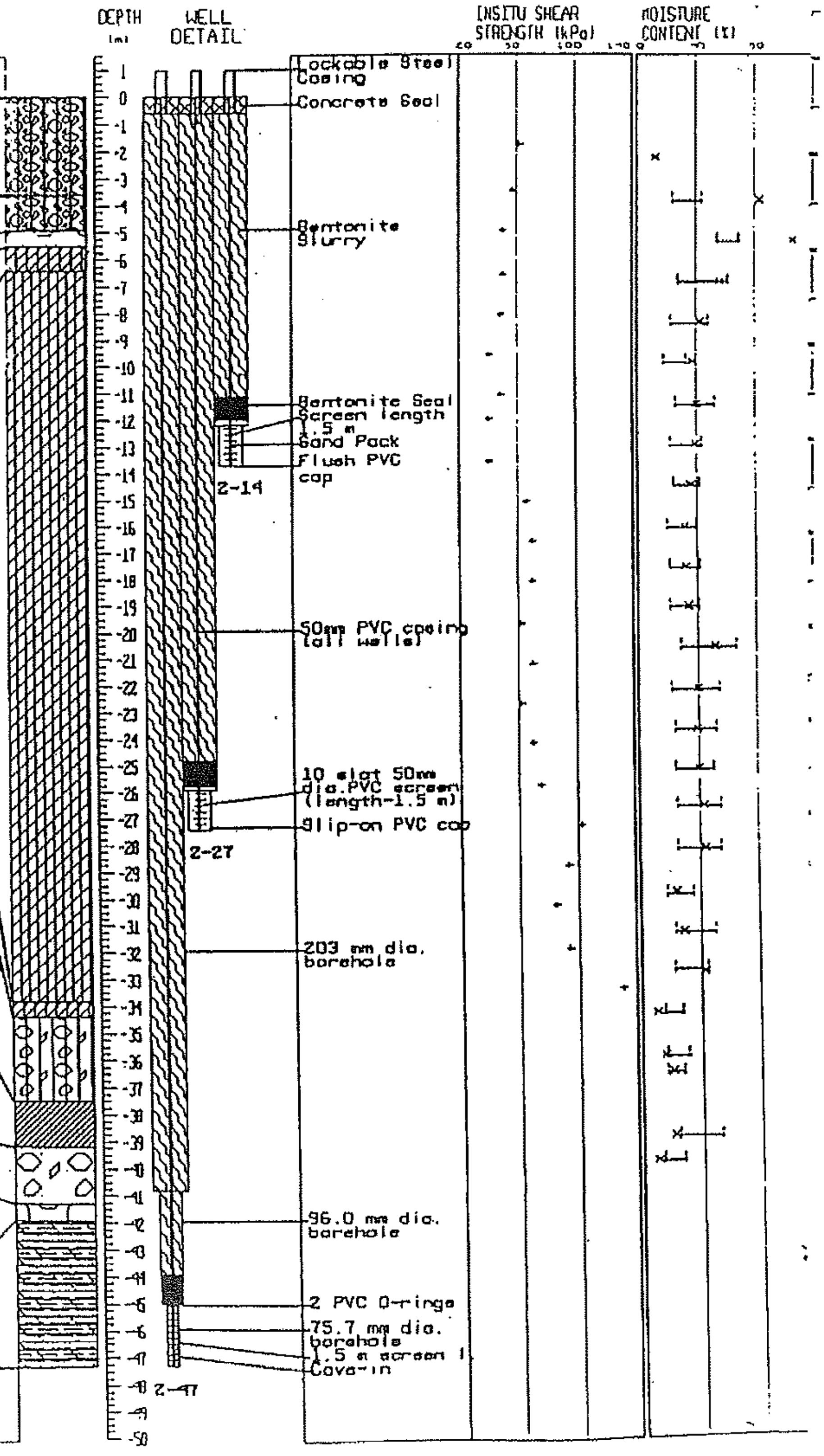
CLAY trace silt, stiff to very stiff, very cohesive, medium brown with occasional sections of alternating red and grey layers with 1-2 mm thick individual laminae, moist.
Occasional silt to fine sand layers below 38 m

GRAVELLY SAND (Till) with silt, trace clay; gravel is subrounded and pebbles are about 5 to 30 mm in diameter, loose to compact, brown, damp to moist

GRAVEL angular to subrounded, microcrystalline to fine grained dolostone and limestone fragments which vary size from approx 3 to 30 mm

SHALEY DOLOSTONE and gypsum irregularly layered, highly fractured (hairline fractures infilled with gypsum), dolostone is medium grey, very fine grained
CORE RECOVERY-12%

End of hole - 47 3 m b g l



OW 3-42, 24, 12

CLIENT MacLaren Engineers Inc. FILE NO 670-901
PROJECT Elm St Landfill LOCATION Port Colborne
GEOLOGIST/ENGINEER I A B DATE COMPLETED OCTOBER 3 1990

STRATIGRAPHIC DESCRIPTION

Ground Elevations (m a s l.) OW3-12=176 0, OW3-24=176 1, OW3-42=176 1.

FILL silt with clay, angular gravel, roots, and abundant gypsum, fine to medium-grained, stiff, some cohesion, medium brown, moist

CLAYEY SILT- stiff, cohesive, greenish-brown, damp, laminated with individual 1-2 mm thick layers, horizontal and some vertical fractures, bluish-grey colour along vertical fracture faces

SILTY CLAY trace sand and fine angular dark grey platy gravel, occasional small (<3 mm diameter) pockets of grey sandy silt, very soft in upper part of unit but becoming stiff with depth, very cohesive, grey-brown to medium brown with sections of alternating (laminated) red and grey layers subdivided into 1-2 mm thick laminae, wet to saturated
Fractured silty sand layers 11 1-11 3 m

Grey silty clay 18 3-19 2 m

1-2 mm thick sandy silt layers at 34 1 and 34 4 m

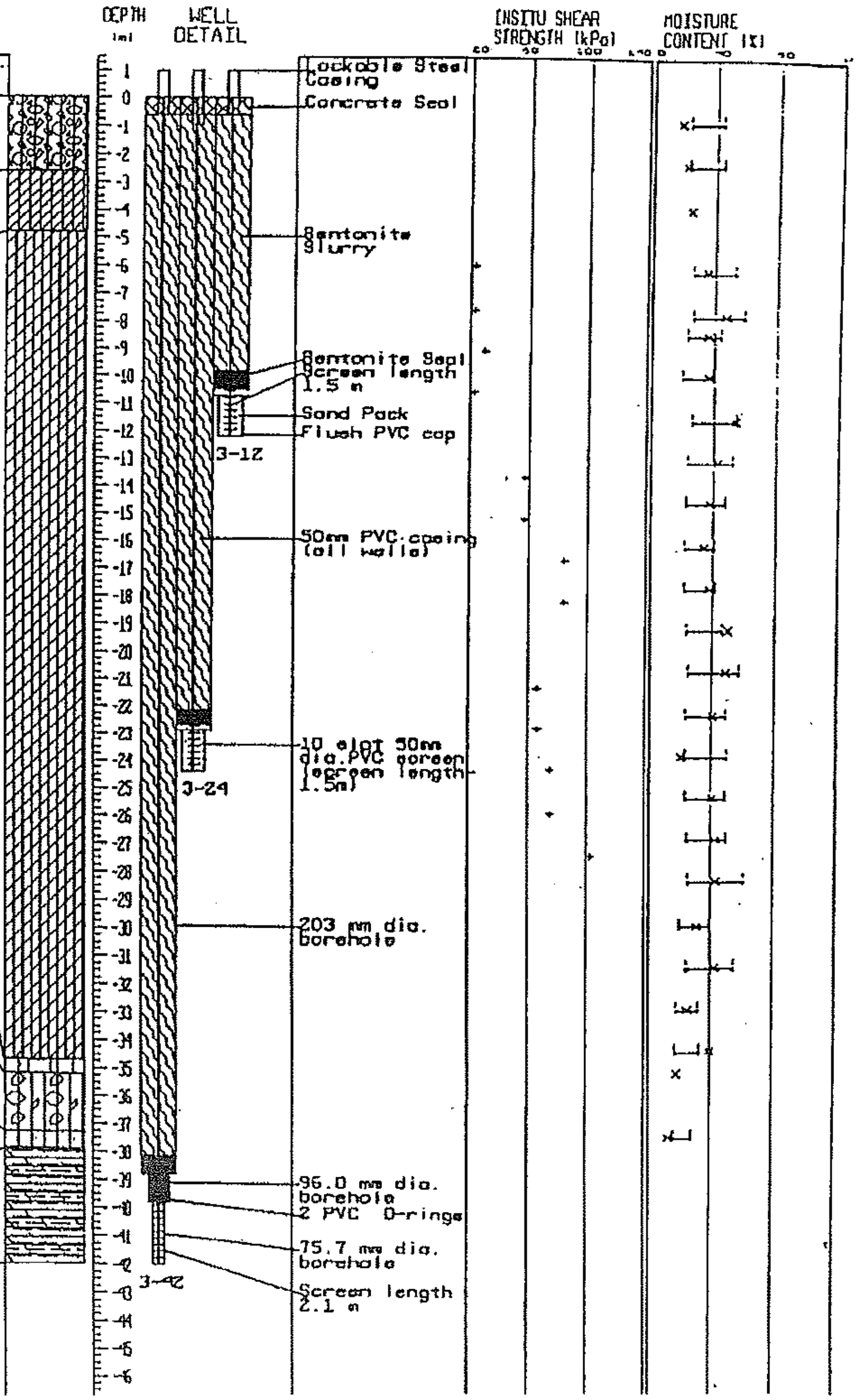
SILTY SAND and GRAVEL gravel is subrounded to angular; loose, grey-brown sand with dark grey gravel, wet to saturated, unsorted but coarsening with depth

GRAVELLY SILT (Till) with sand, trace clay, gravel is fine-grained, dark grey, angular to subrounded and unsorted, very dense, slightly cohesive, medium to dark brown

SANDY SILT (Till) with angular to subrounded gravel, hard, not cohesive, greenish-grey, moist to wet

SHALEY DOLOSTONE very fine-grained, dark grey-brown, uneven subhorizontal fractures at approx 5 cm intervals, lined with black shaley material, gypsum powder noted on some fracture walls

End of hole - 42 m b g.l



OW 7-39, 23, 11

CLIENT MacLaren Engineers Inc. FILE NO 670-901

PROJECT Elm St. Landfill LOCATION Port Colborne

GEOLOGIST/ENGINEER I.A.B. DATE COMPLETED SEPTEMBER 26 1990

STRATIGRAPHIC DESCRIPTION

Ground Elevations (m a.s.l.): OW7-11-175.4, OW7-23-175.3, OW7-39-175.4

FILL: silt with clay, sand, and fine to medium-grained angular gravel, roots and refuse; very stiff, slightly cohesive to crumbly, mottled brown, damp to dry, irregularly fractured

CLAYEY SILT: with sand, abundant horizontal and some vertical fractures, very dense, slight cohesion, mottled yellowish-brown with grey fracture filling, slightly damp.

SILTY CLAY: trace sand and fine angular gravel, trace 2-3 mm diameter pockets of grey sandy silt; very stiff in upper 3-10 m but becoming very soft with depth, very cohesive, grey-brown with occasional sections of alternating (laminated) red and grey layers subdivided into 1-2 mm thick laminae, wet to saturated

SILT (Till): with sand and gravel, trace clay, gravel subangular to subrounded, poorly sorted dolostone/limestone fragments; hard to very hard, slightly cohesive medium brown, moist to damp with depth.

CLAY: trace to minor silt and trace gravel; stiff, alternating red-brown to medium-brown (clay) and grey (silty clay) layers, wet to saturated; subhorizontal fractures along sandy silt seams every 1-6 cm.

SAND (Till): with gravel and silt, gravel subangular to subrounded; brown, stiff to hard, wet to saturated.

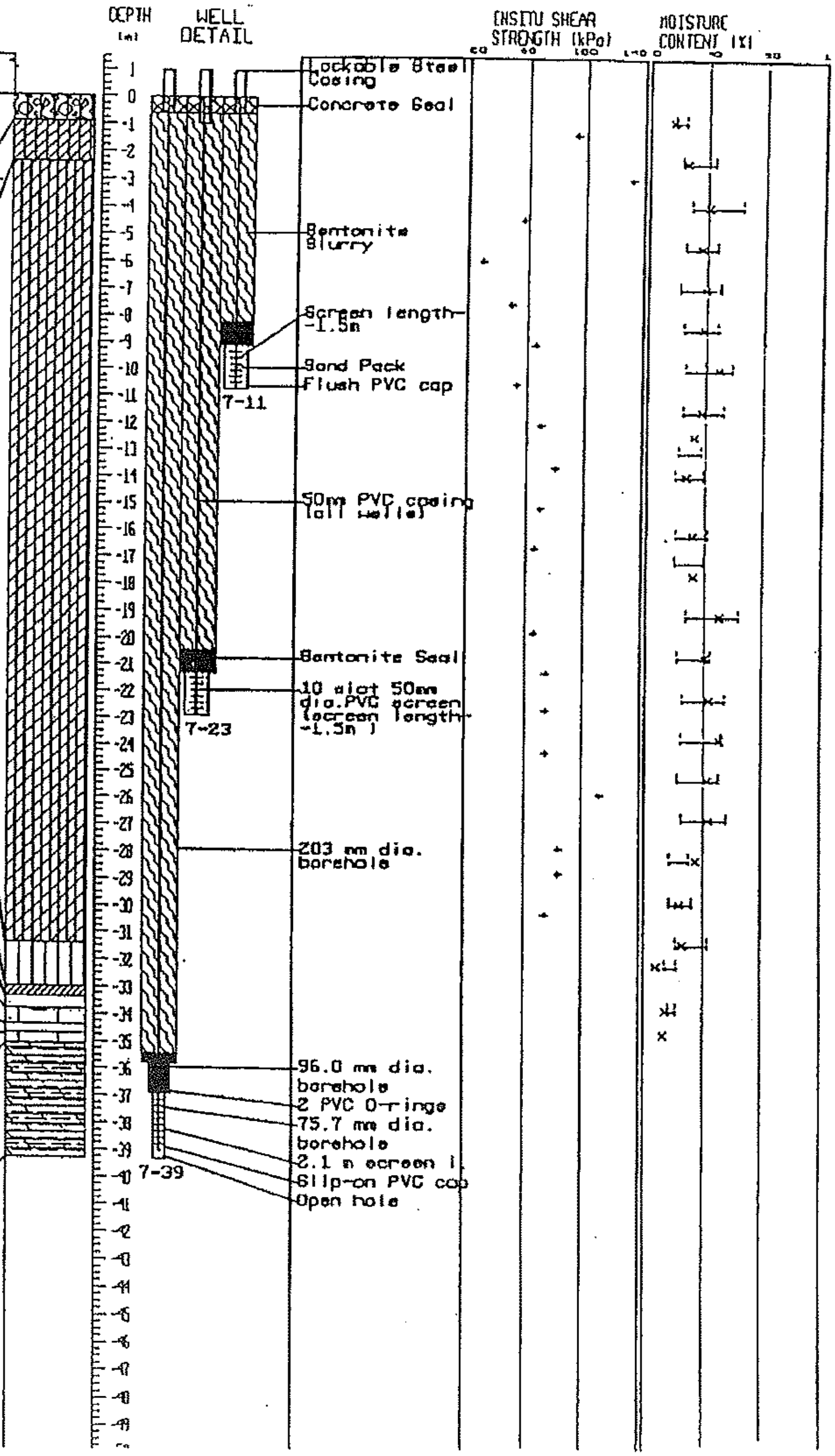
GRAVEL and COARSE SAND: minor silt and clay, gravel angular to subangular, wet

SAND: some silt, fine to coarse with depth, medium brown, saturated.

GRAVEL (dark brownish-grey) with silty sand matrix (greyish-brown), saturated

SHALEY DOLOSTONE: fine-grained, fossiliferous, fairly porous, brown-grey with alternating undulating bands of grey-brown to buff and white between 36.5 and 36.9 m, abundant uneven subhorizontal fractures and <1 mm wide veins, are lined with gypsum
CORE RECOVERY - 30%

End of hole - 39.3 m b.g.l



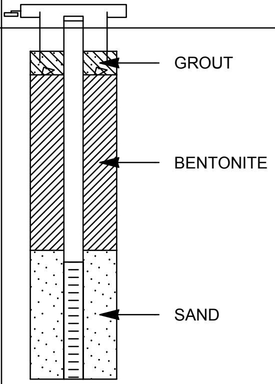
STRATIGRAPHIC AND INSTRUMENTATION LOG
(OVERBURDEN)

Page 1 of 1

PROJECT NAME: STATION ROAD LANDFILL
PROJECT NUMBER: 44545-99
CLIENT: REGIONAL MUNICIPALITY OF NIAGARA
LOCATION: STATION ROAD, WAINFLEET

HOLE DESIGNATION: OW13(5)
DATE COMPLETED: April 13, 2007
DRILLING METHOD: 4 1/4"HSA
FIELD PERSONNEL: KEVIN HOLLINGWORTH

DEPTH m BGS	STRATIGRAPHIC DESCRIPTION & REMARKS	DEPTH m BGS	4 1/4" HSA	SAMPLE			
				NUMBER	INTERVAL	REC (%)	'N' VALUE
	Topsoil, dark brown with silty clay, moist, loose trace rootlets	0.18					
1	SILTY CLAY (ML), trace sand, soft, brown, moist						
2	- 0.03m sand seam, medium grained, brown at 1.83m BGS						
3							
4							
	END OF BOREHOLE @ 4.57m BGS	4.57					
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							



WELL DETAILS
Screened interval:
3.05 to 4.57m BGS
Length: 1.52m
Diameter: 50.8mm
Slot Size: 10
Material: PLASTIC
Seal:
2.59 to 2.90m BGS
Material: BENTONITE
Sand Pack:
2.90 to 4.57m BGS
Material: NO. 2 SILICA SAND

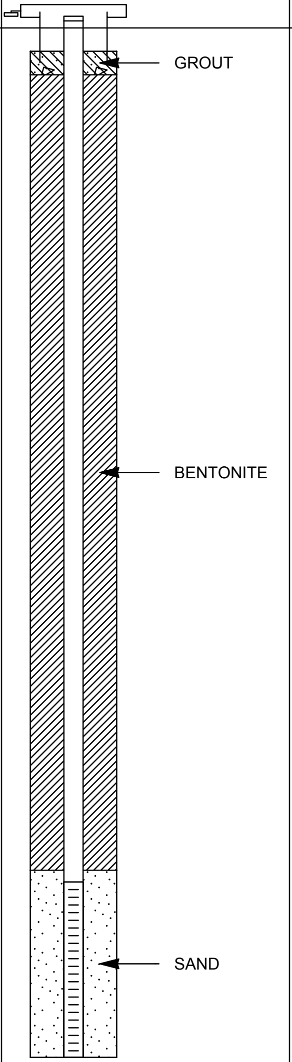
NOTES: MEASURING POINT ELEVATIONS MAY CHANGE; REFER TO CURRENT ELEVATION TABLE

STRATIGRAPHIC AND INSTRUMENTATION LOG
(OVERBURDEN)

PROJECT NAME: STATION ROAD LANDFILL
PROJECT NUMBER: 44545-99
CLIENT: REGIONAL MUNICIPALITY OF NIAGARA
LOCATION: STATION ROAD, WAINFLEET
HOLE DESIGNATION: OW13(14)
DATE COMPLETED: April 13, 2007
DRILLING METHOD: 4 1/4"HSA
FIELD PERSONNEL: KEVIN HOLLINGWORTH

STRATIGRAPHIC DESCRIPTION & REMARKS	DEPTH m BGS
Topsoil, dark brown with silty clay, moist, loose, trace rootlets	0.15
SILTY CLAY (ML), trace sand, soft, brown, moist - 0.03m sand seam, medium grained, brown at 1.83m BGS - very soft at 6.10m BGS - grey gravel seam, 2.54cm thick, poorly graded at 7.62m BGS	8.08
SILTY SAND (SM), medium grained, loose, moist, brown - very wet, very loose at 9.14m BGS - fine grained at 9.75m BGS - bedrock encountered at 10.33m BGS	10.36
Dolostone, light grey w/occasional shale and chart partings, fossiliferous, fine crystaline, thinly bedded	13.41
END OF BOREHOLE @ 13.41m BGS	

4 1/4" HSA



WELL DETAILS
Screened interval:
11.13 to 13.41m BGS
Length: 2.29m
Diameter: 50.8mm
Slot Size: 10
Material: PLASTIC
Seal:
10.06 to 10.97m BGS
Material: BENTONITE
Sand Pack:
10.97 to 13.41m BGS
Material: NO. 2 SILICA SAND

SAMPLE			
NUMBER	INTERVAL	REC (%)	'N' VALUE
1	☒	90	16
2	☒	100	7
3	☒	100	5
4	☒	80	37
5	☒	100	23
6	☒	90	27
7	☒	90	50

NOTES: MEASURING POINT ELEVATIONS MAY CHANGE; REFER TO CURRENT ELEVATION TABLE

BOREHOLE NO. OW14(5)

PAGE 1 of 1

PROJECT NAME: STATION ROAD LANDFILL SITE

PROJECT NO.: 1060291.02

CLIENT: REGIONAL MUNICIPALITY OF NIAGARA

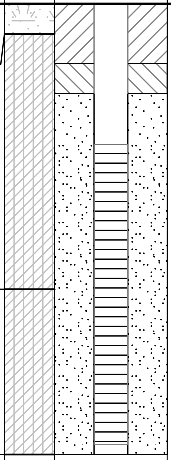
DATE COMPLETED: Dec. 14, 2007

BOREHOLE TYPE: 200 mm DIA. HOLLOW STEM AUGER

SUPERVISOR: AMS

GROUND ELEVATION: 179.9 mASL

REVIEWER: KJF



DEPTH (m)		STRATIGRAPHIC DESCRIPTION	STRATIGRAPHY	MONITOR DETAILS	SAMPLE					CONE PENETRATION	WATER CONTENT %	REMARKS
					TYPE	N VALUE	% WATER	% RECOVERY	RQD (%)	"N" VALUE 10 20 30 SHEAR STRENGTH	10 20 30 WP WL	
0.0		TOPSOIL: BROWN TOPSOIL, SOME CLAY, ORGANICS, ROOTLETS, LOOSE, MOIST.										STRATIGRAPHY BASED ON BOREHOLE OW14(11).
	0.3	SILTY CLAY: BROWN SILTY CLAY, TRACE FINE SAND, OCCASIONAL ORANGE AND GREY MOTTLING, FIRM TO STIFF, APL.										
2.0												
	2.9	SILTY CLAY TO CLAYEY SILT: BECOMING REDDISH BROWN SILTY CLAY TO CLAYEY SILT BELOW 2.9 m; TRACE GRAVEL BELOW 4.6 m.										
4.0												
	4.6	BOREHOLE TERMINATED AT 4.6 m IN SILTY CLAY TO CLAYEY SILT.										
6.0												
8.0												
10.0												
12.0												
14.0												

BOREHOLE NO. OW14(11)

PAGE 1 of 1

PROJECT NAME: STATION ROAD LANDFILL SITE

PROJECT NO.: 1060291.02

CLIENT: REGIONAL MUNICIPALITY OF NIAGARA

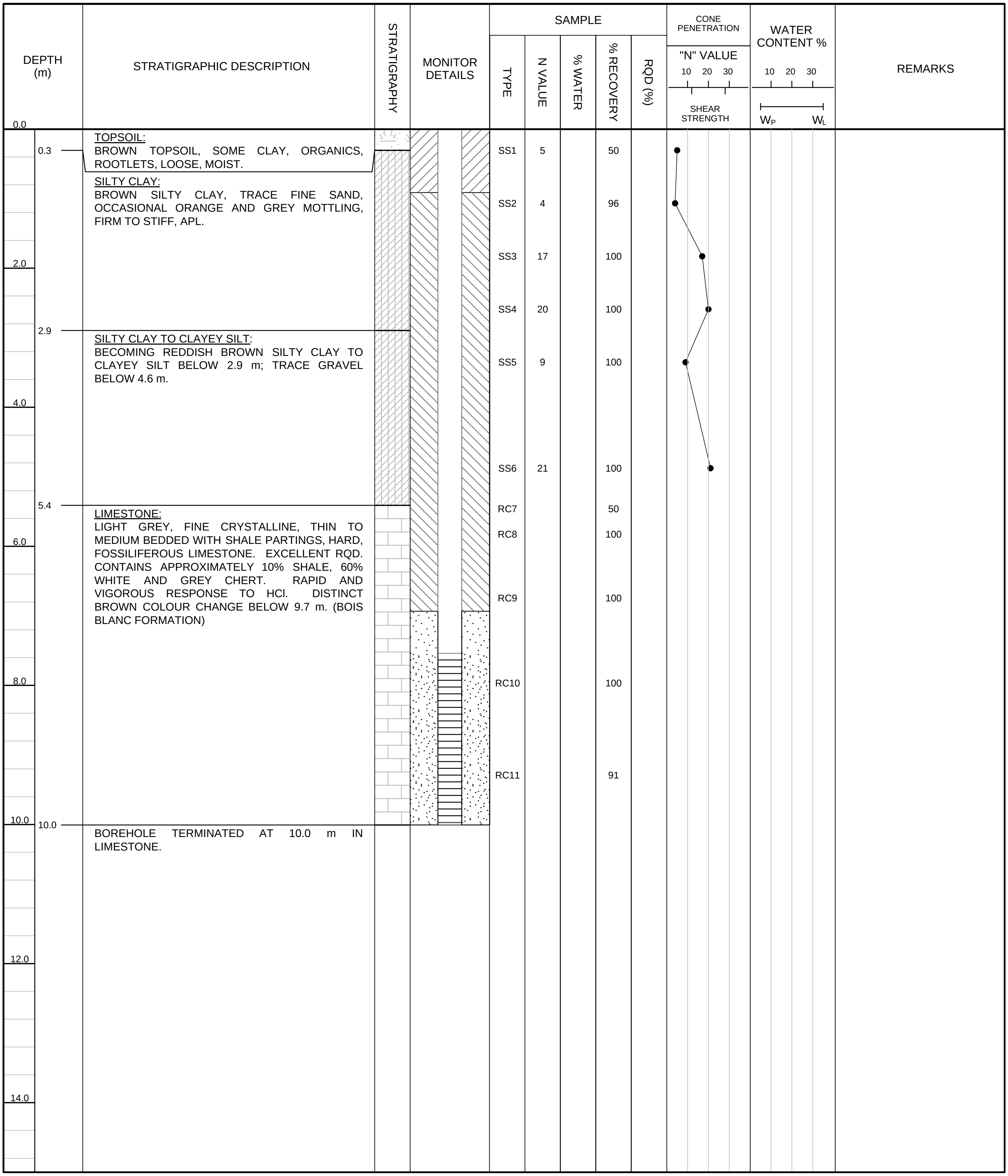
DATE COMPLETED: Dec. 14, 2007

BOREHOLE TYPE: 200 mm DIA. HOLLOW STEM AUGER

SUPERVISOR: AMS

GROUND ELEVATION: 179.9 mASL

REVIEWER: KJF

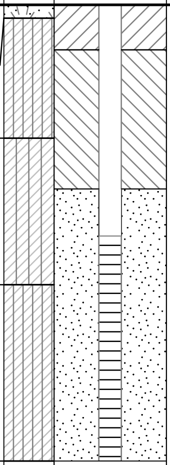


DEPTH (m)	STRATIGRAPHIC DESCRIPTION	TYPE	N VALUE	% WATER	% RECOVERY	RQD (%)
0.0	TOPSOIL: BROWN TOPSOIL, SOME CLAY, ORGANICS, ROOTLETS, LOOSE, MOIST.	SS1	5		50	
0.3	SILTY CLAY: BROWN SILTY CLAY, TRACE FINE SAND, OCCASIONAL ORANGE AND GREY MOTTLING, FIRM TO STIFF, APL.	SS2	4		96	
		SS3	17		100	
		SS4	20		100	
2.9	SILTY CLAY TO CLAYEY SILT: BECOMING REDDISH BROWN SILTY CLAY TO CLAYEY SILT BELOW 2.9 m; TRACE GRAVEL BELOW 4.6 m.	SS5	9		100	
		SS6	21		100	
5.4	LIMESTONE: LIGHT GREY, FINE CRYSTALLINE, THIN TO MEDIUM BEDDED WITH SHALE PARTINGS, HARD, FOSSILIFEROUS LIMESTONE. EXCELLENT RQD. CONTAINS APPROXIMATELY 10% SHALE, 60% WHITE AND GREY CHERT. RAPID AND VIGOROUS RESPONSE TO HCl. DISTINCT BROWN COLOUR CHANGE BELOW 9.7 m. (BOIS BLANC FORMATION)	RC7			50	
		RC8			100	
		RC9			100	
		RC10			100	
		RC11			91	
10.0	BOREHOLE TERMINATED AT 10.0 m IN LIMESTONE.					

BOREHOLE NO. OW15(6)

PAGE 1 of 1

PROJECT NAME: STATION ROAD LANDFILL SITE
PROJECT NO.: 1060291.05
CLIENT: REGIONAL MUNICIPALITY OF NIAGARA
DATE COMPLETED: Nov 21, 2008
BOREHOLE TYPE: 108 mm I.D. HOLLOW STEM AUGER
SUPERVISOR: AMS
GROUND ELEVATION: 179.6 mASL
REVIEWER: RFK / KJF



DEPTH (m)	STRATIGRAPHIC DESCRIPTION	STRATIGRAPHY	MONITOR DETAILS	SAMPLE TYPE	SAMPLE N VALUE	SAMPLE % WATER	SAMPLE % RECOVERY	SAMPLE RQD (%)	CONE PENETRATION "N" VALUE 10 20 30 SHEAR STRENGTH	WATER CONTENT % 10 20 30 WP WL	REMARKS
0.0	<u>TOPSOIL:</u> BROWN TOPSOIL, SOME ORGANICS, LOOSE, MOIST.										STRATIGRAPHY BASED ON BOREHOLE OW15(11).
0.2	<u>SILTY CLAY:</u> BROWN SILTY CLAY, GREY MOTTLING, TRACE ORGANICS, TRACE GRAVEL, APL, FIRM.										
1.8	<u>CLAYEY SILT:</u> REDDISH BROWN CLAYEY SILT, MOIST TO WET, FIRM TO VERY STIFF.										
3.8	<u>SILTY CLAY:</u> REDDISH BROWN SILTY CLAY, TRACE GREY MOTTLING, APL TO WTPL, SOFT.										
6.2	BOREHOLE TERMINATED AT 6.17 m IN SILTY CLAY.										

Depth scale: 0.0, 1.0, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, 9.0, 10.0, 11.0, 12.0, 13.0, 14.0, 15.0, 16.0, 17.0, 18.0, 19.0, 20.0

JHL GEOLOGIC B/W (METRIC) OW15 BH LOG.GPJ JAGGER HIMS BASIC.GDT 8/3/10

BOREHOLE NO. OW15(11)

PROJECT NAME: STATION ROAD LANDFILL SITE

PROJECT NO.: 1060291.05

CLIENT: REGIONAL MUNICIPALITY OF NIAGARA

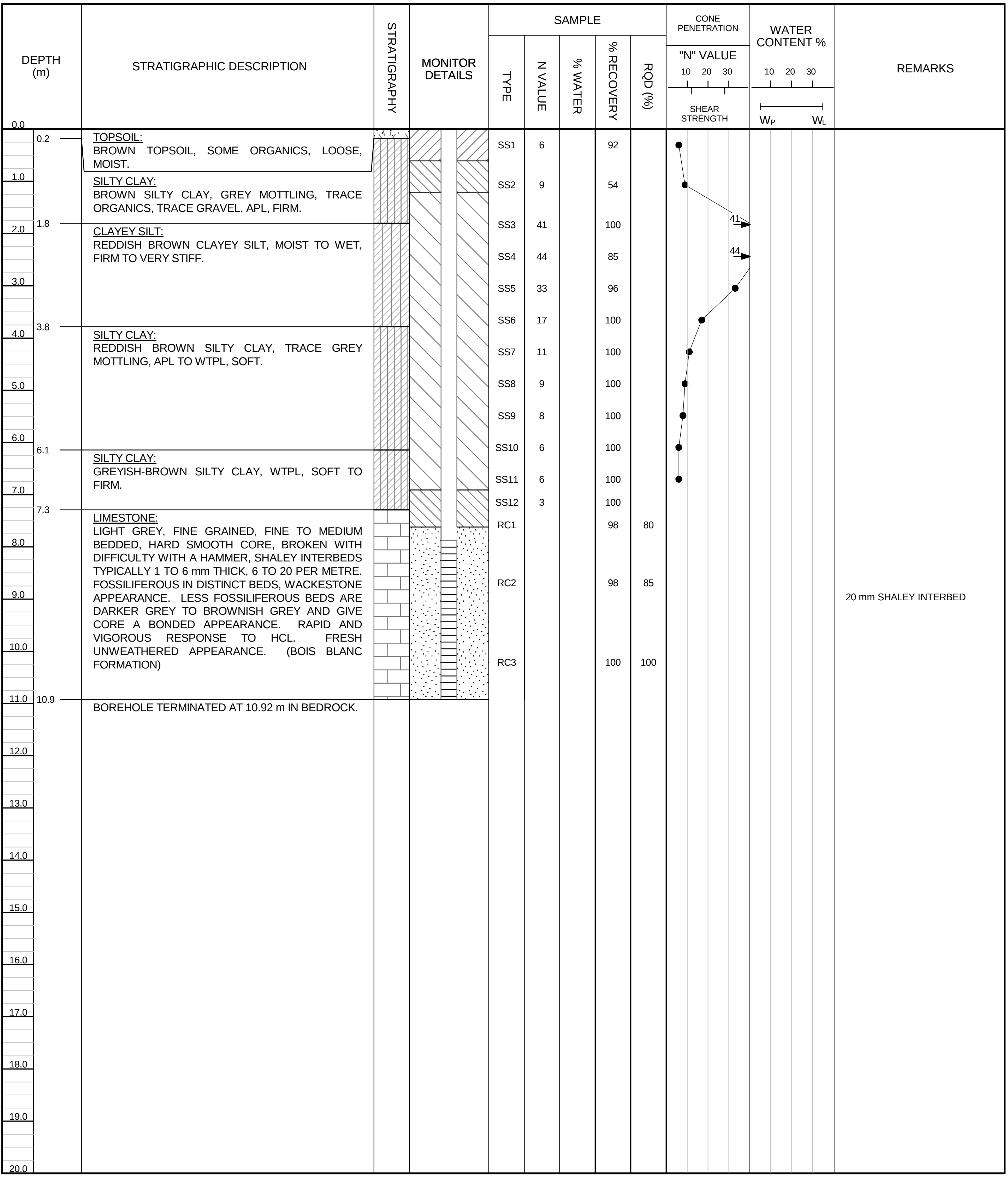
DATE COMPLETED: Nov 21, 2008

BOREHOLE TYPE: 108 mm I.D. HOLLOW STEM AUGER

SUPERVISOR: AMS

GROUND ELEVATION: 179.6 mASL

REVIEWER: RFK / KJF



DEPTH (m)	STRATIGRAPHIC DESCRIPTION	TYPE	N VALUE	% WATER	% RECOVERY	RQD (%)	REMARKS
0.0	TOPSOIL: BROWN TOPSOIL, SOME ORGANICS, LOOSE, MOIST.	SS1	6		92		
0.2	SILTY CLAY: BROWN SILTY CLAY, GREY MOTTLING, TRACE ORGANICS, TRACE GRAVEL, APL, FIRM.	SS2	9		54		
1.8	CLAYEY SILT: REDDISH BROWN CLAYEY SILT, MOIST TO WET, FIRM TO VERY STIFF.	SS3	41		100		
		SS4	44		85		
		SS5	33		96		
		SS6	17		100		
3.8	SILTY CLAY: REDDISH BROWN SILTY CLAY, TRACE GREY MOTTLING, APL TO WTPL, SOFT.	SS7	11		100		
		SS8	9		100		
		SS9	8		100		
6.1	SILTY CLAY: GREYISH-BROWN SILTY CLAY, WTPL, SOFT TO FIRM.	SS10	6		100		
		SS11	6		100		
		SS12	3		100		
7.3	LIMESTONE: LIGHT GREY, FINE GRAINED, FINE TO MEDIUM BEDDED, HARD SMOOTH CORE, BROKEN WITH DIFFICULTY WITH A HAMMER, SHALEY INTERBEDS TYPICALLY 1 TO 6 mm THICK, 6 TO 20 PER METRE. FOSSILIFEROUS IN DISTINCT BEDS, WACKESTONE APPEARANCE. LESS FOSSILIFEROUS BEDS ARE DARKER GREY TO BROWNISH GREY AND GIVE CORE A BONDED APPEARANCE. RAPID AND VIGOROUS RESPONSE TO HCL. FRESH UNWEATHERED APPEARANCE. (BOIS BLANC FORMATION)	RC1			98	80	
		RC2			98	85	20 mm SHALEY INTERBED
		RC3			100	100	
10.9	BOREHOLE TERMINATED AT 10.92 m IN BEDROCK.						

APPENDIX

D

HYDRAULIC CONDUCTIVITY TESTING DATA

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TABLES

FIGURES

APPENDICES

D.1 INTRODUCTION

Various methods were used to perform the hydraulic conductivity testing at the Site, all of which are summarized in this Appendix. A description of the testing undertaken at the Site is provided below.

Section D.2	Packer testing completed during borehole advancement of selected wells to assess relative hydraulic conductivity of discreet bedrock intervals during the 2018 expansion drilling program, undertaken between July 4, 2018 and July 30, 2018. Test data included in **Appendix D-1**.
Section D.3	Single well response testing completed to determine local in-situ hydraulic conductivity. Testing completed between November 20 and December 10, 2019. Test data included in **Appendix D-2**.
Section D.4	Long-term pumping test completed at pumping well PW in 2019 to estimate larger-scale transmissivity of the bedrock aquifer. Stepped-rate test completed on February 6, 2019; long-term constant rate test completed between February 6 – 9, 2019. Test data included in **Appendix D-3**.

D.2 PACKER TESTING

A total of four (4) monitoring well nests were selected for falling head packer testing during advancement of the deep boreholes to assess the hydraulic conductivity along the depth of the borehole at approximately 3 m (10’) intervals. Packer testing was completed at well nests MW1 and MW11 to the east of the proposed quarry expansion and current quarry boundaries along Erie Peat Road and Young’s Road, respectively, MW5 to the north of the proposed quarry expansion, and MW10 to the west. The packer testing analyses are included in **Appendix D-1**, and summarized in **Table D.2.1** below, along with the depth interval, interpreted stratigraphy and rock quality density (RQD).

Table D.2.1 Summary of Packer Testing Analyses

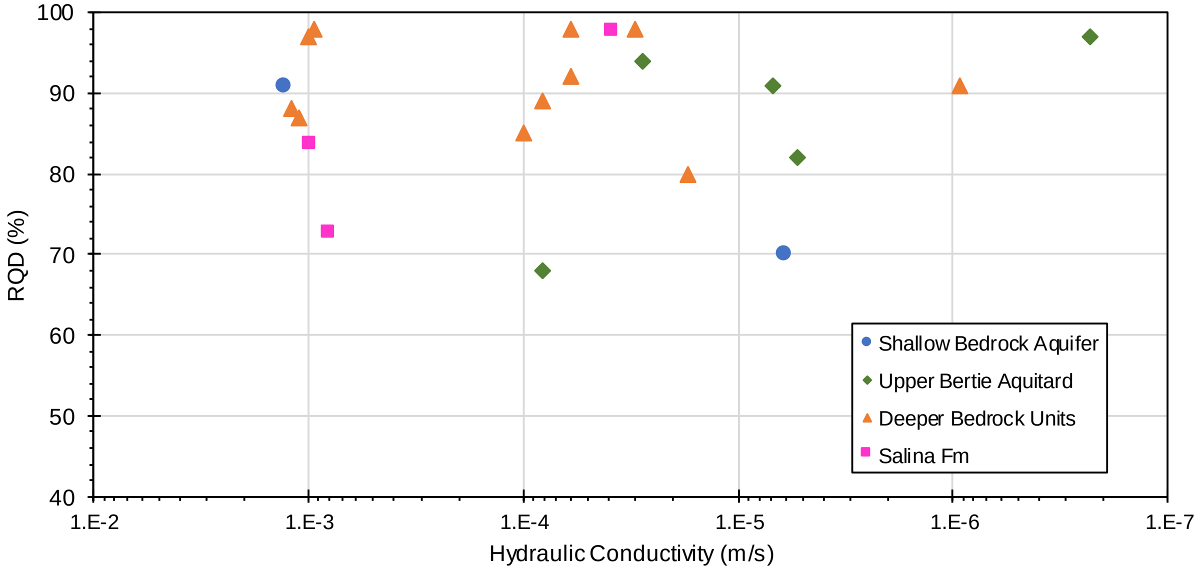
Well Nest	Figure No.	Depth Interval (mbgs)	Hydraulic Conductivity (cm/s)	Stratigraphic Unit from Borehole Log	Average RQD (%)
MW1-I (Erie Peat Road)	1-1-1	6.1 – 9.1	$1.3x10^{-3}$	Springvale Mb	91
	1-1-2	9.1 – 12.2	$2.8x10^{-5}$	Williamsville Mb	94
	1-1-3	12.2 – 15.2	$6.0x10^{-5}$	Falkirk Mb	98
	1-1-4	15.2 – 18.3	$8.1x10^{-5}$	Falkirk Mb	89
	1-1-5	18.3 – 21.3	$1.0x10^{-4}$	Oatka Mb	85
	1-1-6	21.3 – 24.4	$3.0x10^{-5}$	Oatka Mb	98
	1-1-7	24.4 – 27.4	$1.0x10^{-3}$	Salina Fm	84
	1-1-8	25.9 – 27.4	$8.1x10^{-4}$	Salina Fm	73
MW5-I (north)	1-5-1	22.3 – 23.8	$1.3x10^{-6}$	Salina Fm	
MW10-I (west)	1-10-1	4.0 – 7.0	$6.1x10^{-6}$	Springvale Mb	70
	1-10-2	7.0 – 10.1	$6.9x10^{-6}$	Akron Mb	91
	1-10-3	10.1 – 13.1	$7.7x10^{-5}$	Scajaquanda Mb	68
	1-10-4	13.1 – 16.2	$1.2x10^{-3}$	Falkirk Mb	88
	1-10-5	16.2 - 19.2	$1.1x10^{-3}$	Falkirk Mb	87
	1-10-6	19.2 – 22.3	$9.2x10^{-7}$	Oatka Mb	91
	1-10-7	22.3 – 25.3	$3.9x10^{-5}$	Salina Fm	98
	1-10-8	25.3 – 28.3	$1.0x10^{-3}$	Salina Fm	84

Table D.2.1 Summary of Packer Testing Analyses (cont'd)

Well Nest	Figure No.	Depth Interval (mbgs)	Hydraulic Conductivity (m/s)	Stratigraphic Unit from Borehole Log	RQD (%)
MW11-1 (Young's Road)	1-11-1	4.6 – 7.6	$5.3x10^{-6}$	Akron Mb	82
	1-11-2	7.6 – 10.7	$2.3x10^{-7}$	Williamsville Mb	97
	1-11-3	10.7 – 13.7	$9.4x10^{-4}$	Oatka Mb	98
	1-11-4	13.7 – 16.8	$1.0x10^{-3}$	Falkirk Mb	97
	1-11-5	16.8 – 19.8	$1.7x10^{-5}$	Oatka Mb	80
	1-11-6	19.8 – 22.9	$6.0x10^{-5}$	Oatka Mb	92

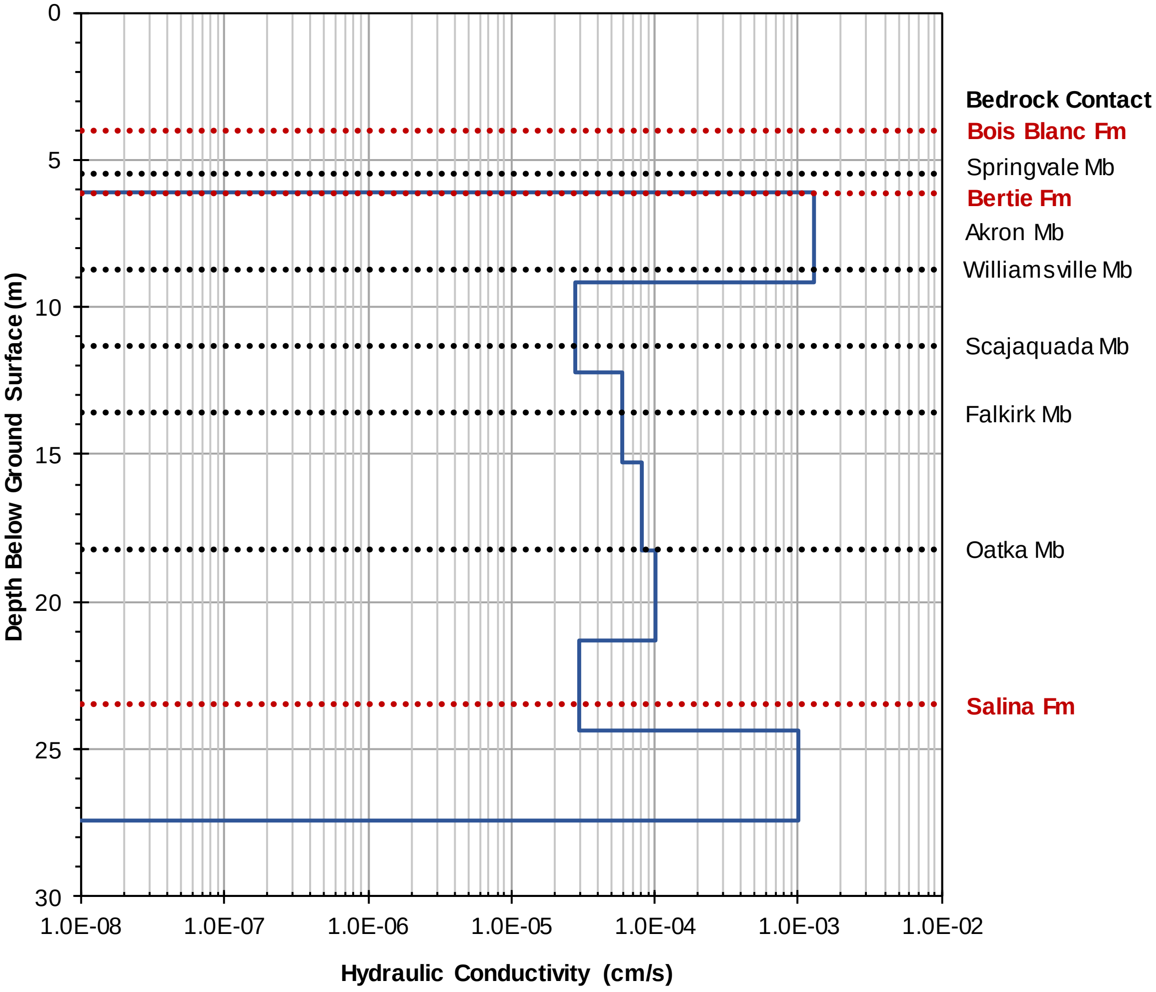
It is noted that the absolute values for conductivity obtained from the packer tests are not expected to be representative of the bulk aquifer, but rather, the values obtained along the depth of each borehole provide an indication of zones of relatively high hydraulic conductivity. This qualitative information was used to enhance the conceptual understanding of the hydrogeology of the Site.

A plot of hydraulic conductivity versus RQD is provided below.



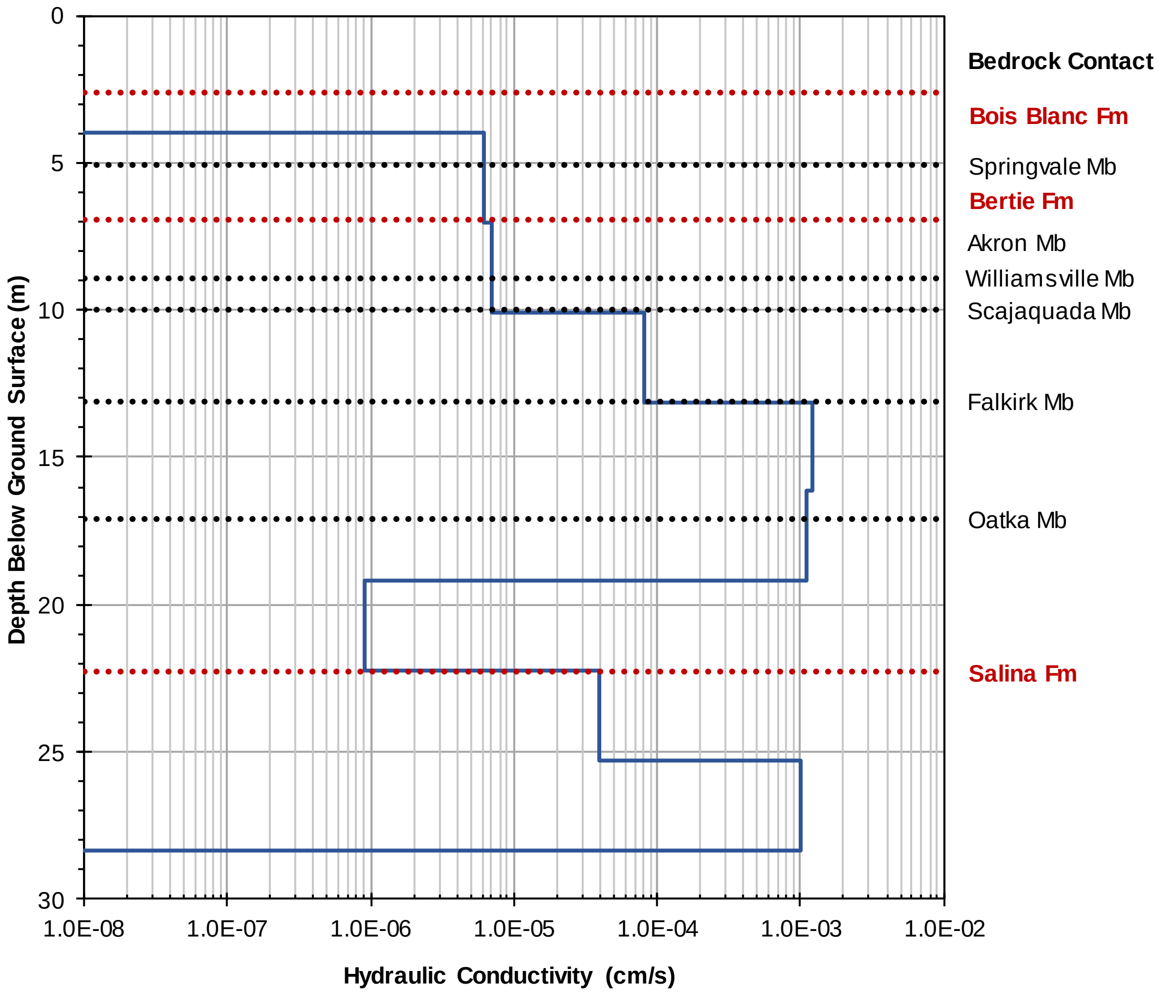
The results from **Table D.2.1** are represented graphically in the figures below for the boreholes where packer testing was completed. Of note, a plot is not included for MW5-I, since there was only 1 interval tested. Packer testing was also completed historically as part of the Law quarry east extension (GLL, 2005) and Reeb quarry (Azimuth Environmental Consulting and Earthfx Inc., 2005 and 2008). The test results are also plotted here for reference.

MW1-I Packer Test Results



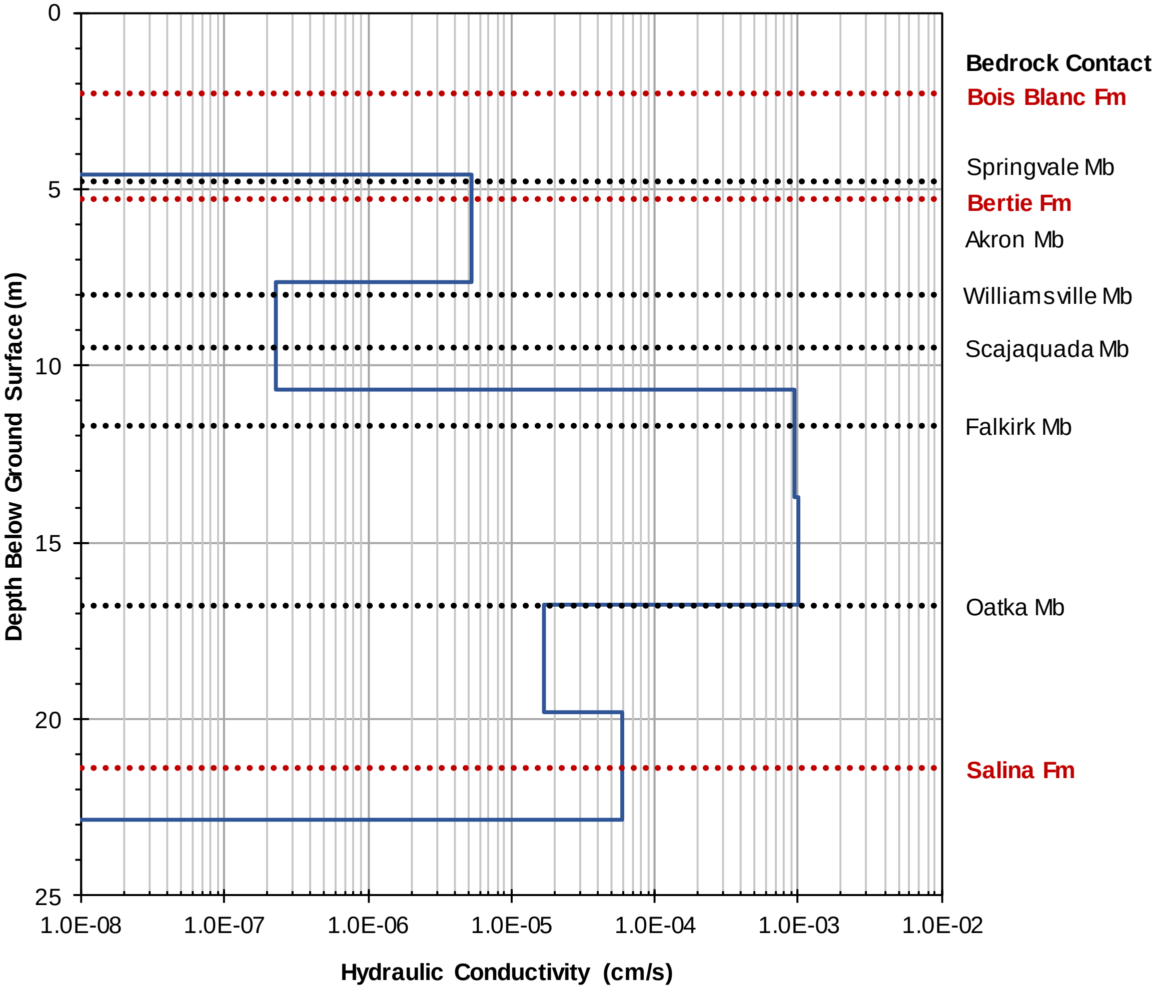
Cumulative Transmissivity = 0.9 cm^2/s (7.9 m^2/day)

MW10-I Packer Test Results



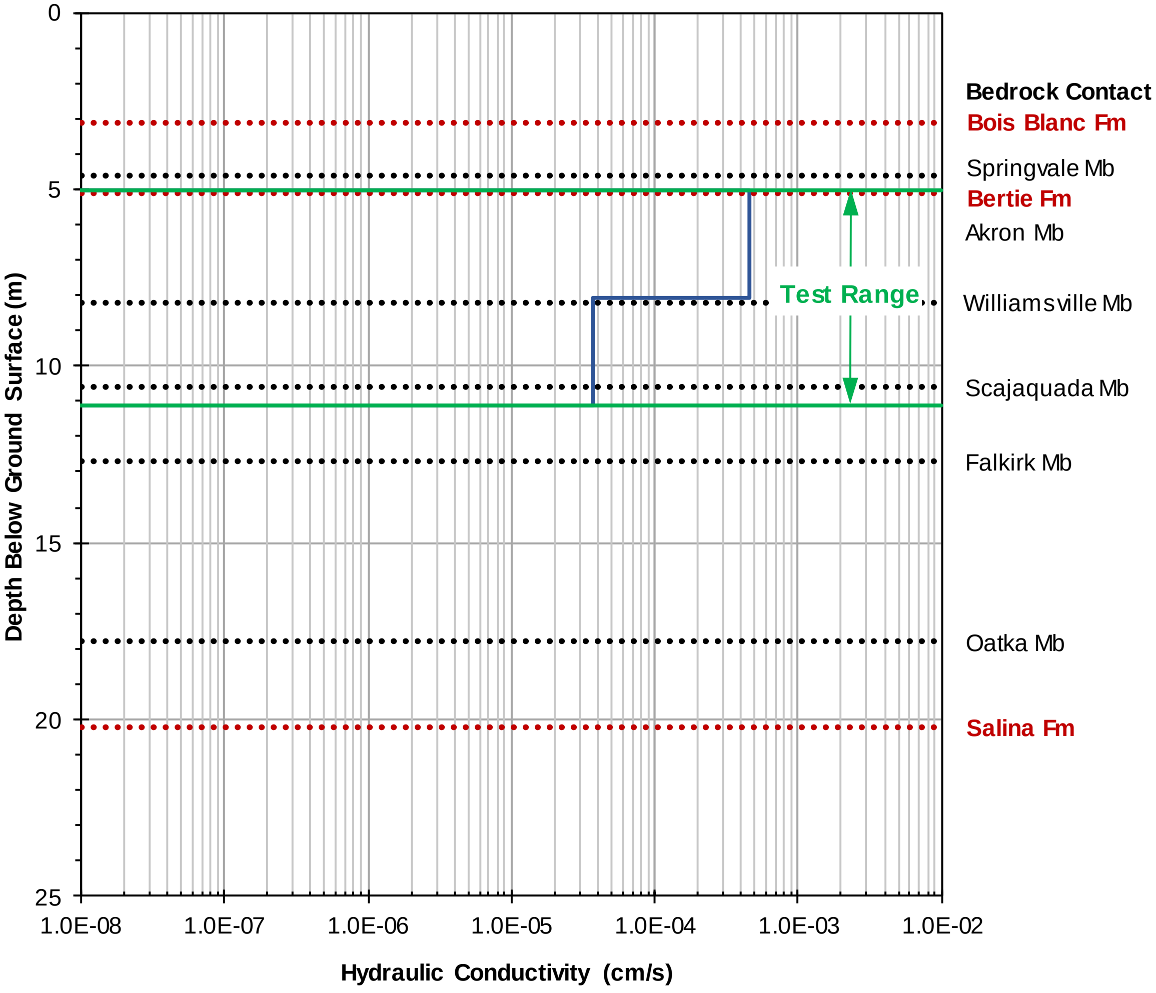
Cumulative Transmissivity = 1.0 cm^2/s (9.0 m^2/day)

MW11-1 Packer Test Results



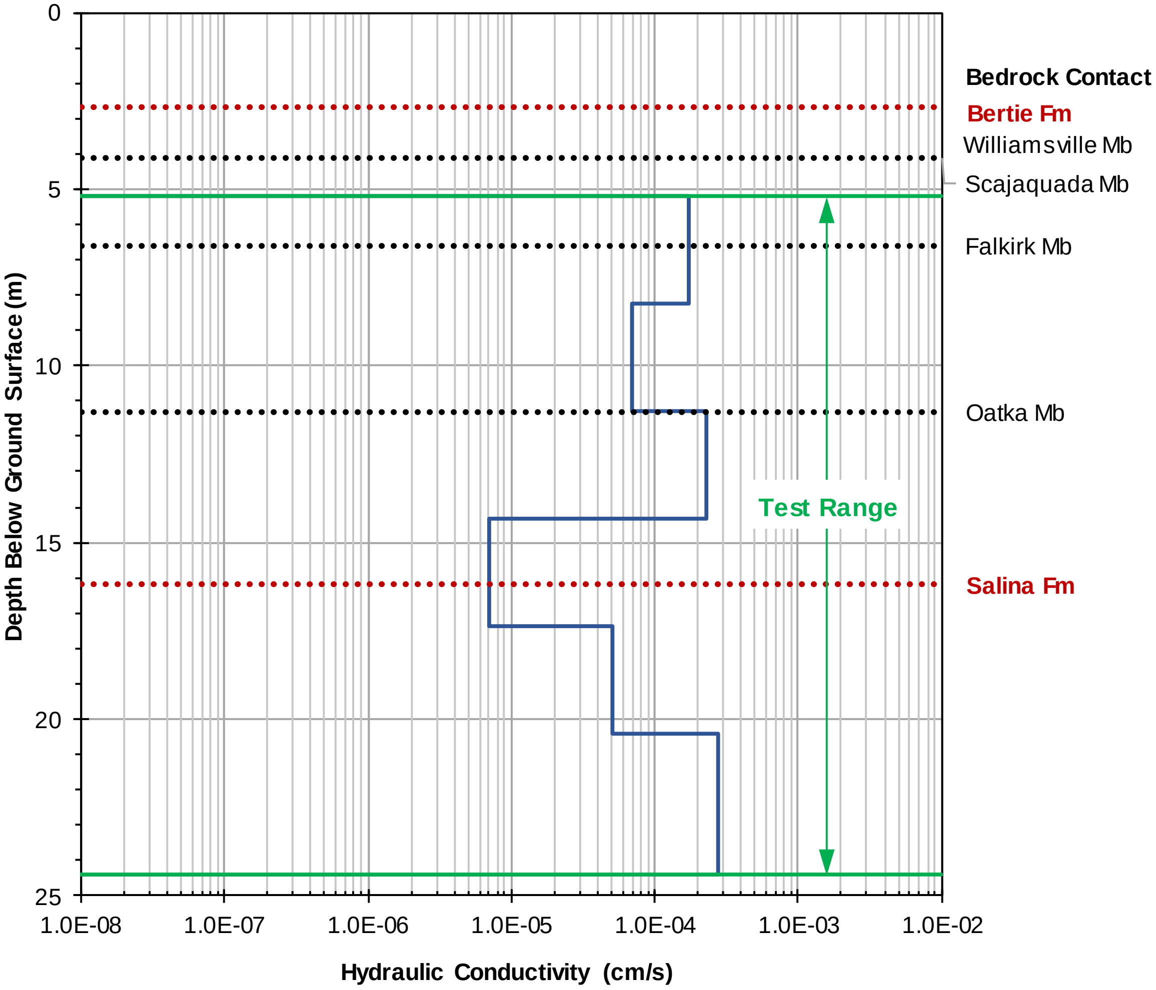
Cumulative Transmissivity = 0.9 cm^2/s (7.9 m^2/day)

GLL-1 Packer Test Results



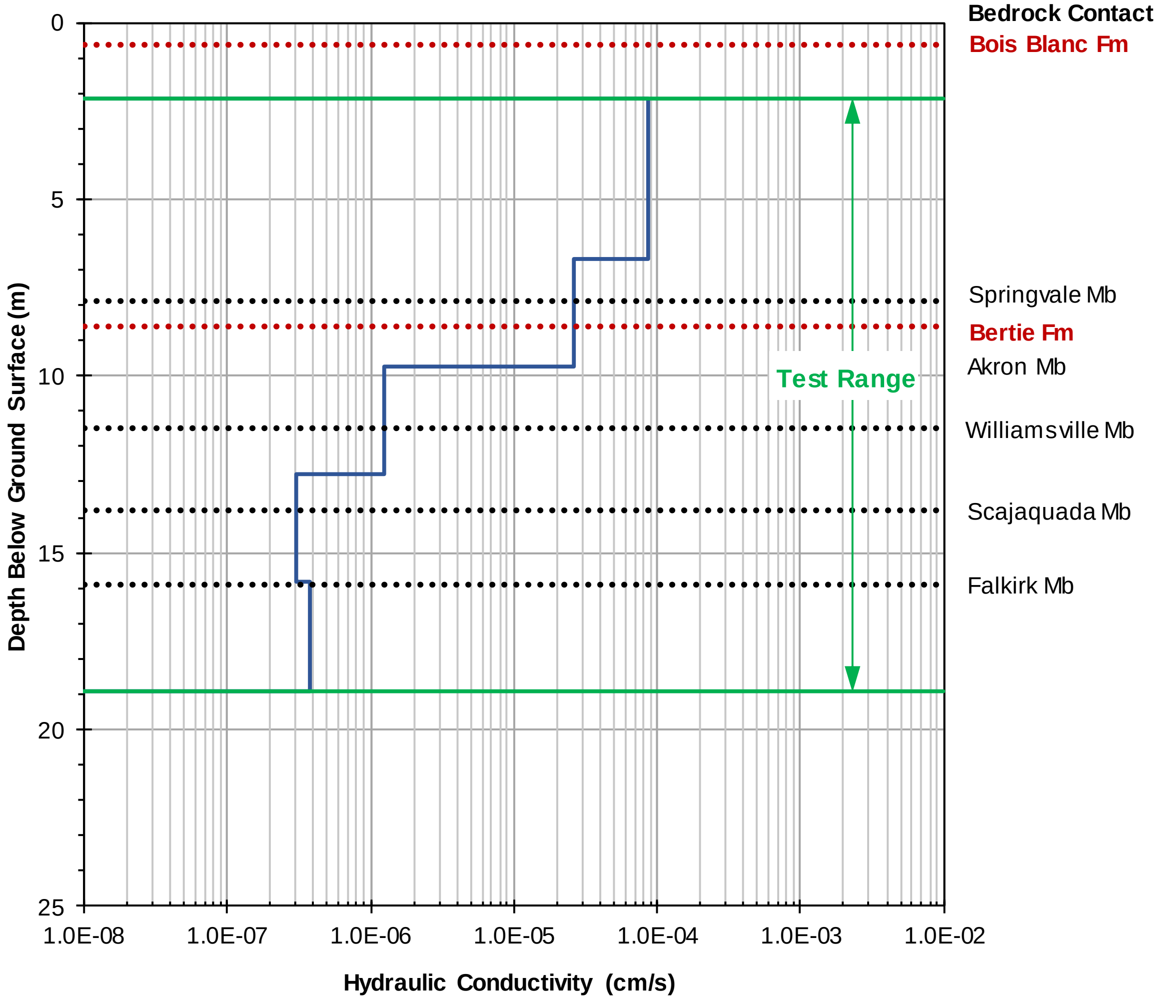
Cumulative Transmissivity = 0.1 cm^2/s (1.3 m^2/day)

GLL-3 Packer Test Results



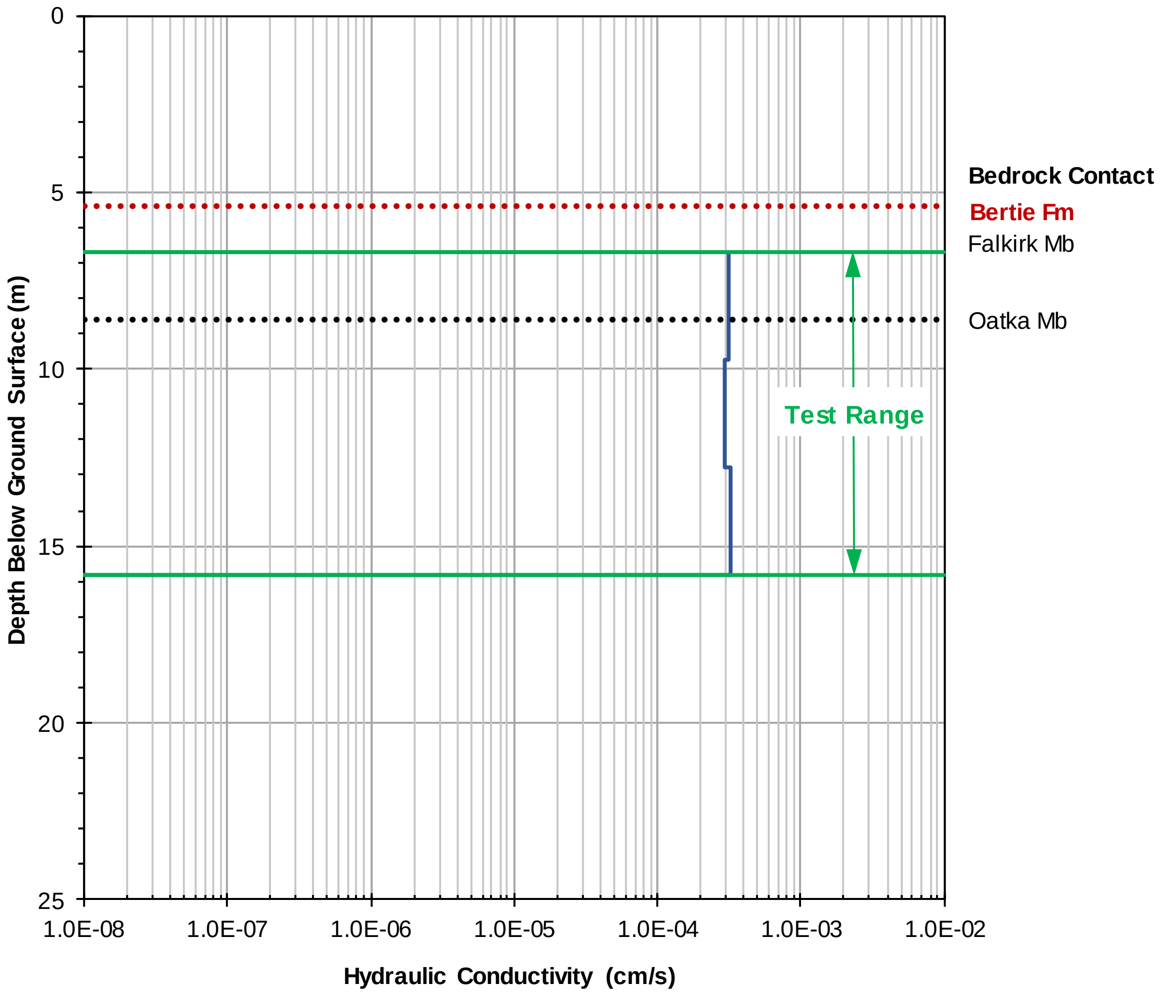
Cumulative Transmissivity = 0.3 cm^2/s (2.3 m^2/day)

GLL-4 Packer Test Results



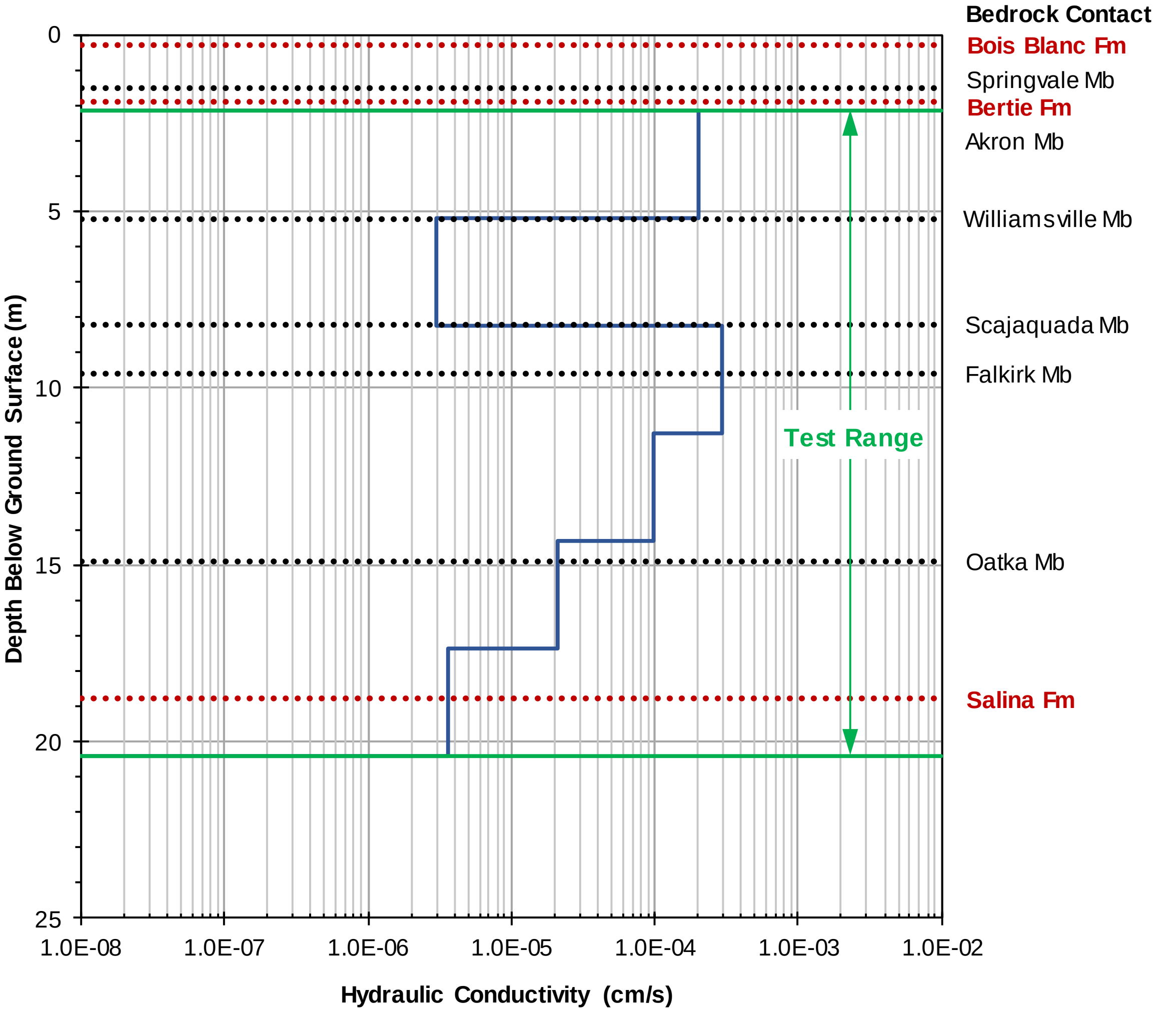
Cumulative Transmissivity = <0.1 cm^2/s (0.4 m^2/day)

GLL-5 Packer Test Results



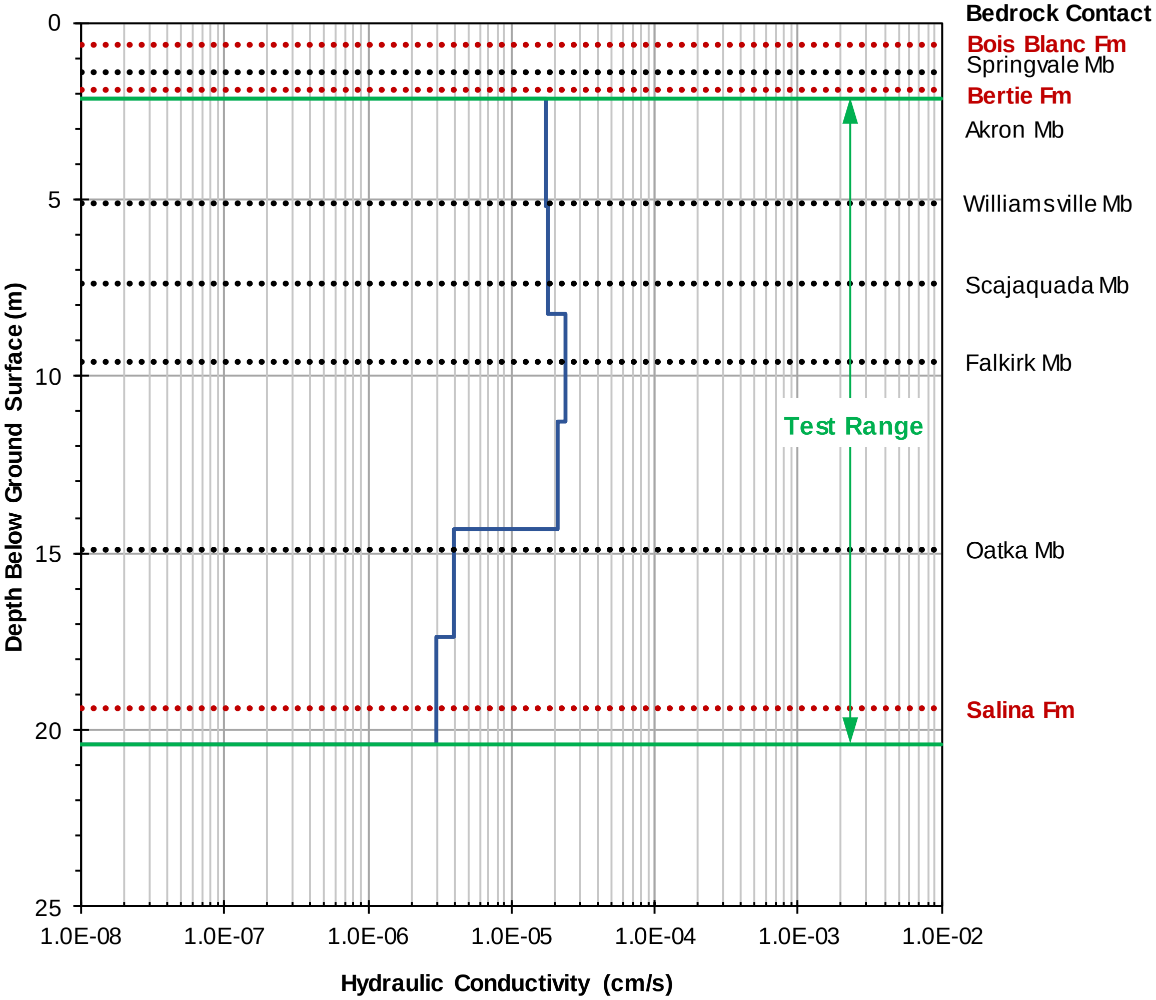
Cumulative Transmissivity = 0.3 cm^2/s (2.4 m^2/day)

GLL-6 Packer Test Results



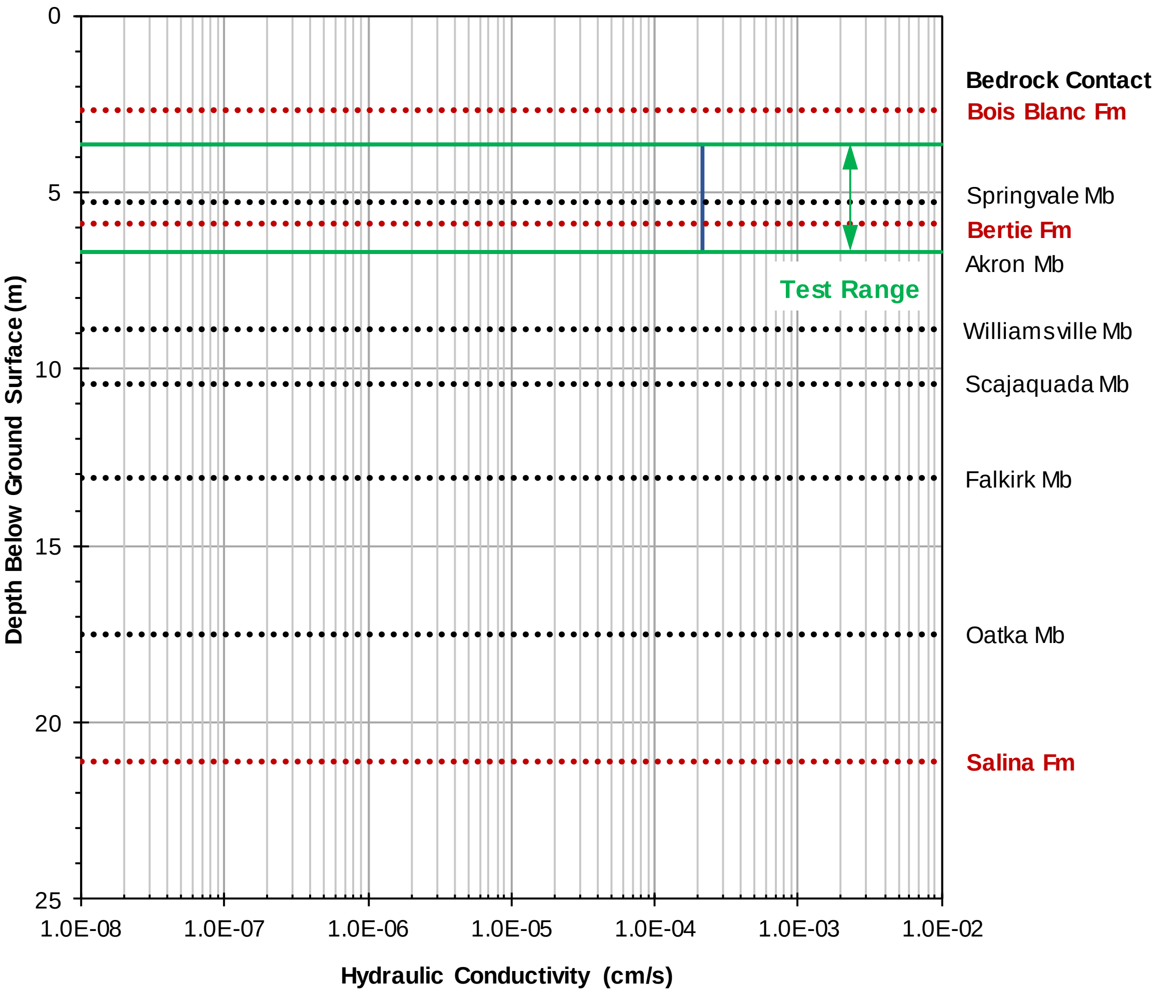
Cumulative Transmissivity = 0.2 cm^2/s (1.6 m^2/day)

GLL-7 Packer Test Results



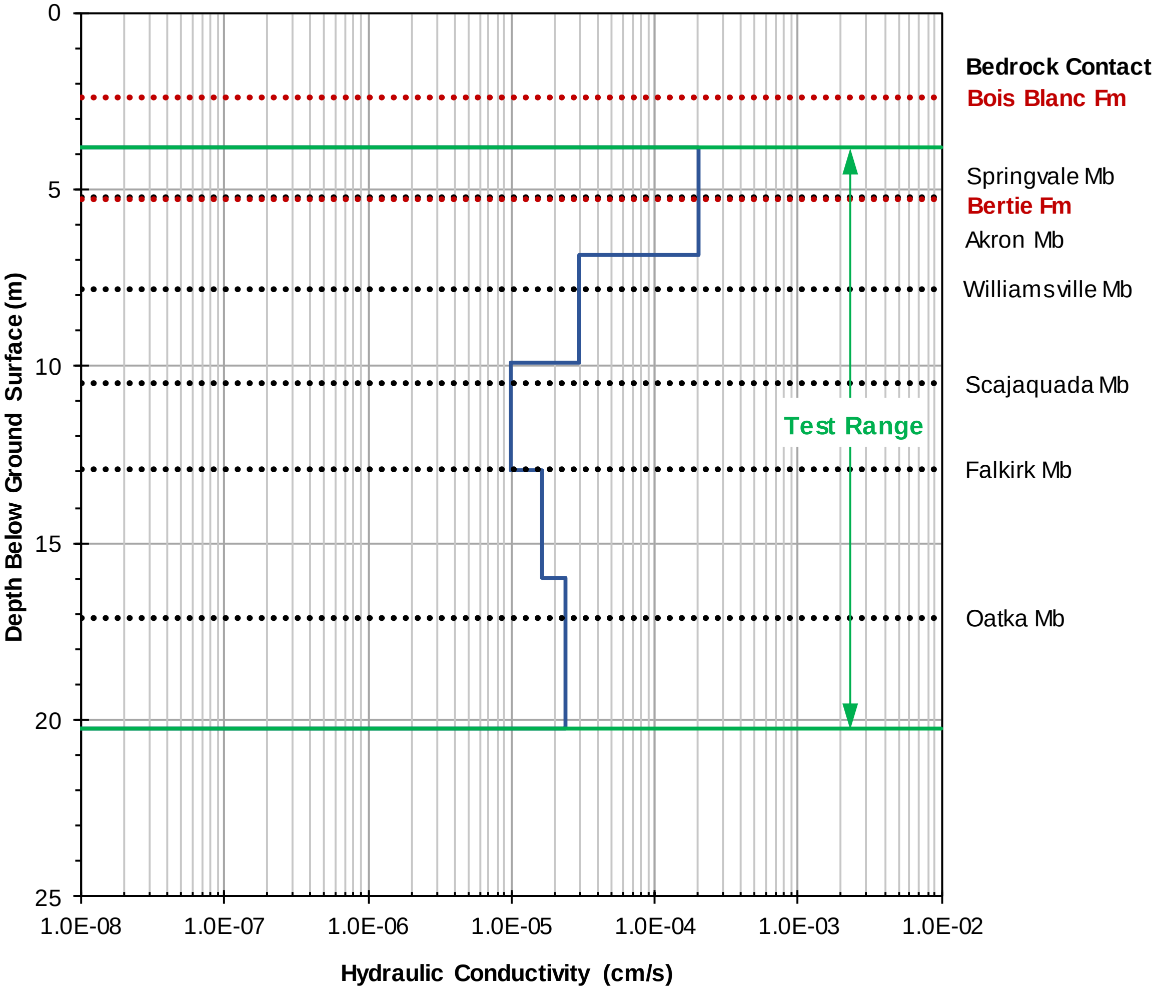
Cumulative Transmissivity = <0.1 cm^2/s (0.2 m^2/day)

GLL-8 Packer Test Results



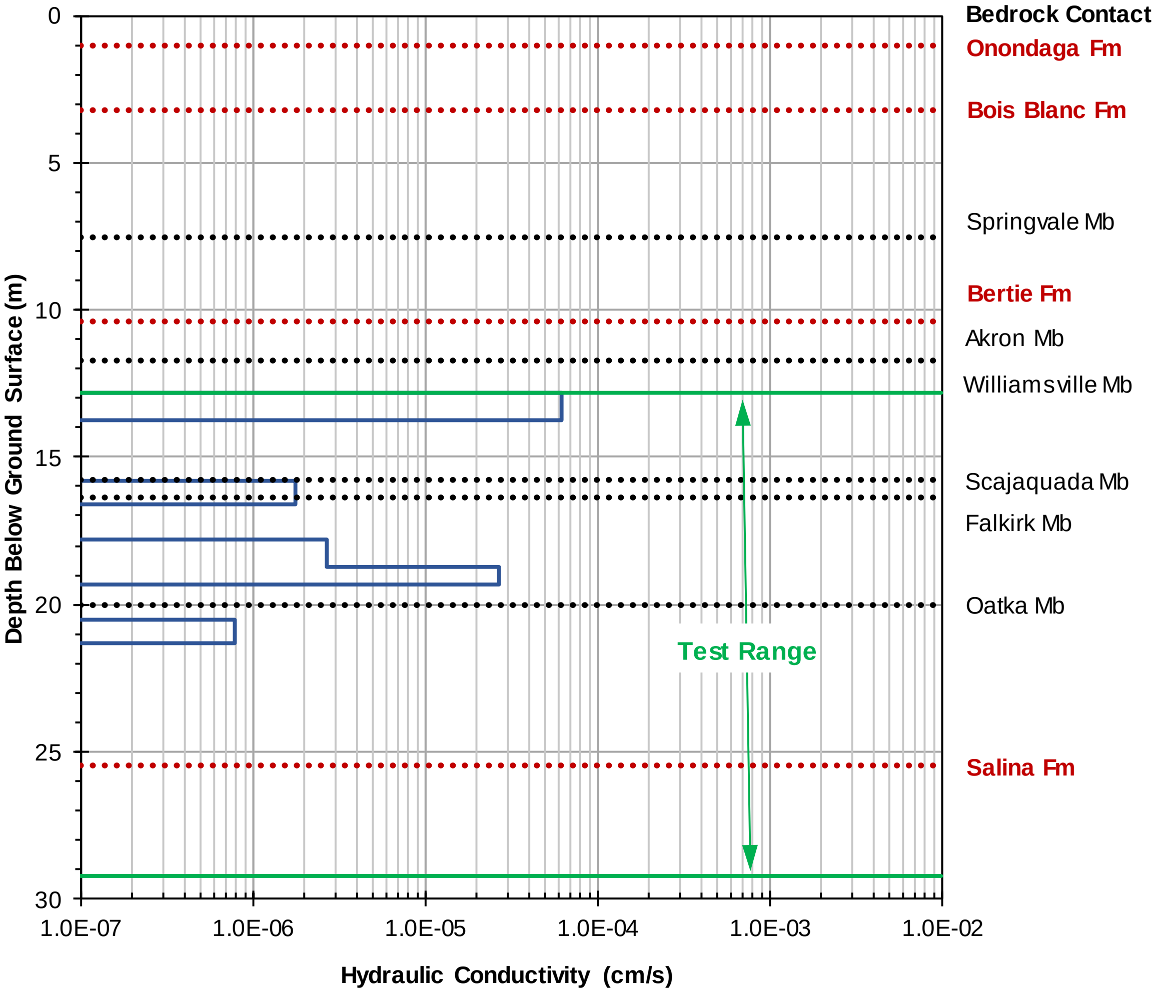
Cumulative Transmissivity = 0.1 cm^2/s (0.6 m^2/day)

GLL-9 Packer Test Results



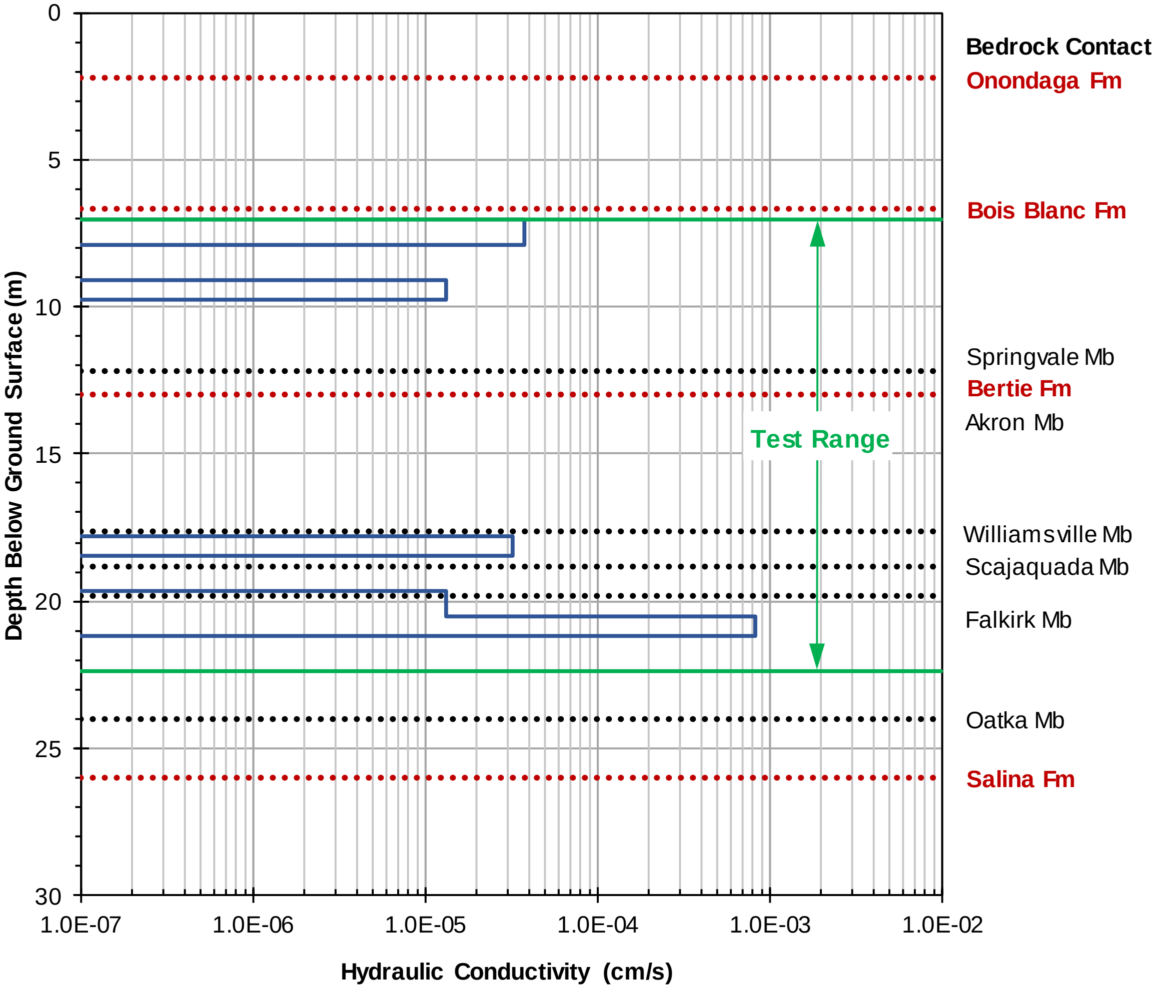
Cumulative Transmissivity = 0.1 cm^2/s (0.8 m^2/day)

OW1 (Reeb Quarry) Packer Test Results



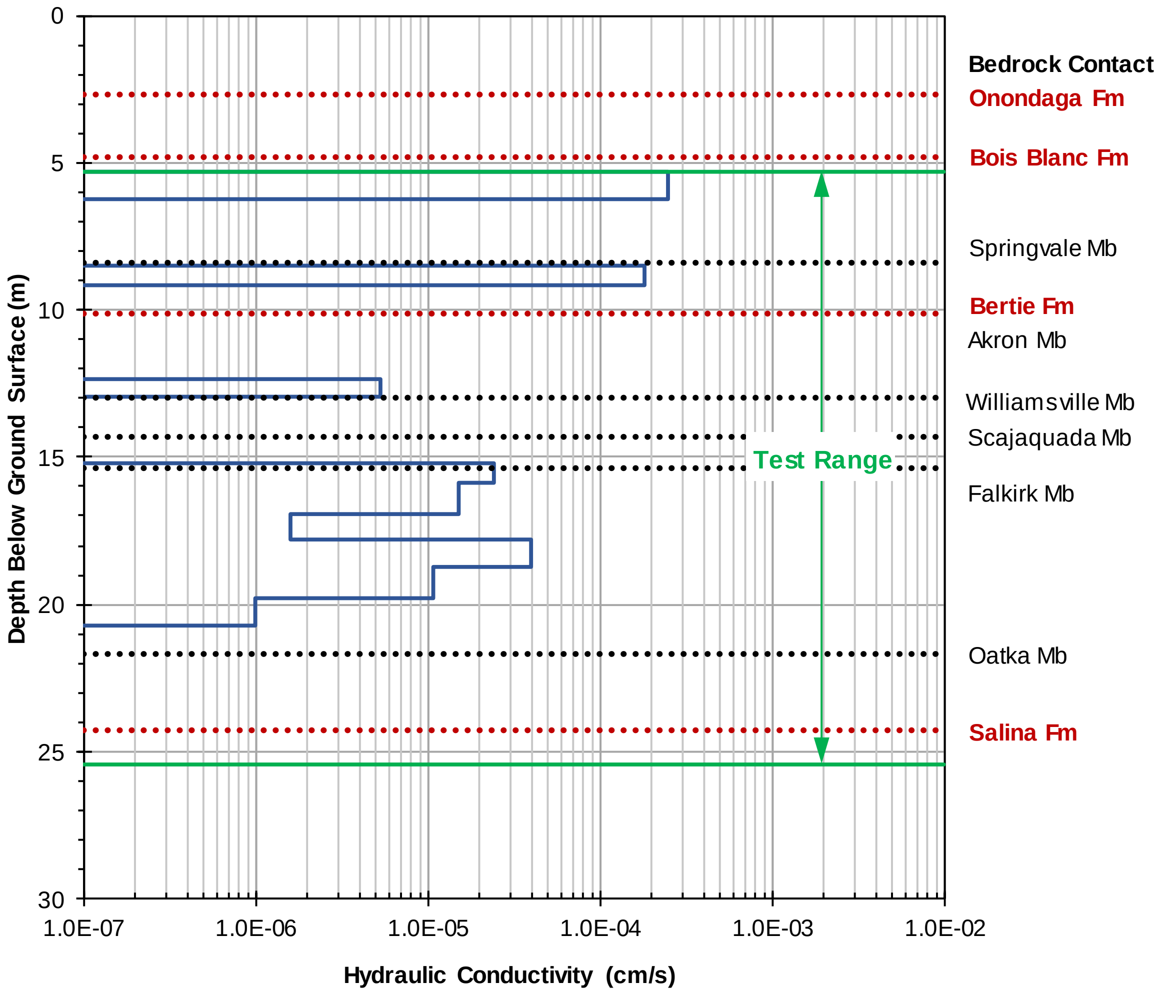
Cumulative Transmissivity = 0.8 cm^2/s (6.9 m^2/day)

OW2 (Reeb Quarry) Packer Test Results



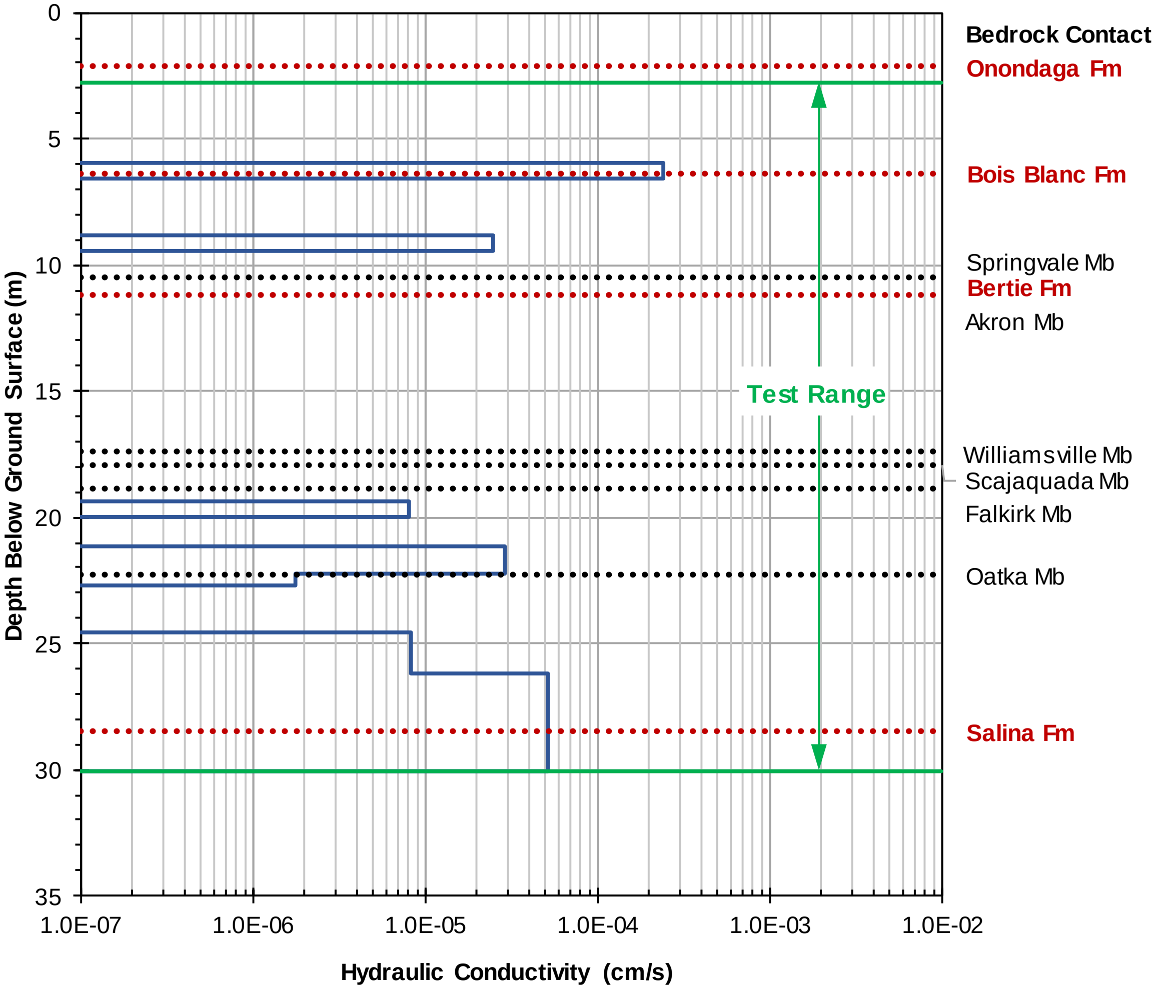
Cumulative Transmissivity = 6.0 cm^2/s (52 m^2/day)

OW3 (Reeb Quarry) Packer Test Results



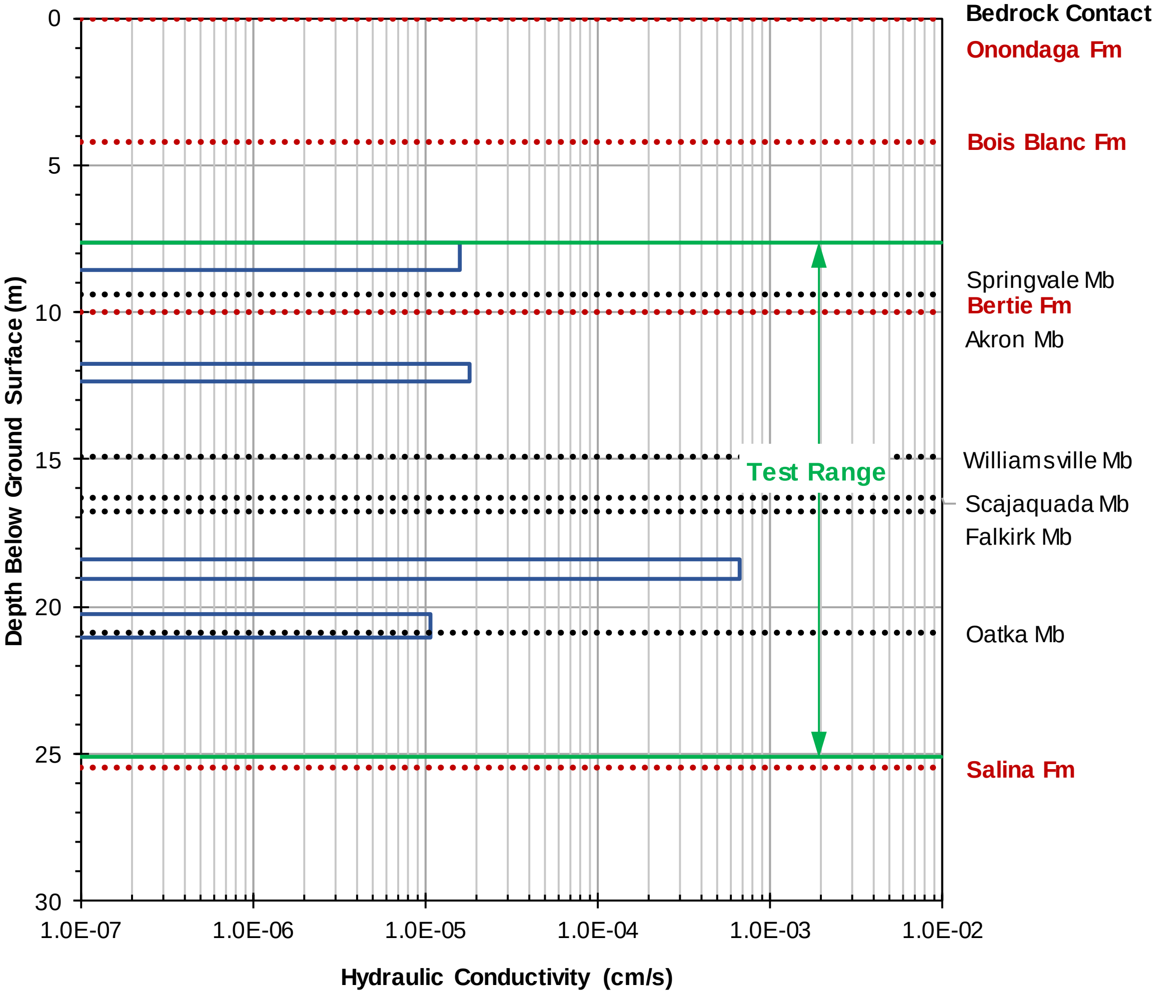
Cumulative Transmissivity = 4.3 cm^2/s (37 m^2/day)

OW4 (Reeb Quarry) Packer Test Results



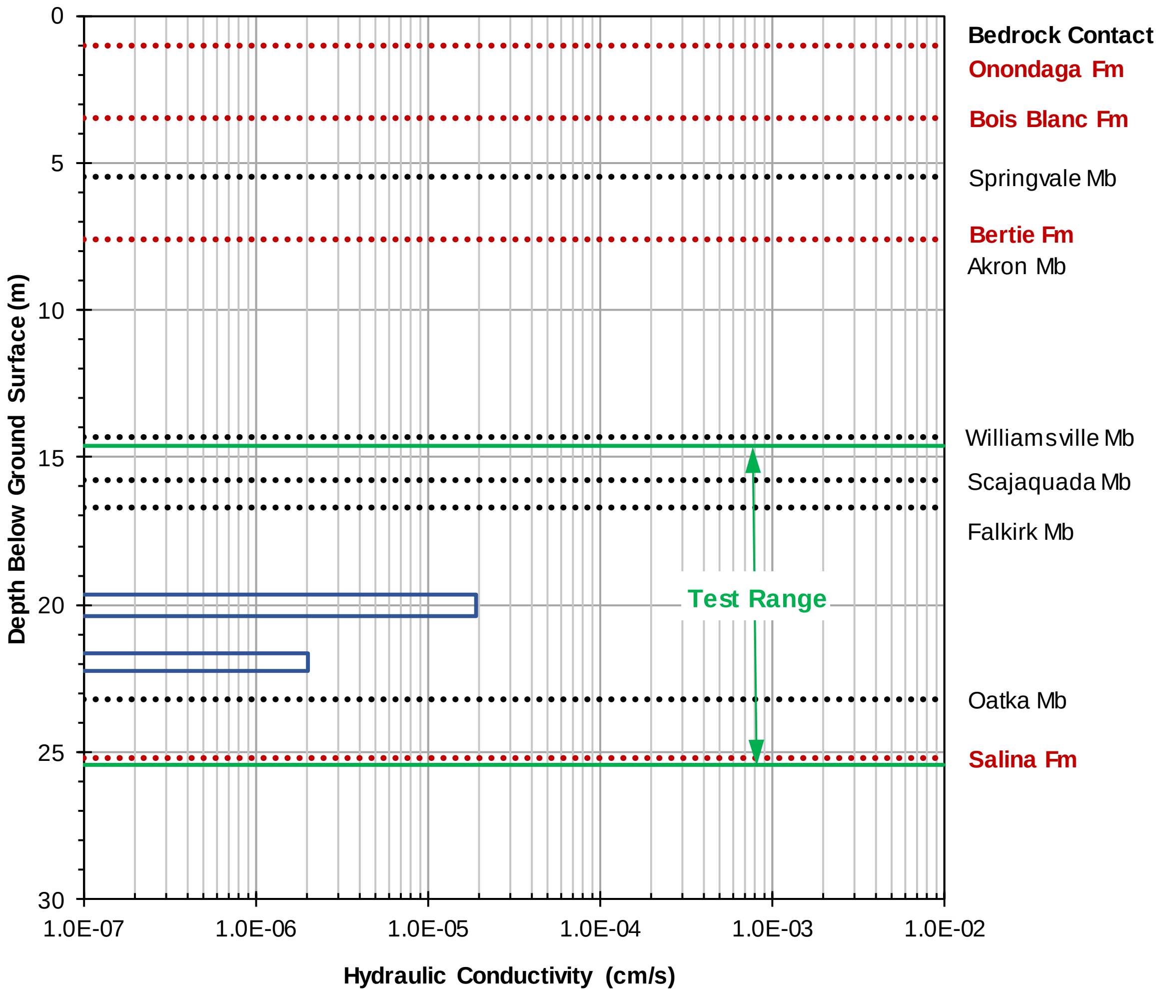
Cumulative Transmissivity = 4.2 cm^2/s (36 m^2/day)

OW5 (Reeb Quarry) Packer Test Results



Cumulative Transmissivity = 4.6 cm^2/s (40 m^2/day)

OW6 (Reeb Quarry) Packer Test Results



Cumulative Transmissivity = 0.2 cm^2/s (1.5 m^2/day)

D.3 SINGLE WELL RESPONSE TESTING

As part of the current hydrogeological investigation undertaken at the Site, in-situ single well response hydraulic conductivity (slug) tests have been completed at most monitoring wells. The slug testing analyses are included in **Appendix D-2**, and summarized in **Tables D.3.1 through D.3.5** below.

Table D.3.1 Hydraulic Conductivity in Shallow Bedrock Aquifer Wells

Well	Figure No.	Hydraulic Conductivity cm/s	Notes
GLL-1	2-1	2.9×10^{-3}	<1 m of head change achieved during test
GLL-3	2-2	1.2×10^{-5}	
GLL-7	2-3	1.6×10^{-6}	
GLL-9	2-4	4.3×10^{-5}	
GLL-10	2-5	3.3×10^{-5}	
GLL-11-II	2-6	1.1×10^{-4}	

Table D.3.2 Hydraulic Conductivity in Falkirk Mb Wells

Well	Figure No.	Hydraulic Conductivity cm/s	Notes
MW1-III	2-7	1.8×10^{-5}	
MW4-III	2-8	4.8×10^{-6}	
GLL-5	2-9	1.2×10^{-3}	
GLL-6	2-10	6.4×10^{-6}	
GLL-8		--	Unable to achieve 1 m of head change
MW9-III	2-11	2.2×10^{-4}	
MW10-III	2-12	8.2×10^{-4}	
GLL-11-I	2-13	7.4×10^{-5}	
MW12-III	2-14	3.8×10^{-5}	

Table D.3.3 Hydraulic Conductivity in Oatka Mb Wells

Well	Figure No.	Hydraulic Conductivity cm/s	Notes
MW1-II	2-15	1.6x10^{-6}	Did not return to static conditions
MW4-II	2-16	4.2x10^{-9}	Did not return to static conditions
MW5-II		--	Unable to achieve 1 m of head change
MW6-II	2-17	5.6x10^{-8}	
MW9-II	2-18	3.6x10^{-7}	
MW10-II	2-19	2.1x10^{-5}	
MW11-1	2-20	1.1x10^{-4}	
MW12-II	2-21	2.4x10^{-5}	

Table D.3.4 Hydraulic Conductivity in Salina Fm Wells

Well	Figure No.	Hydraulic Conductivity cm/s	Notes
MW1-I	2-22	5.3x10^{-5}	
MW5-I		--	Unable to achieve 1 m of head change
MW10-I	2-23	5.3x10^{-4}	

Table D.3.5 Summary of Hydraulic Conductivity in Stratigraphic Units

Stratigraphic Unit	No. of Wells	Hydraulic Conductivity (cm/s)			Published Range * cm/s
		Minimum	Maximum	Geometric Mean	
Shallow Bedrock Aquifer	6	1.6x10^{-6}	2.9x10^{-3}	4.5x10^{-5}	1x10^{-7} to 6x10^{-4} ⁽¹⁾
Deep Bedrock – Falkirk Mb	8	4.8x10^{-6}	1.2x10^{-3}	6.5x10^{-5}	
Deep Bedrock – Oatka Mb	7	4.2x10^{-9}	1.1x10^{-4}	1.3x10^{-6}	
Deep Bedrock – Salina Fm	2	5.3x10^{-5}	5.3x10^{-4}	1.7x10^{-4}	1x10^{-11} to 2x10^{-7} ⁽²⁾

Notes: * From Domenico and Schwartz, 1998.
(1) Limestone and dolomite
(2) Shale

D.4 PUMPING TEST

A ~3 day constant rate pumping test was performed on pumping well PW between February 6 and 9, 2019 to simulate dewatering of the proposed quarry expansion and to determine potential effects on local groundwater users and sensitive features. The pumping test was completed under Permit-to-Take-Water (PTTW) No. 5816-B5FPUV issued by the MECP on October 15, 2018.

During the test, groundwater elevations were monitored at pumping well PW and all Site monitoring wells. Water levels were recorded using automated dataloggers augmented with periodic manual measurements during the pumping test.

Background groundwater elevation data was collected prior to the pumping test monitoring well nest MW10 (refer to **Figure E-10**, **Appendix E** of the Level 2 Hydrogeological Study report). The background data suggest that ambient groundwater elevation trends did not have a significant impact on water level data obtained during the pumping test.

D.4.1 STEP TEST

Prior to the constant rate test, on February 6, 2019, a step test was completed on PW. The results of the step test were reviewed to evaluate the performance of the pumping well and estimate well efficiency.

Well efficiency (E_w) can be calculated using the following equation (Kruseman and de Ridder, 1990).

$$E_w = \left\{ \frac{B_1 Q}{(B_1 + B_2)Q + CQ^P} \right\} \times 100\%$$

Where: B_1 = linear aquifer loss coefficient
B_2 = linear well loss coefficient
$B \approx B_1 + B_2$
C = non-linear well loss coefficient
Q = well discharge
$P = 2$

In an ideal well (i.e., efficiency = 100%), groundwater within the aquifer is able to flow directly into the well bore and the drawdown in the well reflects the actual drawdown within the aquifer. In a fractured bedrock setting, the capacity of the water-bearing fractures is quantified by parameter B_1. Well inefficiency arises due to the alteration of the formation during drilling and the well screen not fully penetrating the aquifer (quantified by parameter B_2) and development of turbulent flow conditions in the pumping well and potentially the formation itself (quantified by parameter C).

The step test at PW consisted of three pumping steps at flow rates of 71 L/min (16 Igpm) for approximately 45 minutes, 114 L/min (25 Igpm) for approximately 56 minutes and 230 L/min (51 Igpm) for approximately 55 minutes. After the third step, the pumping rate was kept constant for the duration of the 72-hour constant rate test. The observed drawdown during the step test is shown in **Figure 3-1**, **Appendix D-3**.

The results of the step test analysis for PW are presented in **Figure 3-2**, **Appendix D-3**.

The water level in PW was lowered during each pumping step. The well efficiency estimated from the step test at PW decreased from 96% to 87% at the pumping rates used in the step test.

D.4.2 CONSTANT RATE TEST

On February 6, 2019, Country Water Systems, under the supervision of WSP personnel, held the final rate of the step test constant for approximately 72 hours (4,270 minutes) at pumping well PW. A target pumping rate of approximately 185 L/min (41 Igpm) was used for the constant rate test, with a pump intake depth of approximately 30.5 m below top of pipe (mbtop), within the Salina Formation shale. The pumping rate was maintained within ±10% of this flow for the duration of the constant rate test. During the period between 1 am and 11 am on February 8, the pumping rate was reduced due to movement of the discharge piping during an ice and wind storm event. A plot of the PW drawdown water level data is shown in **Figure 3-3**, **Appendix D-3**. A maximum drawdown of approximately 16.9 m was observed in the pumping well prior to pump shutdown. This represents approximately 73% of the available drawdown (approximately 23 m).

During the constant rate test, groundwater levels at well nest MW10 located 28 m west of the pumping well were observed to lower in the deep Salina Formation (MW10-I), Oatka / Salina contact (MW10-II) and Falkirk member (MW10-III) in response to pumping at PW. However, there was no observed effect within the shallow bedrock aquifer (GLL-10) at the same nest. Groundwater levels at well nests MW9 located 230 m north of the pumping well and MW12 located 365 m east of the pumping well were also observed to lower in the Oatka / Salina contact and Falkirk member intervals in response to pumping. Plots of the well water level data where pumping test responses were observed are shown in **Figures 3-4 through 3-10**, **Appendix D-3**. A summary of the total observed drawdown prior to pump shutdown at each well is summarized in **Table D.4.1** below.

Table D.4.1 Summary of Drawdown at Observation Wells

Direction from Pumping Well	Observation Well	Hydrostratigraphic Formation	Figure No.	Distance from Pumping Well (m)	Total Drawdown (m)
West	**MW10-I**	Deep Salina	3-4	28	14.6
	MW10-II	Oatka / Salina Contact	3-5		12.8
	MW10-III	Falkirk	3-6		3.2
North	**MW9-II**	Oatka / Salina Contact	3-7	230	0.9
	MW9-III	Falkirk	3-8		0.4
East	**MW12-II**	Oatka / Salina Contact	3-9	365	3.7
	MW12-III	Falkirk	3-10		1.0

Upon completion of the constant rate test at PW, the groundwater elevation recovery was monitored at the pumping well and observation wells. On February 10, 2019, after a period of 900 minutes (15 hours) since pump shutdown (i.e., 5,170 minutes total elapsed time since the start of the constant rate test), the water level in PW had stabilized at approximately 10.4 mbtop, which corresponds to a recovery of about 97% from the pre-test static water level of 10.1 mbtop. It is noted that on February 6, a total of 15 mm of precipitation was recorded at the Environment Canada Port Colborne climate station. It is likely that the ambient groundwater elevations within the bedrock were on a slight downward trend following this precipitation event and is likely the reason why the pumping well did not recover fully to pre-test static conditions.

Similar rates of recovery and timeframes were observed at well nest MW10. The water levels at MW9 and MW12 appeared to take longer to recover to static conditions. It is noted that the deeper bedrock unit water levels at MW9 and MW12 generally experienced a lower percentage of recovery to pre-test static conditions. It is inferred that ambient conditions within these bedrock units are the cause of the lower rates of recovery at MW9 and MW12.

The pumping test data were analyzed using AQTESOLV v.4.50 (HydroSOLVE Inc., 2007) software. The pumping well logger data were "thinned out" to show only representative levels on a log scale for the duration of the test. A number of different analyses were completed on the data as summarized below.

Pumping Well Recovery Cooper-Jacob Straight-Line Analysis

The Cooper-Jacob Straight-Line (CJSL) analysis was completed on the pumping well PW recovery curve to obtain an initial estimate of aquifer transmissivity, as shown on **Figure 3-11**, **Appendix D-3**. Only the recovery curve was used for this analysis since stepped rates were used prior to the commencement of the constant rate test. An average discharge rate of approximately 180 L/min was used for the recovery analysis, which was estimated for the entire duration of the combined step and constant rate tests.

Using this method, the bulk transmissivity of the bedrock sequence is estimated to be 4 m^2/day. Assuming a thickness of 23.4 m, the hydraulic conductivity is estimated as 0.2 m/day (2.3×10^{-4} cm/s). This is within the range of reported values for the Falkirk and Oatka members in **Table D.3.5** above, and similar to the geometric mean of the slug test results for the Salina Formation. Of note, the storage coefficient reported by the software for this analysis is not physically realistic and is a result of the limitations of using the CJSL analysis; however, the estimated transmissivity (i.e., slope of the best-fit straight line) is not affected by the limitations of the method.

The CJSL analysis is only used to obtain an initial estimate of transmissivity, since the pumping well response deviates from an "ideal" aquifer. For an ideal aquifer:

- ➔ The aquifer is confined and has an "apparent" infinite extent;
- ➔ The aquifer is homogeneous, isotropic and of uniform thickness over the area influenced by pumping;
- ➔ The piezometric surface is horizontal prior to pumping;
- ➔ The well is pumped at a constant rate;
- ➔ The well is fully penetrating;
- ➔ Water removed from storage is discharged instantaneously with decline in head;
- ➔ The well diameter is small, so well storage is negligible; and
- ➔ The values of u are small (typically, u < 0.01), where

$$u = \frac{r^2 S}{4Tt}$$

and *r* = distance from the pumped well to a point where drawdown is measured
S = storage coefficient

T = transmissivity
t = time

Using the Cooper-Jacob methodology to analyze the test results implicitly assumes an equivalent porous medium approach, where the response of the fractured bedrock is approximated by an equivalent aquifer consisting of unconsolidated porous media. This means that the predicted drawdown in the pumping well assumes that flow to the well is radial so that the response provides an impression of depth-averaged conditions.

The derivative plot of the data is also included in **Figure 3-11** (green symbols). In an 'ideal' infinite aquifer, the drawdown would continue indefinitely at a rate proportional to the aquifer transmissivity, and the derivative plot would initially increase and then level off at a value of around '1'. The derivative curve on **Figure 3-11** indicates that after approximately 20 minutes elapsed time, the recovery curve deviates from the straight line and the rate of increase in the recovery levels off. This response may either be the result of leakage from the overlying bedrock strata, or the result of the pumping well being situated within a zone of higher permeability than the bulk aquifer properties outside of the zone around the pumping well. Either of the above scenarios results in a plateau in the derivative, and then a decrease.

Pumping Well Recovery Theis Analysis

Pumping well PW recovery data was also analyzed using Theis recovery analysis, as shown in **Figure 3-12**, **Appendix D-3**. The plotted early recovery time is on the right and the late recovery is on the left (i.e., the timescale is inverted). In an ideal aquifer where the drawdown reaches steady-state by the time the pump is shut off, the recovery in the pumping well would be expected to mirror that of the drawdown.

On **Figure 3-12**, the ideal aquifer response curve is shown as the red line. However, the pumping well water level recovers to pre-test static conditions faster than the drawdown time. The plot of recovery water levels versus t/t' reaches zero to the right of the graph origin. This pattern is also indicative of an increase in recharge to the shallow bedrock aquifer. The estimated transmissivity of the aquifer based on the Theis analysis of the recovery data is approximately 14 m^2/day. Assuming an aquifer thickness of 23.4 m, the hydraulic conductivity is estimated as 0.6 m/day ($7.1x10^{-4}$ cm/s). These results compare favourably to the CJSL analytical results.

Pumping Well Recovery Non-Uniform Aquifer Analysis

The pumping well PW recovery data were analyzed assuming a non-uniform aquifer (after Butler, 1988). For this conceptual aquifer model, the solution assumes that the pumping well is located at the centre of a cylinder of radius R embedded within an infinite aquifer. The hydrogeological properties of the cylinder (T_1, S_1) and the infinite aquifer (T_2, S_2) differ from each other. The results of the non-uniform aquifer analysis for the recovery of PW are shown in **Figure 3-13**, **Appendix D-3**.

Using the assumption of a non-uniform aquifer, the transmissivity of the shallow bedrock aquifer outside of the cylinder surrounding the pumping well (i.e., T_2) is calculated to be approximately 41 m^2/day, which is marginally higher than the result from the CJSL analysis above. Assuming an aquifer thickness of 23.4 m, the hydraulic conductivity is calculated as 1.8 m/day ($2.0x10^{-3}$ cm/s). This is marginally above the range of reported values for the shallow bedrock aquifer in **Table D.3.5** above, and marginally above the geometric mean of the slug test results for the Salina Formation.

For the cylinder surrounding the pumping well PW, the calculated transmissivity (i.e., T_1) is 25 m^2/day. Assuming an aquifer thickness of 23.4 m, the hydraulic conductivity is calculated as 1.1 m/day ($1.2x10^{-3}$ cm/s).

Observation Well Distance-Drawdown Analysis

Finally, the observation well drawdowns prior to pump shutoff during the constant rate test were analyzed using the distance-drawdown method, assuming a confined ideal aquifer (Theis). The results are shown in **Figure 3-14**, **Appendix D-3**.

As shown in **Figure 3-14**, the estimated aquifer transmissivity using the Theis distance-drawdown method for an ideal confined aquifer is approximately 21 m^2/day with a storage coefficient of approximately $8x10^{-5}$. As shown in the figure, the best-fit line is roughly situated along the centroid of the observation well drawdown results, with the exception of MW9 north of the pumping well. Assuming a thickness of 23.4 m, the hydraulic conductivity is estimated as 0.9 m/day ($1.0x10^{-3}$ cm/s). This is marginally above the range of reported values for the shallow bedrock aquifer in **Table D.3.5** above, and marginally above the geometric mean of the slug test results for the Salina Formation.

4.2.1 COMPARISON TO 2005 PUMPING TEST

A 72-hour pumping test at pumping well PW was previously completed by others on February 1, 2005, as part of the Law quarry east extension Level 2 Hydrogeological Study (GLL, 2005). The well was pumped at a rate of 227 L/min (50 Igpm), and a maximum drawdown of 15.9 m was observed after 3 hours of pumping and this water level was sustained for the remainder of the test. The pumping well recovered to 95% of the static water level 7 hours into the recovery period. There was no response observed in any of the shallow bedrock aquifer wells present at the time of the test (there were no monitoring wells completed to the deeper bedrock units at that time). It was speculated that the casing in the pumping well may have been set deep enough such that the well may not be hydraulically connected to the shallow bedrock aquifer. The only well which appeared to respond to the pumping at PW was an unused private well situated approximately 200 m to the west of PW (no address provided). At the private well, a maximum drawdown of 0.72 m was observed over the course of the test. However, the data suggest that the water levels may also have been partially decreasing due to ambient conditions in the aquifer. A transmissivity of 3 m^2/day to 74 m^2/day was estimated, with a storativity between $4x10^{-3}$ to $2x10^{-1}$. Assuming an aquifer thickness of 21.5 m, a hydraulic conductivity range of 0.13 m/day to 3.4 m/day ($2x10^{-4}$ cm/s to $4x10^{-3}$ cm/s) was calculated.

In the Reeb quarry Addendum Hydrogeological Investigation Report (Azimuth Consulting Engineers, 2008), it was noted that a response to the 2005 pumping test at PW was observed in the logger data for several Reeb quarry monitoring wells. It is somewhat difficult to interpret from the graph of water level data presented in the report, but it appears that responses to the 2005 pumping test at PW were observed within the deeper bedrock units at well nest OW6 (situated 1 km east of PW), OW1 (1 km southeast of PW) and OW3 (1.6 km southeast of PW). The maximum drawdown appears to range between approximately 0.25 m at the closer well nests, and 0.1 m at the more distant well nest. No impact to the shallow bedrock aquifer is inferred from the plot of the water level data.

Many of the observations from the 2005 test were repeated during the 2019 test, which is not unexpected. The majority of the drawdown in PW occurred during the first 3 hours of the test. A slightly lower pumping rate was used for the long-term portion of the 2019 test; however, slightly more drawdown was observed. This may be an indication that the pumping well efficiency has decreased over time (i.e., clogging of fractures in borehole because of disuse). Most importantly, no drawdown was observed within the shallow bedrock aquifer during the 2019 test. Drawdown was only observed within the deeper bedrock units at monitoring well nests situated in relatively close proximity to the pumping well. Using the various analyses outlined above, the estimated transmissivity of the bulk aquifer is between 4 m^2/day to 41 m^2/day, which is similar to the range of values estimated from the 2005 results.

D.4.3 DISCHARGE CHEMISTRY

Field measurements for pH, conductivity and temperature, as well as a sample of the pumping test discharge was collected within 6 hours of the start of pumping and submitted to Eurofins Environmental Testing Canada Inc. for analysis. The sample results are presented in **Table D.4.2** below.

Table D.4.2 Summary of Pumping Well PW Discharge Chemical Results

Parameter	ODWQS	Sample Date
		6-Feb-19
Field Measurements		
pH (pH units)	6.5 – 8.5	7.2
Conductivity (µS/cm)		3,220
Temperature (ºC)		9.2
Clarity		Clear
Colour		Colourless
Odour		Sulphur
General Parameters		
Fluoride	1.5	1.26
Oil & Grease – Total		1.00
Phosphorus		0.007
Sulphide	0.05 AO	10.0
Hydrogen Sulphide (undissociated)		4.37
Turbidity		0.50
Major Ions		
Chloride	250 AO	88
Sulphate	500 AO	1,380
Calcium		503
Magnesium		130
Sodium	200 AO	59
Potassium		20
Nutrients and Organic Indicators		
Ammonia		1.80
Un-ionized Ammonia		0.01
Total Kjeldahl Nitrogen		3.60
Total Organic Carbon		1.60

Notes: Concentrations in mg/L unless otherwise noted.

Table D4.2 Summary of Pumping Well PW Discharge Chemical Results (*cont'd*)

Parameter	ODWQS	Sample Date
		6-Feb-19
Total Metals		
Bromine		0.26
Boron	5	4.90
Chromium	0.05	0.002
Iron	0.3 AO	0.05
Manganese	0.05 AO	0.01
Strontium		11.3

Notes: Concentrations in mg/L unless otherwise noted.

The pumping test sample collected on February 6, 2019 was collected directly from the pumping well discharge pipe. Only parameters which were detected above the lab reported detection limit are included on the table below.

In general, the laboratory results were below Ontario Drinking Water Standards, with the exception aesthetic objective exceedances of sulphide and sulphate. The discharge from the pumping well during the pumping test was observed to be clear and colourless. A sulfur odour was noted during the sample collection.

REFERENCES

Azimuth Environmental Consulting, Inc., and Earthfx Inc. 2008. *Addendum Hydrogeological Assessment / Numerical Modelling Report, Reeb Quarry.* Prepared for M.A.Q Aggregates Inc., January 2008.

Butler, J.J. Jr., 1988. *Pumping Tests in Non-Uniform Aquifers – The Radially Symmetric Case*. Journal of Hydrology, Vol. 101, pp. 15-30.

Domenico, P.A., and Schwartz, F.W., 1998. *Physical and Chemical Hydrogeology*. John Wiley & Sons, New York, 506 p.

Gartner Lee Limited. 2005. *Hydrogeological Assessment for Below Water Extraction, Law Quarry Eastern Extension, Township of Wainfleet, Region of Niagara*.

Kruseman, G.P. and de Ridder, N.A., 1990. *Analysis and Evaluation of Pumping Test Data, 2nd Edition*.

APPENDIX

D-1 PACKER TEST ANALYSES

Figure 1-1-1

MW1-1 (6.1m - 9.1m)

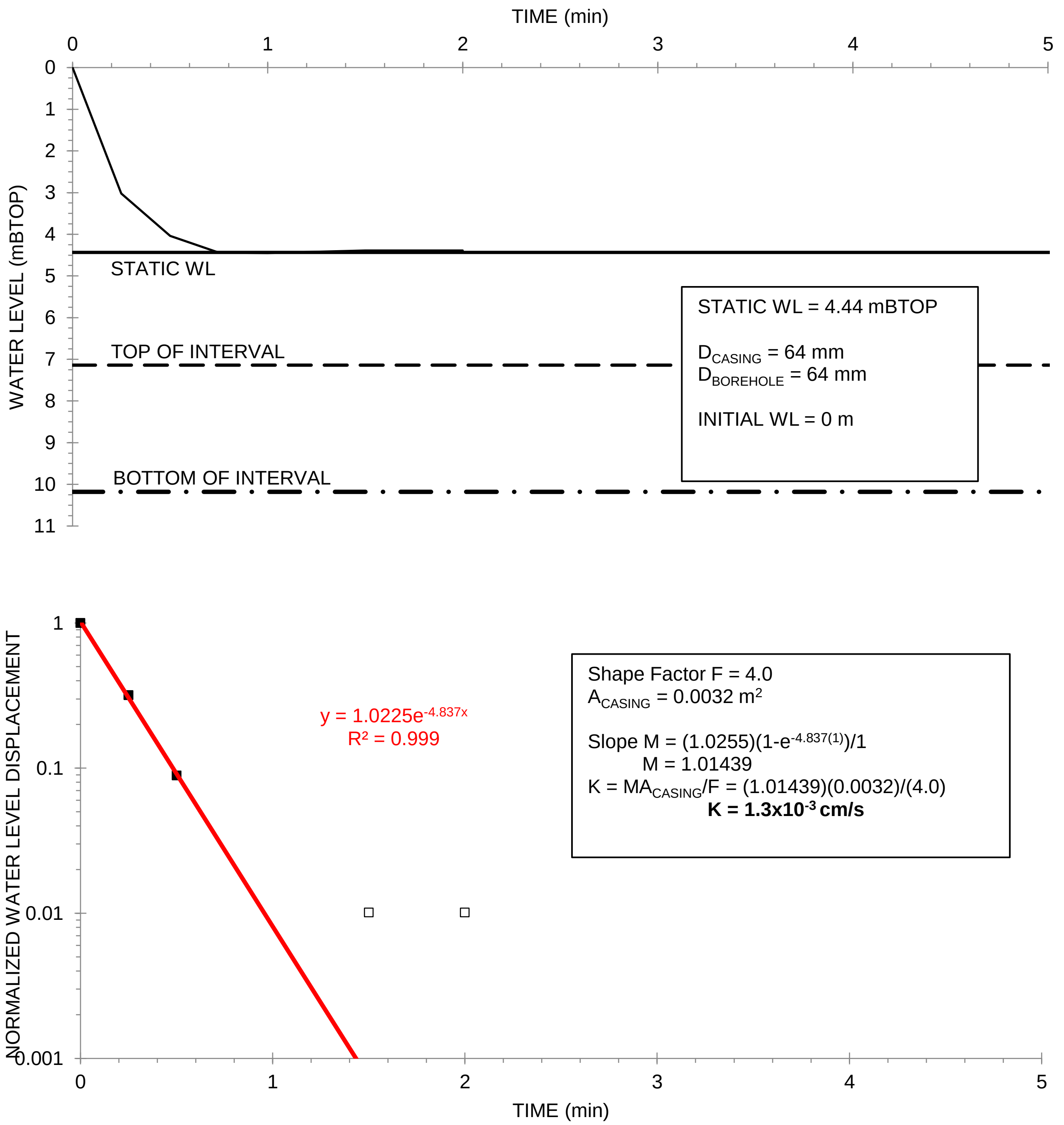
Falling Head Packer Test Analysis

Hvorslev Method

Law Quarry Extension

Date: July 4, 2018

Performed by: CS



STATIC WL = 4.44 mBTOP

D_{CASING} = 64 mm
$D_{BOREHOLE}$ = 64 mm

INITIAL WL = 0 m

Shape Factor F = 4.0
A_{CASING} = 0.0032 m^2

Slope M = (1.0255)(1-e$^{-4.837(1)}$)/1
M = 1.01439
K = MA_{CASING}/F = (1.01439)(0.0032)/(4.0)
K = 1.3x10^{-3} cm/s

Figure 1-1-2

MW1-1 (9.1m - 12.2m)

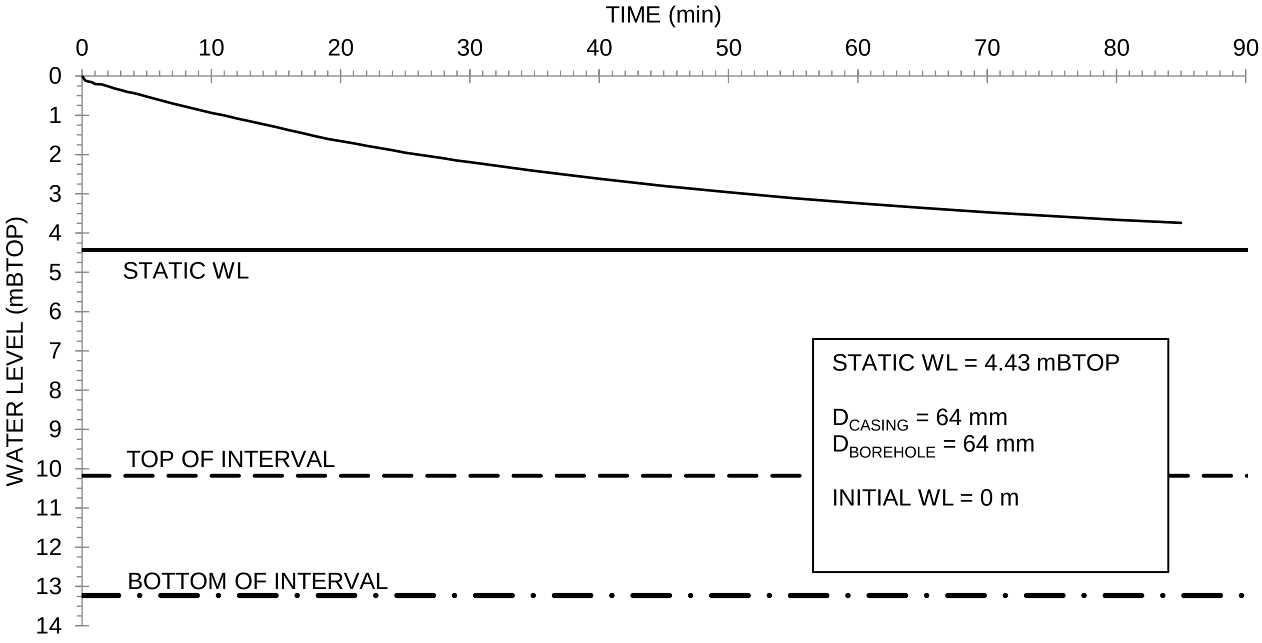
Falling Head Packer Test Analysis

Hvorslev Method

Law Quarry Extension

Date: July 4, 2018

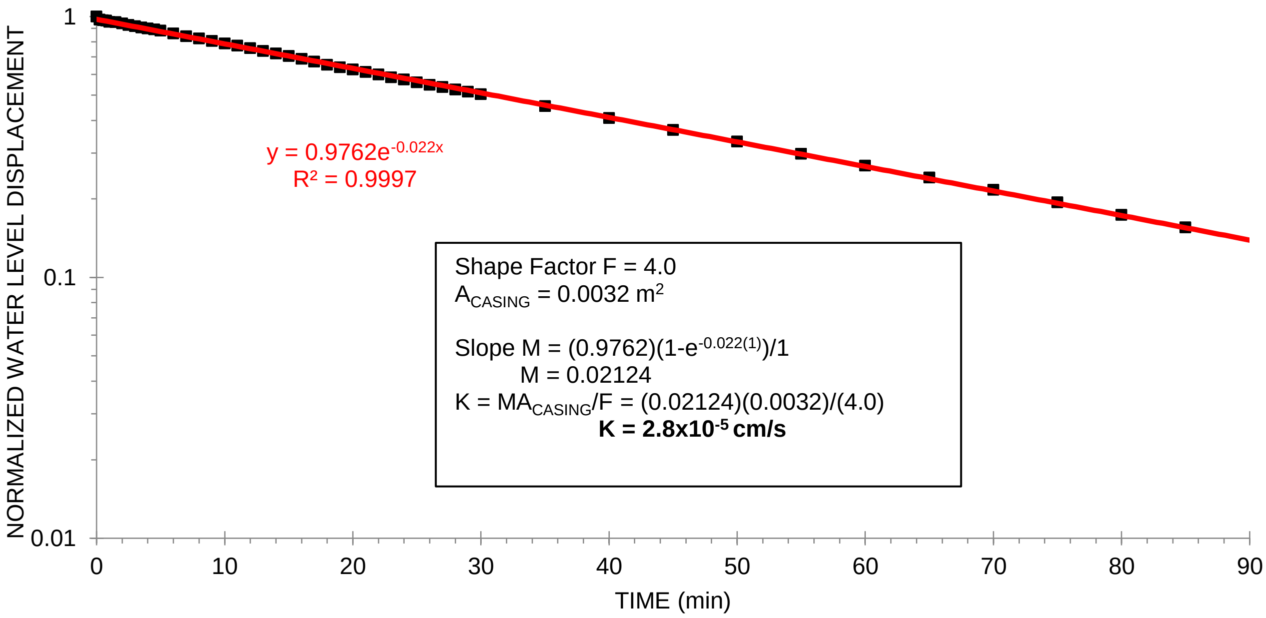
Performed by: CS



STATIC WL = 4.43 mBTOP

D_{CASING} = 64 mm
$D_{BOREHOLE}$ = 64 mm

INITIAL WL = 0 m



Shape Factor F = 4.0
A_{CASING} = 0.0032 m^2

Slope M = $(0.9762)(1-e^{-0.022(1)})/1$
M = 0.02124
K = MA_{CASING}/F = (0.02124)(0.0032)/(4.0)
K = 2.8×10^{-5} cm/s

Figure 1-1-3

MW1-1 (12.2m - 15.2m)

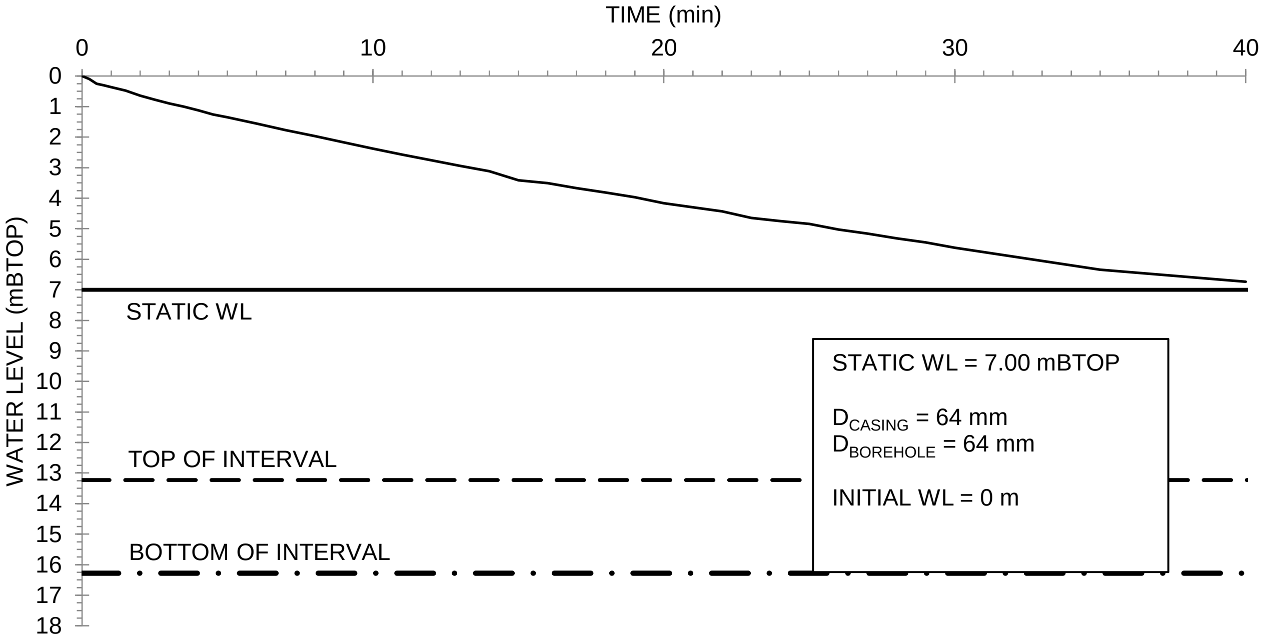
Falling Head Packer Test Analysis

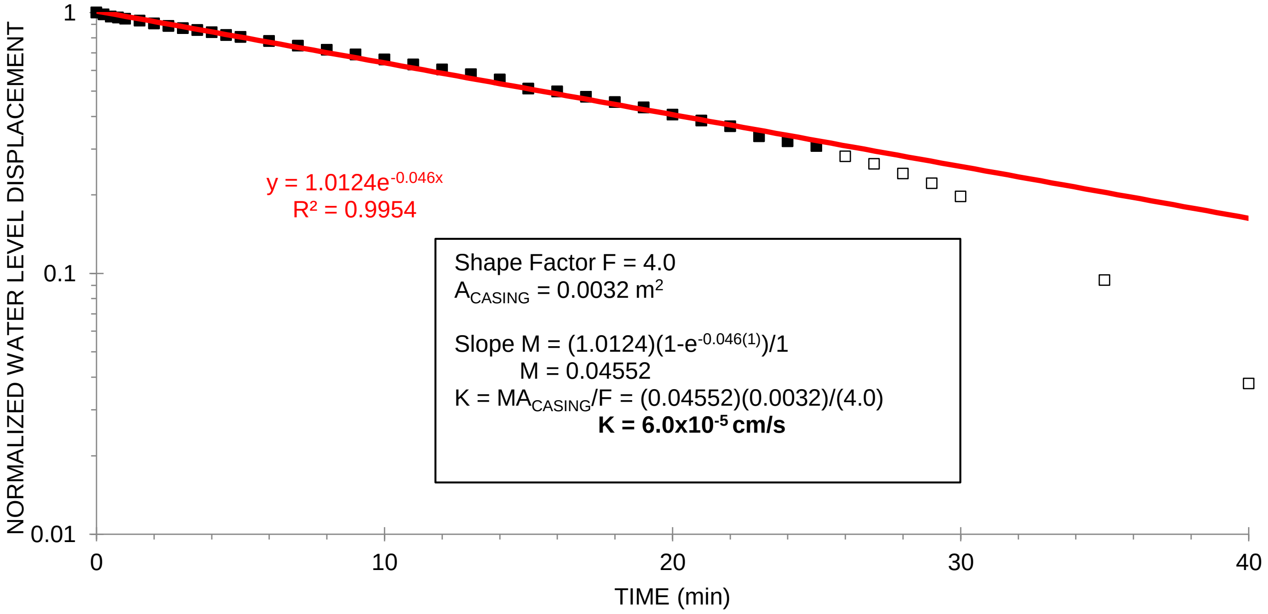
Hvorslev Method

Law Quarry Extension

Date: July 4, 2018

Performed by: CS





Shape Factor F = 4.0
$A_{CASING} = 0.0032\ m^2$

Slope M = $(1.0124)(1-e^{-0.046(1)})/1$
M = 0.04552
$K = MA_{CASING}/F = (0.04552)(0.0032)/(4.0)$
$K = 6.0x10^{-5}$ cm/s

Figure 1-1-4

MW1-1 (15.2m - 18.3m)

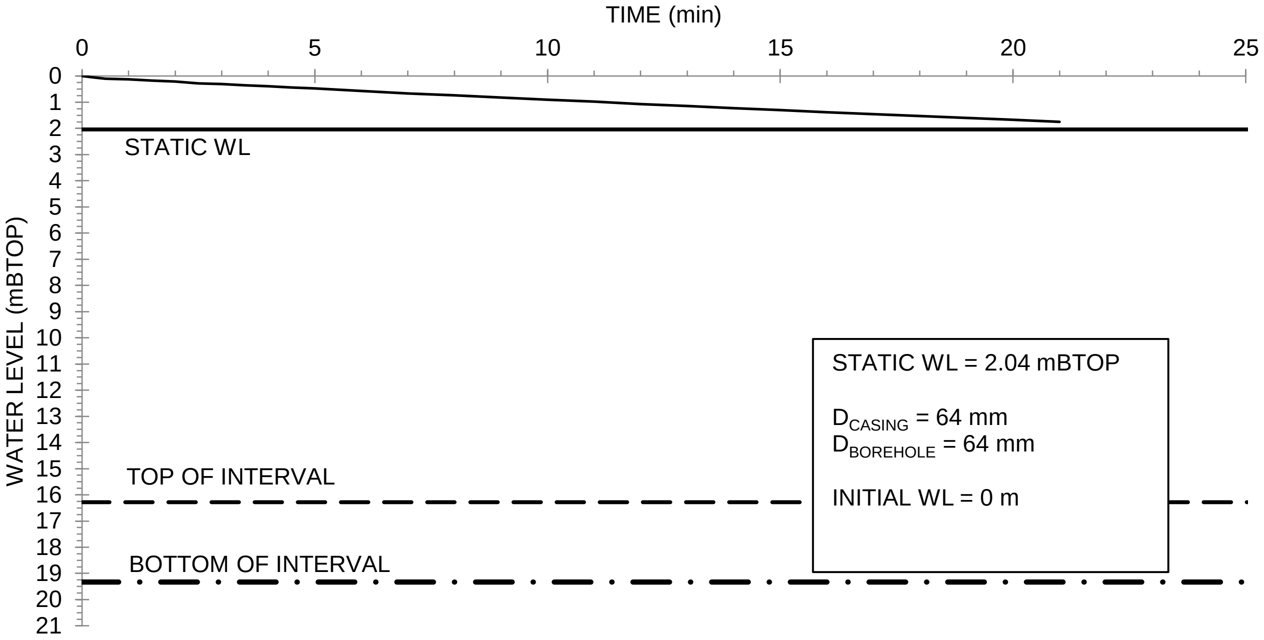
Falling Head Packer Test Analysis

Hvorslev Method

Law Quarry Extension

Date: July 4, 2018

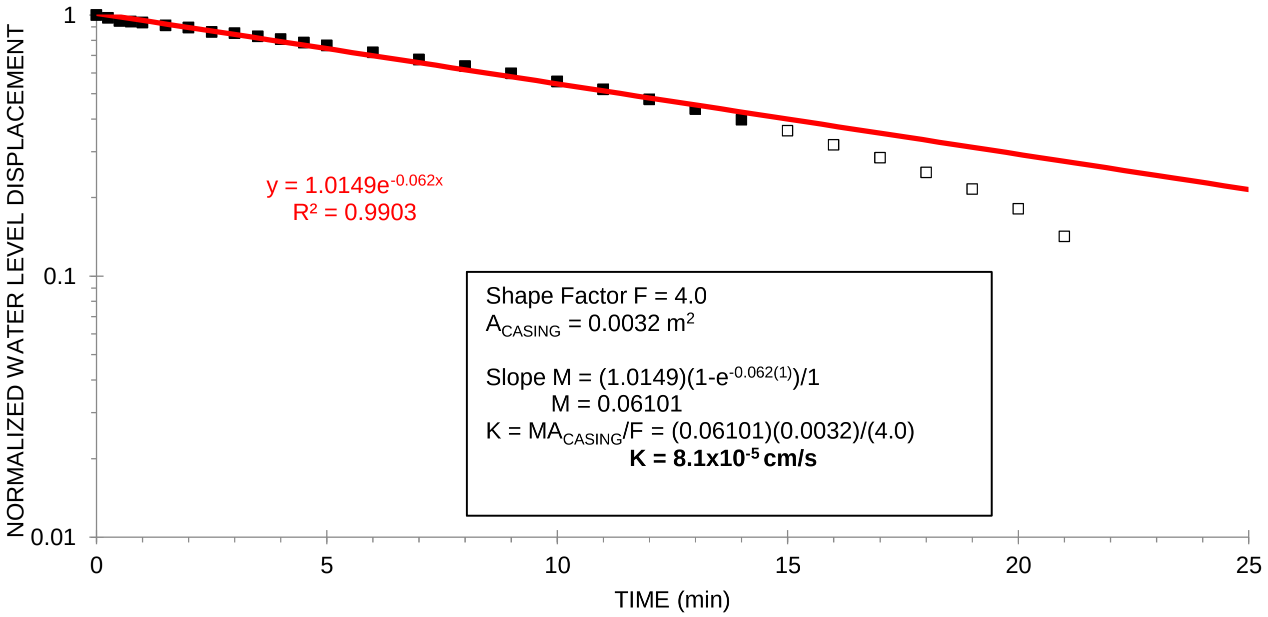
Performed by: CS



STATIC WL = 2.04 mBTOP

D_{CASING} = 64 mm
$D_{BOREHOLE}$ = 64 mm

INITIAL WL = 0 m



$y = 1.0149e^{-0.062x}$
$R^2 = 0.9903$

Shape Factor F = 4.0
$A_{CASING} = 0.0032\ m^2$

Slope M = $(1.0149)(1-e^{-0.062(1)})/1$
M = 0.06101
K = MA_{CASING}/F = (0.06101)(0.0032)/(4.0)
K = $8.1x10^{-5}$ cm/s

Figure 1-1-5

MW1-1 (18.3m - 21.3m)

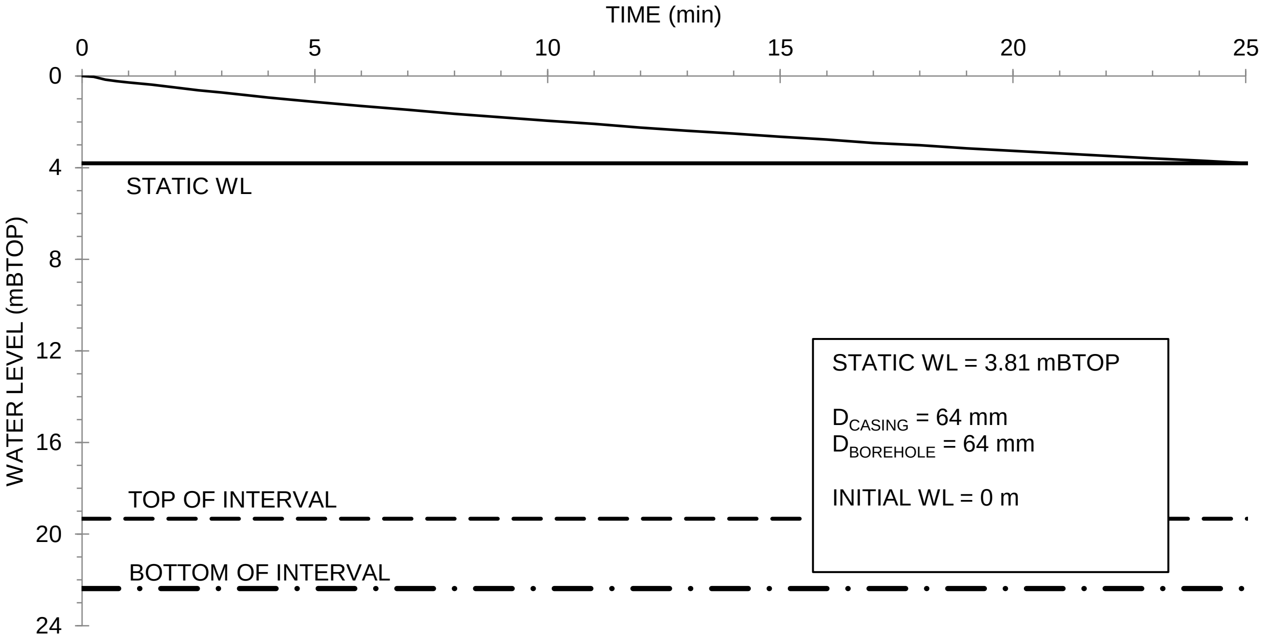
Falling Head Packer Test Analysis

Hvorslev Method

Law Quarry Extension

Date: July 4, 2018

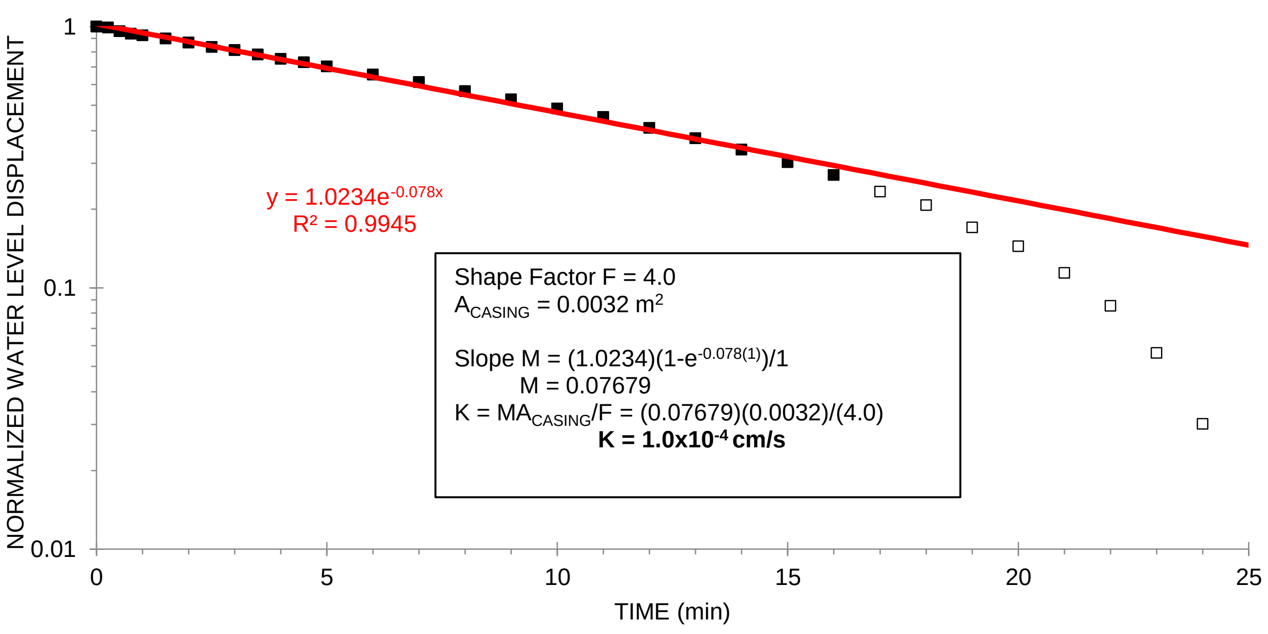
Performed by: CS



STATIC WL = 3.81 mBTOP

D_{CASING} = 64 mm
$D_{BOREHOLE}$ = 64 mm

INITIAL WL = 0 m



Shape Factor F = 4.0
A_{CASING} = 0.0032 m^2

Slope M = $(1.0234)(1-e^{-0.078(1)})/1$
M = 0.07679
K = MA_{CASING}/F = (0.07679)(0.0032)/(4.0)
K = 1.0x10^{-4} cm/s

Figure 1-1-6

MW1-1 (21.3m - 24.4m)

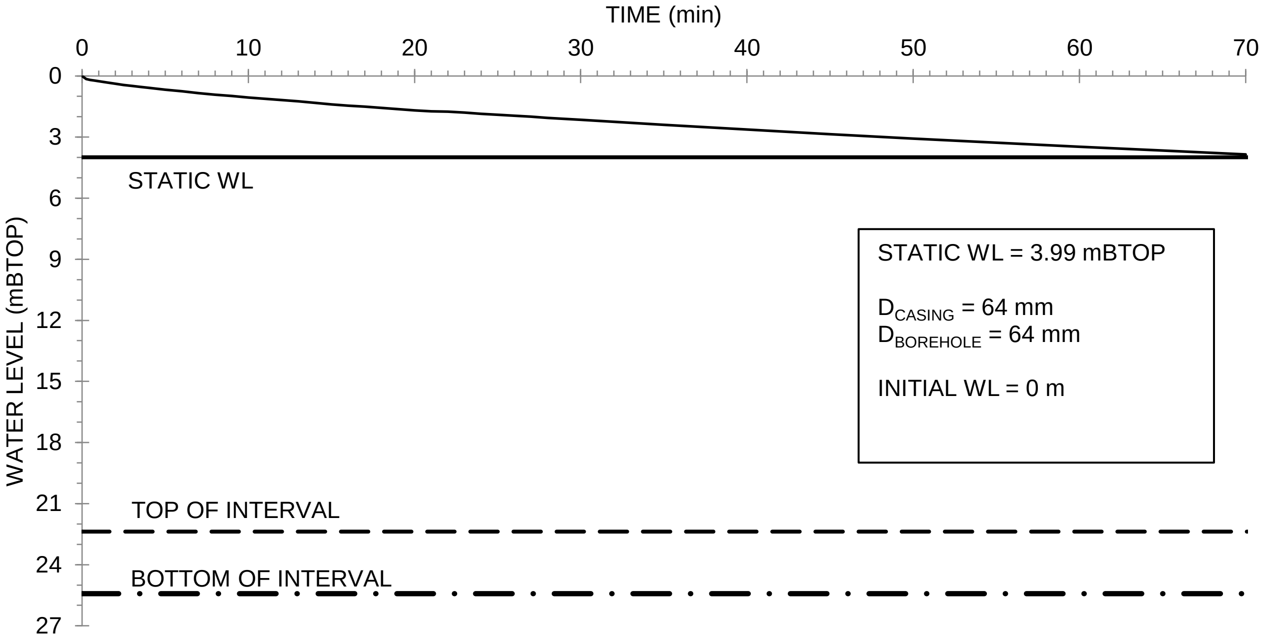
Falling Head Packer Test Analysis

Hvorslev Method

Law Quarry Extension

Date: July 3, 2018

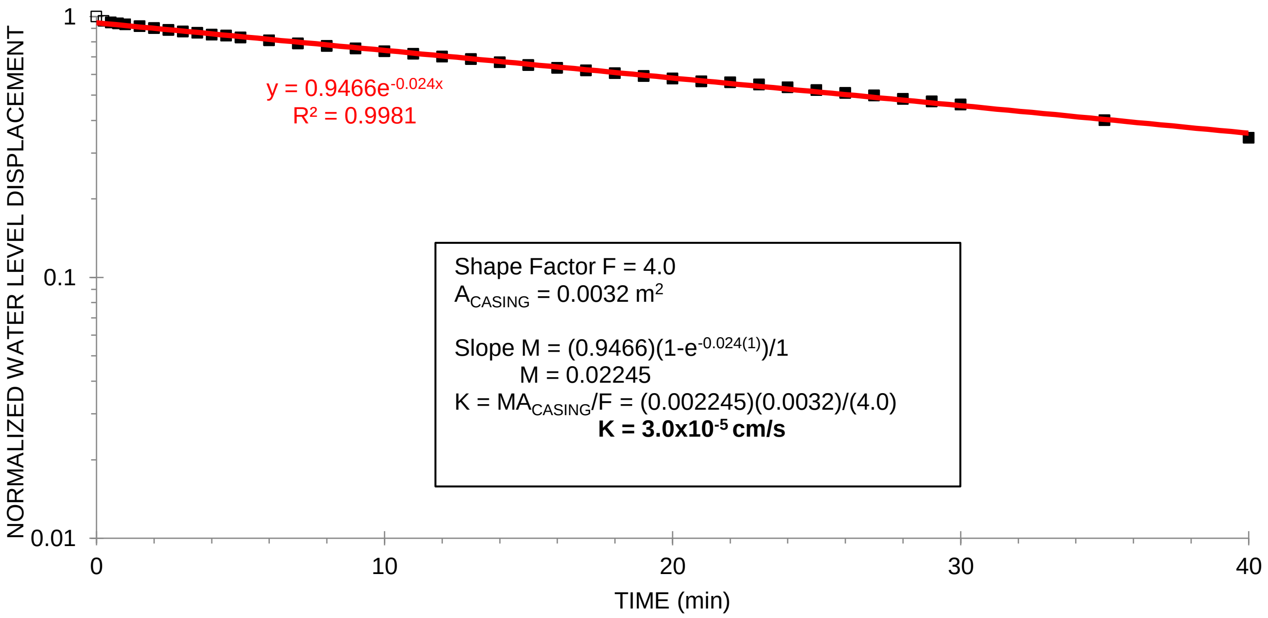
Performed by: CS



STATIC WL = 3.99 mBTOP

D_{CASING} = 64 mm
$D_{BOREHOLE}$ = 64 mm

INITIAL WL = 0 m



Shape Factor F = 4.0
$A_{CASING} = 0.0032\ m^2$

Slope M = $(0.9466)(1-e^{-0.024(1)})/1$
M = 0.02245
K = MA_{CASING}/F = (0.002245)(0.0032)/(4.0)
K = 3.0×10^{-5} cm/s

Figure 1-1-7

MW1-1 (24.6m - 27.7m)

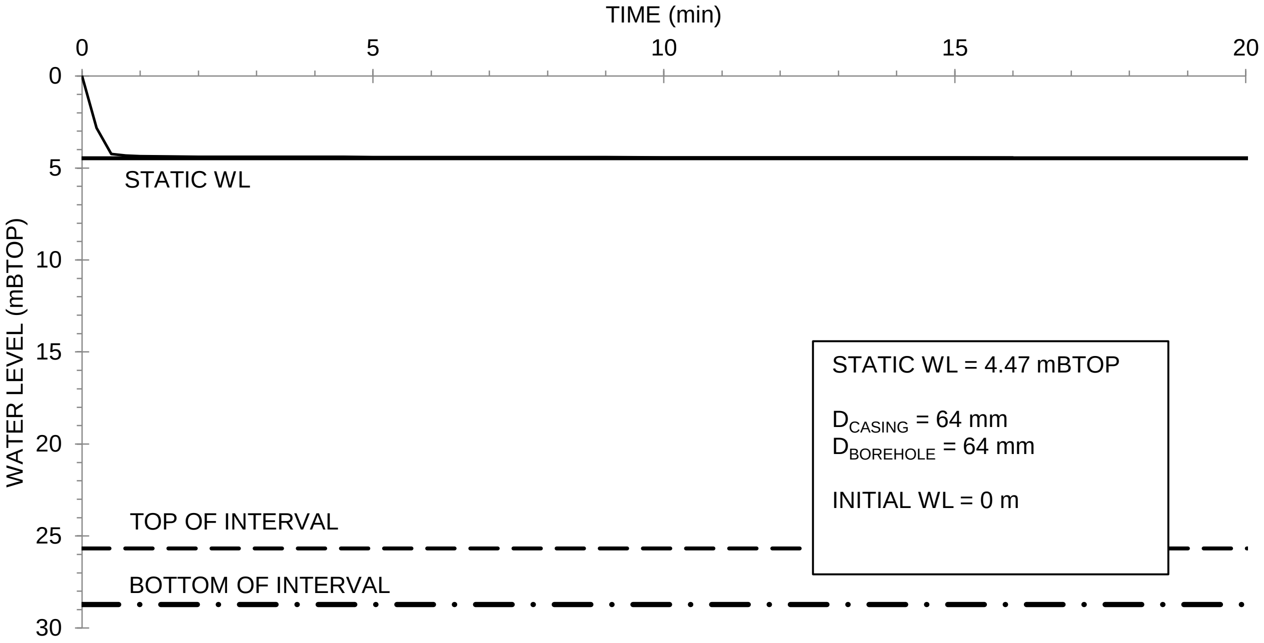
Falling Head Packer Test Analysis

Hvorslev Method

Law Quarry Extension

Date: July 3, 2018

Performed by: CS



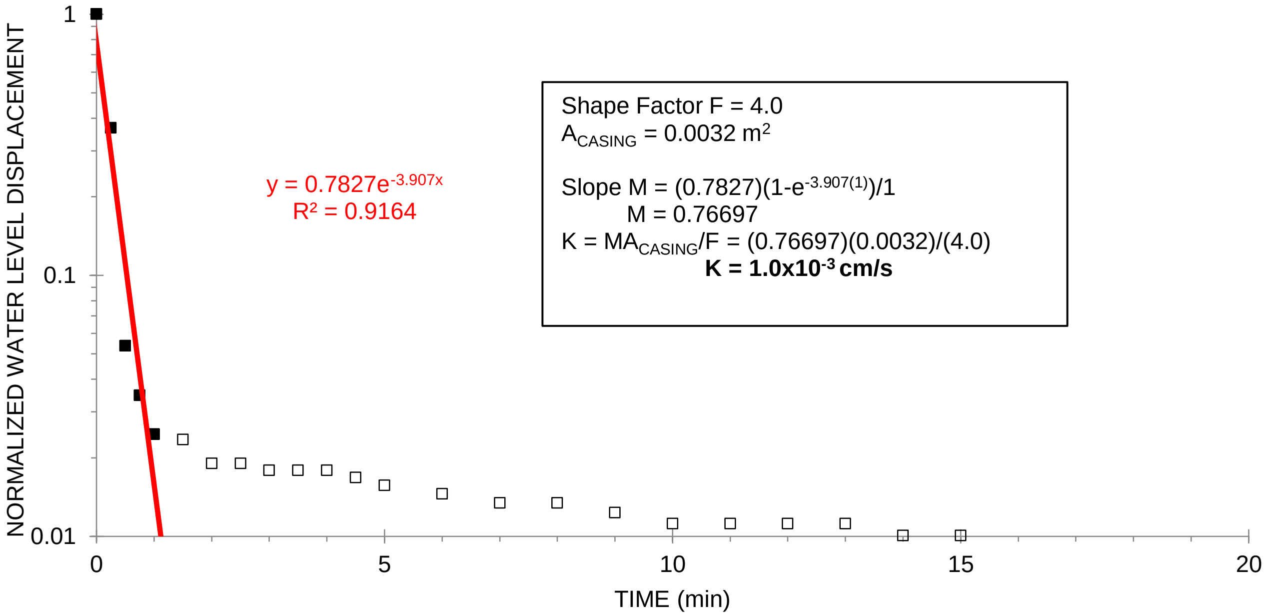


Figure 1-1-8

MW1-1 (26.2m - 27.7m)

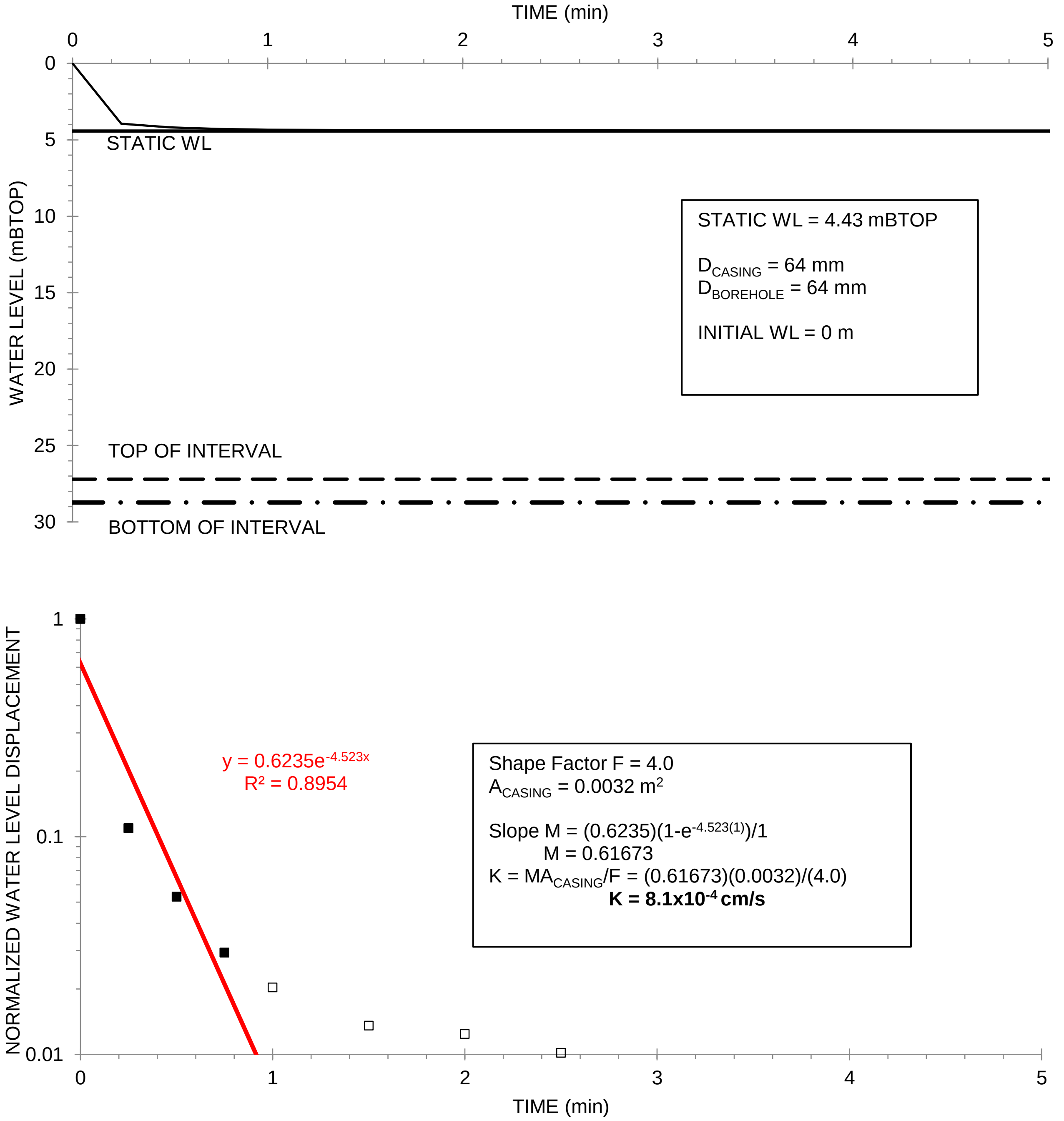
Falling Head Packer Test Analysis

Hvorslev Method

Law Quarry Extension

Date: July 3, 2018

Performed by: CS



STATIC WL = 4.43 mBTOP

D_{CASING} = 64 mm
$D_{BOREHOLE}$ = 64 mm

INITIAL WL = 0 m

Shape Factor F = 4.0
A_{CASING} = 0.0032 m^2

Slope M = (0.6235)(1-e$^{-4.523(1)}$)/1
M = 0.61673
K = MA_{CASING}/F = (0.61673)(0.0032)/(4.0)
K = 8.1x10^{-4} cm/s

Figure 1-5-1

MW5-1 (22.3m - 23.8m)

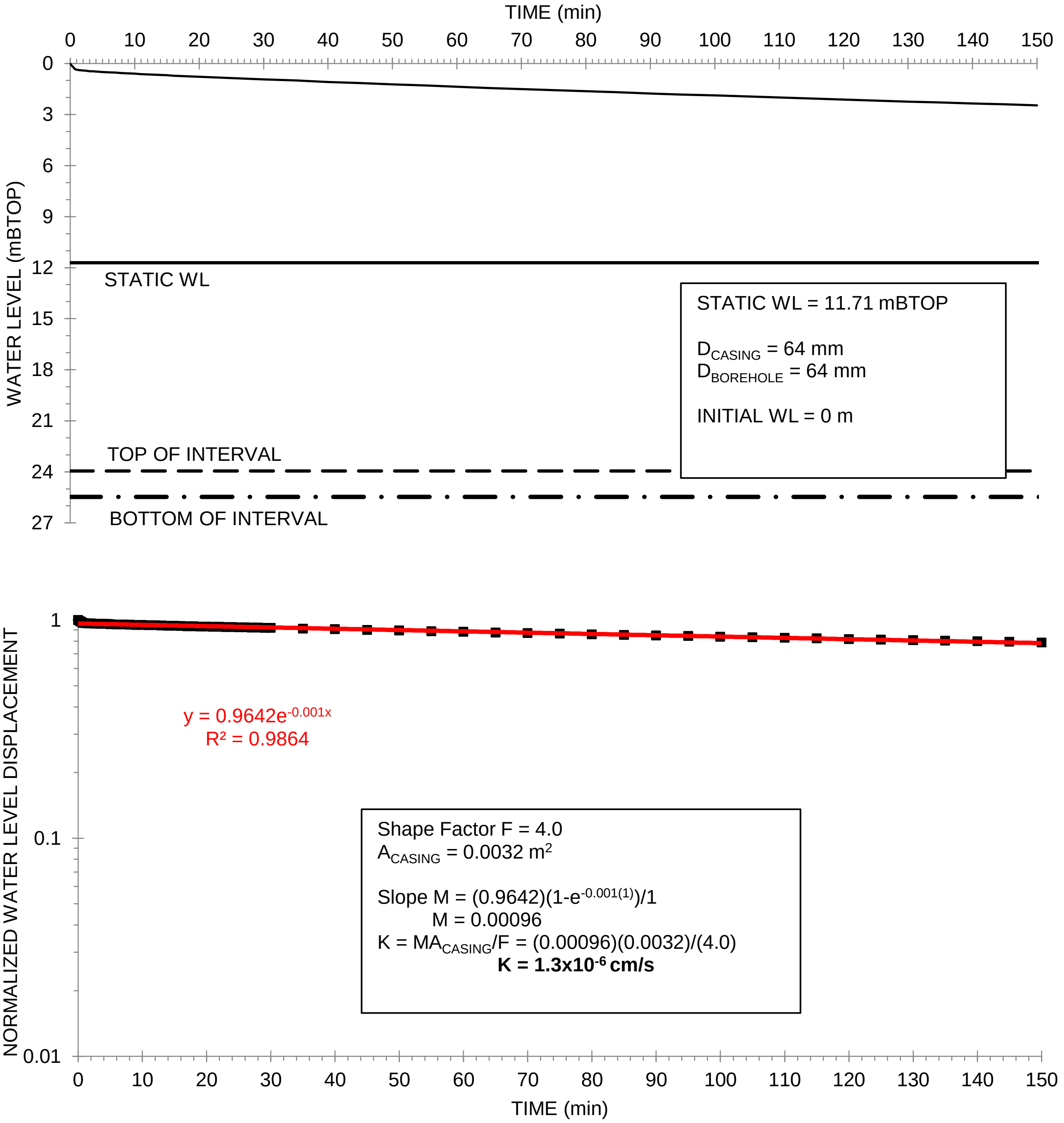
Falling Head Packer Test Analysis

Hvorslev Method

Law Quarry Extension

Date: July 23, 2018

Performed by: CS



STATIC WL = 11.71 mBTOP

D_{CASING} = 64 mm
$D_{BOREHOLE}$ = 64 mm

INITIAL WL = 0 m

Shape Factor F = 4.0
A_{CASING} = 0.0032 m^2

Slope M = (0.9642)(1-e$^{-0.001(1)}$)/1
M = 0.00096
K = MA_{CASING}/F = (0.00096)(0.0032)/(4.0)
K = 1.3x10^{-6} cm/s

Figure 1-10-1

MW10-1 (4.0m - 7.0m)

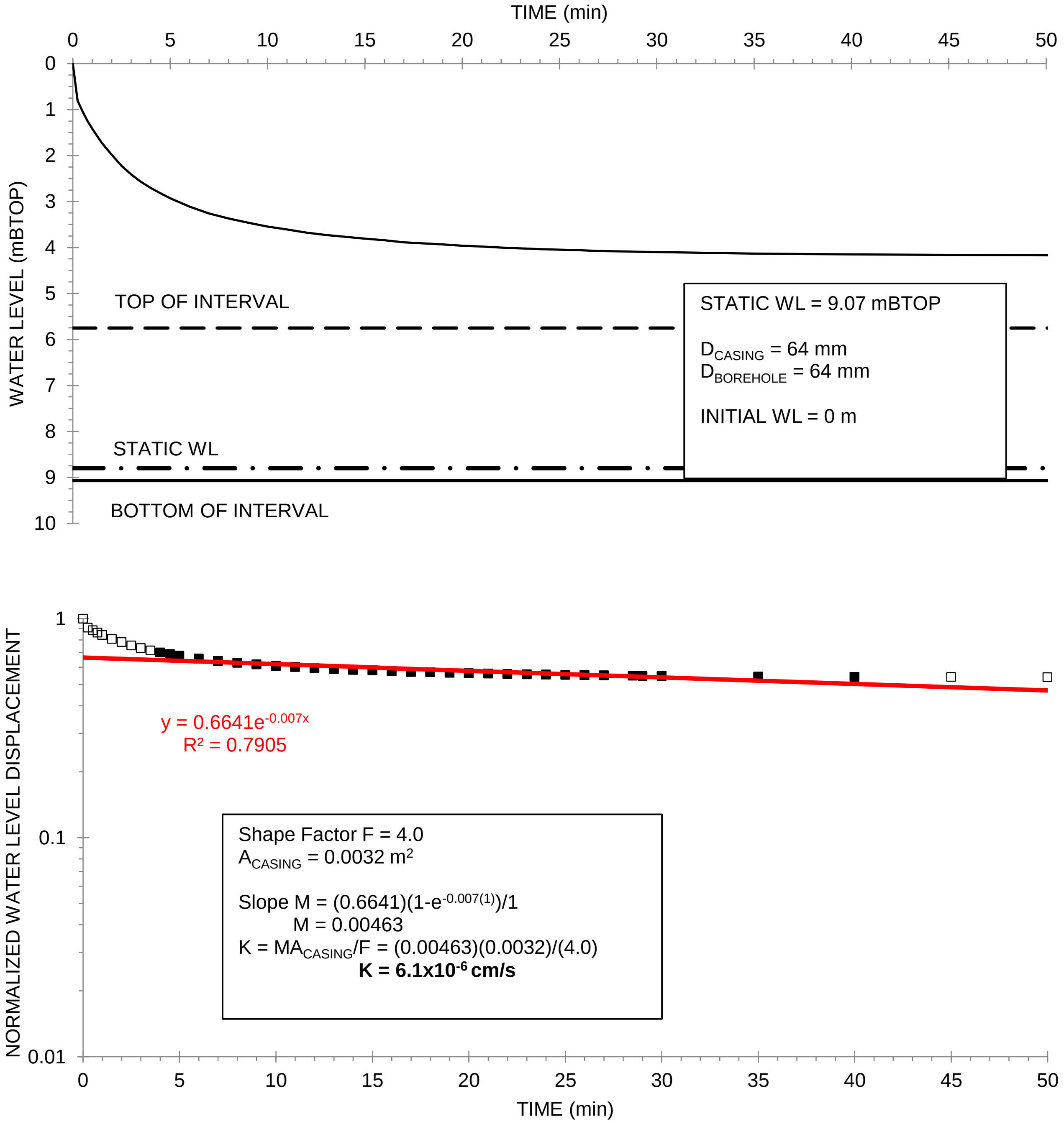
Falling Head Packer Test Analysis

Hvorslev Method

Law Quarry Extension

Date: July 16, 2018

Performed by: CS



STATIC WL = 9.07 mBTOP

D_{CASING} = 64 mm
$D_{BOREHOLE}$ = 64 mm

INITIAL WL = 0 m

Shape Factor F = 4.0
A_{CASING} = 0.0032 m^2

Slope M = $(0.6641)(1-e^{-0.007(1)})/1$
M = 0.00463
K = MA_{CASING}/F = (0.00463)(0.0032)/(4.0)
K = 6.1x10^{-6} cm/s

Figure 1-10-2

MW10-1 (7.0m - 10.1m)

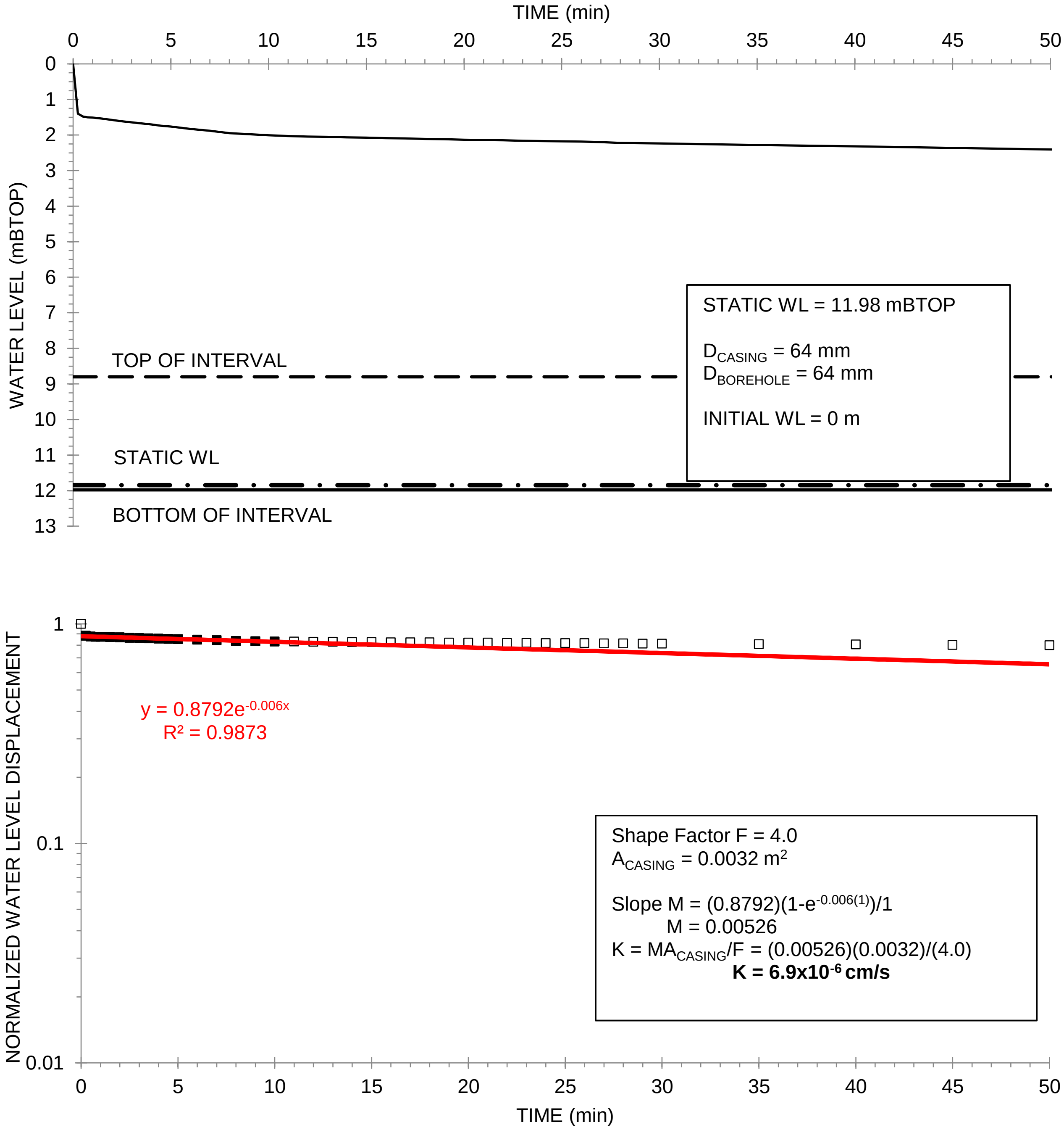
Falling Head Packer Test Analysis

Hvorslev Method

Law Quarry Extension

Date: July 16, 2018

Performed by: CS



STATIC WL = 11.98 mBTOP

D_{CASING} = 64 mm
$D_{BOREHOLE}$ = 64 mm

INITIAL WL = 0 m

Shape Factor F = 4.0
A_{CASING} = 0.0032 m^2

Slope M = $(0.8792)(1-e^{-0.006(1)})/1$
M = 0.00526
K = MA_{CASING}/F = (0.00526)(0.0032)/(4.0)
K = $6.9x10^{-6}$ cm/s

Figure 1-10-3

MW10-1 (10.1m - 13.1m)

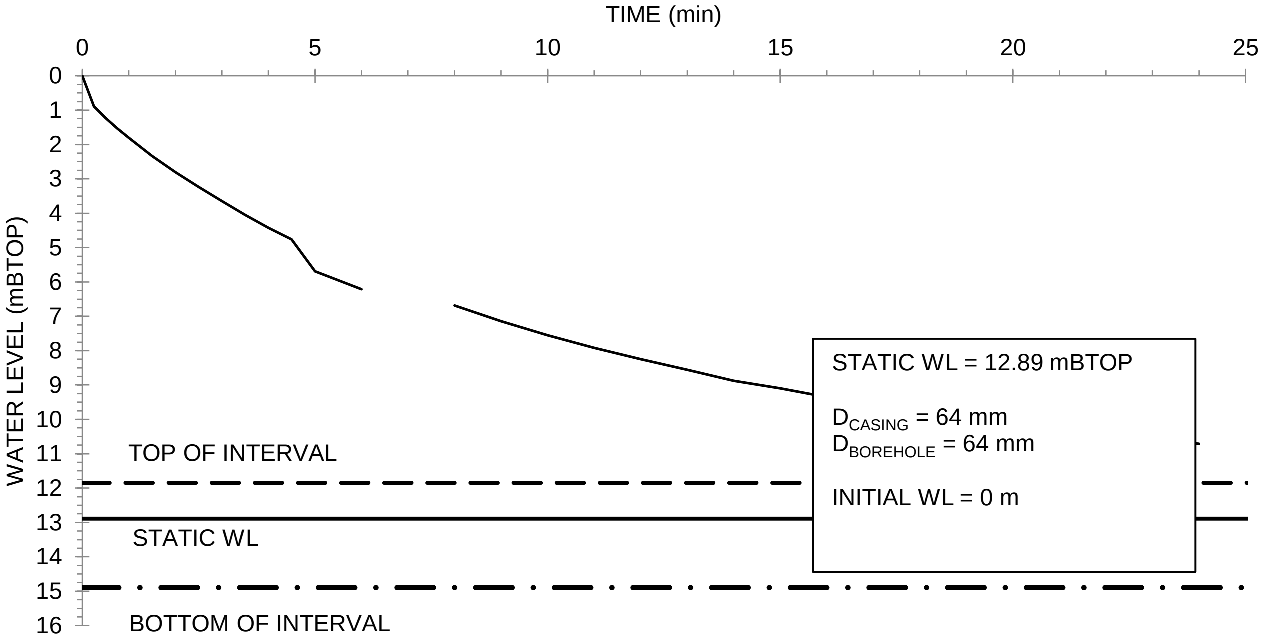
Falling Head Packer Test Analysis

Hvorslev Method

Law Quarry Extension

Date: July 16, 2018

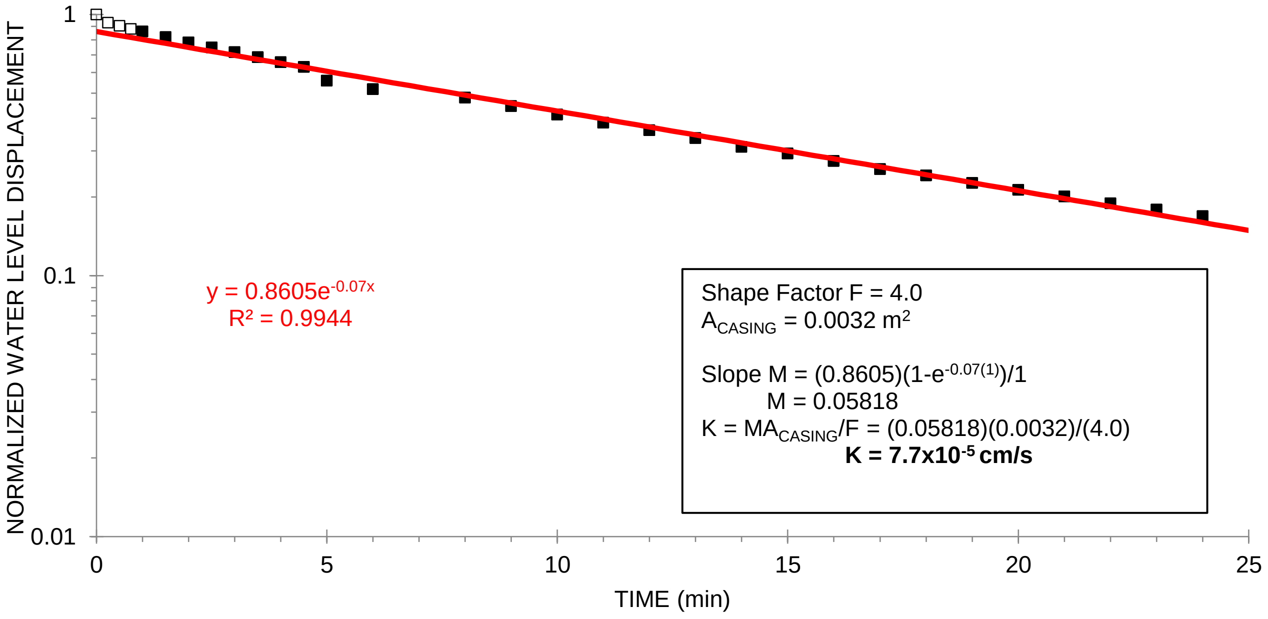
Performed by: CS



STATIC WL = 12.89 mBTOP

D_{CASING} = 64 mm
$D_{BOREHOLE}$ = 64 mm

INITIAL WL = 0 m



$y = 0.8605e^{-0.07x}$
$R^2 = 0.9944$

Shape Factor F = 4.0
$A_{CASING} = 0.0032\ m^2$

Slope M = $(0.8605)(1-e^{-0.07(1)})/1$
M = 0.05818
K = MA_{CASING}/F = (0.05818)(0.0032)/(4.0)
K = 7.7×10^{-5} cm/s

Figure 1-10-4

MW10-1 (13.1m - 16.2m)

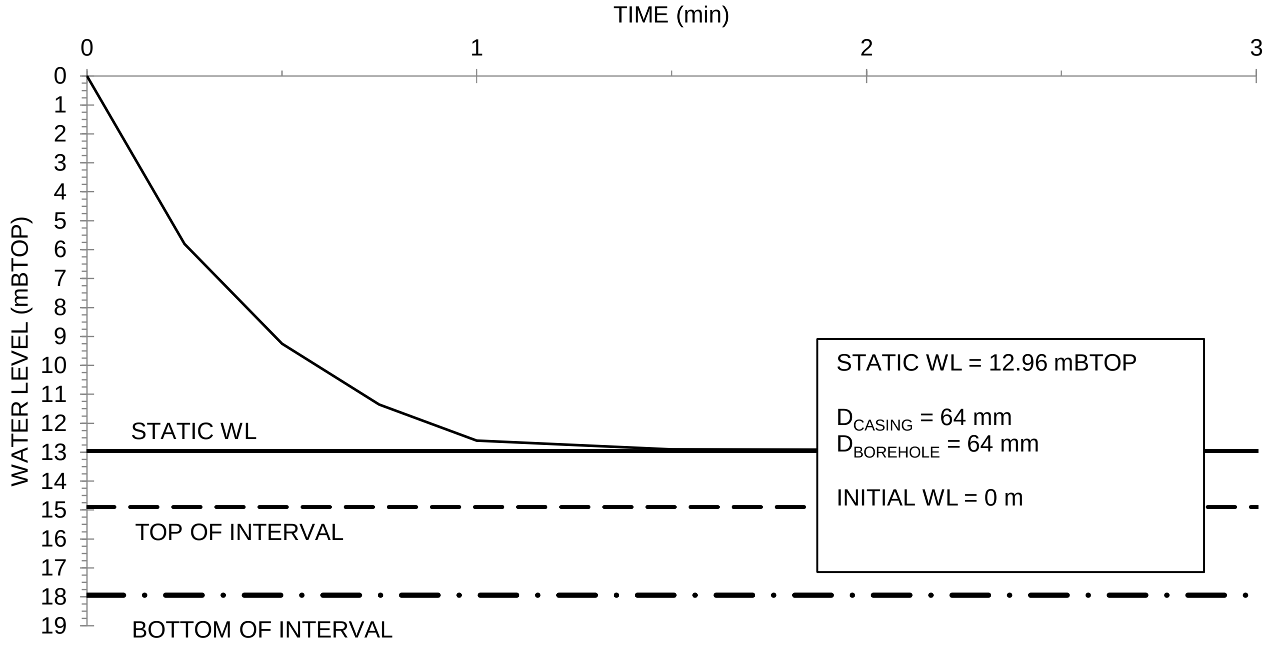
Falling Head Packer Test Analysis

Hvorslev Method

Law Quarry Extension

Date: July 16, 2018

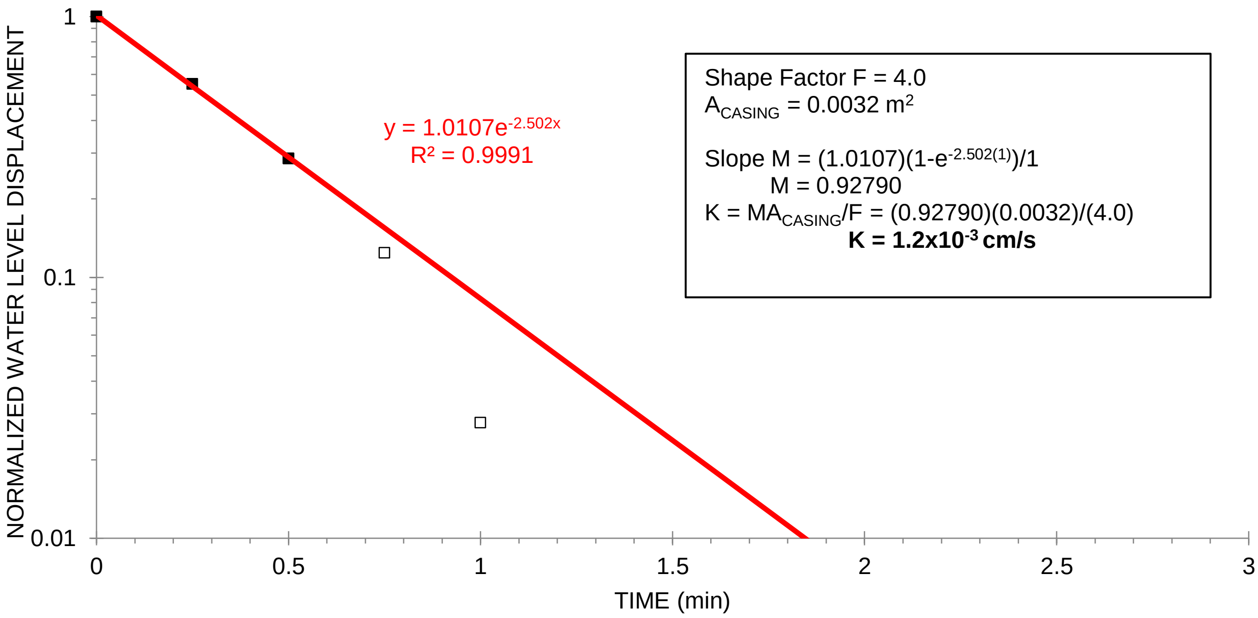
Performed by: CS



STATIC WL = 12.96 mBTOP

D_{CASING} = 64 mm
$D_{BOREHOLE}$ = 64 mm

INITIAL WL = 0 m



Shape Factor F = 4.0
A_{CASING} = 0.0032 m^2

Slope M = $(1.0107)(1-e^{-2.502(1)})/1$
M = 0.92790
K = MA_{CASING}/F = (0.92790)(0.0032)/(4.0)
K = 1.2×10^{-3} cm/s

Figure 1-10-5

MW10-1 (16.2m - 19.2m)

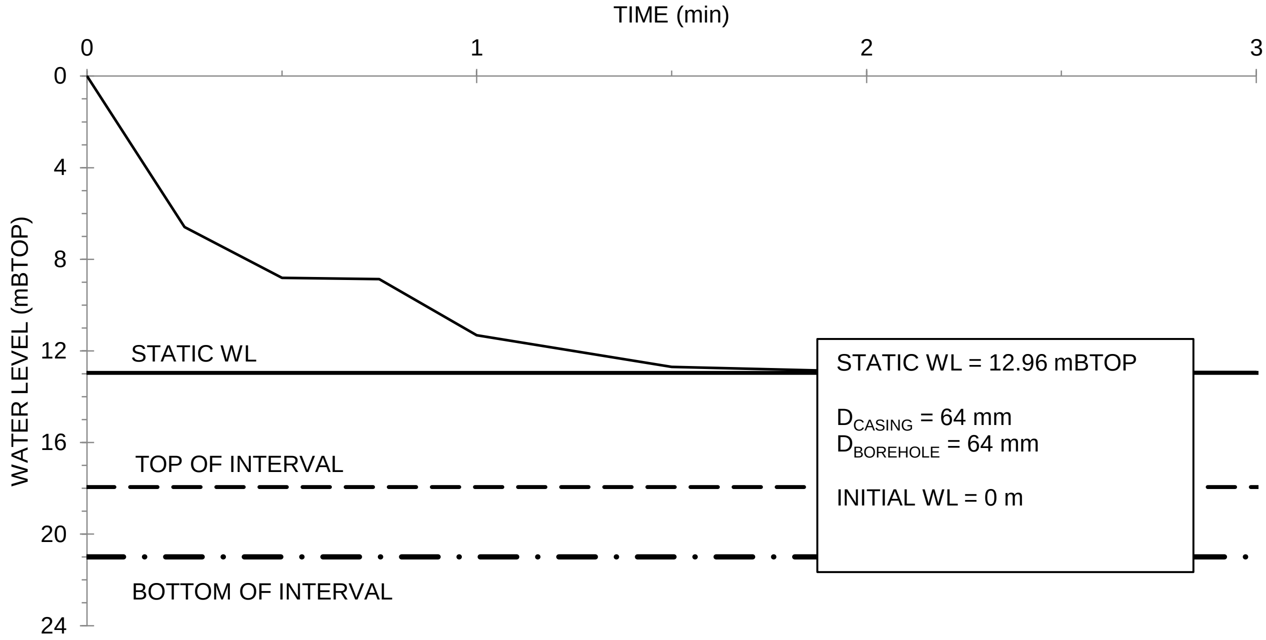
Falling Head Packer Test Analysis

Hvorslev Method

Law Quarry Extension

Date: July 16, 2018

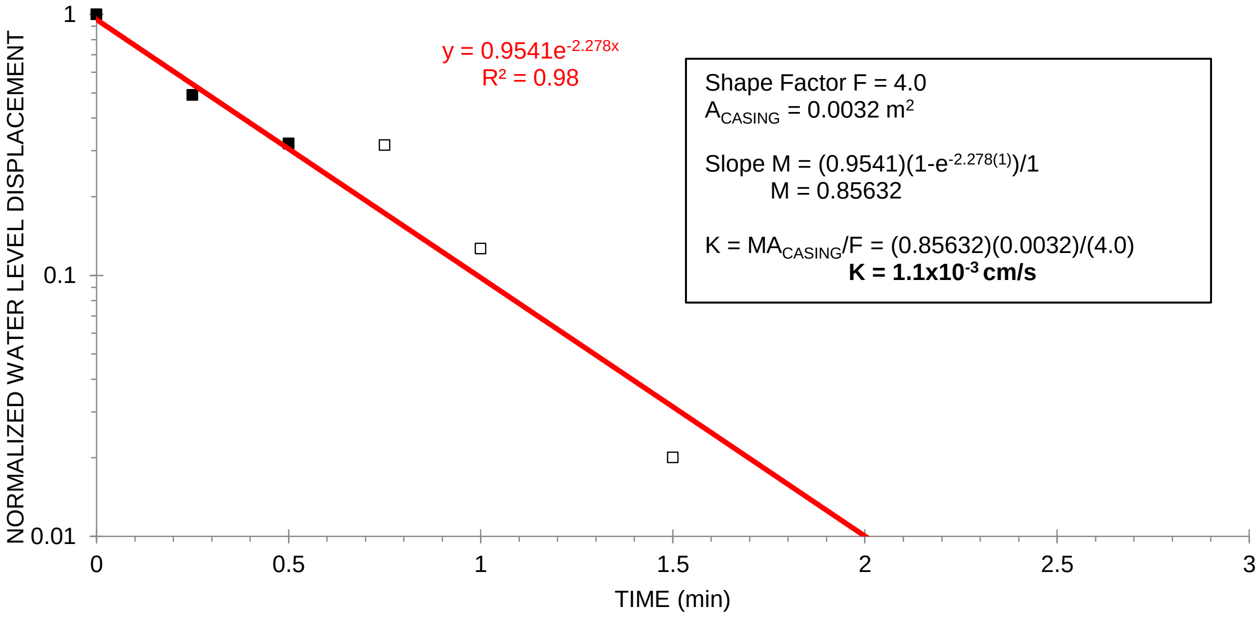
Performed by: CS



STATIC WL = 12.96 mBTOP

D_{CASING} = 64 mm
$D_{BOREHOLE}$ = 64 mm

INITIAL WL = 0 m



Shape Factor F = 4.0
A_{CASING} = 0.0032 m^2

Slope M = $(0.9541)(1\text{-}e^{-2.278(1)})/1$
M = 0.85632

K = MA_{CASING}/F = (0.85632)(0.0032)/(4.0)
K = $1.1\text{x}10^{-3}$ cm/s

Figure 1-10-6

MW10-1 (19.2m - 22.3m)

Falling Head Packer Test Analysis

Hvorslev Method

Law Quarry Extension

Date: July 13, 2018

Performed by: CS

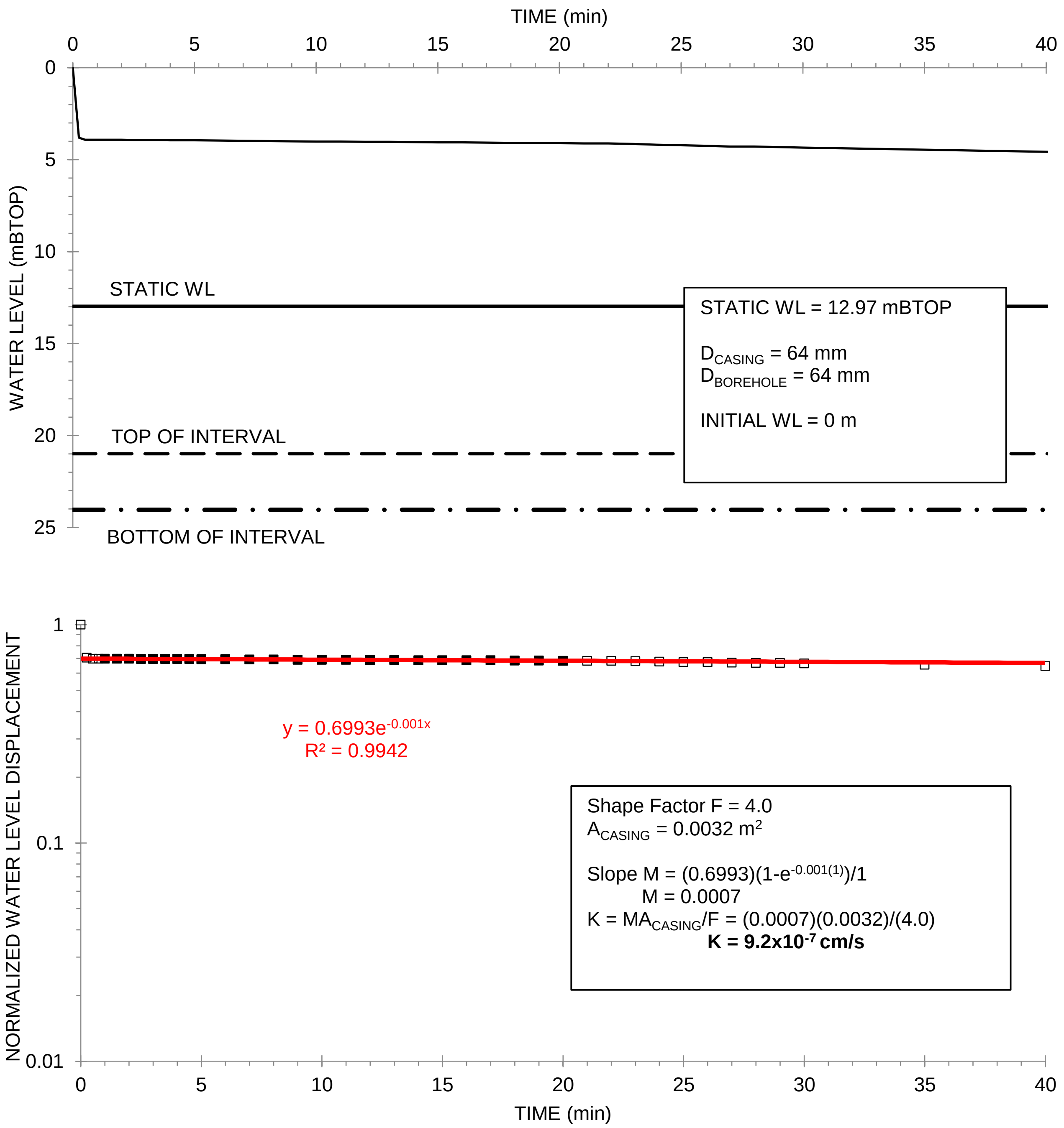


Figure 1-10-7

MW10-1 (22.3m - 25.3m)

Falling Head Packer Test Analysis

Hvorslev Method

Law Quarry Extension

Date: July 13, 2018

Performed by: CS

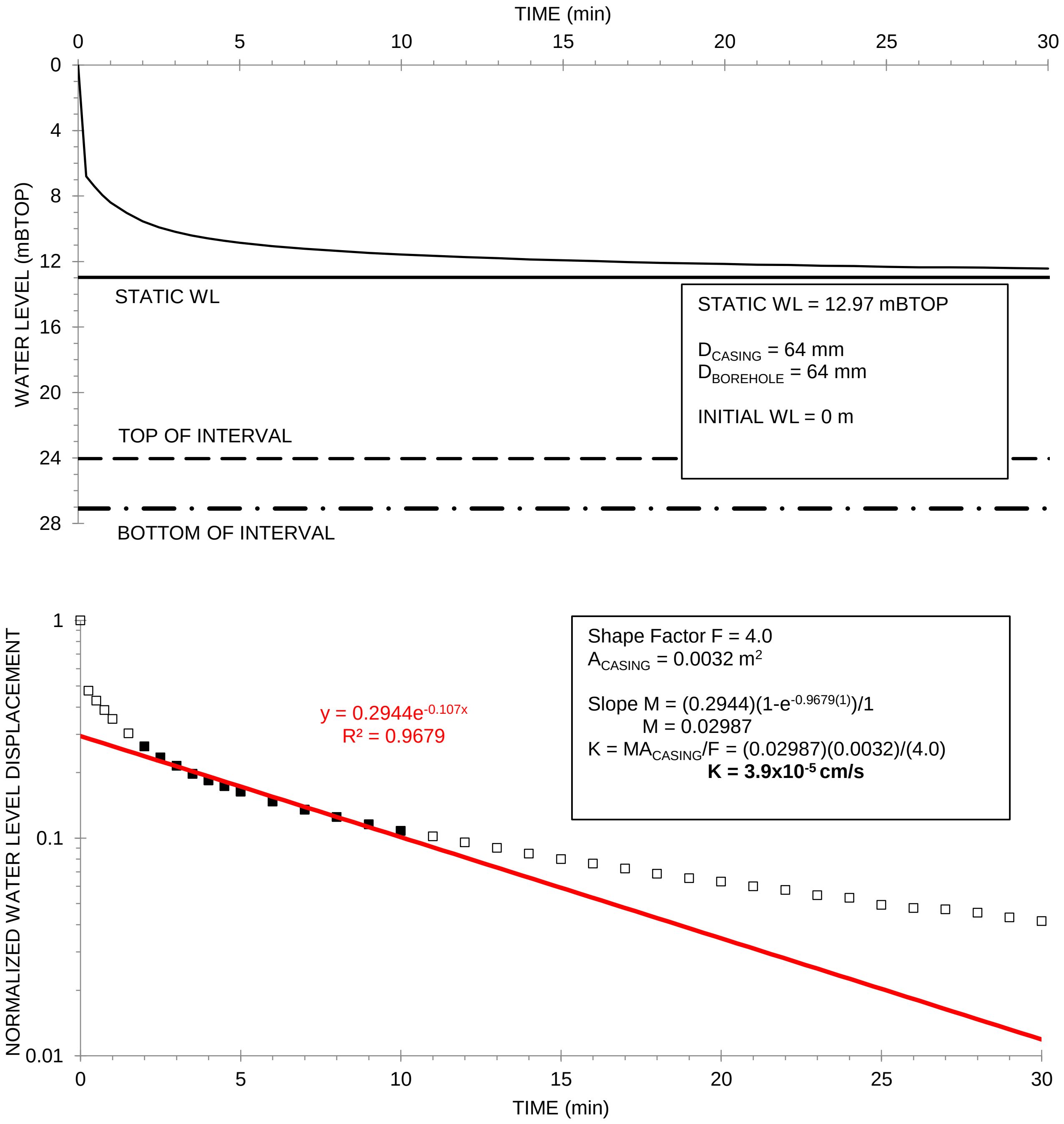


Figure 1-10-8

MW10-1 (25.3m - 28.4m)

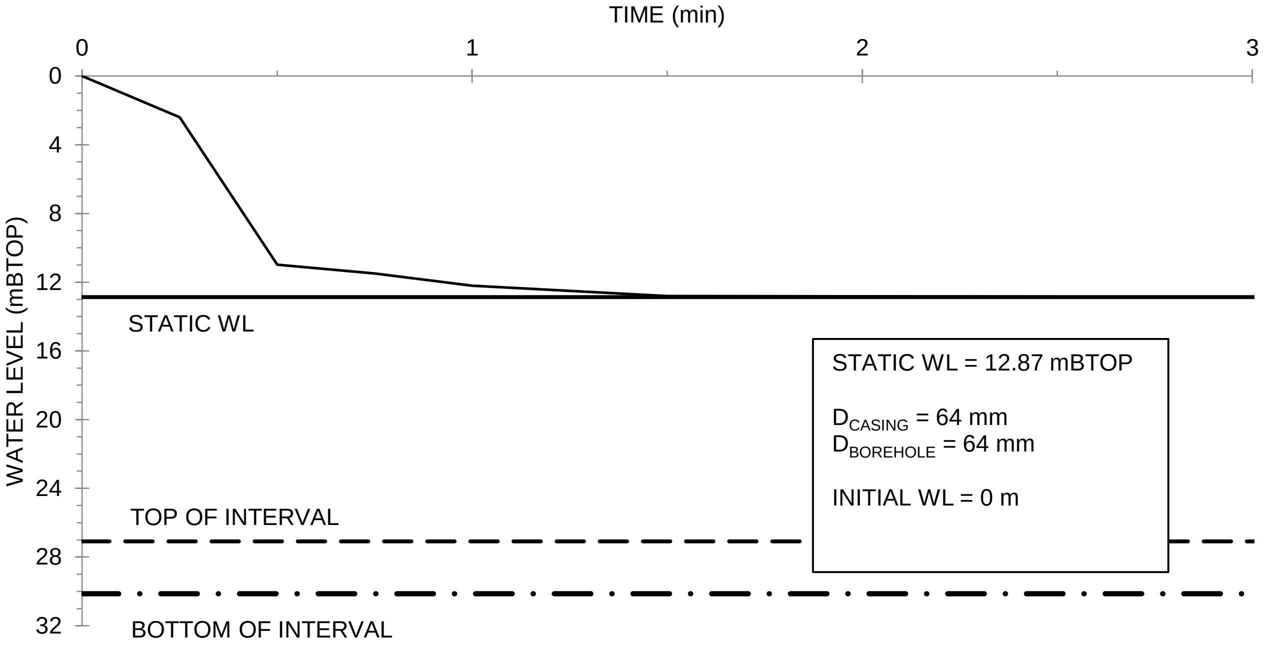
Falling Head Packer Test Analysis

Hvorslev Method

Law Quarry Extension

Date: July 13, 2018

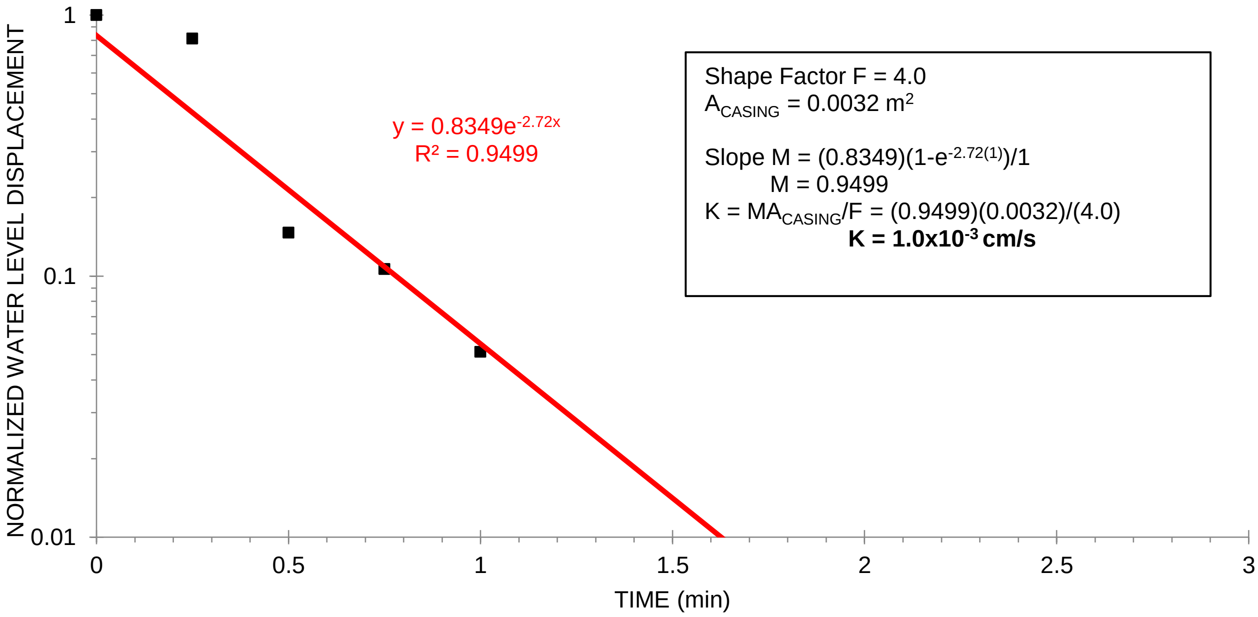
Performed by: CS



STATIC WL = 12.87 mBTOP

D_{CASING} = 64 mm
$D_{BOREHOLE}$ = 64 mm

INITIAL WL = 0 m



$y = 0.8349e^{-2.72x}$
$R^2 = 0.9499$

Shape Factor F = 4.0
A_{CASING} = 0.0032 m^2

Slope M = $(0.8349)(1-e^{-2.72(1)})/1$
M = 0.9499
K = MA_{CASING}/F = (0.9499)(0.0032)/(4.0)
K = $1.0\text{x}10^{-3}$ cm/s

Figure 1-11-1

MW11-1 (4.6m - 7.6m)

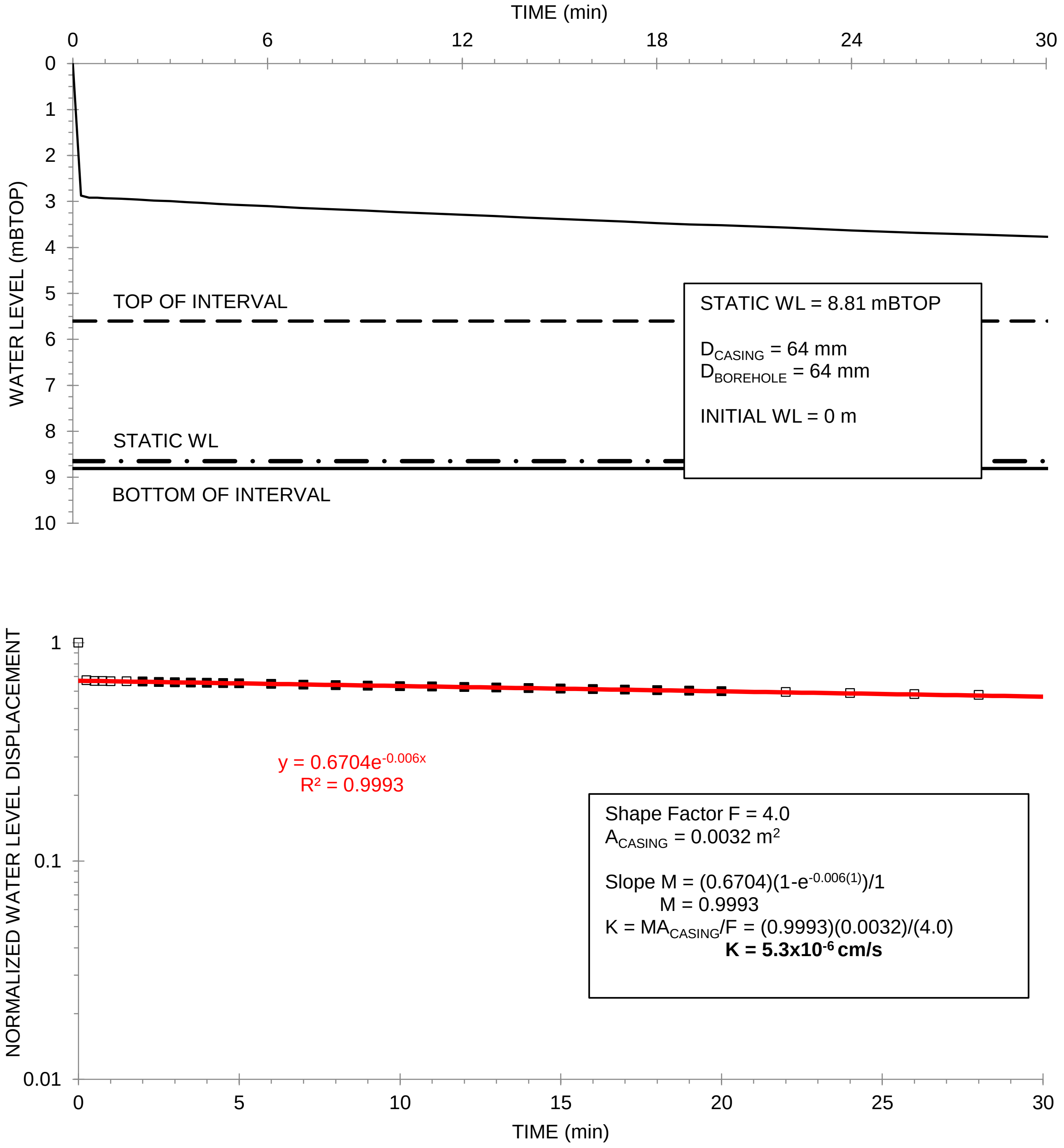
Falling Head Packer Test Analysis

Hvorslev Method

Law Quarry Extension

Date: July 30, 2018

Performed by: CS



STATIC WL = 8.81 mBTOP

D_{CASING} = 64 mm
$D_{BOREHOLE}$ = 64 mm

INITIAL WL = 0 m

$y = 0.6704e^{-0.006x}$
$R^2 = 0.9993$

Shape Factor F = 4.0
$A_{CASING} = 0.0032\ m^2$

Slope M = $(0.6704)(1-e^{-0.006(1)})/1$
M = 0.9993
K = MA_{CASING}/F = (0.9993)(0.0032)/(4.0)
K = $5.3x10^{-6}$ cm/s

Figure 1-11-2

MW11-1 (7.6m - 10.7m)

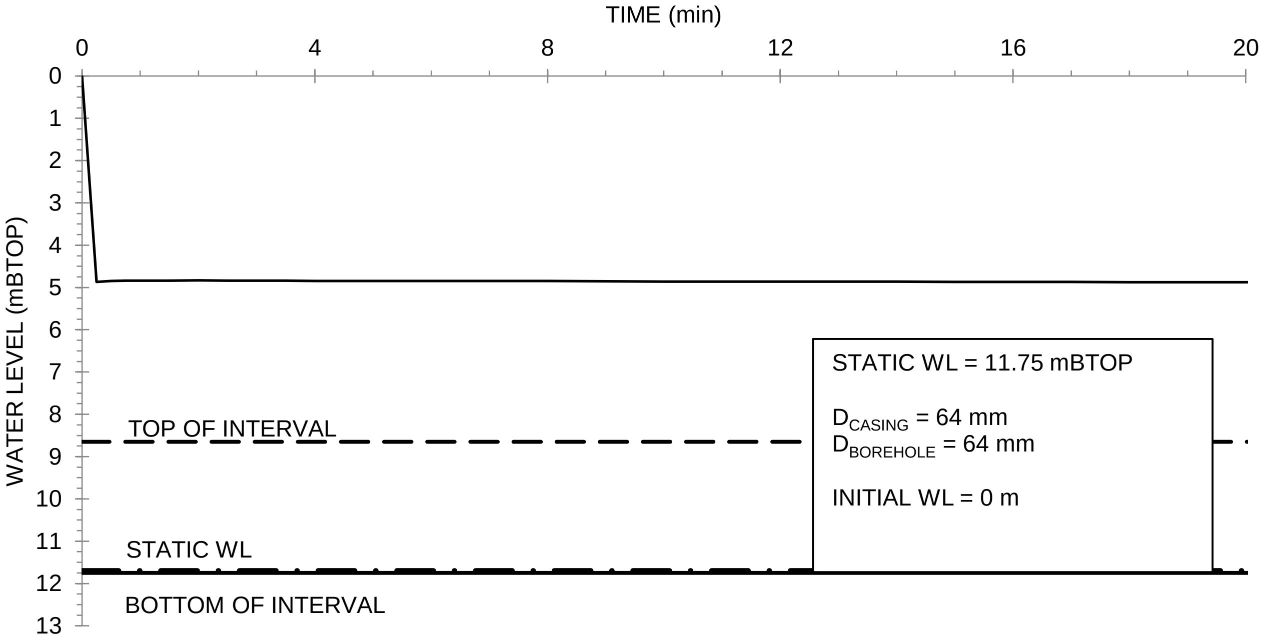
Falling Head Packer Test Analysis

Hvorslev Method

Law Quarry Extension

Date: July 30, 2018

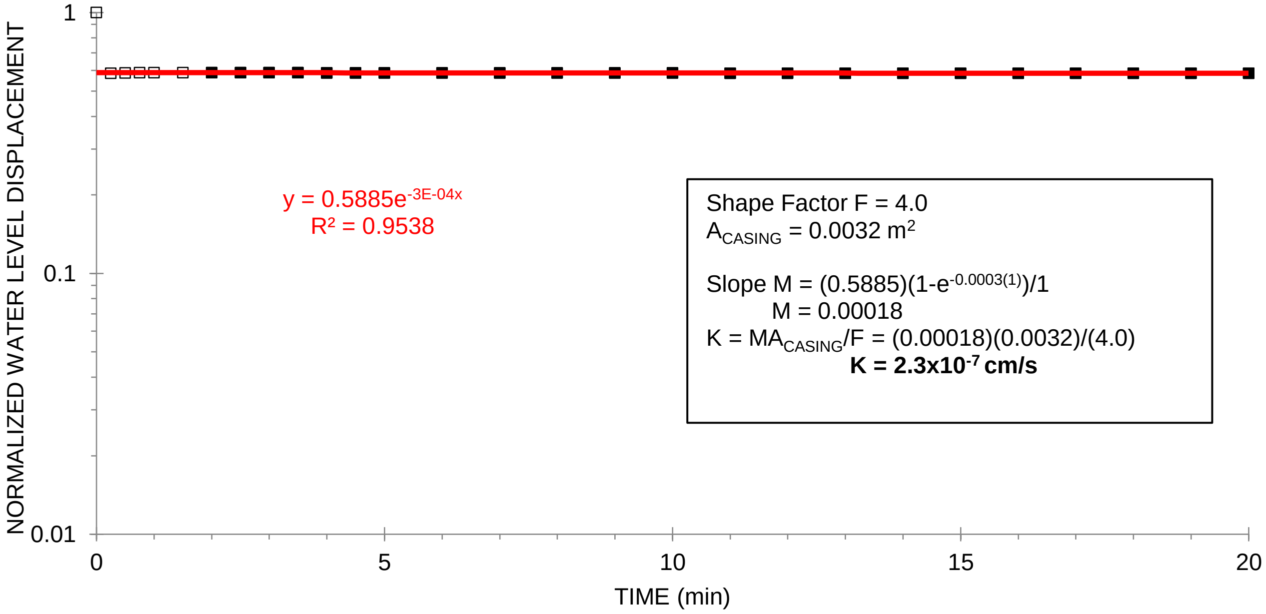
Performed by: CS



STATIC WL = 11.75 mBTOP

D_{CASING} = 64 mm
$D_{BOREHOLE}$ = 64 mm

INITIAL WL = 0 m



Shape Factor F = 4.0
A_{CASING} = 0.0032 m^2

Slope M = $(0.5885)(1-e^{-0.0003(1)})/1$
M = 0.00018
K = MA_{CASING}/F = (0.00018)(0.0032)/(4.0)
K = $2.3x10^{-7}$ cm/s

Figure 1-11-3

MW11-1 (10.7m - 13.7m)

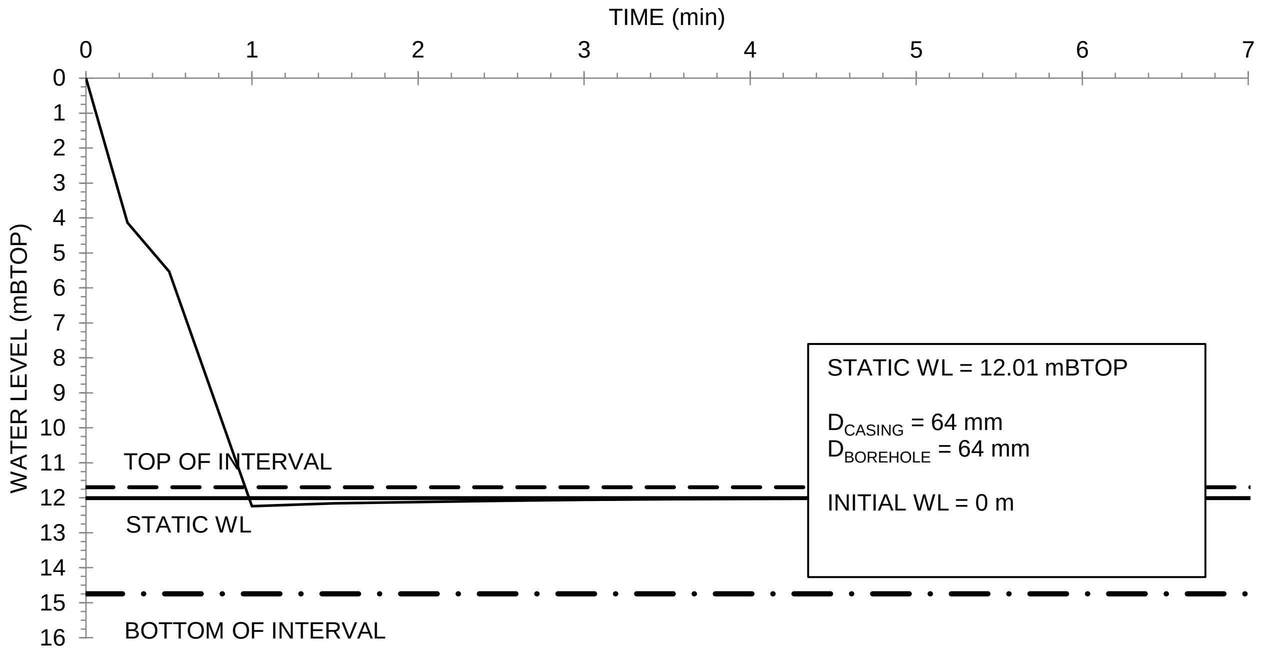
Falling Head Packer Test Analysis

Hvorslev Method

Law Quarry Extension

Date: July 30, 2018

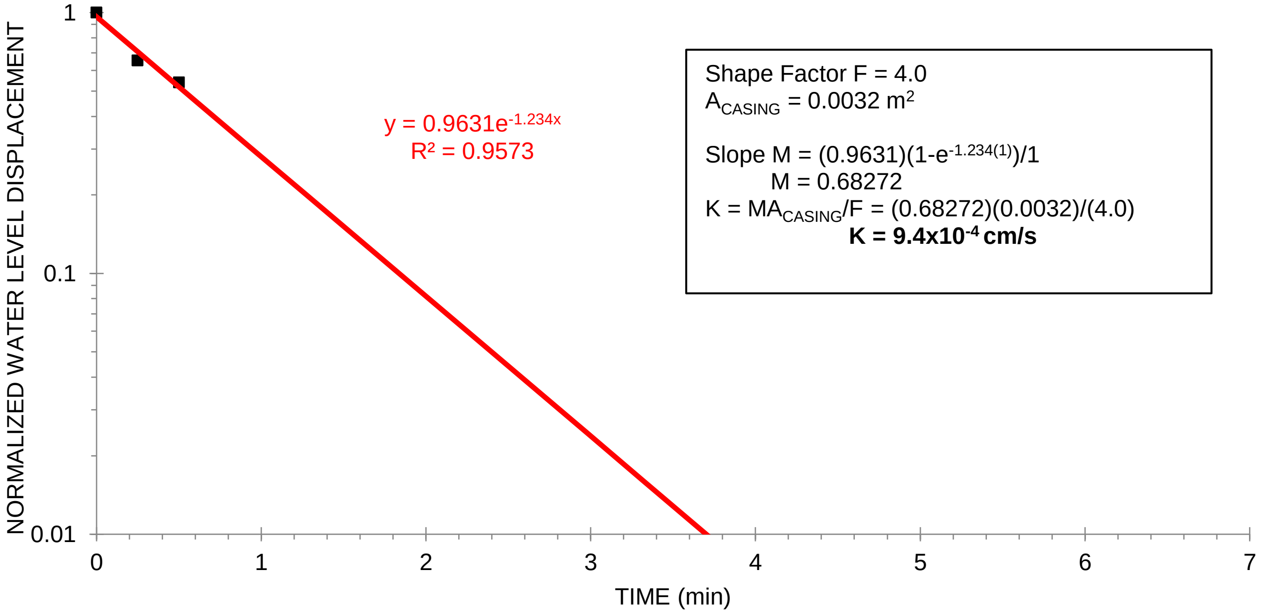
Performed by: CS



STATIC WL = 12.01 mBTOP

D_{CASING} = 64 mm
$D_{BOREHOLE}$ = 64 mm

INITIAL WL = 0 m



Shape Factor F = 4.0
A_{CASING} = 0.0032 m^2

Slope M = $(0.9631)(1-e^{-1.234(1)})/1$
M = 0.68272
K = MA_{CASING}/F = (0.68272)(0.0032)/(4.0)
K = 9.4×10^{-4} cm/s

Figure 1-11-4

MW11-1 (13.7m - 16.8m)

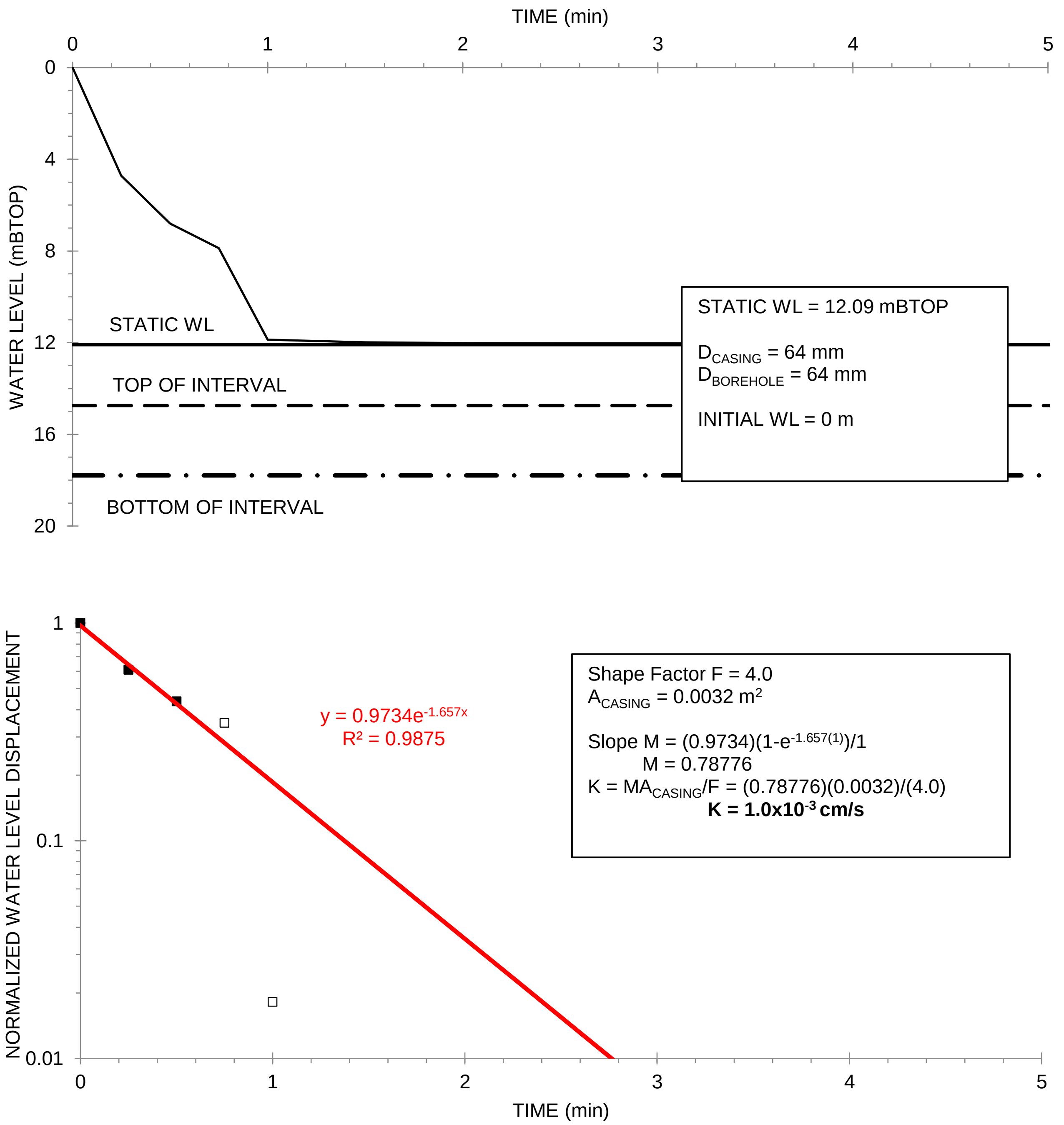
Falling Head Packer Test Analysis

Hvorslev Method

Law Quarry Extension

Date: July 30, 2018

Performed by: CS



STATIC WL = 12.09 mBTOP

D_{CASING} = 64 mm
$D_{BOREHOLE}$ = 64 mm

INITIAL WL = 0 m

Shape Factor F = 4.0
A_{CASING} = 0.0032 m^2

Slope M = (0.9734)(1-e$^{-1.657(1)}$)/1
M = 0.78776
K = MA_{CASING}/F = (0.78776)(0.0032)/(4.0)
K = 1.0x10^{-3} cm/s

Figure 1-11-5

MW11-1 (16.8m - 19.8m)

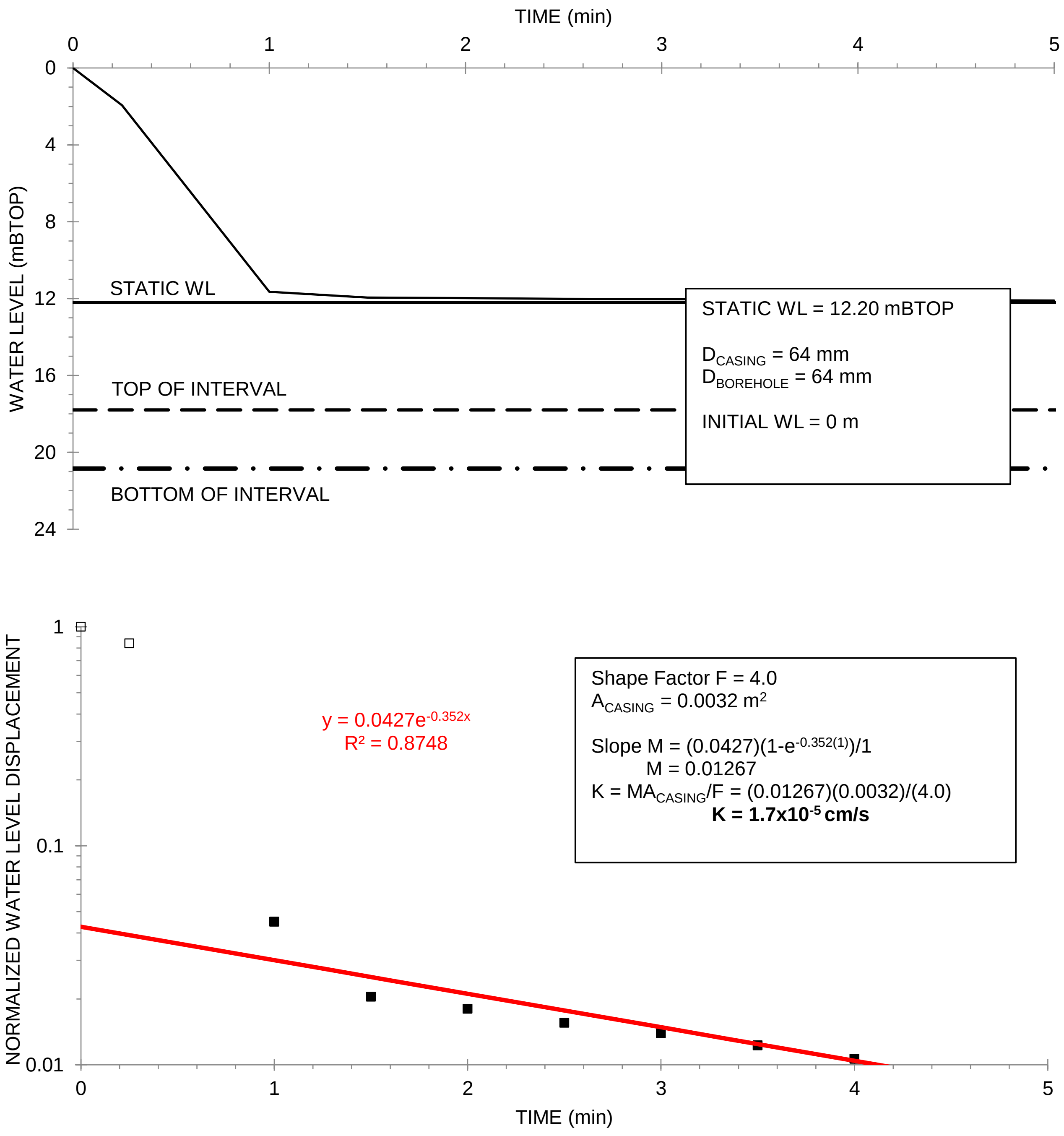
Falling Head Packer Test Analysis

Hvorslev Method

Law Quarry Extension

Date: July 30, 2018

Performed by: CS



STATIC WL = 12.20 mBTOP

D_{CASING} = 64 mm
$D_{BOREHOLE}$ = 64 mm

INITIAL WL = 0 m

$y = 0.0427e^{-0.352x}$
$R^2 = 0.8748$

Shape Factor F = 4.0
A_{CASING} = 0.0032 m^2

Slope M = $(0.0427)(1-e^{-0.352(1)})/1$
M = 0.01267
K = MA_{CASING}/F = (0.01267)(0.0032)/(4.0)
K = $1.7\text{x}10^{-5}$ cm/s

Figure 1-11-6

MW11-1 (19.8m - 22.9m)

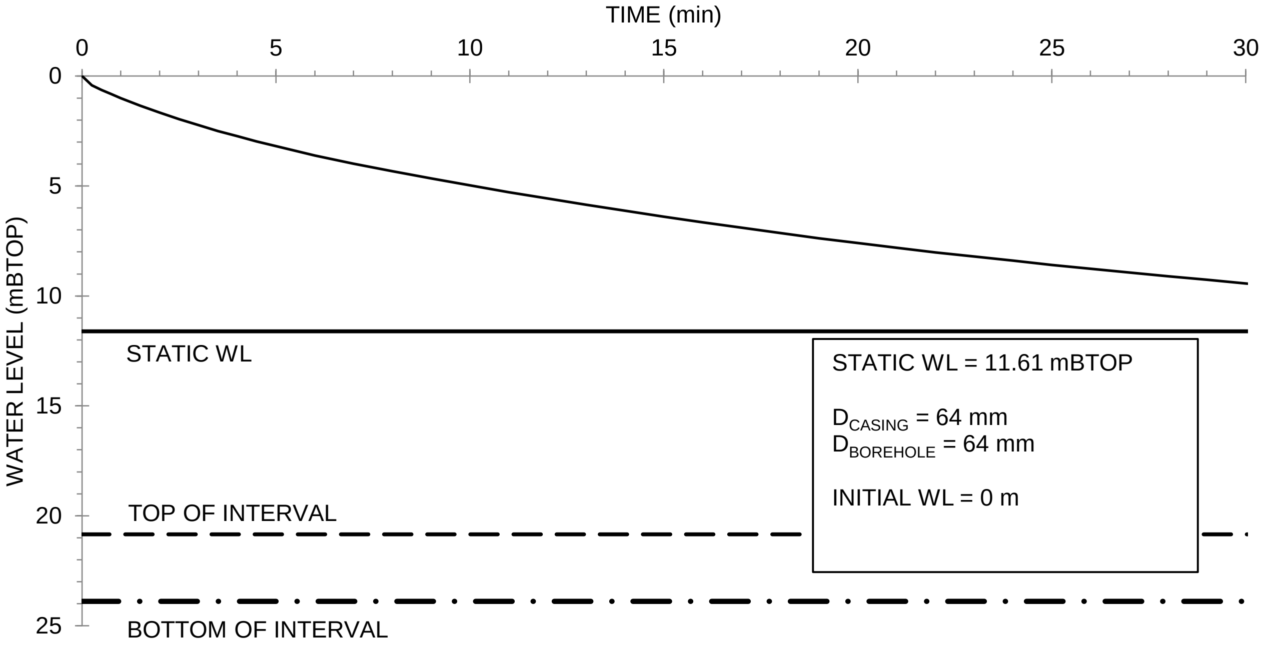
Falling Head Packer Test Analysis

Hvorslev Method

Law Quarry Extension

Date: July 30, 2018

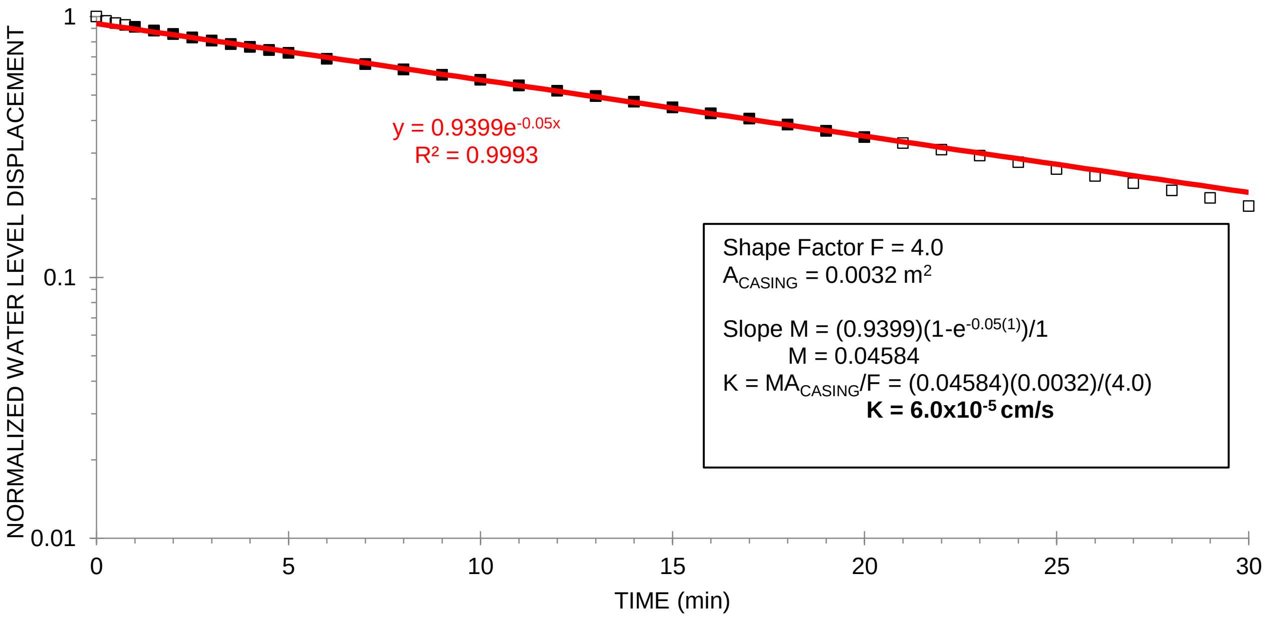
Performed by: CS



STATIC WL = 11.61 mBTOP

D_{CASING} = 64 mm
$D_{BOREHOLE}$ = 64 mm

INITIAL WL = 0 m



Shape Factor F = 4.0
A_{CASING} = 0.0032 m^2

Slope M = $(0.9399)(1-e^{-0.05(1)})/1$
M = 0.04584
K = MA_{CASING}/F = (0.04584)(0.0032)/(4.0)
K = 6.0×10^{-5} cm/s

APPENDIX

D-2 SLUG TEST ANALYSES

Figure 2-1

GLL-1

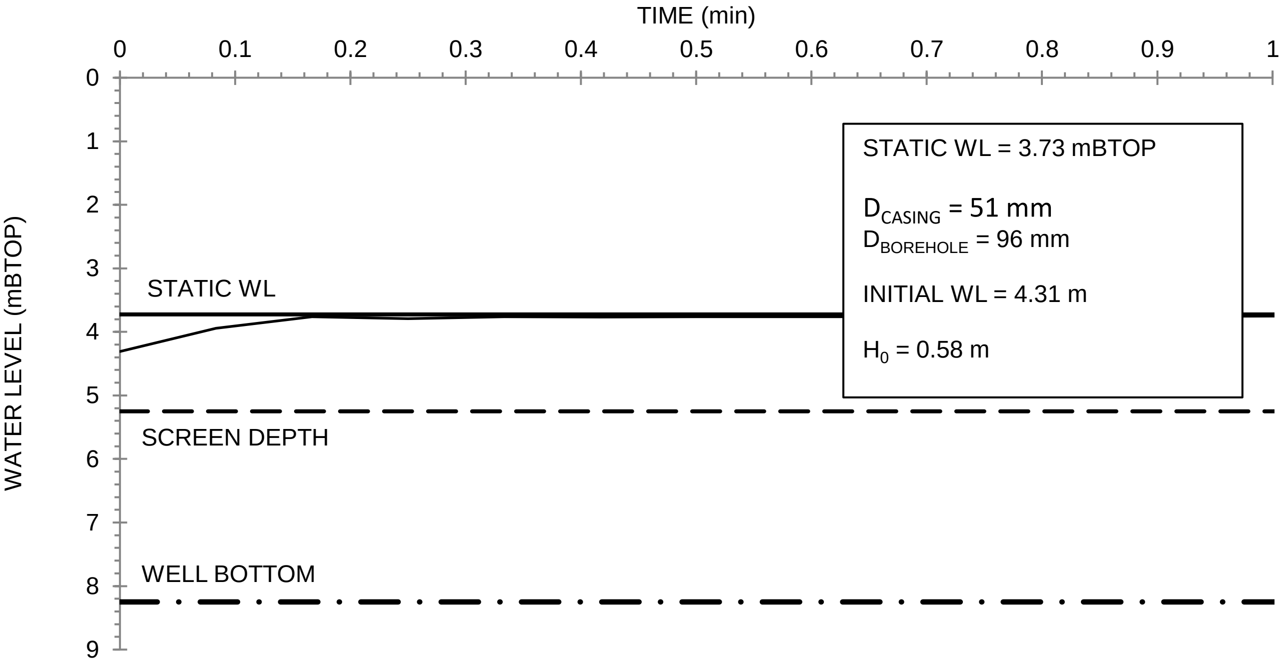
Rising Head Slug Test Analysis

Hvorslev Method

Law Quarry Extension

Date: November 21, 2019

Performed by: BC

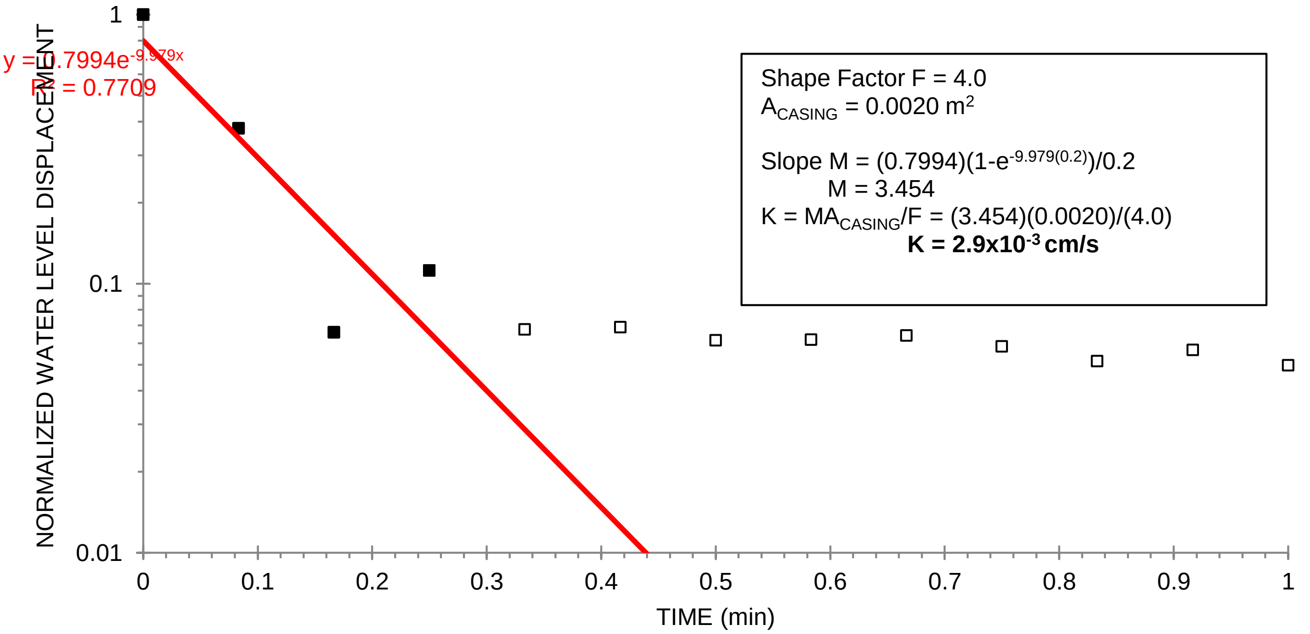


STATIC WL = 3.73 mBTOP

D_{CASING} = 51 mm
$D_{BOREHOLE}$ = 96 mm

INITIAL WL = 4.31 m

H_0 = 0.58 m



Shape Factor F = 4.0
A_{CASING} = 0.0020 m^2

Slope M = $(0.7994)(1-e^{-9.979(0.2)})/0.2$
M = 3.454
K = MA_{CASING}/F = (3.454)(0.0020)/(4.0)
K = 2.9×10^{-3} cm/s

Figure 2-2

GLL-3

Rising Head Slug Test Analysis

Hvorslev Method

Law Quarry Extension

Date: November 21, 2019

Performed by: BC

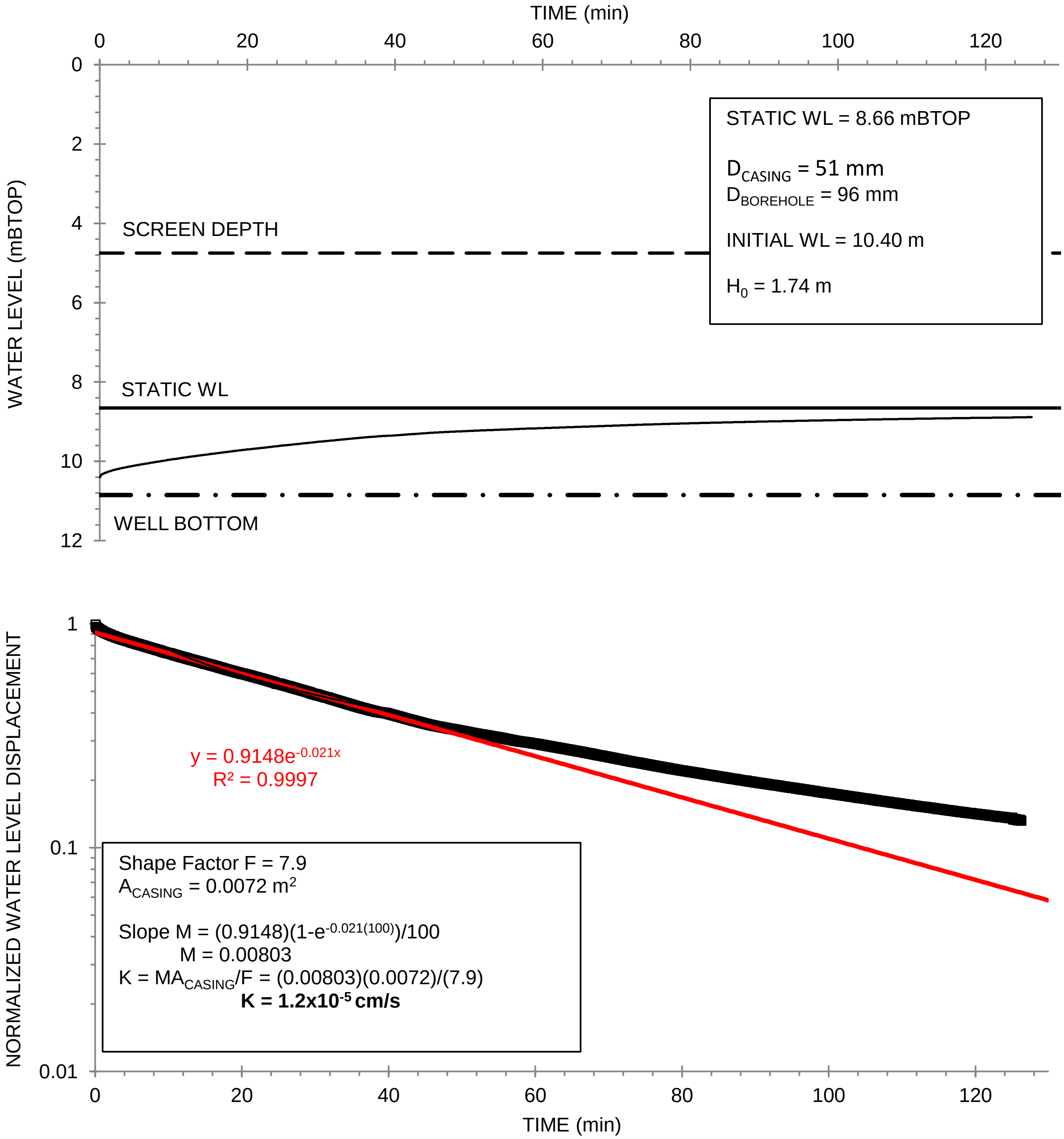


Figure 2-3

GLL-7

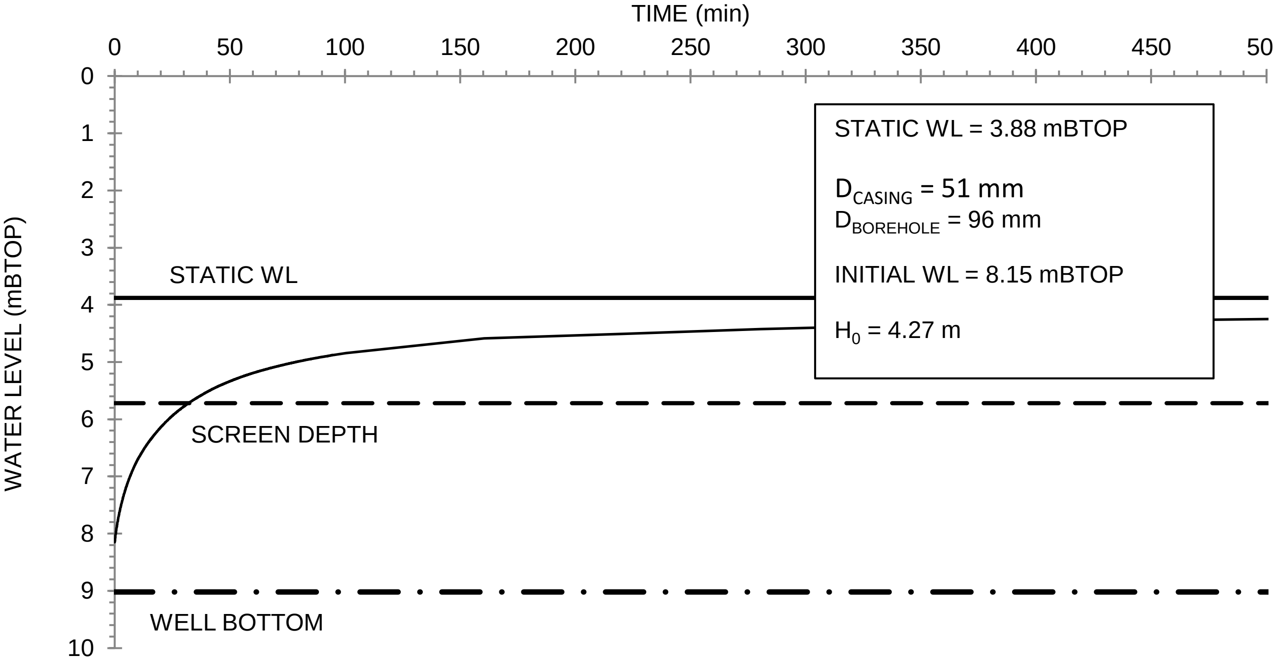
Rising Head Slug Test Analysis

Hvorslev Method

Law Quarry Extension

Date: December 6, 2019

Performed by: BC

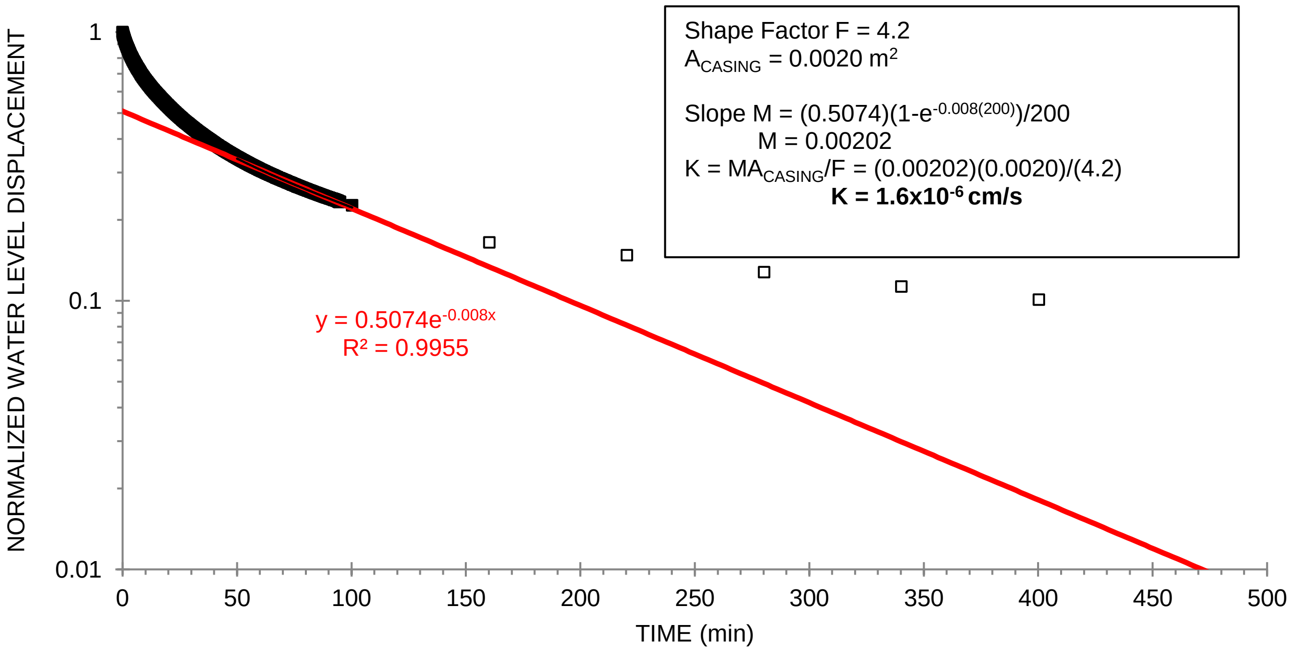


STATIC WL = 3.88 mBTOP

D_{CASING} = 51 mm
$D_{BOREHOLE}$ = 96 mm

INITIAL WL = 8.15 mBTOP

H_0 = 4.27 m



Shape Factor F = 4.2
A_{CASING} = 0.0020 m^2

Slope M = $(0.5074)(1-e^{-0.008(200)})/200$
M = 0.00202
K = MA_{CASING}/F = (0.00202)(0.0020)/(4.2)
K = $1.6\text{x}10^{-6}$ cm/s

Figure 2-4

GLL-9

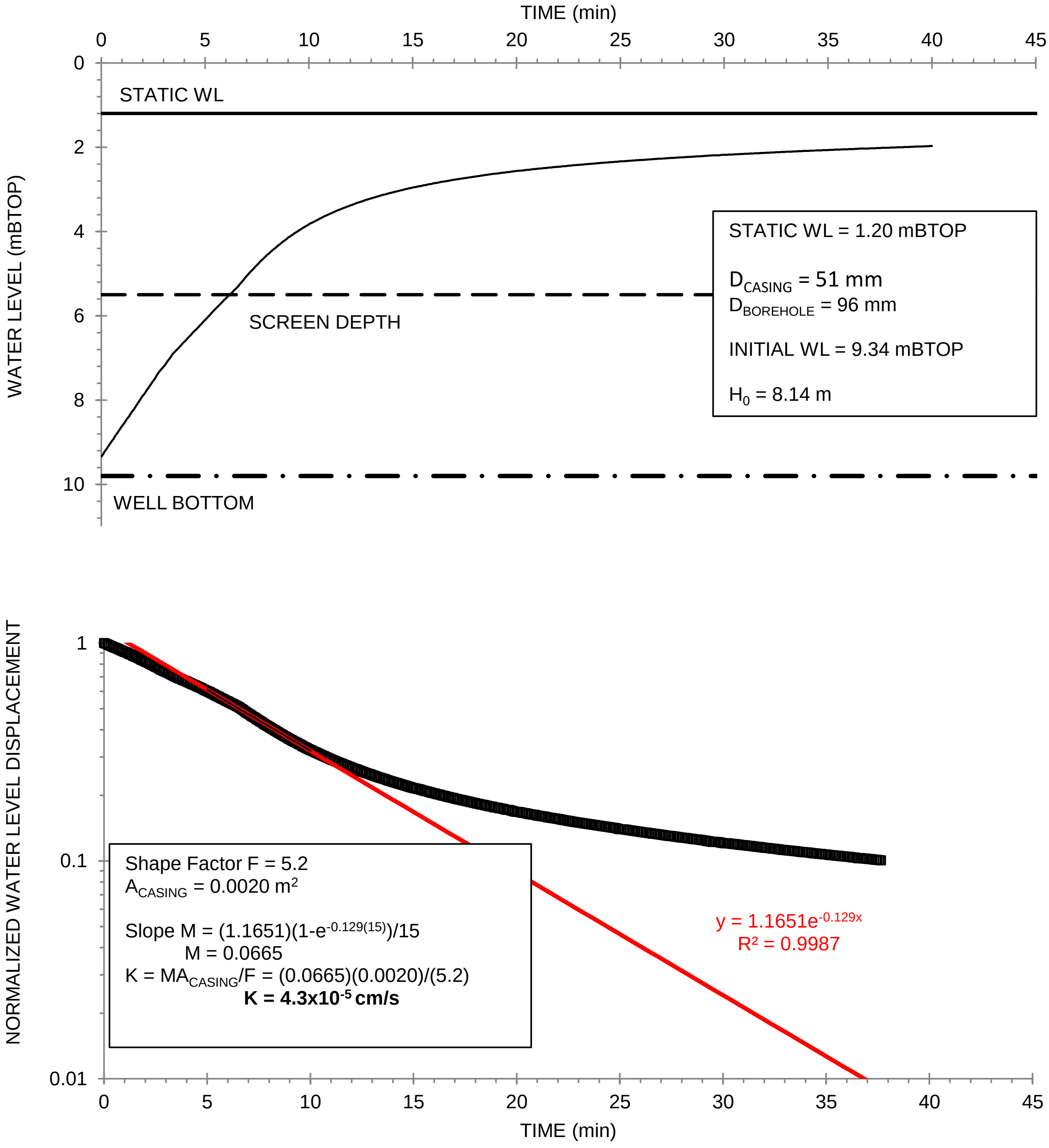
Rising Head Slug Test Analysis

Hvorslev Method

Law Quarry Extension

Date: December 5, 2019

Performed by: BC


STATIC WL = 1.20 mBTOP

D_{CASING} = 51 mm
$D_{BOREHOLE}$ = 96 mm

INITIAL WL = 9.34 mBTOP

H_0 = 8.14 m

Shape Factor F = 5.2
A_{CASING} = 0.0020 m^2

Slope M = (1.1651)(1-e$^{-0.129(15)}$)/15
M = 0.0665
K = MA_{CASING}/F = (0.0665)(0.0020)/(5.2)
K = 4.3x10^{-5} cm/s

y = 1.1651e$^{-0.129x}$
R² = 0.9987

Figure 2-5

GLL-10

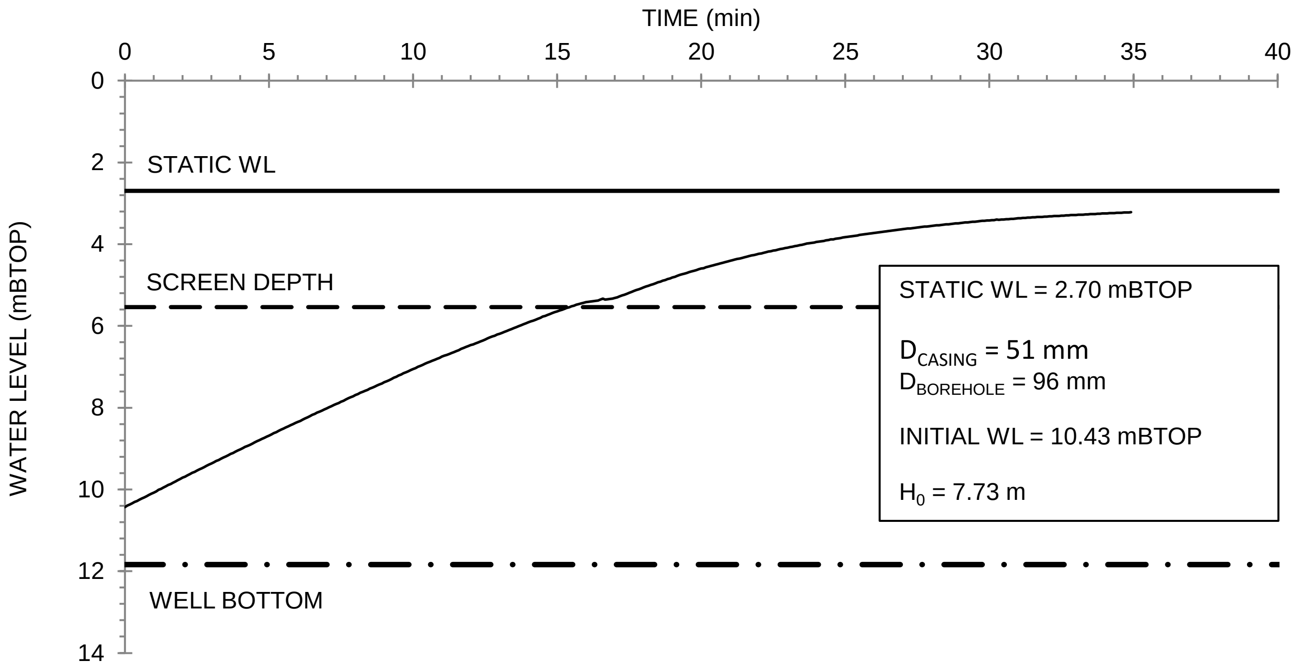
Rising Head Slug Test Analysis

Hvorslev Method

Law Quarry Extension

Date: December 5, 2019

Performed by: BC



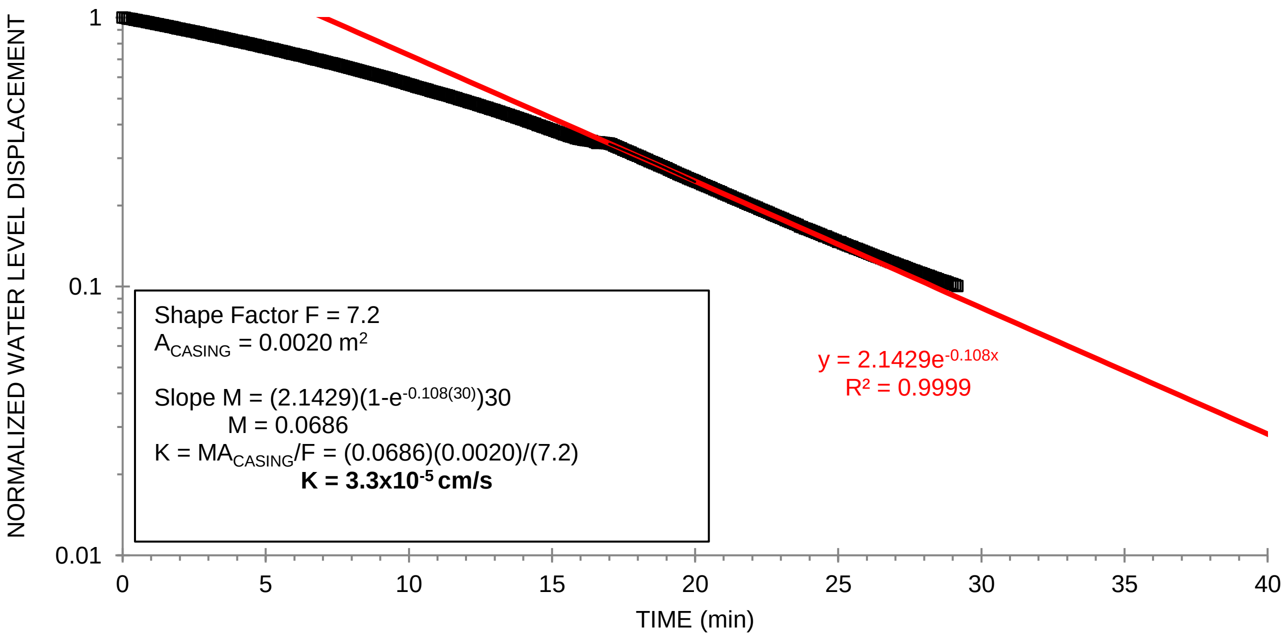


Figure 2-6

GLL-11-II

Rising Head Slug Test Analysis

Hvorslev Method

Law Quarry Extension

Date: November 20, 2019

Performed by: BC

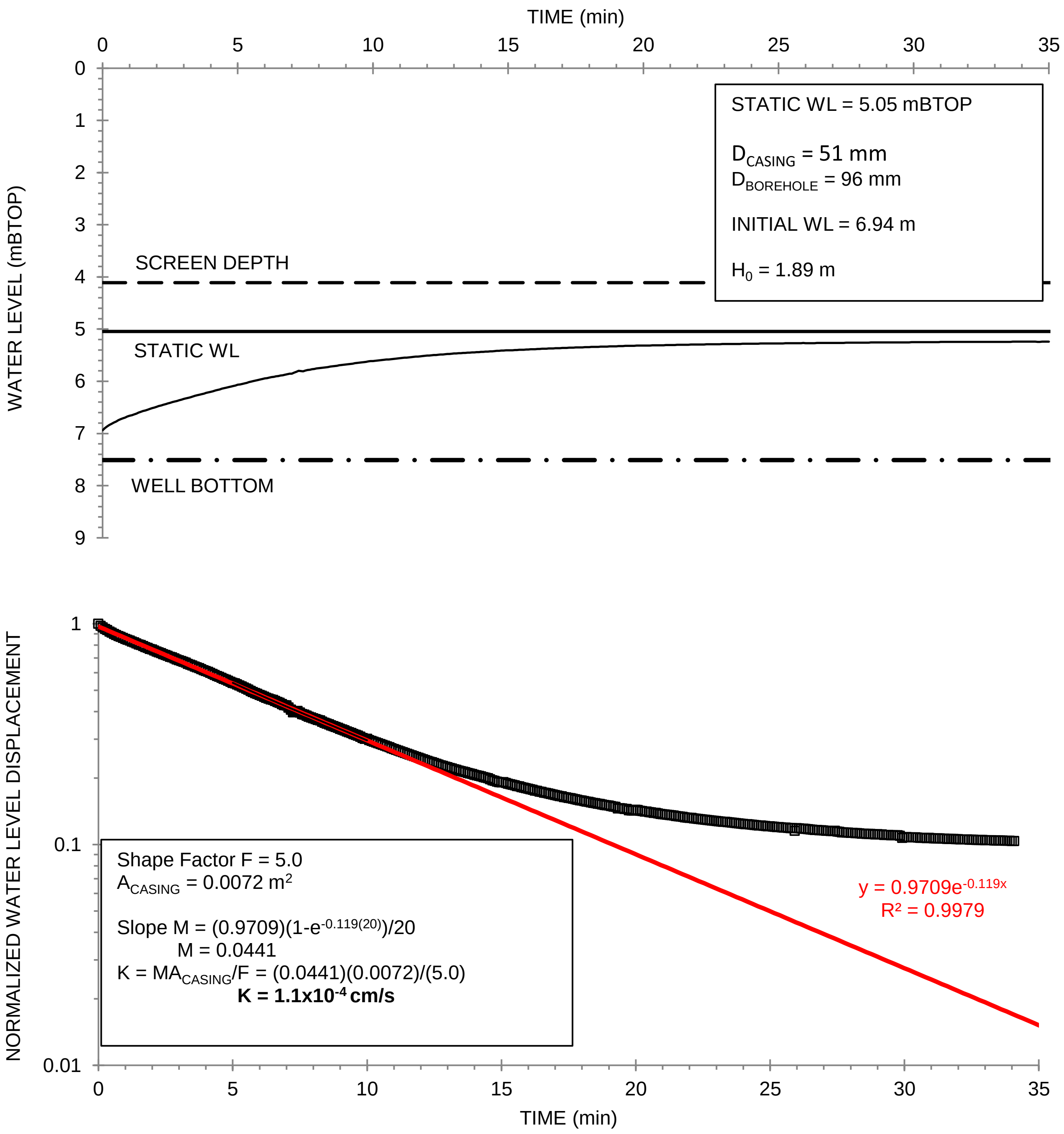


Figure 2-7

MW1-III

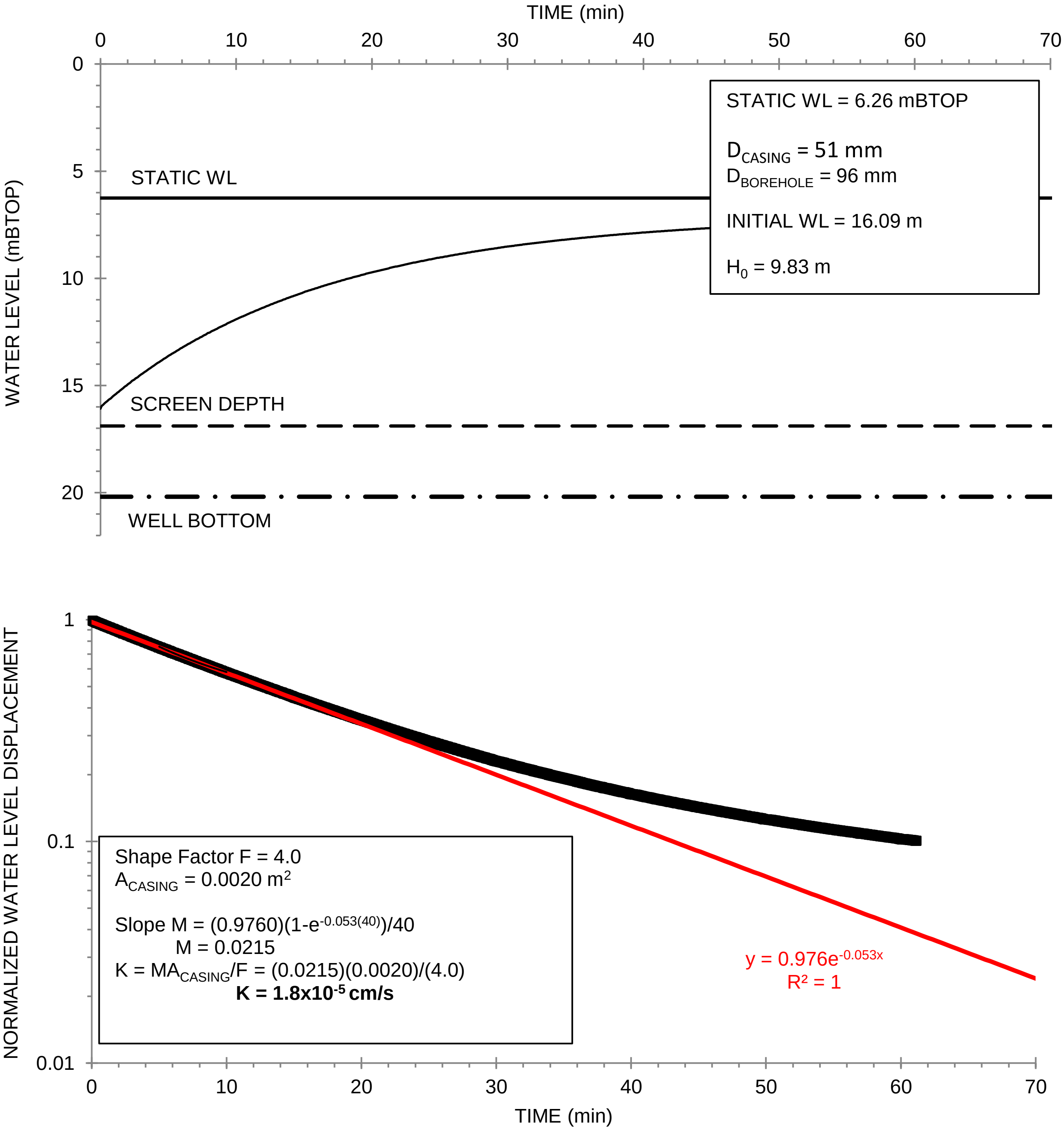
Rising Head Slug Test Analysis

Hvorslev Method

Law Quarry Extension

Date: November 21, 2019

Performed by: BC



STATIC WL = 6.26 mBTOP

D_{CASING} = 51 mm
$D_{BOREHOLE}$ = 96 mm

INITIAL WL = 16.09 m

H_0 = 9.83 m

Shape Factor F = 4.0
A_{CASING} = 0.0020 m^2

Slope M = $(0.9760)(1-e^{-0.053(40)})/40$
M = 0.0215
K = MA_{CASING}/F = (0.0215)(0.0020)/(4.0)
K = 1.8x10^{-5} cm/s

Figure 2-8

MW4-III

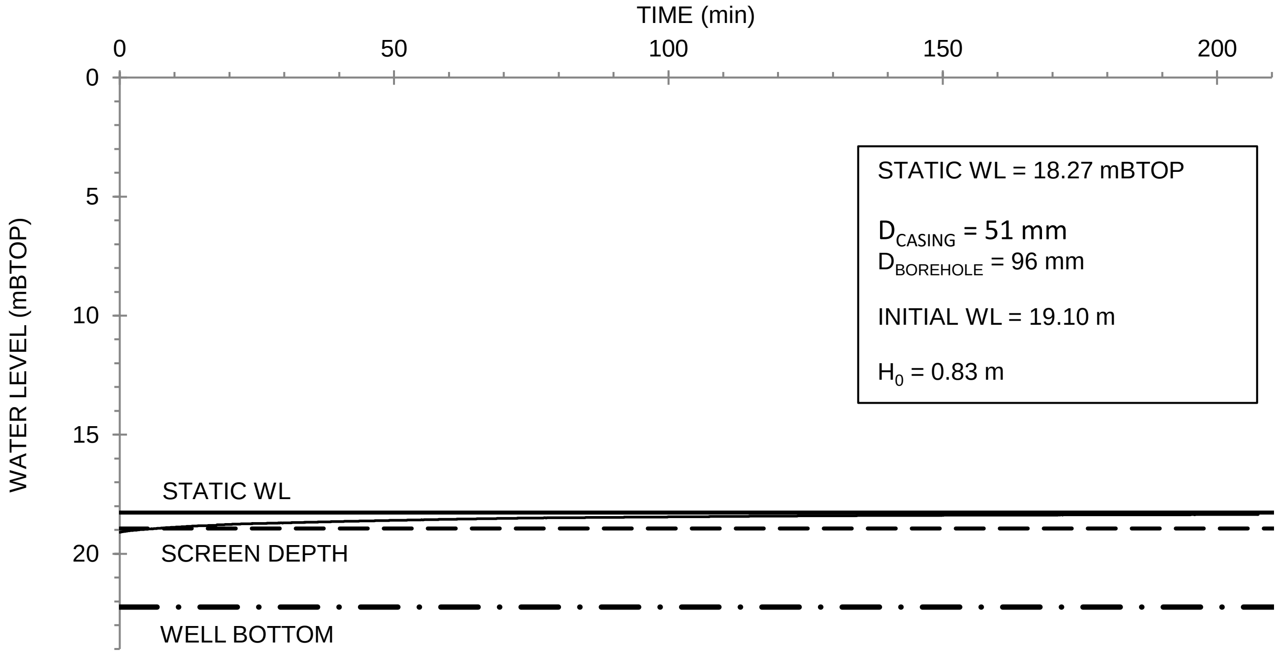
Rising Head Slug Test Analysis

Hvorslev Method

Law Quarry Extension

Date: December 4, 2019

Performed by: BC

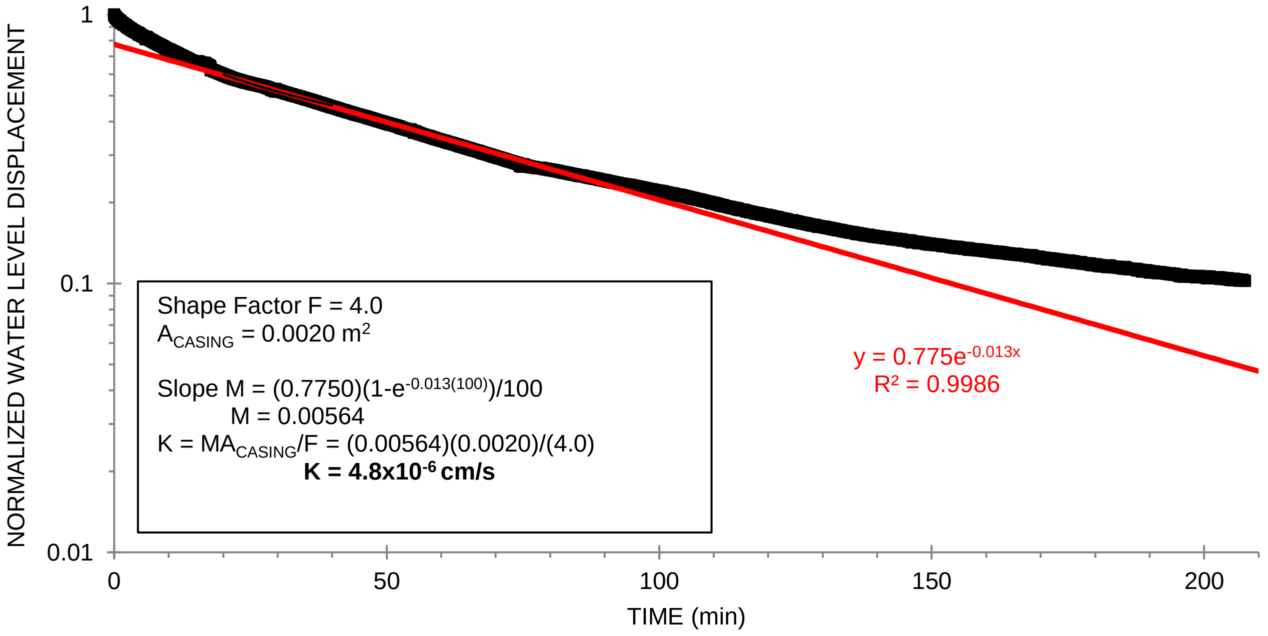


STATIC WL = 18.27 mBTOP

D_{CASING} = 51 mm
$D_{BOREHOLE}$ = 96 mm

INITIAL WL = 19.10 m

H_0 = 0.83 m



Shape Factor F = 4.0
A_{CASING} = 0.0020 m^2

Slope M = $(0.7750)(1-e^{-0.013(100)})/100$
M = 0.00564
K = MA_{CASING}/F = (0.00564)(0.0020)/(4.0)
K = $4.8\text{x}10^{-6}$ cm/s

Figure 2-9

GLL-5

Rising Head Slug Test Analysis

Hvorslev Method

Law Quarry Extension

Date: November 22, 2019

Performed by: BC

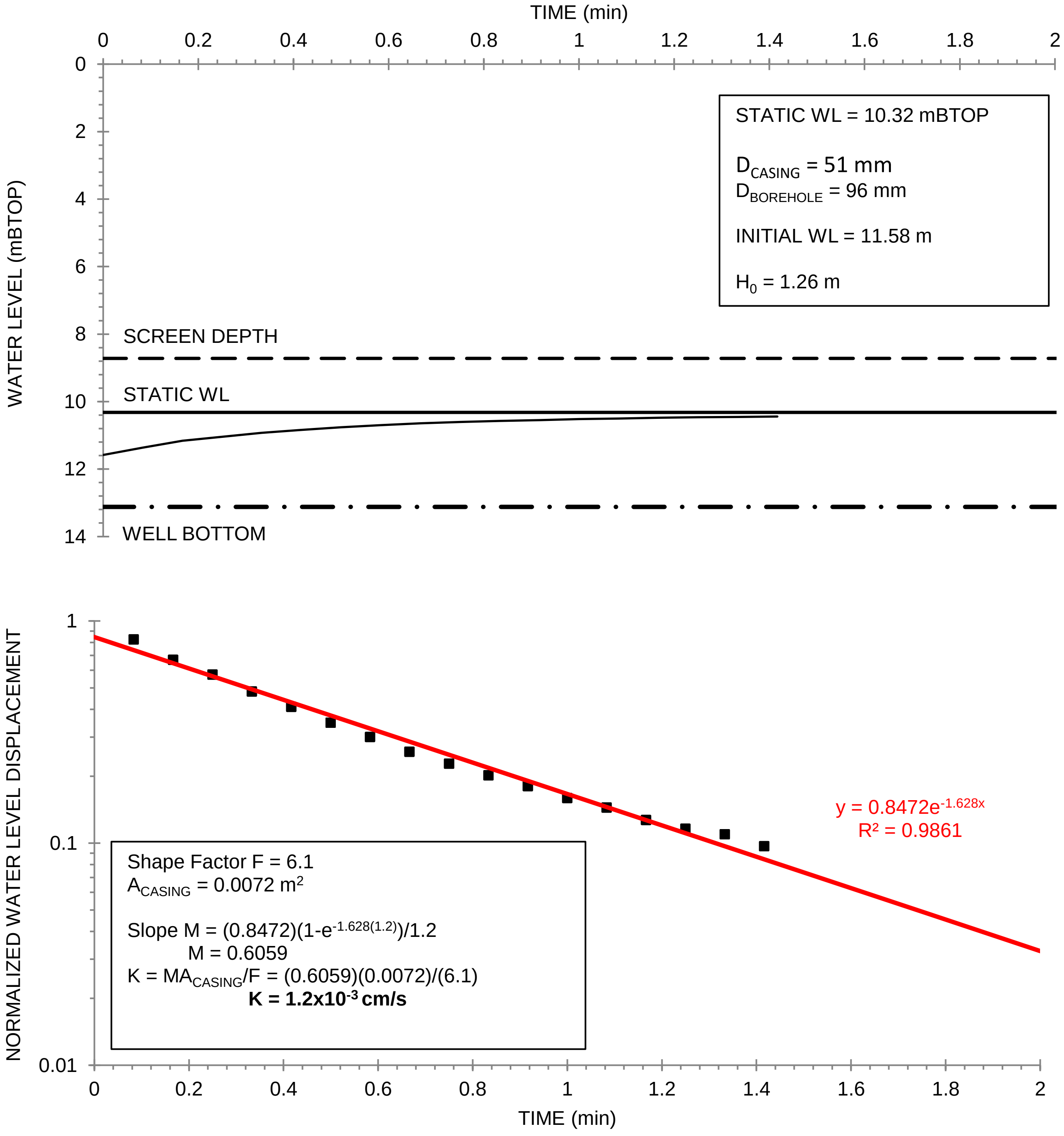


Figure 2-10

GLL-6

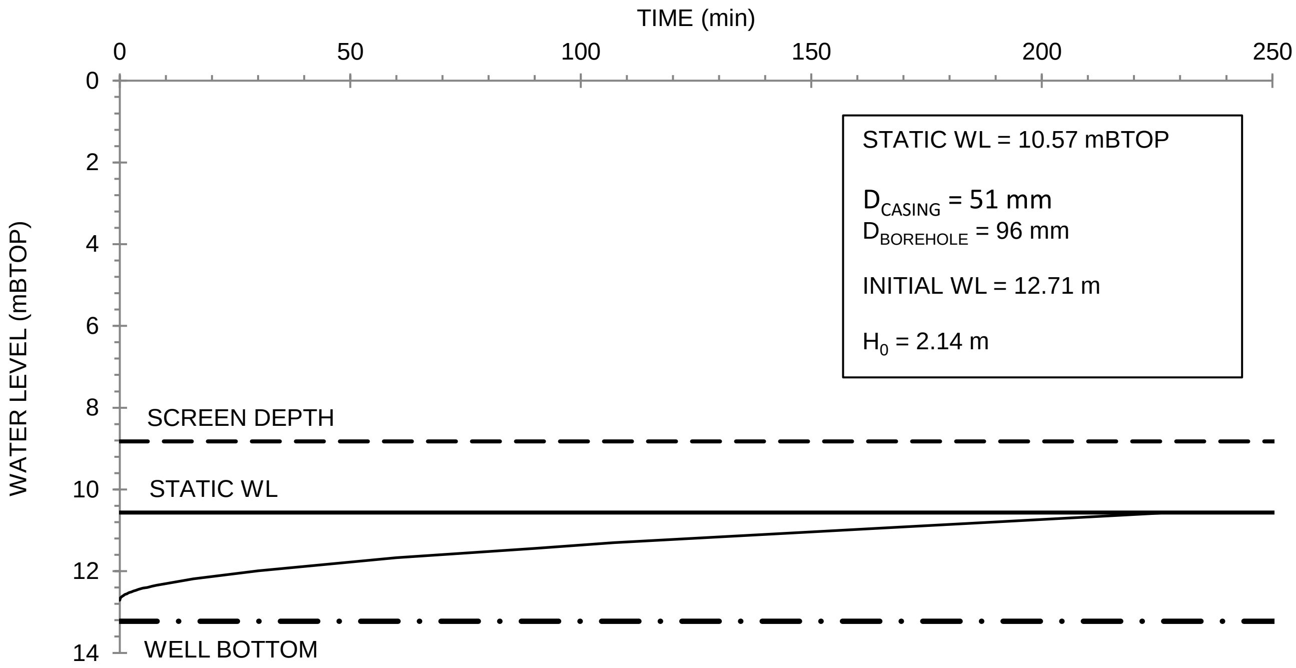
Rising Head Slug Test Analysis

Hvorslev Method

Law Quarry Extension

Date: November 22, 2019

Performed by: BC

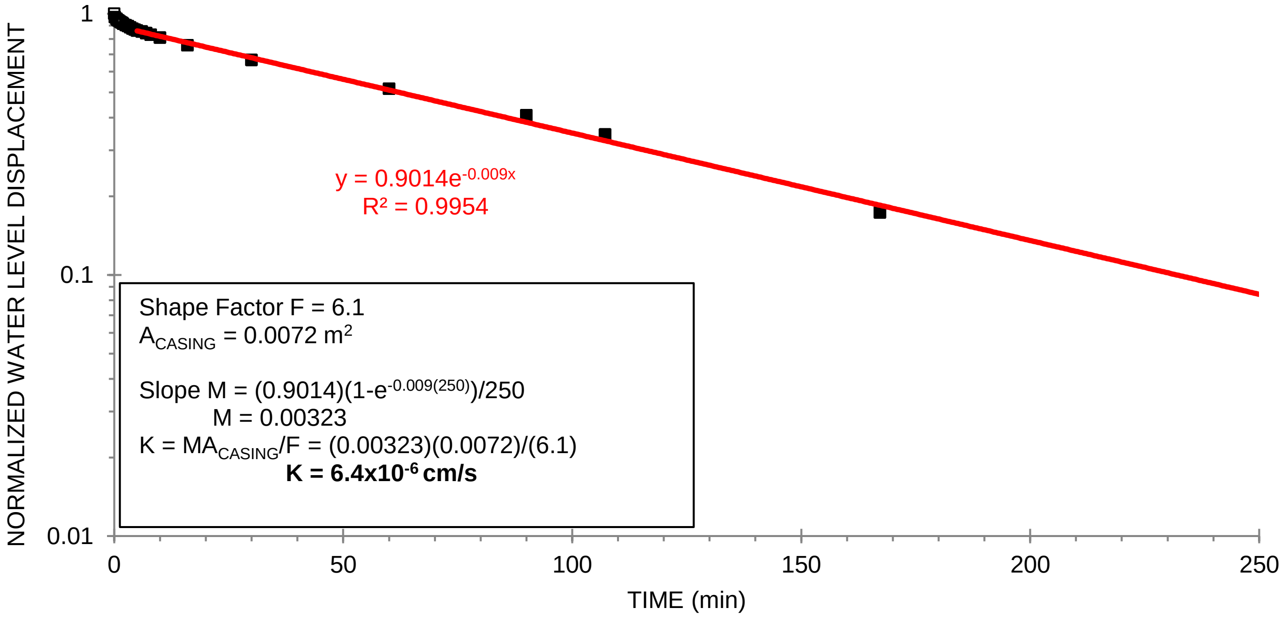


STATIC WL = 10.57 mBTOP

D_{CASING} = 51 mm
$D_{BOREHOLE}$ = 96 mm

INITIAL WL = 12.71 m

H_0 = 2.14 m



Shape Factor F = 6.1
A_{CASING} = 0.0072 m^2

Slope M = (0.9014)(1-$e^{-0.009(250)}$)/250
M = 0.00323
K = MA_{CASING}/F = (0.00323)(0.0072)/(6.1)
K = 6.4x10^{-6} cm/s

Figure 2-11

MW9-III

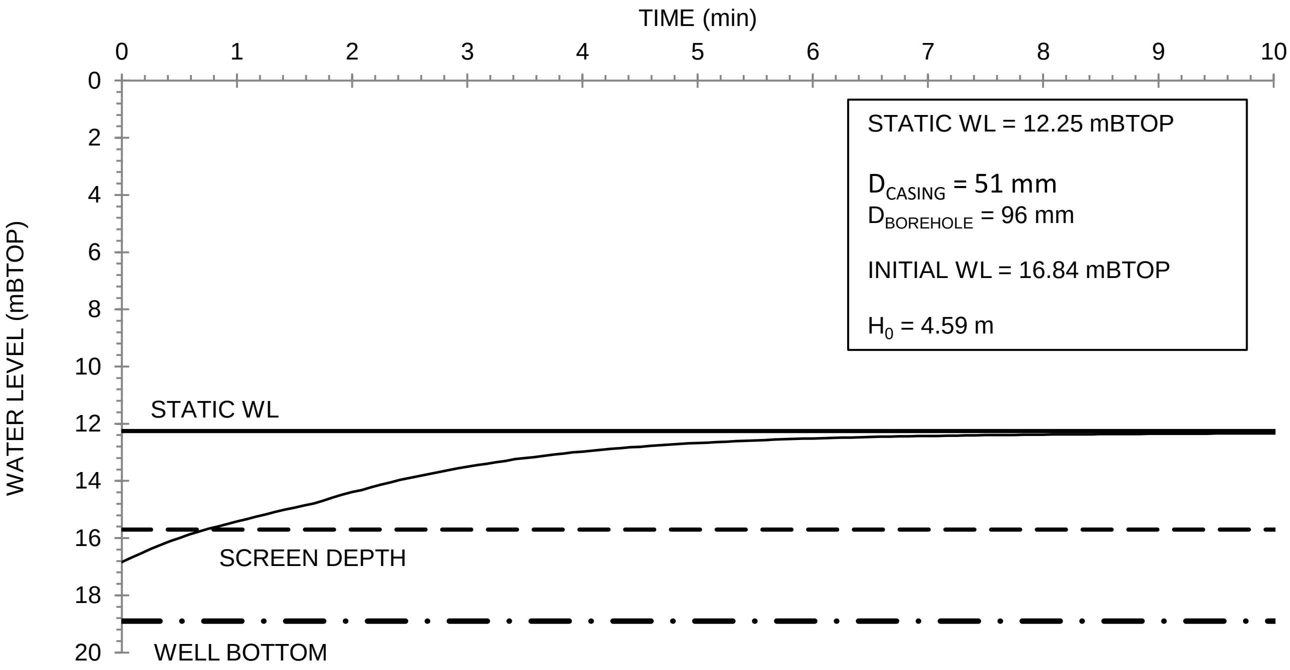
Rising Head Slug Test Analysis

Hvorslev Method

Law Quarry Extension

Date: December 5, 2019

Performed by: BC

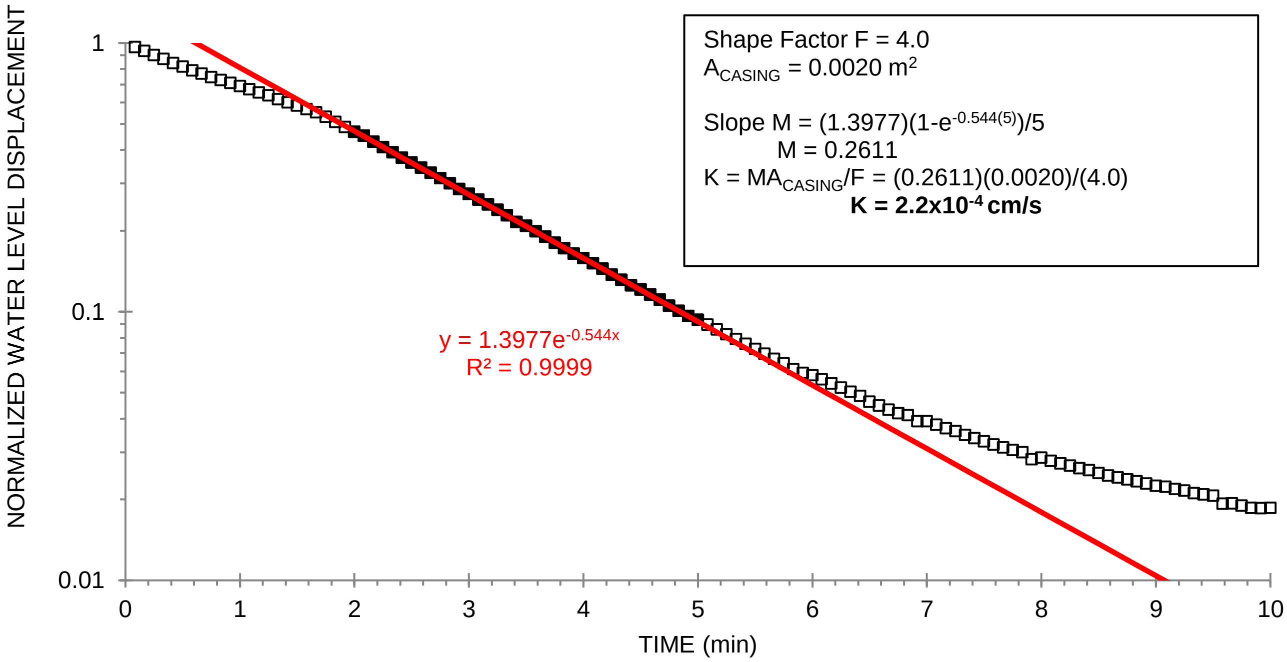


STATIC WL = 12.25 mBTOP

D_{CASING} = 51 mm
$D_{BOREHOLE}$ = 96 mm

INITIAL WL = 16.84 mBTOP

H_0 = 4.59 m



Shape Factor F = 4.0
A_{CASING} = 0.0020 m^2

Slope M = $(1.3977)(1-e^{-0.544(5)})/5$
M = 0.2611
K = MA_{CASING}/F = (0.2611)(0.0020)/(4.0)
K = 2.2×10^{-4} cm/s

Figure 2-12

MW10-III

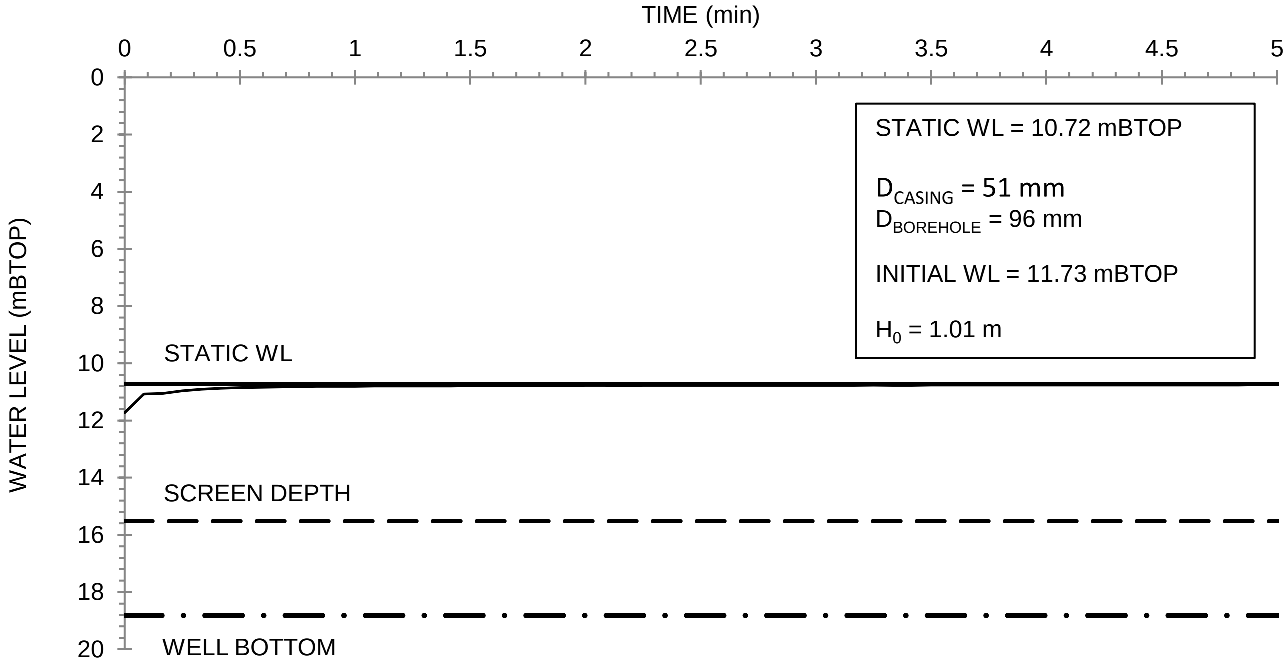
Rising Head Slug Test Analysis

Hvorslev Method

Law Quarry Extension

Date: December 5, 2019

Performed by: BC



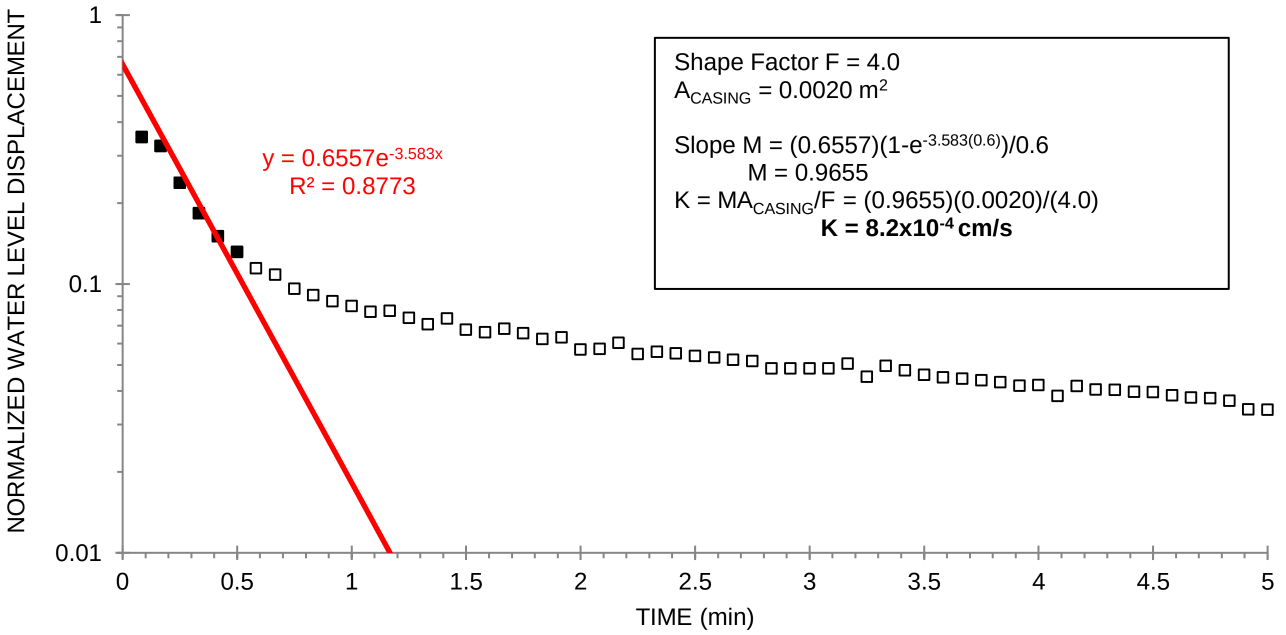


Figure 2-13

GLL-11-I

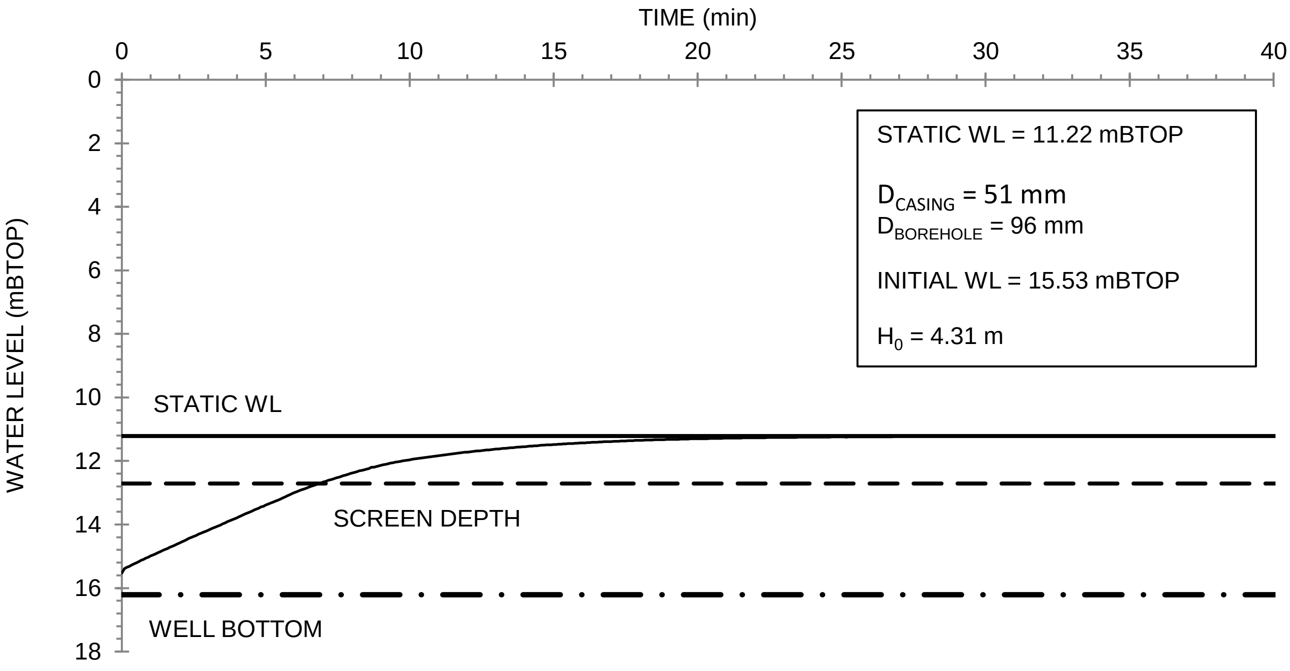
Rising Head Slug Test Analysis

Hvorslev Method

Law Quarry Extension

Date: November 20, 2019

Performed by: BC



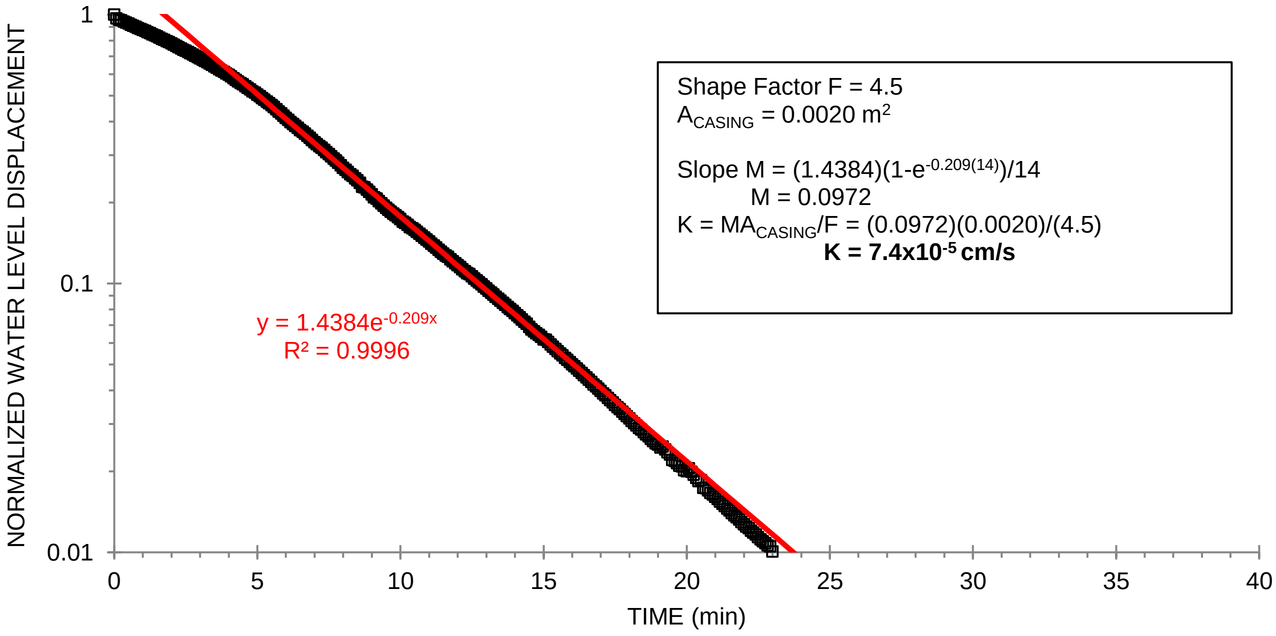


Figure 2-14

MW12-III

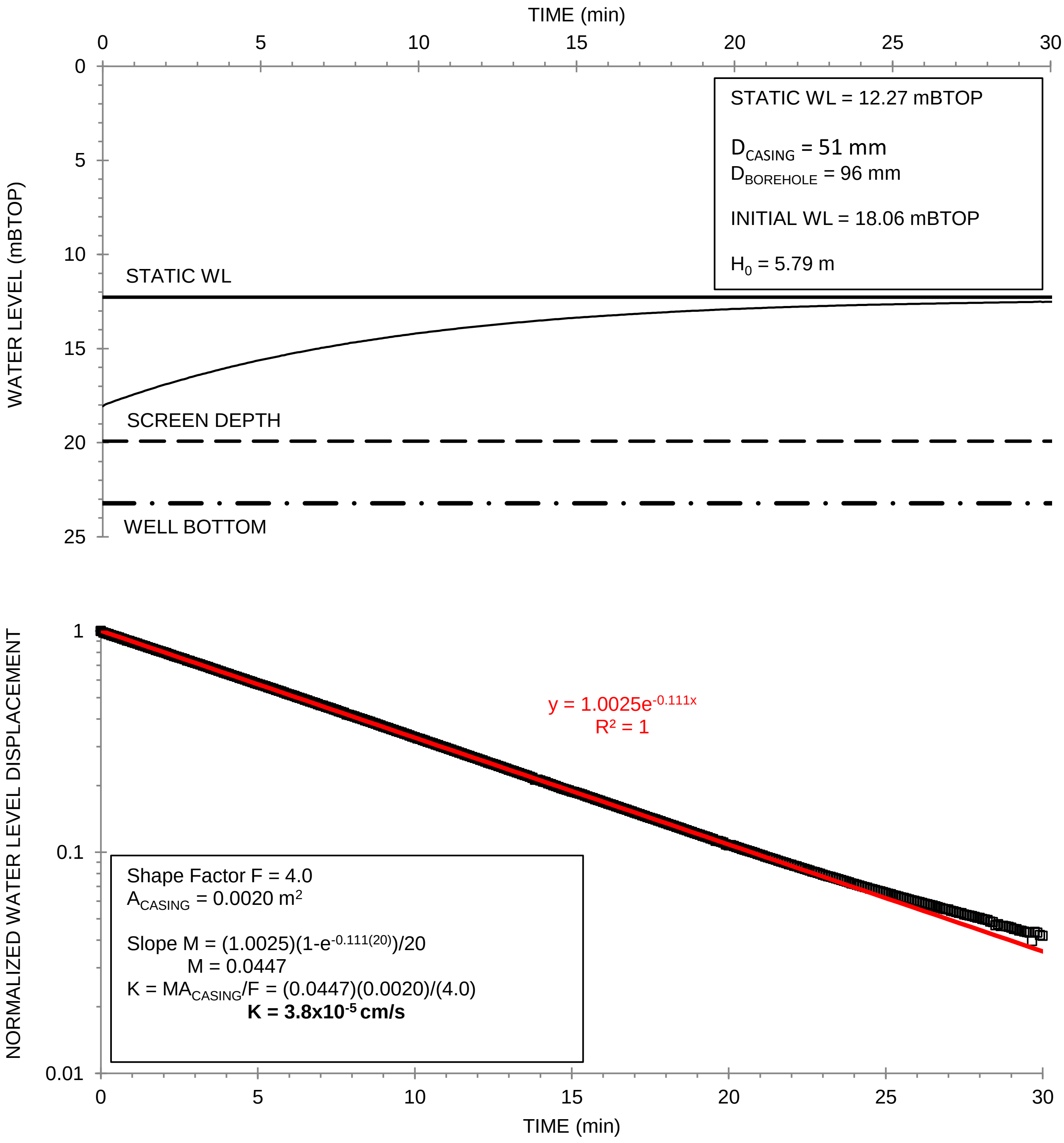
Rising Head Slug Test Analysis

Hvorslev Method

Law Quarry Extension

Date: December 4, 2019

Performed by: BC



STATIC WL = 12.27 mBTOP

D_{CASING} = 51 mm
$D_{BOREHOLE}$ = 96 mm

INITIAL WL = 18.06 mBTOP

H_0 = 5.79 m

Shape Factor F = 4.0
A_{CASING} = 0.0020 m^2

Slope M = $(1.0025)(1-e^{-0.111(20)})/20$
M = 0.0447
K = MA_{CASING}/F = (0.0447)(0.0020)/(4.0)
K = $3.8\text{x}10^{-5}$ cm/s

Figure 2-15

MW1-II

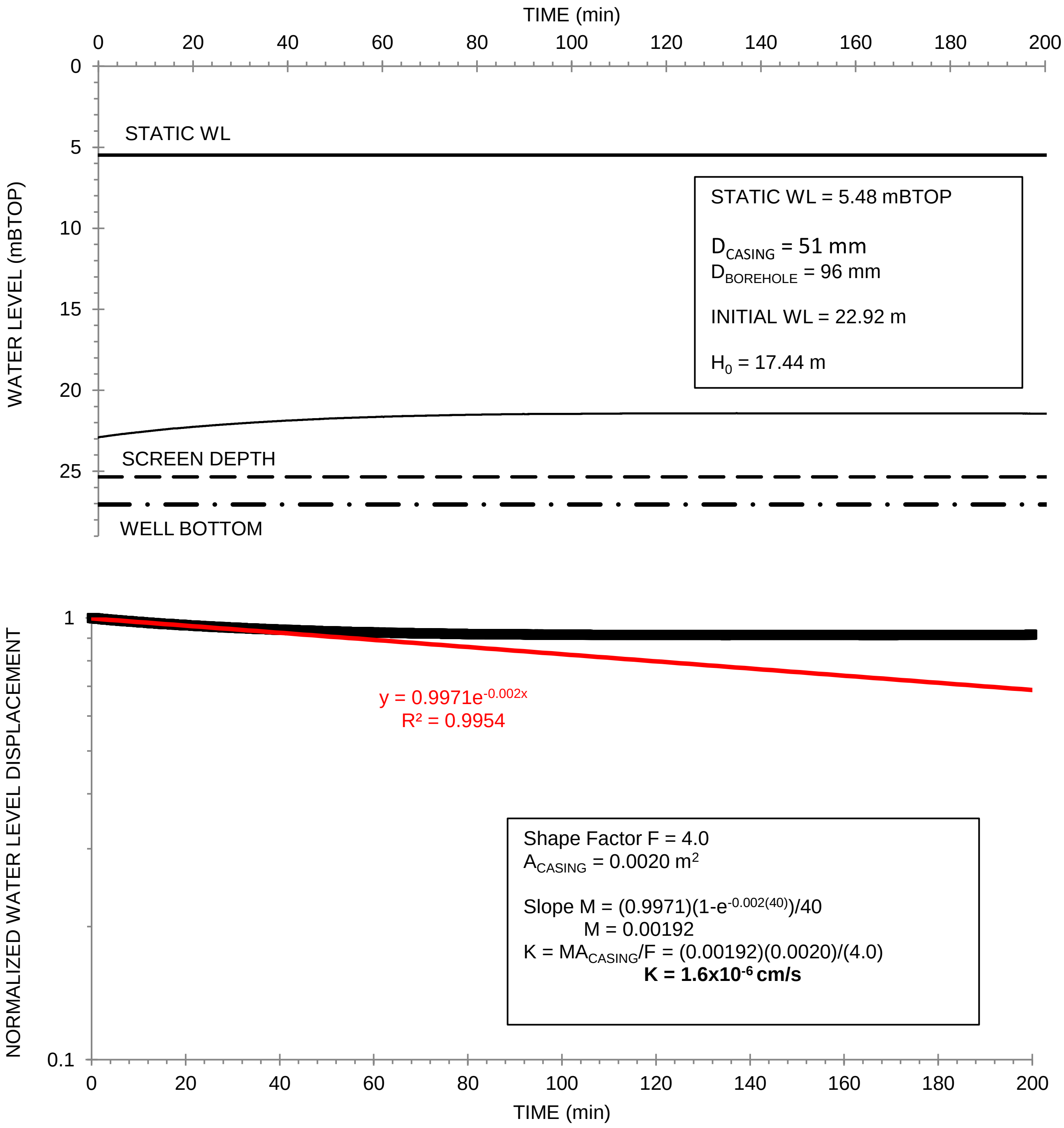
Rising Head Slug Test Analysis

Hvorslev Method

Law Quarry Extension

Date: November 21, 2019

Performed by: BC



STATIC WL = 5.48 mBTOP

D_{CASING} = 51 mm
$D_{BOREHOLE}$ = 96 mm

INITIAL WL = 22.92 m

H_0 = 17.44 m

Shape Factor F = 4.0
A_{CASING} = 0.0020 m^2

Slope M = $(0.9971)(1-e^{-0.002(40)})/40$
M = 0.00192
K = MA_{CASING}/F = (0.00192)(0.0020)/(4.0)
K = $1.6x10^{-6}$ cm/s

Figure 2-16

MW4-II

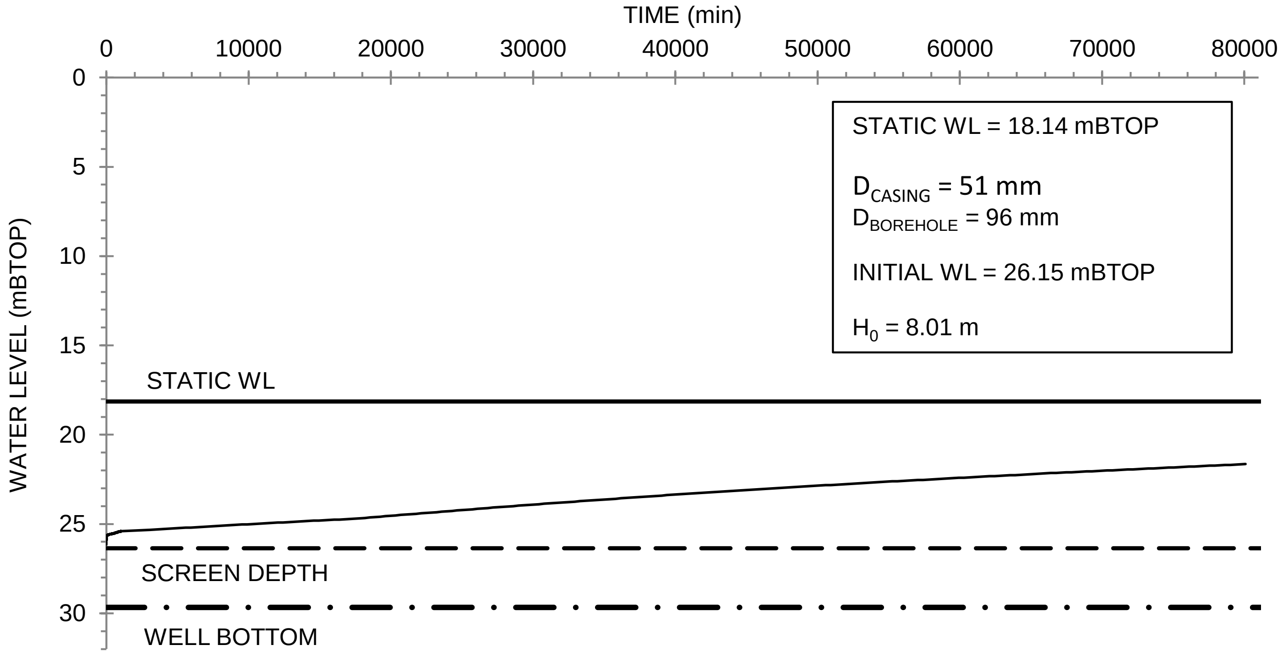
Rising Head Slug Test Analysis

Hvorslev Method

Law Quarry Extension

Date: December 4, 2019

Performed by: BC

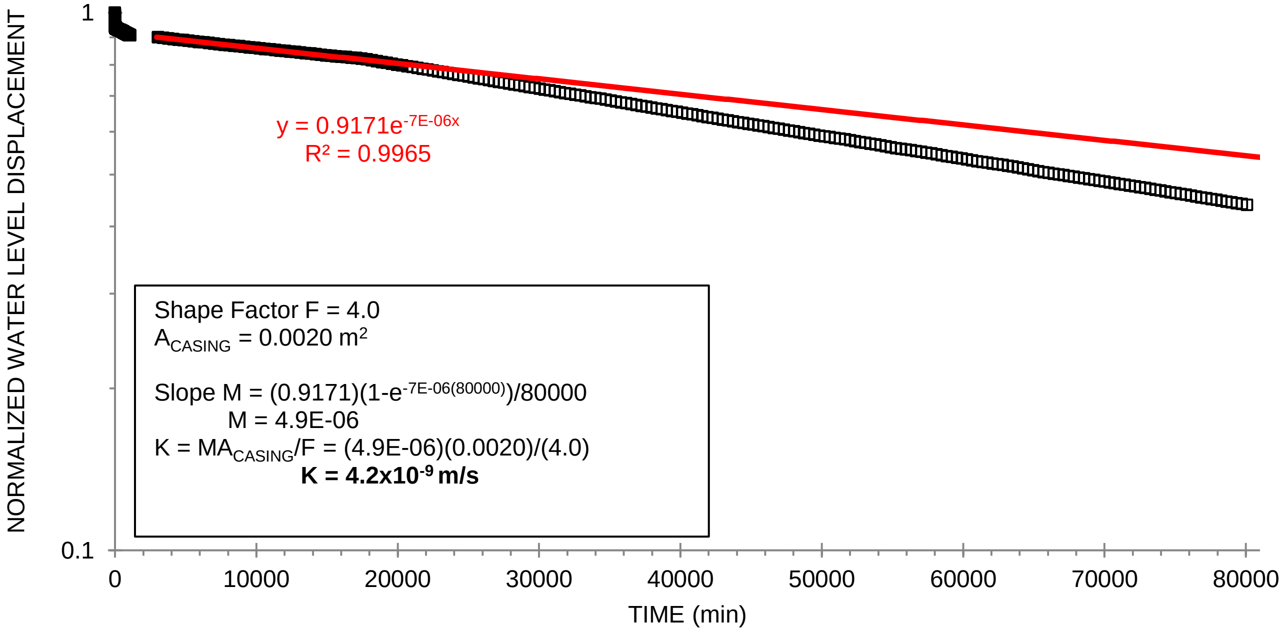


STATIC WL = 18.14 mBTOP

D_{CASING} = 51 mm
$D_{BOREHOLE}$ = 96 mm

INITIAL WL = 26.15 mBTOP

H_0 = 8.01 m



$y = 0.9171e^{-7E-06x}$
$R^2 = 0.9965$

Shape Factor F = 4.0
A_{CASING} = 0.0020 m^2

Slope M = $(0.9171)(1-e^{-7E-06(80000)})/80000$
M = 4.9E-06
K = MA_{CASING}/F = (4.9E-06)(0.0020)/(4.0)
K = 4.2×10^{-9} m/s

Figure 2-17

MW6-II

Rising Head Slug Test Analysis

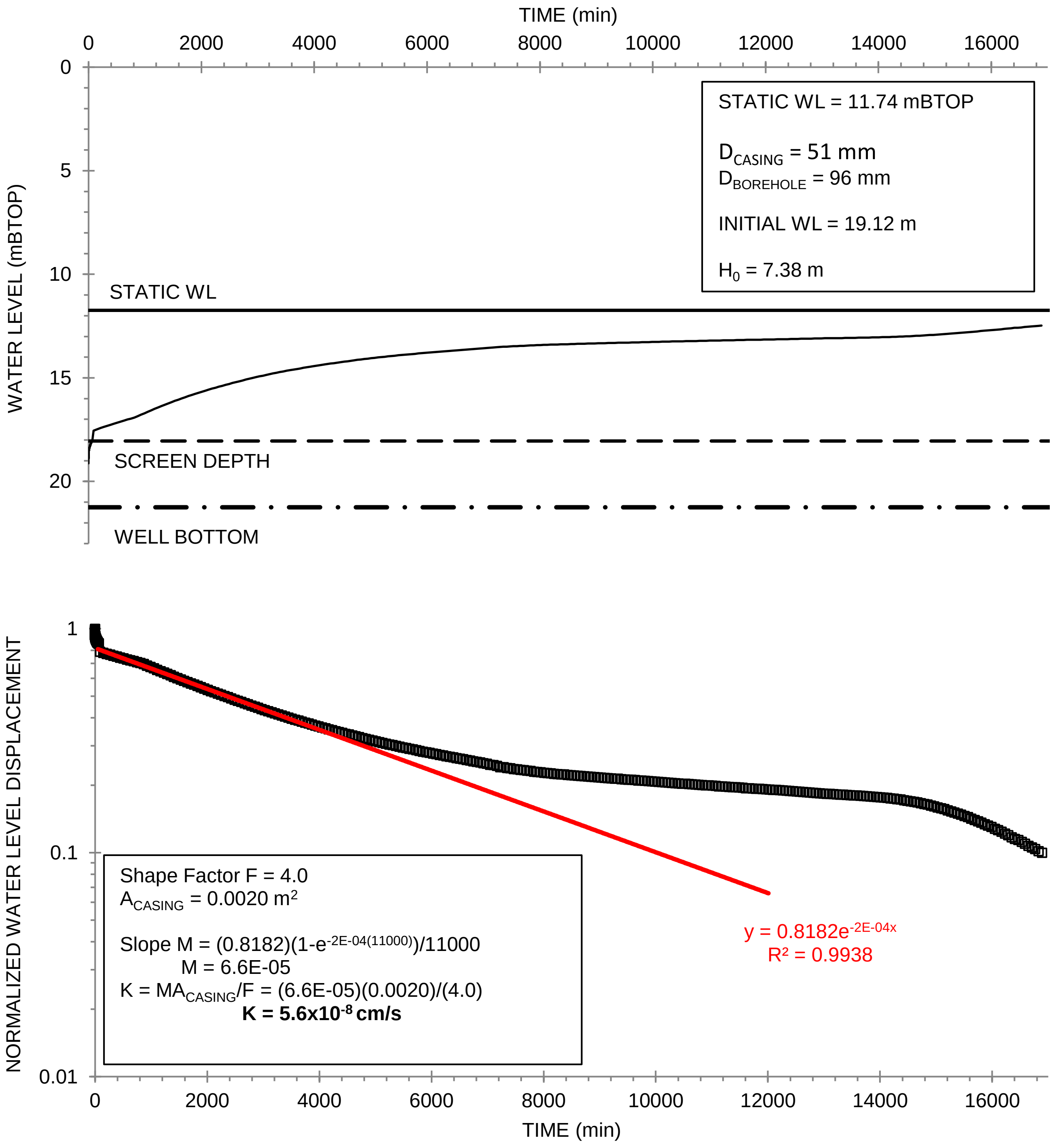
Hvorslev Method

Law Quarry Extension

wsp

Date: November 22, 2019

Performed by: BC



STATIC WL = 11.74 mBTOP

D_{CASING} = 51 mm
$D_{BOREHOLE}$ = 96 mm

INITIAL WL = 19.12 m

H_0 = 7.38 m

Shape Factor F = 4.0
A_{CASING} = 0.0020 m^2

Slope M = $(0.8182)(1-e^{-2E-04(11000)})/11000$
M = 6.6E-05
K = MA_{CASING}/F = (6.6E-05)(0.0020)/(4.0)
K = 5.6×10^{-8} cm/s

y = $0.8182e^{-2E-04x}$
$R^2 = 0.9938$

Figure 2-18

MW9-II

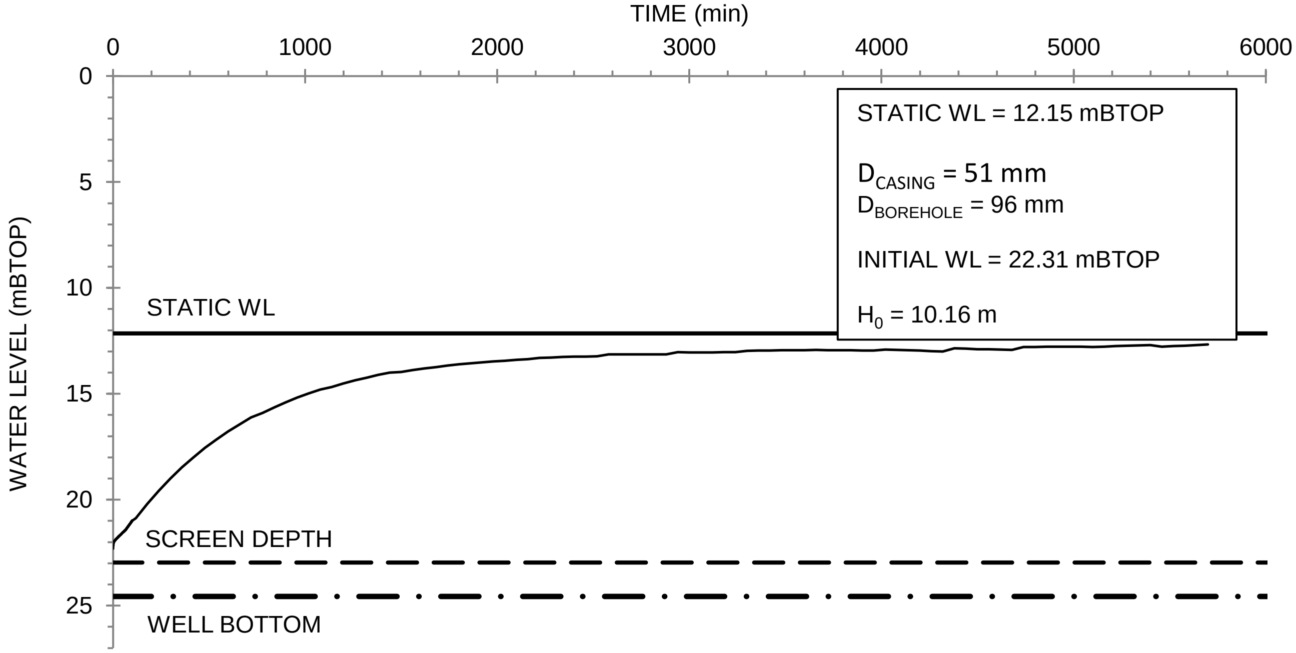
Rising Head Slug Test Analysis

Hvorslev Method

Law Quarry Extension

Date: December 6, 2019

Performed by: BC

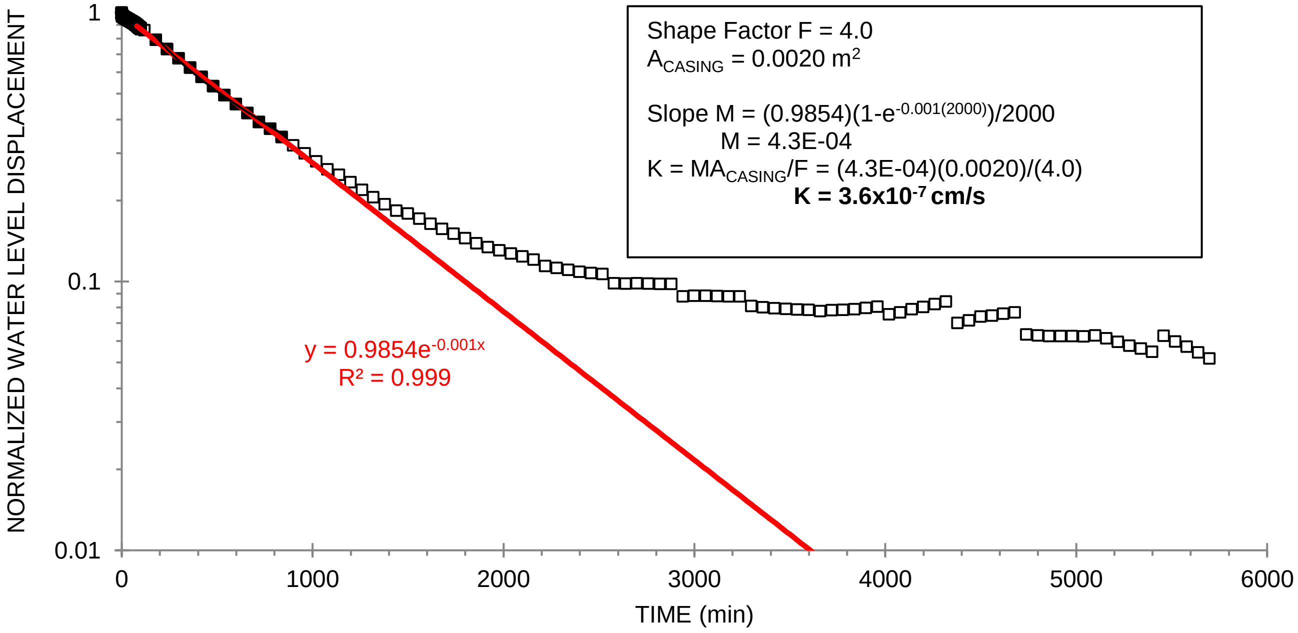


STATIC WL = 12.15 mBTOP

D_{CASING} = 51 mm
$D_{BOREHOLE}$ = 96 mm

INITIAL WL = 22.31 mBTOP

H_0 = 10.16 m



Shape Factor F = 4.0
A_{CASING} = 0.0020 m^2

Slope M = (0.9854)(1-$e^{-0.001(2000)}$)/2000
M = 4.3E-04
K = MA_{CASING}/F = (4.3E-04)(0.0020)/(4.0)
K = $3.6x10^{-7}$ cm/s

Figure 2-19

MW10-II

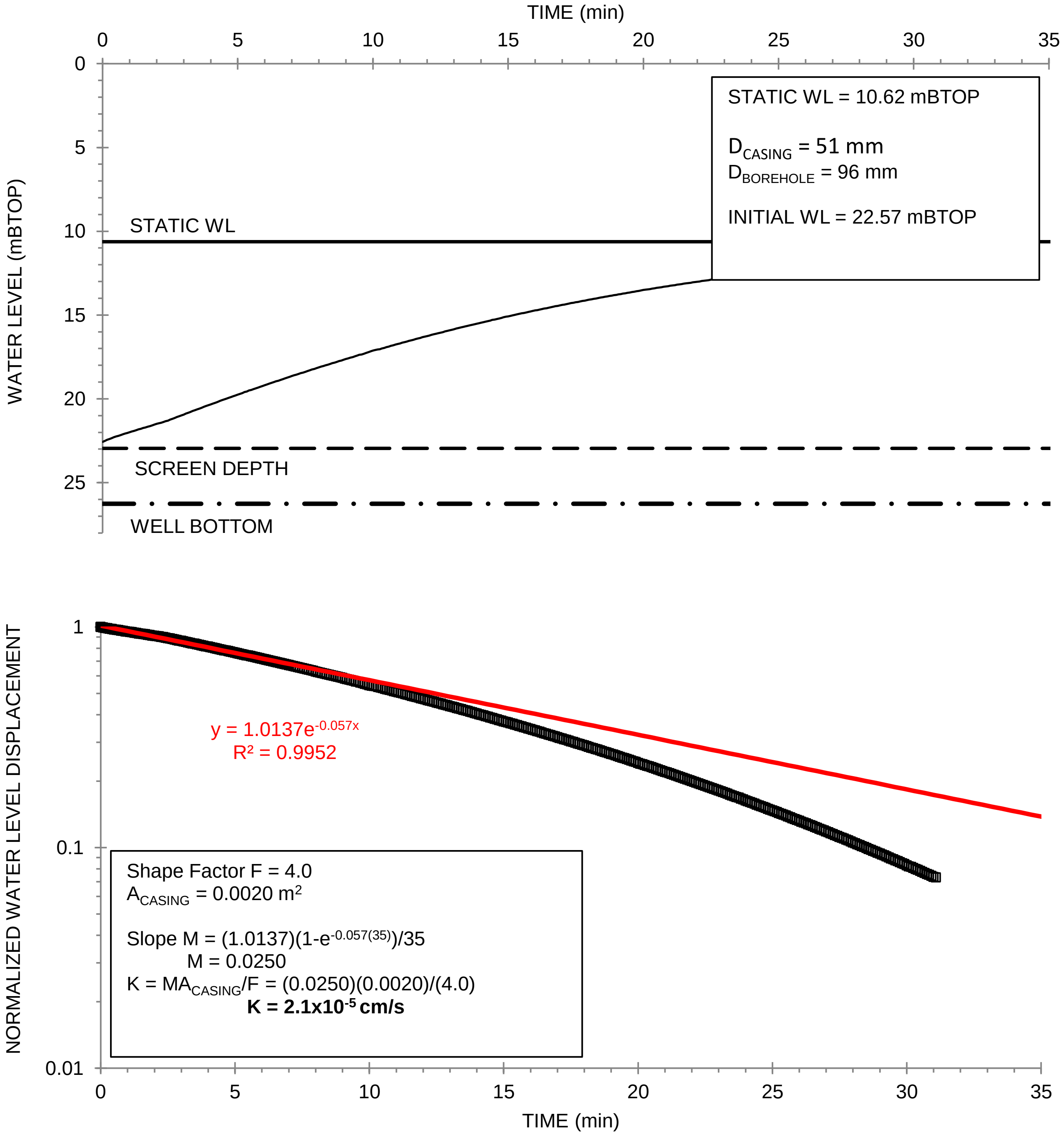
Rising Head Slug Test Analysis

Hvorslev Method

Law Quarry Extension

Date: December 5, 2019

Performed by: BC



STATIC WL = 10.62 mBTOP

D_{CASING} = 51 mm
$D_{BOREHOLE}$ = 96 mm

INITIAL WL = 22.57 mBTOP

Shape Factor F = 4.0
$A_{CASING} = 0.0020\ m^2$

Slope M = $(1.0137)(1-e^{-0.057(35)})/35$
M = 0.0250
K = $MA_{CASING}/F = (0.0250)(0.0020)/(4.0)$
K = $2.1\text{x}10^{-5}$ cm/s

Figure 2-20

MW11-1

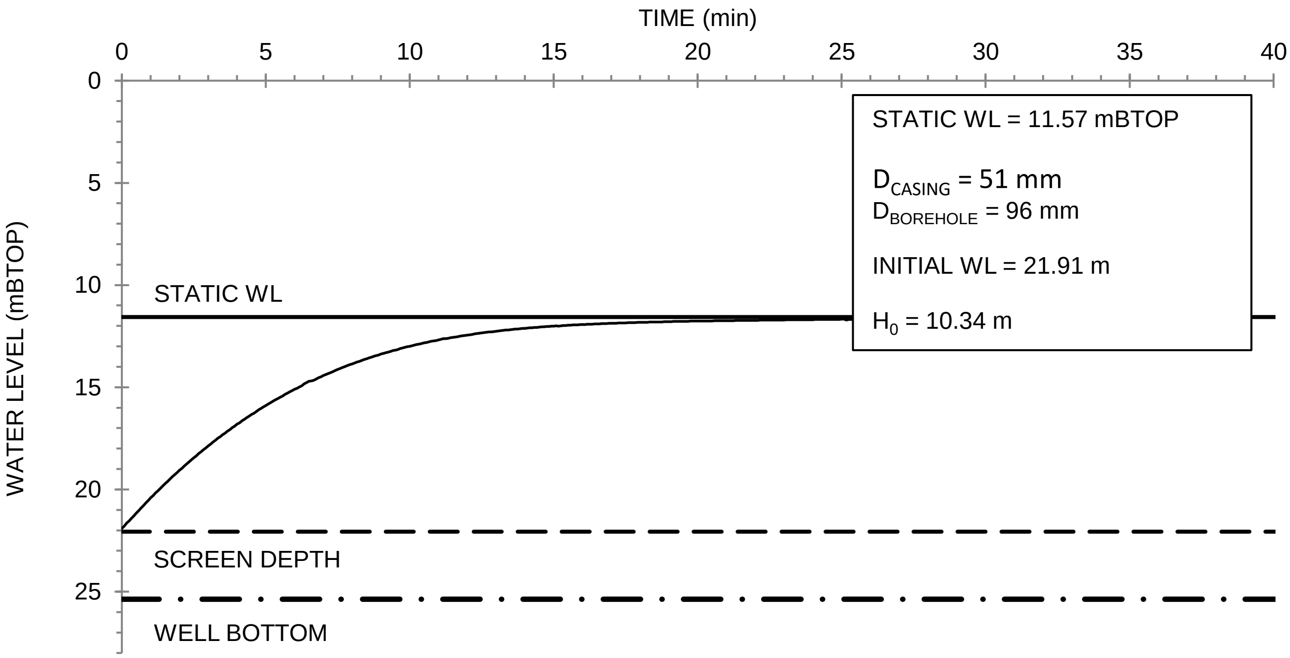
Rising Head Slug Test Analysis

Hvorslev Method

Law Quarry Extension

Date: November 20, 2019

Performed by: BC

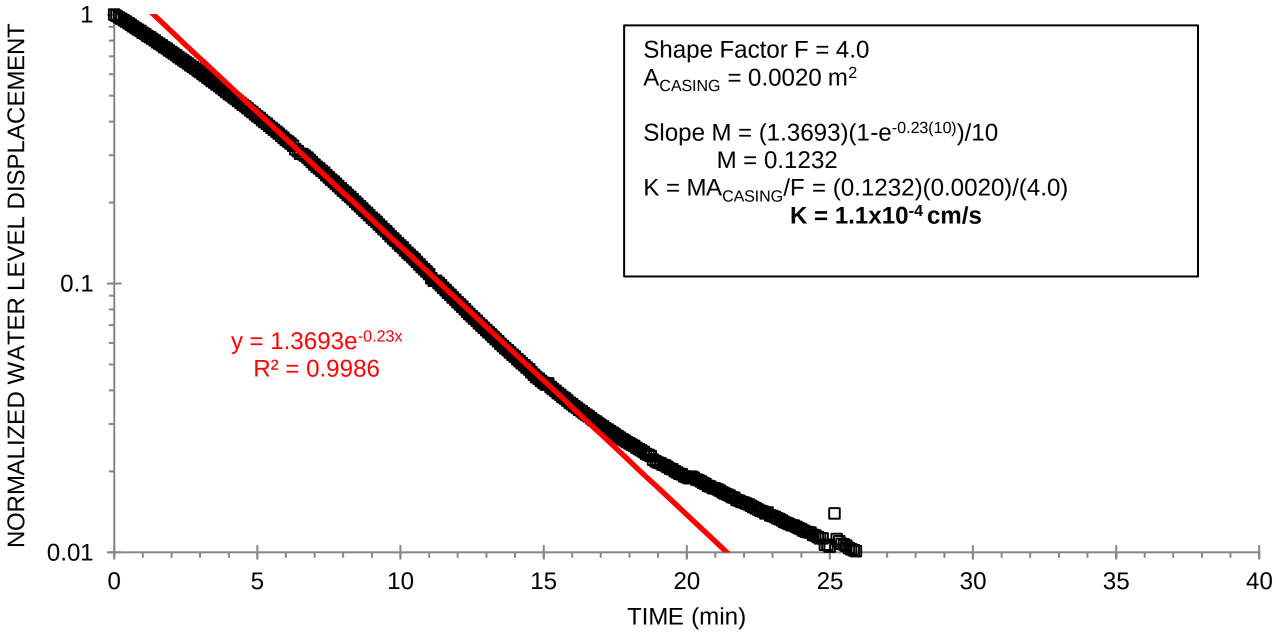


STATIC WL = 11.57 mBTOP

D_{CASING} = 51 mm
$D_{BOREHOLE}$ = 96 mm

INITIAL WL = 21.91 m

H_0 = 10.34 m



Shape Factor F = 4.0
A_{CASING} = 0.0020 m^2

Slope M = $(1.3693)(1-e^{-0.23(10)})/10$
M = 0.1232
K = MA_{CASING}/F = (0.1232)(0.0020)/(4.0)
K = 1.1×10^{-4} cm/s

Figure 2-21

MW12-II

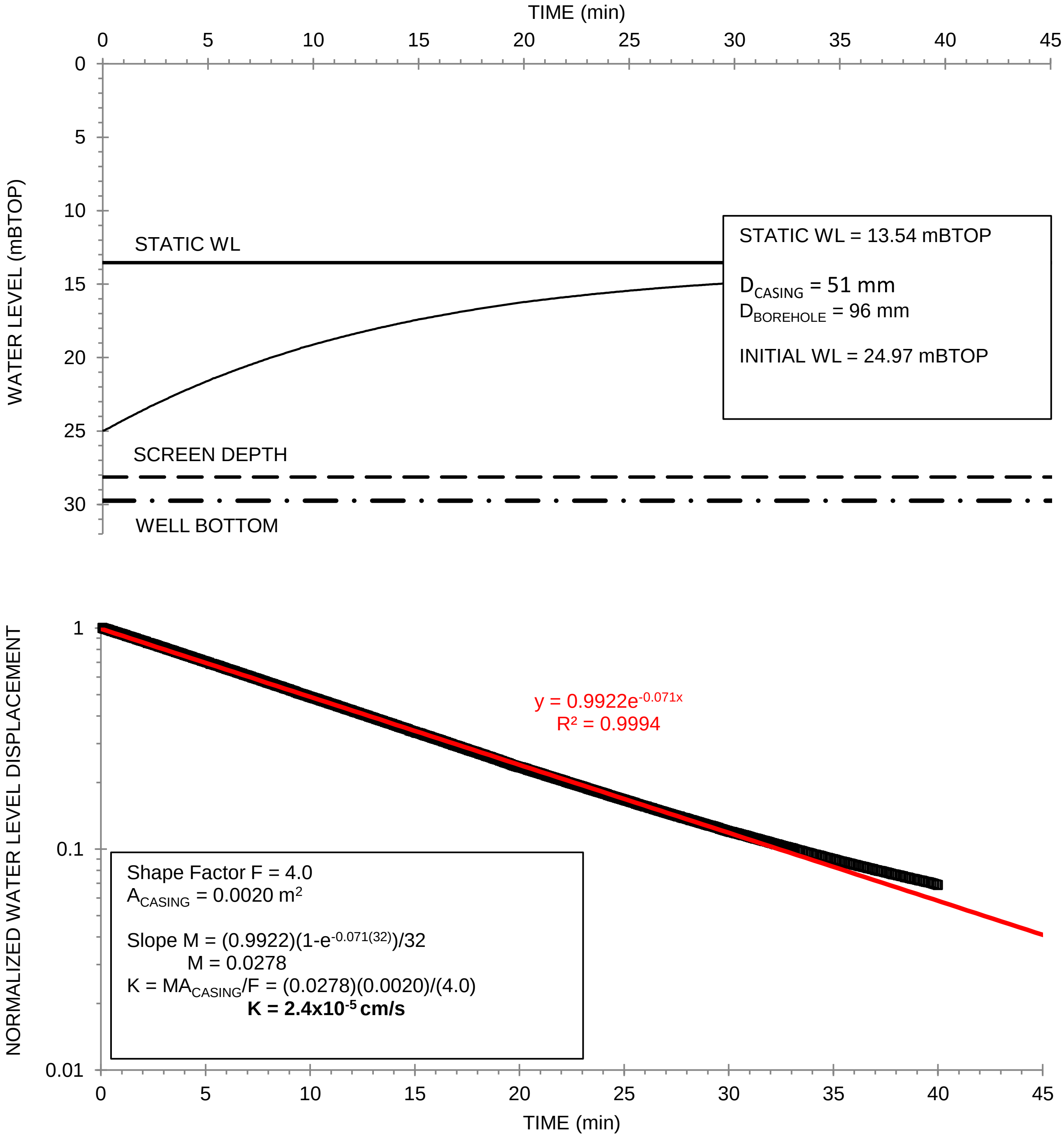
Rising Head Slug Test Analysis

Hvorslev Method

Law Quarry Extension

Date: December 4, 2019

Performed by: BC



STATIC WL = 13.54 mBTOP

D_{CASING} = 51 mm
$D_{BOREHOLE}$ = 96 mm

INITIAL WL = 24.97 mBTOP

$y = 0.9922e^{-0.071x}$
$R^2 = 0.9994$

Shape Factor F = 4.0
$A_{CASING} = 0.0020\ m^2$

Slope M = $(0.9922)(1-e^{-0.071(32)})/32$
M = 0.0278
$K = MA_{CASING}/F = (0.0278)(0.0020)/(4.0)$
$K = 2.4x10^{-5}$ cm/s

Figure 2-22

MW1-I

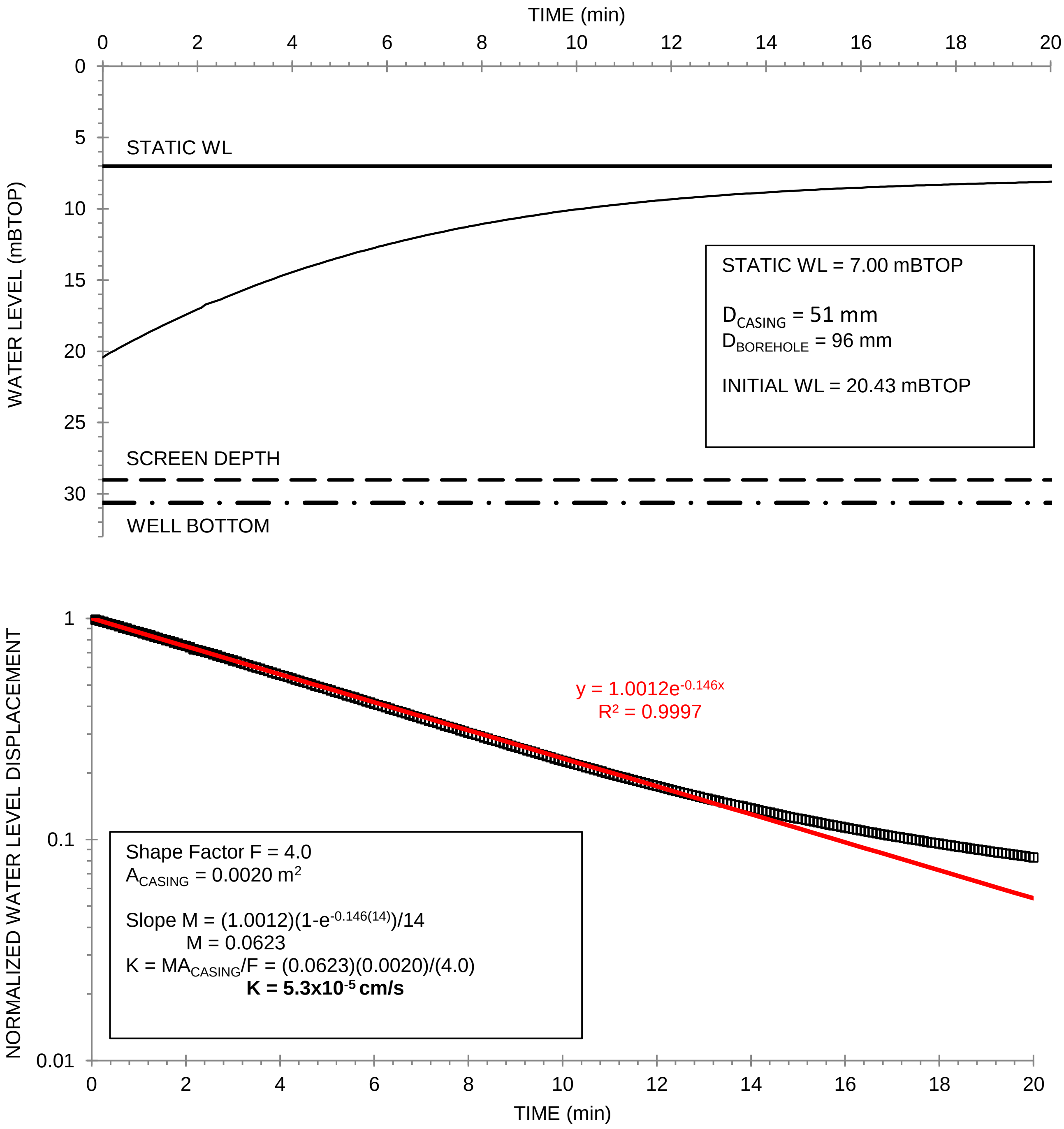
Rising Head Slug Test Analysis

Hvorslev Method

Law Quarry Extension

Date: December 4, 2019

Performed by: BC



STATIC WL = 7.00 mBTOP

D_{CASING} = 51 mm
$D_{BOREHOLE}$ = 96 mm

INITIAL WL = 20.43 mBTOP

Shape Factor F = 4.0
A_{CASING} = 0.0020 m^2

Slope M = (1.0012)(1-e$^{-0.146(14)}$)/14
M = 0.0623
K = MA_{CASING}/F = (0.0623)(0.0020)/(4.0)
K = 5.3x10^{-5} cm/s

Figure 2-23

MW10-I

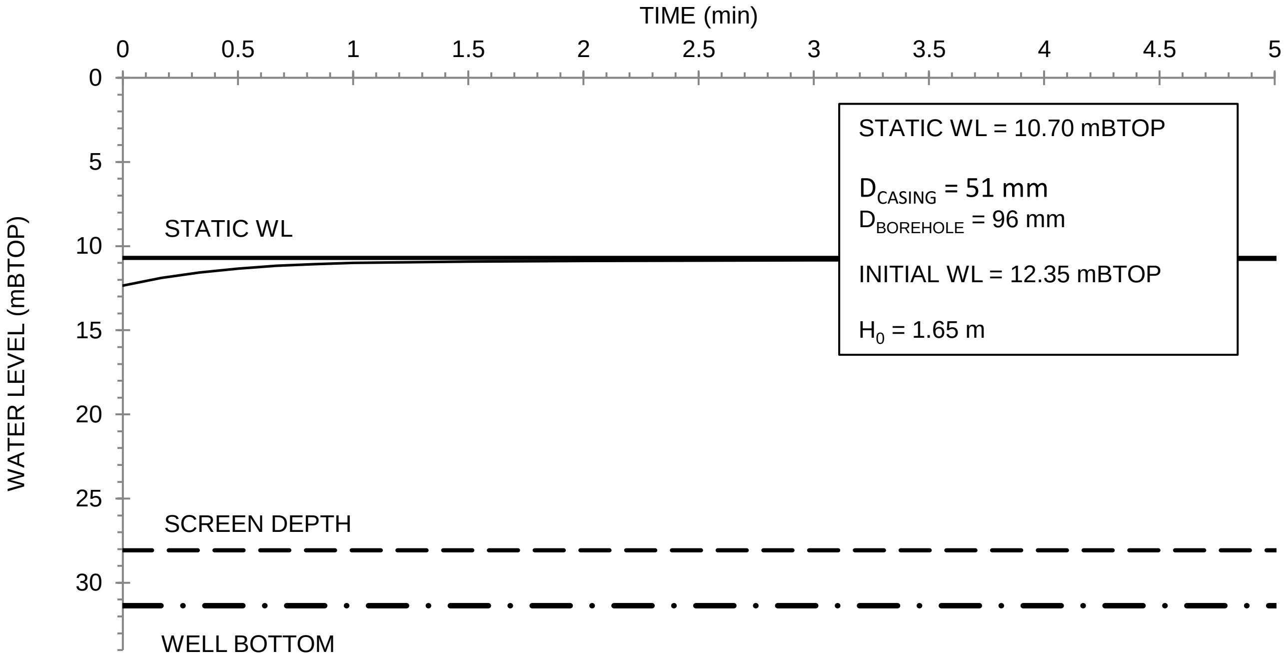
Rising Head Slug Test Analysis

Hvorslev Method

Law Quarry Extension

Date: December 5, 2019

Performed by: BC

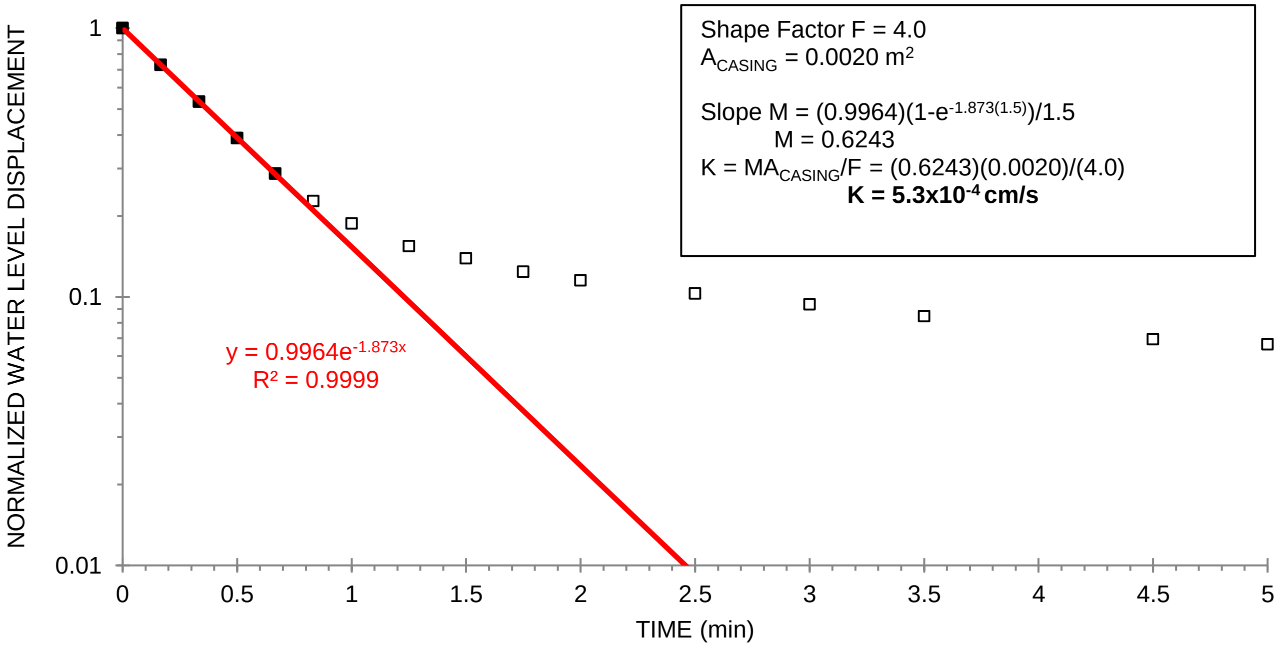


STATIC WL = 10.70 mBTOP

D_{CASING} = 51 mm
$D_{BOREHOLE}$ = 96 mm

INITIAL WL = 12.35 mBTOP

H_0 = 1.65 m



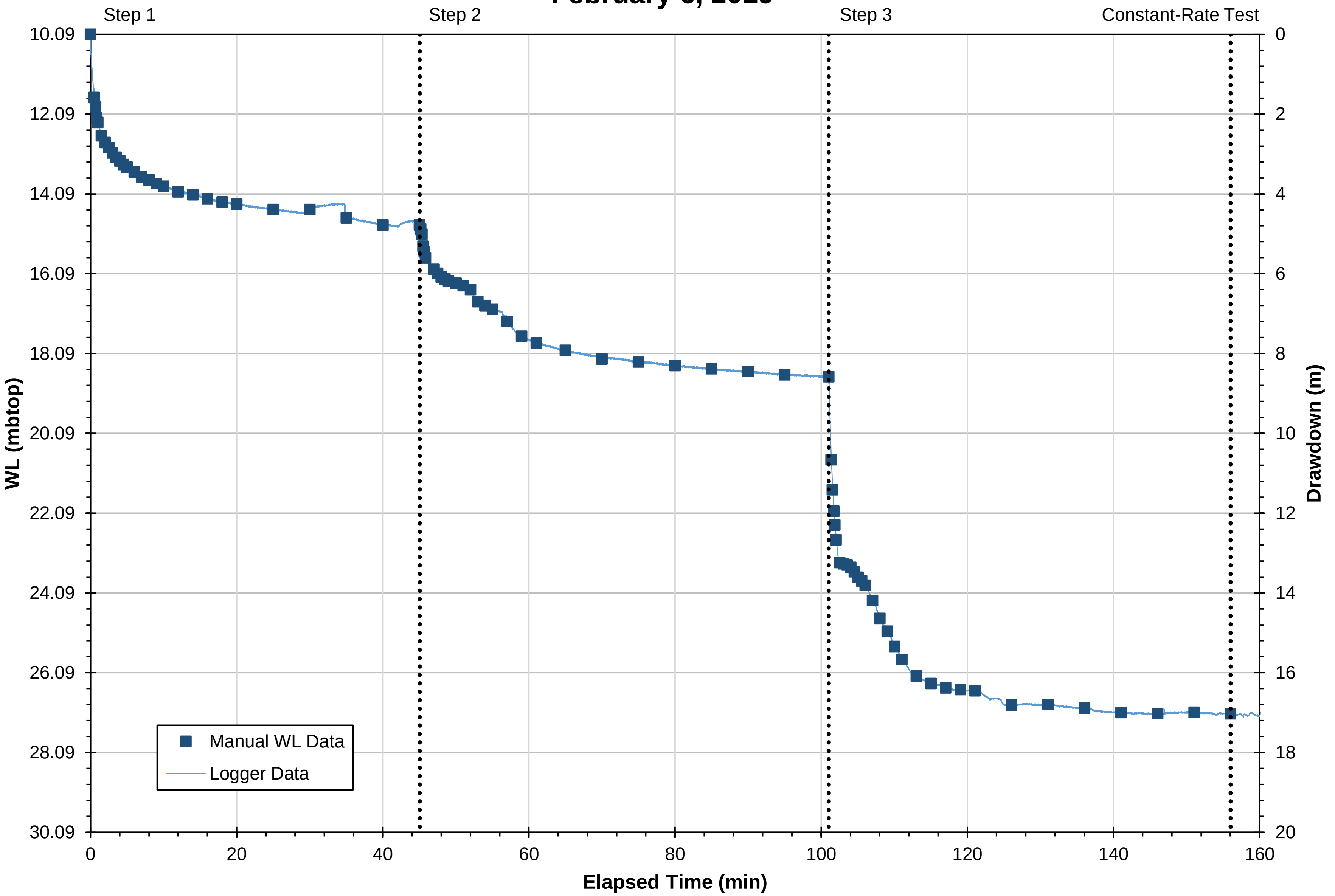
Shape Factor F = 4.0
$A_{CASING} = 0.0020\ m^2$

Slope M = $(0.9964)(1-e^{-1.873(1.5)})/1.5$
M = 0.6243
K = MA_{CASING}/F = (0.6243)(0.0020)/(4.0)
K = 5.3×10^{-4} cm/s

APPENDIX

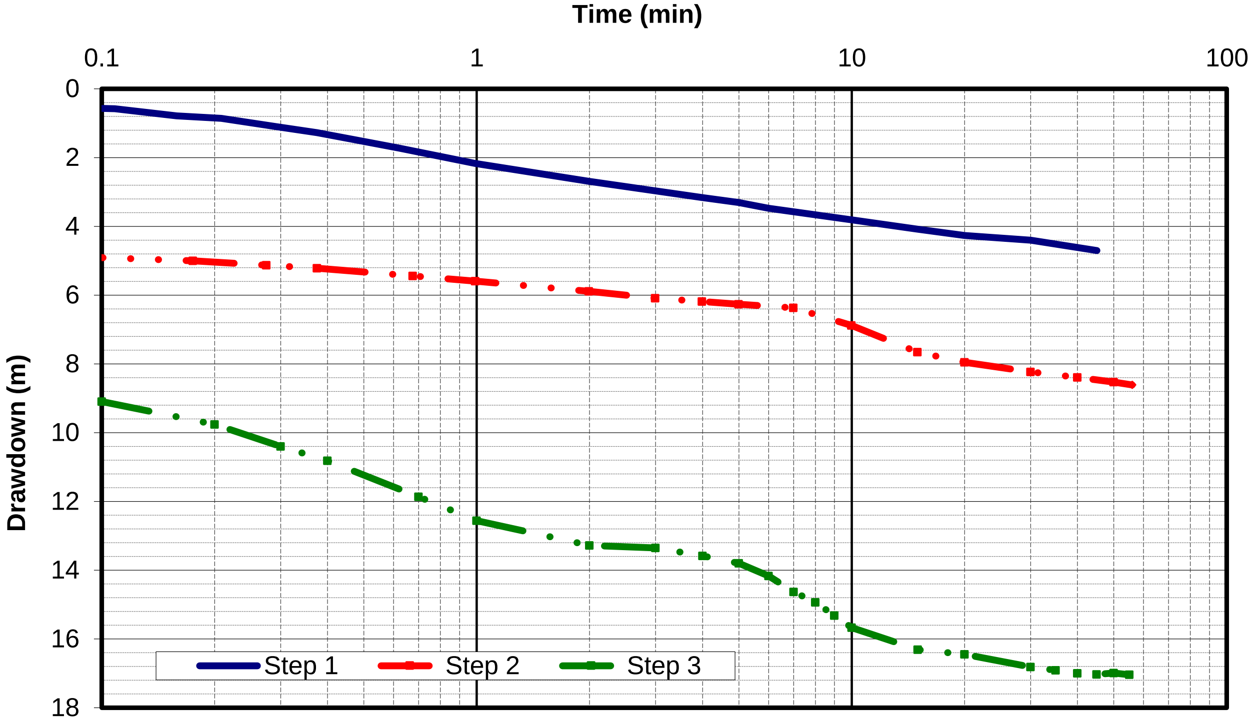
D-3 PUMPING TEST ANALYSES

Figure 3 -1 - Step Test Water Levels
February 6, 2019



LAW QUARRY EXTENSION
\\CASCR1DAT01\vol1\Projects\2011\111-53023 Law Quarry\06 2018 Level 2 HydroG Report\Tech\App D_Hyd Cond Testing Data\Pumping Test\ST PW WLs.xlsx

Figure 3-2 - Step Test Analysis



Interval (n)	Qn m^3/hr	^deltaSwn m	Sw(n) m	Swn/Qn hr/m^2	Well Efficiency %
1	4.3	4.70	4.70	1.09	96%
2	6.8	3.91	8.61	1.27	93%
3	13.7	8.43	17.04	1.24	87%

Constants (from Graph):

B = 1.1024 Intercept

C = 0.0119 Slope

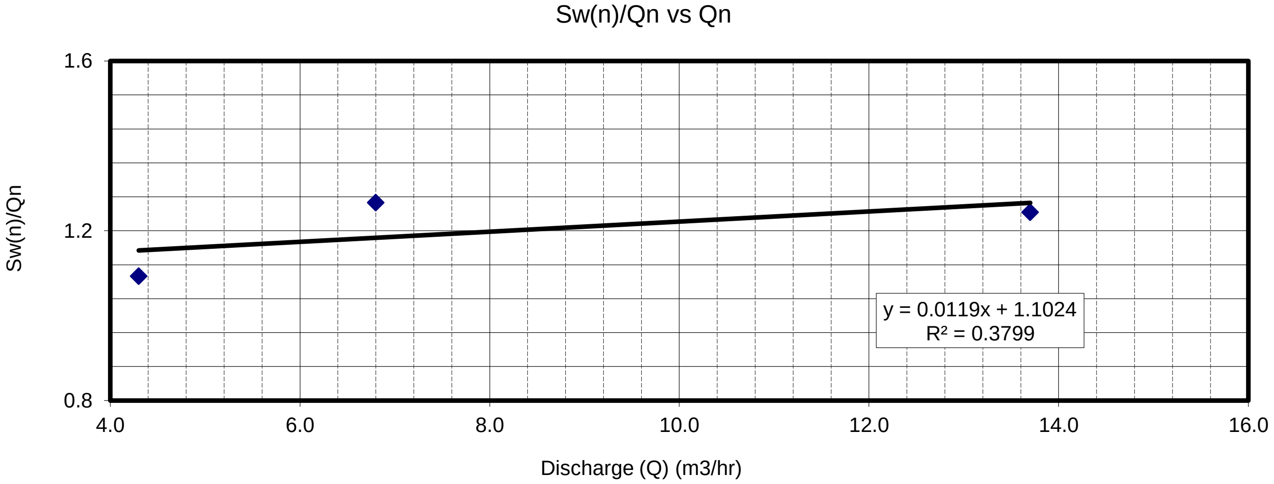


Figure 3-3 - Pumping Well Drawdown
February 6 - 12, 2019

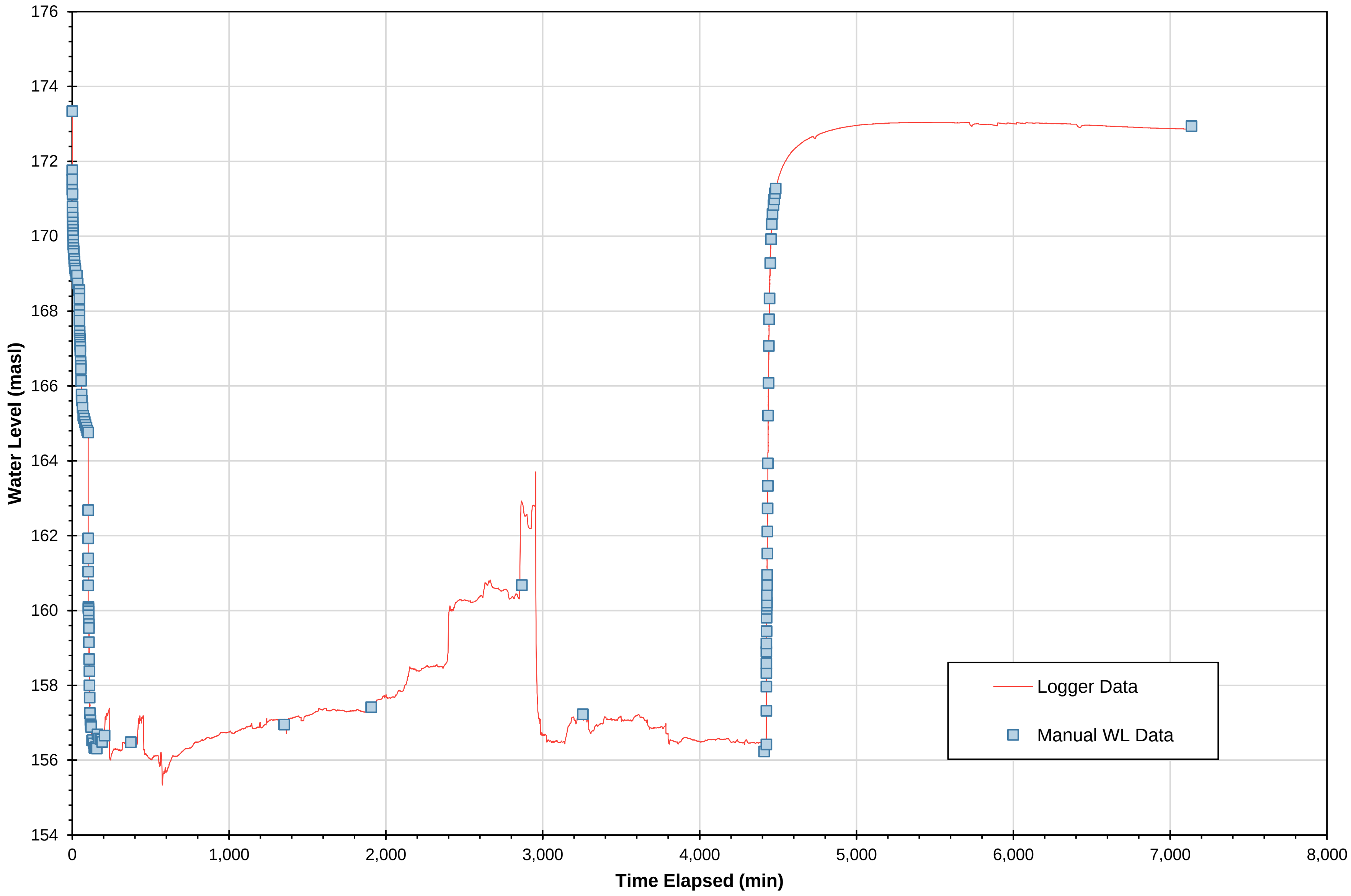


Figure 3-4 - Observation Well MW10-I (Deep Salina Fm) Drawdown
February 6 - 12, 2019

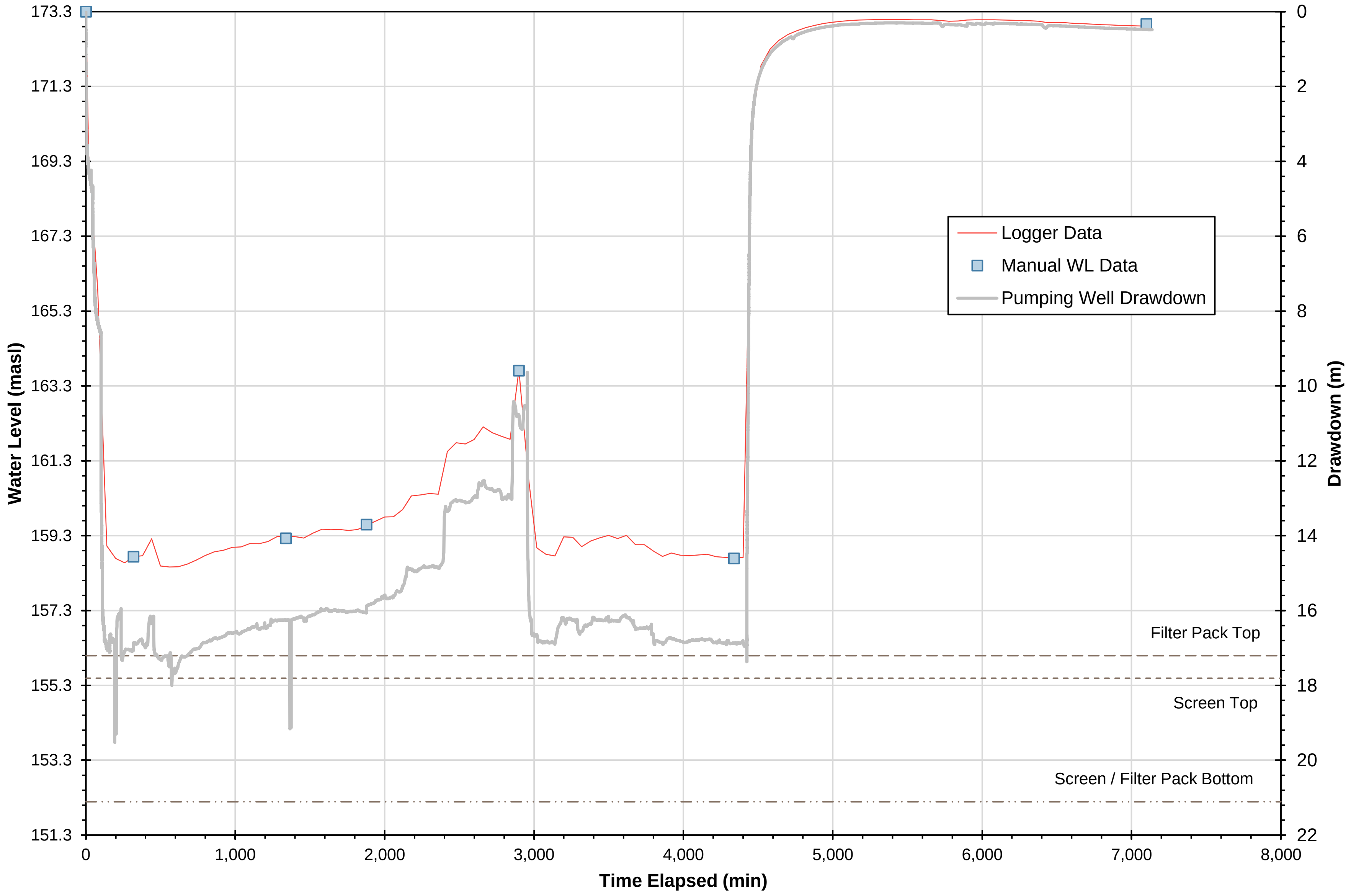


Figure 3-5 - Observation Well MW10-II (Oatka / Salina Contact) Drawdown
February 6 - 12, 2019

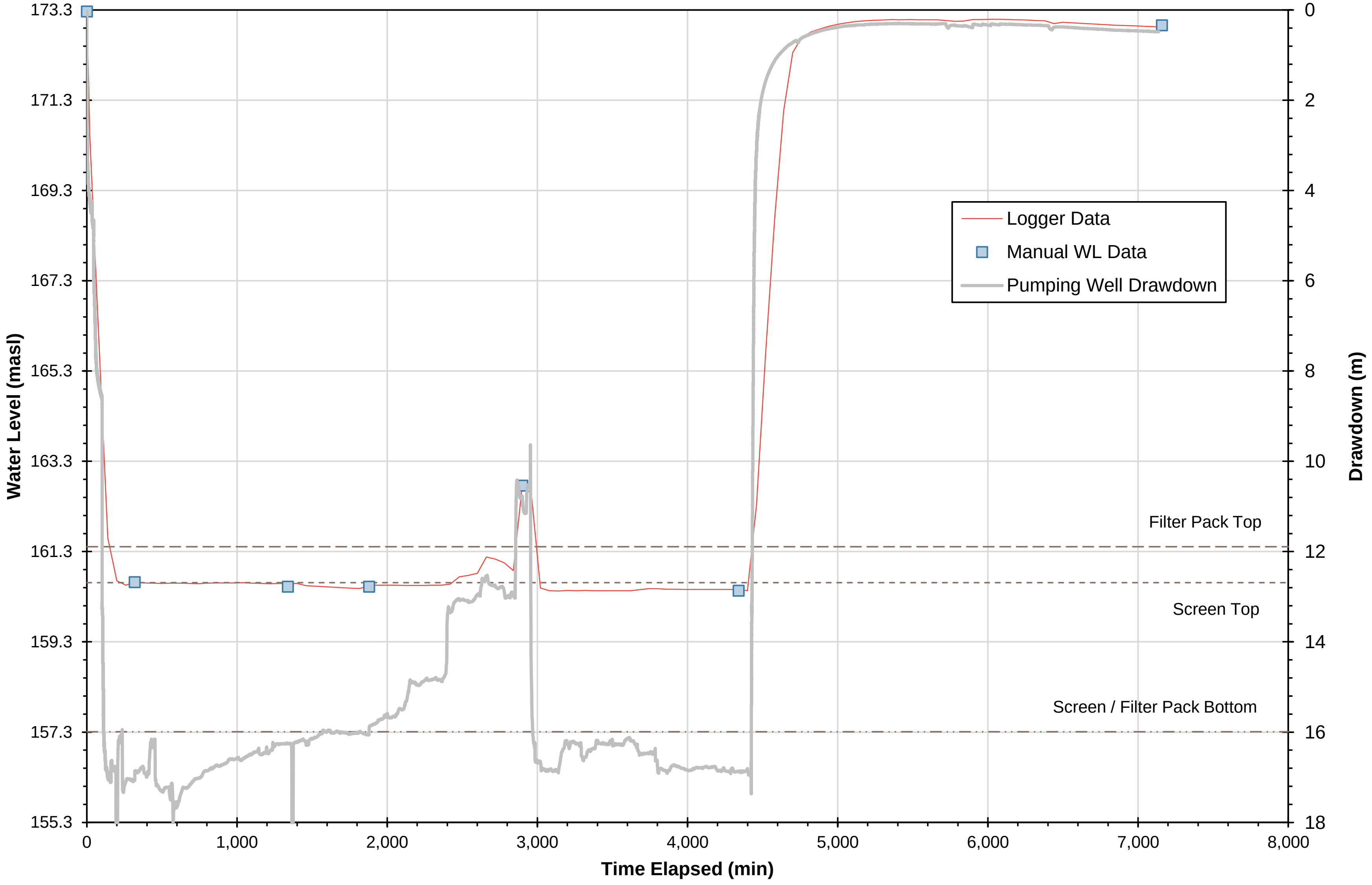


Figure 3-6 - Observation Well MW10-III (Falkirk Mb) Drawdown
February 6 - 12, 2019

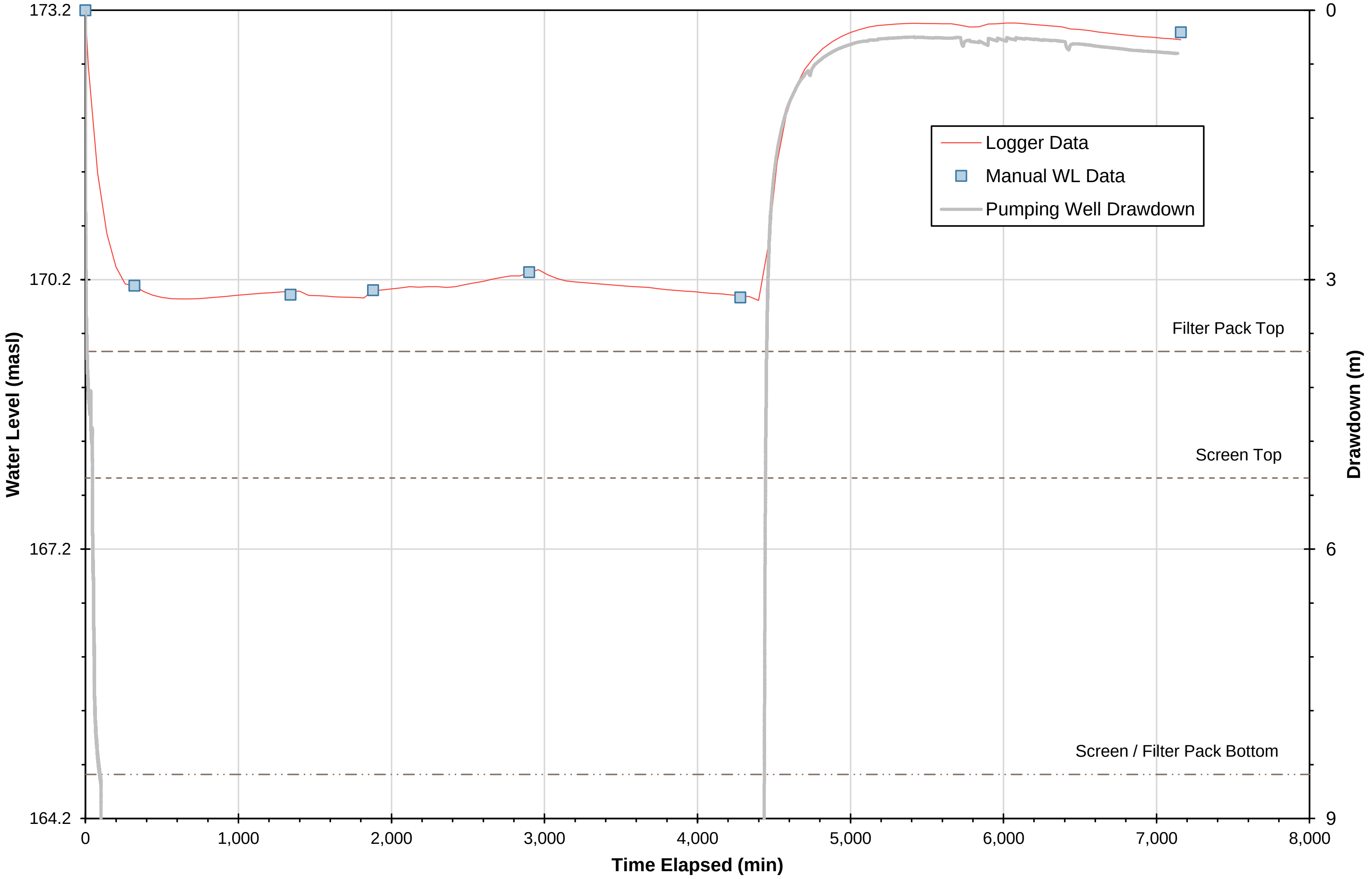


Figure 3-7 - Observation Well MW9-II (Oatka / Salina Contact) Drawdown

February 6 - 12, 2019

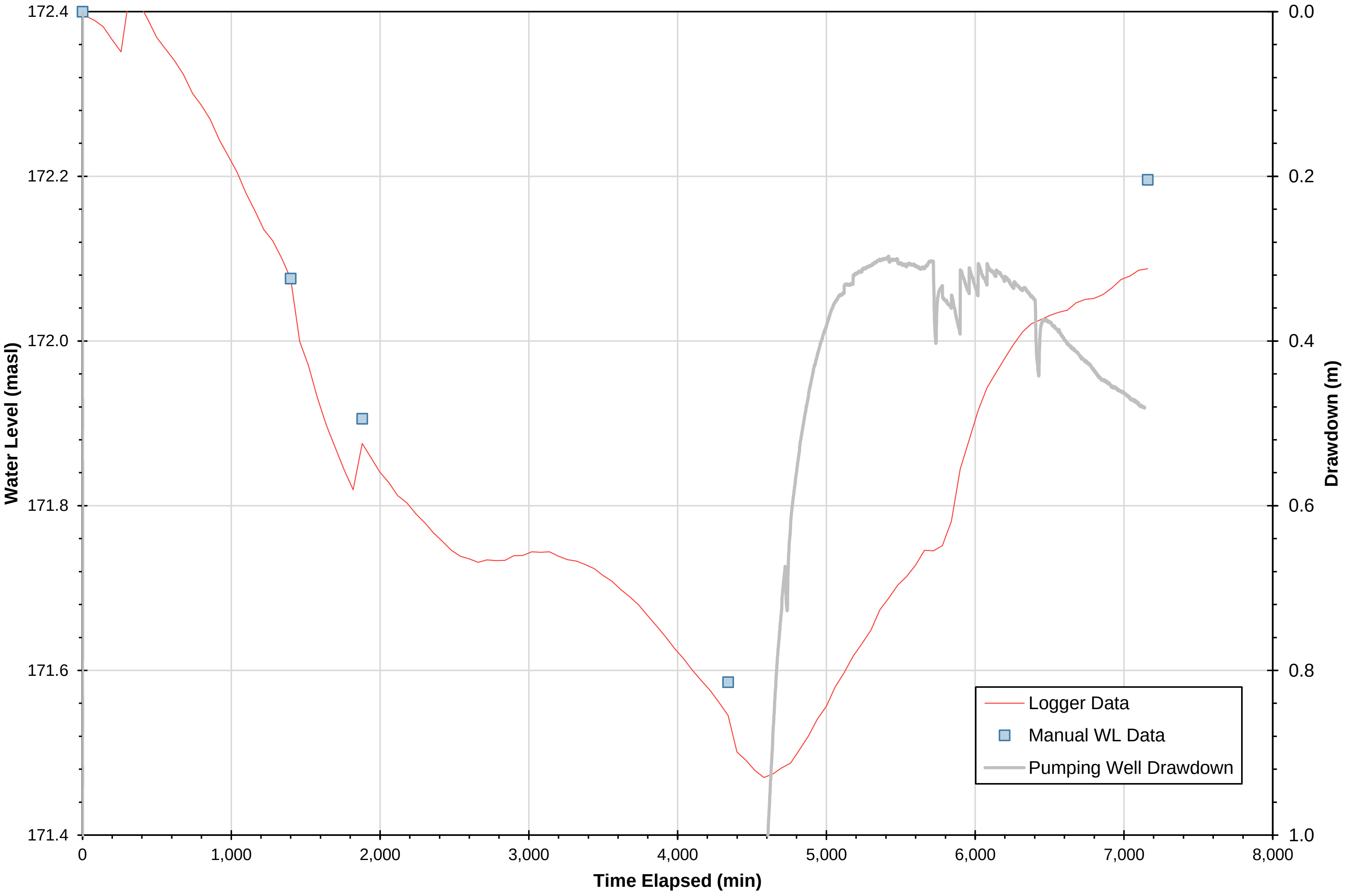


Figure 3-8 - Observation Well MW9-III (Falkirk Mb) Drawdown
February 6 - 12, 2019

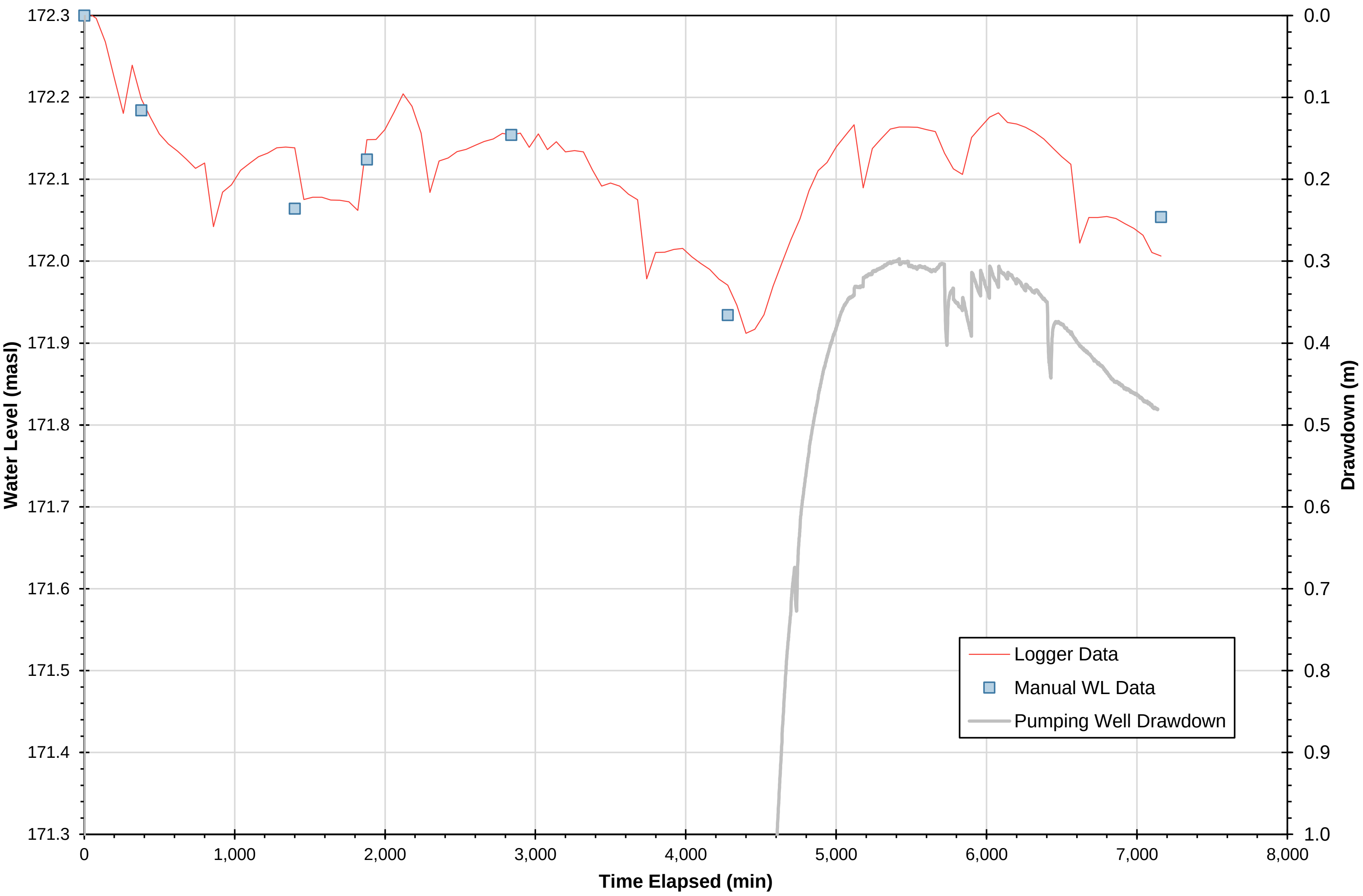
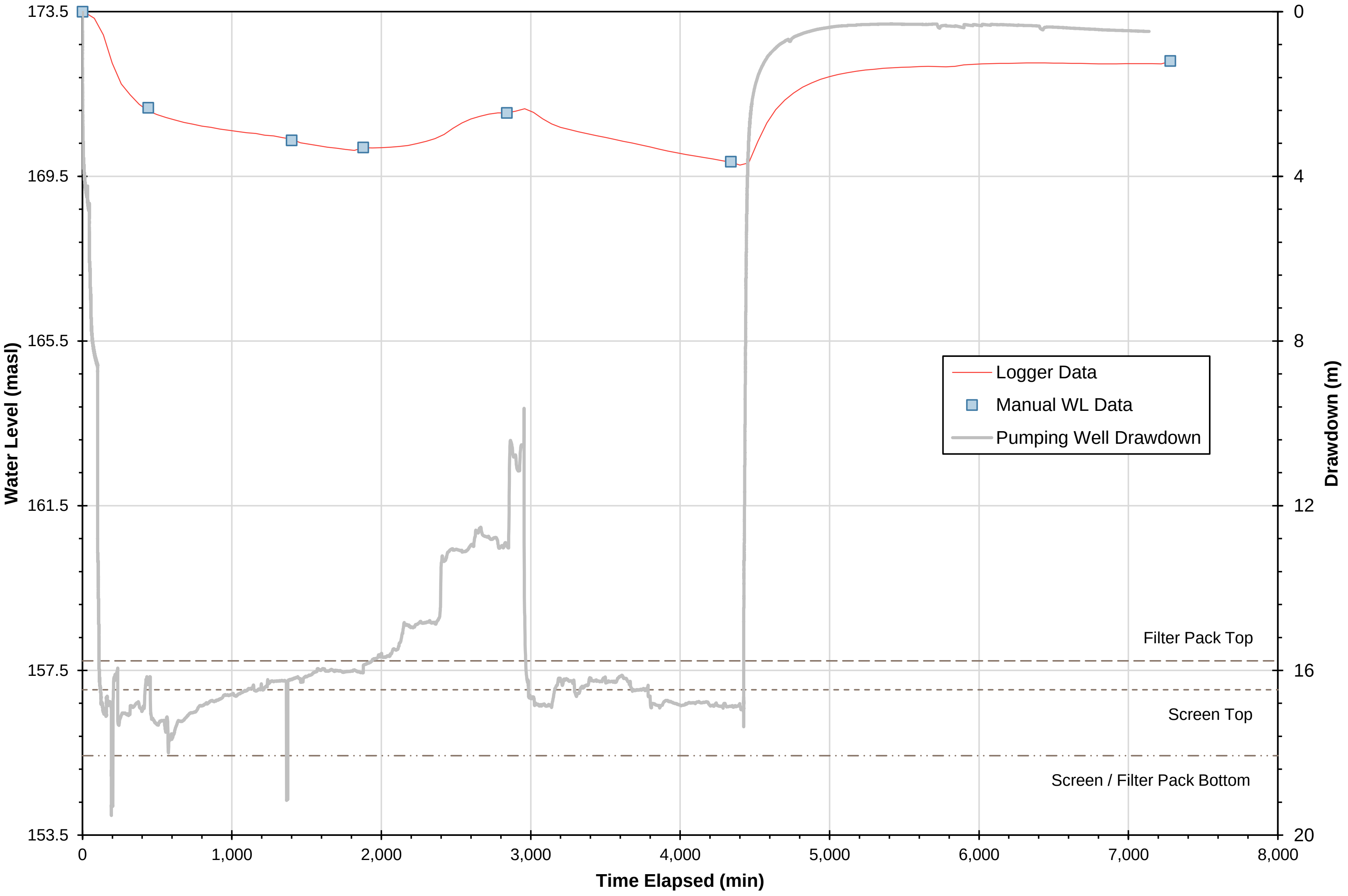
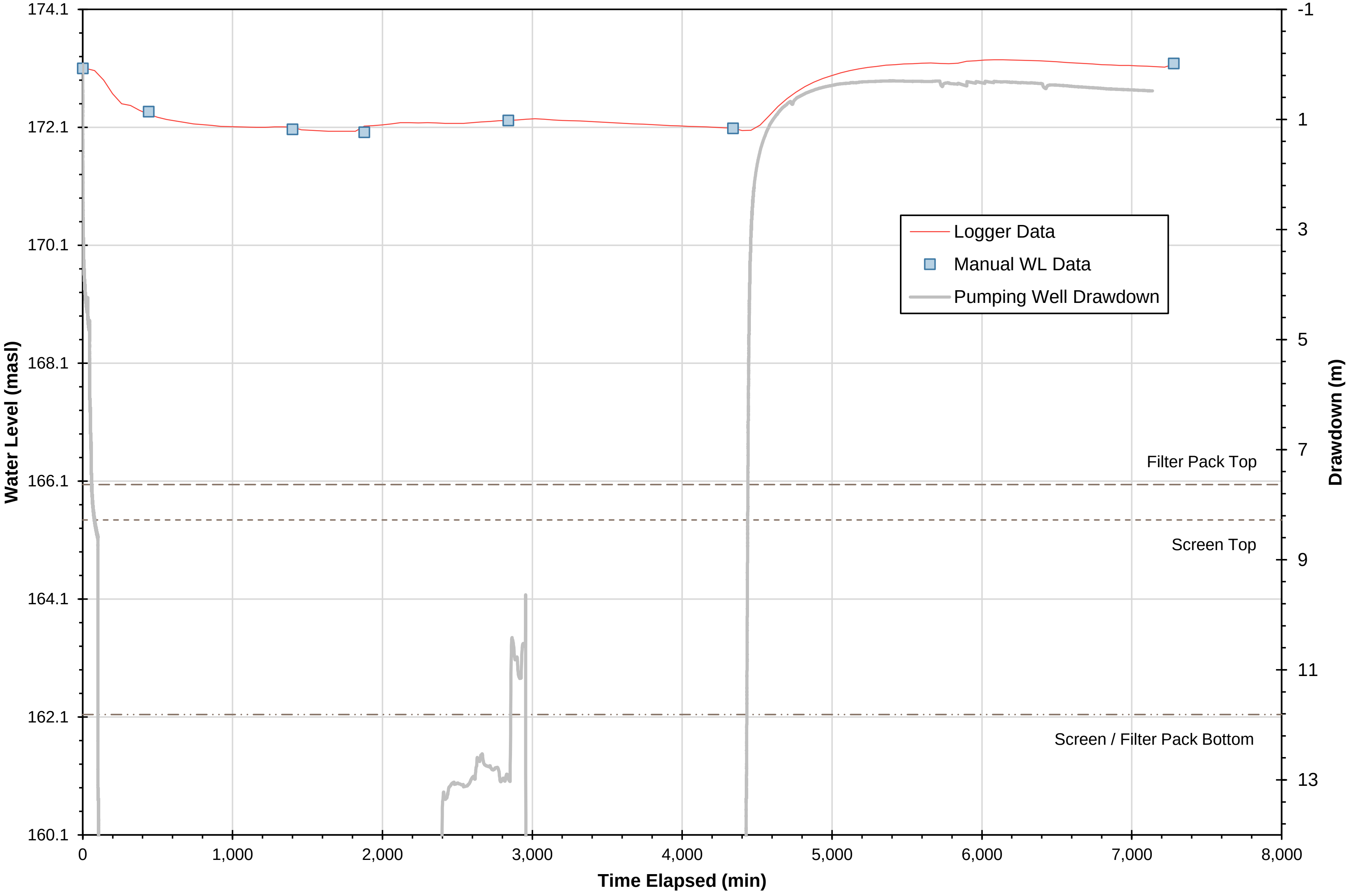


Figure 3-9 - Observation Well MW12-II (Oatka / Salina Contact) Drawdown
February 6 - 12, 2019



LAW QUARRY EXTENSION
\\CASCR01DAT01\vol1\Projects\2011\111-53023 Law Quarry\06 2018 Level 2 HydroG Report\Tech\App D_Hyd Cond Testing Data\Pumping Test\Pumping Test_hydrographs.xlsx

Figure 3-10 - Observation Well MW12-III (Falkirk Mb) Drawdown
February 6 - 12, 2019



LAW QUARRY EXTENSION
\\CASCR1DAT01\vol1\Projects\2011\111-53023 Law Quarry\06 2018 Level 2 HydroG Report\Tech\App D_Hyd Cond Testing Data\Pumping Test\Pumping Test_hydrographs.xlsx

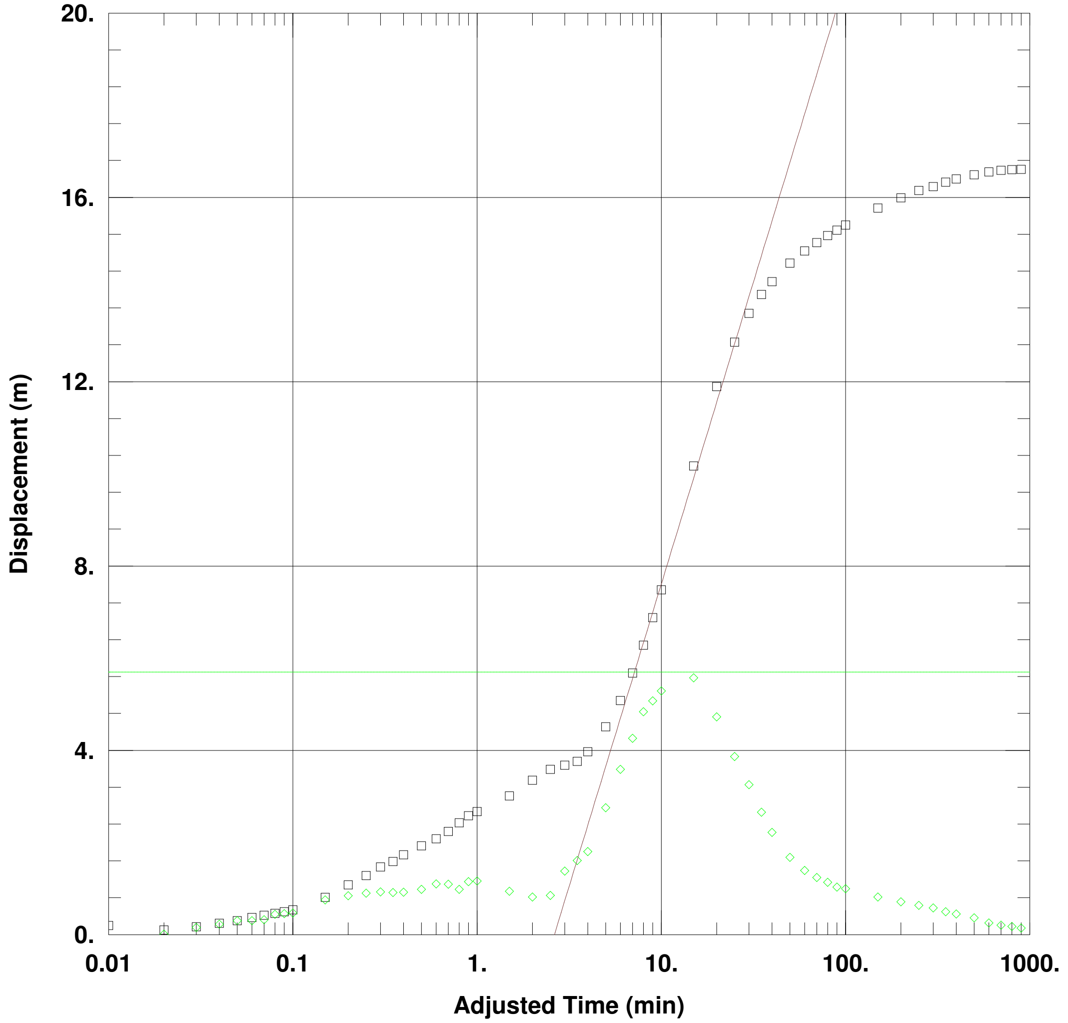


FIGURE 3-11 - PW RECOVERY CJSL ANALYSIS

Data Set: C:\Users\Leigh.Davis\Desktop\Law PT\Pumping Test\JLD\PW rec CJSL.aqt
Date: 05/07/20 Time: 21:29:12

PROJECT INFORMATION

Company: WSP
Client: Waterford Sand and Gravel Ltd.
Project: 111-53023-06
Location: Law Quarry
Test Well: PW
Test Date: 6-Feb-2019

AQUIFER DATA

Saturated Thickness: 23.4 m Anisotropy Ratio (Kz/Kr): 0.1

SOLUTION

Aquifer Model: Confined Solution Method: Cooper-Jacob

T = 3.562 m^2/day S = 2.601

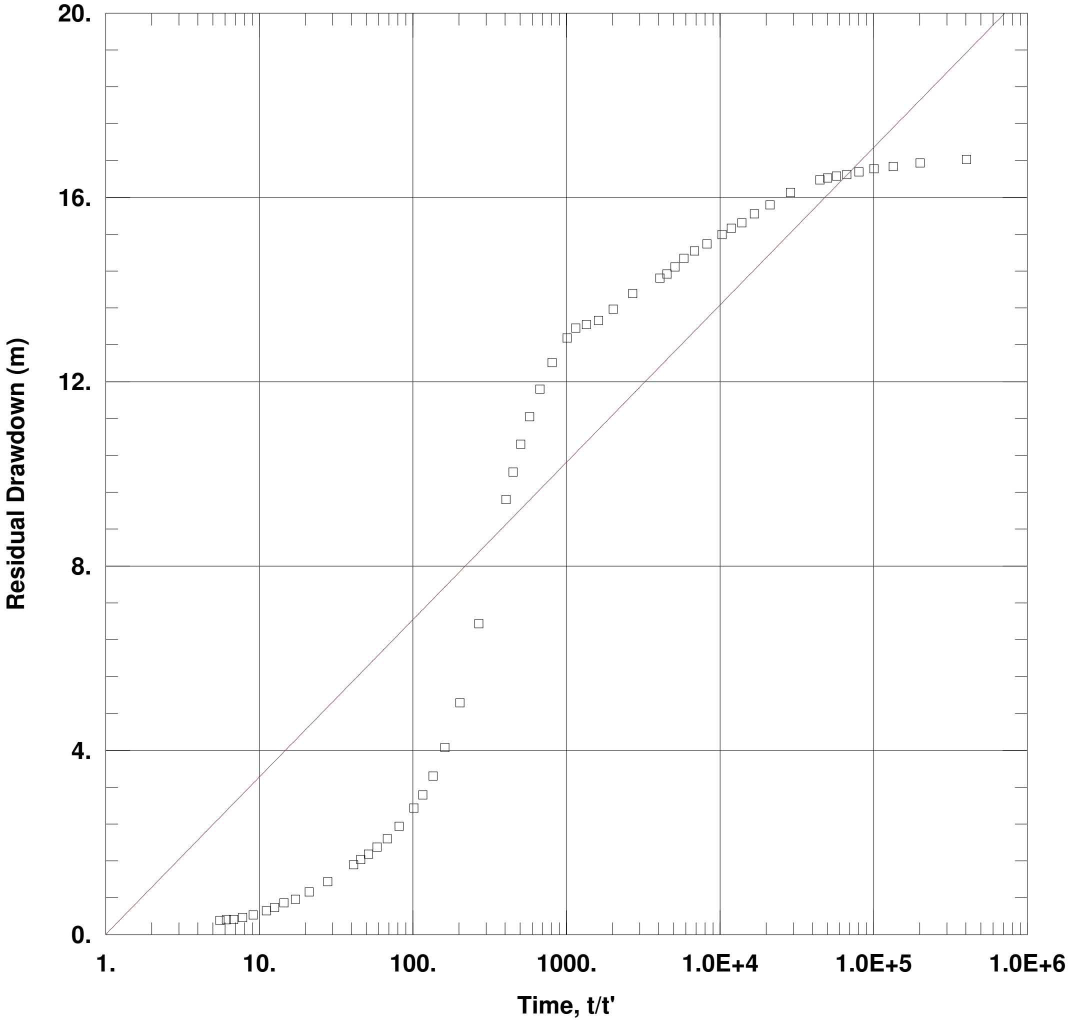


FIGURE 3-12 - PW RECOVERY THEIS ANALYSIS

Data Set:
Date: 05/08/20 Time: 20:10:35

PROJECT INFORMATION

Company: WSP
Client: Waterford Sand and Gravel Ltd.
Project: 111-53023-06
Location: Law Quarry
Test Well: PW
Test Date: 6-Feb-2019

AQUIFER DATA

Saturated Thickness: 23.4 m Anisotropy Ratio (Kz/Kr): 0.1

SOLUTION

Aquifer Model: Confined Solution Method: Theis (Recovery)
T = 14.29 m^2/day S/S' = 1.

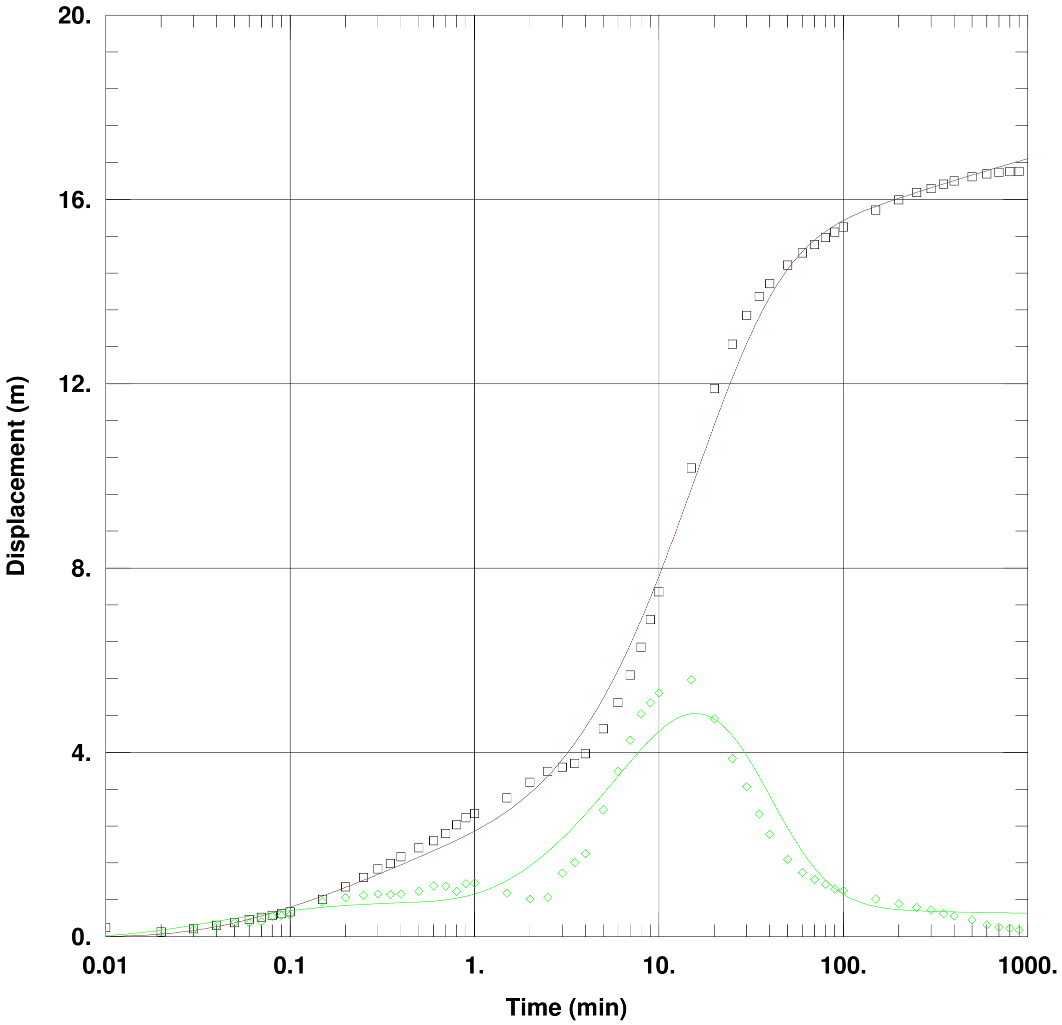


FIGURE 3-13 - PW RECOVERY NON-UNIFORM AQUIFER ANALYSIS

Data Set: C:\Users\Leigh.Davis\Desktop\Law PT\Pumping Test\JLD\PW rec nonuniform.aqt
Date: 05/08/20 Time: 20:48:01

PROJECT INFORMATION

Company: WSP
Client: Waterford Sand and Gravel Ltd.
Project: 111-53023-06
Location: Law Quarry
Test Well: PW
Test Date: 6-Feb-2019

AQUIFER DATA

Saturated Thickness: 23.4 m
Anisotropy Ratio (Kz/Kr): 0.001636

SOLUTION

Aquifer Model: Confined
Solution Method: Butler

T1 = 25.24 m^2/day
T2 = 41.4 m^2/day
R = 0.3936 m

S1 = 0.4383
S2 = 1.0E-10

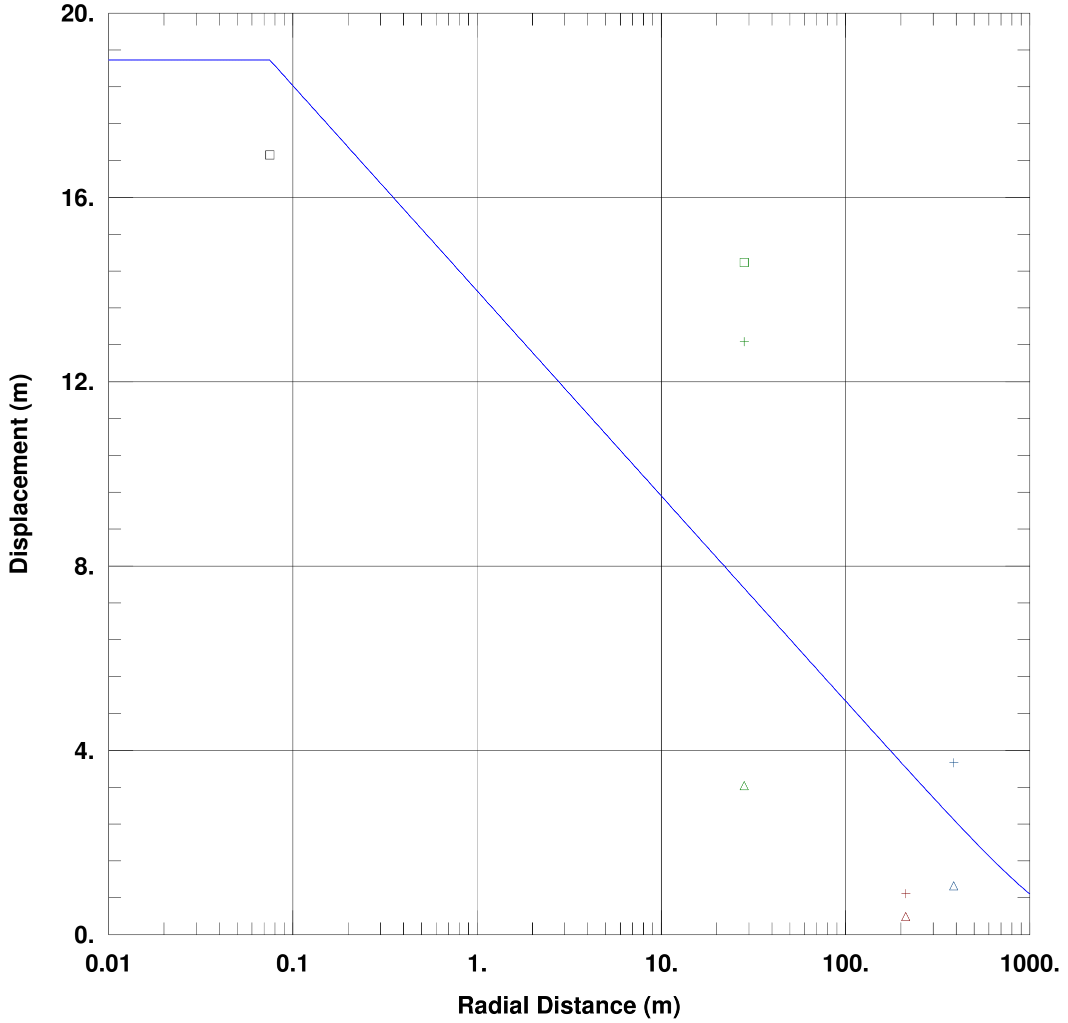


FIGURE 3-14 - THEIS DISTANCE-DRAWDOWN ANALYSIS

Data Set: C:\Users\Leigh.Davis\Desktop\Law PT\Pumping Test\JLD\CJSL Dist-Ddn.aqt
Date: 05/11/20 Time: 14:43:58

PROJECT INFORMATION

Company: WSP
Client: Waterford Sand and Gravel Ltd.
Project: 111-53023-06
Location: Law Quarry
Test Well: PW
Test Date: 6-Feb-2019

SOLUTION

Aquifer Model: Confined Solution Method: Theis

T = 20.98 m^2/day S = 7.635E-5
Kz/Kr = 0.1 b = 23.4 m

APPENDIX

E WATER LEVEL DATA

Figure E-1 Groundwater Hydrograph

Well Nest 1

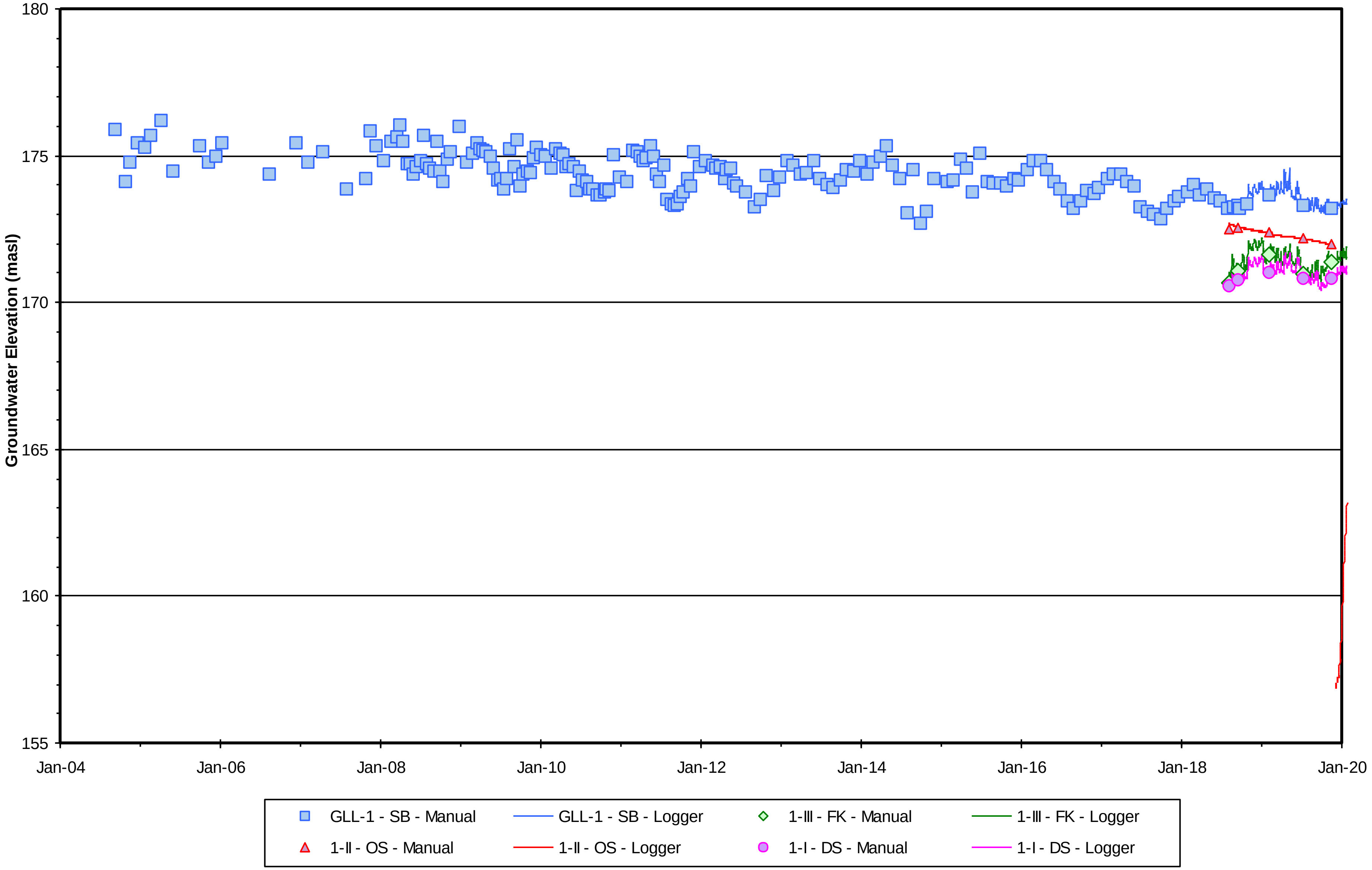


Figure E-2 Groundwater Hydrograph

Well Nest 3

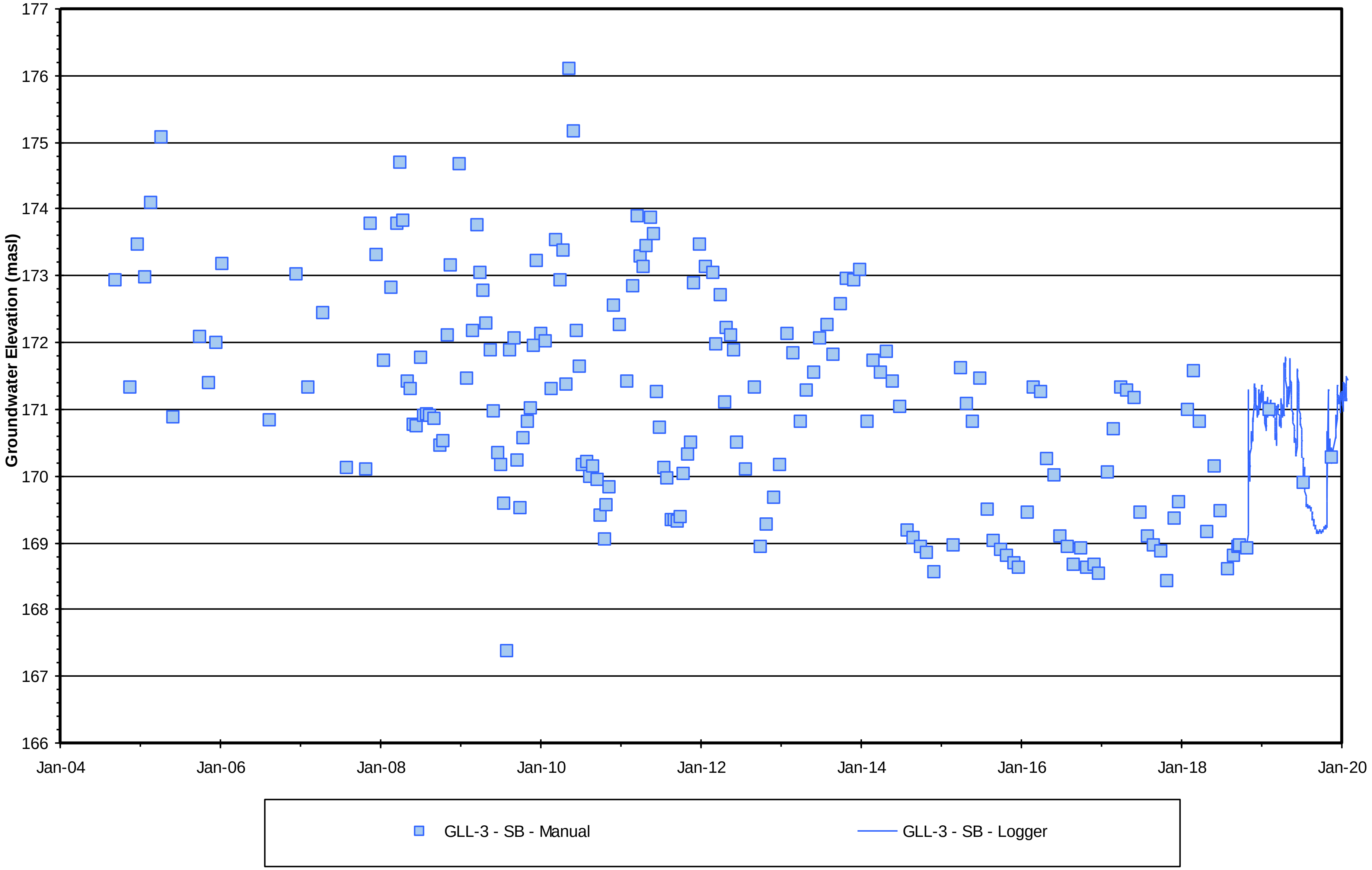


Figure E-3 Groundwater Hydrograph

Well Nest 4

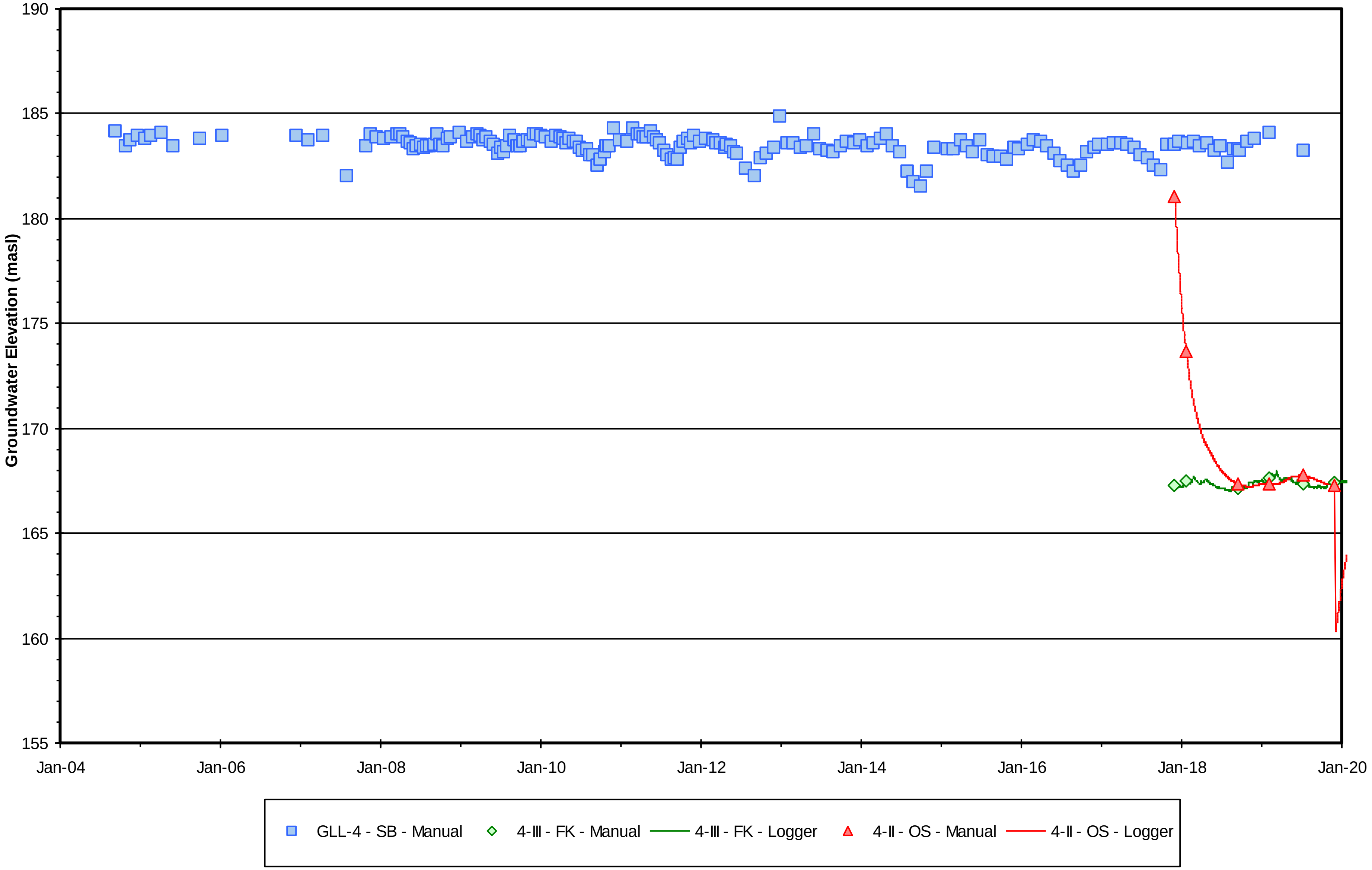


Figure E-4 Groundwater Hydrograph

Well Nest 5

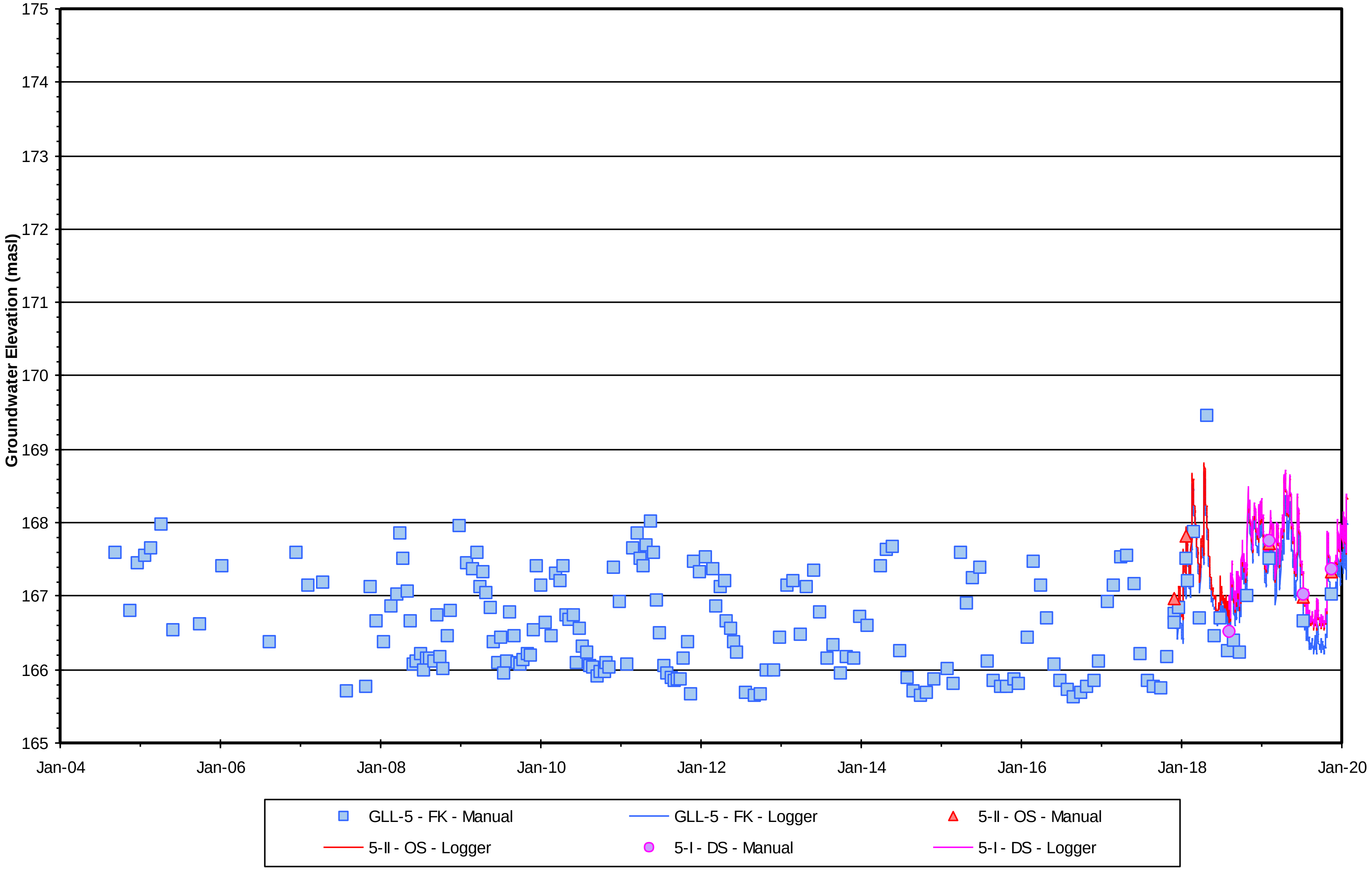
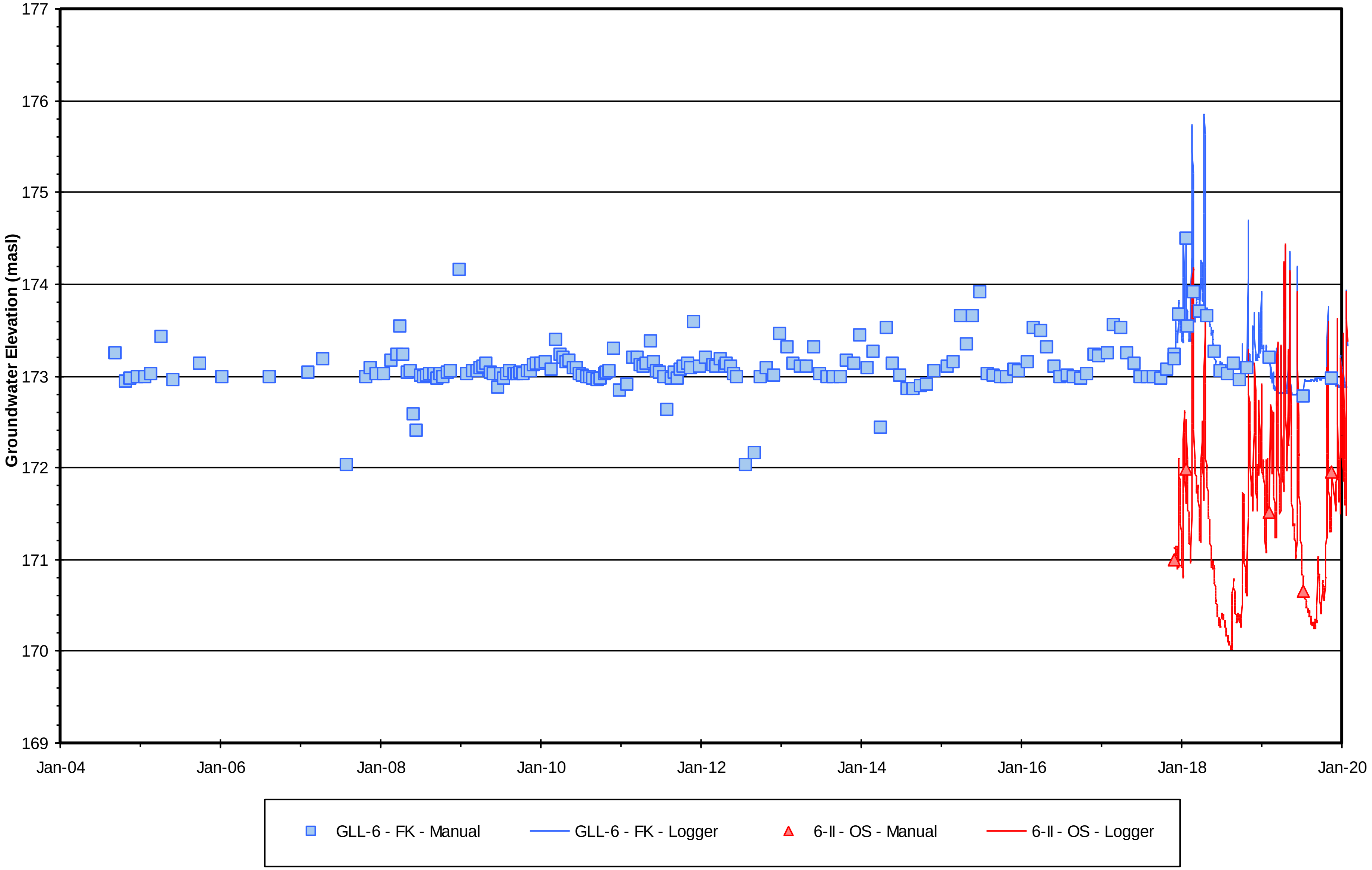


Figure E-5 Groundwater Hydrograph

Well Nest 6



LAW QUARRY
(Report Tools v.1.2 / Reports_LawQuarry.accdb / 1115302306 / Apr-20)

Figure E-6 Groundwater Hydrograph

Well Nest 7

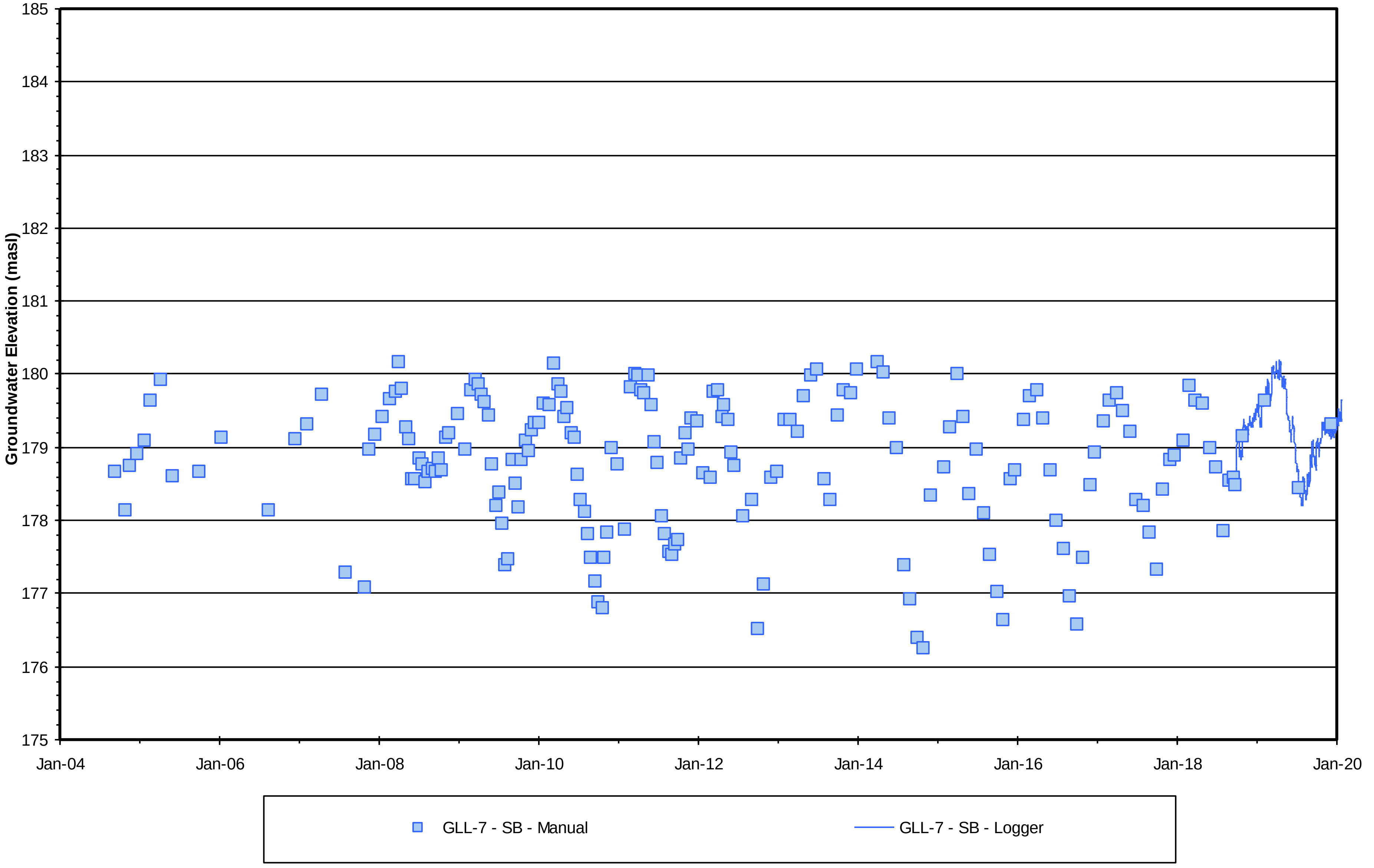


Figure E-7 Groundwater Hydrograph

Well Nest 8

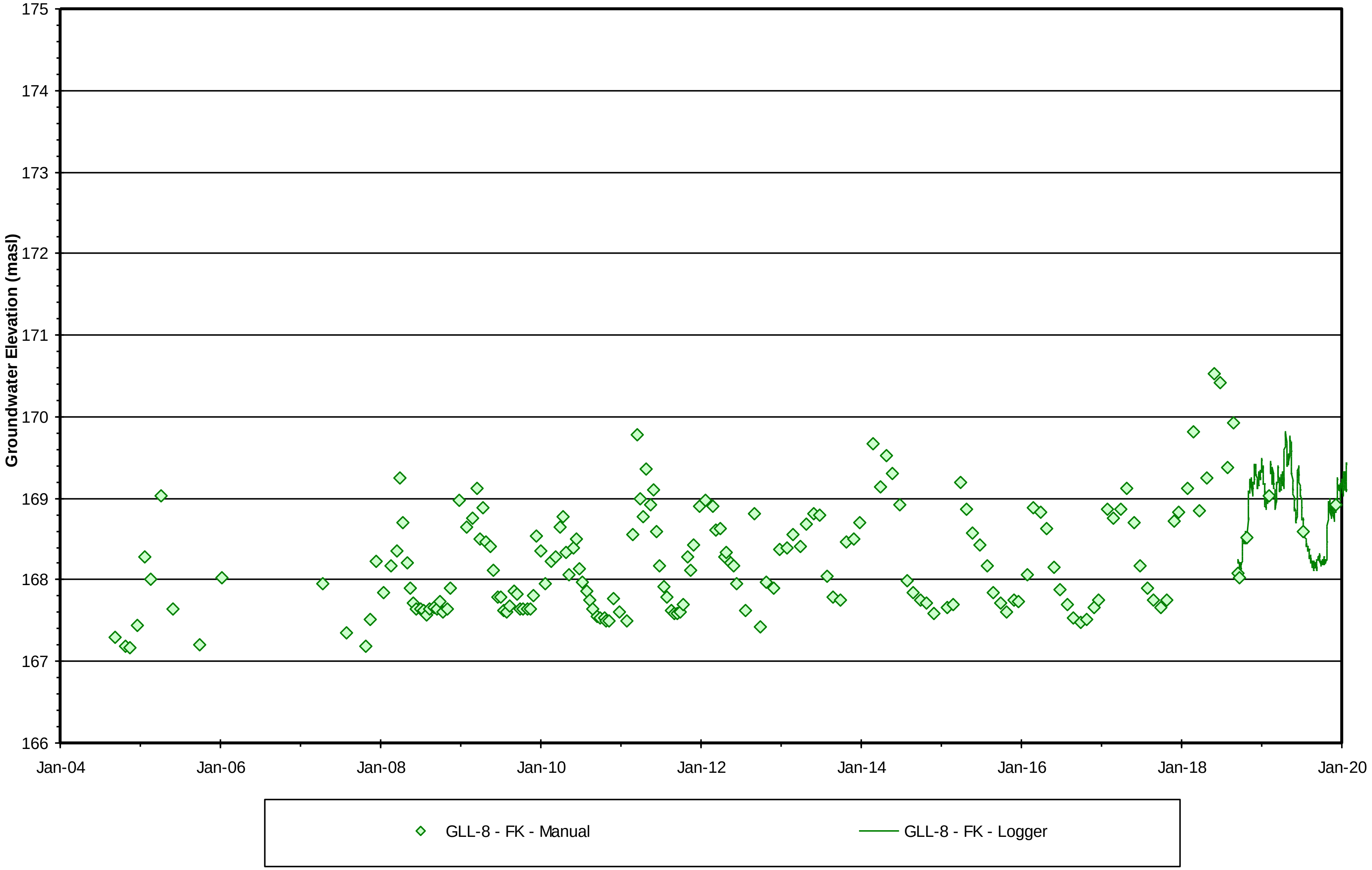
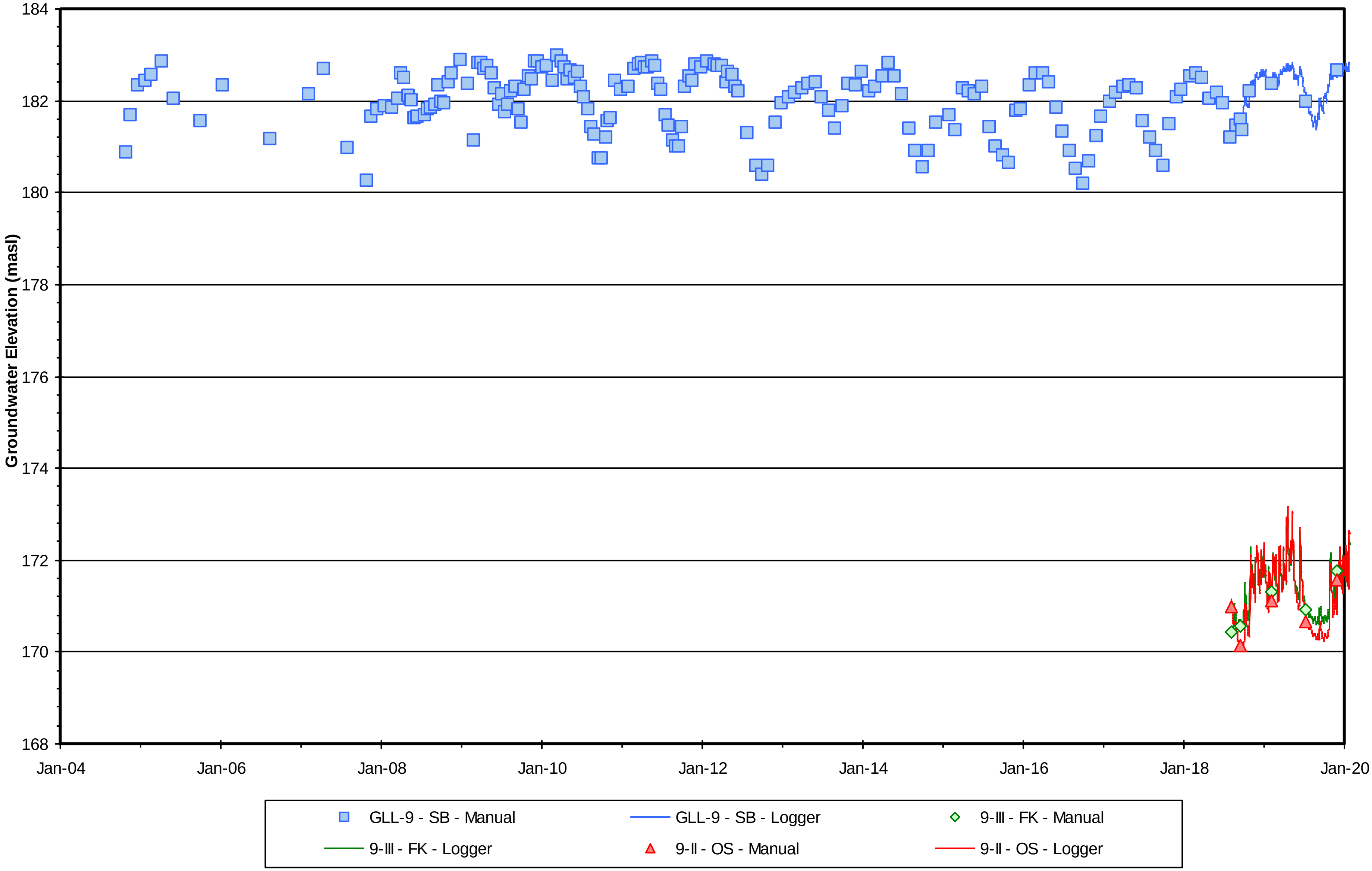


Figure E-8 Groundwater Hydrograph

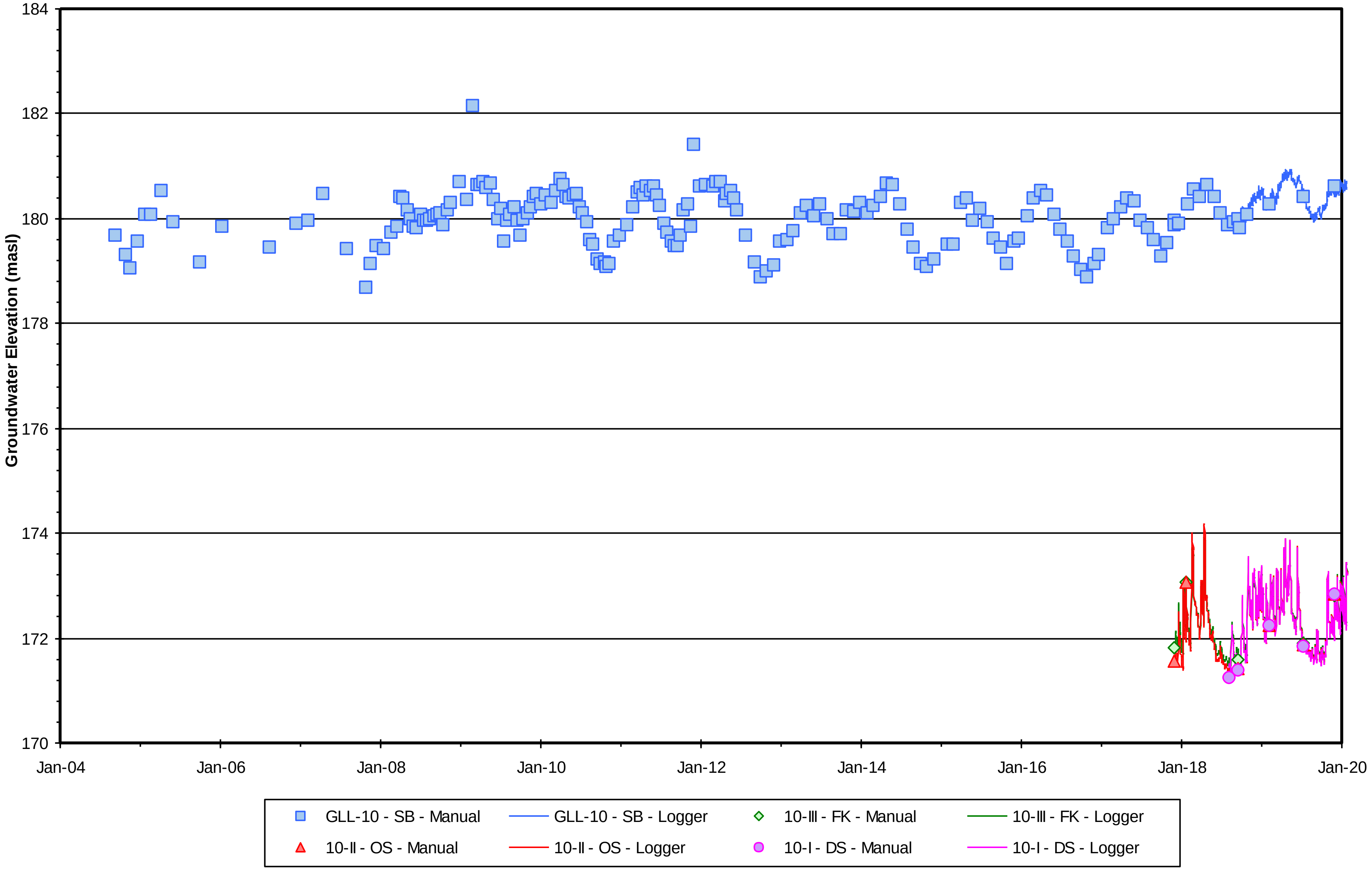
Well Nest 9



LAW QUARRY
(Report Tools v.1.2 / Reports_LawQuarry.accdb / 1115302306 / Apr-20)

Figure E-9 Groundwater Hydrograph

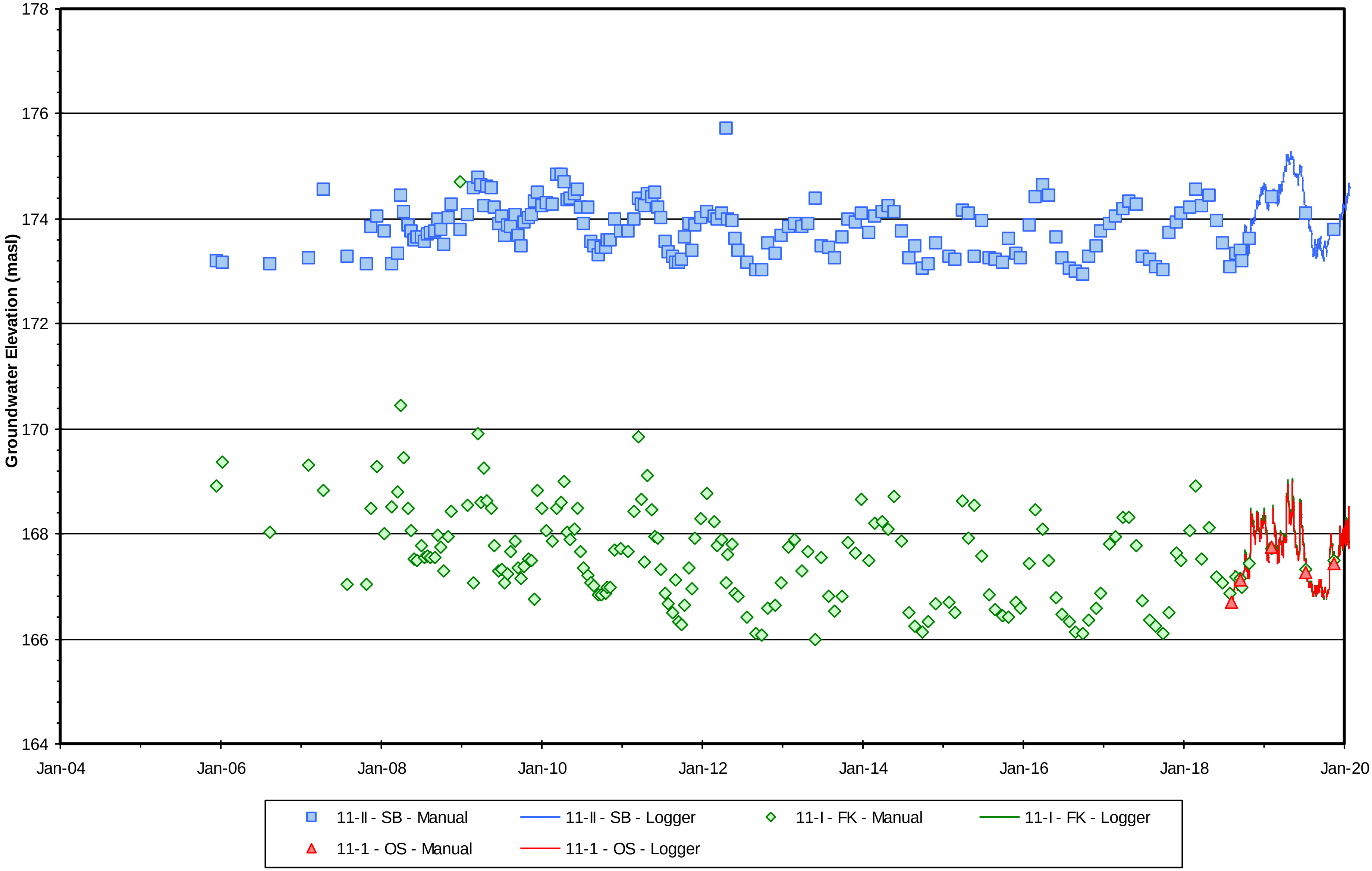
Well Nest 10



LAW QUARRY
(Report Tools v.1.2 / Reports_LawQuarry.accdb / 1115302306 / Apr-20)

Figure E-10 Groundwater Hydrograph

Well Nest 11



LAW QUARRY
(Report Tools v.1.2 / Reports_LawQuarry.accdb / 1115302306 / Apr-20)

Figure E-11 Groundwater Hydrograph

Well Nest 12

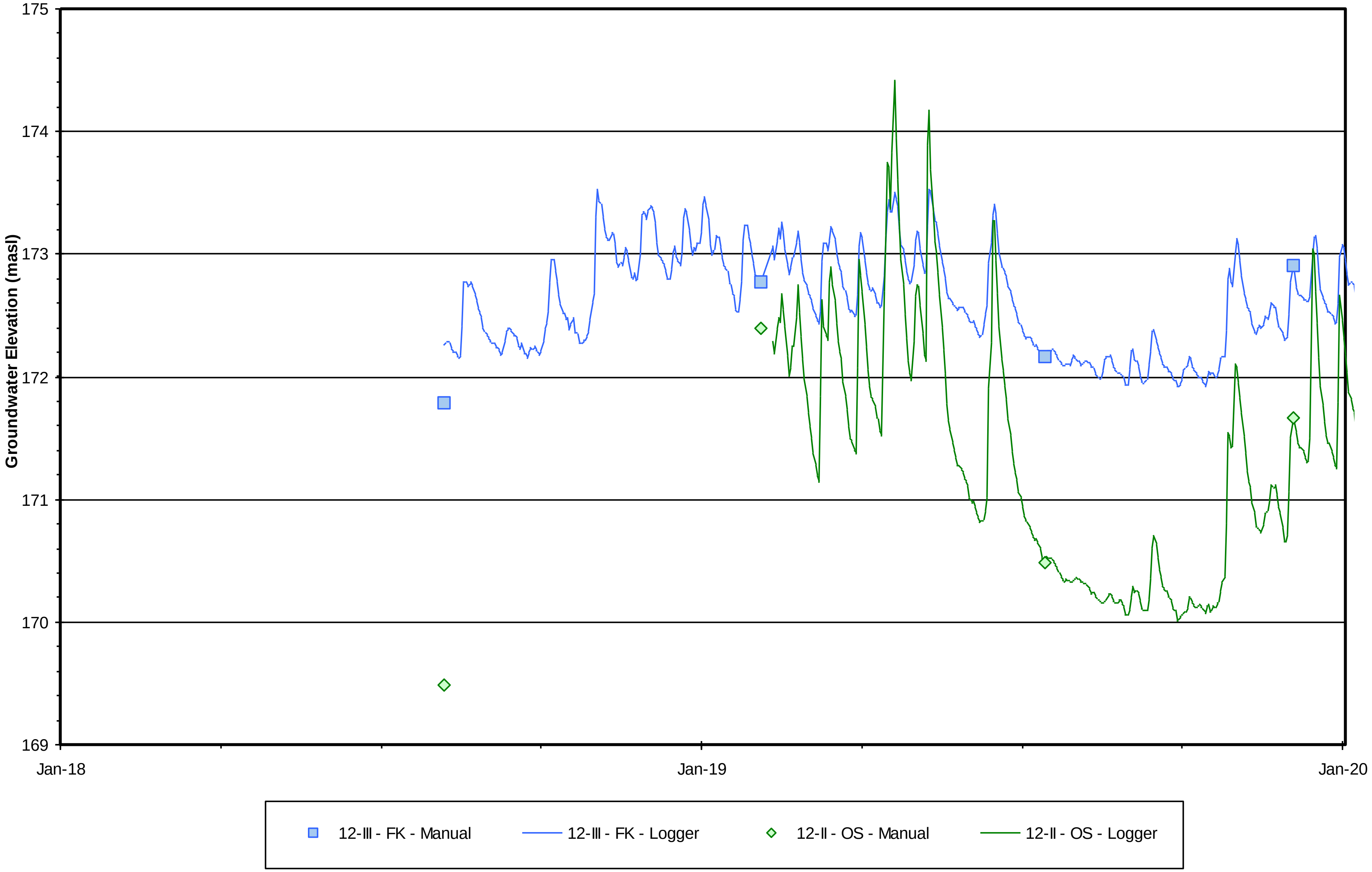


Figure E-12 Groundwater Hydrograph

Pumping Well

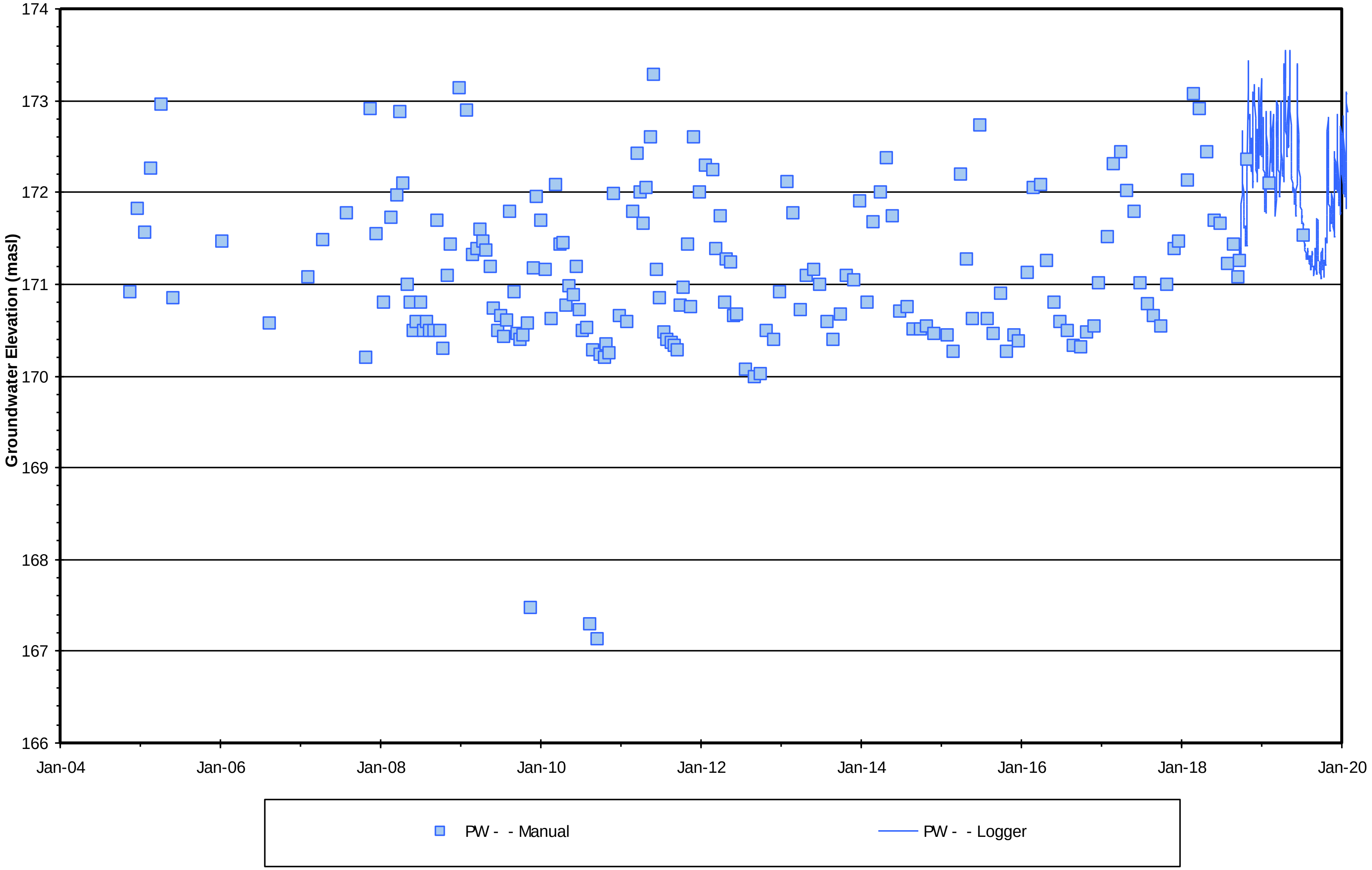
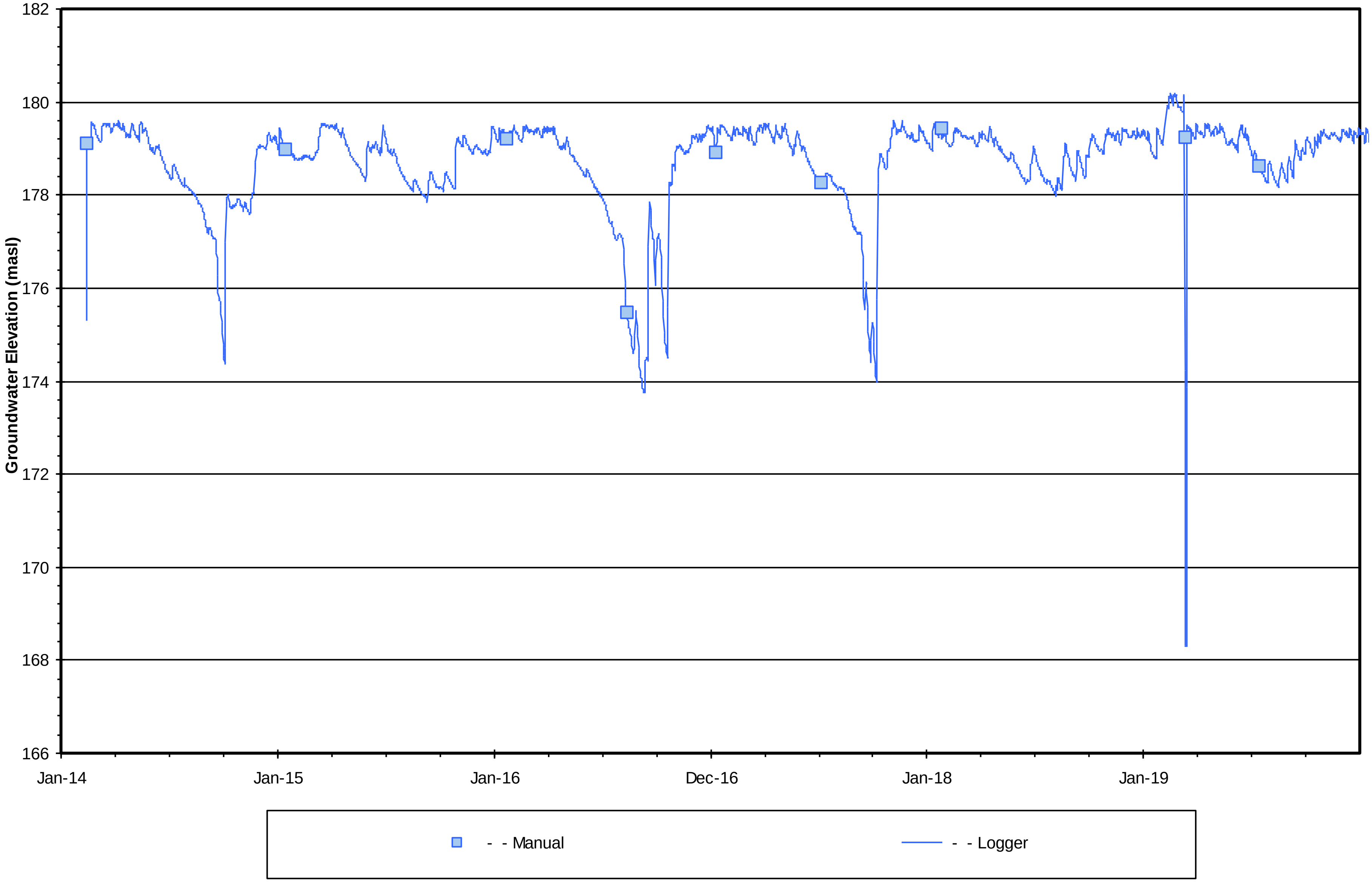


Figure E-13 Groundwater Hydrograph

20246 Youngs Road



LAW QUARRY
(Report Tools v.1.2 / Reports_LawQuarry.accdb / 1115302306 / Apr-20)

Figure E-14 Groundwater Hydrograph

722 Highway 3

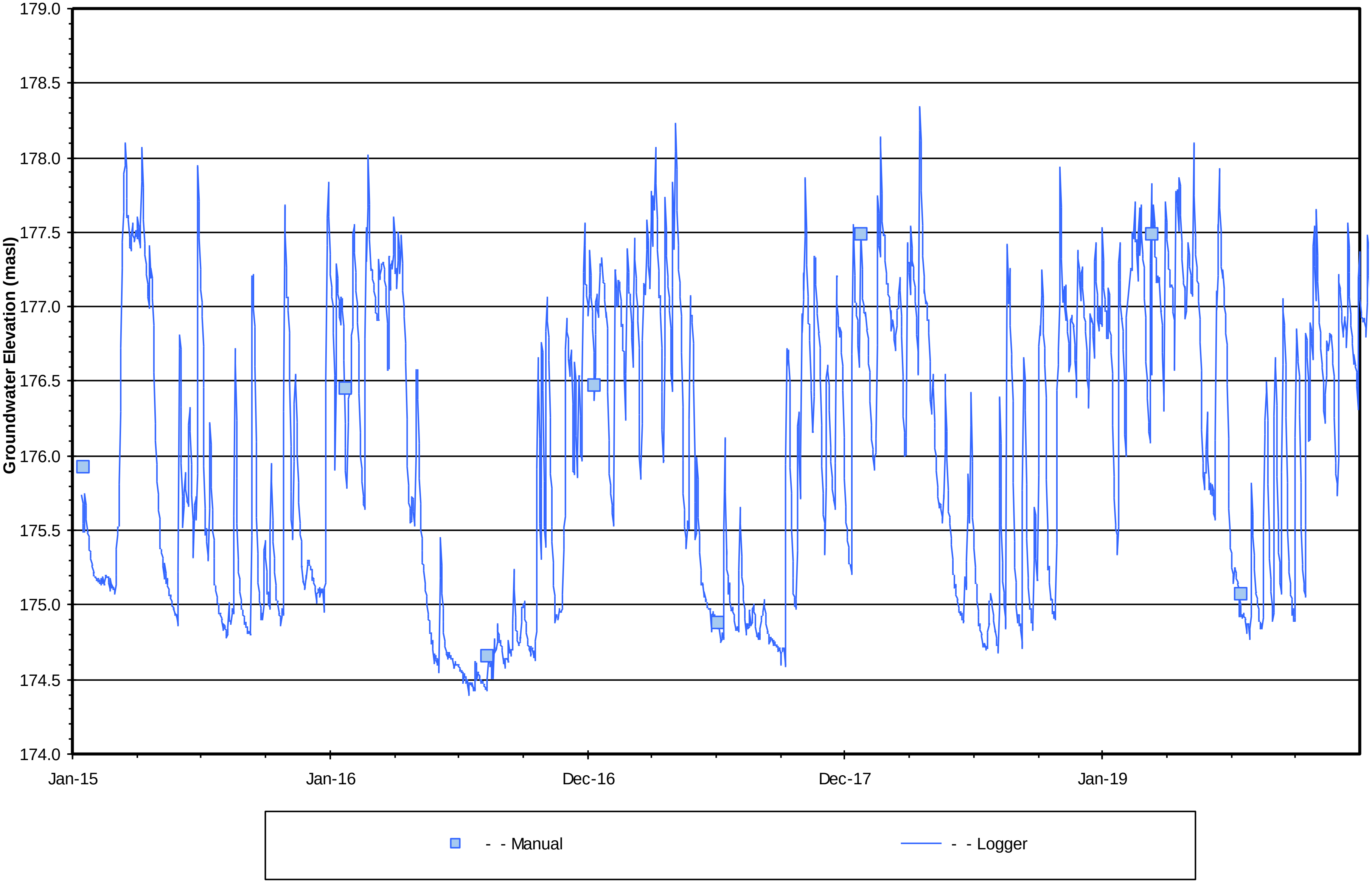
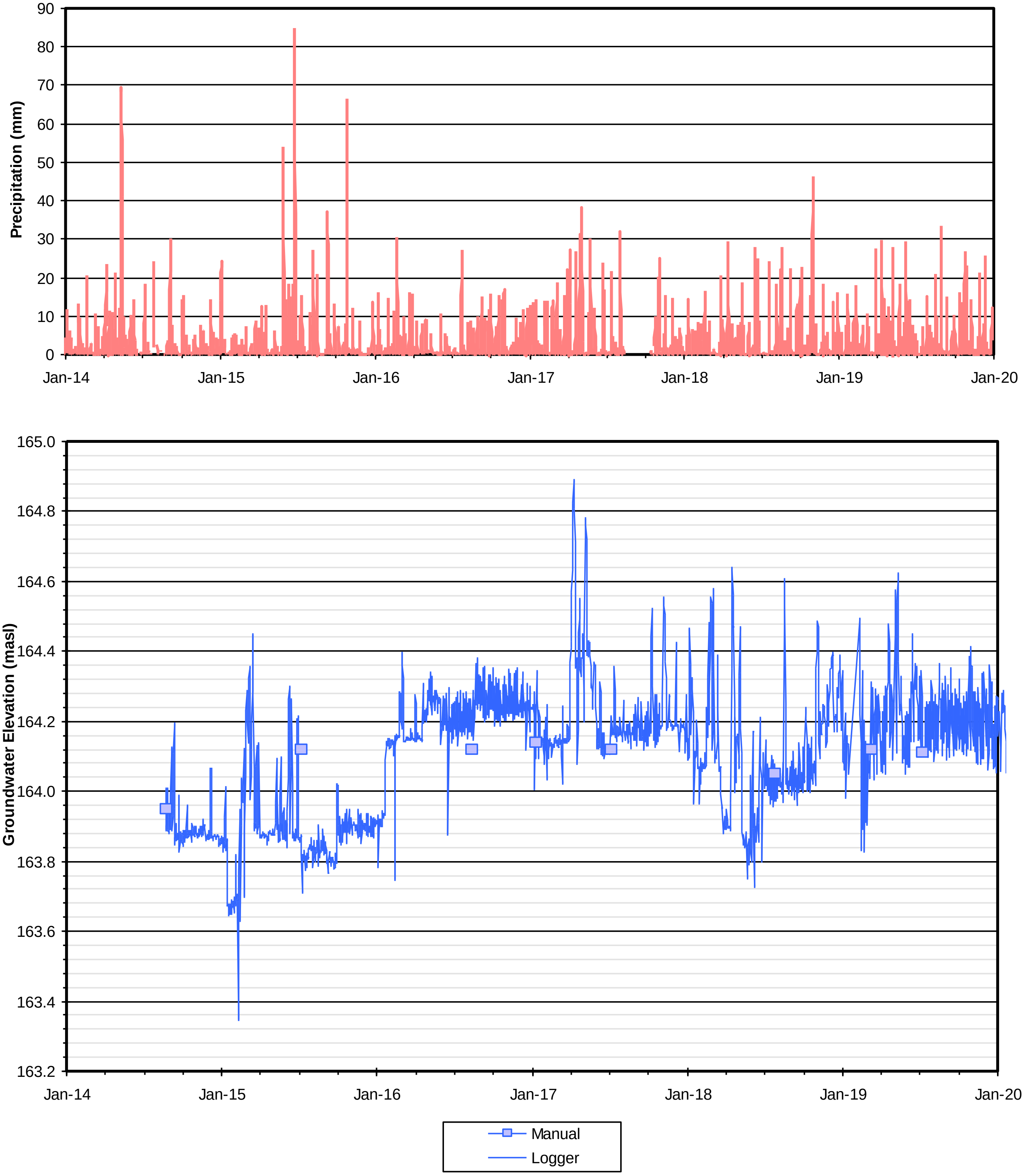


Figure E-15 Hydrograph

Sump



APPENDIX

F

GROUNDWATER CHEMICAL RESULTS

TABLE F-1
GROUNDWATER CHEMISTRY
LAW QUARRY

Parameter	ODWQS	Law Quarry	Private	Reeb Quarry**														
		PW	20808 Graybiel Rd	OW6-I Bertie (Akron)						OW6-II Bertie (Falkirk)				OW6-III Bertie (Falkirk)		OW6-IV Salina		
		Feb-19	Feb-19	Oct-04	Apr-05	Aug-05	Nov-05	Apr-06	Apr-07	Oct-04	Aug-04	Nov-05	Apr-06	Aug-04	Apr-07	Aug-04	Apr-05	Aug-05
pH (unitless)	6.5-8.5 OG	7.2		8.18	7.89	8.34	7.94	8.17	8.11	8.07	7.58	7.74	8.1	7.58	8.32	7.27	7.57	8.12
Conductivity (µs/cm)		3220		1080	1220	1270	1170	985	1680	1600	1320	1730	1850	1320	1530	2600	2660	2420
Total Hardness (as CaCO3)	80-100 OG			**413**	**479**	**545**	**463**	**421**	**624**	**856**	**348**	**847**	**928**	**519**	**593**	**1470**	**1570**	**1670**
Alkalinity	30 - 500 OG			270	220	236	238	225	249	210	300	214	223	216	247	220	190	193
Total Organic Carbon		1.6	5.6	3	3	3	2	2	5.8	17	3	<1	2	12	11.7	12	2	2
Total Kjeldahl Nitrogen		3.6	2.4															
Total Phosphorus		0.007	0.774	0.07	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.21	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Total Suspended Solids		<2	6															
Turbidity (NTU)	5 AO	0.5	**81.8**	1.5	3.6	2.2	**6.7**	<0.5	1.4	2.0	**15.7**	5	**9.5**	**26.7**	1.3	**32.7**	0.9	2.3
Ammonia		1.8	1.11	<0.05	1.07	0.8	0.92	0.95	1.78	<0.05	0.15	1.09	0.94	<0.05	1.94	<0.05	0.17	0.52
Un-ionized Ammonia		0.01																
Nitrite	1 MAC	<0.10	<0.10	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.17	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Nitrate	10 MAC	<0.10	<0.10	<0.05	5.87	0.41	<0.05	<0.05	<0.05	<0.05	0.74	<0.05	<0.05	0.31	<0.05	0.1	1.76	0.85
Orthophosphate		<0.03	0.8	8.27	<0.05	<0.05	<0.05	<0.05	<0.05	5.87	<0.05	0.06	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Aluminum	0.1 OG	<0.01	0.02	0.035	0.008	0.005	0.008	0.012	<0.004	0.005	0.052	0.013	0.012	0.015	<0.004	0.015	**0.201**	<0.004
Arsenic	0.025 IMAC	<0.001	0.001	0.004	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
Boron	5 IMAC	4.9	1.59	0.049	0.019	0.009	0.004	0.007	0.008	0.404	0.216	0.669	0.68	0.097	0.81	0.588	0.799	0.731
Barium	1 MAC	<0.01	0.04	0.049	0.019	0.009	0.004	0.007	0.008	0.034	0.019	0.065	0.038	0.049	0.01	0.03	0.022	0.018
Bromide		0.26	0.27	<0.05	<0.05	<0.05	<0.05	<0.05	0.12	<0.05	<0.05	0.57	<0.05	<0.05	0.1	<0.05	<0.05	<0.05
Calcium		503	190	85.9	106	118	100	90	135	285	96.1	258	296	162	133	516	587	606
Cadmium	0.005 MAC	<0.0001	<0.0001	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Chloride	250 AO	88	98	114	195	215	167	169	**311**	64.4	106	164	126	47.6	**301**	100	77.3	98.4
Chromium	0.05 MAC	0.002	<0.001	<0.003	<0.003	<0.003	0.004	<0.003	0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
Copper	1 AO	<0.001	<0.001	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	0.007	<0.002	<0.002	0.005	<0.002	0.005	<0.002	<0.002
Flouride	1.5 MAC	1.26	0.83	0.92	1.2	1.41	1.4	1.34	1.36	0.7	0.47	0.22	<0.05	0.31	**1.53**	**36**	0.42	0.45
Iron	0.3 AO	0.05	**0.76**	0.285	0.276	0.233	0.26	**0.819**	**0.351**	**1.42**	0.28	**1.69**	**5.11**	**0.795**	**0.384**	**2.08**	**2.15**	**1.34**
Mercury	0.001 MAC	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Potassium		20	37	2.8	7.31	6.3	6.04	5.57	7.16	4.57	4.06	6.31	6.2	2.29	7.72	6.64	9.09	9.33
Magnesium		130	108	48.3	51.9	61	51.5	47.6	69.6	35.7	26.3	49.4	45.9	27.9	63.4	44.9	37.9	38.2
Manganese	0.05 AO	0.01	**0.12**	0.01	0.009	0.005	0.002	0.003	0.004	0.045	**0.062**	0.03	0.023	**0.127**	0.006	**0.198**	0.038	0.012
Molybdenum		<0.005	<0.005	0.019	<0.002	<0.002	<0.002	<0.002	<0.002	0.006	0.009	<0.002	<0.002	0.047	<0.002	0.013	0.003	<0.002
Sodium	200 AO	59	38	70.2	53.3	56.6	43.7	43.7	82.4	51.7	153	48.7	85.8	97.4	72.3	124	69.0	64.3
Nickel		<0.005	<0.005	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	0.005
Oil & Grease - Total		1.00	1.00															
Lead	0.01 MAC	<0.001	<0.001	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	**0.21**	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Sulphide	0.05 AO	**10.0**	**7.0**															
Un-dissociated Hydrogen Sulphide		4.37																
Antimony	0.006 IMAC	<0.0005	<0.0005															
Selenium	0.01 MAC	<0.001	0.001	<0.004	<0.004	0.009	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
Sulphate	500 AO	**1380**	**1070**	159	95.1	127	99.2	94.7	130	**629**	214	484	**734**	440	156	**1260**	**1440**	**1440**
Silver		<0.0001	<0.0001	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Strontium		11.3	11.7	6.3	5.19	5.46	5.23	5.98	9.44	7.33	1.98	6.95	9.1	2.35	7.65	7.03	9.6	7.83
Thallium		<0.0001	<0.0001	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
Uranium	0.02 MAC	<0.001	0.002	0.017	<0.001	<0.001	<0.001	<0.001	<0.001	0.005	0.005	0.001	<0.001	0.008	<0.001	0.006	0.001	<0.001
Vanadium		<0.001	<0.001	<0.001	0.001	<0.001	0.001	<0.001	0.002	<0.001	0.001	0.002	<0.001	<0.001	<0.001	<0.001	0.001	<0.001
Zinc	5 AO	<0.01	<0.01	0.024	0.01	0.013	<0.004	0.004	0.014	<0.004	0.079	0.006	0.004	0.043	0.009	0.026	0.211	<0.004

Notes:

- Blank indicates data are not available
- all concentrations in mg/L unless stated otherwise
- ** Data obtained from Reeb Quarry Hydrogeological Study (Azimuth Environmental Consulting Inc., 2008)
- ODWQS - Ontario Drinking Water Quality Standards (June 2003)
- Bold and shading indicates that result exceeds ODWQS
- MAC - Maximum Acceptable Concentration
- IMAC - Interim Maximum Acceptable Concentration
- OG - Operational Guideline
- AO - Aesthetic Objective

APPENDIX

G

SURFACE WATER CHEMICAL RESULTS

Appendix G: Surface Water Notation Details

Notation	Description		
mg/L	milligrams per Litre	D O	Dissolved Oxygen
	• values in mg/L unless otherwise noted	T D S	Total Dissolved Solids
pH	provided in Scientific Units	T S S	Total Suspended Solids
E C	Electrical Conductivity	T K N	Total Kjeldahl Nitrogren
	provided in microSiemens per centimetre	T O C	Total Organic Carbon
T	Temperature		
	provided in degrees Celsius		
QA / QC			
RDL	laboratory reported detection limit		
RPD	relative percent difference, provided in %		
	bold and shading indicates RPD greater than 20% or >2 RDL		
PWQO	Provincial Water Quality Objectives (1994)		
( )	interim PWQO		
nc	no PWQO criteria		
▨	shading indicates an exceedance of the PWQO criteria		
(a)	**dissolved oxygen** is temperature dependent: value should not be less than the range of 4 mg/L (0 °C) to 7 mg/L (25 °C) for warm water biota		
(b)	**turbidity** does not have a firm objective: Suspended matter should not be added to surface water in concentrations that will change the natural Secchi disc reading by more than 10%		
(c)	**oil & grease** does not have a firm objective: Oil or petrochemicals should not be present in concentrations that: • can be detected as visible film, sheen or discolouration on the surface; • can be detected by odour; • can cause tainting of edible aquatic organisms; • can form deposits on shorelines and bottom sediments that are detectable by sight or odour, or are deleterious to resident aquatic organisms		
(d)	**alkalinity** should not decrease by more than 25% of the natural concentration		
(e)	**un-ionized ammonia** value calculated value using the fraction (*f*) of NH_3 from: $f = 1 \div (10^{pKa-pH} + 1)$ *where:* pKa = 0.09018 + 2729.92 ÷ T T = ambient water temperature in Kelvin (K) K = °C + 273.16 Field pH and temperature values and laboratory total ammonia results are used in the equation		
(f)	**total phosphorus** does not have a firm objective: excessive plant growth in rivers and streams should be eliminated at a concenctration below 0.03 mg/L		
(1)	NSD - station dry		
(2)	NSF - frozen		
blank	parameter not analysed during sampling event		
< value	parameter not detected above associated laboratory reported detection limit		

Table G-1: Surface Water Quality Results

Station	Date	Field				General Parameters							Major Ions						
		pH	E C	T	D O	TSS	Turbidity	Total Oil & Grease	Sulphide	Undissociated Hydrogen Sulphide	Fluoride	Phosphate	Alkalinity	Chloride	Sulphate	Calcium	Magnesium	Sodium	Potassium
	Units	S U	µS/cm	˚C															
	PWQO	6.5 - 8.5	nc	nc		nc	nc	nc	nc	0.002	nc	nc	nc	nc	nc	nc	nc	nc	nc
SW1	24-Jan-18	7.3	238	1.7	12.6	7	34.6	<1	<0.002	<0.001	0.35	<0.03		14	11	34	9	5	4
	24-Apr-18	7.5	480	10.0	4.5	41	44.4	<1	0.004	0.001	0.32	0.09		12	10	48	12	6	3
	19-Jul-18	7.4	631	21.0	1.4	41	19.7	7	0.011	**0.003**	<0.10	0.340		21	3	89	20	7	4
	31-Oct-18	8.2	332	9.5	8.8	84	>100	<1	0.002	0.0001	0.29	0.74		22	25	36	16	7	15
	04-Dec-18	6.9	168	0.2	11.2	53	66	<1	0.003	0.002	0.16	0.25		15	5	15	5	7	3
	12-Apr-19	7.4	446	5.5	8.5	29	3.4	<1	0.003	0.001	0.36	<0.2		19	18	58	16	9	3
	09-Jul-19	7.2	570	19.4	0.4	32	23.9	1	0.016	**0.007**	0.29	0.682		21	54	68	19	17	4
	11-Oct-19	7.6	1,050	11.1	3.8	6	6.9	1	0.01	**0.003**	0.32	<0.2	320	112	119	131	44	56	8
SW2	24-Jan-18	7.2	343	2.6	13.3	3	1.1	<1	0.008	**0.004**	0.75	<0.03		181	911	434	55	86	6
	24-Apr-18	7.6	2,630	10.8	8.2	2	2.3	<1	0.019	**0.005**	0.68	<0.03		185	1110	585	56	76	7
	19-Jul-18	7.8	2,410	21.0	6.5	6	1.7	1	0.005	0.0008	<0.10	<0.03		272	1340	647	60	88	8
	31-Oct-18	7.8	2,450	11.0	8.6	8	7.2	<1	<0.002	<0.0004	0.68	<0.03		210	1310	463	63	83	8
	04-Dec-18	7.2	2,070	3.3	8.9	22	11	<1	0.03	0.0011	0.54	<0.03		182	1050	360	42	62	5
	12-Apr-19	7.9	2,330	7.0	11.0	4	3.9	<1	0.004	0.0004	0.63	<0.2		131	981	516	58	69	6
	09-Jul-19	7.5	2,530	20.4	9.1	13	2.5	1	0.022	0.0005	0.64	<0.0092		127	1130	430	50	63	7
	11-Oct-19	7.9	2,290	14.6	11.8	23	11.5	1	0.005	0.0008	0.67	<2.0	171	195	961	489	53	87	8
SW3	24-Jan-18	7.1	590	0.1	13.2	13	35.3	<1	0.005	**0.0032**	0.31	0.090		75	48	55	12	38	4
	24-Apr-18	7.6	2,810	10.8	7.8	3	2.6	<1	0.019	**0.0052**	0.64	<0.03		153	1070	545	53	69	6
	19-Jul-18	8.0	2,490	24.9	10.4	11	6.4	<1	0.003	0.0003	<0.10	<0.03		241	1480	513	64	92	9
	31-Oct-18	7.8	908	9.5	9.5	17	47	<1	0.002	0.0004	0.21	<0.03		115	68	66	15	95	3
	04-Dec-18	7.8	1,113	1.5	10.7	24	34.3	1	0.011	**0.0028**	0.32	0.12		87	329	144	19	40	4
	12-Apr-19	7.5	2,130	7.5	10.9	6	6.5	<1	0.004	0.0014	0.61	<0.2		143	877	444	52	75	6
	09-Jul-19	8.0	2,460	21.9	12.1	24	7.7	1	0.004	0.0004	0.63	<0.0092		136	1110	414	51	68	7
	11-Oct-19	8.1	2,310	13.4	9.4	10	6.3	<1	0.004	0.0004	0.62	<2.0	179	204	1000	498	57	94	7

Table G-1: Surface Water Quality Results

Station	Date	*Nutrients and Organic Indicators*							*Total Metals*								
		Nitrate	Nitrite	TKN	Ammonia	Un-ionized Ammonia	Total Phosphorus	TOC	Aluminum	Antimony	Arsenic	Barium	Beryllium	Boron	Bromine	Cadmium	Chromium
	Units PWQO	nc	nc	nc	nc	0.020	0.03	nc	nc	0.02	0.10	nc	0.011	0.2	nc	0.0002	nc
SW1	24-Jan-18	1.53	<0.10	0.9	0.06	0.0001	**0.09**	9.6	1.42	<0.0005	<0.001	0.02	<0.0005	0.01	<0.25	<0.0001	0.001
	24-Apr-18	0.31	<0.10	3.7	0.08	0.0005	**0.14**	10.5	1.68	<0.0005	<0.001	0.03	<0.0005	0.02	<0.25	<0.0001	0.002
	19-Jul-18	0.15	<0.10	1.3	0.07	0.0007	**0.625**	19.9	0.32	<0.0005	0.002	0.03	<0.0005	0.05	<0.25	<0.0001	<0.001
	31-Oct-18	1.22	<0.10	2.1	0.16	0.0044	**0.686**	18.6	16.1	<0.0005	0.003	0.12	0.0006	0.04	<0.25	0.0002	0.02
	04-Dec-18	0.86	<0.10	2.7	0.05	0.0000	**0.179**	7.4	1.18	<0.0005	<0.001	0.02	<0.0005	0.01	<0.25	<0.0001	0.001
	12-Apr-19	0.62	<0.10	0.9	0.06	0.0002	**0.094**	6.5	0.68	<0.0005	<0.001	0.03	<0.0005	0.02	<0.25	<0.0001	0.001
	09-Jul-19	<0.10	<0.10	1.84	0.513	0.0029	**0.418**	16.7	0.57	<0.0005	0.003	0.03	<0.0005	0.06	<0.25	<0.0001	<0.001
	11-Oct-19	<0.10	<0.10	1.5	0.3	0.0026	**0.419**	15.2	0.14	<0.0005	0.001	0.05	<0.0005	0.10	<0.25	<0.0001	<0.001
SW2	24-Jan-18	0.24	<0.10	<0.8	0.25	0.0004	<0.01	2.7	0.03	<0.0005	<0.001	0.03	<0.0005	**0.52**	1.01	<0.0001	<0.001
	24-Apr-18	0.13	<0.10	0.5	0.21	0.0016	**0.04**	2.5	0.03	<0.0005	0.001	0.03	<0.0005	**0.59**	1.11	<0.0001	<0.001
	19-Jul-18	<0.10	<0.10	0.4	0.17	0.0044	0.012	7.4	0.03	<0.0005	<0.001	0.04	<0.0005	**0.65**	1.53	<0.0001	<0.001
	31-Oct-18	0.21	<0.10	0.3	0.13	0.0016	0.015	3.9	0.17	<0.0005	<0.001	0.04	<0.0005	**0.55**	1.54	<0.0001	<0.001
	04-Dec-18	0.29	<0.10	0.6	0.25	0.0004	0.022	2.8	0.06	<0.0005	0.001	0.03	<0.0005	**0.55**	0.43	<0.0001	<0.001
	12-Apr-19	0.23	<0.10	0.4	0.15	0.0017	0.010	1.4	0.09	<0.0005	<0.001	0.05	<0.0005	**0.56**	0.94	<0.0001	<0.001
	09-Jul-19	<0.10	<0.10	0.32	0.042	0.0005	0.008	3.5	0.03	<0.0005	0.001	0.03	<0.0005	**0.58**	0.88	<0.0001	<0.001
	11-Oct-19	<0.10	<0.10	0.3	0.17	0.0032	0.009	3.1	0.07	<0.0005	<0.001	0.04	<0.0005	**0.67**	1.37	<0.0001	<0.001
SW3	24-Jan-18	4.61	<0.10	1.1	0.07	0.0001	**0.13**	7.3	1.7	<0.0005	<0.001	0.03	<0.0005	0.05	<0.25	<0.0001	0.001
	24-Apr-18	0.11	<0.10	0.8	0.15	0.0012	**0.05**	2.6	0.04	<0.0005	<0.001	0.03	<0.0005	**0.52**	0.88	<0.0001	<0.001
	19-Jul-18	<0.10	<0.10	0.4	<0.05	0.0001	0.023	5.7	0.2	<0.0005	<0.001	0.04	<0.0005	**0.67**	1.52	<0.0001	<0.001
	31-Oct-18	<0.10	<0.10	0.9	0.08	0.0009	**0.063**	11.6	2.13	<0.0005	<0.001	0.03	<0.0005	0.04	<0.25	<0.0001	0.003
	04-Dec-18	0.64	<0.10	0.8	0.12	0.0007	**0.127**	5.5	0.93	<0.0005	<0.001	0.03	<0.0005	**0.22**	<0.25	<0.0001	0.001
	12-Apr-19	0.27	<0.10	0.5	0.16	0.0008	0.028	2.1	0.36	<0.0005	<0.001	0.05	<0.0005	**0.48**	0.82	<0.0001	0.001
	09-Jul-19	<0.10	<0.10	0.31	0.012	0.0006	0.022	4.2	0.27	<0.0005	0.001	0.04	<0.0005	**0.58**	0.92	<0.0001	<0.001
	11-Oct-19	<0.10	<0.10	0.3	0.07	0.0022	0.015	3.5	0.21	<0.0005	<0.001	0.04	<0.0005	**0.60**	1.31	<0.0001	<0.001

Table G-1: Surface Water Quality Results

Station	Date	Total Metals															
		Cobalt	Copper	Iron	Lead	Manganese	Mercury	Molybdenum	Nickel	Selenium	Silver	Strontium	Thallium	Uranium	Vanadium	Zinc	Zirconium
	Units																
	PWQO	0.0009	0.005	0.30	0.005	nc	0.0002	0.04	0.025	0.1	0.0001	nc	0.0003	0.005	0.006	0.03	0.004
SW1	24-Jan-18	0.0002	0.002	**0.73**	<0.001	0.02	<0.0001	<0.005	<0.005	<0.001	<0.0001	0.134	<0.0001	<0.001	0.002	<0.01	<0.002
	24-Apr-18	0.0005	0.002	**1.09**	<0.001	0.05	<0.0001	<0.005	<0.005	<0.001	<0.0001	0.295	<0.0001	<0.001	0.003	0.02	0.002
	19-Jul-18	0.0004	<0.001	**1.81**	<0.001	0.21	<0.0001	<0.005	<0.005	<0.001	<0.0001	0.802	<0.0001	<0.001	0.001	0.02	0.003
	31-Oct-18	0.0045	**0.012**	**12.2**	**0.008**	0.10	<0.0001	<0.005	0.024	0.001	<0.0001	0.356	0.0002	0.001	**0.027**	**0.07**	**0.010**
	04-Dec-18	0.0005	0.003	**0.83**	0.001	0.03	<0.0001	<0.005	0.005	<0.001	<0.0001	0.139	<0.0001	<0.001	0.002	0.01	<0.002
	12-Apr-19	0.0003	0.003	**0.65**	<0.001	0.03	<0.0001	<0.005	0.006	<0.001	<0.0001	0.413	<0.0001	<0.001	0.001	0.01	<0.002
	09-Jul-19	0.0004	0.001	**1.2**	<0.001	0.39	<0.0001	<0.005	<0.005	<0.001	<0.0001	0.787	<0.0001	<0.001	0.001	0.02	<0.002
	11-Oct-19	0.0005	<0.001	**0.82**	<0.001	0.43	<0.0001	<0.005	<0.005	<0.001	<0.0001	2.26	<0.0001	0.002	<0.001	0.01	<0.002
SW2	24-Jan-18	<0.0002	<0.001	0.07	<0.001	0.02	<0.0001	<0.005	<0.005	<0.001	<0.0001	9.35	<0.0001	0.002	<0.001	<0.01	<0.002
	24-Apr-18	0.0004	<0.001	0.17	<0.001	0.03	<0.0001	0.005	<0.005	<0.001	<0.0001	11.0	<0.0001	0.004	<0.001	<0.01	<0.002
	19-Jul-18	<0.0002	<0.001	0.22	<0.001	0.04	<0.0001	<0.005	<0.005	<0.001	<0.0001	11.6	<0.0001	0.003	<0.001	<0.01	0.004
	31-Oct-18	0.0004	<0.001	**0.31**	<0.001	0.10	<0.0001	0.006	<0.005	<0.001	<0.0001	10.8	<0.0001	0.003	<0.001	<0.01	<0.002
	04-Dec-18	0.0004	<0.001	0.18	<0.001	0.05	<0.0001	<0.005	<0.005	<0.001	<0.0001	10.5	<0.0001	0.003	<0.001	<0.01	<0.002
	12-Apr-19	0.0002	0.001	0.16	<0.001	0.03	<0.0001	<0.005	<0.005	<0.001	<0.0001	10	<0.0001	0.002	<0.001	<0.01	<0.002
	09-Jul-19	0.0003	<0.001	0.27	<0.001	0.05	<0.0001	<0.005	<0.005	<0.001	<0.0001	10.4	<0.0001	0.002	<0.001	<0.01	<0.002
	11-Oct-19	<0.0002	<0.001	0.24	<0.001	0.04	<0.0001	<0.005	<0.005	<0.001	<0.0001	9.76	<0.0001	0.002	<0.001	<0.01	0.002
SW3	24-Jan-18	0.0003	0.002	**0.82**	<0.001	0.02	<0.0001	<0.005	<0.005	<0.001	<0.0001	0.796	<0.0001	<0.001	0.002	0.01	0.002
	24-Apr-18	0.0003	<0.001	0.14	<0.001	0.03	<0.0001	<0.005	<0.005	<0.001	<0.0001	10.7	<0.0001	0.003	<0.001	<0.01	<0.002
	19-Jul-18	<0.0002	<0.001	0.26	<0.001	0.02	<0.0001	<0.005	<0.005	<0.001	<0.0001	11.6	<0.0001	0.003	<0.001	<0.01	0.003
	31-Oct-18	0.0006	0.003	**1.31**	0.001	0.01	<0.0001	<0.005	<0.005	<0.001	<0.0001	0.854	<0.0001	0.001	0.004	0.02	<0.002
	04-Dec-18	0.0005	0.002	**0.77**	<0.001	0.04	<0.0001	<0.005	<0.005	<0.001	<0.0001	3.88	<0.0001	0.001	0.001	0.03	<0.002
	12-Apr-19	0.0003	0.002	**0.32**	<0.001	0.03	<0.0001	<0.005	<0.005	<0.001	<0.0001	8.58	<0.0001	0.002	<0.001	<0.01	<0.002
	09-Jul-19	0.0003	<0.001	**0.33**	<0.001	0.03	<0.0001	0.012	<0.005	<0.001	<0.0001	10.4	<0.0001	0.002	<0.001	<0.01	<0.002
	11-Oct-19	<0.0002	<0.001	0.21	<0.001	0.03	<0.0001	<0.005	<0.005	<0.001	<0.0001	9.96	<0.0001	0.002	<0.001	<0.01	<0.002

APPENDIX

H

GROUNDWATER NUMERICAL MODEL DOCUMENTATION

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H.1 INTRODUCTION

This report summarizes the numerical groundwater modeling activities undertaken as part of the Level 2 Hydrogeological Study report prepared in support of the Category 2 Class A licence application for the proposed Law Quarry Extension under the Aggregate Resources Act (R.S.O., 1990). The purpose of the groundwater modeling is to predict the potential effects of the quarry extension during the operational phase and final rehabilitation to a lake on the local groundwater users and surface water features.

The calibrated baseline model incorporates an extensive data set consisting of borehole stratigraphy, hydraulic testing results, groundwater elevations, and surface water flows. The work program for this study was completed between 2017 and 2019, and data collection is on-going. Climatic data from local Environment Canada stations were used to estimate recharge to the groundwater system from infiltration of water surplus (precipitation less evapotranspiration).

A steady-state baseline model was constructed for this study, representing average October baseline conditions observed at the Site. Calibration targets include Site groundwater elevation data, as well as additional groundwater elevation data from other known sites within the model domain where groundwater monitoring data is available. Water level data from Ministry of the Environment, Conservation and Parks (MECP) water well records were also included. Finally, flow rate targets were used for the dewatering operations within the existing quarry, to the south at Quarry Lakes, to the southeast at the Scholfield Avenue Pumping Station, and to the northeast at Townline Road Tunnel.

H.1.1 MODEL OBJECTIVES

The primary objectives of the numerical groundwater modeling are as follows.

- ➔ Formulate the conceptual hydrogeologic setting of the Site and construct a steady-state numerical groundwater flow model representing the conceptualization. Calibrate the model to observed baseline groundwater conditions.
- ➔ Complete an analysis of uncertainty and sensitivity of the calibrated baseline model parameters in order to aid in the calibration and determine if the model is significantly robust to generate reliable predictions.
- ➔ Modify the baseline model to simulate the west quarry extension and the maximum radius of influence, the contribution of groundwater inflows to quarry dewatering and assess any changes to the water balance during the operational phase.
- ➔ Include the Licensed Reeb Quarry in the future scenario to assess the cumulative impacts of both operations.
- ➔ Use the modified model to simulate groundwater conditions under final rehabilitation to a lake to assess any long-term changes to the water balance.

H.1.2 PREVIOUS INVESTIGATIONS

Prior to the current study, a number of hydrogeological investigations were undertaken, including well interference studies (GLL, 1979 and Jackman, 1980), an investigation of the impact on the Wainfleet Bog from the existing Law Quarry (Crowe et al, 2002) and Level 2 Hydrogeological Studies for the Law Quarry east extension (GLL, 2005) and the Reeb Quarry (Azimuth Environmental Consulting and Earthfx, 2005 and 2008). The Reeb Quarry study included a numerical groundwater model to simulate the impacts of the proposed quarry. The results of these previous investigations were reviewed throughout the course of the current study. Some initial parameter values for the current study model were adopted from these previous works.

H.2 CONCEPTUAL MODEL

The first step in constructing a numerical groundwater model is to create a “conceptual model” that describes in general terms the hydrogeologic conditions and water budget of the natural system to be simulated and other physical elements of the undertaking to be considered. Some components of the conceptual model include:

- ➔ A decision on the areal extent to be studied;
- ➔ Identification of the geologic framework and hydrogeologic properties of the subsurface;
- ➔ Derivation of hydrostratigraphic units (aquifers and aquitards) in the subsurface;
- ➔ An understanding of the regional movement of groundwater, including groundwater elevations and trends as well as hydraulic gradients;
- ➔ Identification of hydrologic features, such as watershed divides, groundwater seeps and springs and watercourses; and
- ➔ A basic understanding of water budget components that include recharge and discharge conditions and controls.

The conceptual understanding is used to make decisions regarding the construction of the numerical model to provide adequately representative simulations. The initial decision relates to the extent of the overall model domain and the scale to be used in representing the hydrogeologic systems in both the horizontal and vertical dimensions.

In formulating the conceptual model there are three key steps (Anderson and Woessner, 1992):

- ➔ Defining hydrostratigraphic units;
- ➔ Defining the groundwater and surface water system; and
- ➔ Analyzing elements of the water budget.

The conceptual model and the subsequent construction of the computer model involve some simplification and categorization of the data to represent the groundwater system in sufficient detail to provide reasonably representative results. Ultimately, model accuracy depends on the ability of the conceptual model to approximate observed conditions. Calibration statistics show how well the numerical model simulates these observed conditions.

The conceptual model for the Site is based on the topography, physiography, geology, hydrogeology and water budget outlined in **Section 2** of the main report.

H.3 SIMULATION CODE SELECTION

The numerical simulation code selected for this study was MODFLOW-USG (**U**n-**S**tructured **G**rid) developed and maintained by the United States Geological Survey (USGS) (Panday, S., et al, 2013). Like previous versions of MODFLOW (USGS 1988-2005), MODFLOW-USG is a modular numerical groundwater flow simulator capable of representing the complex three-dimensional multi-layer systems for steady-state conditions in the confined and unconfined aquifers within the study area using the finite-difference method. However, MODFLOW-USG allows for more robust grid refinement in areas of increased interest. The MODFLOW family of software is the most widely used groundwater modeling code in the world and has been extensively tested and applied in the research and consulting communities. The MODFLOW-USG code is public domain and freely distributed. For this study, version 1.5.0 of the MODFLOW-USG code (released in February 2019) was used.

Model input datasets include the physical geometry of the system, boundary conditions (no-flow, recharge or discharge) and aquifer properties (hydraulic conductivity). Groundwater flow can be modeled for many different types of sources or sinks, including lakes, rivers, drains, recharge from infiltration of precipitation, and pumping wells, among others. The code is flexible when modeling aquifer properties, allowing heterogeneity and anisotropy in three dimensions.

The flow system being modeled is split up into layers comprised of many smaller blocks referred to as nodes (or cells for previous versions of MODFLOW) based on the conceptual hydrogeological understanding of the model domain. The MODFLOW-USG code solves the groundwater flow mass balance equation for each node using the model input parameters. The general mass balance equation can be expressed as:

$$\text{Sum of Boundary Inflows} + \text{Sum of Internal Sources of Water} = \text{Sum of Boundary Outflows} + \text{Sum of Internal Sinks of Water}$$

The mass balance equation for an unconfined aquifer with recharge, discharge and leakage (Bear, 1979) can be written as:

$$\frac{\partial}{\partial x}\left[(h-b)\left(K_{xx}\frac{\partial h}{\partial x}\right)\right]+\frac{\partial}{\partial y}\left[(h-b)\left(K_{yy}\frac{\partial h}{\partial y}\right)\right]+\frac{K'}{B'}(H_0-h)+N-W=0$$

Where: K_{xx} = hydraulic conductivity in the x-direction;

K_{yy} = hydraulic conductivity in the y-direction;

h = hydraulic head;

b = elevation of the unit bottom;

K' = vertical hydraulic conductivity of an underlying confining unit;

B' = thickness of the confining unit;

H_0 = head in the aquifer underlying the confining unit;

N = a general source term representing groundwater recharge; and
W = a general sink term representing groundwater discharge.

Similar equations can be written for each aquifer in a layered sequence of aquifers / aquitards. When an aquifer is confined, the saturated thickness (h-b) is replaced with the total aquifer thickness.

MODFLOW-USG computes a mass balance for each time step specified by the model input, as well as cumulative flow volumes for each type of source / sink included in the model.

The solution to the mass balance equation is obtained by iteratively solving the system of equations for each model node. Initial conditions for the hydraulic head in each node are specified in the model input. A calculation procedure is used to adjust the initial head estimates and produce a new estimate of the heads which are closer to the solution of the system of equations. The procedure is repeated until the maximum head change in a model node between successive iterations falls below a closure criterion which is user specified. MODFLOW-USG provides two solver modules to obtain the model solution. For this study, the χMD solver was used with a closure criterion of 0.001 m.

MODFLOW-USG is accompanied by a utility program called ZONBUDUSG, a water budget calculator which sums the flow volumes from the various groundwater sources / sinks over a zone of interest. The program was modified from the earlier ZoneBudget version 3.01 (Harbaugh, 1990) to work with un-structured grid models. ZONBUDUSG was used in this study to calculate the water balance components of the study area, as well as predicting the discharge volume due to proposed quarry extension dewatering.

The model construction and calibration process was completed using Groundwater Vistas version 7.24 (Environmental Simulations Inc., 2017). Groundwater Vistas is a pre- and post-processor that is capable of creating MODFLOW-USG input files as well as reading output files in a user-friendly graphical user interface. Groundwater Vistas is also capable of importing model input datasets created by third-party software, including ArcGIS (ESRI, 2017). Both of these software programs were used to interactively prepare, edit and manage the information needed for model development.

To calibrate the baseline model, PEST (**P**arameter **EST**imation) version 17.0 (Doherty, May 2019) software was used. PEST facilitates computer-assisted calibration of MODFLOW-USG models by back-calculating model parameters to match observation data such as groundwater elevation data, surface watercourse baseflow rates and horizontal and vertical hydraulic gradients. This procedure is referred to as “inverse modeling”. Additional utilities included in the Groundwater Data Utilities suite (Doherty, 2015b) were also used in tandem with PEST during the calibration process.

Particle tracking analysis was completed using mod-PATH3DU (Muffels et al, 2018), a particle-tracking model that uses MODFLOW-USG groundwater flow velocity vector output to delineate the travel path and time-of-travel for unstructured model grids.

H.3.1 EQUIVALENT POROUS MEDIA APPROACH

Numerical modeling of groundwater flow through saturated porous media typically simulates water movement through a continuous fully-saturated medium such as sand and gravel with assigned distributions of porosity and hydraulic conductivity. Within fractured bedrock, the groundwater movement is typically greater within the fractures than within the surrounding matrix. Assuming sufficient fracture density and hydraulic connectivity among fractures, the fractured rock can be simulated as an “equivalent porous media” using a model constructed to simulate flow through porous media with appropriate hydraulic properties. On a small scale, actual groundwater movement and simulated groundwater movement can be different. With simulations at a larger scale, the equivalent porous media approach provides a reasonable representation of groundwater flow patterns that is accepted by industry.

H.4 MODEL CONSTRUCTION

The groundwater model construction consisted of the following five phases:

- ➔ Spatial domain and grid discretization;
- ➔ Input of model layers;
- ➔ Boundary condition implementation; and
- ➔ Selection and input of hydraulic properties.

The following sub-sections describe each stage of the groundwater model construction.

H.4.1 SPATIAL DOMAIN AND GRID DISCRETIZATION

The model domain was set to encompass approximately 23,380 ha, with the proposed quarry extension footprint located in the approximate centre of the domain, as shown in **Figure H-1**. The dimensions of the model are 16,700 metres on the north and south sides, and 14,000 metres on the east and west sides. The lower left corner of the model is located at UTM coordinates 628,100 E and 4,744,300 N (NAD83 Zone 17N).

The size of the domain was set to incorporate regional “boundaries” where possible, including Lake Erie to the south and the Welland Canal to the east. These features generally represent natural groundwater boundary conditions for the model domain. The northwest boundary coincides with the Feeder Canal, a channelized surface water feature which formerly provided flow to historic versions of the Welland Canal, but still flows today. Due to the large thickness of low permeability clay overburden present along this boundary, there is inferred to be minimal interaction between the surface water and groundwater. As such, the Feeder Canal is not an ideal boundary for the groundwater model, but it is reasonably distant from the proposed quarry excavation footprint such that edge effects of the model boundaries do not have a direct influence on the groundwater flow patterns in the vicinity of the Site. Outside of these boundaries, the model cells were set as no-flow boundaries (inactive). Groundwater Vistas was set to remove inactive model cells from the MODFLOW-USG input files to reduce the model numerical burden.

Quadtree grid refinement was used at the Site and for other features of interest as shown in **Figure H-1**. Quadtree grid refinement is compatible with MODFLOW-USG and is implemented in Groundwater Vistas. For a quadtree-refined grid, parent grid cells are divided into smaller cells by powers of 2 (i.e., 2^x where x is the order of the desired refinement). The grid is then “smoothed” around the refined cells, such that no cell is refined by more than a factor of 2 compared to any adjacent cell. The quadtree approach provides numerical stability and reduces the number of unnecessary grid cells that are typically present in more traditional grid refinement methods.

Initially, a uniform grid of 140 rows by 167 columns was set up, resulting in grid spacing of 100 m in the x- and y-directions. Third order refinement (i.e., 8x8 sub-divided cells) was used for the model cells at the Site and the Wainfleet Bog to the north, resulting in a local grid spacing of 12.5 m square as shown in **Figure H-1A**. Second order refinement was used for cells coincident with watercourses and other wetland features of interest.

H.4.2 MODEL LAYERS

Ten (10) hydrostratigraphic layers were established in the model, representing the overburden and bedrock stratigraphy outlined in **Section 2.3** of the main report, as summarized in **Table H.4.1** below.

Table H.4.1 Model Layer Thicknesses

<table>
<tr><th>Model Layer</th><th colspan="2">Description</th><th>Layer Thickness (m)</th><th>Layer Type</th></tr>
<tr><td>1</td><td colspan="2">Surficial Soils</td><td>Up to 3.0</td><td rowspan="10">Upstream Water (Type 4)</td></tr>
<tr><td>2</td><td colspan="2">Overburden Aquitard</td><td>Varies</td></tr>
<tr><td>3</td><td colspan="2">Wentworth Till</td><td>Up to 1.0</td></tr>
<tr><td>4</td><td rowspan="3">Shallow Bedrock Aquifer</td><td>Onondaga Fm</td><td>Varies</td></tr>
<tr><td>5</td><td>Bois Blanc Fm</td><td>Up to 2.0</td></tr>
<tr><td>6</td><td>Bois Blanc Fm – Springvale Mb</td><td>Up to 0.9</td></tr>
<tr><td>7</td><td colspan="2">Upper Bertie Fm Aquitard</td><td>Up to 7.1</td></tr>
<tr><td>8</td><td colspan="2">Bertie Formation – Falkirk Mb</td><td>Up to 5.0</td></tr>
<tr><td>9</td><td colspan="2">Bertie Formation – Oatka Mb</td><td>Up to 4.7</td></tr>
<tr><td>10</td><td colspan="2">Salina Formation Bedrock</td><td>Up to 3.0</td></tr>
</table>

Layer 10 of the model represents the upper hydraulically active portion of the Salina formation shale, below which is an inferred lower no-flow boundary. Layer 10 is present throughout the entire model domain; however, two different conductivity zones are used to represent the inferred weathered portion north of the buried Onondaga Escarpment. All of the layers were set as type 4 upstream water (i.e., the conductivity of the model cells is computed using the upstream weighting method included in MODFLOW-USG).

The ground surface elevation (top of layer 1) is based on the 1 m Digital Elevation Model (DEM) released in 2013 and by the Niagara Peninsula Conservation Authority (NPCA). The contours were used to interpolate a raster data set using ArcGIS Desktop (ESRI, 2017). The interpolation at the Site was verified using ground surface spot elevation data acquired during the monitoring well surveys.

As noted above, the top of bedrock (top of layer 4) was interpolated using Site data, high-quality data from other Sites within the model domain, outcrops, oil and gas well data and the MECP water well database. The raster calculator tool included in ArcGIS Desktop was used to ensure the interpolated top of bedrock was equal to or below the ground surface elevation.

It is interpreted that the surficial soils mapping applies to the upper 3 m of overburden, as such the conductivity zones corresponding to surficial soil types are only present in layer 1. The Wentworth Till (layer 3) is only present north of the buried Onondaga Escarpment. The overburden aquitard is also predominantly situated north of the buried escarpment; however, in areas where a significant thickness of overburden is present south of the escarpment and the surficial soil type is classified as glaciolacustrine clay, pockets of the overburden aquitard were also interpolated to exist. The thickness of the overburden aquitard was calculated by taking the difference between the bottom of layer 1 and the top of the Wentworth Till (north of the escarpment) and top of bedrock (south of the escarpment).

It is understood that the stratigraphic contact surfaces between the various bedrock units are not perfectly planar over Site specific distances, but planar surfaces are inferred to be a reasonable approximation over larger regional study areas. In the conceptual (and numerical) hydrogeological model for the study area, flat planar surfaces were interpolated from the Site borehole data to represent the stratigraphic contacts, and then extrapolated over the study area. A summary of the Site borehole stratigraphic details is provided on **Table C-2, Appendix C** of the main report.

The “trend” tool in ArcGIS was used to calculate a best-fit, flat (polynomial order 1) planar surface by performing a linear regression analysis in two dimensions (latitude and longitude). The Bertie Formation, Akron member contacts from the Site boreholes and Reeb Quarry boreholes were used to perform the linear regression analysis, since it is amongst the most distinct contact to pick at the Site and is inferred to most closely approximate a flat planar surface. An equation for the best-fit planar surface was calculated, and then the predicted contact elevations for each of the Site boreholes was compared to the actual values to determine the error at each point, and the overall root-mean-square error (RMSE), a measure of the plane’s fit to the available data. The results of the analysis yield a planar surface for the that declines to the southeast with a slope of 0.7%. These results compare favourably to the generally accepted interpretation of the Niagara Peninsula stratigraphy published elsewhere. The RMSE of the best-fit plane is 0.5 m, which indicates that approximately two-thirds of the interpreted contact elevations from the bedrock core fall within ±0.5 m of this best-fit plane. Another useful measure of fit is normalized RMSE (NRMS), which divides the RMSE by the range of observed values. In this case, the NRMS is approximately 5%, indicating the planar surface is a good fit to the data.

To simplify the conceptual model, it is assumed that the stratigraphic contacts for the other bedrock units fall along planar surfaces which are parallel (i.e. have the same slope and dip angle) to the Akron member contact as described above. To accomplish this, the z-axis coefficient of the equation of the best-fit Akron member contact planar surface was modified to fit the observed contact data for the other bedrock units at the Site.

A summary of the stratigraphic interpretation is provided in the table below.

Stratigraphic Layer	Calculated NRMS (%)	Interpolated Thickness (m)
Bois Blanc Formation – Springvale Member	6.5	0.9
Bertie Formation – Akron Member	4.9	2.9
– Williamsville Member	9.2	1.6
– Scajaquada Member	10.0	2.6
– Falkirk Member	9.5	5.0
– Oatka Member	10.0	4.7
Salina Formation	--	(assumed 3 m thickness)

Layers 4 through 6 in the model represents the shallow bedrock aquifer. The thicknesses of the lower two layers is interpolated based on Site data, while the thickness of the Onondaga formation (layer 4) is variable. In the southern portion of the model domain, layer 4 is up to 26 m thick due to the known top of bedrock and the dip angle of the Bois Blanc contact. The bedrock unit layer thicknesses and dip angle were set using the stratigraphic interpolation of the Site data as noted above. Where an underlying bedrock layer intersected the bottom of layer 3, the layer thickness was set at a nominal value of 0.1 m. Groundwater Vistas was set to pinch-out model cells with a thickness of 0.1 m or less and set them as inactive. As such, layer 4 through 9 model cells north of their respective sub-crops were inactive.

A 3-dimensional oblique view of the model domain showing the model layers and hydraulic conductivity zones is provided in **Figure H-2**. This figure illustrates how the lower bedrock layers 4 through 9 pinch out where they intersect the bottom of layer 3.

H.4.3 BOUNDARY CONDITIONS

The boundary conditions assigned to the model are shown in **Figure H-3**. The boundary conditions in the vicinity of the Site are shown in **Figure H-3A**.

The active model domain consists of the local study area. As noted above, all model cells outside of this lateral extent are set as no-flow boundaries (inactive). Additional no-flow boundary cells were simulated within the existing Law Quarry footprint (shown in **Figure H-3A**).

H.4.3.1 CONSTANT HEAD BOUNDARIES

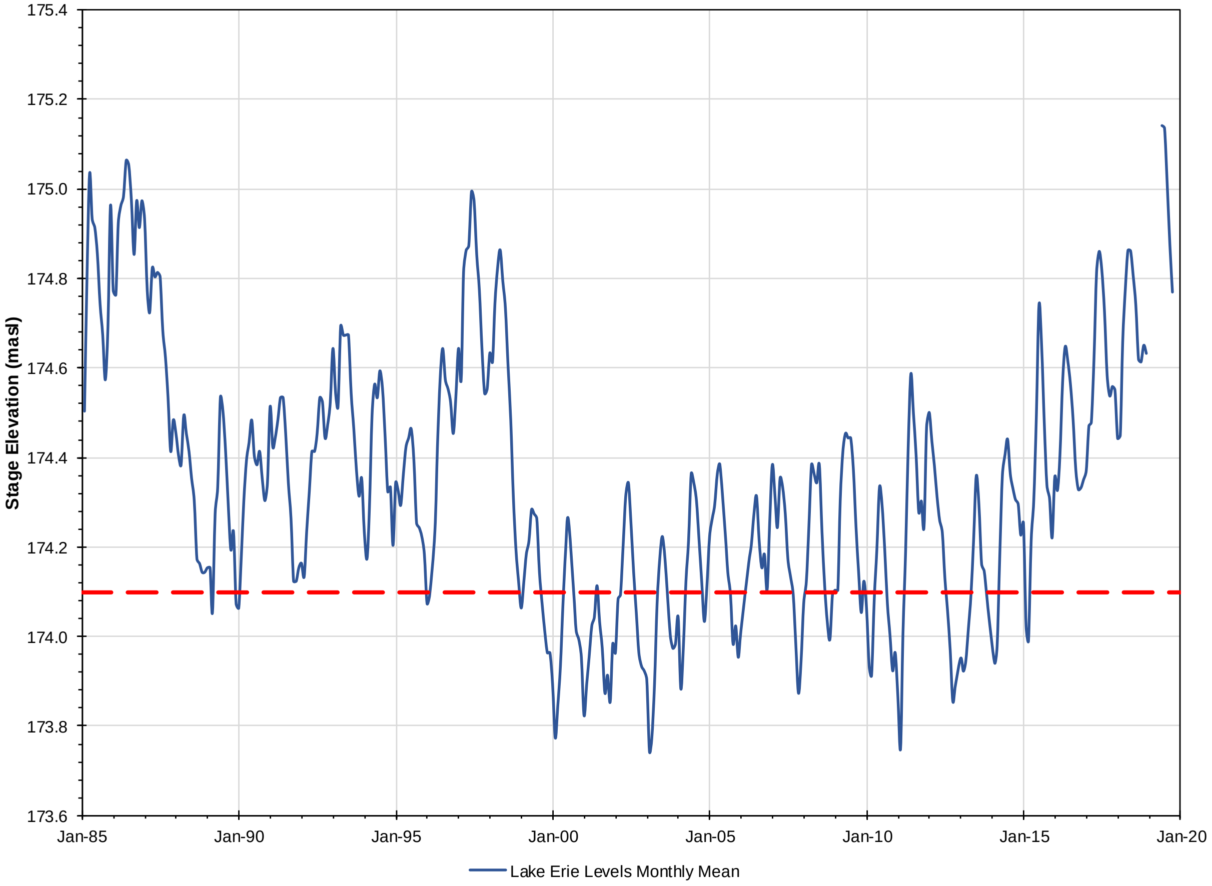
Constant head boundaries were used to represent Lake Erie and the Welland Canal. The 3,291 constant head boundaries used in the model are summarized in **Table H.4.2** below.

Table H.4.2 Constant Head Boundary Parameter Values

Reach	Description	No. of Cells	Layer	Stage Elevation (masl)
0	Lake Erie	2,666	1	174.1
1	Welland Canal (above Lock 8)	97		174.1
2	Welland Canal (below Lock 8)	528		174.0

Constant head boundaries are used for model cells for which the head is specified in advance of the simulation and held at the specified value through all model time steps.

The stage elevation for Lake Erie varies depending on time of day, seasonally and annually depending on precipitation amounts. Since the baseline model is a steady-state simulation of conditions, an appropriate value was chosen to represent the lake stage as a constant value during the simulated baseline conditions (i.e., autumn conditions with an excavation footprint similar to the era between approximately 2011 and 2017). The Lake Erie stage elevation is monitored at the Water Survey of Canada station 02HA017 at Port Colborne. Monthly mean stage elevation data from this station since 1985 are plotted below.



As shown in the plot, for the period between 2000 and 2015, the annual lake stage fluctuations were fairly consistent, ranging between approximately 173.8 masl and 174.6 masl. A representative value of 174.1 masl was chosen based on this range of data. The most recent data since 2016 was not used in the analysis since historically elevated stages were observed, which are inferred to be abnormal and not representative of average conditions.

Lock 8 on the Welland Canal (situated near Highway 3 within Port Colborne proper) regulates the stage elevation within the canal to the north. Above Lock 8, the stage elevation within the canal is essentially the same as that of Lake Erie. Below Lock 8, the stage elevation in the canal is reportedly maintained to within about 1 m of the Lake Erie stage; as such, a stage elevation of 174.0 masl was assumed.

H.4.3.2 RIVERS

River boundary cells were used to represent smaller waterbodies, watercourses, the Wainfleet Bog and other wetland features. The 6,456 river boundaries used in the model are summarized in **Table H.4.3** below.

Table H.4.3 River Boundary Parameter Values

Reach	Description	No. of Cells	Layer	Stage Elevation (masl)	Bottom Elevation (masl)	Conductance (m^2/day)
0	Wainfleet Bog	4,713	1	GS	GS – 1.0 m	0.1
1	Biederman Drain	122				
2	Eagle Marsh Drain	125				
3	Feeder Canal	318				
4	The Clay Pits	40				5.0
5	Small Undifferentiated Waterbodies	64				
6	Other Wetlands	1,074				

Notes: GS – Ground surface

River boundaries are capable of simulating both discharge from and recharge to the groundwater system (i.e., groundwater sinks or sources) depending on the specified stage elevation of the boundary. Each river boundary requires three parameters which must be specified in the MODFLOW-USG input file: stage elevation, bottom elevation and conductance. As noted above, the stage elevation determines the gradient between the boundary condition and the adjacent model cell. The bottom elevation dictates which layer the boundary condition is placed in. Finally, the conductance of the river boundary governs the rate of flux to or from the groundwater system. River conductance is an aggregate of several parameters including stream width, bed thickness and bed vertical hydraulic conductivity of the streambed the river boundary represents. In Groundwater Vistas, river boundaries may be grouped together into reaches to represent different features of interest. The parameters for each reach included in the model are provided in **Table H.4.3** above.

All river boundaries in the baseline model are assigned a stage elevation equivalent to the interpolated ground surface, and a bottom elevation 1.0 m below ground surface. Conductance values of 0.1 m^2/day were adopted for the Wainfleet Bog, the two local drains and the Feeder Canal, while marginally higher conductance values of 5.0 m^2/day were adopted for the Clay Pits ponds and other small waterbody and wetland features.

H.4.3.3 DRAINS

Drain boundary cells were used to represent ephemeral watercourses, the existing Law Quarry active dewatering sump, the Quarry Lakes dewatering sump operated by the NPCA, the Scholfield Avenue pumping station operated by the City of Port Colborne and the Townline Tunnel dewatering sump operated by the St. Lawrence Seaway Management Corporation (SLSMC). The 1,979 drain boundaries used in the model are summarized in **Table H.4.4** below.

Drain boundaries are only capable of simulating discharge from the groundwater system (i.e., groundwater sinks). Each drain boundary requires two parameters which must be specified in the MODFLOW-USG input file: stage elevation and conductance. As noted above, the stage elevation determines the gradient between the boundary condition and the adjacent model cell. Finally, the conductance of the drain boundary serves the same purpose as that of river boundaries. Similar to river boundaries, drain boundaries may be grouped together into reaches to represent different features of interest. The parameters for each reach included in the model are provided in **Table H.4.4** below.

Table H.4.4 Drain Boundary Parameter Values

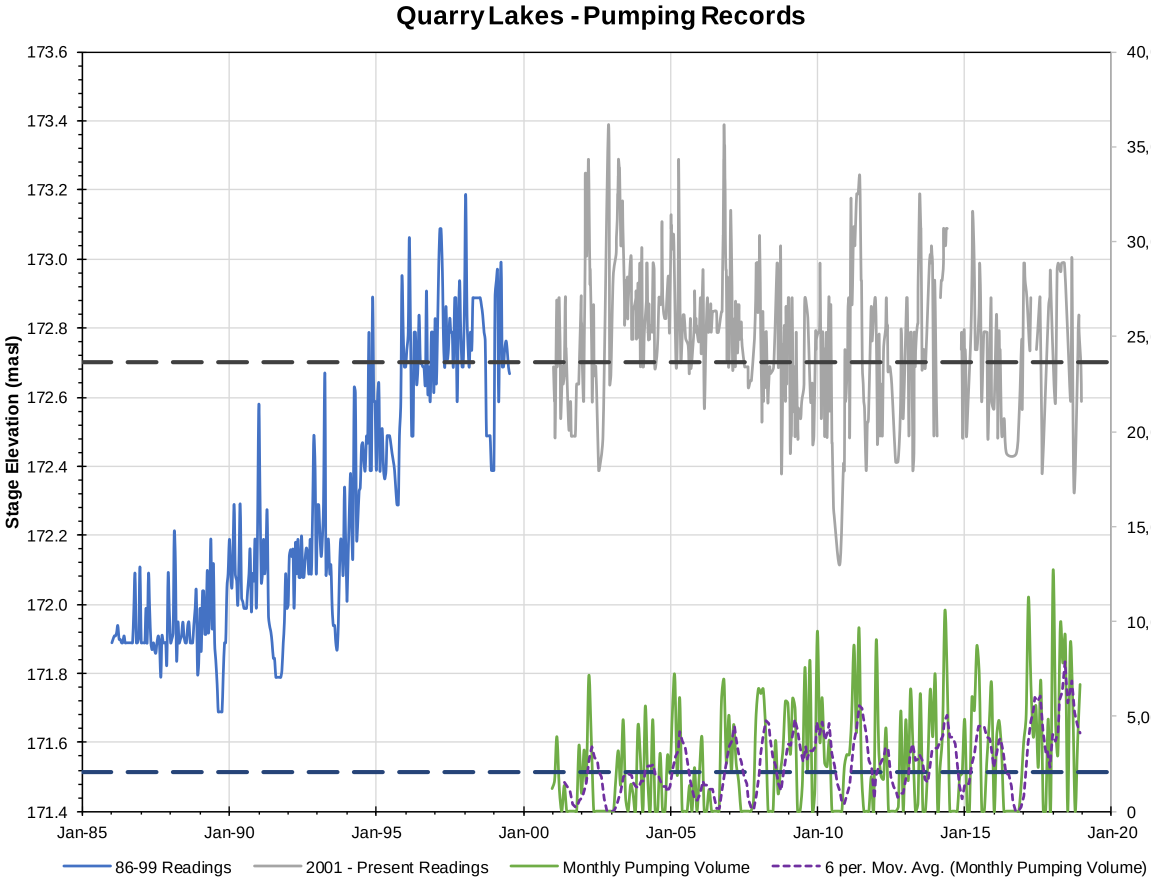
Reach	Description	Layer	No. of Cells	Stage Elevation (masl)	Conductance (m^2/day)
0	Mill Race Creek	1	584	GS	0.1
1	Biederman Drain Tributaries		34		
2	Eagle Marsh Drain Tributaries		43		
3	Other Tributaries		271		
4	Active Quarry Sump	8	1,041	Varies (*see below*)	1,000
5	Quarry Lakes Sump	4	1	172.7	10,000
6	Scholfield Avenue Pumping Station		1	171.7	
7	Townline Tunnel Dewatering Sump	10	4	153	

Notes: GS = Ground surface, L8 Top = Top of Layer 8

The stage elevation of the ephemeral streams (reaches 0 through 3) were assumed to be equal to ground surface, with a conductivity of 0.1 m^2/day. The remaining drains (reaches 4 through 7) represent anthropogenic features, and high conductance values were used so that outflow from the model was not artificially constrained.

For the existing Law Quarry sump, drains were input across the base of the active quarry footprint configuration for the baseline period (i.e., between 2011 and 2017). These drains were assigned an elevation equal to the greater of 164 masl or the bottom of layer 8 (i.e., bottom of the Falkirk member) plus a nominal value of 0.1 m to reduce numerical instability. As shown in **Figure E-15**, **Appendix E** of the main report, the water level in the sump was typically maintained to an elevation of 164 masl over the baseline period.

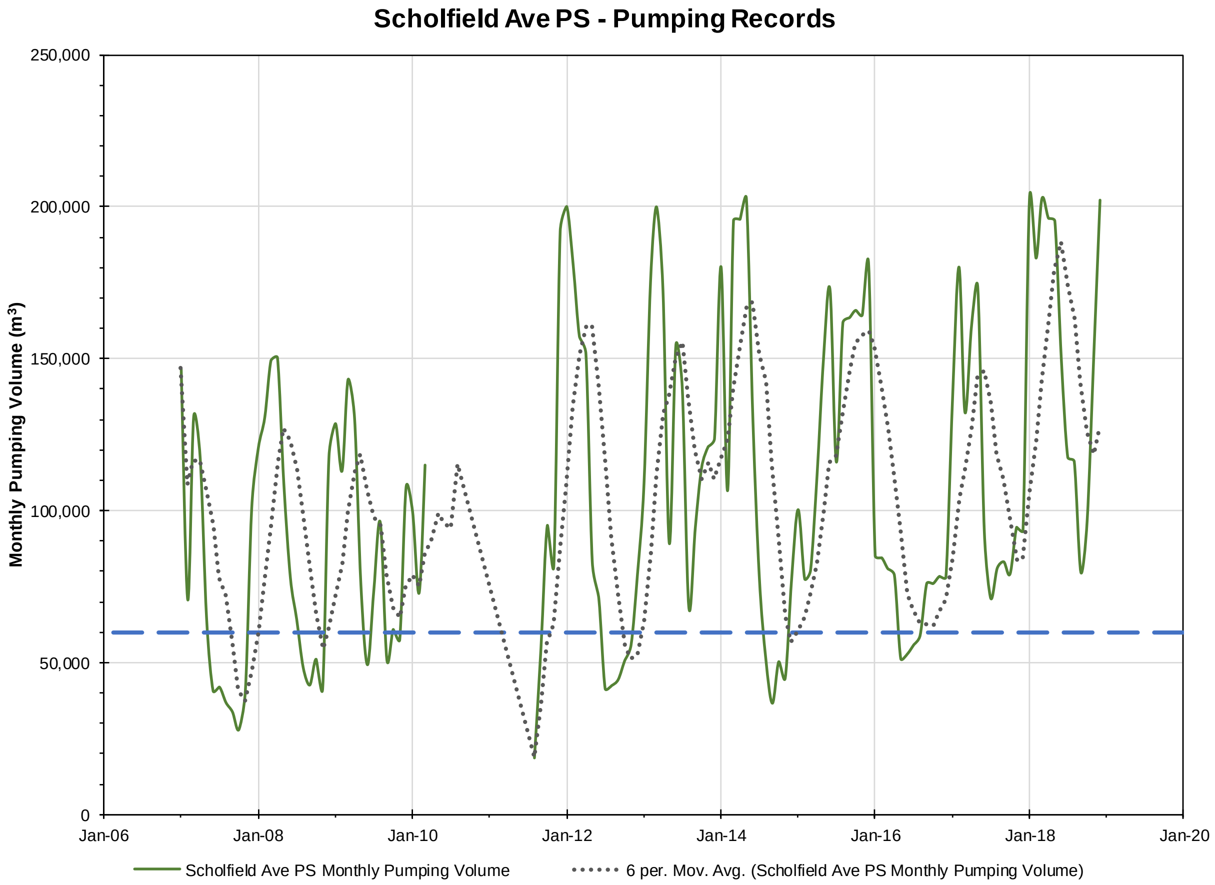
Elevation and flow data for the Quarry Lakes dewatering sump were provided by Mr. Thomas Proks of the NPCA. Originally, the operation of the sump required a Permit-to-Take-Water (PTTW), which required the operator to record elevation and flow data. However, the operation was exempted a number of years ago. Nonetheless, the NPCA has continued to periodically monitor elevation and flow data for the dewatering sump. Elevation data are available from 1986 to present, although the post-2008 data is provisional as the measurement datum changed and has not yet been verified by geodetic survey. Flow volume data are available from 2001 to present. Again, these flow data are considered provisional since the pump rating curve and on/off time were used to estimate flows. It is unclear when or if the pump has been calibrated. The available data are plotted on the figure below.



For the baseline period (between 2011 and 2017), 172.7 masl was chosen as the representative sump elevation. A representative flow rate of approximately 2,500 m^3/month (80 m^3/day) was chosen using the 6-month rolling average of monthly flow data, as the raw data is rather noisy. The representative flow rate was not specified in the model; rather, it was used as a target for calibration. Further discussion is provided in **Section H.5** below.

The Scholfield Avenue pumping station is operated under PTTW no. 7885-8JSLJM issued August 23, 2011, replacing the previous PTTW no. 79-P-2038 issued July 20, 2000. A Freedom of Information (FOI) request was submitted to the MECP for all data submitted to the Water Taking Reporting System (WTRS) for these two PTTWs, as well as a copy of a hydrogeological study previously completed by others to satisfy Condition 4.2 of the current PTTW. WTRS flow data are available from 2007 to 2018, as plotted in the figure below.

As shown in the figure, the flow data varies seasonally by a relatively wide range with the lowest flows observed during the autumn. Since the baseline model is intended to represent steady-state conditions during the autumn, a representative flow volume of approximately 60,000 m^3/month (1,950 m^3/day) was chosen for average baseline conditions. Similar to the Quarry Lakes sump, the representative flow rate was not specified in the model; rather, it was used as a target for calibration. Further discussion is provided in **Section H.5** below.



A hydrogeological assessment (Coffey Geotechnics Inc., 2012) completed to satisfy Condition 4.2 of the current PTTW includes information on the pump operation. The submersible pump is activated and deactivated by two float-operated switches. The pump is activated when the high-level float at elevation 173.0 masl is tripped and deactivated when the low-level float at elevation 171.7 masl is tripped. The low-level float elevation of 171.7 masl was used for the drain boundary in the numerical model.

Finally, the Townline Tunnel dewatering sump is not subject to provincial regulation and as such, a PTTW is not required for its operation. An inquiry was made to Ms. Cassie Kelly of SLSMC in St. Catharines for any monitoring data that may have been recorded over its operational history. Flow rates and groundwater elevations at a number of monitoring wells localized around the dewatering sump are reportedly recorded. However, recent flow data were not provided, and only very limited elevation data were provided for the sump monitoring wells. A “county wide” water well monitoring program is reportedly also undertaken at selected private domestic supply wells; however, these data were not provided.

The SLSMC did provide a number of historical engineering reports which allowed estimations of the elevation and flow rate for the dewatering sump. A “design summary” report (H.G. Acres Limited, 1970) indicates that the elevation of groundwater within the sump approximately 152.6 masl, while a “situation report” (Whittington, 1994) indicates that between 1978 and 1983, groundwater flow to the dewatering sump averaged between 930 US gallons per minute (gpm) to 1,020 US gpm (5,000 m^3/day to 5,600 m^3/day). Therefore, a sump elevation of 153 masl was adopted for the drain elevation. The representative flow rate for the model was estimated by assuming that the sump drains the Salina formation shale bedrock radially in all directions equally. Since the active model domain only covers approximately 1/8 of the radial area around the sump, a proportionate amount of flow to the sump was assumed for the model, estimated as 650 m^3/day.

H.4.3.4 GENERAL HEAD BOUNDARIES

During the early stage of the calibration process, it was observed that negative mass balance errors (i.e., more flow out of the cells than in) were being induced in the southwestern portion of the active model domain. To remedy the mass balance errors, general head boundaries were included along the southern edge of the active model domain.

Similar to river boundaries, general head boundaries are capable of simulating both discharge from and recharge to the groundwater system (i.e., groundwater sinks or sources). However, flow into or out of the model domain is dependent on the groundwater elevation in the adjacent model cell within the active model domain and the specified elevation of the apparent recharge boundary outside of the model domain. Each general head boundary requires two parameters which must be specified in the MODFLOW-USG input file: recharge boundary elevation and conductance. As noted above, the recharge boundary elevation determines the gradient between the apparent recharge boundary outside of the active model domain and the adjacent model cell. The conductance of the general head boundary governs the rate of flux to or from the groundwater system and is related to the hydraulic conductivity of the hydrostratigraphic layer. In layer 4 (Onondaga formation bedrock), 286 general head boundaries were used in the model, set as reach 0. In layer 10 (Salina formation bedrock), 144 general head boundaries were used in the model, set as reach 1. For both reaches, the elevation of the apparent recharge boundary was set as 175 masl, and a conductance of 10 m^2/day was specified.

H.4.3.5 RECHARGE

Recharge boundaries were used in the uppermost active model cell to represent infiltration to the groundwater system. It is noted that for this study, infiltration to the groundwater system is defined as total precipitation less evapotranspiration and runoff to surface water features. In the model, the recharge boundaries were applied to the uppermost active cell in the vertical column (i.e., NRCHOP = 3)

Eight (8) zones were used to define areas of similar surficial soil types based on the surficial geology mapping provided in **Figure 4** of the main report. The recharge zones are shown in **Figure H-4**, and the calibrated baseline model parameter values are summarized in **Table H.4.5** below.

To estimate initial recharge zone values, the 1981 – 2010 climate normal data from the Environment Canada station at Port Colborne was used, as shown in **I-1**, **Appendix I** of the main report. In summary, the average annual precipitation at the Site is approximately 984 mm, with an annual evapotranspiration rate of approximately 643 mm. This leaves approximately 342 mm/year of water surplus available as surface water runoff or discharge to the groundwater system. Initial recharge values were estimated based on the available water surplus and surficial soils types for zones 1 through 5. However, the values were revised during the calibration process.

For the Quarry Lakes ponds (zone 6), an annual evaporation rate of 850 mm was assumed (Hydrogeological Atlas of Canada, 1978, Plate 17, Mean Annual Lake Evaporation). Subtracting the evaporation rate from the average annual precipitation leaves approximately 130 mm/year as net recharge to the Quarry Lakes ponds.

Table H.4.5 Recharge Zone Parameter Values

Zone	Description	Recharge	
		mm/year	m/day
1	Glaciolacustrine Clay	3.7	$1.0x10^{-5}$
2	Wainfleet Bog Deposits	1.0	$2.7x10^{-6}$
3	Bedrock Outcrops	58	$1.6x10^{-4}$
4	Sand Deposits	145	$4.0x10^{-4}$
5	Manmade Deposits	5	$1.4x10^{-5}$
6	Quarry Lakes	130	$3.6x10^{-4}$
7	Active Quarry Excavation	200	$5.5x10^{-4}$
8	Lake Erie	0	0

For the existing Law Quarry excavation (zone 7), an evaporation rate from the quarry floor of 80% was assumed, which equates to 787 mm/year. Therefore, the net recharge to the active quarry excavation sump is approximately 200 mm/year.

Finally, since Lake Erie is simulated as a constant head boundary in the model, recharge to the feature does not have an influence in the model. Therefore, the recharge was set to nil for zone 8.

H.4.4 HYDRAULIC PROPERTIES

Zones were used to represent hydraulic conductivity and vertical anisotropy for the various hydrostratigraphic units present within the study area. The calibrated model values for each of the fifteen (15) zones used in the model are summarized below in **Table H.4.7** below.

Four zones (zones 9 – 12) were used to represent hydraulic conductivity and vertical anisotropy of similar surficial soil types in model layer 1 based on the surficial geology mapping provided in **Figure 4** of the main report. The zones in layer 1 are shown in **Figure H-5**. The sand deposits (zone 11) were included with the same extent in layer 2 in the calibrated baseline model. The bedrock outcrops in layer 1 share the same zone as the shallow bedrock aquifer (zone 6). The Salina formation bedrock (model layer 10) was broken up into two zones (zones 1 and 2) to represent the inferred weathered and unweathered portions, as shown in **Figure H-6**. The remaining layers are generally simulated using a single zone; however, a higher-permeability zone (zone 15) was simulated in layers 4 through 9 to represent the inferred more intensely weathered zone along the buried Onondaga escarpment. Two additional high-permeability zones (zones 13 and 14) were added to represent anthropogenic features (i.e., the Quarry Lakes ponds, Cement Plant ponds and the existing Law Quarry excavation), also shown in **Figure H-5**.

Initial horizontal hydraulic conductivity and anisotropy values were set based on the discussion provided in **Section 2.4.2** of the main report and published ranges available in the literature. Horizontal hydraulic conductivity values were adjusted during the course of the model calibration to improve the fit with observation data, while the vertical anisotropy values remained fixed.

Table H.4.6 Hydraulic Conductivity Parameter Values

Layer	Description	Zone	Horizontal Hydraulic Conductivity (K_H) (m/day)	Vertical Anisotropy (K_Z / K_H) (Unitless)
1	Weathered Glaciolacustrine Clay	9	$9.3x10^{-4}$	0.5
	Wainfleet Bog Deposits	10	5.2	0.5
	Bedrock Outcrops	6	58	0.5
	Sand Deposits	11	0.10	1.0
	Manmade Deposits	12	6.6	0.5
2	Overburden Aquitard	8	$2.8x10^{-4}$	0.1
	Sand Deposits	11	*(refer to zone 11 above)*	
3	Wentworth Till	7	111	0.5
4 - 6	Shallow Bedrock Aquifer	6	*(refer to zone 6 above)*	
7	Upper Bertie Fm. Aquitard	5	10	0.01
8	Bertie Fm. – Falkirk Mb.	4	0.67	0.5
9	Bertie Fm. – Oatka Mb.	3	12	0.1
10	*Weathered* Salina Fm.	1	0.13	1.0
	Unweathered Salina Fm.	2	0.39	0.1
--	Quarry Lakes	13	100,000	1.0
--	Active Quarry Excavation	14		
--	Onondaga Escarpment Weathered Zone	15	0.40	1.0

H.5 MODEL CALIBRATION

H.5.1 OBJECTIVES AND METHODOLOGY

The objective of the groundwater flow model calibration is to achieve an approximation of the observed baseline groundwater elevation and flow patterns within the study area. The quantification of the model fit to calibration targets is evaluated using “residuals”. Residuals are calculated as the difference between the calibration target values and the simulated model output (i.e., observed minus simulated).

Model calibration statistics typically include max / min residual values, residual mean, absolute residual mean, sum of squared error (SSE), root mean square error (RMSE), and normalized root mean sum of squares (NRMS). The residual mean is an average of the residuals; a value approaching zero is desired (i.e., there is a balance of over-prediction and under-prediction occurring in the model). The spatial distribution of residuals is also considered; randomly distributed positive and negative residuals are desired. The mean of the absolute value of residuals provides an estimate of the total error of the model output. The SSE is calculated by summing the squares of the residuals. RMSE is calculated by taking the square root of the SSE divided by the total number of calibration targets. Another indicator of a successful model calibration is if the RMSE is comparable to the variance of the calibration target values. Finally, NRMS is calculated by dividing the RMSE by the total range in the calibration target values. An industry accepted target for the NRMS is less than or equal to 10% (Spitz and Moreno, 1996).

The model calibration was also evaluated using the volumetric water budget output summarized by MODFLOW-USG at the end of each simulation. The volumetric water budget provides the simulated water balance (groundwater flow into and out of the model domain) broken down by boundary condition type. An acceptable water balance error is less than 0.1%.

As noted in **Section 2.4.2** of the main report, natural fluctuations in groundwater elevations occur as a result of seasonal climatic conditions. However, the potential impacts from dewatering of the proposed quarry are inferred to be worst during the drier period of the year (i.e., September to November). Therefore, the study area is simulated using a single steady-state stress period representing average conditions in the month of October. The mean and variance of the baseline water level data for the month of October was used as the calibration targets for the Site wells. For high-quality data from other site wells, representative autumn water level data were used as the calibration targets, where available.

As noted above, PEST was used to assist in the model calibration, along with various utility programs developed by Watermark Numerical Computing. Groundwater Vistas was used to import calibration targets into the model in order to provide PEST with the observation data required to perform the inverse modeling. Sensitivity analyses of the model parameters were completed throughout the calibration process to determine which parameters were most sensitive to the model output.

The following sections describe the calibration target data and model parameters used in the PEST calibration.

H.5.2 CALIBRATED PARAMETERS

Where used, the PEST automated calibration process was allowed to modify the horizontal hydraulic conductivity for 13 of the 15 zones identified in **Table H.4.7** above. Zones 13 and 14 were not included in the automated parameter calibration process, as they have values which represent anthropogenic features. As noted previously, the vertical anisotropy values remained fixed during the model calibration. The baseline model calibration was found to be generally insensitive to the recharge zone values, with the exception of zone 1 (glaciolacustrine clay) and zone 3 (bedrock outcrops). Therefore, the two sensitive recharge zones were included in the calibration process.

H.5.3 CALIBRATION TARGETS

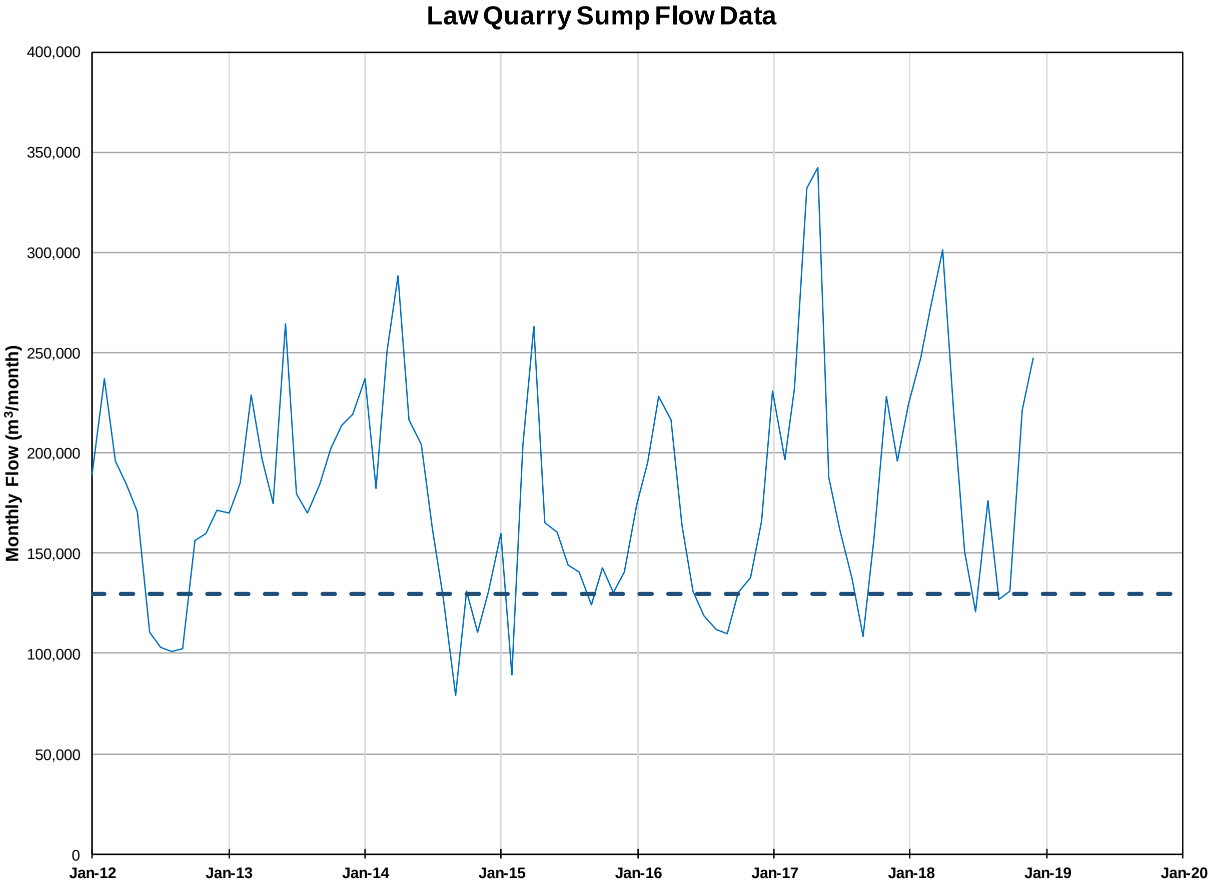
For this study, a total of 403 targets were used to calibrate the model to baseline conditions, described in the sections below. Summary tables of the target values and calibrated residuals are provided in **Section H.5.4** below.

H.5.3.1 SITE OBSERVATION DATA

A statistical analysis was completed on the baseline water level data for the Site monitoring wells to calculate the mean groundwater elevation and associated variance for the month of October. These elevations were imported to Groundwater Vistas as head targets, designated as Group 1. There are a total of twenty-eight (28) groundwater monitoring wells and two (2) private domestic supply wells in the Site monitoring network; however, there are only twenty-six (26) head targets included in Group 1. Monitoring well GLL-4 was removed from the calibration dataset as the well riser pipe is damaged and the seal is suspect. Also, the private domestic well at 722 Highway 3 was removed from the calibration dataset due to noise from active pumping of the well. The overall variance (σ^2) for all of the October baseline water level data is calculated as 28.1 m^2 (standard deviation s = 5.3 m).

The mean water level data from nested Site wells were also used to calculate vertical hydraulic gradients between the various bedrock units. A total of twenty-three (23) vertical hydraulic gradient (head difference) targets were imported to Groundwater Vistas, designated as Group 4.

Finally, a flux target was assigned for the existing Law Quarry sump. As per the current PTTW for the Site, total flow volumes are recorded on a daily basis for submission to the WTRS. The daily flow data since 2012 were aggregated into monthly totals and plotted on the figure below. As shown on the figure, there is a relatively large seasonal variation between spring and autumn conditions. A representative value of 130,000 m^3/month (4,200 m^3/day) was chosen for autumn conditions during the baseline period. This flux target was imported to Groundwater Vistas as Group 5.



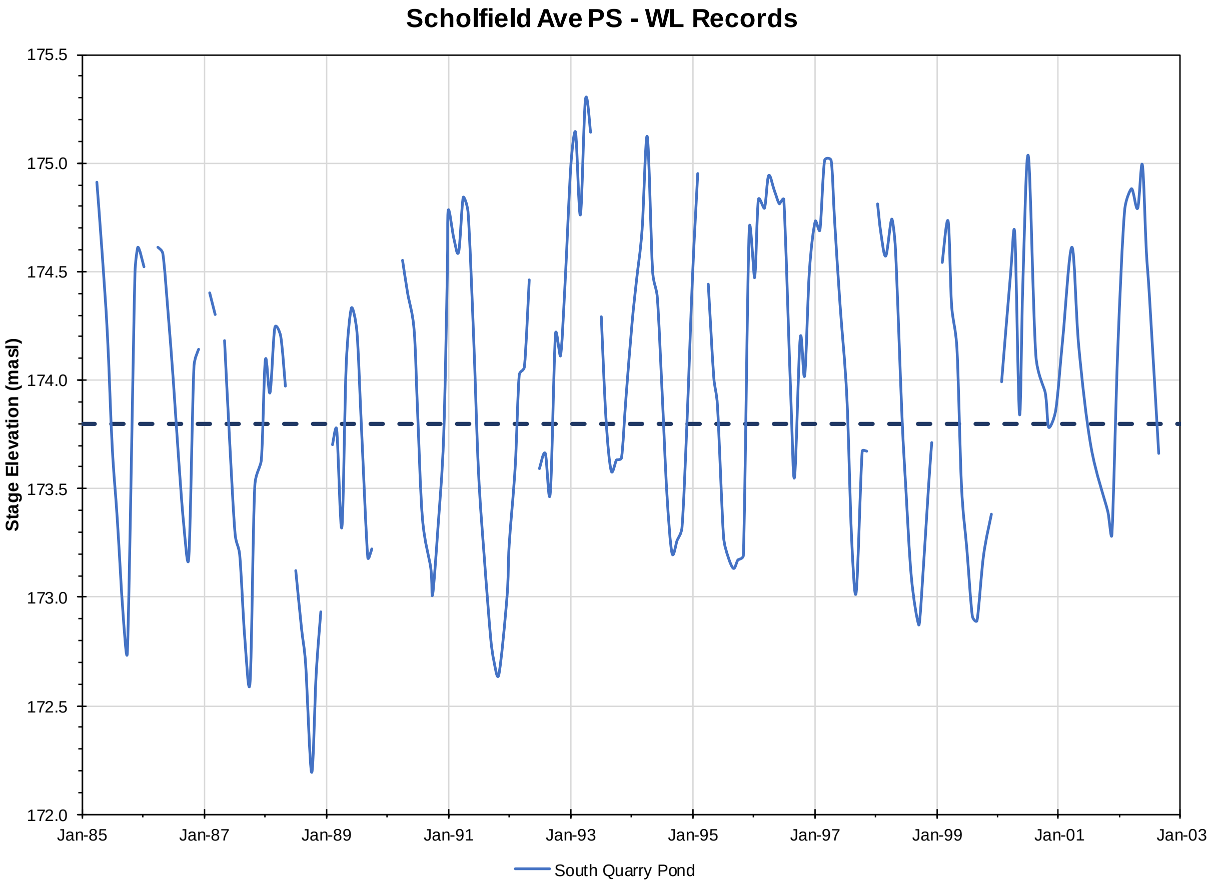
H.5.3.2 OTHER HIGH-QUALITY OBSERVATION DATA

High-quality autumn water level data (where available) from monitoring wells at other sites within the study area were imported to Groundwater Vistas as head targets, designated as Group 2. Data from a total of twenty-eight (28) off-site monitoring wells is included in Group 2.

Where possible, autumn water level data from off-site nested monitoring wells were also used to calculate vertical hydraulic gradients between the various model layers. A total of fourteen (14) off-site head difference targets were imported to Groundwater Vistas and added to Group 4.

As noted previously in **Section H.4.3.3**, a representative flow rate of 80 m^3/day was chosen as the calibration target for the Quarry Lakes sump and imported to Groundwater Vistas as Group 6. A representative stage elevation of 172.7 masl for the Quarry Lakes ponds was imported to Groundwater Vistas as Group 9. For the Scholfield Avenue pumping station, a representative flow rate of 1,950 m^3/day was chosen as the calibration target and imported to Groundwater Vistas as Group 7. Finally, a representative flow rate of 650 m^3/day was chosen as the calibration target for the Townline Tunnel dewatering sump and imported to Groundwater Vistas as Group 8. Separate groups were used for these flux targets to provide greater control during the automated calibration process.

The hydrogeological assessment completed for the Scholfield Avenue pumping station (Coffey Geotechnics Inc., 2012) also includes groundwater elevation data for a private domestic supply well at 658 Main Street West in Port Colborne (formerly Young's Auto) for the period between 1985 and 2002. A representative autumn water level of 178.4 masl was assigned as a calibration target for this private well and added to the Group 2 targets. Stage elevation data were also provided for the Cement Plant Ponds south quarry pond to the east of the Site (sometimes referred to as the Horseshoe Lakes ponds). Stage elevation data are available from the period between 1985 and 2002. The data are plotted in the figure below. A representative stage elevation of 173.8 masl was chosen for the south quarry pond and imported to Groundwater Vistas as Group 10.



H.5.3.3 WATER WELL RECORDS

Lower-quality water level data from MECP water well records within the study area were imported to Groundwater Vistas as head targets, designated as Group 3. The water well record data was parsed to remove data of low reliability. A total of 305 water levels were included in Group 3.

It is noted that the MECP water well record target data represent a single “snapshot” in time. Calculated residuals of up to ± 5 m between the model simulated head and water level reported on the record are not unexpected. The reasons for such a relatively large discrepancy include, among others, (1) seasonal variance at the well during the period in which the level was measured, (2) incomplete recovery after the well was installed, (3) poor (or no) elevation control on the data and (4) inaccuracy in the reported well location. As such, a weighting of 0.5 was used throughout the calibration process to calculate the residuals. The weighted residuals are used in the residual plots in **Section H.5.4** and model statistics in **Section H.5.5** below.

H.5.4 CALIBRATION RESULTS

H.5.4.1 CALCULATED RESIDUALS

Group 1 Head Targets

The Group 1 (Site data) head targets and calculated residuals from the calibrated baseline model are summarized in **Table H.5.1** below.

Table H.5.1 Group 1 Head Targets Calculated Residuals

No.	Description	Easting	Northing	Model Layer	Head Target			Calculated Residual (m)
					October Baseline Data		Simulated (masl)	
					Mean (masl)	Standard Deviation (m)		
1	LQ_GLL-1	639543	4750253	5	173.4	0.3	171.8	1.6
2	LQ_1-III	639543	4750253	8	171.3	0.2	170.1	1.2
3	LQ_1-II	639543	4750253	9	172.5	<0.1	170.1	2.4
4	LQ_1-I	639543	4750253	10	170.9	0.1	170.1	0.8
5	LQ_GLL-3	639503	4751187	8	169.1	0.5	167.8	1.3
6	LQ_4-III	638316	4750276	8	167.2	<0.1	166.3	0.9
7	LQ_4-II	638316	4750276	9	167.3	<0.1	166.2	1.1
8	LQ_GLL-5	638214	4751282	8	167.1	0.4	165.2	1.9
9	LQ_5-II	638214	4751282	9	167.4	0.2	165.2	2.2
10	LQ_5-I	638214	4751282	10	167.4	0.2	165.2	2.2
11	LQ_GLL-6	637501	4750899	8	173.1	0.1	167.6	5.5
12	LQ_6-II	637501	4750899	9	170.9	0.4	167.6	3.3
13	LQ_GLL-7	637884	4750924	5	178.9	0.5	180.9	-2.0
14	LQ_GLL-8	637926	4750549	8	168.3	0.3	167.3	1.0
15	LQ_GLL-9	637500	4750412	5	181.9	0.4	178.8	3.1
16	LQ_9-III	637500	4750412	8	170.9	0.3	168.7	2.2
17	LQ_9-II	637500	4750412	9	170.5	0.3	168.7	1.8
18	LQ_GLL-10	637506	4750213	5	180.0	0.3	177.6	2.4
19	LQ_10-III	637506	4750213	8	172.0	0.3	169.5	2.5
20	LQ_10-II	637506	4750213	9	171.9	0.3	169.5	2.4

21	LQ_10-I	637506	4750213	10	171.9	0.3	169.5	2.4
22	LQ_11-II	639947	4750822	5	173.5	0.2	174.2	-0.7
23	LQ_11-I	639947	4750822	8	167.3	0.3	170.4	-3.1
24	LQ_11-1	639947	4750822	9	167.3	0.2	170.4	-3.1
25	LQ_12-III	637913	4750138	8	172.5	0.2	169.2	3.3
26	LQ_20246_YR	639910	4751231	5	177.8	1.5	176.9	0.9

Group 2 Head Targets

The Group 2 (other site high-quality data) head targets and calculated residuals from the calibrated baseline model are summarized in **Table H.5.2** below.

Table H.5.2 Group 2 Head Targets Calculated Residuals

No.	Description	Location	Easting	Northing	Model Layer	Head Target (masl)		Calculated Residual (m)
						Representative Autumn Groundwater Elevation	Simulated	
1	Rb_1-IR	Reeb Quarry	638431	4749636	7	173.5	172.1	1.4
2	Rb_1-III		638431	4749636	8	175.0	172.1	2.9
3	Rb_2-I		638912	4749615	4	175.1	172.1	3.0
4	Rb_2-II		638912	4749615	5	174.7	172.0	2.7
5	Rb_2-III		638912	4749615	7	173.1	172.0	1.1
6	Rb_3-II		639173	4749929	5	175.3	171.1	4.2
7	Rb_3-IV		639173	4749929	8	174.1	170.7	3.4
8	Rb_4-III		639558	4749647	8	174.7	172.1	2.6
9	Rb_5-I		639570	4750151	5	175.1	171.2	3.9
10	Rb_5-II		639570	4750151	7	175.1	170.8	4.3
11	Rb_5-IIIR		639570	4750151	8	174.8	170.8	4.0
12	Rb_5-IV		639570	4750151	10	175.1	170.8	4.3
13	Rb_6-I		638558	4750127	7	173.8	167.5	6.3
14	Rb_6-IV		638558	4750127	10	173.2	167.4	5.8
15	SRLF_13-5	Station Road Landfill Site	632486	4748589	2	177.5	180.2	-2.7
16	SRLF_13-14		632486	4748589	9	174.3	179.6	-5.3
17	SRLF_14-5		632187	4749202	2	179.3	179.0	0.3
18	SRLF_14-11		632187	4749202	9	178.4	178.2	0.2

19	SRLF_15-6		632575	4749037	2	177.8	179.8	-2.0
20	SRLF_15-11		632575	4749037	9	178.0	178.7	-0.7
21	ESLF_1-11	Elm Street Landfill Site	641931	4754331	2	172.3	172.2	0.1
22	ESLF_1-39		641931	4754331	10	170.4	168.6	1.8
23	ESLF_2-14		642277	4754022	2	174.3	171.6	2.7
24	ESLF_2-47		642277	4754022	10	169.8	168.5	1.3
25	ESLF_3-12		641961	4753721	2	173.7	171.9	1.8
26	ESLF_3-42		641961	4753721	10	170.7	168.8	1.9
27	ESLF_7-11		642256	4754346	2	173.3	172.1	1.2
28	ESLF_7-39		642256	4754346	10	169.6	168.4	1.2
29	Young's Auto LT Avg		641154	4750343	4	178.4	173.0	5.4

Group 3 Head Targets

Due to the large number of targets in Group 3 (water well record data), the summary of residuals is not included in the report. Only the calibration statistics are presented below in **Section H.5.4.2**.

Group 4 Head Difference Targets

The Group 4 head difference targets and calculated residuals from the calibrated baseline model are summarized in **Table H.5.3** below.

Table H.5.3 Group 4 Head Difference Targets Calculated Residuals

No.	Description	Location	Easting	Northing	Model Layers	Head Difference Target (m)		Residual (m)
						Observed	Simulated	
1	LQ_GLL-1/1-III	Site	639543	4750253	5 / 8	2.1	1.7	0.4
2	LQ_GLL-1/1-II		639543	4750253	5 / 9	0.9	1.7	-0.8
3	LQ_GLL-1/1-I		639543	4750253	5 / 10	2.5	1.7	0.8
4	LQ_1-III/II		639543	4750253	8 / 9	-1.2	0.0	-1.2
5	LQ_1-III/I		639543	4750253	8 / 10	0.4	0.0	0.4
6	LQ_1-II/I		639543	4750253	9 / 10	1.6	0.0	1.6
7	LQ_4-III/II		638316	4750276	8 / 9	-0.1	0.0	-0.1
8	LQ_GLL-5/5-II		638214	4751282	8 / 9	-0.3	0.0	-0.3
9	LQ_GLL-5/5-I		638214	4751282	8 / 10	-0.3	0.0	-0.3
10	LQ_5-II/I		638214	4751282	9 / 10	0.0	0.0	0.0
11	LQ_GLL-6/6-II		637501	4750899	8 / 9	2.2	0.0	2.2

12	LQ_GLL-9/9-III		637500	4750412	5 / 8	11.0	10.1	0.9
13	LQ_GLL-9/9-II		637500	4750412	5 / 9	11.4	10.1	1.3
14	LQ_9-III/II		637500	4750412	8 / 9	0.4	0.0	0.4
15	LQ_GLL-10/10-III		637506	4750213	5 / 8	8.0	8.1	-0.1
16	LQ_GLL-10/10-II		637506	4750213	5 / 9	8.1	8.1	0.0
17	LQ_GLL-10/10-I		637506	4750213	5 / 10	8.1	8.1	0.0
18	LQ_10-III/II		637506	4750213	8 / 9	0.1	0.0	0.1
19	LQ_10-III/I		637506	4750213	8 / 10	0.1	0.0	0.1
20	LQ_10-II/		637506	4750213	9 / 10	0.0	0.0	0.0
21	LQ_11-II/I		639947	4750822	5 / 8	6.2	3.8	2.4
22	LQ_11-II/1		639947	4750822	5 / 9	6.2	3.8	2.4
23	LQ_11-I/1		639947	4750822	8 / 9	0.0	0.0	0.0
24	Rb_1-IR/III	Reeb Quarry	638431	4749636	7 / 8	-1.5	0.0	-1.5
25	Rb_2-I/II		638912	4749615	4 / 5	0.4	0.0	0.4
26	Rb_2-I/III		638912	4749615	4 / 7	2.0	0.1	1.9
27	Rb_2-II/III		638912	4749615	5 / 7	1.6	0.0	1.6
28	Rb_3-II/IV		639173	4749929	5 / 8	1.2	0.4	0.8
29	Rb_5-I/IIIR		639570	4750151	5 / 8	0.3	0.4	-0.1
30	Rb_6-I/IV		638558	4750127	7 / 10	0.6	0.0	0.6
31	SRLF_13-5/14	Station Road Landfill Site	632486	4748589	2 / 9	3.2	0.6	2.6
32	SRLF_14-5/11		632187	4749202	2 / 9	0.9	0.8	0.1
33	SRLF_15-6/11		632575	4749037	2 / 9	-0.2	1.0	-1.2
34	ESLF_1-11/39	Elm Street Landfill Site	641931	4754331	2 / 10	1.9	3.6	-1.7
35	ESLF_2-14/47		642277	4754022	2 / 10	4.5	3.1	1.4
36	ESLF_3-12/42		641961	4753721	2 / 10	3.0	3.1	-0.1
37	ESLF_7-11/39		642256	4754346	2 / 10	3.7	3.7	0.0

Other Target Groups

The Group 5 to 8 flux targets for the calibrated baseline model are summarized in **Table H.5.4** below.

Table H.5.4 Flux Targets

Group	Description	Drain Boundary Reach No.	Flux Target (m^3/day)	
			Observed	Simulated
5	Existing Law Quarry Sump	4	4,200	4,200
6	Quarry Lakes Sump	5	80	81
7	Scholfield Avenue Pumping Station	6	1,950	1,950
8	Townline Tunnel Dewatering Sump	7	650	650

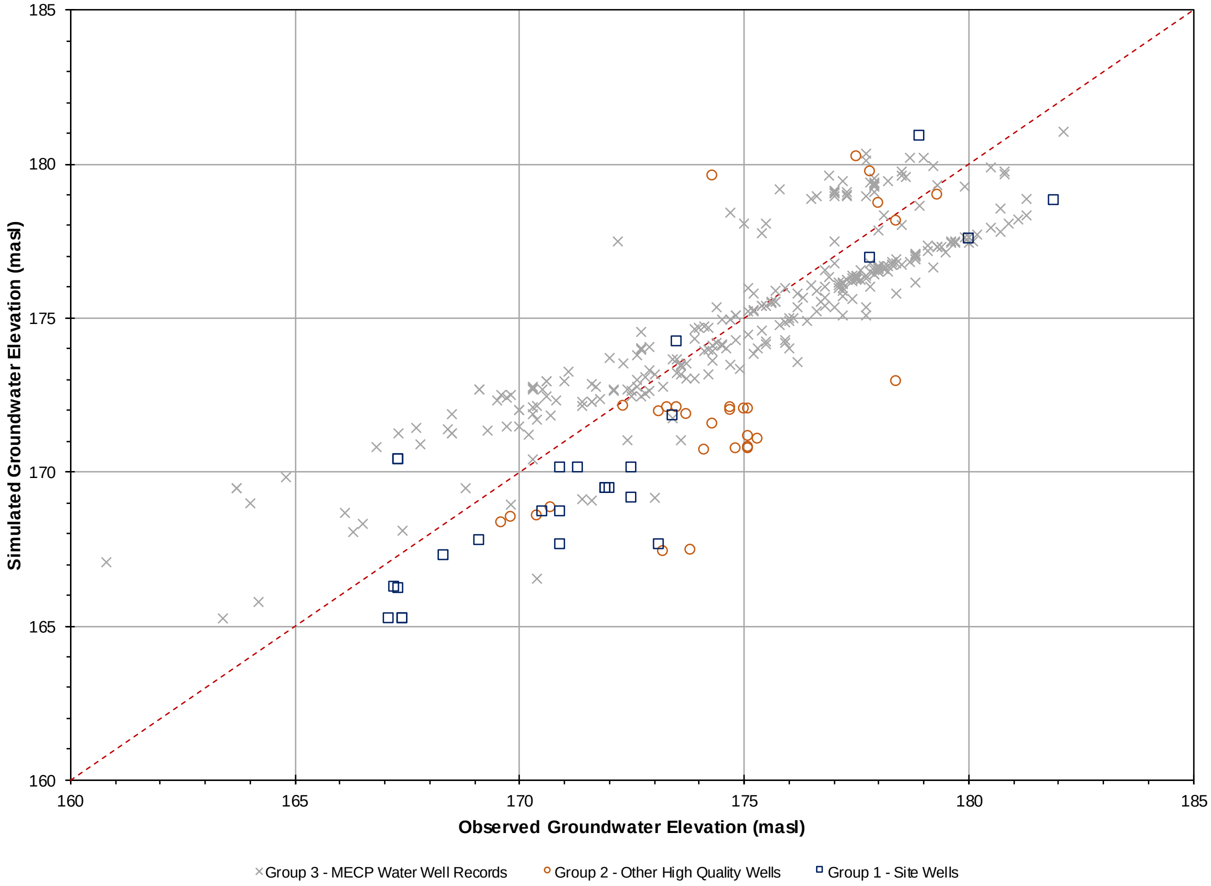
The Group 9 and 10 pond head targets for the calibrated baseline model are summarized in **Table H.5.5** below.

Table H.5.5 Pond Head Targets

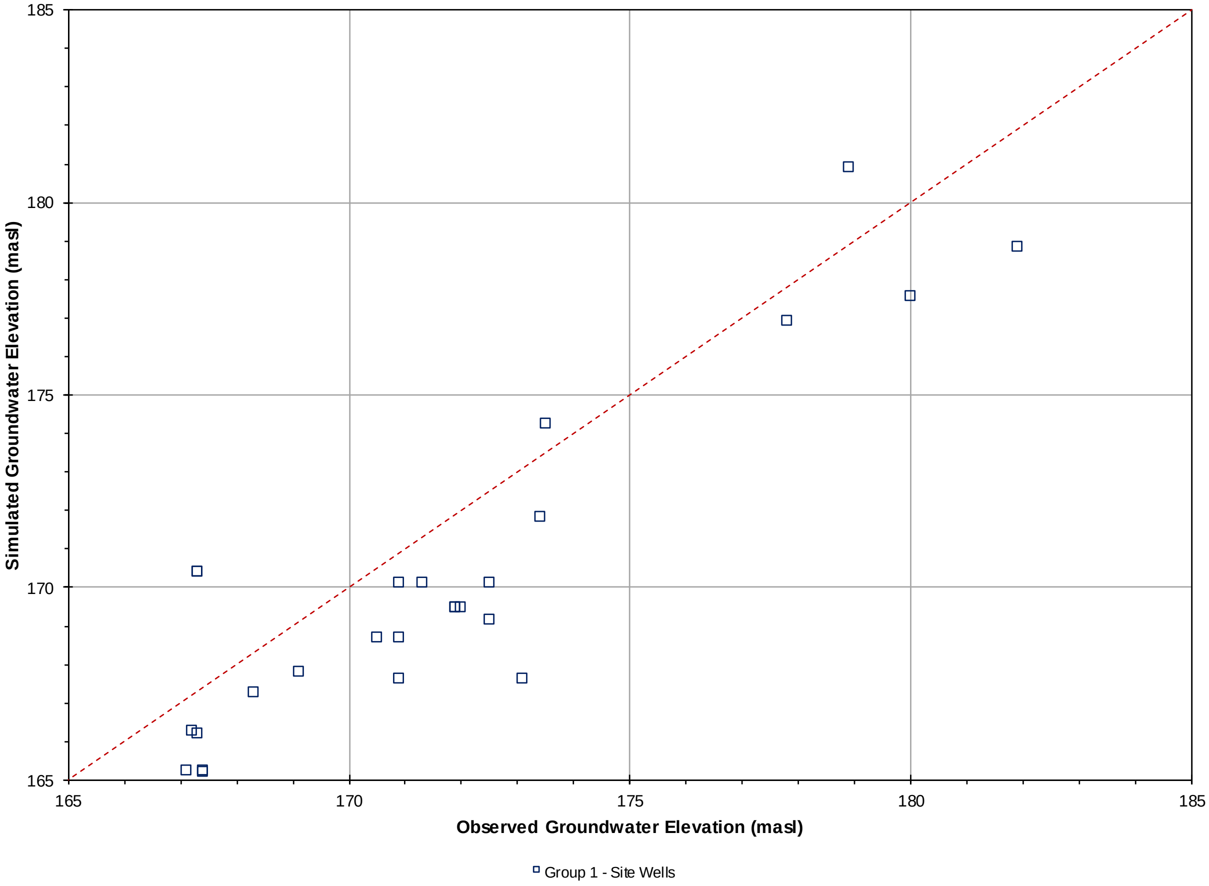
Group	Description	Head Target (masl)		Calculated Residual (m)
		Observed	Simulated	
9	Quarry Lakes Ponds	172.7	172.7	0.0
10	Cement Plant Lakes South Quarry Pond	173.8	172.8	1.0

H.5.4.2 DIAGNOSTIC RESIDUAL PLOTS

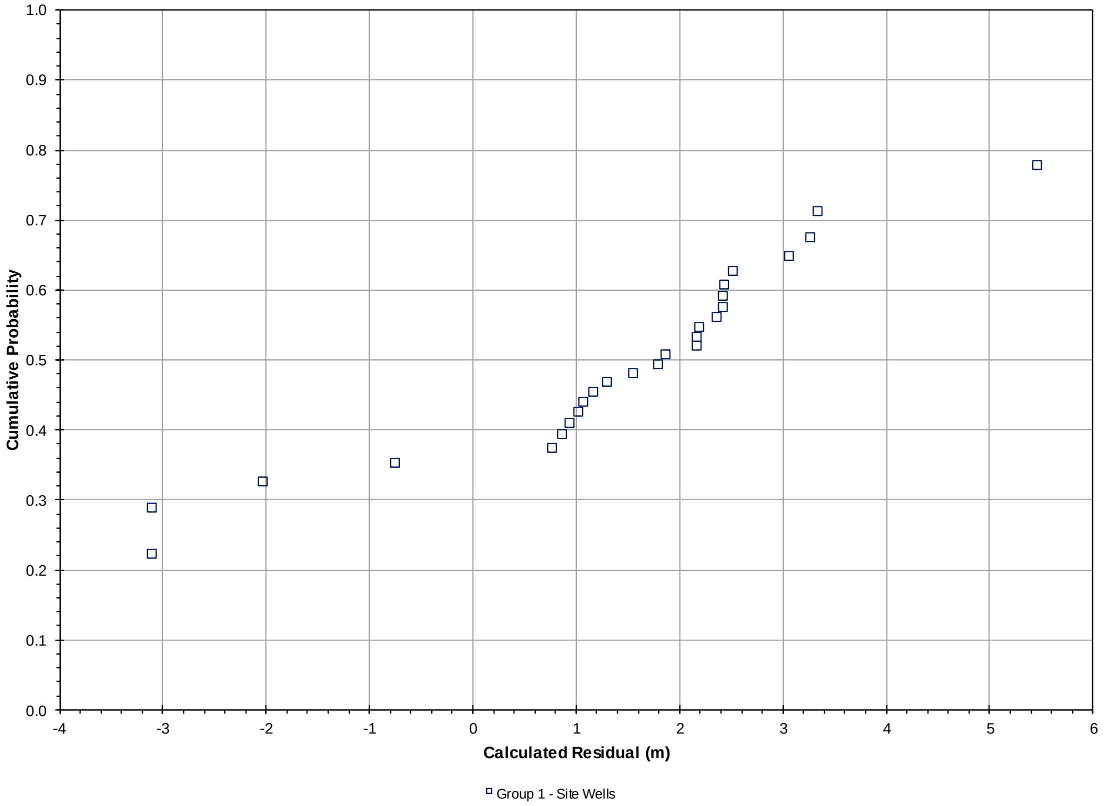
A scatterplot of the weighted calculated residuals for the calibrated baseline model is shown below, with different symbols representing the different head target groups discussed above.

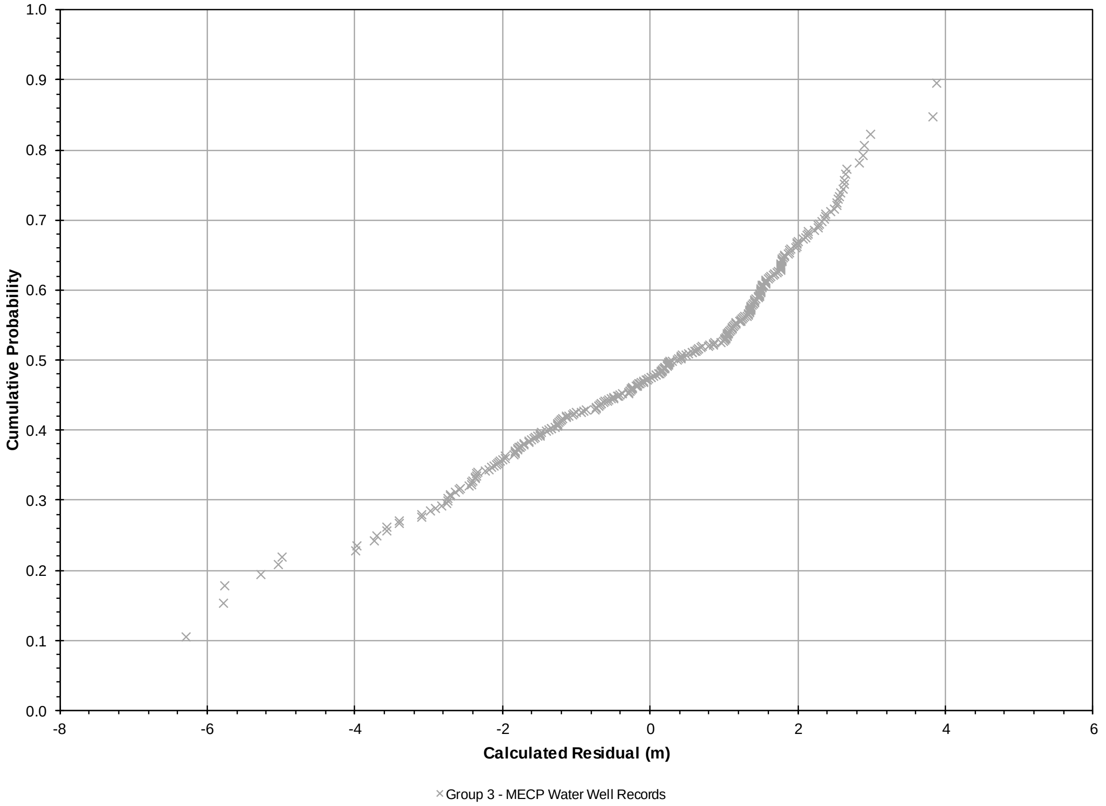


A scatterplot of the calculated residuals for the calibrated baseline model for the Site well data only is shown below.



Cumulative probability plots for Group 1 (Site data) and Group 3 (water well record data) for the calibrated baseline model are provided below.


1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Cumulative Probability
-4
-3
-2
-1
0
1
2
3
4
5
6
Calculated Residual (m)
Group 1 - Site Wells


1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Cumulative Probability
-8
-6
-4
-2
0
2
4
6
Calculated Residual (m)
Group 3 - MECP Water Well Records

The spatial distribution of calculated residuals from the calibrated baseline model is shown in **Figure H-7** (shallow bedrock aquifer, model layers 4 through 6) and **Figure H-8** (deeper bedrock units, model layers 8 through 10).

H.5.4.3 CALIBRATION STATISTICS

The weighted calibration statistics for the various target groups in the calibrated baseline model are summarized in **Table H.5.6** below.

Table H.5.6 Weighted Calibration Statistics

Statistical Measurement	Unit	Head Targets				Head Difference Targets
		Overall	Group 1	Group 2	Group 3	Group 4
Number of Observations	**--**	362	26	29	305	37
Min Residual	**m**	-6.3	-3.1	-5.3	-6.3	-1.7
Max Residual	**m**	6.3	5.5	6.3	3.9	2.6
Residual Mean	**m**	0.3	1.4	2.0	0.1	0.4
Absolute Residual Mean	**m**	1.6	2.1	2.7	1.5	0.8
SSE	**m^2**	1,500	150	300	1,000	50
RMSE	**m**	2.0	2.4	3.2	1.8	1.1
Range of Observations	**m**	21.3	14.8	9.7	21.3	12.9
NRMS	**%**	**9.5**	**16.0**	**33.1**	**8.6**	**8.7**

H.5.4.4 MASS BALANCE ERROR

The mass balance for the calibrated baseline model is shown in **Table H.5.7** below.

Table H.5.7 Baseline Calibrated Model Mass Balance

Boundary Type	Mass Balance (m^3/day)		
	Inflows	Outflows	Outflow – Inflow
Recharge (RCH)	4,328	0	-4,328
Constant Head (CHD)	1,226	47	-1,179
General Head (GHB)	1,379	224	1,155
River (RIV)	345	129	-216
Drain (DRN)	0	6,877	6,877
TOTAL	**7,278**	**7,277**	**1.0**
Discrepancy (%)			**-0.003**

H.5.5 CALIBRATED BASELINE MODEL SENSITIVITY ANALYSIS

PEST was used to complete a sensitivity analysis to estimate the calibrated baseline model parameter correlation and sensitivity (i.e., NOPTMAX set to -1).

Parameter Correlation

Parameter correlation coefficients (PCCs) are used to evaluate whether parameter values can be estimated uniquely and are calculated for each parameter pair. PCCs can be expressed as the covariance of a parameter pair divided by the product of the square roots of the variances of the parameters. The calibrated baseline model PCC matrix for horizontal hydraulic conductivity is shown in **Table H.5.8**.

Generally, a correlation coefficient with an absolute value greater than about 0.95 indicates that the two parameters involved likely cannot be estimated uniquely with the available data.

Composite Scaled Sensitivity

Composite scaled sensitivity (CSS) values are used to evaluate the overall sensitivity of a parameter and are calculated as the sum of the square roots of the dimensionless scaled sensitivity (DSS) divided by the number of observations. The DSS is the partial derivative of the simulated observation with respect to the parameter, multiplied by the square root of the weight assigned to the observation. DSS is used to evaluate the importance of an observation relative to the estimation of a single parameter.

The CSS typically is a good measure of the information that observations contribute to the estimation of parameters. The relative size of CSS values can be used to assess whether additional parameters can be estimated. A relatively large CSS value indicates that observations contain enough information to represent that aspect of the system. A relatively small CSS value (about two orders of magnitude less than the largest CSS value) indicates that the observations provide insufficient information with which to estimate the parameter. CSS values are useful in identifying those parameters which may be degrading, or are likely to degrade, the performance of the parameter estimation process through lack of sensitivity to model outcomes.

It is noted that some hydrogeological model parameters, such as hydraulic conductivity, are log transformed in PEST for easier processing. Therefore, sensitivity is expressed with respect to the log of the parameter. The relative composite sensitivity of a log-transformed parameter is determined by multiplying the composite sensitivity of that parameter by the absolute log of the value of that parameter. The CSS values for model parameters included in the calibration process are shown in **Table H.5.9** below.

Table H.5.8 Horizontal Hydraulic Conductivity Correlation Coefficients

		Horizontal Hydraulic Conductivity Zone													Recharge Zone 1 – Glaciolacustrine Clay
		1	2	3	4	5	6	7	8	9	10	11	12	15	
		Weathered Salina Fm.	*Unweathered* Salina Fm.	Bertie Fm. – Oatka Mb.	Bertie Fm. – Falkirk Mb.	Upper Bertie Fm. Aquitard	Shallow Bedrock Aquifer	Wentworth Till	Overburden Aquitard	Weathered Glaciolacustrine Clay	Wainfleet Bog Deposits	Sand Deposits	Manmade Deposits	Onondaga Escarpment Weathered Zone	
Rch. Zn	**3**	0.40	0.40	0.54	-0.55	-0.54	0.16	-0.28	0.43	-0.16	-0.52	-0.88	0.44	0.08	0.41
	1	0.33	-0.17	0.33	-0.40	-0.15	-0.18	-0.15	0.71	0.05	-0.85	-0.32	0.86	0.40	
Horizontal Hydraulic Conductivity Zone	**15**	-0.48	-0.87	0.62	-0.66	-0.34	-0.90	0.28	0.35	-0.20	-0.30	0.01	0.29		
	12	0.31	-0.06	0.26	-0.35	-0.10	-0.07	-0.26	0.74	0.01	-0.83	-0.34			
	11	-0.45	-0.44	-0.55	0.53	0.66	-0.22	0.31	-0.22	-0.19	0.35				
	10	-0.33	0.04	-0.29	0.40	0.08	0.09	0.27	-0.78	0.01					
	9	0.27	0.13	-0.07	0.13	-0.08	0.04	-0.19	-0.29						
	8	0.24	-0.13	0.28	-0.37	-0.08	-0.11	-0.19							
	7	-0.69	-0.37	0.08	-0.10	0.03	-0.34								
	6	0.54	0.91	-0.36	0.38	0.12									
	5	-0.02	0.05	-0.88	0.69										
	4	0.19	0.34	-0.94											
	3	-0.16	-0.32												
	2	0.60													

Table H.5.9 Composite Scaled Sensitivies for Calibrated Parameters

			All Targets	Group 1 Targets Only
Recharge Zone 1 – Glaciolacustrine Clay			0.28	0.03
Recharge Zone 3 – Bedrock Outcrops			3.82	0.19
Horizontal Hydraulic Conductivity Zone	**1**	***Weathered* Salina Fm.**	0.24	0.03
	2	***Unweathered* Salina Fm.**	0.42	0.02
	3	**Bertie Fm. – Oatka Mb.**	3.98	0.27
	4	**Bertie Fm. – Falkirk Mb.**	0.38	0.04
	5	**Upper Bertie Fm. Aquitard**	3.66	0.11
	6	**Shallow Bedrock Aquifer**	5.93	0.11
	7	**Wentworth Till**	0.14	0.04
	8	**Overburden Aquitard**	0.10	0.02
	9	**Weathered Glaciolacustrine Clay**	0.11	0.01
	10	**Wainfleet Bog Deposits**	0.01	0.01
	11	**Sand Deposits**	1.76	0.02
	12	**Manmade Deposits**	0.02	0.001
	15	**Onondaga Escarpment Weathered Zone**	0.18	0.03

H.5.6 CALIBRATION SUMMARY

A number of calibration targets and statistics related to different aspects of the conceptual understanding of the study area have been provided above. The objective of the calibration process for this study was to achieve a reasonable balance of these various targets.

The target residuals for each of the target groups presented in **Section H.5.4.1** are summarized by the calibration statistics given in **Table H.5.6.** The overall statistics for the head targets show that the model NRMS of 9.5% is within the industry accepted value of 10%. The residual mean error of 0.3 m indicates that there is a reasonable balance of over- and under-prediction of groundwater elevation within the model. The NRMS for the individual groups of targets is higher than the overall model NRMS, which demonstrates the difficulty with fitting a deliberately simplified regional model to different collections of target data. In this case, it was more desirable to obtain a satisfactory balance between over- and under-prediction in the simulated groundwater elevation. Of note, the RMSE for the Site well head targets (Group 1) is approximately 2.4 m, which is well below the standard deviation of the October baseline water level data (approximately 5.3 m).

Flux targets (Group 6) were also considered in the model calibration, as summarized in **Table H.5.4**. As shown in the table, the simulated flux values from the calibrated baseline model are an excellent match to the observed flux targets.

Target residuals were plotted on scatterplots as shown in **Section H.5.4.2**. If a model were perfectly calibrated to fit the observation data, all of the points on the scatterplot would fall along the 45º line (i.e., the dotted red line on the plot). The scatterplot of all of the head targets (Groups 1 through 3) indicates that there is a reasonable balance between over- and underprediction in the calibrated baseline model. The scatterplot for the Site wells (Group 1) only indicates that the residuals follow the trend of the 45º line.

The spatial distributions of head target residuals are shown in **Figures H-7 and H-8** for the shallow bedrock aquifer (model layers 4 through 6) and the deeper bedrock units (model layers 8 through 10), respectively. The simulated groundwater elevation contours are also shown. Model over- and under-predictions generally appear to be randomly dispersed throughout the active model domain and are not spatially correlated.

Cumulative probability plots for the Site well head targets (Group 1) and MECP water well record data (Group 3) are provided in **Section H.5.4.2**. In practice, error is inherent in all numerical models due to various factors. However, it is desirable that the model error is not biased to one extreme. Cumulative probability plots are an indication of whether the error in the model simulated groundwater elevation is randomly distributed. If this is the case, all of the calibration targets tend to plot along a straight line. For this study, the majority of head target residuals in the cumulative probability plots for these two groups generally plot along a straight line, which indicates that the model error is generally randomly distributed.

At the two extremes of the cumulative probability plots, outlier targets (i.e., targets with extreme residual values which a reasonably calibrated model may not be capable of reproducing) tend to plot off of the straight line. For the plot of Group 1 targets, the residual for GLL-6 (approximately +5.5 m) is the largest absolute residual for the Site well data, and it plots off of the upper end of the straight line. The baseline data suggest that the groundwater elevations at this well have not been impacted by the existing quarry dewatering; however, in the model a degree of dewatering impact is simulated. This is a conservative (i.e., over-prediction) of drawdown at this well location. For the plot of Group 3 targets, calculated residuals of less than -4 m and more than +3.5 m deviate marginally from the straight line. This is not unexpected, given the potential error associated with MECP water well record data previously discussed in **Section H.5.3.3** above. A reasonably calibrated model would be expected to have difficulty reproducing anomalous head targets. The residual for well record no. 7179584 (approximately -6.3 m) is the largest absolute residual for the MECP water well record data, and it plots off of the lower end of the straight line. This well is situated along the Lake Erie shore; as such, the constant head boundary used to simulate the lake in the model may be the cause of the error in predicted groundwater elevation. The remaining 5 water well record residuals which plot off of the lower end of the straight line appear to have no obvious explanation for the elevated residuals calculated for these locations.

The mass balance error for the calibrated baseline model is approximately 0.003% as shown in **Table H.5.7**, which indicates that there are no major mass-balance issues in the calibrated model.

A sensitivity analysis was completed on the calibrated baseline model and included the 15 calibrated parameters outlined in **Section H.5.2**. The purpose of the sensitivity analysis was to identify parameters which are highly correlated (i.e., different combinations of the correlated parameters may result in similar model predictions), and to quantify the sensitivity of the different parameters to the model calibration. **Table H.5.8** indicates that in general, most model parameters are not correlated to a high degree. The exceptions are the horizontal hydraulic conductivities of zone 6 (shallow bedrock aquifer) and zone 15 (Onondaga Escarpment weathered zone), zone 6 and zone 2 (unweathered Salina formation) and zone 3 (Bertie Fm, Oatka mb) and zone 4 (Bertie Fm, Falkirk mb). For these zones, different combinations of these pairs of parameter values may result in similar model predictions (i.e., a non-unique solution).

Because of this, care was taken to ensure the calibration represents physically realistic values for these zones following the automated calibration process.

Parameter sensitivities for the overall model calibration and the model calibration to Site well data only (Group 1 head targets) are shown in **Table H.5.9**. The most sensitive parameters for the overall model calibration are the horizontal hydraulic conductivities of the shallow bedrock aquifer (zone 6), the Oatka member of the Bertie formation (zone 3), the upper Bertie formation aquitard (zone 5) and the recharge to the bedrock outcrops (recharge zone 3). For the Site wells, the most sensitive parameters are the horizontal hydraulic conductivities of the Oatka member of the Bertie formation (zone 3), shallow bedrock aquifer (zone 6) and upper Bertie formation aquitard (zone 5) and the recharge to the bedrock outcrops (recharge zone 3).

For both target groups, the horizontal hydraulic conductivities of the weathered and unweathered Salina formation (zones 1 and 2), the Wainfleet Bog deposits (zone 10) and manmade deposits (zone 12) were relatively insensitive to the model calibration.

Like many fractured-bedrock settings in southern Ontario, the hydrogeological setting of the study area is complex. The numerical model is a deliberate simplification of a complex natural system and has been calibrated to achieve a best-fit with the available data at the time this report was published. The objective of the calibration process is not to capture every detail of the hydrogeological setting and match every observation. Instead, the goal is to achieve a reasonable balance between over- and under-prediction of the simulated groundwater elevations. In practice, all models have some degree of error; however, ensuring that model error is randomly distributed helps to reduce the possibility of bias in the model predictions.

The calibrated baseline model represents the best-fit to the available data, with a reasonable balance between over- and under-prediction of the simulated groundwater elevations and a random distribution of error. The parameters that are most sensitive to the model calibration are physically realistic values based on the available data. Parameters which are relatively insensitive and cannot be inferred through the model calibration process have been assigned values which are physically realistic and within the ranges of published data. As such, the calibrated baseline model can be used to simulate the predicted effects of the proposed quarry extension with a high degree of confidence in the results.

H.6 CALIBRATED BASELINE MODEL

The baseline Site water balance is shown in **Table H.6.1** below. Flow terms are shown both in the model units (m^3/day), as well as values normalized by the Site area (approximately 0.8 km^2) in mm/year.

Table H.6.1 Site Water Balance – Baseline Conditions

Boundary Type	Inflows		Outflows		Outflow – Inflow (m^3/day)
	(m^3/day)	(mm/year)	(m^3/day)	(mm/year)	
Recharge (RCH)	114.33	52.16	0	0	-114.33
River (RIV)	8.56	3.91	0.02	<0.01	-8.54
Lateral GW Flow	904.76	412.80	1,027.64	468.86	122.88
TOTAL	**1,027.65**	**468.87**	**1,027.66**	**468.87**	**<0.01**
Discrepancy (%)					**<0.001**

The baseline water balance for the Site indicates that about 10% of the total inflow to the Site originates as recharge, under 1% originates as discharge from the Wainfleet Bog deposits (i.e., river boundaries) with the remaining ~90% originating as lateral groundwater inflow from the surrounding areas. Less than 0.1% of the total outflow from the Site discharges to the Wainfleet Bog deposits, equivalent to a rate of less than 0.01 mm/year, with the remainder discharging as lateral groundwater outflow to the surrounding areas. There is an overall net outflow of groundwater from the Site to the surrounding areas, at a rate of approximately 123 m^3/day, or 56 mm/year.

The water balance for the Biederman Drain subwatershed for the calibrated baseline model is shown in **Table H.6.2** below. Flow terms are shown both in the model units (m^3/day), as well as values normalized by the subwatershed area (approximately 18.2 km^2) in mm/year.

Table H.6.2 Biederman Drain Subwatershed Water Balance – Baseline Conditions

Boundary Type	Inflows		Outflows		Outflow – Inflow (m^3/day)
	(m^3/day)	(mm/year)	(m^3/day)	(mm/year)	
Recharge (RCH)	368.3	7.4	0	0	-368.3
River (RIV)	146.8	2.9	21.9	0.4	-124.9
Drain (DRN)	0	0	97.8	2.0	97.8
Lateral GW Flow	1,995.0	40.0	2,390.4	47.9	395.4
TOTAL	**2,510.1**	**50.3**	**2,510.1**	**50.3**	**0.0**
Discrepancy (%)					**-0.002**

The baseline water balance for the Biederman Drain subwatershed indicates that approximately 15% of the total inflow to the subwatershed originates as recharge, and a smaller contribution of approximately 6% from the Wainfleet Bog deposits. Approximately 0.9% of the total outflow from the subwatershed discharges to the Wainfleet Bog deposits, equivalent to a rate of 0.4 mm/year. An additional 3.9% of the total outflow discharges to the surficial watercourses (i.e., drain boundaries), equivalent to a rate of 2.0 mm/year.

Finally, it is noted that there is an overall net outflow of groundwater from the subwatershed to the surrounding areas, at a rate of approximately 395 m^3/day, or 8 mm/year.

Under baseline autumn conditions, the simulated stage in the Quarry Lakes ponds south of the Site is approximately 172.7 masl, with an average sump discharge rate of approximately 81 m^3/day. These values are nearly identical to the calibration targets outlined in **Section H.5.3.2**. The simulated stage elevation in the Cement Plant Lakes south quarry pond southeast of the Site is approximately 172.8 masl, which is about 1 m lower than the calibration target. The simulated sump flow rates for the baseline Law Quarry excavation footprint, Scholfield Avenue pumping station and Townline Tunnel dewatering sump also closely match their calibration targets as shown in **Table H.5.4**.

H.7 FULL DEVELOPMENT MODEL

Dewatering of the proposed quarry extension is required to maintain dry working conditions in the excavation. Groundwater will percolate through fractures in the quarry working face and drain by gravity through an internal network of ditches to the quarry sump. Direct precipitation on the quarry floor (less evaporation) will also accumulate in the sump. A dewatering pump will operate within the sump to remove excess water as needed, with discharge to the Eagle Marsh Drain at the discharge location for the existing quarry.

The additional dewatering of the proposed extension described above will manifest as an additional ‘stress’ to the baseline subwatershed water balance. The shallow bedrock aquifer and deeper bedrock units will be impacted as a result of the additional stress, and a cone of depression will expand radially from the quarry extension to reach a new equilibrium. The ultimate size of the cone of depression (i.e., the radius of influence) and the annual dewatering rate are dependant on the properties of the hydrostratigraphic layers present within the study area. The cone of depression will expand such that the total inflow over the radius of influence will be equal to the increase in the rate of groundwater withdrawal by the quarry dewatering sump.

Numerical groundwater modeling was completed to predict the long-term steady-state effects of the proposed quarry extension dewatering at full development. The calibrated baseline model was adapted to simulate full development of the east quarry extension to determine the drawdown as a result of dewatering of the previously licensed quarry. This intermediate model was then adapted to simulate full development of the proposed west extension to determine the drawdown over and above that of the existing licensed areas. Adaptation of the calibrated baseline model included the following modifications:

- ➔ Within the remainder of the east extension and the proposed west extension footprints, no flow boundaries were imported in layers 1 through 7. Hydraulic conductivity zone 14 (i.e., the zone representing the active quarry dewatering) was extended in model layer 8 (i.e., Bertie formation, Falkirk member) within the extended footprint to simulate the extraction of the bedrock resource.
- ➔ Recharge zone 7 (i.e., the zone representing the active quarry excavation) was extended to cover the remainder of the east extension and the proposed west extension footprints. As noted previously, the volumetric flow rate for this zone simulates the water surplus (i.e., precipitation less evaporation) at the existing quarry.
- ➔ A total of 422 model cells are situated within the remainder of the east extension footprint, while a total of 1,108 model cells are situated within the proposed west extension footprint. Drain boundaries were set within each of these cells in model layer 8 (i.e., Bertie formation, Falkirk member), with a specified elevation of the greater of 164 masl or 0.1 m above the cell bottom to represent the extended internal drainage network hydraulically connected to the existing quarry dewatering sump. High conductance values were used such that there was no simulated hydraulic gradient across the proposed quarry extension. The additional drain boundaries were specified as Reaches 8 and 9 to facilitate estimation of the predicted annual water takings for dewatering the proposed quarry extension.

- ➔ The simulated groundwater elevations from the intermediate model (i.e., full development within the licensed east quarry extension) were used as the initial head values in the full development model. This was implemented to allow the predicted drawdown from the proposed quarry extension to be calculated directly by the MODFLOW code (i.e., the 'DDN' output file).

H.7.1 PREDICTED QUARRY EXTENSION EFFECTS

The predicted cone of depression induced by the extension of the quarry dewatering sump is shown on **Figure H-9** for the deeper bedrock units.

It is noted that due to the presence of the inferred upper Bertie formation aquitard, no measurable impacts to the shallow bedrock aquifer are predicted in the model. This prediction is similar to the baseline model which showed no impacts to the shallow bedrock aquifer under existing conditions using baseline water level data for calibration.

A drawdown of up to approximately 4 m relative to baseline water levels in the deeper bedrock units is predicted for a small number of parcels adjacent to the southwest of the proposed extension lands. The radius of influence (i.e., 1 m drawdown contour) in the deeper bedrock units extends to the west and south by approximately 1,000 m and 800 m, respectively.

The predicted average annual dewatering rate for the fully developed quarry (i.e., both east and west extensions excavated) is approximately 2.1 Mm^3/year (5,700 m^3/day) under autumn conditions. This value includes both groundwater inflow and runoff from direct precipitation (less evaporation) and represents a nearly 35% increase over baseline simulated conditions. It is expected that the daily dewatering rate will be higher during the spring freshet, based on the observed sump flow rate seasonality observed at the existing quarry. Using the proposed full quarry footprint area of approximately 1.9 km^2 (includes east and west extensions) and an estimated water surplus of 200 mm/year, direct precipitation accounts for approximately 17% of the total annual dewatering rate. The remaining 1.7 Mm^3/year (approximately 4,700 m^3/day) is due to the predicted groundwater influx to the quarry excavation.

The interim conditions (i.e., east extension) model suggests that when the existing licensed extraction area is fully excavated, the autumn average stage elevation in the Quarry Lakes pond will be reduced by approximately 0.1 m. The full development (i.e., west extension) model suggests that during autumn conditions, the Quarry Lakes average stage elevation would be further reduced by approximately 0.5 m. Because of the way that the Quarry Lakes sump was simulated, it is not possible to provide an exact estimate of the future predicted sump pumping rate is not provided; however, the rate would be somewhat lower than baseline conditions.

The interim conditions (i.e., east extension) model also suggests that when the existing licensed extraction area is fully excavated, the autumn average stage elevation in the Cement Plant Ponds south pond will be reduced by approximately 0.4 m. The full development (i.e., west extension) model suggests that the proposed west extension will not further impact the stage elevation in the Cement Plant Ponds to a significant degree. This is not unexpected, as the proposed extension is more distant from this feature.

Finally, the full development model suggests that the average autumn sump discharge from the Scholfield Avenue pumping station will decrease by approximately 16% compared to baseline conditions; however, the majority of the decrease is again due to the previously licensed portions of the existing quarry. The average autumn sump discharge form the Townline Tunnel may also decrease by up to 2% compared to baseline conditions.

These impacts are relatively small and will likely be obscured by short-term seasonal and longer-term climatic fluctuations in the ambient groundwater system conditions.

H.7.2 FULL DEVELOPMENT WATER BALANCE

The full development Site water balance is shown in **Table H.7.1** below.

Table H.7.1 Site Water Balance - Full Development

Boundary Type	Inflows		Outflows		Outflow – Inflow (m^3/day)
	(m^3/day)	(mm/year)	(m^3/day)	(mm/year)	
Recharge (RCH)	370.54	169.06	0	0	-370.54
River (RIV)	8.10	3.70	0.02	<0.01	-8.08
Drain (DRN)	0	0	1,467.21	669.41	1,467.21
Lateral GW Flow	1,644.32	750.22	555.72	253.55	-1,088.60
TOTAL	**2,022.96**	**922.98**	**2,022.95**	**922.97**	**<0.01**
Discrepancy (%)					**<0.001**

The full development Site water balance indicates that the predicted annual dewatering rate for the proposed west extension (simulated by the drain boundaries) is approximately 1,467 m^3/day (approximately 0.5 Mm^3/year). The dewatering rate for the remaining portion of the quarry is approximately 4,400 m^3/day (1.6 Mm^3/year). The total inflow from recharge also increases to about 169 mm/year due to the removal of the overburden within the quarry extension footprint. However, the increase in total inflow from recharge is insufficient to equilibrate with the total outflow due to dewatering. As a result, the net lateral groundwater flow switches from marginally net outward flow to a net inward flow, and accounts for approximately 74% of the predicted annual dewatering rate.

The water balance for the Biederman Drain subwatershed for the full development model is shown in **Table H.7.2** below.

Table H.7.2 Biederman Drain Subwatershed Water Balance - Full Development

Boundary Type	Inflows		Outflows		Outflow – Inflow (m^3/day)
	(m^3/day)	(mm/year)	(m^3/day)	(mm/year)	
Recharge (RCH)	286.7	5.9	0	0	-286.7
River (RIV)	152.2	3.2	20.6	0.4	-131.6
Drain (DRN)	0	0	0.1	<0.01	0.1
Lateral GW Flow	1,213.9	25.1	1,632.0	33.8	418.1
TOTAL	**1,652.8**	**34.2**	**1652.7**	**34.2**	**<0.01**
Discrepancy (%)					**<0.001**

It is noted that all water that collects within the proposed extension footprint will be directed to the existing quarry sump via an internal drainage network. The sump discharge will continue to be directed to Eagle Marsh Drain; therefore, the Biederman Drain subwatershed area will decrease slightly to approximately 17.6 km^2. The above mass balance applies to the reduced subwatershed area.

Under full quarry development, there is a marginal decrease in recharge, and a net increase of lateral groundwater outflow of approximately 20 m^3/day or 6% compared to baseline conditions. Recharge from / discharge to the Wainfleet Bog deposits (i.e., river boundaries) largely remains the same as baseline conditions. Finally, groundwater discharge as baseflow to the Biederman Drain will be reduced by approximately 2 mm/year relative to baseline conditions. However, it is noted that even under baseline conditions, groundwater flux to the Biederman Drain was minimal.

H.7.3 CUMULATIVE IMPACT ASSESSMENT

As noted previously in **Section H.4.3.3**, known permitted groundwater users are included in the calibrated baseline model. These users have also been included in the full development model to assess the cumulative impacts from the proposed quarry extension and existing permitted groundwater users.

The Reeb Quarry, situated southeast of the proposed quarry extension, is licensed for extraction; however, excavation has not yet commenced. As part of this study, an additional future scenario model was created to simulate the impacts of both the proposed quarry extension and the Reeb Quarry at full development.

In the Addendum Hydrogeological Assessment (Azimuth Environmental Consulting and Earthfx Inc., 2008), it is noted that the Reeb Quarry will be developed in 2 phases. Phase 1 is west of Bessey Road, and Phase 2 is east of Bessey Road. Once phase 1 extraction has been completed, the water management plan for the site allows discharge water collected in phase 2 to accumulate in phase 1, with a stage elevation to be maintained at 174 masl. The purpose of the phase 1 pond is to mitigate potential groundwater impacts to the west of the quarry. It is expected that impact from both quarries would be greatest when the Law Quarry extension is fully completed and the Reeb Quarry phase 1 excavation is completed and not yet inundated. Therefore, this scenario was chosen to provide a conservative estimate for the cumulative impact assessment including the effects of Reeb Quarry under full development conditions.

The full development model was adapted to include the Reeb Quarry as follows:

- ➔ No flow boundaries were imported in layers 1 through 7 within the Reeb Quarry Phase 1 footprint. Hydraulic conductivity zone 14 was imported in model layer 8 within the Reeb Quarry phase 1 footprint to simulate the extraction of the bedrock resource.
- ➔ Recharge zone 7 was imported to cover the Reeb Quarry phase 1 footprint using the same water surplus as that used for the proposed Law Quarry west extension.
- ➔ A total of 60 model cells are situated within the Reeb Quarry phase 1 footprint. Drain boundaries were set within each of these cells in model layer 8, with a specified head elevation of 0.1 m above the cell bottom. High conductance values were used such that there was no simulated hydraulic gradient across the quarry. The additional drain boundaries were specified as Reach 10 to facilitate estimation of the predicted annual water takings for dewatering of Reeb phase 1.

- ➔ The simulated groundwater elevations from the intermediate conditions (i.e., east extension) model were used as the initial head values to allow computation of drawdown directly by MODFLOW.

H.7.3.1 PREDICTED CUMULATIVE EFFECTS

The predicted cone of depression induced by the west extension of the Law Quarry dewatering sump and full extraction within Reeb Phase 1 is shown on **Figure H-10** for the shallow bedrock aquifer and **Figure H-11** for the deeper bedrock units.

In the shallow bedrock aquifer, predicted drawdown of up to 3 m occurs to the south of Reeb phase 1 covering mostly vacant conservation lands. The 2 m drawdown contour covers the western portion of the community of Camelot Beach on the Lake Erie north shore. The radius of influence (i.e., 1 m drawdown contour) extends to Golf Club Road in the west, Cement Road in the east and south to the Lake Erie shoreline. It is inferred that the drawdown within the shallow bedrock aquifer is the result of dewatering of the Reeb Quarry, as the full development model for the proposed Law Quarry extension showed no drawdown in this unit. The drawdown contours also suggest that the Quarry Lakes pond could be subject to a decrease of up to 3 m for autumn average conditions, while the Cement Plant Ponds could be subject to a decrease of up to 0.6 m. In the Reeb Quarry Addendum Hydrogeological investigation report (Azimuth Environmental Consulting and Earthfx Inc., 2008), it was stated that development of Reeb phase 1 would cause no impacts to water levels in either of these features.

In the deeper bedrock units, a drawdown of up to 10 m relative to baseline water levels is predicted immediately adjacent to Reeb phase 1. The 1 m drawdown cone covers roughly the same extent as that of the shallow bedrock aquifer, with the addition of the drawdown to the west of the proposed extension.

In this scenario, it is predicted that the average annual dewatering rate for Reeb phase 1 is approximately 2.7 Mm^3/year (7,400 m^3/day) under autumn conditions, which includes both groundwater inflow and runoff from direct precipitation (less evaporation). It is expected that the daily dewatering rate will be higher during the spring freshet. Using the Reeb phase 1 footprint area of 0.34 km^2 and an estimated water surplus of 200 mm/year, direct precipitation accounts for approximately 3% of the total annual dewatering rate. The remaining 2.6 Mm^3/year (approximately 7,200 m^3/day) is due to the predicted groundwater influx to Reeb phase 1. In the Reeb Quarry Addendum Hydrogeological investigation report (Azimuth Environmental Consulting and Earthfx Inc., 2008), the full development dewatering rate for Reeb phase 1 was simulated as approximately 1.1 Mm^3/year (3,000 m^3/day).

It is also predicted that the average annual dewatering rate for the fully developed Law Quarry will decrease by nearly 80% relative to the scenario without considering Reeb phase 1 cumulative effects. When Reeb phase 1 is fully developed, an average annual dewatering rate of approximately 0.5 Mm^3/year (1,250 m^3/day) at Law Quarry could be expected for autumn conditions. It was acknowledged in the Reeb Quarry Addendum Hydrogeological investigation that because the Reeb Quarry is situated down dip relative to Law Quarry, the drawdown was expected to be of increased magnitude. However, it was predicted that the excavation of Reeb phase 1 would only reduce the Law Quarry dewatering rate by approximately 30%. Based on these observations, the discharge to Eagle Marsh Drain from the Law Quarry would be substantially reduced when the Reeb Quarry is developed.

Finally, when cumulative effects of the proposed quarry extension and Reeb phase 1 are considered, the average autumn sump discharge from the Scholfield Avenue pumping station and Townline Tunnel dewatering sump will decrease by approximately 45% and 2%, respectively, relative to baseline conditions. Both the proposed quarry extension and Reeb phase 1 appear to have minimal impact on pumping at the Townline Tunnel; however, the reduction in pumping at the Scholfield Avenue pumping station is predicted to be significant. Since the pumping station is in place to reduce groundwater infiltration to the City of Port Colborne sewer system and local basement sumps, neither the proposed west quarry extension nor Reeb phase 1 will negatively impact its operation.

H.7.3.2 CUMULATIVE ASSESSMENT WATER BALANCE

The cumulative assessment Site water balance is shown in **Table H.7.3** below.

Table H.7.3 Site Water Balance – Cumulative Assessment

Boundary Type	Inflows		Outflows		Outflow – Inflow (m^3/day)
	(m^3/day)	(mm/year)	(m^3/day)	(mm/year)	
Recharge (RCH)	370.54	169.06	0	0	-370.54
River (RIV)	8.10	4.26	0.02	<0.01	-8.08
Drain (DRN)	0	0	224.43	102.40	224.43
Lateral GW Flow	574.29	262.02	728.50	332.38	154.21
TOTAL	**952.94**	**434.78**	**952.95**	**434.78**	**0.01**
Discrepancy (%)					**<0.001**

The cumulative assessment Site water balance indicates that the predicted annual dewatering rate for the proposed west extension decreases from approximately 1,467 m^3/day to 224 m^3/day when Reeb phase 1 is fully developed, which represents a decrease of nearly 85%. There is a net lateral groundwater flow outward to the surrounding aquifer.

The water balance for the Biederman Drain subwatershed for the cumulative assessment model is shown in **Table H.7.4** below.

Table H.7.4 Biederman Drain Subwatershed Water Balance – Cumulative Assessment

Boundary Type	Inflows		Outflows		Outflow – Inflow (m^3/day)
	(m^3/day)	(mm/year)	(m^3/day)	(mm/year)	
Recharge (RCH)	286.7	5.9	0	0	-286.7
River (RIV)	154.6	3.2	20.2	0.4	-134.4
Drain (DRN)	0	0	0.1	<0.1	0.1
Lateral GW Flow	1,181.5	24.5	1,602.4	33.2	420.9
TOTAL	**1,622.8**	**33.6**	**1,622.7**	**33.6**	**<0.1**
Discrepancy (%)					**<0.001**

The cumulative assessment water balance for Biederman Drain subwatershed indicates that when both the proposed west quarry extension and Reeb phase 1 are fully developed, the water balance components remain similar to the scenario with full development only at the proposed west quarry extension. There is marginally increased inflow from the Wainfleet Bog deposits (i.e., river boundaries), and marginally increased lateral groundwater outflow to the surrounding aquifer.

H.8 REHABILITATED MODEL

Once the quarry extension excavation is complete, the dewatering sump will be decommissioned, and the excavation will be allowed to fill naturally with precipitation and groundwater discharge. As such, the proposed end use of the quarry is a lake.

Numerical groundwater modeling was completed to predict the long-term steady-state effects of the proposed end use. The full development model was adapted to simulate the final rehabilitation of the Site to a lake. Adaptation of the full development model included the following modifications:

- ➔ The drain boundaries representing the quarry dewatering sump (Reach 4, 8 and 9) were deleted from layer 8 (Falkirk mb) of the model. No flow boundaries within the quarry footprint were also deleted from layers 1 through 7.
- ➔ The high hydraulic conductivity zone used to simulate the active quarry (i.e., zone 14) was copied from layer 8 to layers 1 through 7.
- ➔ Recharge within the quarry footprint was reduced from 200 mm/year to 130 mm/year to simulate precipitation less evaporation from the future quarry lake. This is the same value that was used to simulate recharge to the Quarry Lakes pond and Cement Plant Ponds (refer to **Section H.4.3.5**).

H.8.1 PREDICTED FINAL LAKE EFFECTS

The rehabilitation model predicts a steady-state autumn average stage elevation of approximately 174.4 masl in the final quarry lake. This is similar to the stage elevation of ± 175 masl shown in the east extension Rehabilitation Plan (Law Quarry Extension, Figure 3 of 4, Licence No. 607541, MHBC Planning, Revised June 2006).

The lowest natural ground surface elevation around the perimeter of the existing quarry is situated within the southeastern portion of the east extension lands, with an elevation of approximately 178 masl. As such, it is predicted that there will be no discharge from the future quarry lake to surface water drainage features under natural climatic conditions. This is consistent with the Site Plans for both the original and east extension which indicated no discharge points.

At final rehabilitation, the steady-state autumn average stage elevation in the Quarry Lakes ponds is predicted to increase by 0.2 m relative to baseline conditions, and discharge from the sump is predicted to average approximately 2,350 m^3/day (0.9 Mm^3/year). This is a significant increase from the average discharge rate under baseline conditions, estimated as 80 m^3/day. The autumn average stage elevation in the Cement Plant Ponds south pond is predicted to increase by 1 m relative to baseline conditions. Finally, the steady-state autumn discharge from the Scholfield Avenue pumping station is predicted to average approximately 2,750 m^3/day (1.0 Mm^3/year), which represents an increase of about 40% compared to baseline conditions.

H.8.2 REHABILITATED WATER BALANCE

The rehabilitated model Site water balance is shown in **Table H.8.1** below.

Table H.8.1 Site Water Balance – Rehabilitated Conditions

Boundary Type	Inflows		Outflows		Outflow – Inflow (m^3/day)
	(m^3/day)	(mm/year)	(m^3/day)	(mm/year)	
Recharge (RCH)	245.75	112.12	0	0	-245.75
River (RIV)	7.79	3.55	0.06	0.02	-7.73
Lateral GW Flow	65.64	29.95	318.41	145.27	252.77
TOTAL	**319.18**	**145.63**	**318.47**	**145.30**	**0.71**
Discrepancy (%)					**0.2**

At final rehabilitation, over 75% of the total inflow to the Site originates as recharge. After the steady-state stage elevation is reached, net groundwater flow will be outwards to the surrounding aquifer, similar to baseline conditions. However, the rate of outward groundwater flow doubles relative to baseline conditions. Discharge from the Wainfleet Bog deposits (i.e., river boundaries) also marginally decreases relative to baseline conditions, due to the cessation of the sump in the existing quarry which was simulated in the baseline model.

The water balance for the Biederman Drain subwatershed for the rehabilitated model is shown in **Table H.8.2** below. It is noted that since the lake will not discharge to Biederman Drain at final rehabilitation, the Biederman Drain subwatershed will retain the slightly reduced area of 17.6 km^2 as assumed for the full development conditions.

Table H.8.2 Biederman Drain Subwatershed Water Balance – Rehabilitated Conditions

Boundary Type	Inflows		Outflows		Outflow – Inflow (m^3/day)
	(m^3/day)	(mm/year)	(m^3/day)	(mm/year)	
Recharge (RCH)	286.7	5.9	0	0	-286.7
River (RIV)	107.4	2.2	29.7	0.6	-77.7
Drain (DRN)	0	0	0.4	<0.1	0.4
Lateral GW Flow	817.6	16.9	1,181.6	24.5	364.0
TOTAL	**1,211.7**	**25.1**	**1,211.7**	**25.1**	**<0.01**
Discrepancy (%)					**<0.001**

After rehabilitation to the final lake, the total inflow from recharge in the Biederman Drain subwatershed decreases by approximately 22% due to the permanent removal of bedrock outcrops (i.e., a high groundwater recharge area) within the proposed quarry extension footprint. Much of the remaining subwatershed area is underlain by low permeability glaciolacustrine clays, which results in a lower average groundwater recharge estimated for rehab conditions. The very limited recharge from the Wainfleet Bog deposits (i.e., river boundaries) to the deep groundwater system notably decreases by approximately 38% below baseline conditions as the pressure differential decreases due to the cessation of the sump in the existing Law Quarry which was simulated in the baseline model. Predicted groundwater discharge as baseflow to Biederman Drain, which is currently low, remains reduced at final rehabilitation, although at the watershed scale, this represents a reduction of 2 mm/year. Finally, the net outward groundwater flux to the surrounding aquifer marginally reduces by approximately 8% relative to baseline conditions.

H.8.3 CUMULATIVE IMPACT ASSESSMENT

A cumulative impact assessment for the Reeb Quarry at final rehabilitation to quarry lakes has also been completed as part of this study. For the final rehab cumulative assessment, it is assumed that both phases of the Reeb Quarry are excavated and inundated to form final quarry lakes. In the Addendum Hydrogeological Assessment (Azimuth Environmental Consulting and Earthfx, 2008), it is noted that an outlet to the Eagle Marsh Drain would be situated on the east side of the phase 2 pond with a control elevation at 175.5 masl. The predicted steady-state average stage elevation in the ponds was specified as between 176 masl and 177 masl.

The rehabilitated conditions model was adapted to include the Reeb Quarry as follows:

- ➔ The drain boundaries representing the quarry dewatering sump (Reach 10) were deleted from layer 8 (Falkirk mb) of the model. No flow boundaries within the phase 1 footprint were also deleted from layers 1 through 7.
- ➔ The high hydraulic conductivity zone used to simulate the active phase 1 quarry (i.e., zone 14) was copied from layer 8 to layers 1 through 7. In addition, this zone was also added to layers 1 through 8 for the phase 2 footprint east of Bessey Road.
- ➔ Recharge within both phases of Reeb Quarry was set as 130 mm/year to simulate precipitation less evaporation from the future quarry lakes.

H.8.3.1 PREDICTED CUMULATIVE EFFECTS

At Law Quarry, the cumulative rehabilitated conditions model predicts a steady-state autumn average stage elevation of 174.1 masl with the presence of the Reeb Quarry final lakes to the south. This is a decrease of 0.3 m in comparison to the rehabilitated conditions model simulating only the Law Quarry. The predicted steady-state autumn average stage elevation in the Reeb Quarry final lakes is predicted to be approximately 173.5 masl. This estimate is 2.5 m to 3.5 m lower than the predictions from the Addendum Hydrogeological Assessment. At this lower elevation, flow from the lakes to Eagle March Drain would not occur in the autumn under normal climatic conditions.

In the cumulative scenario for rehabilitated conditions, the steady-state autumn average stage elevation in the Quarry Lakes ponds is predicted to increase by less than 0.1 m relative to the rehabilitated scenario where only Law Quarry is simulated. Likewise, the steady-state average autumn discharge from the sump is predicted to increase to 2,800 m^3/day (1.0 Mm^3/year), a nearly 20% increase relative to rehab conditions considering Law Quarry only. The autumn average stage elevation in the Cement Plant Ponds south pond is predicted to decrease by 0.2 m, and steady-state autumn discharge from the Scholfield Avenue pumping station is predicted to decrease slightly to 2,600 m^3/day (0.95 Mm^3/year).

H.8.3.2 CUMULATIVE ASSESSMENT WATER BALANCE

The cumulative assessment Site water balance for rehabilitated conditions is shown in **Table H.8.3** below.

Table H.8.3 Site Water Balance – Rehabilitated Conditions Cumulative Assessment

Boundary Type	Inflows		Outflows		Outflow – Inflow (m^3/day)
	(m^3/day)	(mm/year)	(m^3/day)	(mm/year)	
Recharge (RCH)	245.75	112.12	0	0	-245.75
River (RIV)	7.94	3.62	0.06	0.03	-7.88
Lateral GW Flow	61.33	27.98	314.95	143.70	253.62
TOTAL	**315.02**	**143.73**	**315.01**	**143.72**	**-0.01**
Discrepancy (%)					**<0.001**

The water balance for the Biederman Drain subwatershed for the cumulative assessment model for rehabilitated conditions is shown in **Table H.8.4** below.

Table H.8.4 Biederman Drain Subwatershed Water Balance – Rehabilitated Conditions Cumulative Assessment

Boundary Type	Inflows		Outflows		Outflow – Inflow (m^3/day)
	(m^3/day)	(mm/year)	(m^3/day)	(mm/year)	
Recharge (RCH)	286.7	5.9	0	0	-286.7
River (RIV)	110.2	2.3	28.8	0.6	-81.4
Drain (DRN)	0	0	0.3	<0.1	0.3
Lateral GW Flow	822.2	17.0	1,189.9	24.6	367.7
TOTAL	**1,219.1**	**25.2**	**1,219.0**	**25.2**	**-0.1**
Discrepancy (%)					**<0.001**

The cumulative assessment Site and Biederman Drain subwatershed water balances for rehabilitated conditions are not substantially different from when only the Law Quarry rehabilitated conditions are simulated.

H.9 LIMITATIONS

MODFLOW-USG was used to simulate steady-state groundwater movement for baseline October conditions at the Site and to simulate steady-state groundwater flow conditions under full quarry extension and rehabilitated conditions. Transient effects, such as daily or seasonal fluctuations in aquifer potentials, storage, and changes in precipitation and evapotranspiration were outside of the scope of this study. The steady-state model provides a reasonable representation of groundwater conditions during the driest part of the year and allows for the simulation of changes to these groundwater conditions as a result of the proposed quarry extension. This model and its predictions can be updated if desired as more information becomes available, to incorporate additional subsurface observations, and to test and re-evaluate the model predictions.

Services performed by WSP Canada Inc. were conducted in a manner consistent with a level of care and skill ordinarily exercised by members of the environmental engineering and consulting profession. This report presents the results of data compilation and computer simulations of a complex geologic setting. Due to the nature of subsurface investigations which explore a relatively large volume of material with a small number of boreholes, data gaps are likely to be present in the information obtained by and supplied to WSP Canada Inc. Models constructed from these data are limited by the quality and completeness of the information available at the time the work was performed. Computer models represent a deliberate simplification of the actual geologic conditions. This report does not exhaustively cover an investigation of all possible environmental conditions or circumstances that may exist in the study area. It should be recognized that the passage of time affects the information provided in this report.

Environmental conditions and the amount of data available can change. Discussions relating to the baseline conditions are based upon information that existed at the time the conclusions were formulated.

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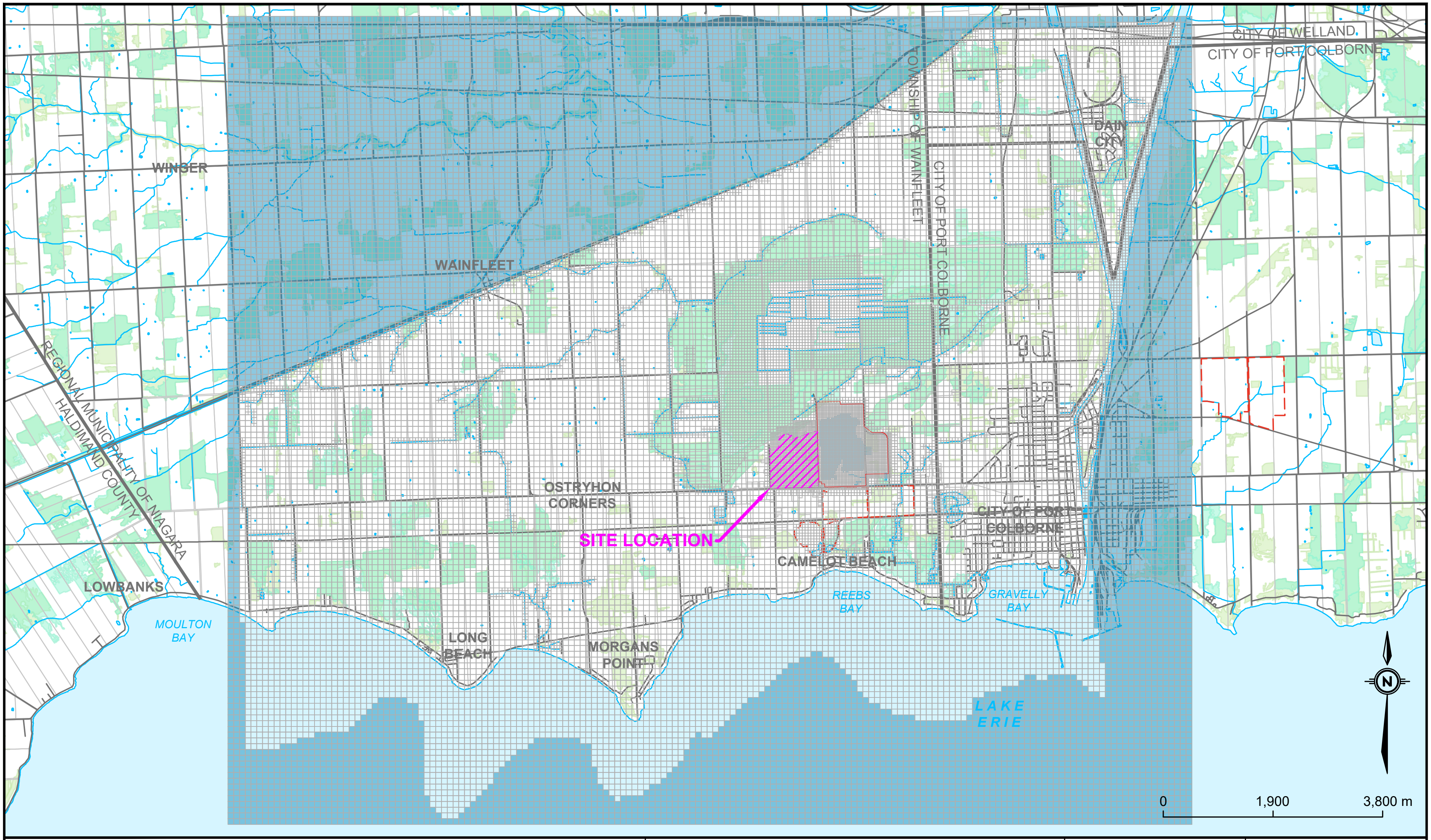
FIGURES



LEGEND

☐ MODEL GRID

🟦 NO FLOW BOUNDARY

MODEL DOMAIN GRID

NUMERICAL GROUNDWATER MODEL REPORT
LAW QUARRY EXTENSION
WAINFLEET, ON
For Waterford Sand & Gravel Ltd.

DATE: DECEMBER 2021

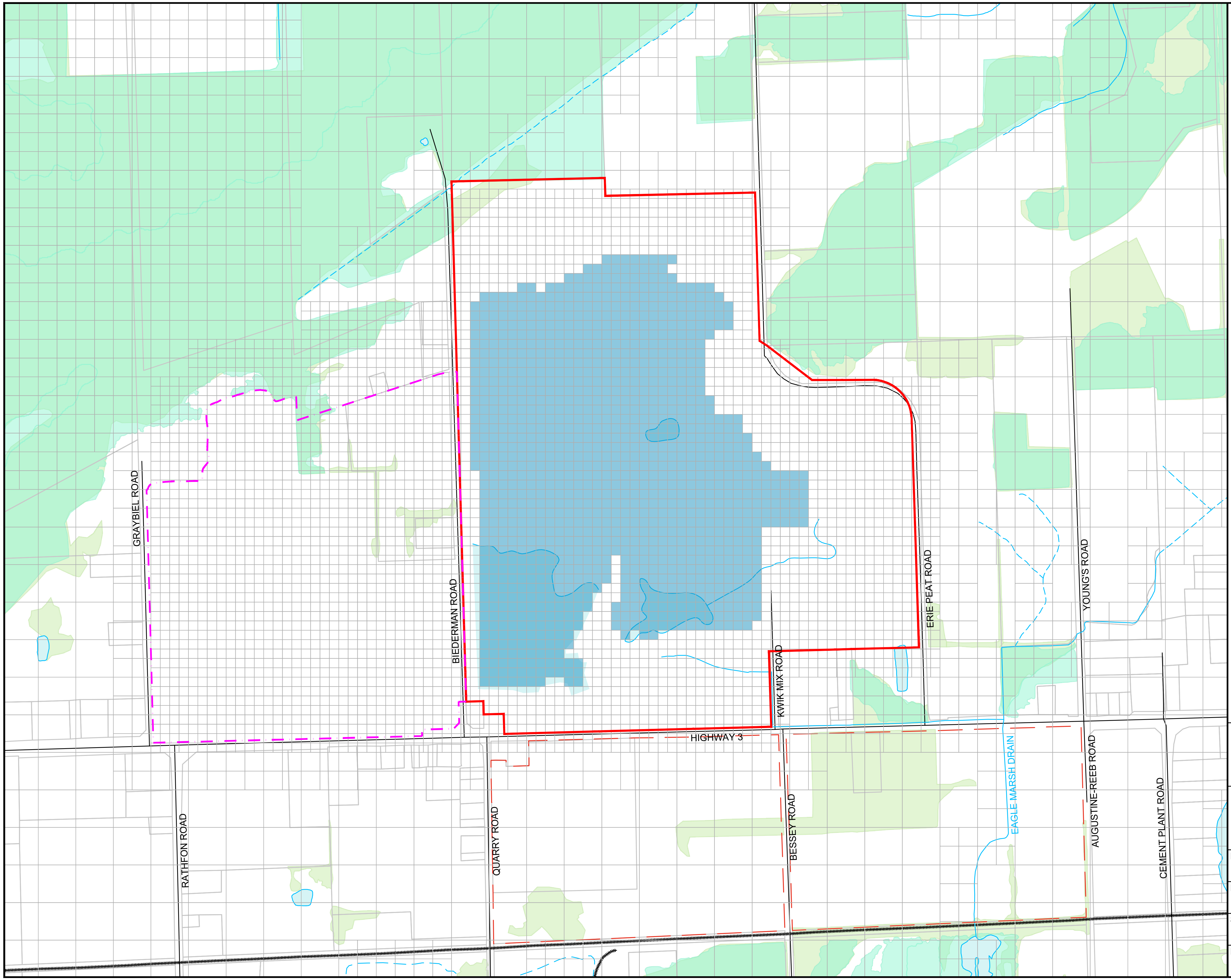
PROJECT: 111-53023-05

DRAWN BY: JLD

SCALE: 1 : 95,000

FIGURE No: **H-1**

\\CASCR1DAT01\VOL1\PROJECTS\2011\111-53023 LAW QUARRY\05 2018 LEVEL 2 GW MODELLING\GRAPHICS\111-53023-05-FH1-SP.DWG



LEGEND

- PROPOSED WEST EXTENSION
- EXISTING QUARRY LICENCE
- APPROXIMATE LAND PARCEL
- REEB QUARRY LICENCE
- 🟩 WOODLOT
- 🟩 WETLAND
- PERMANENT STREAM
- INTERMITTENT STREAM
- ☐ MODEL GRID
- 🟦 NO FLOW BOUNDARY

N

0 200 400 m

LOCAL MODEL GRID

NUMERICAL GROUNDWATER MODEL REPORT
LAW QUARRY EXTENSION
WAINFLEET, ON
For Waterford Sand & Gravel Ltd.

DATE: DECEMBER 2021
PROJECT: 111-53023-05
SCALE: 1 : 10,000
DRAWN BY: JLD

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FIGURE No: **H-1A**

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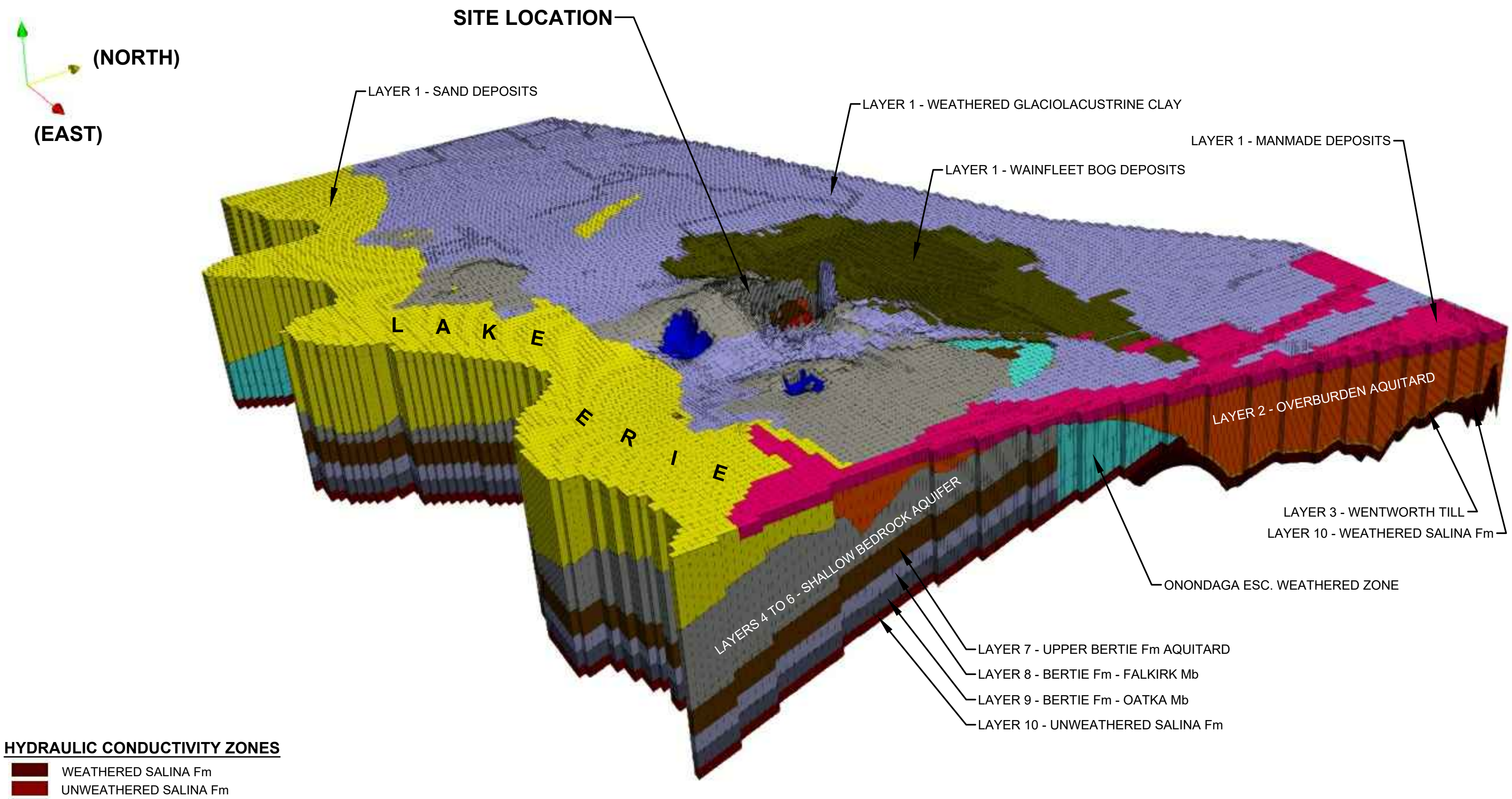


HYDRAULIC CONDUCTIVITY ZONES

- 🟫 WEATHERED SALINA Fm
- 🟥 UNWEATHERED SALINA Fm
- ▨ BERTIE Fm - OATKA Mb
- 🟪 BERTIE Fm - FALKIRK Mb
- 🟫 UPPER BERTIE AQUITARD
- ⬜ SHALLOW BEDROCK AQUIFER / BEDROCK OUTCROPS
- 🟧 WENTWORTH TILL
- 🟧 OVERBURDEN AQUITARD
- 🟪 WEATHERED GLACIOLACUSTRINE CLAY
- 🟩 WAINFLEET BOG DEPOSITS
- 🟨 SAND DEPOSITS
- 🟥 MANMADE DEPOSITS
- 🟦 QUARRY LAKES
- 🟥 ACTIVE QUARRY EXCAVATION
- 🟦 ONONDAGA ESC. WEATHERED ZONE

3-DIMENSIONAL VIEW OF MODEL LAYERS

NUMERICAL GROUNDWATER MODEL REPORT
LAW QUARRY EXTENSION
WAINFLEET, ON
For Waterford Sand & Gravel Ltd.

DATE: DECEMBER 2021
PROJECT: 111-52023-05
DRAWN BY: JLD
SCALE: NOT TO SCALE
FIGURE No: H-2

\\CASCR1DAT01\VOL1\PROJECTS\2011\111-53023 LAW QUARRY\05 2018 LEVEL 2 GW MODELLING\GRAPHICS\111-53023-05-FH2-SP.DWG

LEGEND

▭ ACTIVE MODEL GRID

NO-FLOW BOUNDARY

■ ACTIVE QUARRY EXCAVATION **(LAYERS 1 - 7)**

RIVERS (REACH / DESCRIPTION)

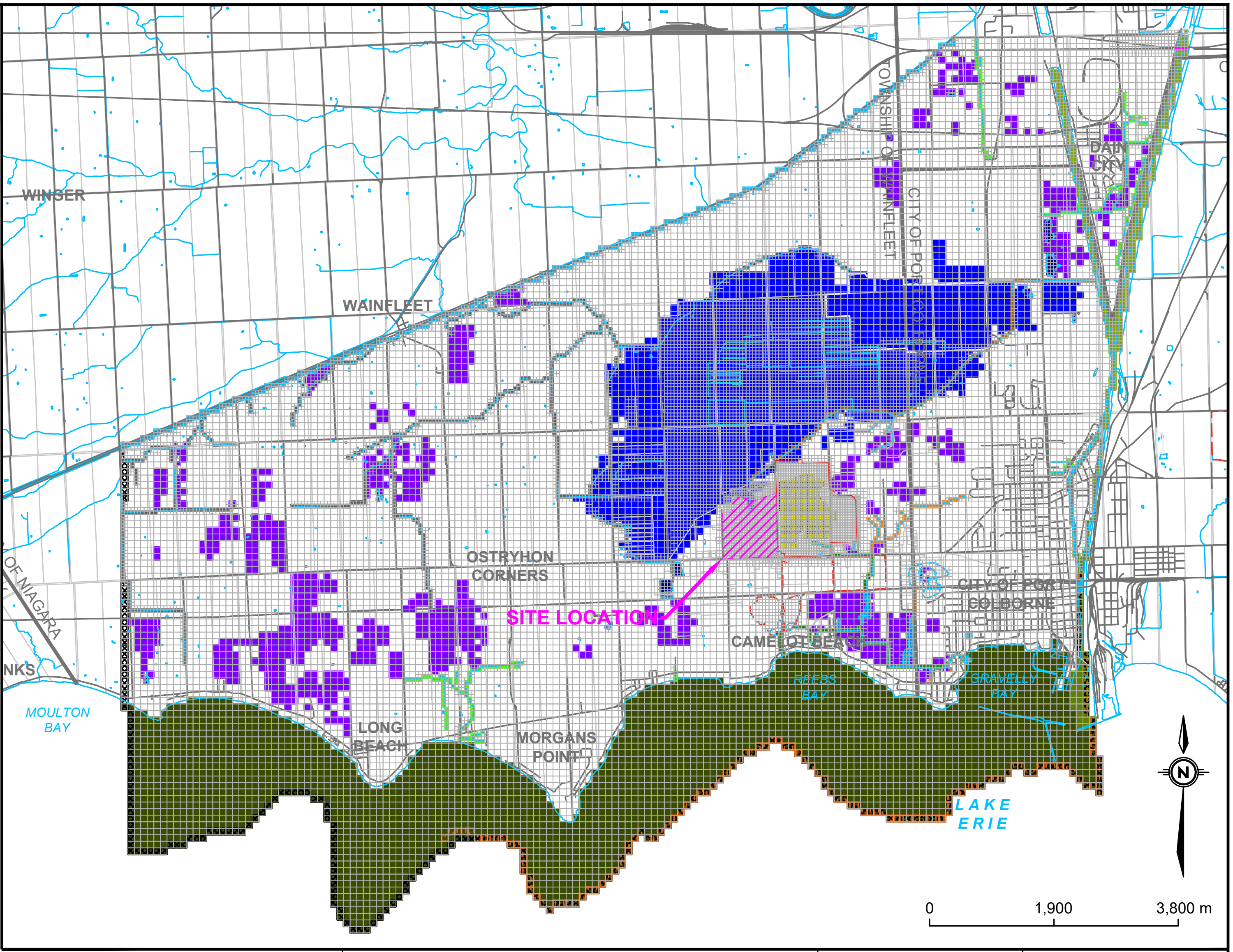
🟦	0	WAINFLEET BOG	(LAYER 1)
🟫	1	BIEDERMAN DRAIN	
🟩	2	EAGLE MARSH DRAIN	
🟦	3	FEEDER CANAL	
🟦	4	THE CLAY PITS	
■	5	SMALL UNDIFFERENTIATED WATERBODIES	
🟪	6	OTHER WETLANDS	

GENERAL HEAD BOUNDARY (REACH)

▩	0	**(LAYER 10)**
▣	1	**(LAYER 4)**

DRAINS (REACH / DESCRIPTION)

■	0	MILL RACE CREEK	(LAYER 1)
■	1	BIEDERMAN DRAIN TRIBUTARIES	
🟧	2	EAGLE MARSH DRAIN TRIBUTARIES	
🟩	3	OTHER TRIBUTARIES	
▨	4	ACTIVE QUARRY SUMP **(LAYER 8)**	
🟪	5	QUARRY LAKES SUMP **(LAYER 4)**	
■	6	SCHOLFIELD AVENUE PUMPING STATION **(LAYER 4)**	
▨	7	TOWNLINE TUNNEL DEWATERING SUMP **(LAYER 10)**	



CONSTANT HEAD BOUNDARY (REACH / DESCRIPTION)

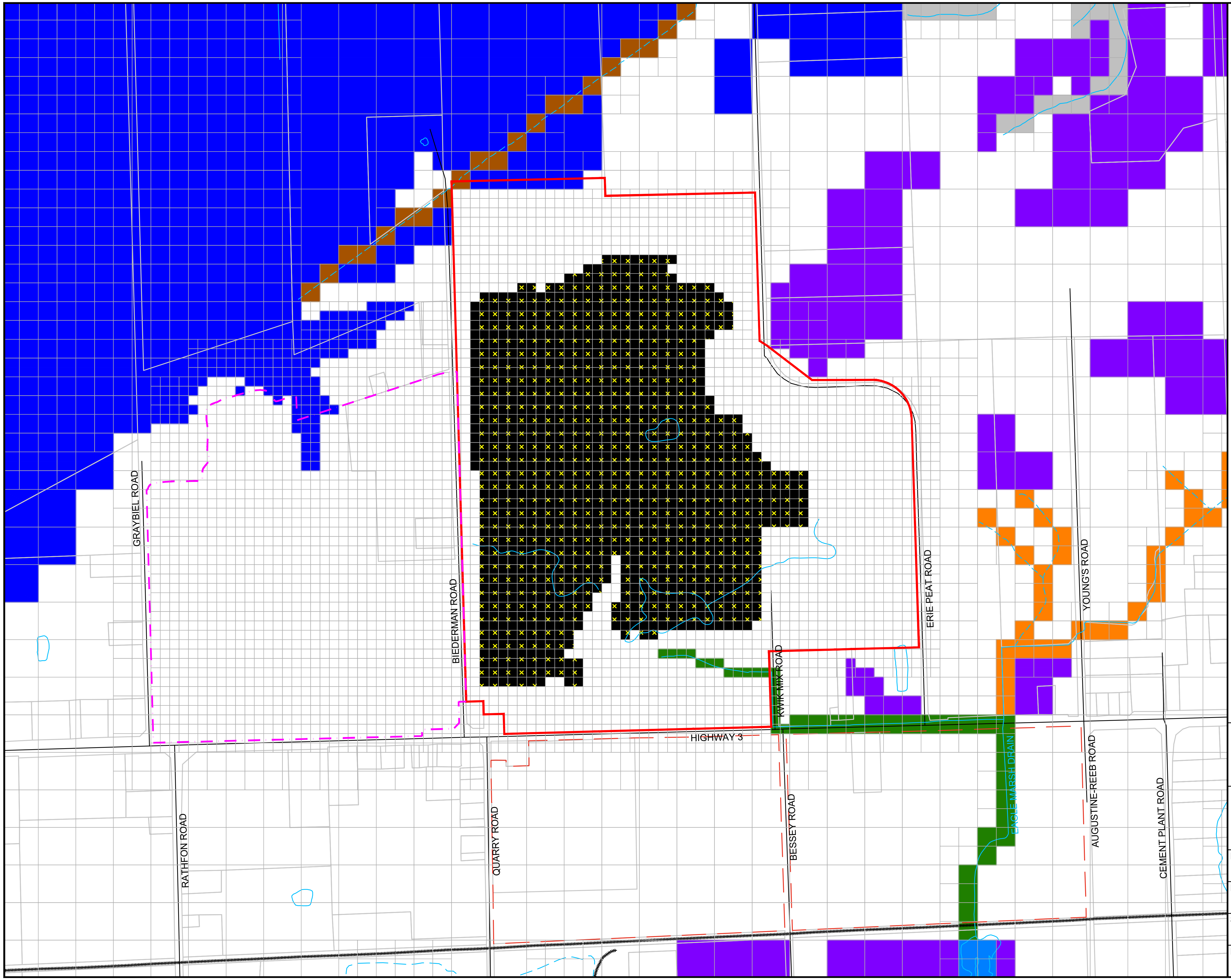
■	0	LAKE ERIE	(LAYER 1)
■	1	WELLAND CANAL (ABOVE LOCK 8)	
■	2	WELLAND CANAL (BELOW LOCK 8)	

BOUNDARY CONDITIONS

NUMERICAL GROUNDWATER MODEL REPORT
LAW QUARRY EXTENSION
WAINFLEET, ON
For Waterford Sand & Gravel Ltd.

DATE: DECEMBER 2021
PROJECT: 111-53023-05
DRAWN BY: JLD
SCALE: 1 : 95,000
FIGURE No: **H-3**

\\CASCR1DAT01\VOL1\PROJECTS\2011\111-53023 LAW QUARRY\05 2018 LEVEL 2 GW MODELLING\GRAPHICS\111-53023-05-FH3-SP.DWG



LEGEND

- PROPOSED WEST EXTENSION
- EXISTING QUARRY LICENCE
- APPROXIMATE LAND PARCEL
- REEB QUARRY LICENCE
- PERMANENT STREAM
- INTERMITTENT STREAM
- ☐ ACTIVE MODEL GRID

NO-FLOW BOUNDARY

- ■ ACTIVE QUARRY EXCAVATION **(LAYERS 1 - 7)**

RIVERS (REACH / DESCRIPTION) **(LAYER 1)**

🟦	0	WAINFLEET BOG
🟫	1	BIEDERMAN DRAIN
🟩	2	EAGLE MARSH DRAIN
🟦	4	THE CLAY PITS
🟪	6	OTHER WETLANDS

DRAINS (REACH / DESCRIPTION) **(LAYER 1)**

⬜	1	BIEDERMAN DRAIN TRIBUTARIES
🟧	2	EAGLE MARSH DRAIN TRIBUTARIES
☒	4	ACTIVE QUARRY SUMP **(LAYER 8)**

N

0 200 400 m

LOCAL BOUNDARY CONDITIONS

NUMERICAL GROUNDWATER MODEL REPORT
LAW QUARRY EXTENSION
WAINFLEET, ON
For Waterford Sand & Gravel Ltd.

DATE: DECEMBER 2021
PROJECT: 111-53023-05
SCALE: 1 : 10,000
DRAWN BY: JLD

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FIGURE No: **H-3A**

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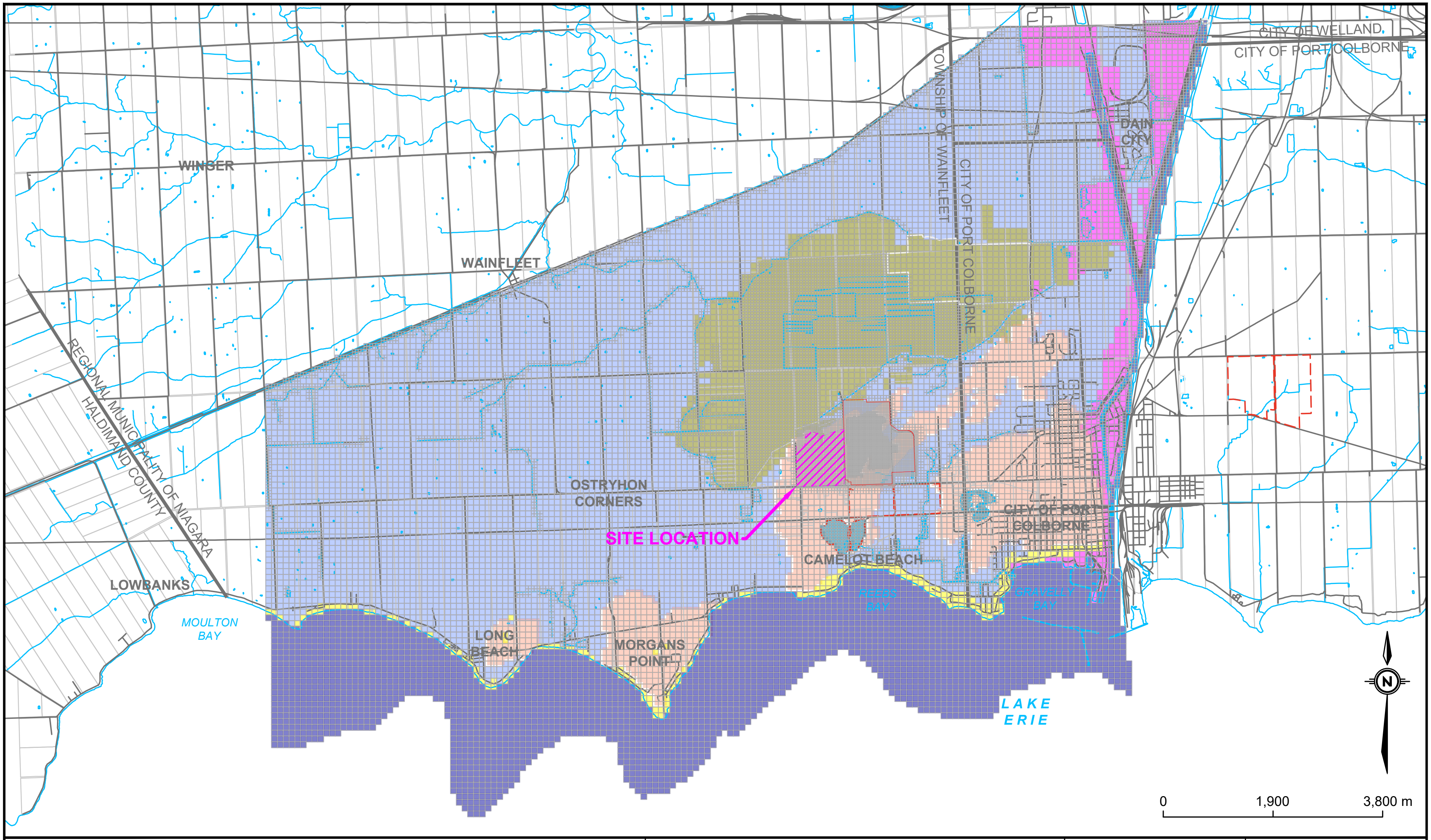

LEGEND

☐ ACTIVE MODEL GRID

RECHARGE (ZONE / DESCRIPTION)

■ 1 GLACIOLACUSTRINE CLAY
■ 2 WAINFLEET BOG DEPOSITS
■ 3 BEDROCK OUTCROPS
■ 4 SAND DEPOSITS
■ 5 MANMADE DEPOSITS
■ 6 QUARRY LAKES
■ 7 ACTIVE QUARRY EXCAVATION
■ 8 LAKE ERIE

RECHARGE ZONES

NUMERICAL GROUNDWATER MODEL REPORT
LAW QUARRY EXTENSION
WAINFLEET, ON
For Waterford Sand & Gravel Ltd.

DATE: DECEMBER 2021
PROJECT: 111-53023-05
DRAWN BY: JLD
SCALE: 1 : 95,000
FIGURE No: **H-4**

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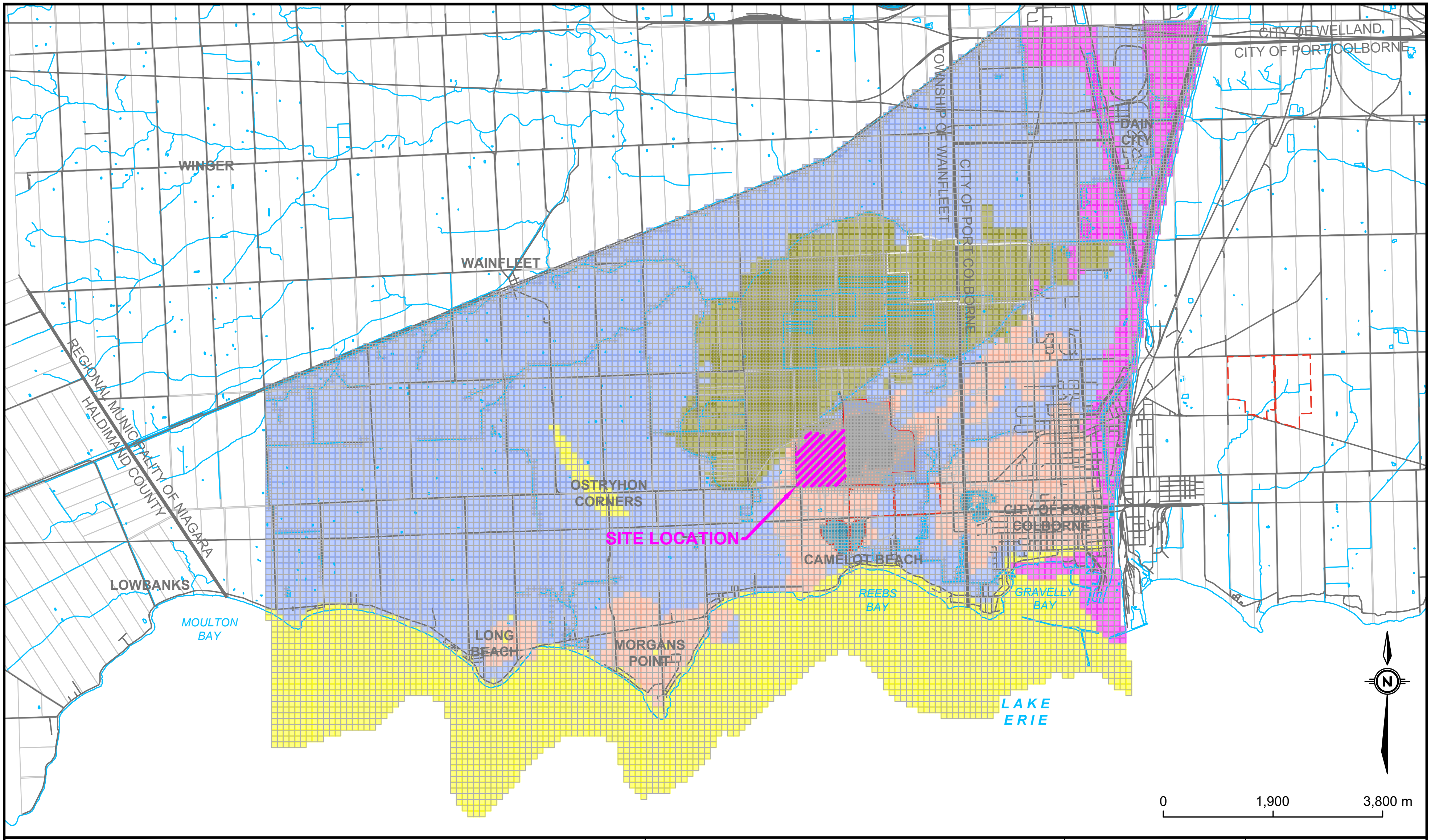


LEGEND

▭ ACTIVE MODEL GRID

HYDRAULIC CONDUCTIVITY (ZONE / DESCRIPTION)

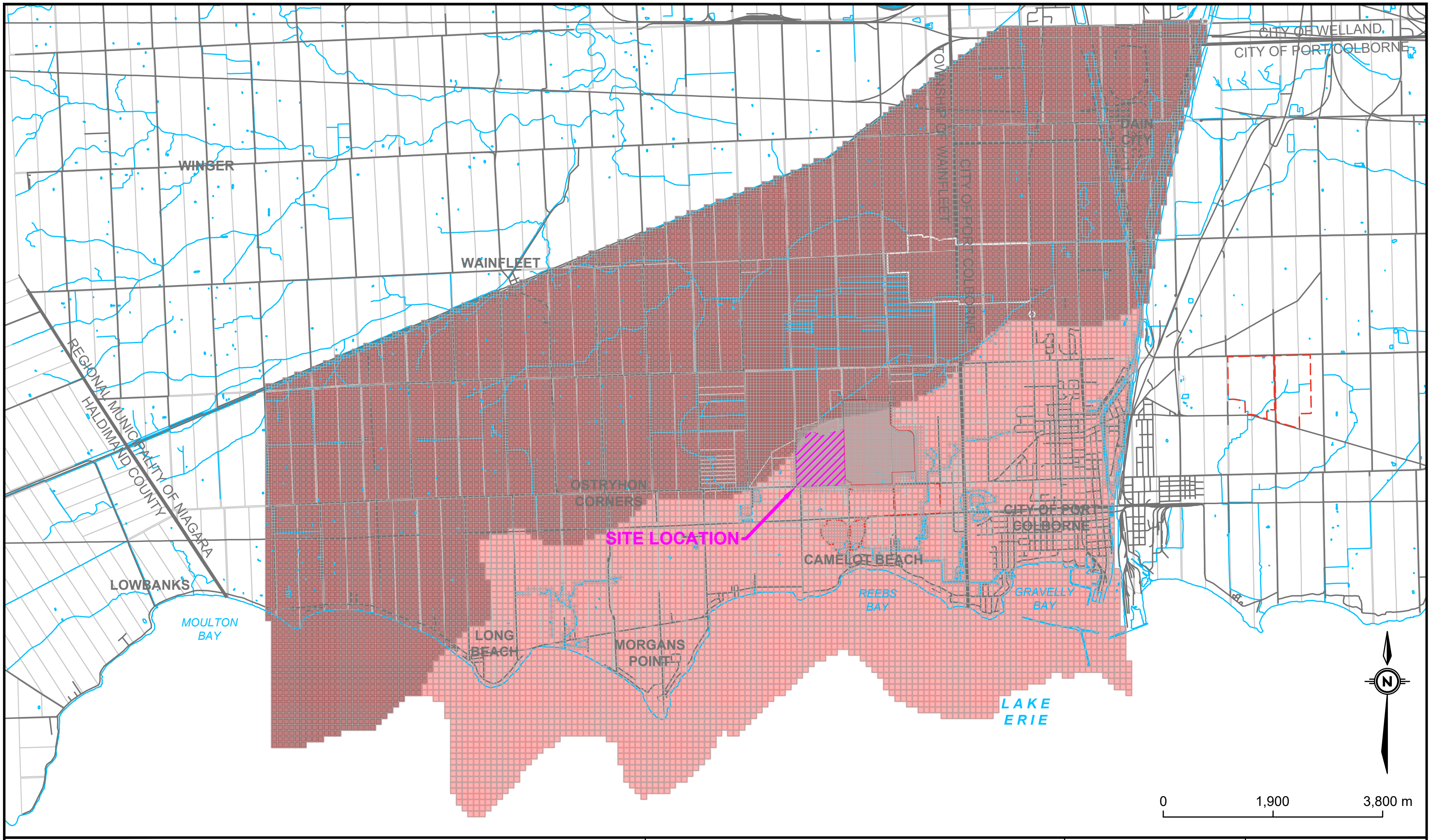
■ 6 BEDROCK OUTCROPS
■ 9 GLACIOLACUSTRINE CLAY
■ 10 WAINFLEET BOG DEPOSITS
■ 11 SAND DEPOSITS
■ 12 MANMADE DEPOSITS
■ 13 QUARRY LAKES
■ 14 ACTIVE QUARRY EXCAVATION

LAYER 1 CONDUCTIVITY ZONES

NUMERICAL GROUNDWATER MODEL REPORT
LAW QUARRY EXTENSION
WAINFLEET, ON
For Waterford Sand & Gravel Ltd.

DATE: DECEMBER 2021
PROJECT: 111-53023-05
DRAWN BY: JLD
SCALE: 1 : 95,000
FIGURE No: **H-5**

\\CASCR1DAT01\VOL1\PROJECTS\2011\111-53023 LAW QUARRY\05 2018 LEVEL 2 GW MODELLING\GRAPHICS\111-53023-05-FH5-SP.DWG



LEGEND

☐ ACTIVE MODEL GRID

HYDRAULIC CONDUCTIVITY (ZONE / DESCRIPTION)

■ 1 *WEATHERED* SALINA FORMATION

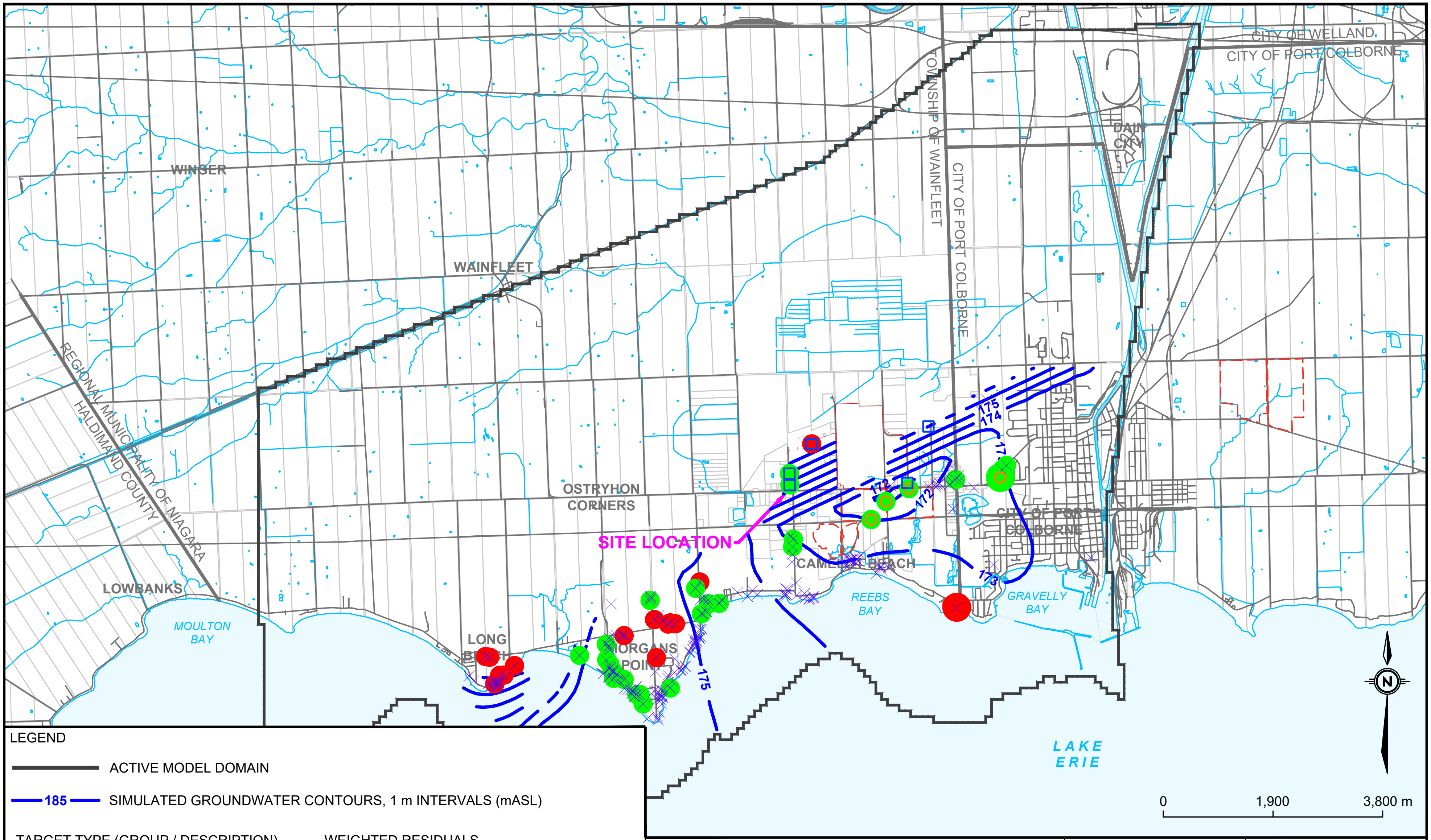
■ 2 *UNWEATHERED* SALINA FORMATION

LAYER 10
CONDUCTIVITY ZONES

NUMERICAL GROUNDWATER MODEL REPORT
LAW QUARRY EXTENSION
WAINFLEET, ON
For Waterford Sand & Gravel Ltd.

DATE:	DECEMBER 2021
PROJECT:	111-53023-05
DRAWN BY:	JLD
SCALE:	1 : 95,000
FIGURE No:	H-6

\\CASCR1DAT01\VOL1\PROJECTS\2011\111-53023 LAW QUARRY\05 2018 LEVEL 2 GW MODELLING\GRAPHICS\111-53023-05-FH6-SP.DWG



LEGEND

ACTIVE MODEL DOMAIN

185 SIMULATED GROUNDWATER CONTOURS, 1 m INTERVALS (mASL)

TARGET TYPE (GROUP / DESCRIPTION)

- □ 1 SITE WELL DATA
- ○ 2 OTHER HIGH-QUALITY WELLS
- × 3 MECP WATER WELL RECORDS

WEIGHTED RESIDUALS

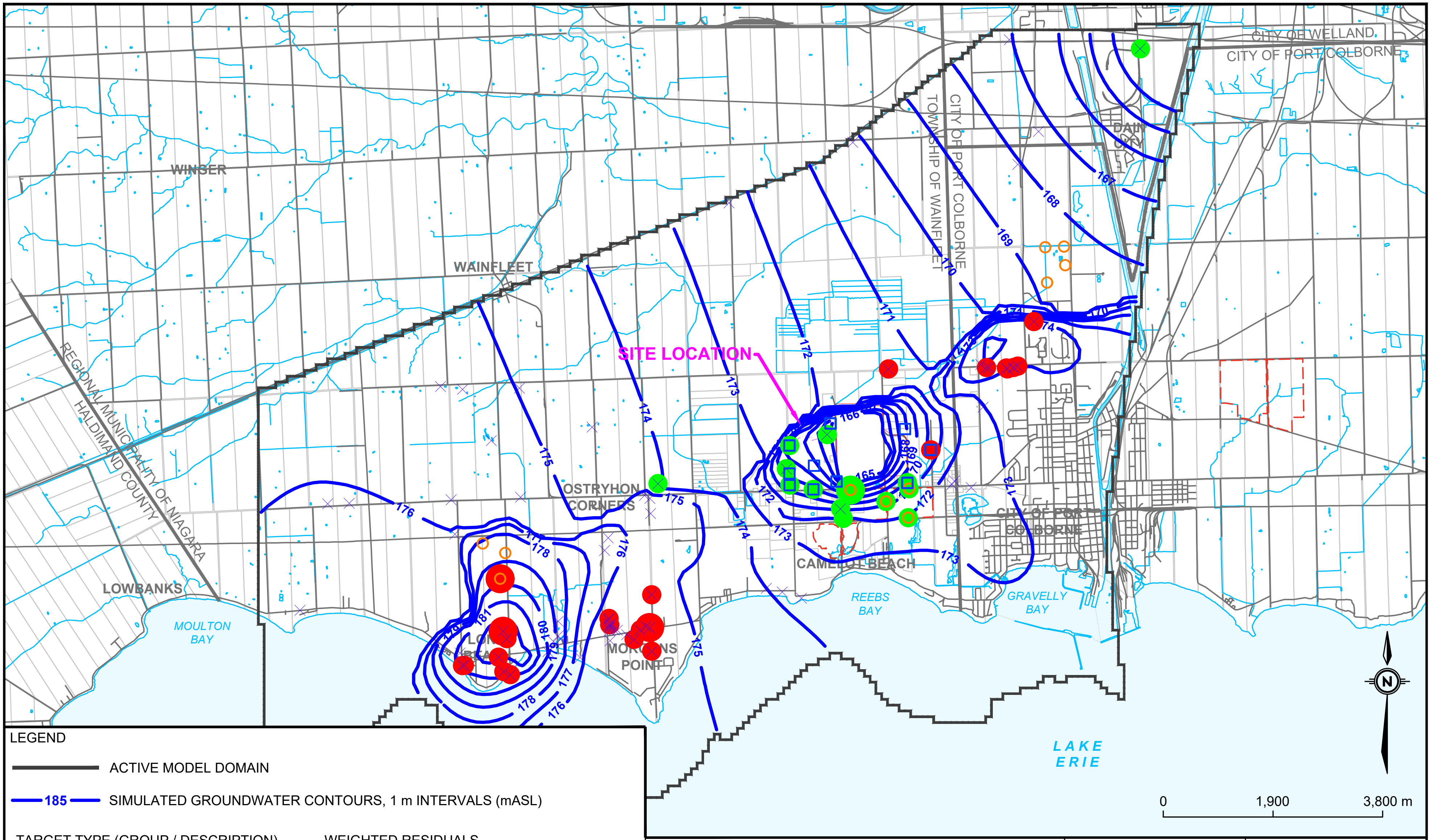
- ● OVER-PREDICTION > 5 m
- ● OVER-PREDICTION 2 m - 5 m
- ○ ± 2 m
- ● UNDER-PREDICTION 2 m - 5 m
- ● UNDER-PREDICTION > 5 m

SPATIAL DISTRIBUTION OF CALIBRATED RESIDUALS - SHALLOW BEDROCK AQUIFER

NUMERICAL GROUNDWATER MODEL REPORT
LAW QUARRY EXTENSION
WAINFLEET, ON
For Waterford Sand & Gravel Ltd.

DATE:	DECEMBER 2021
PROJECT:	111-53023-05
DRAWN BY:	JLD
SCALE:	1 : 95,000
FIGURE No:	H-7

\\CASCR1DAT01\VOL1\PROJECTS\2011\111-53023 LAW QUARRY\05 2018 LEVEL 2 GW MODELLING\GRAPHICS\111-53023-05-FH7-SP.DWG



LEGEND

ACTIVE MODEL DOMAIN

185 SIMULATED GROUNDWATER CONTOURS, 1 m INTERVALS (mASL)

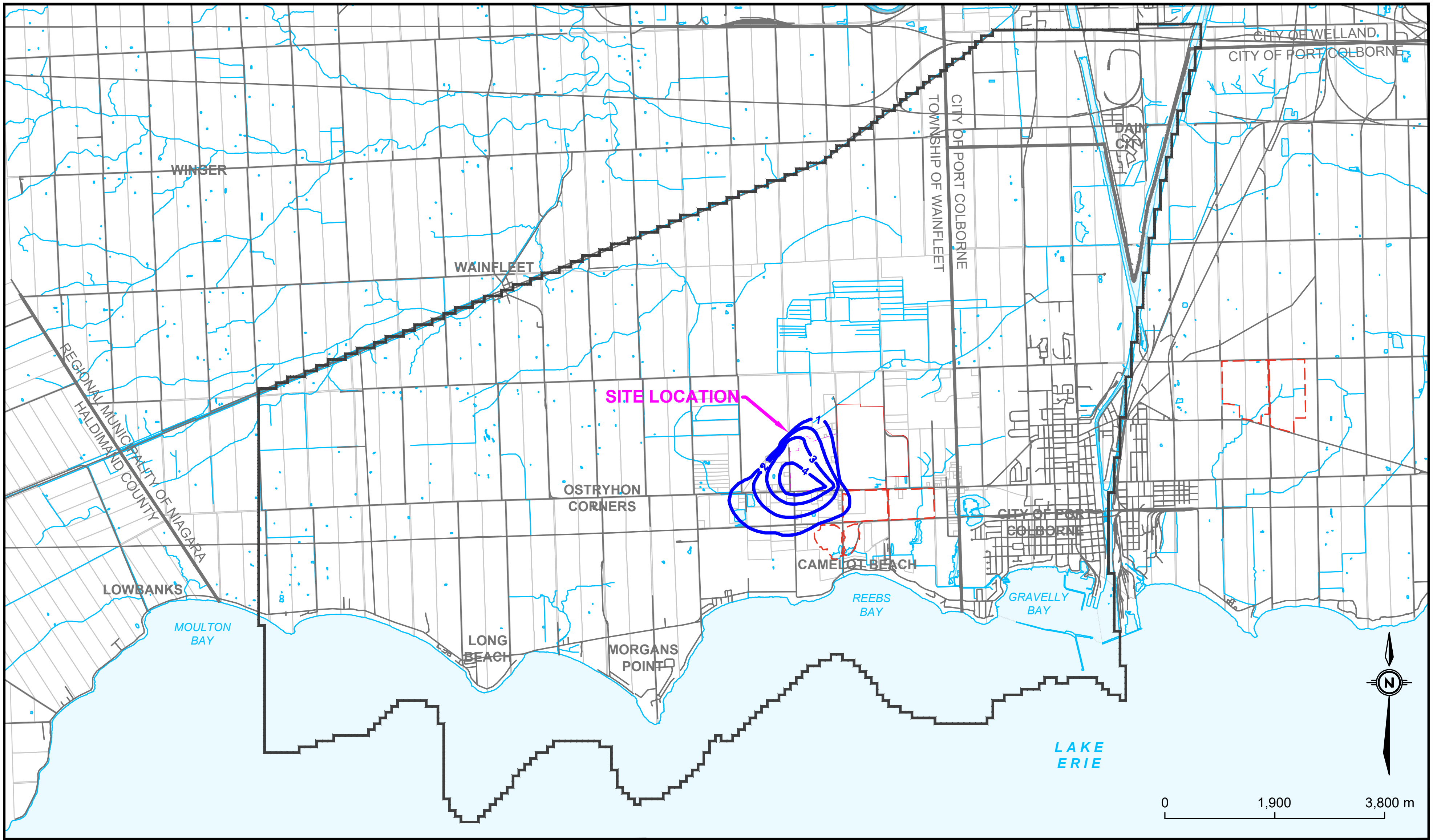
TARGET TYPE (GROUP / DESCRIPTION)			WEIGHTED RESIDUALS	
□	1	SITE WELL DATA	●	OVER-PREDICTION > 5 m
○	2	OTHER HIGH-QUALITY WELLS	●	OVER-PREDICTION 2 m - 5 m
×	3	MECP WATER WELL RECORDS	○	± 2 m
			●	UNDER-PREDICTION 2 m - 5 m
			●	UNDER-PREDICTION > 5 m

SPATIAL DISTRIBUTION OF CALIBRATED RESIDUALS - DEEPER BEDROCK UNITS

NUMERICAL GROUNDWATER MODEL REPORT
LAW QUARRY EXTENSION
WAINFLEET, ON
For Waterford Sand & Gravel Ltd.

DATE: DECEMBER 2021
PROJECT: 111-53023-05
DRAWN BY: JLD
SCALE: 1 : 95,000
FIGURE No: H-8

\\CASCR1DAT01\VOL1\PROJECTS\2011\111-53023 LAW QUARRY\05 2018 LEVEL 2 GW MODELLING\GRAPHICS\111-53023-05-FH8-SP.DWG



LEGEND

ACTIVE MODEL DOMAIN

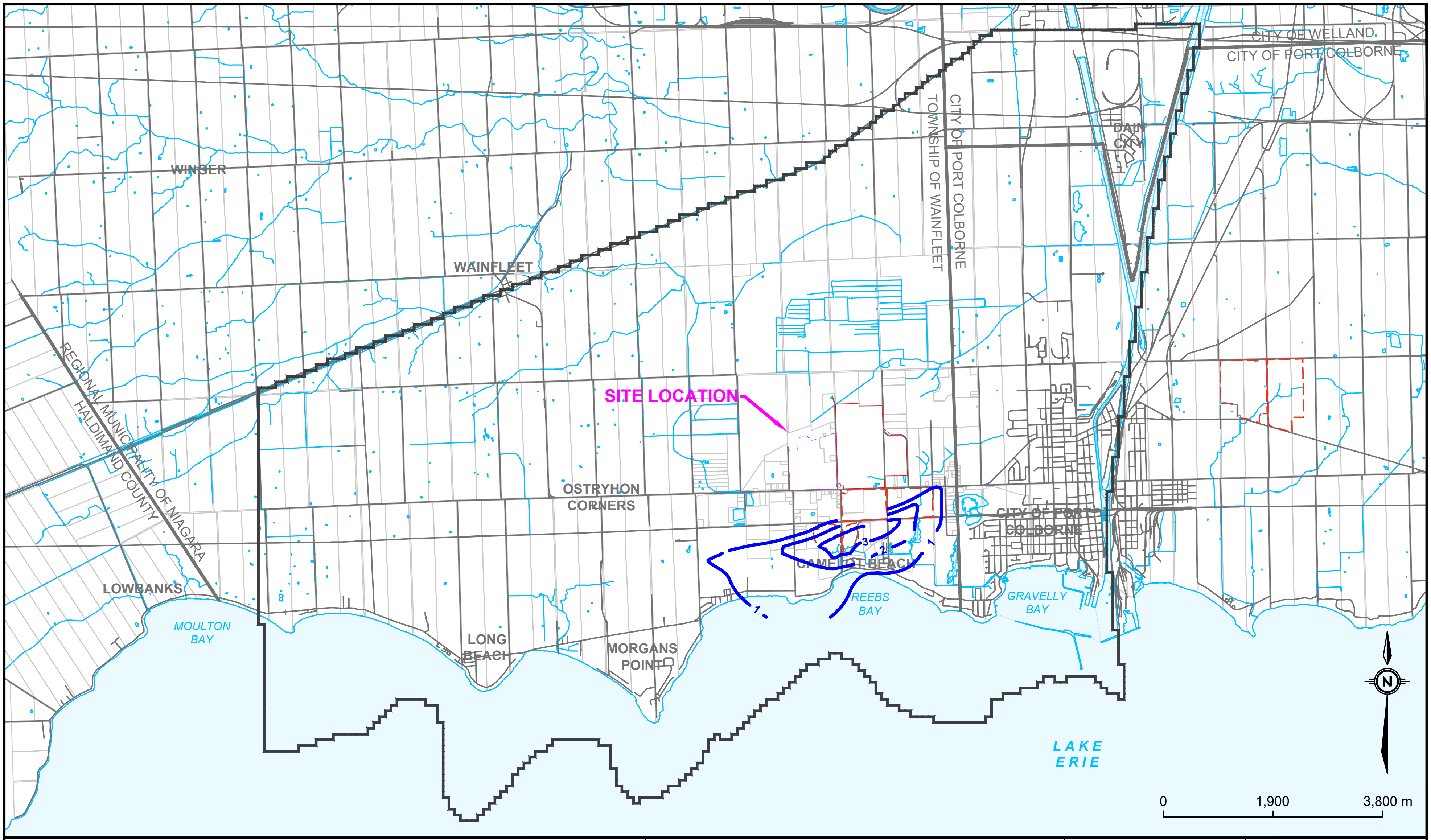
1 SIMULATED DRAWDOWN CONTOURS, 1 m INTERVALS (m)

PREDICTED DRAWDOWN AT FULL QUARRY DEVELOPMENT - DEEPER BEDROCK UNITS

NUMERICAL GROUNDWATER MODEL REPORT
LAW QUARRY EXTENSION
WAINFLEET, ON
For Waterford Sand & Gravel Ltd.

DATE:	DECEMBER 2021
PROJECT:	111-53023-05
DRAWN BY:	JLD
SCALE:	1 : 95,000
FIGURE No:	H-9

\\CASCR1DAT01\VOL1\PROJECTS\2011\111-53023 LAW QUARRY\05 2018 LEVEL 2 GW MODELLING\GRAPHICS\111-53023-05-FH9-SP.DWG



LEGEND

ACTIVE MODEL DOMAIN

1 SIMULATED DRAWDOWN CONTOURS, 1 m INTERVALS (m)

CUMULATIVE IMPACTS AT FULL QUARRY DEVELOPMENT - SHALLOW BEDROCK AQUIFER

NUMERICAL GROUNDWATER MODEL REPORT
LAW QUARRY EXTENSION
WAINFLEET, ON
For Waterford Sand & Gravel Ltd.

DATE: DECEMBER 2021

PROJECT: 111-53023-05

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SCALE: 1 : 95,000

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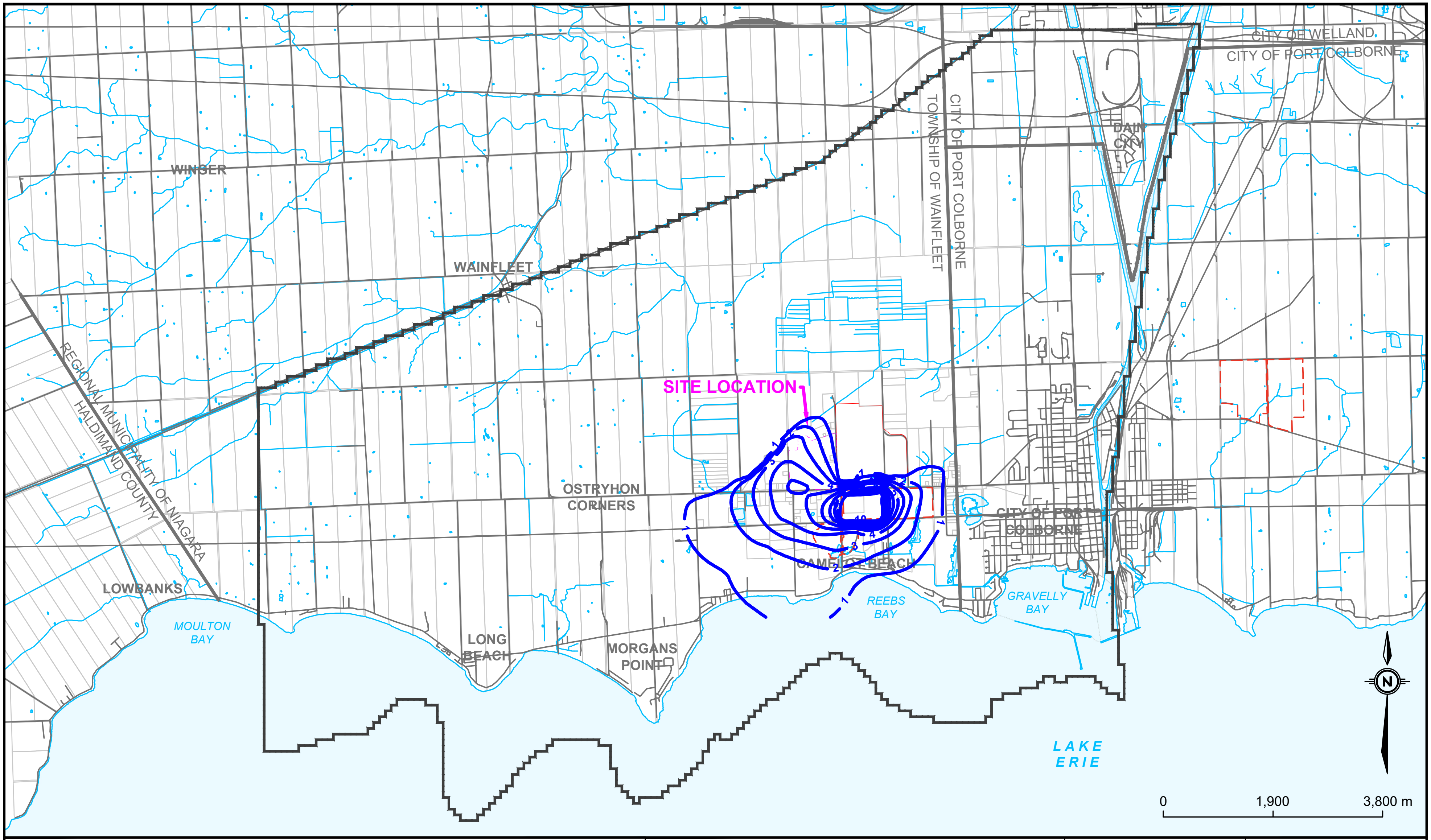
FIGURE No: **H-10**

\\CASCR1DAT01\VOL1\PROJECTS\2011\111-53023 LAW QUARRY\05 2018 LEVEL 2 GW MODELLING\GRAPHICS\111-53023-05-FH10-SP.DWG



LEGEND

ACTIVE MODEL DOMAIN

1 SIMULATED DRAWDOWN CONTOURS, 1 m INTERVALS (m)

CUMULATIVE IMPACTS AT FULL QUARRY DEVELOPMENT - DEEPER BEDROCK UNITS

NUMERICAL GROUNDWATER MODEL REPORT
LAW QUARRY EXTENSION
WAINFLEET, ON
For Waterford Sand & Gravel Ltd.

DATE: DECEMBER 2021
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FIGURE No: H-11

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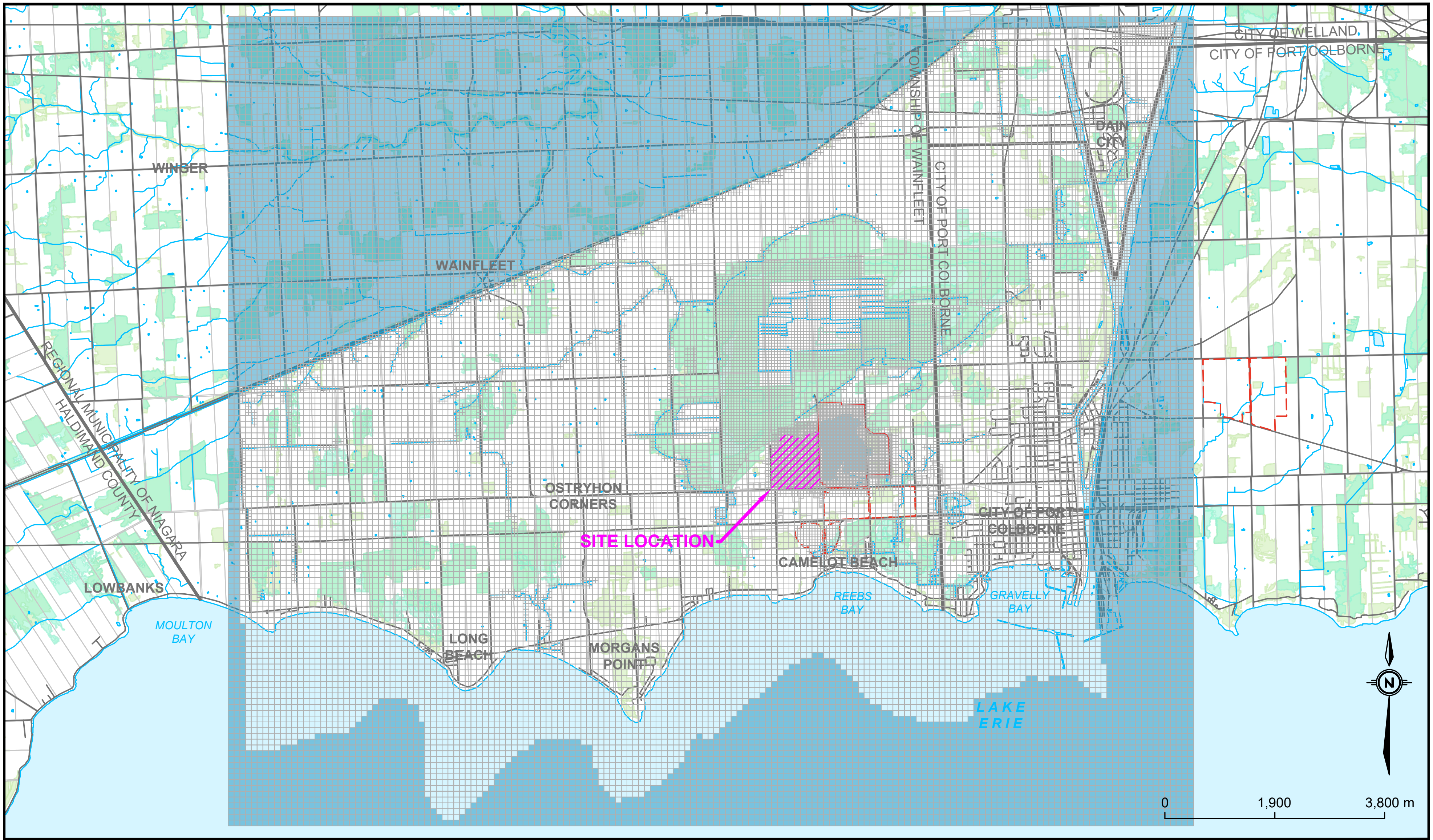
FIGURES



LEGEND

☐ MODEL GRID

▨ NO FLOW BOUNDARY

MODEL DOMAIN GRID

NUMERICAL GROUNDWATER MODEL REPORT
LAW QUARRY EXTENSION
WAINFLEET, ON
For Waterford Sand & Gravel Ltd.

DATE: DECEMBER 2021

PROJECT: 111-53023-05

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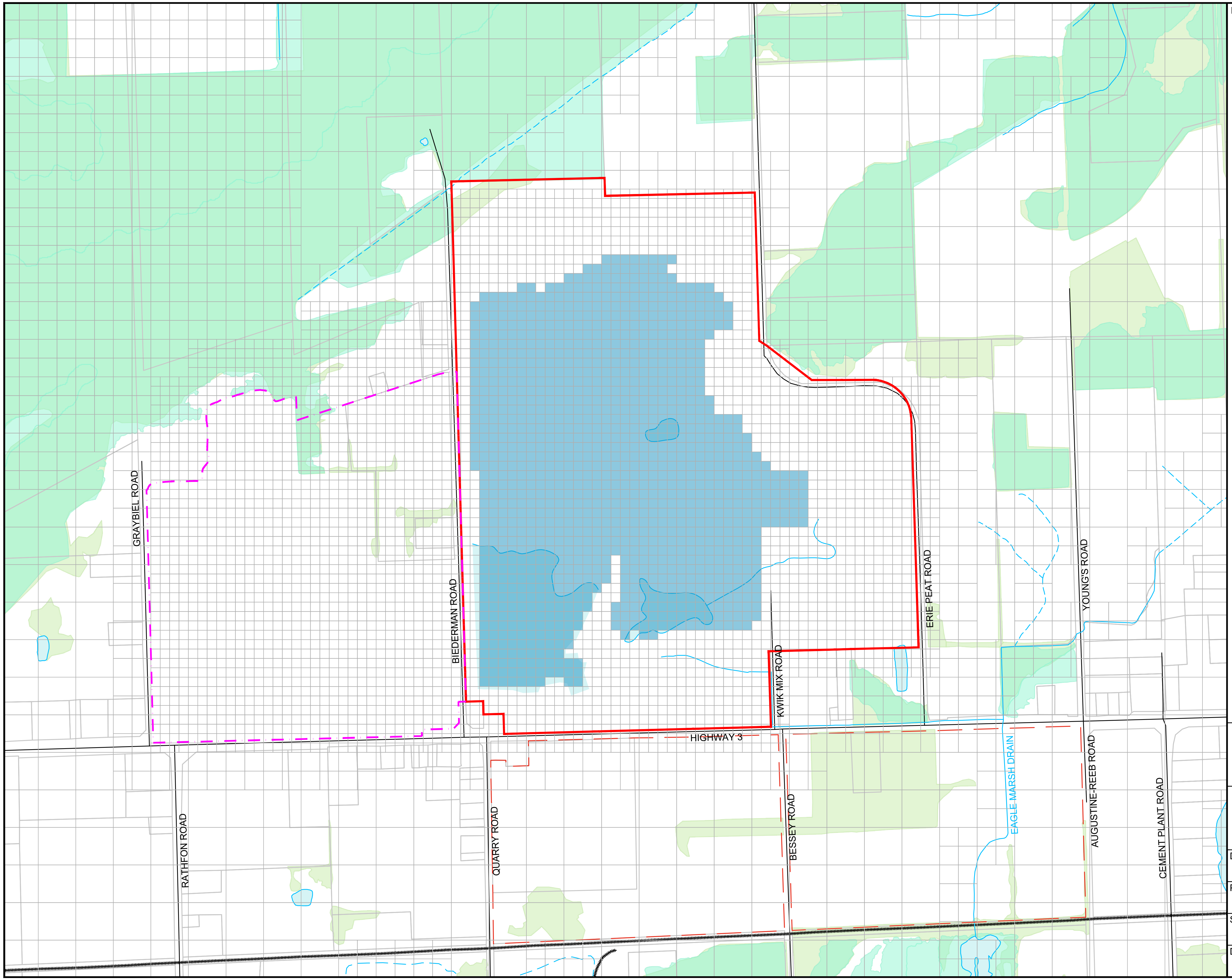
SCALE: 1 : 95,000

FIGURE No: **H-1**

\\CASCR1DAT01\VOL1\PROJECTS\2011\111-53023 LAW QUARRY\05 2018 LEVEL 2 GW MODELLING\GRAPHICS\111-53023-05-FH1-SP.DWG



LEGEND

— · —	PROPOSED WEST EXTENSION
——	EXISTING QUARRY LICENCE
——	APPROXIMATE LAND PARCEL
— —	REEB QUARRY LICENCE
🟩	WOODLOT
🟩	WETLAND
～	PERMANENT STREAM
- -	INTERMITTENT STREAM
☐	MODEL GRID
🟦	NO FLOW BOUNDARY

N

0 200 400 m

LOCAL MODEL GRID

NUMERICAL GROUNDWATER MODEL REPORT
LAW QUARRY EXTENSION
WAINFLEET, ON
For Waterford Sand & Gravel Ltd.

DATE: DECEMBER 2021

PROJECT: 111-53023-05

SCALE: 1 : 10,000

DRAWN BY: JLD

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FIGURE No: H-1A

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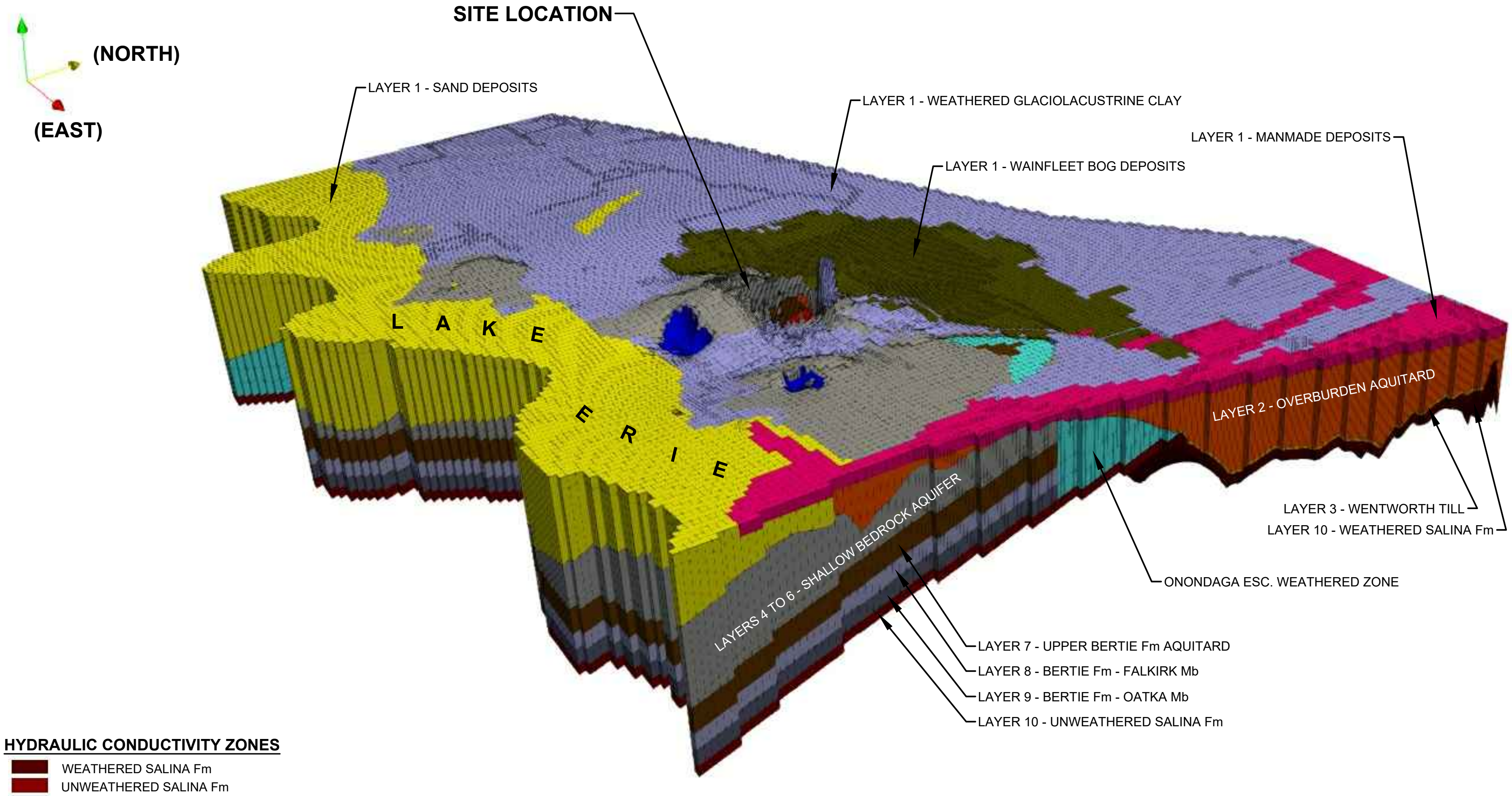


HYDRAULIC CONDUCTIVITY ZONES

- WEATHERED SALINA Fm
- UNWEATHERED SALINA Fm
- BERTIE Fm - OATKA Mb
- BERTIE Fm - FALKIRK Mb
- UPPER BERTIE AQUITARD
- SHALLOW BEDROCK AQUIFER / BEDROCK OUTCROPS
- WENTWORTH TILL
- OVERBURDEN AQUITARD
- WEATHERED GLACIOLACUSTRINE CLAY
- WAINFLEET BOG DEPOSITS
- SAND DEPOSITS
- MANMADE DEPOSITS
- QUARRY LAKES
- ACTIVE QUARRY EXCAVATION
- ONONDAGA ESC. WEATHERED ZONE

3-DIMENSIONAL VIEW OF MODEL LAYERS

NUMERICAL GROUNDWATER MODEL REPORT
LAW QUARRY EXTENSION
WAINFLEET, ON
For Waterford Sand & Gravel Ltd.

DATE: DECEMBER 2021
PROJECT: 111-52023-05
DRAWN BY: JLD
SCALE: NOT TO SCALE
FIGURE No: H-2

LEGEND

⬜ ACTIVE MODEL GRID

NO-FLOW BOUNDARY

■ ACTIVE QUARRY EXCAVATION **(LAYERS 1 - 7)**

RIVERS (REACH / DESCRIPTION)

🟦 0 WAINFLEET BOG
🟫 1 BIEDERMAN DRAIN
🟩 2 EAGLE MARSH DRAIN
🟦 3 FEEDER CANAL
🟦 4 THE CLAY PITS
■ 5 SMALL UNDIFFERENTIATED WATERBODIES
🟪 6 OTHER WETLANDS

(LAYER 1)

GENERAL HEAD BOUNDARY (REACH)

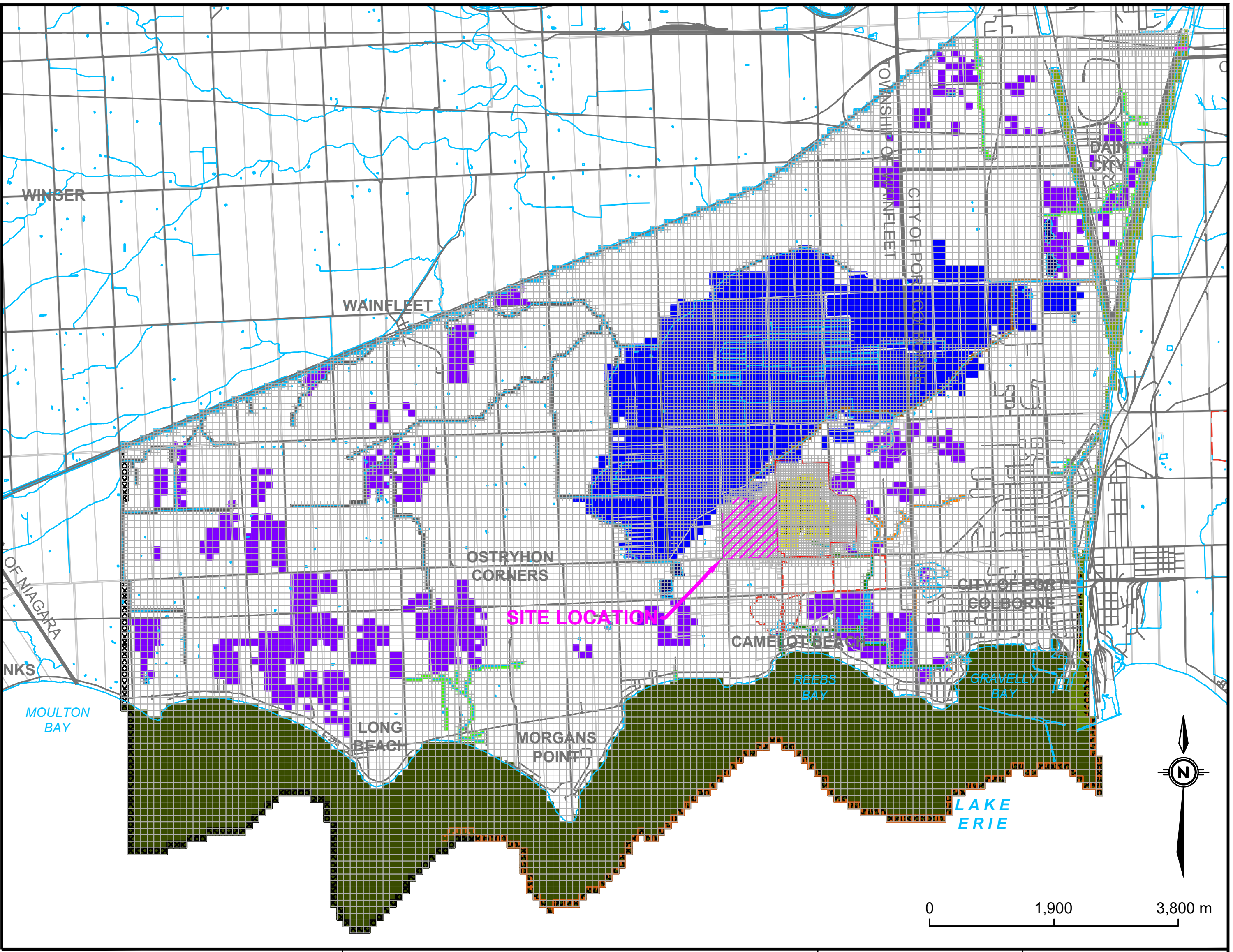
▩ 0 **(LAYER 10)**
▣ 1 **(LAYER 4)**

DRAINS (REACH / DESCRIPTION)

■ 0 MILL RACE CREEK
⬜ 1 BIEDERMAN DRAIN TRIBUTARIES
🟧 2 EAGLE MARSH DRAIN TRIBUTARIES
🟩 3 OTHER TRIBUTARIES

(LAYER 1)

🟨 4 ACTIVE QUARRY SUMP **(LAYER 8)**
🟪 5 QUARRY LAKES SUMP **(LAYER 4)**
🟦 6 SCHOLFIELD AVENUE PUMPING STATION **(LAYER 4)**
▨ 7 TOWNLINE TUNNEL DEWATERING SUMP **(LAYER 10)**



CONSTANT HEAD BOUNDARY (REACH / DESCRIPTION)

■ 0 LAKE ERIE
■ 1 WELLAND CANAL (ABOVE LOCK 8)
■ 2 WELLAND CANAL (BELOW LOCK 8)

(LAYER 1)

BOUNDARY CONDITIONS

NUMERICAL GROUNDWATER MODEL REPORT
LAW QUARRY EXTENSION
WAINFLEET, ON
For Waterford Sand & Gravel Ltd.

DATE:	DECEMBER 2021
PROJECT:	111-53023-05
DRAWN BY:	JLD
SCALE:	1 : 95,000
FIGURE No:	H-3

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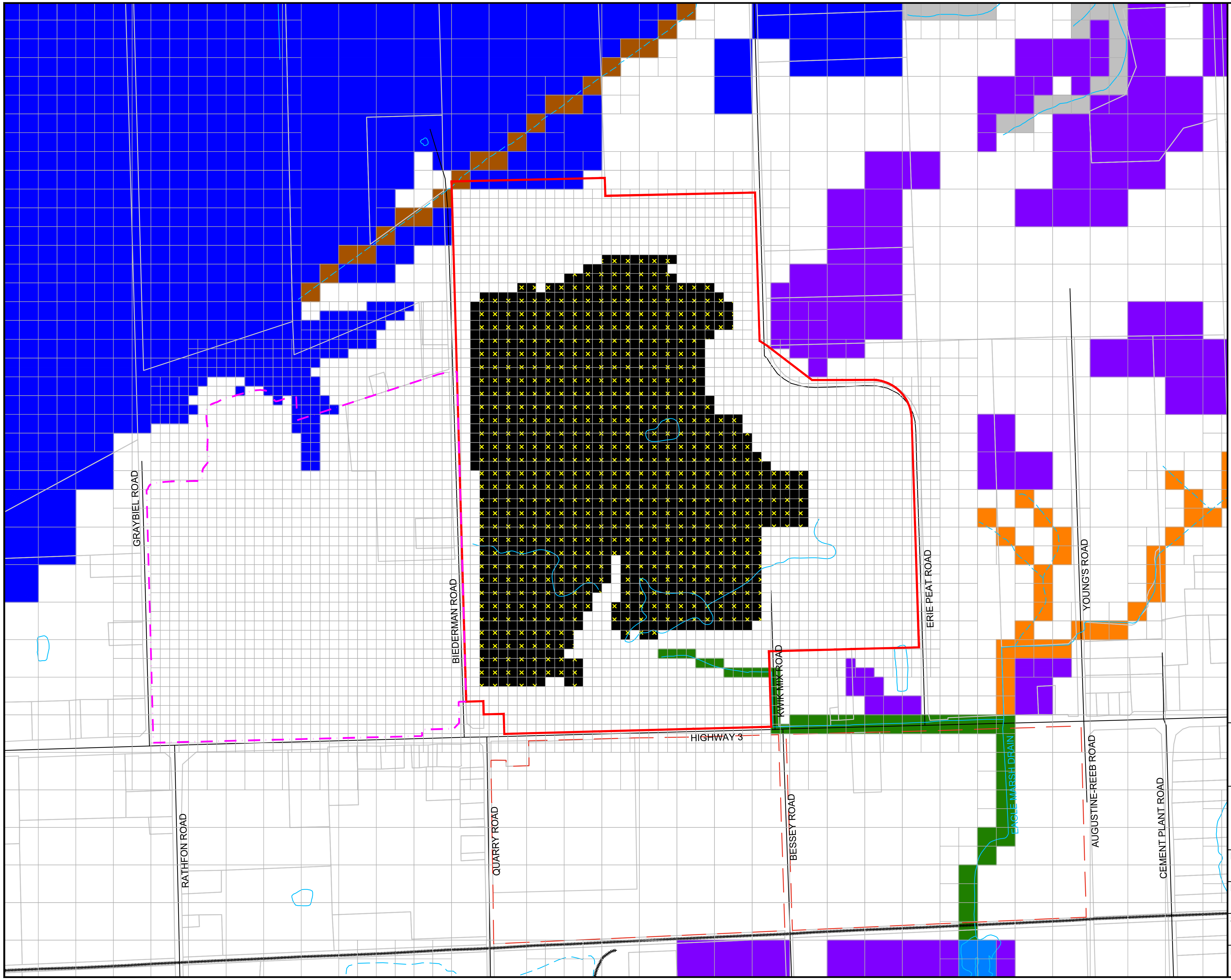

LEGEND

- PROPOSED WEST EXTENSION
- EXISTING QUARRY LICENCE
- APPROXIMATE LAND PARCEL
- REEB QUARRY LICENCE
- PERMANENT STREAM
- INTERMITTENT STREAM
- ☐ ACTIVE MODEL GRID

NO-FLOW BOUNDARY

- ■ ACTIVE QUARRY EXCAVATION **(LAYERS 1 - 7)**

RIVERS (REACH / DESCRIPTION) (LAYER 1)

🟦	0	WAINFLEET BOG
🟫	1	BIEDERMAN DRAIN
🟩	2	EAGLE MARSH DRAIN
🟦	4	THE CLAY PITS
🟪	6	OTHER WETLANDS

DRAINS (REACH / DESCRIPTION) (LAYER 1)

⬜	1	BIEDERMAN DRAIN TRIBUTARIES
🟧	2	EAGLE MARSH DRAIN TRIBUTARIES
☒	4	ACTIVE QUARRY SUMP **(LAYER 8)**

N

0 200 400 m

LOCAL BOUNDARY CONDITIONS

NUMERICAL GROUNDWATER MODEL REPORT
LAW QUARRY EXTENSION
WAINFLEET, ON
For Waterford Sand & Gravel Ltd.

DATE: DECEMBER 2021
PROJECT: 111-53023-05
SCALE: 1 : 10,000
DRAWN BY: JLD
FIGURE No: **H-3A**

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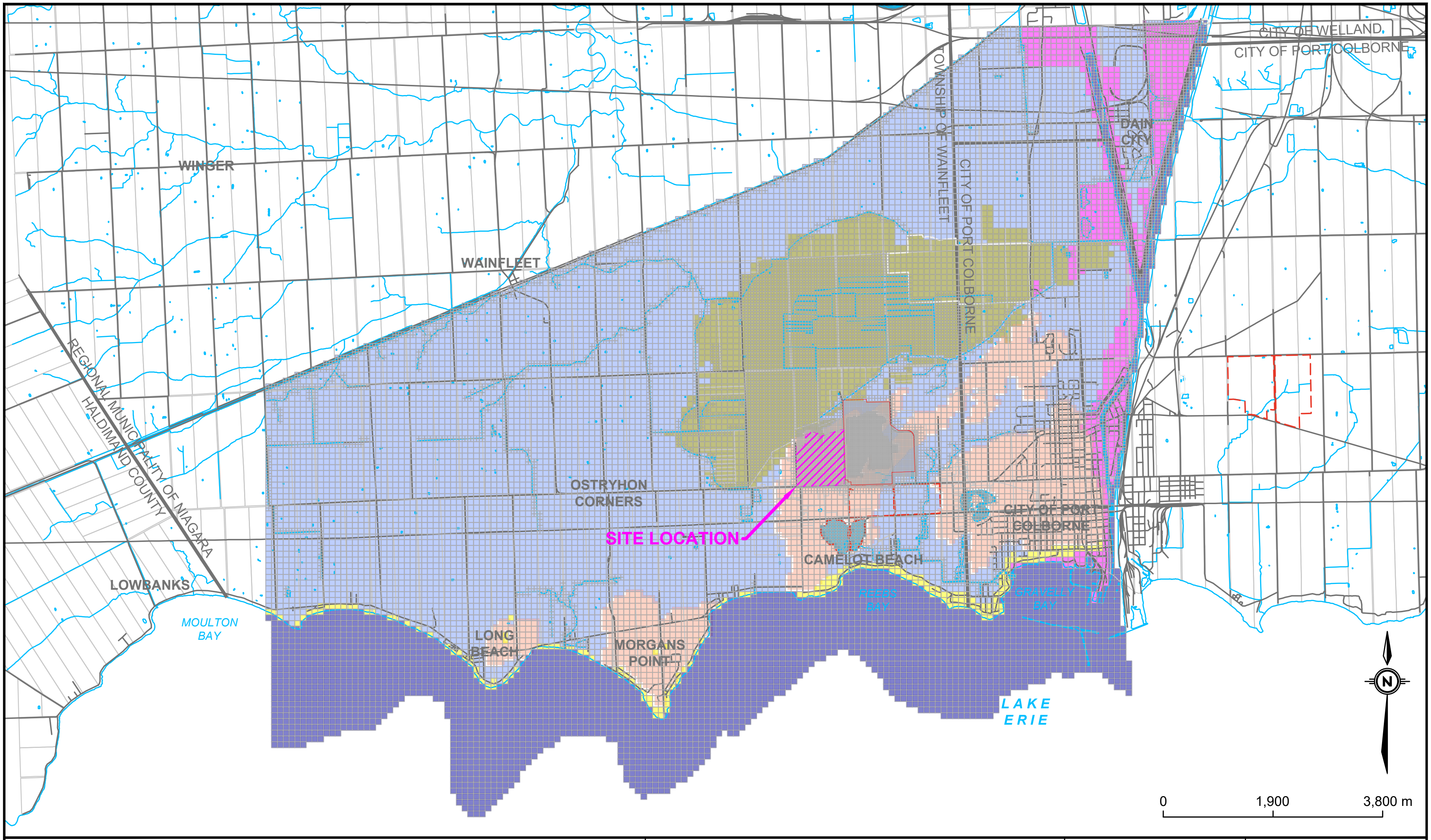


LEGEND

☐ ACTIVE MODEL GRID

RECHARGE (ZONE / DESCRIPTION)

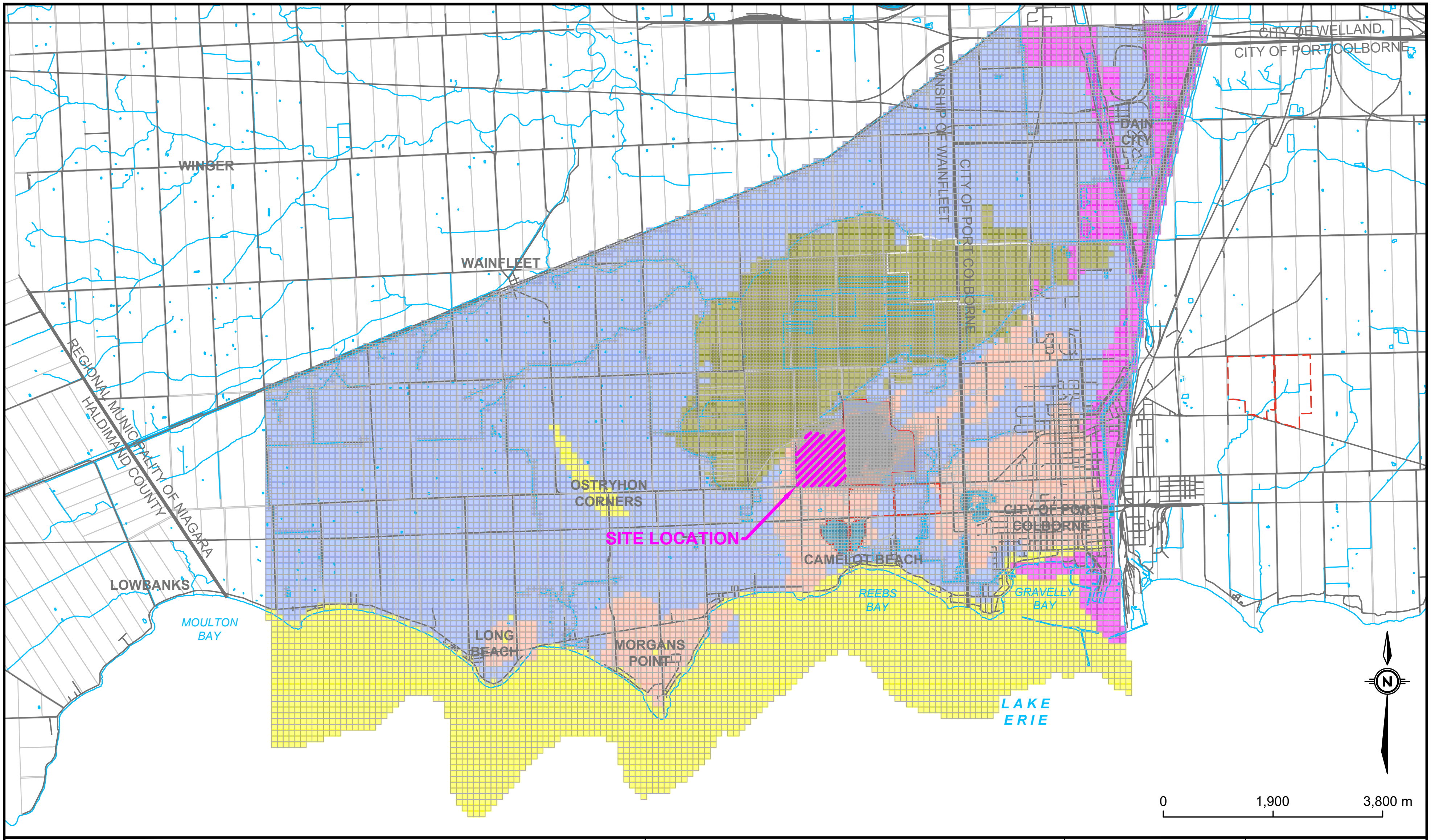
■	1	GLACIOLACUSTRINE CLAY
■	2	WAINFLEET BOG DEPOSITS
■	3	BEDROCK OUTCROPS
■	4	SAND DEPOSITS
■	5	MANMADE DEPOSITS
■	6	QUARRY LAKES
■	7	ACTIVE QUARRY EXCAVATION
■	8	LAKE ERIE

RECHARGE ZONES

NUMERICAL GROUNDWATER MODEL REPORT
LAW QUARRY EXTENSION
WAINFLEET, ON
For Waterford Sand & Gravel Ltd.

DATE: DECEMBER 2021
PROJECT: 111-53023-05
DRAWN BY: JLD
SCALE: 1 : 95,000
FIGURE No: **H-4**

\\CASCR1DAT01\VOL1\PROJECTS\2011\111-53023 LAW QUARRY\05 2018 LEVEL 2 GW MODELLING\GRAPHICS\111-53023-05-FH4-SP.DWG



LEGEND

☐ ACTIVE MODEL GRID

HYDRAULIC CONDUCTIVITY (ZONE / DESCRIPTION)

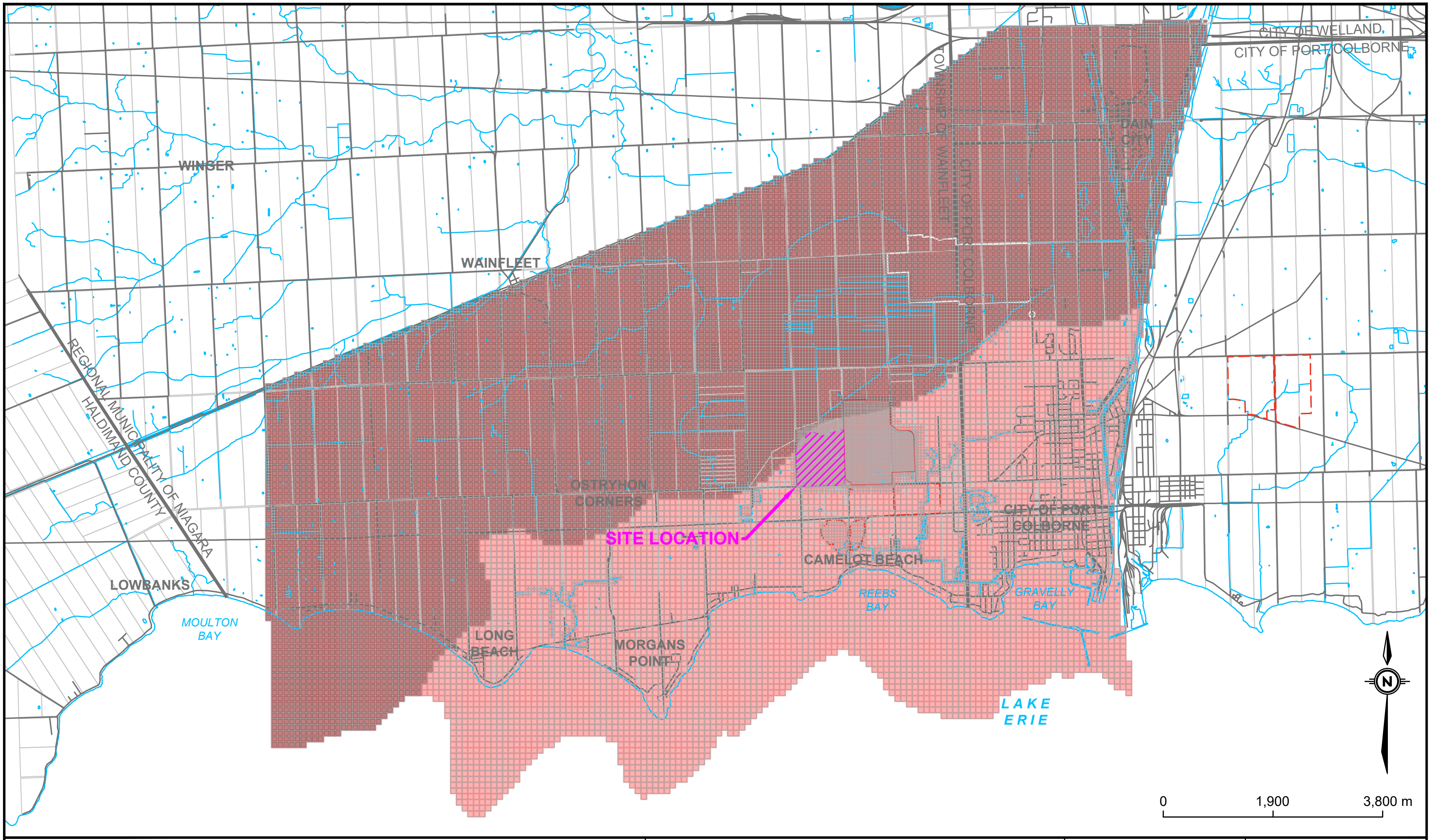
■	6	BEDROCK OUTCROPS
■	9	GLACIOLACUSTRINE CLAY
■	10	WAINFLEET BOG DEPOSITS
■	11	SAND DEPOSITS
■	12	MANMADE DEPOSITS
■	13	QUARRY LAKES
■	14	ACTIVE QUARRY EXCAVATION

LAYER 1
CONDUCTIVITY ZONES

NUMERICAL GROUNDWATER MODEL REPORT
LAW QUARRY EXTENSION
WAINFLEET, ON
For Waterford Sand & Gravel Ltd.

DATE: DECEMBER 2021
PROJECT: 111-53023-05
DRAWN BY: JLD
SCALE: 1 : 95,000
FIGURE No: **H-5**

\\CASCR1DAT01\VOL1\PROJECTS\2011\111-53023 LAW QUARRY\05 2018 LEVEL 2 GW MODELLING\GRAPHICS\111-53023-05-FH5-SP.DWG



LEGEND

☐ ACTIVE MODEL GRID

HYDRAULIC CONDUCTIVITY (ZONE / DESCRIPTION)

🟫 1 *WEATHERED* SALINA FORMATION

🟥 2 *UNWEATHERED* SALINA FORMATION

LAYER 10
CONDUCTIVITY ZONES

NUMERICAL GROUNDWATER MODEL REPORT
LAW QUARRY EXTENSION
WAINFLEET, ON
For Waterford Sand & Gravel Ltd.

DATE: DECEMBER 2021

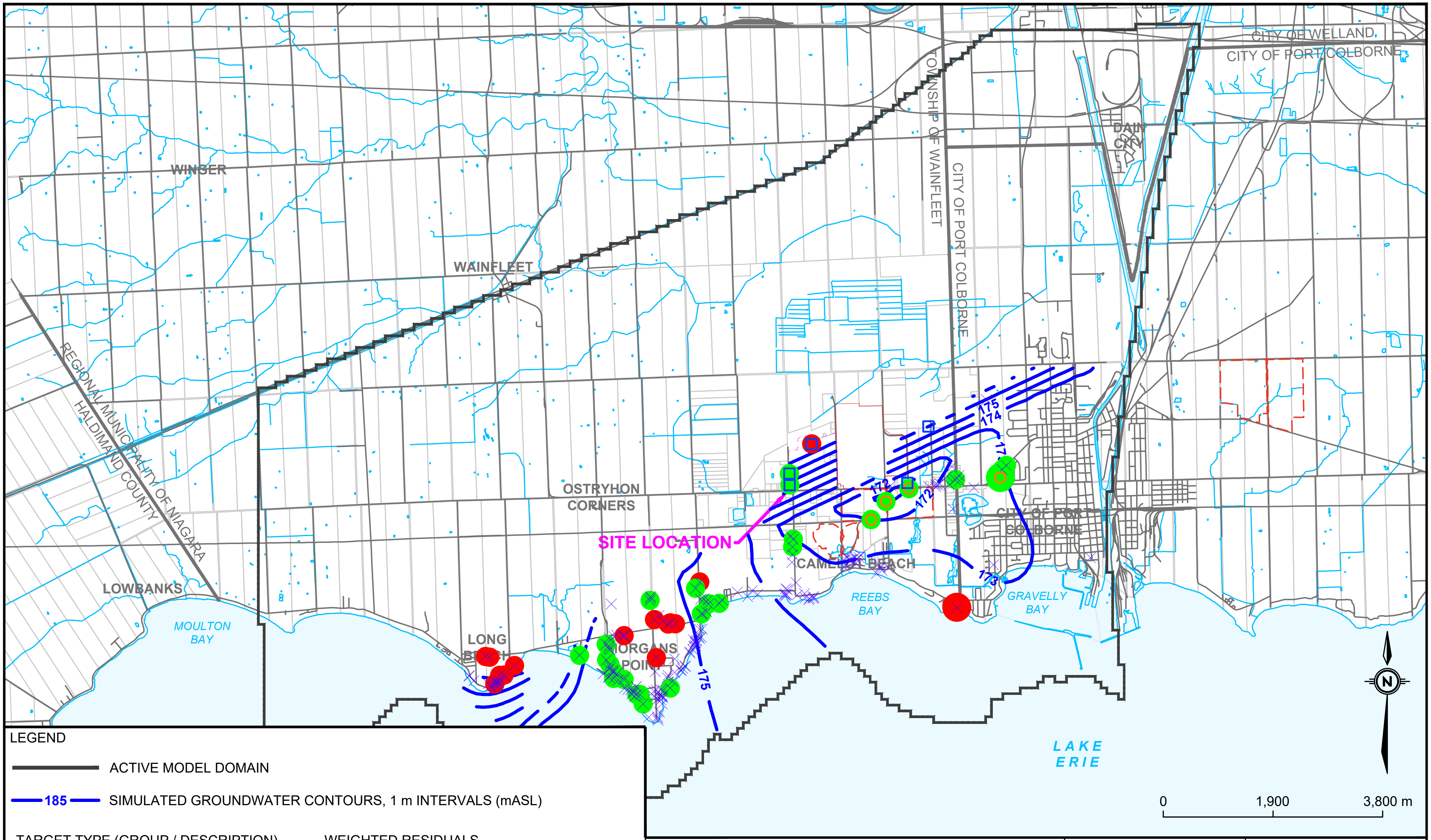
PROJECT: 111-53023-05

DRAWN BY: JLD

SCALE: 1 : 95,000

FIGURE No: **H-6**

\\CASCR1DAT01\VOL1\PROJECTS\2011\111-53023 LAW QUARRY\05 2018 LEVEL 2 GW MODELLING\GRAPHICS\111-53023-05-FH6-SP.DWG



LEGEND

ACTIVE MODEL DOMAIN

185 SIMULATED GROUNDWATER CONTOURS, 1 m INTERVALS (mASL)

TARGET TYPE (GROUP / DESCRIPTION)

☐ 1 SITE WELL DATA
○ 2 OTHER HIGH-QUALITY WELLS
× 3 MECP WATER WELL RECORDS

WEIGHTED RESIDUALS

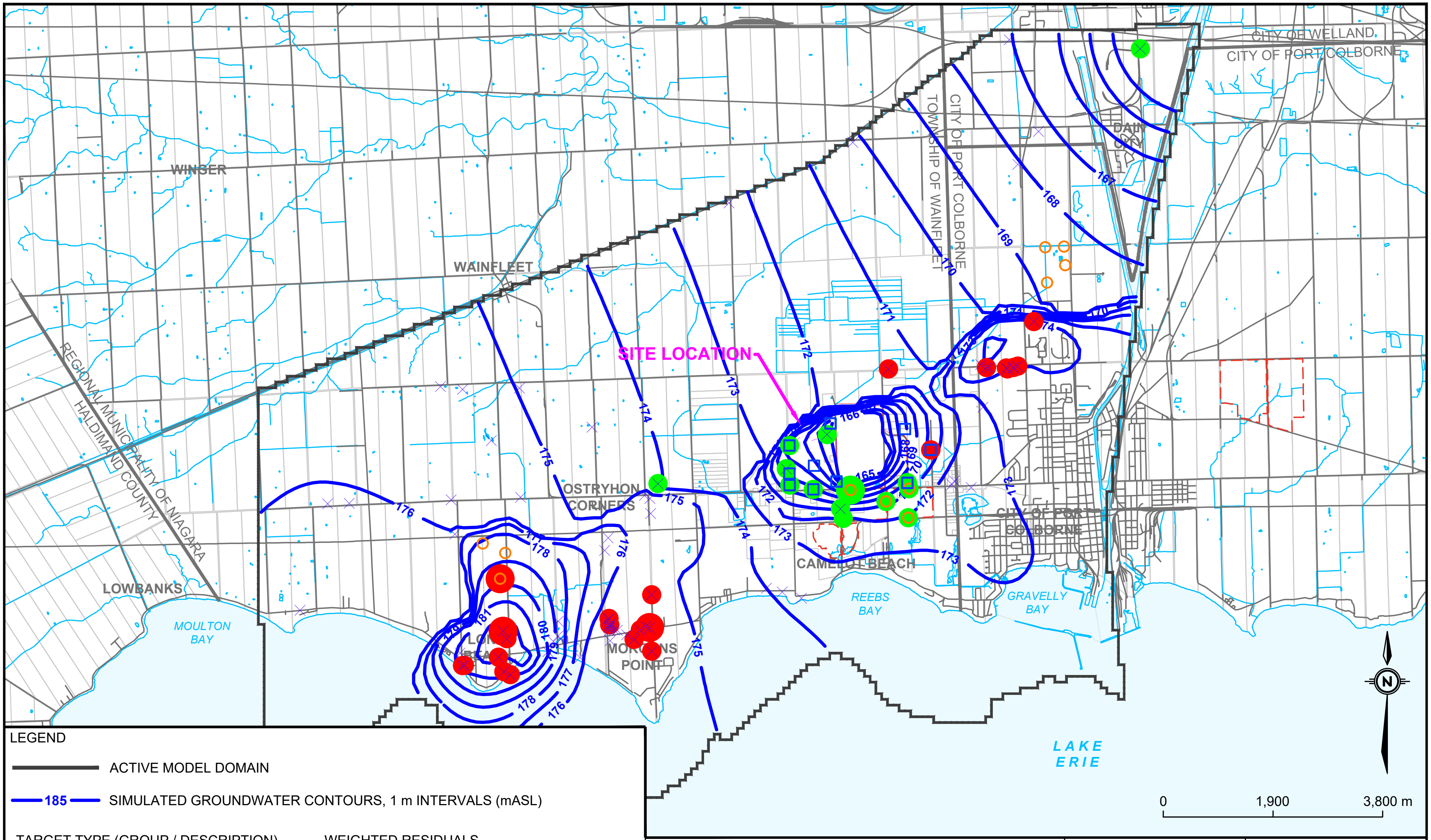
● OVER-PREDICTION > 5 m
● OVER-PREDICTION 2 m - 5 m
○ ± 2 m
● UNDER-PREDICTION 2 m - 5 m
● UNDER-PREDICTION > 5 m

SPATIAL DISTRIBUTION OF CALIBRATED RESIDUALS - SHALLOW BEDROCK AQUIFER

NUMERICAL GROUNDWATER MODEL REPORT
LAW QUARRY EXTENSION
WAINFLEET, ON
For Waterford Sand & Gravel Ltd.

DATE: DECEMBER 2021
PROJECT: 111-53023-05
DRAWN BY: JLD
SCALE: 1 : 95,000
FIGURE No: **H-7**

wsp



LEGEND

ACTIVE MODEL DOMAIN

185 SIMULATED GROUNDWATER CONTOURS, 1 m INTERVALS (mASL)

TARGET TYPE (GROUP / DESCRIPTION)		
□	1	SITE WELL DATA
○	2	OTHER HIGH-QUALITY WELLS
×	3	MECP WATER WELL RECORDS

WEIGHTED RESIDUALS	
●	OVER-PREDICTION > 5 m
●	OVER-PREDICTION 2 m - 5 m
○	± 2 m
●	UNDER-PREDICTION 2 m - 5 m
●	UNDER-PREDICTION > 5 m

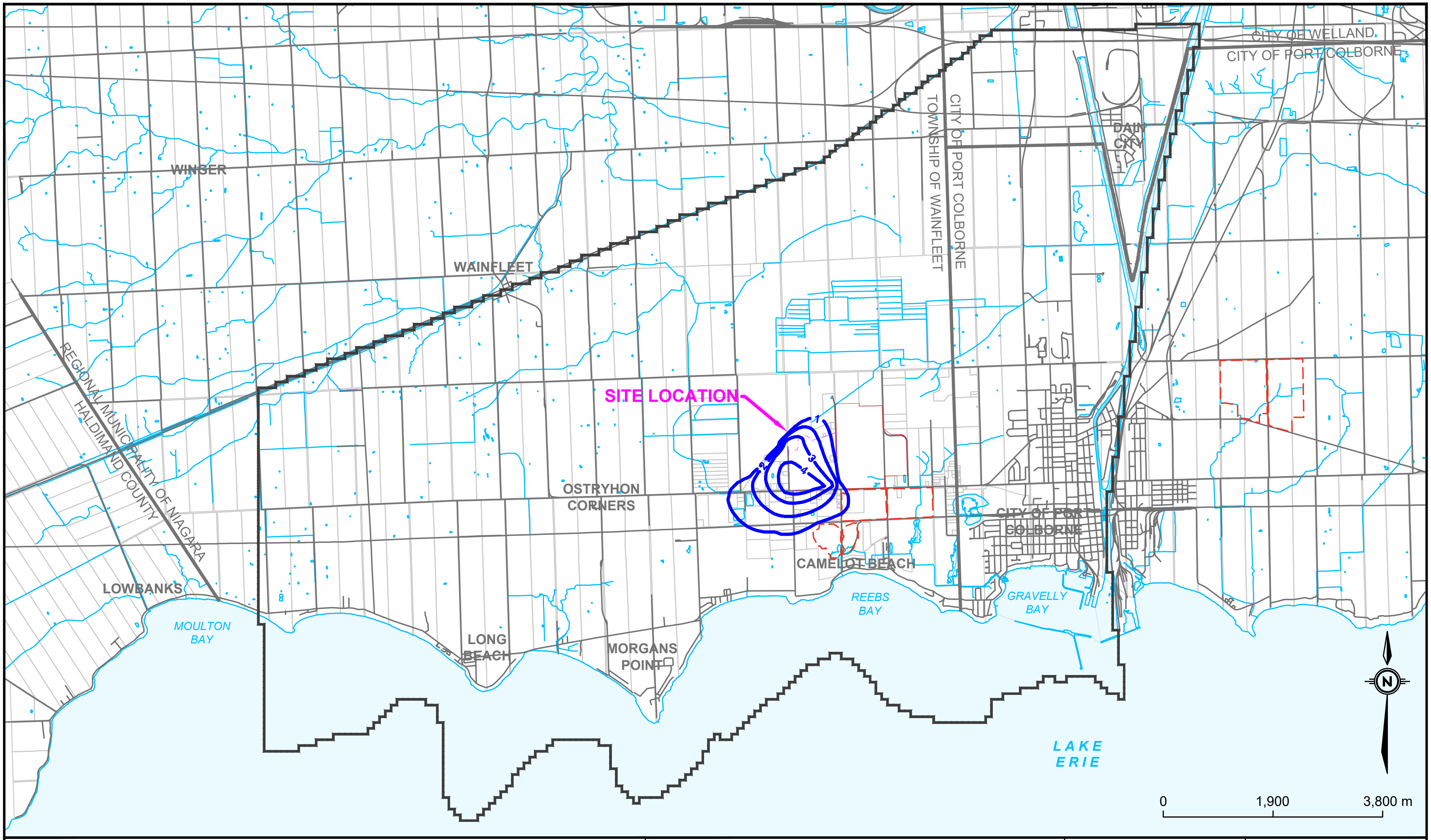
SPATIAL DISTRIBUTION OF CALIBRATED RESIDUALS - DEEPER BEDROCK UNITS

NUMERICAL GROUNDWATER MODEL REPORT
LAW QUARRY EXTENSION
WAINFLEET, ON
For Waterford Sand & Gravel Ltd.

DATE: DECEMBER 2021
PROJECT: 111-53023-05
DRAWN BY: JLD
SCALE: 1 : 95,000
FIGURE No: H-8

wsp

\\CASCR1DAT01\VOL1\PROJECTS\2011\111-53023 LAW QUARRY\05 2018 LEVEL 2 GW MODELLING\GRAPHICS\111-53023-05-FH8-SP.DWG



LEGEND

ACTIVE MODEL DOMAIN

1 SIMULATED DRAWDOWN CONTOURS, 1 m INTERVALS (m)

PREDICTED DRAWDOWN AT FULL QUARRY DEVELOPMENT - DEEPER BEDROCK UNITS

NUMERICAL GROUNDWATER MODEL REPORT
LAW QUARRY EXTENSION
WAINFLEET, ON
For Waterford Sand & Gravel Ltd.

DATE: DECEMBER 2021

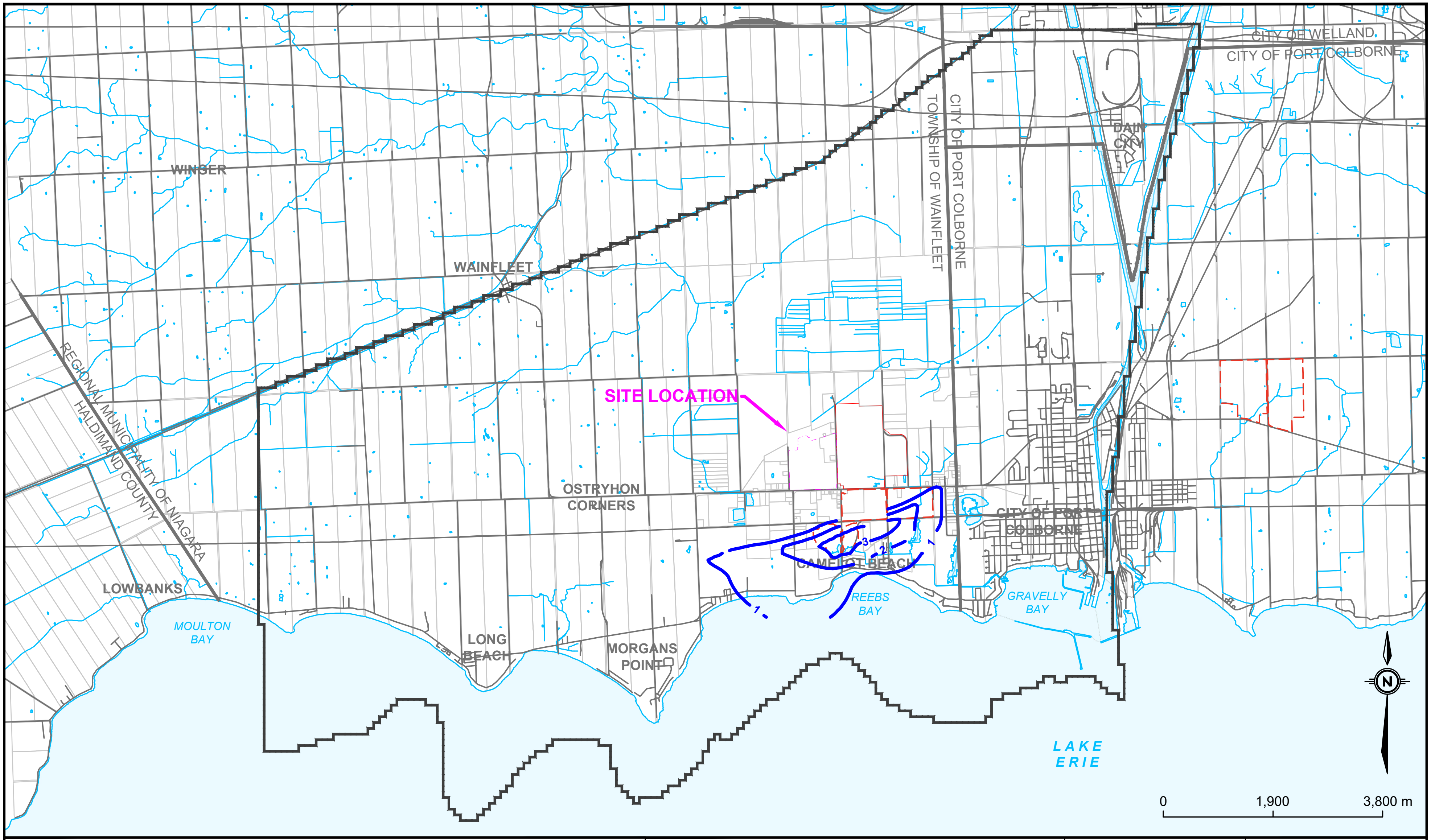
PROJECT: 111-53023-05

DRAWN BY: JLD

SCALE: 1 : 95,000

FIGURE No: **H-9**

\\CASCR1DAT01\VOL1\PROJECTS\2011\111-53023 LAW QUARRY\05 2018 LEVEL 2 GW MODELLING\GRAPHICS\111-53023-05-FH9-SP.DWG



LEGEND

▬ ACTIVE MODEL DOMAIN

— 1 — SIMULATED DRAWDOWN CONTOURS, 1 m INTERVALS (m)

CUMULATIVE IMPACTS AT FULL QUARRY DEVELOPMENT - SHALLOW BEDROCK AQUIFER

NUMERICAL GROUNDWATER MODEL REPORT
LAW QUARRY EXTENSION
WAINFLEET, ON
For Waterford Sand & Gravel Ltd.

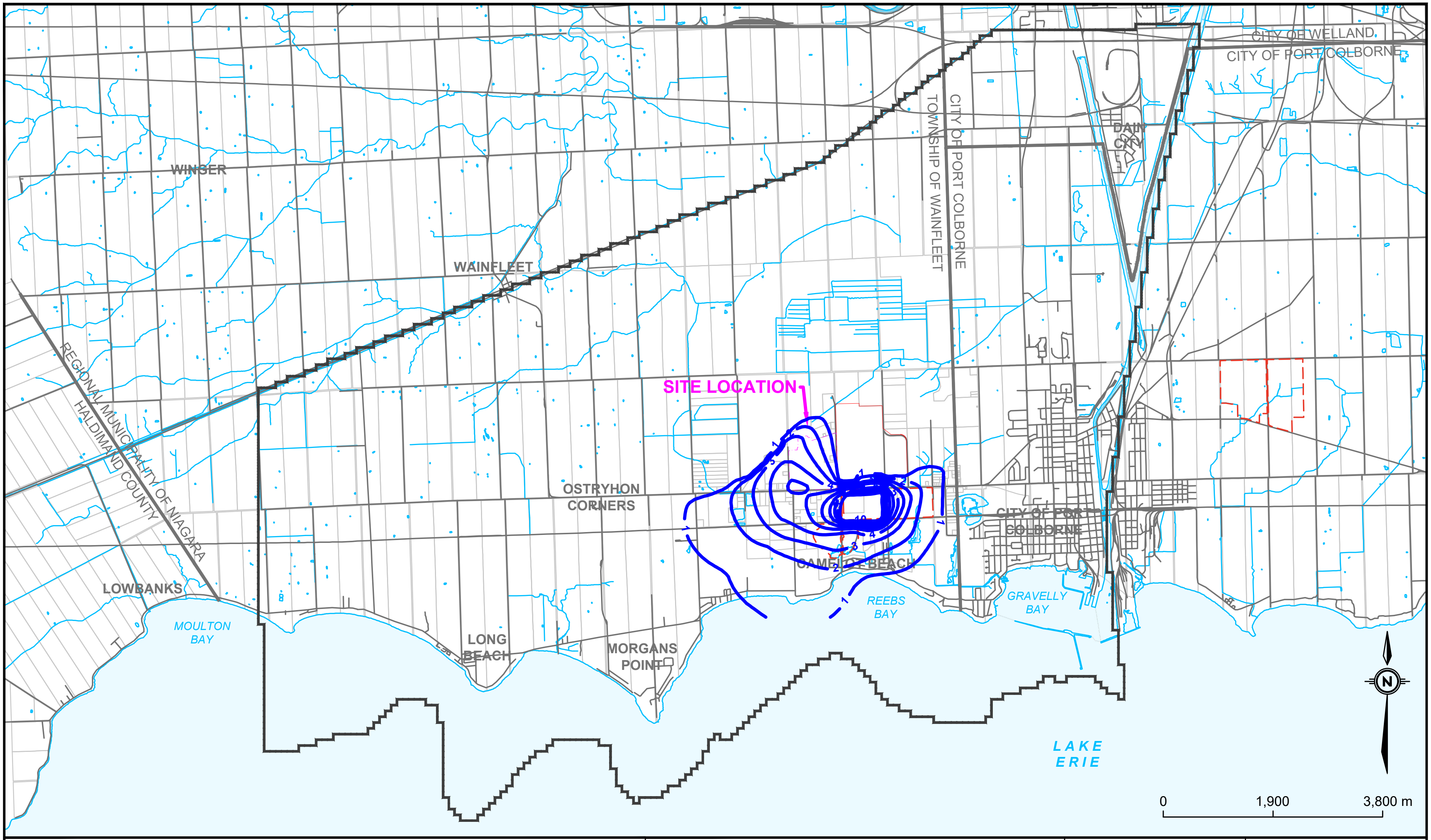
DATE: DECEMBER 2021

PROJECT: 111-53023-05

DRAWN BY: JLD

SCALE: 1 : 95,000

FIGURE No: **H-10**



LEGEND

ACTIVE MODEL DOMAIN

1 SIMULATED DRAWDOWN CONTOURS, 1 m INTERVALS (m)

CUMULATIVE IMPACTS AT FULL QUARRY DEVELOPMENT - DEEPER BEDROCK UNITS

NUMERICAL GROUNDWATER MODEL REPORT
LAW QUARRY EXTENSION
WAINFLEET, ON
For Waterford Sand & Gravel Ltd.

DATE: DECEMBER 2021

PROJECT: 111-53023-05

DRAWN BY: JLD

SCALE: 1 : 95,000

FIGURE No: **H-11**

\\CASCR1DAT01\VOL1\PROJECTS\2011\111-53023 LAW QUARRY\05 2018 LEVEL 2 GW MODELLING\GRAPHICS\111-53023-05-FH11-SP.DWG

APPENDIX

I

CLIMATE DATA

Table I-1: 30 Year Climate Normal (1981 - 2010)

Month	Mean Temperature °C	I	E mm	Daylight Factor	E Adj. mm	Total Precipitation mm	WHC mm	Surplus mm	Deficit mm
January	-3.7	0.0	0.0	0.8	0.0	73.1	200.0	73.1	0.0
February	-2.9	0.0	0.0	0.8	0.0	57.0	200.0	57.0	0.0
March	0.8	0.1	2.3	1.0	2.4	66.8	200.0	64.4	0.0
April	7.0	1.7	28.8	1.1	32.3	76.1	200.0	43.8	0.0
May	13.2	4.3	60.1	1.3	76.4	89.7	200.0	13.3	0.0
June	18.7	7.3	90.1	1.3	115.3	78.9	163.6	0.0	0.0
July	21.9	9.3	108.2	1.3	140.7	82.2	105.1	0.0	0.0
August	21.3	8.9	104.8	1.2	125.7	82.5	61.9	0.0	0.0
September	17.4	6.6	82.9	1.0	86.2	98.0	73.7	0.0	0.0
October	11.0	3.3	48.7	1.0	46.2	90.4	117.9	0.0	0.0
November	5.5	1.2	21.8	0.8	17.6	100.9	200.0	1.1	0.0
December	-0.4	0.0	0.0	0.8	0.0	88.8	200.0	88.8	0.0
Total	**9.2**	**42.6**			**642.8**	**984.4**		**341.6**	**0.0**
					Net Water Surplus	**341.6**	**mm**		

Table I-2: 2011 Water Budget

Month	Mean Temperature °C	I	E mm	Daylight Factor	E Adj. mm	Total Precipitation mm	WHC mm	Surplus mm	Deficit mm
January	-4.9	0.0	0.0	0.8	0.0	32.3	200.0	32.3	0.0
February	-3.7	0.0	0.0	0.8	0.0	72.9	200.0	72.9	0.0
March	0.6	0.0	1.2	1.0	1.3	138.6	200.0	137.3	0.0
April	7.2	1.7	26.9	1.1	30.1	158.6	200.0	128.5	0.0
May	14.1	4.8	61.8	1.3	78.4	181.8	200.0	103.4	0.0
June	19.0	7.5	89.4	1.3	114.4	63.3	148.9	0.0	0.0
July	24.1	10.7	120.0	1.3	156.0	31.4	24.3	0.0	0.0
August	22.1	9.4	107.8	1.2	129.4	57.2	0.0	0.0	47.9
September	18.8	7.4	88.2	1.0	91.8	113.8	22.0	0.0	0.0
October	11.9	3.7	50.1	1.0	47.6	85.2	59.7	0.0	0.0
November	8.7	2.3	34.0	0.8	27.5	49.6	81.8	0.0	0.0
December	1.9	0.2	5.2	0.8	4.0	44.3	122.1	0.0	0.0
Total	**10.0**	**47.9**			**680.4**	**1029.0**		**474.4**	**47.9**
					Net Water Surplus	**426.5**	**mm**		

Notes:

- calculations based on Thornthwaite Mather Method
- °C calculated mean of daily temperatures for the month, in degrees Celcius
- I denotes Heat Index
- E denotes Evapotranspiration
- WHC denotes Water Holding Capacity
- A value of 200 mm was used for the water holding capacity of the soils (clay loam soil moderately deep-rooted crops).
- Climate normal data from the Port Colborne climatological station located at latitude 42°53'00"N, longitude 79°15'00"W
- Temperature and precipitation data from the Port Colborne climatological station located at latitude 42°53'00"N, longitude 79°15'00"W

Table I-3: 2012 Water Budget

Month	Mean Temperature °C	I	E mm	Daylight Factor	E Adj. mm	Total Precipitation mm	WHC mm	Surplus mm	Deficit mm
January	0.1	0.0	0.1	0.8	0.1	82.2	200.0	82.1	0.0
February	0.3	0.0	0.4	0.8	0.3	50.8	200.0	50.5	0.0
March	8.2	2.1	29.6	1.0	30.3	63.6	200.0	33.3	0.0
April	7.3	1.8	25.5	1.1	28.5	49.4	200.0	20.9	0.0
May	16.7	6.2	74.3	1.3	94.3	25.9	131.6	0.0	0.0
June	19.9	8.1	93.2	1.3	119.3	70.6	82.9	0.0	0.0
July	24.5	11.0	122.0	1.3	158.6	38.8	0.0	0.0	36.9
August	22.3	9.6	108.0	1.2	129.6	26.0	0.0	0.0	103.6
September	18.8	7.4	86.6	1.0	90.1	99.6	9.5	0.0	0.0
October	12.3	3.9	50.0	1.0	47.5	168.7	130.7	0.0	0.0
November	5.0	1.0	15.6	0.8	12.6	19.0	137.1	0.0	0.0
December	3.0	0.5	8.1	0.8	6.3	85.2	200.0	16.0	0.0
Total	**11.5**	**51.5**			**717.6**	**779.8**		**202.7**	**140.5**
					Net Water Surplus	**62.2**	**mm**		

Table I-4: 2013 Water Budget

Month	Mean Temperature °C	I	E mm	Daylight Factor	E Adj. mm	Total Precipitation mm	WHC mm	Surplus mm	Deficit mm
January	-0.9	0.0	0.0	0.8	0.0	61.4	200.0	61.4	0.0
February	-2.3	0.0	0.0	0.8	0.0	89.0	200.0	89.0	0.0
March	0.8	0.1	2.0	1.0	2.1	6.6	200.0	4.5	0.0
April	7.7	1.9	30.5	1.1	34.2	86.0	200.0	51.8	0.0
May	16.0	5.8	73.6	1.3	93.4	105.3	200.0	11.9	0.0
June	18.6	7.3	88.2	1.3	112.9	186.1	200.0	73.2	0.0
July	22.7	9.8	112.1	1.3	145.7	90.0	144.3	0.0	0.0
August	21.1	8.8	102.6	1.2	123.2	91.8	113.0	0.0	0.0
September	17.4	6.6	81.4	1.0	84.6	83.2	111.5	0.0	0.0
October	13.2	4.3	58.4	1.0	55.5	195.9	200.0	52.0	0.0
November	4.7	0.9	16.9	0.8	13.7	67.6	200.0	53.9	0.0
December	-1.3	0.0	0.0	0.8	0.0	115.2	200.0	115.2	0.0
Total	**9.8**	**45.5**			**665.2**	**1178.1**		**512.9**	**0.0**
					Net Water Surplus	**512.9**	**mm**		

Notes:
- calculations based on Thornthwaite Mather Method
- °C calculated mean of daily temperatures for the month, in degrees Celcius
- I denotes Heat Index
- E denotes Evapotranspiration
- WHC denotes Water Holding Capacity
- A value of 200 mm was used for the water holding capacity of the soils (clay loam soil moderately deep-rooted crops).
- Temperature and precipitation data from the Port Colborne climatological station located at latitude 42°53'00"N, longitude 79°15'00"W

Table I-5: 2014 Water Budget

Month	Mean Temperature °C	I	E mm	Daylight Factor	E Adj. mm	Total Precipitation mm	WHC mm	Surplus mm	Deficit mm
January	-6.2	0.0	0.0	0.8	0.0	62.6	200.0	62.6	0.0
February	-6.8	0.0	0.0	0.8	0.0	45.0	200.0	45.0	0.0
March	-2.0	0.0	0.0	1.0	0.0	36.4	200.0	36.4	0.0
April	6.6	1.5	26.7	1.1	29.9	129.6	200.0	99.7	0.0
May	12.7	4.1	57.2	1.3	72.7	79.0	200.0	6.3	0.0
June	20.8	8.6	101.8	1.3	130.3	61.6	131.3	0.0	0.0
July	20.9	8.7	102.3	1.3	133.0	78.4	76.7	0.0	0.0
August	21.6	9.1	106.3	1.2	127.6	19.9	0.0	0.0	31.0
September	17.9	6.9	85.4	1.0	88.8	49.7	0.0	0.0	39.1
October	11.8	3.7	52.5	1.0	49.9	127.0	77.1	0.0	0.0
November	3.0	0.5	10.6	0.8	8.6	55.4	123.9	0.0	0.0
December	1.0	0.1	2.9	0.8	2.3	39.5	161.1	0.0	0.0
Total	**8.4**	**43.1**			**643.1**	**784.1**		**250.1**	**70.1**
					Net Water Surplus	**179.9**	**mm**		

Table I-6: 2015 Water Budget

Month	Mean Temperature °C	I	E mm	Daylight Factor	E Adj. mm	Total Precipitation mm	WHC mm	Surplus mm	Deficit mm
January	-6.1	0.0	0.0	0.8	0.0	78.7	200.0	78.7	0.0
February	-10.9	0.0	0.0	0.8	0.0	80.0	200.0	80.0	0.0
March	-1.4	0.0	0.0	1.0	0.0	54.7	200.0	54.7	0.0
April	7.0	1.7	26.1	1.1	29.3	83.9	200.0	54.6	0.0
May	15.2	5.4	68.0	1.3	86.4	24.2	137.8	0.0	0.0
June	18.0	6.9	83.8	1.3	107.2	69.4	100.0	0.0	0.0
July	21.6	9.1	104.9	1.3	136.4	49.8	13.5	0.0	0.0
August	21.0	8.7	101.3	1.2	121.6	77.1	0.0	0.0	31.0
September	21.0	8.7	101.3	1.0	105.4	90.4	0.0	0.0	15.0
October	11.5	3.5	48.2	1.0	45.8	80.3	34.5	0.0	0.0
November	8.7	2.3	34.2	0.8	27.7	14.2	21.0	0.0	0.0
December	5.6	1.2	19.8	0.8	15.5	59.0	64.6	0.0	0.0
Total	**9.3**	**47.5**			**675.1**	**761.7**		**268.0**	**46.0**
					Net Water Surplus	**222.0**	**mm**		

Notes:
- calculations based on Thornthwaite Mather Method
- °C calculated mean of daily temperatures for the month, in degrees Celcius
- I denotes Heat Index
- E denotes Evapotranspiration
- WHC denotes Water Holding Capacity
- A value of 200 mm was used for the water holding capacity of the soils (clay loam soil moderately deep-rooted crops).
- Temperature and precipitation data from the Port Colborne climatological station located at latitude 42°53'00"N, longitude 79°15'00"W

Table I-7: 2016 Water Budget

Month	Mean Temperature °C	I	E mm	Daylight Factor	E Adj. mm	Total Precipitation mm	WHC mm	Surplus mm	Deficit mm
January	-1.1	0.0	0.0	0.8	0.0	32.8	200.0	32.8	0.0
February	-0.6	0.0	0.0	0.8	0.0	21.6	200.0	21.6	0.0
March	4.4	0.8	13.0	1.0	13.3	32.6	200.0	19.3	0.0
April	8.7	2.3	31.6	1.1	35.4	20.4	185.0	0.0	0.0
May	15.6	5.6	67.7	1.3	85.9	18.0	117.1	0.0	0.0
June	19.7	7.9	91.7	1.3	117.4	53.6	53.3	0.0	0.0
July	23.0	10.0	112.2	1.3	145.9	48.2	0.0	0.0	44.4
August	24.9	11.3	124.5	1.2	149.4	52.4	0.0	0.0	97.0
September	20.2	8.2	94.8	1.0	98.6	67.1	0.0	0.0	31.5
October	12.6	4.0	51.2	1.0	48.7	62.0	13.3	0.0	0.0
November	7.4	1.8	25.6	0.8	20.7	67.4	60.0	0.0	0.0
December	1.0	0.1	1.9	0.8	1.5	52.4	111.0	0.0	0.0
Total	**11.3**	**52.1**			**716.7**	**528.5**		**73.7**	**172.8**
					Net Water Surplus	**-99.2**	**mm**		

Table I-8: 2017 Water Budget

Month	Mean Temperature °C	I	E mm	Daylight Factor	E Adj. mm	Total Precipitation mm	WHC mm	Surplus mm	Deficit mm
January	0.0	0.0	0.0	0.8	0.0	48.2	200.0	48.2	0.0
February	1.5	0.2	3.8	0.8	3.1	44.0	200.0	40.9	0.0
March	1.7	0.2	4.5	1.0	4.6	90.3	200.0	85.7	0.0
April	10.2	2.9	41.3	1.1	46.3	111.9	200.0	65.6	0.0
May	13.5	4.5	58.5	1.3	74.3	112.4	200.0	38.1	0.0
June	20.1	8.2	95.8	1.3	122.6	52.4	129.8	0.0	0.0
July	21.8	9.2	106.0	1.3	137.7	49.8	41.8	0.0	0.0
August	21.3	8.9	103.0	1.2	123.5	73.0	0.0	0.0	8.7
September	18.7	7.3	87.6	1.0	91.1	23.8	0.0	0.0	67.3
October	15.3	5.4	68.3	1.0	64.9	113.4	48.5	0.0	0.0
November	5.4	1.1	18.8	0.8	15.2	94.9	128.2	0.0	0.0
December	-3.9	0.0	0.0	0.8	0.0	62.2	190.4	0.0	0.0
Total	**10.5**	**48.0**			**683.4**	**876.3**		**278.6**	**76.0**
					Net Water Surplus	**202.5**	**mm**		

Notes:
- calculations based on Thornthwaite Mather Method
- °C calculated mean of daily temperatures for the month, in degrees Celcius
- I denotes Heat Index
- E denotes Evapotranspiration
- WHC denotes Water Holding Capacity
- A value of 200 mm was used for the water holding capacity of the soils (clay loam soil moderately deep-rooted crops).
- Temperature and precipitation data from the Port Colborne climatological station located at latitude 42°53'00"N, longitude 79°15'00"W

Table I-9: 2018 Water Budget

Month	Mean Temperature °C	I	E mm	Daylight Factor	E Adj. mm	Total Precipitation mm	WHC mm	Surplus mm	Deficit mm
January	-3.0	0.0	0.0	0.8	0.0	42.8	200.0	42.8	0.0
February	-3.4	0.0	0.0	0.8	0.0	29.3	200.0	29.3	0.0
March	0.1	0.0	0.1	1.0	0.1	2.0	200.0	1.9	0.0
April	3.5	0.6	11.2	1.1	12.6	61.2	200.0	48.6	0.0
May	16.3	6.0	74.3	1.3	94.4	52.8	158.4	0.0	0.0
June	19.7	7.9	93.8	1.3	120.0	59.9	98.3	0.0	0.0
July	23.5	10.3	116.5	1.3	151.4	56.3	3.2	0.0	0.0
August	23.5	10.3	116.5	1.2	139.8	344.4	200.0	7.8	0.0
September	19.5	7.8	92.6	1.0	96.3	68.0	171.7	0.0	0.0
October	12.0	3.8	51.0	1.0	48.5	110.0	200.0	33.2	0.0
November	2.4	0.3	7.1	0.8	5.7	114.5	200.0	108.8	0.0
December	1.2	0.1	3.0	0.8	2.4	70.0	200.0	67.6	0.0
Total	**9.6**	**47.2**			**671.2**	**1011.2**		**340.0**	**0.0**
					Net Water Surplus	**340.0**	**mm**		

Table I-10: 2019 Water Budget

Month	Mean Temperature °C	I	E mm	Daylight Factor	E Adj. mm	Total Precipitation mm	WHC mm	Surplus mm	Deficit mm
January	-4.8	0.0	0.0	0.8	0.0	84.0	200.0	84.0	0.0
February	-3.2	0.0	0.0	0.8	0.0	48.8	200.0	48.8	0.0
March	-1.4	0.0	0.0	1.0	0.0	74.5	200.0	74.5	0.0
April	5.9	1.3	24.5	1.1	27.4	114.4	200.0	87.0	0.0
May	12.1	3.8	55.4	1.3	70.3	97.8	200.0	27.5	0.0
June	18.0	6.9	87.0	1.3	111.3	90.4	179.1	0.0	0.0
July	22.9	10.0	114.4	1.3	148.7	70.1	100.5	0.0	0.0
August	21.0	8.7	103.6	1.2	124.4	86.9	63.0	0.0	0.0
September	17.1	6.4	82.1	1.0	85.3	110.4	88.1	0.0	0.0
October	11.8	3.7	53.8	1.0	51.1	152.4	189.3	0.0	0.0
November	2.1	0.3	7.6	0.8	6.1	29.4	200.0	12.6	0.0
December	0.1	0.0	0.2	0.8	0.2	78.2	200.0	78.0	0.0
Total	**8.5**	**41.0**			**624.9**	**1037.3**		**412.4**	**0.0**
					Net Water Surplus	**412.4**	**mm**		

Notes:
- calculations based on Thornthwaite Mather Method
- °C calculated mean of daily temperatures for the month, in degrees Celcius
- I denotes Heat Index
- E denotes Evapotranspiration
- WHC denotes Water Holding Capacity
- A value of 200 mm was used for the water holding capacity of the soils (clay loam soil moderately deep-rooted crops).
- Temperature and precipitation data from the Port Colborne climatological station located at latitude 42°53'00"N, longitude 79°15'00"W