APPENDIX A
Characterization Final Report

July 2011

CITY OF GUELPH TIER THREE WATER BUDGET AND LOCAL AREA RISK ASSESSMENT

Appendix A: Characterization Final Report

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REPORT

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1.0 INTRODUCTION

1.1 Study Objectives

The City of Guelph and the GRCA are undertaking a pilot Tier Three Water Budget and Local Area Risk Assessment (Tier Three Assessment) for the City of Guelph municipal water supplies. A Tier Two Water Quantity Stress Assessment was completed for the Grand River Watershed (AquaResource, 2009) as part of the Clean Water Act Technical Assessment process. For the Tier Two Assessment, subwatershed areas were assessed and assigned a potential stress ranking to prioritize areas of municipal water taking that warranted a more in-depth Tier Three Assessment. The City of Guelph municipal water supplies lie within the Upper Speed River and Eramosa Subwatershed Assessment Areas, which were identified in the Tier Two Assessment as potentially moderately stressed from a groundwater and surface water perspective respectively, and hence the Tier Three Assessment was initiated for this area.

The key objective of this Tier Three Assessment is to evaluate the sustainability of the City of Guelph's water supply system from a quantity perspective, and to identify potential threats to that sustainability. The understanding gained through this evaluation will help the City in managing a reliable water supply system for this and future generations.

This report describes the characterization and conceptual model development components of the Tier Three Assessment, which form the basis for the development and calibration of a numerical groundwater flow model to be used in the Tier Three water quantity risk assessment. A separate report describes Tier Three project numerical model development and calibration (AquaResource, 2011).

A conceptual and numerical model of the City of Guelph municipal aquifer system was developed as part of the Guelph-Puslinch Groundwater Study (Golder, 2006a). It was recognized at that time that this model was a simplification of a complex stratigraphic system and more reliable corehole data was required to develop an appropriately reliable model of this important bedrock aquifer system. Since the Guelph-Puslinch Study, a large amount of hydrogeologic data has been collected in the City of Guelph area bringing about a need to update this previous model. This recent hydrogeologic data is mostly limited to the area within and immediately surrounding the City of Guelph and therefore a field program was developed and conducted as part of this project to address key data gaps regarding regional bedrock hydrogeological characteristics of the City's aquifer system outside of the City. The field investigations included a monitoring well installation program at 11 sites and a stream baseflow monitoring program that included three rounds of measurements at stations throughout the Study Area.

The Ontario Geologic Survey is currently mapping the Silurian carbonate strata along the Niagara Escarpment region and has proposed revisions to the Silurian Stratigraphy of this area. The updated stratigraphic framework described by the OGS (Brunton, 2009) has formed the basis for and warranted the re-interpretation and revisions to the Guelph area conceptual hydrogeological model.

This revised bedrock aquifer conceptual model represents a major improvement over earlier simplified conceptualizations. Further refinement and the ongoing collection of water level, pumping and stream flow data will continue to improve this basis for assessing the sustainability of municipal water supplies over the long term.

1.2 Study Team

The City of Guelph Tier Three Assessment Project is led by AquaResource Inc. with subconsultant Golder Associates Ltd. (Golder). Golder has been primarily responsible for the field program, characterization and hydrogeological conceptual model development work components of the project that are presented in this Characterization Study Report.

1.3 Scope of Work

The work scope of the Tier Three Characterization Study consisted of the following key components:

- **Background Review and Initial Data Gap Assessment:** The first stage of Characterization Study involved a general review of background information and an initial data gap assessment in order to complete a detailed workplan for a field program to address some of the key gaps. Considerable new field data including recent drilling and monitoring well installations and pumping test programs have improved the current understanding of local geology and regional hydrogeology. Much of this data addresses some of the identified information gaps in Guelph's hydrogeological conceptual model and three-dimensional FEFLOW model; however additional field data collection needs were identified. Also as part of the background review, a summary of subwatershed characteristics was completed and is included with this report. This summary of the subwatersheds is based on a review of past subwatershed studies and was primarily completed by AquaResource staff with some input from Golder.

- **Data Compilation:** This characterization study included an update to the Guelph-Puslinch Study borehole database to include more recent borehole data in the Study Area. Borehole information including well construction, geophysical testing, water level monitoring, municipal pumping and borehole geology was compiled in the database. Also consultant borehole logs were compiled in an indexed PDF format.

- **Field Program:** The field program completed for this project is a relatively large component of the work scope of this study and has provided valuable new information on the regional groundwater flow system of the municipal supply aquifer. The field program has included a borehole drilling and multi-level well installation program that has been conducted in collaboration with the OGS and the University of Guelph (U of G). The monitoring well program included drilling, testing and monitoring investigations at 11 borehole sites in areas of limited data coverage outside of the City of Guelph. A stream baseflow monitoring program was also conducted as part of this study.

- **Hydrogeological Characterization and Conceptual Model Refinement:** Based on the compilation of existing data and the new data collected as part of this Study, the hydrogeological conceptual model of the municipal aquifer system was revised as part of this study. This included modifications to the bedrock hydrostratigraphic framework of the area taking into account the revised stratigraphy recently developed by the OGS (Brunton, 2009). Conceptual model surfaces were developed based on geologic picks made at higher quality boreholes. An analysis of municipal pumping and water level data was completed and key aquifer tests summarized. A regional characterization of the groundwater flow system is provided including discussion of groundwater flow directions, vertical gradients, aquifer parameters and flow producing zones within the bedrock aquifer.

The methodology and results of these components of the Tier Three project work scope are provided in this Characterization Study Report.

1.4 Acknowledgments

The Ontario Geological Survey (OGS) contributed funding to the City of Guelph for additional field investigations that were incorporated into this project. These OGS funded field investigations provided valuable new information for characterizing the bedrock hydrogeology of the Study Area. Frank Brunton from the OGS participated in numerous meetings with the Project Team, to provide input on the revised borehole geologic interpretations and conceptual hydrogeologic model surfaces that were developed as part of this project. Bedrock cores developed from this program have been retained by the OGS for further assessment including geochemical analyses.

The OGS also provided funding to the U of G as part of a collaboration with the Tier Three Project Team to apply new hydrogeologic testing methods at the Tier Three Project borehole sites. The U of G contributed staff and student resources to conduct some components of the field investigations at the project borehole sites. These investigations were coincident with the University's research objectives and provided key additional hydrogeologic information at the borehole sites. Borehole testing and monitoring equipment manufacturers including Solinst, Westbay and FLUTe provided academic equipment discounts and staff training to assist with the application and testing of new field methods.

The project drilling sites were on GRCA (ten sites) and Wellington County (one site) lands. Staff from both the GRCA and Wellington County were cooperative in providing and arranging site assess for the drilling including on-site meetings with Golder and subcontractors. This cooperation allowed for drilling site access to be arranged in a short time period.

1.5 Report Organization

As described above, this report focuses on the characterization and conceptual model development components of the Tier Three Assessment and should be read in conjunction with the report entitled City of Guelph Tier Three Numerical Modelling Report (AquaResource, 2011), which provides detail on the numerical model development and calibration.

The report is organized into five (5) sections including this introduction (Section 1). Section 2 provides a brief background review of the Study Area. Section 3 provides a description of the data compilation and project borehole database development. Section 4 provides a description of the field program. Section 5 provides discussion of the hydrogeological characterization and conceptual model refinement. Appendices A through G include select existing borehole logs within the Study Area (see Appendix A), logs for boreholes drilled as part of this project (see Appendix B), project field program data (see Appendix C), municipal pumping and water level data (see Appendix D), high quality borehole details (see Appendix E), bedrock conceptual model surface elevation and isopach (thickness) mapping (see Appendix F) and hydraulic testing information including aquifer parameter estimates and bedrock flow profiling summaries (see Appendix G).

2.0 BACKGROUND

2.1 Study Area

The Study Area is shown on Figure 1. The City of Guelph obtains the majority of its water from a deep regional bedrock aquifer system. A key factor defining the Study Area was the need to extend the numerical model domain (and hence the greater Study Area) to distant natural boundaries of the regional aquifer that would not be influenced by the City of Guelph area pumping. The chosen model domain is shown on Figure 1 and extends to the Niagara Escarpment in the east at the limit of the City of Guelph bedrock aquifer system and to the Grand River to the north and west. The model domain covers a very large area (1,932 km^2); however the primary focus of the study is on the City of Guelph and the immediately surrounding area.

The City of Guelph's wells lie within the Upper Speed Groundwater Assessment Area that was identified in the Tier Two study to have a moderate potential for stress (AquaResource, 2009). The City of Guelph's Eramosa River Intake lies within the Eramosa Surface Water Assessment Area, which was identified in the Tier Two study to have a moderate potential for stress (AquaResource, 2009). The Study Area encompasses these Subwatershed Assessment Areas. A number of municipalities adjacent to Guelph obtain water supply from the same bedrock aquifer system. These primarily include Elora and Fergus to the north, Rockwood and Acton to the east and Cambridge to the southwest. The City of Guelph is surrounded by the Township of Guelph-Eramosa to the north and the Township of Puslinch to the south.

Adjacent Tier Three Assessments are ongoing to the east of Guelph in Halton Region (Acton/Georgetown) and to the southwest of Guelph in the Region of Waterloo (Cambridge, Waterloo and Kitchener). The first pilot Tier Three Assessment was completed in Orangeville, which is located to the north of the Guelph Tier Three Study Area.

2.2 City of Guelph Municipal Water Supplies

The City of Guelph meets its water demands primarily from groundwater sources including 23 groundwater wells and an artificial recharge system with a shallow groundwater collector referred to as the Glenn Collector. The locations of the City of Guelph Municipal wells are shown on Figure 2. The City of Guelph supplies are typically grouped into four quadrants and the supply sources in each of these quadrants are shown in Table 2.1 and are briefly described below. Additional discussion of the municipal wells and their pumping rates is provided in Section 5.1.1.

In the southeast quadrant, the Arkell Spring Grounds provide a large portion of the City of Guelph water supply. The Arkell Spring Grounds consists of five bedrock wells (Arkell 6, 7, 8, 14 and 15), one overburden well (Arkell 1) and the shallow collector system (Glenn Collector). The Glenn Collector system collects groundwater in the overburden through gravity drainage into a network of buried perforated pipes. To augment the water collected in this system, water is pumped from the Eramosa River to a pit and trench where the water artificially recharges the shallow overburden groundwater system. Also in the southeast quadrant of Guelph are the Carter wells and the Burke Well.

The municipal wells in the southwest quadrant of Guelph also provide a large portion of the municipal supply. There are six wells in the southwest quadrant including Water Street Well, Membro Well, Dean Avenue Well, University Well and Downey Road Well.

In the northeast quadrant the municipal wells include Park Wells #1 and #2, Emma Street Well, Helmar Well and the Clythe Creek Well. The Calico Well, Smallfield Well, Sacco Well, Paisley Road Well and Queensdale Well are in the northwest quadrant of the City. The Smallfield and Sacco Wells are currently offline due to water quality concerns.

2.3 Topography and Drainage

The topography across the Study Area is shown on Figure 3. The ground surface elevation varies by approximately 270 m, ranging from a high of 500 metres above sea level (masl) in the northernmost part of the Study Area (north of Hillsburgh) to a low of 230 masl below the Niagara Escarpment in the southeastern part of the Study Area. Superimposed on this general trend are the topographic ridges of the various moraines (as described in Sections 2.6 and 2.7) and some of the deeply incised river valleys.

The area lies mainly within the Grand River Watershed with surface drainage controlled by the Grand River and its numerous tributaries within the Study Area. Some of the main tributaries include the Speed River, Eramosa River and Mill Creek. The surface water features and subwatershed delineations in the Study Area are shown on Figure 4. Surface water flow in the area is generally in a southerly direction with a south westerly component evident in the main tributaries. As previously mentioned, some of these rivers are often deeply incised into well defined valleys, many of which are cut into the underlying bedrock. With the exception of Puslinch Lake (a large, relatively shallow natural kettle lake in the southern portion of the Study Area), there are no large natural surface water bodies in the Study Area. However, some artificial lakes and reservoirs have been constructed for flood control and recreational purposes including: Belwood Lake in Centre Wellington; and Guelph Lake in Guelph-Eramosa.

The eastern portion of the Study Area lies within the Credit Valley Watershed and the southeastern portion of the Study Area lies within both the Halton and Hamilton area Watersheds. Surface water flow in this area is generally in a southeasterly direction. The largest surface water features in the area are Guelph Lake to the north of the City and Mountsburg Lake in Puslinch to the southeast.

2.4 Land Use

The land use within the Study Area includes a mix of agriculture, forest and built up areas (residential/commercial/industrial) as shown on Figure 5. The largest built up urban areas include the City of Guelph at the centre of the Study Area, and Cambridge, located in the southwest part of the Study Area. The surrounding smaller towns, villages and hamlets include Erin, Hillsburgh, Fergus, Elora, Acton, Rockwood, Eden Mills, Everton, Aberfoyle, Morriston, Maryhill, Marden and Ennotville. Most of these small urban areas are surrounded by a rural setting consisting mainly of agricultural land use.

In general, the land use outside of the built up areas can be divided into two areas east and west of the Speed and Eramosa Rivers. The land use west of these rivers is predominantly agricultural, consisting of crops and forage. Forested areas and wetlands are interspersed throughout this area. The land use east of the rivers is a mix between agricultural and forested areas. Again, the agricultural land use is a mix of crops and forage. The Study Area also includes numerous connected and fragmented wooded areas associated with stream valley corridors and designated greenspaces in addition to wetland areas associated with valley bottom lands and poorly drained areas adjacent to the Paris and Orangeville Moraines. Numerous aggregate extraction sites and various golf courses are also situated throughout the Study Area.

2.5 Surface Water and Environmentally Sensitive Features

2.5.1 Overview of Surface Water Features

Surface Water Hydrology

The Study Area is located northwest of Lake Ontario and immediately west of the Niagara Escarpment. The climate in this area is generally continental but is modified by the proximity of the Great Lakes, which moderate extreme temperatures. This area lies in the humid mixed wood plains ecozone of the Great Lakes – St. Lawrence River valley (Environment Canada Website). The Study Area was historically dominated by mixed coniferous and deciduous forest with some Carolinian ecosystem areas in the south; however, the majority of upland areas have been cleared and converted to agricultural land uses over the past approximately 150 years.

A majority of the Study Area drains to the Grand River via its tributaries as shown on Figure 4. As previously mentioned, smaller parts of the Study Area, along the Niagara Escarpment, drain east to the Credit River basin with small areas in the southeast and south draining to Conservation Halton and Hamilton Region, respectively.

The Study Area was selected to include known natural boundaries to facilitate numerical modelling, however the focus of this discussion of the hydrologic setting is on the central part of the Study Area including the Lower Speed River area and the City of Guelph. The watersheds that are included in this area include the Upper Speed River, Upper Eramosa River, Lutteral Creek, Middle Speed River, Lower Speed River, Clythe Creek, Lower Eramosa River, Blue Springs Creek, Torrance Creek, Hanlon Creek, Irish Creek and Mill Creek as shown on Figure 4. Lutteral Creek, Eramosa River, Hanlon Creek and Irish Creek contribute directly to the Speed River, while Blue Springs Creek, Clythe Creek and Torrance Creek contribute to the Eramosa River. Mill Creek contributes directly to the Grand River near the southwestern corner of the Study Area. A more detailed description of some of these watersheds is included in Sections 2.5.2 to 2.5.4.

The Meteorological Service of Canada (MSC) maintains data from several weather stations in and close to the Study Area as shown on Figure 6. A summary of the Climate Normals for the most significant datasets is provided in Table 2.2.

Mean annual temperature in the Study Area averages 6.6 degrees Celsius and ranges between 6.0 degrees at Orangeville and 7.2 degrees at Cambridge for the six stations summarised in Table 2.2. Mean annual precipitation in the Study Area averages 909.9 mm and ranges between 885.0 mm at Georgetown and 938.5 mm at Fergus for the six stations summarised in Table 2.2.

The Water Survey of Canada (WSC) and the Grand River Conservation Authority (GRCA) collect and maintain records of stream flow throughout the Study Area. A summary of the most significant streamflow data is provided in Table 2.3. The station locations are shown on Figure 6. Of the hydrometric stations listed in Table 2.3, the Speed River Below Guelph Station (WSC 02GA015) has the longest and most recent period of record. This station has been located just upstream of the Edinburgh Road bridge over the Speed River since 1999. Prior to 1999 it was located approximately one kilometre downstream at the Hanlon Parkway (Hwy #6 North) crossing of the Speed River but was moved because of bridge construction. The station drains approximately 593 km^2 of the Study Area including the Eramosa River and its tributaries as well as the Upper, Middle and part of the Lower Speed River and its tributaries.

The mean annual flow for the Speed River below Guelph for the period of 1950 to 2005 is reported as 5.67 m^3/s or 302 mm/y as shown in Table 2.3. For the period of 1971 to 2000, which is consistent with the period used to generate the climate normals shown in Table 2.2, the mean annual flow at this station is approximately 5.93 m^3/s or 316 mm/y. A comparison of the mean annual precipitation for the Study Area (909.9 mm/y) shown in Table 2.2 to the mean annual flow at the Speed River Below Guelph station for the period of 1971 to 2000 (316 mm/y) shows that, on average, approximately 594 mm/y is lost to actual evapotranspiration or groundwater infiltration that does not report to the river in this area.

Surficial geology in the Study Area is described in Section 2.7 and can be summarized as a mix of silty to sandy tills and sand and gravel deposits. The soil mapping of the area (see Figure 7) identifies these tills as predominantly Guelph Loam in the centre and east of the Study Area ranging to London Loam in the west. Guelph Loam is identified as a well-drained member of the Grey-Brown Podzolic soil group. London Loam is identified as an imperfectly-drained member of the Grey-Brown Podzolic soil group. Where present, the overburden is primarily identified as Dumfries Loam, which is a well-drained member of the Grey-Brown Podzolic soil group. Stratified ice contact deposits overlie the regional till layers along the alignment of the Paris Moraine ranging from Acton and Rockwood at its northeast extent, through the southern part of the City of Guelph, to Cambridge at the Study Area boundary in the southwest. Surficial soils in this area are predominantly identified as Burford Loam, which is identified as a well-drained member of the Grey Brown Podzolic soil group. A significant area of stratified ice contact deposits associated with the Orangeville Moraine is also present ranging between Fergus, Hillsburgh, Erin and the northern boundary of the Study Area near Orangeville. Surficial soils in this area are predominantly Hillsburgh Sandy Loam, which is identified as a well-drained member of the Grey-Brown Podzolic Soil Group.

Environmentally Sensitive Features

There are numerous environmentally sensitive features in the Study Area including Cold Water Streams, Provincially Significant Wetlands (PSWs), Environmentally Sensitive Areas (ESAs), Areas of Natural and Scientific Interest (ANSIs). The Ontario Ministry of Natural Resources identifies the last three of these areas as follows:

- PSWs – Wetland areas identified by the Ontario Ministry of Natural Resources using the Ontario Wetland Evaluation System and are recognized as having ecological significance;
- ESAs – Areas identified by municipalities as being ecologically important; and

- Areas of Natural and Scientific Interest (ANSIs) – Areas identified by the Ontario Ministry of Natural Resources and broken down as earth science (having provincially or regionally significant representative geological features) or life science (having provincially or regionally significant representative ecological features).

Many of the streams in the Study Area, particularly in the headwaters, are classified as cold water streams as shown on Figure 8a (entire Study Area) and Figure 8b (Guelph area). Some of these include all of or parts of Eramosa River, Blue Springs Creek, Clythe Creek, Hanlon Creek, Speed River, Irish Creek, Mill Creek and Hopewell Creek. Due to the presence of on-line ponds, some of the stream designations have changed from cold water streams to cool or warm water designations, as shown on Figures 8a and 8b.

Provincially significant wetlands are shown on Figures 8a and 8b. There are numerous provincially significant wetlands in the Study Area including Torrance Creek Swamp, Speed River Wetland Complex, Hall's Pond Complex, Mill Creek Wetland, Arkell Bog Wetland Complex, Eramosa/Blue Springs Creek Wetland and Guelph Northeast Wetland Complex.

The cold water stream and provincially significant wetland data sets shown on Figures 8a and 8b were provided by the GRCA.

There are numerous ESAs identified in the Study Area. Some of these include, Eramosa River Valley, Rockwood Limestone Cliffs, Knatchbull Swamp, Blue Springs Swamp, Blue Springs Creek Valley, Hillsburgh Sand Hills, Paris Moraine Complex, Hanlon Creek Swamp, Galt Creek and Forest and Aberfoyle Woods.

In addition, there are various ANSIs that have been identified in the Study Area. Some of the key ANSIs in the area include the Paris, Galt and Moffat Morraines, Guelph Esker, Eramosa River Valley, Guelph Drumlin Field, Blue Springs Creek Wetlands and Puslinch Lake Bog and Wetlands.

Specifically, within or immediately around the City of Guelph, the following key environmentally sensitive features are present:

- Eight PSW Complexes (Guelph Northeast Complex, Clythe Creek Wetland, Torrance Creek Swamp, Halls Pond Complex, Hanlon Creek Swamp, Ellis Creek Complex, Marden South Complex and Speed River Wetland Complex);
- Four ANSIs (Guelph Drumlin Field, Arkell Meltwater Channel, Paris Moraine and Oil Well Bog); and
- Large areas of what are currently identified as ecological corridors, buffers and linkages and locally significant wetlands.

As is indicated by the features in the City of Guelph alone, the Guelph Tier Three Study Area is ecologically rich.

A review and summary of subwatershed studies in the Study Area was completed by staff from AquaResource with input from Golder. Based on the review of subwatershed study reports, the basic hydrologic and ecologic characteristics of each subwatershed were summarized as presented in the below sections.

2.5.2 Eramosa River

The Eramosa River Watershed covers an area of approximately 270 km^2 and includes the Torrance Creek, Clythe Creek and Blue Springs Creek Subwatersheds, in addition to the Upper and Lower Eramosa River Subwatersheds. Torrance Creek, Clythe Creek and Blue Springs Creek all discharge into the Eramosa River. The watershed is bounded by the Speed River Watershed to the west, and the Credit and Sixteen Mile River Watersheds to the east, both of which are Lake Ontario tributaries.

The main branch of the Eramosa River and its largest tributary, Blue Springs Creek, are discussed below. This is followed by discussion of two smaller tributaries, Clythe Creek and Torrance Creek, which are both located mainly within the City of Guelph.

Eramosa River/Blue Springs Creek

Some previous watershed studies in the area include:

- **Eramosa-Blue Springs Watershed Study Report** (Beak and Aquafor, 1999)
  - **Part 1 – Watershed Report Card, Part 2 – Watershed Goals and Objectives**
- **Eramosa-Blue Springs Watershed Study – Part 3: Recommended Plan and Implementation Plan** (Beak et al., 1999)
- **Eramosa River-Blue Springs Creek Linear Corridor Initiative** (Proctor & Redfern Ltd.,1995)

Hydrologic Setting

- The Eramosa River and Blue Springs Creek Watersheds are located in the central eastern part of the Study Area and extend in a northerly and partially easterly direction. Smaller towns and hamlets are scattered along the Eramosa River including Arkell, Eden Mills, Rockwood, Everton and Ospringe.
- The Upper and Lower Eramosa River and their tributaries including the Blue Springs Creek subwatershed cover a drainage area of 270 km^2 (Beak and Aquafor, 1999) along the Eastern edge of the GRCA watershed. The Eramosa River flows south from Hillsburgh, which is the area of highest elevation at about 500 m above sea level, through Rockwood and Eden Mills and into the City of Guelph. There, it discharges into the Speed River at a low elevation of 310 m.
- Blue Springs Creek with its confluence at Eden Mills, as well as Torrance Creek and Clythe Creek that discharge within the City of Guelph are major tributaries of the Eramosa River.
- The Eramosa River flows mostly through a bed of poorly drained organic soil. Through Rockwood and to areas in the south, the soil is mainly well-drained, shallow loam till over bedrock, as is found beneath Blue Springs Creek. For the most part, the soils of the Eramosa/Blue Springs Creek subwatersheds have good drainage. Loam till is the most common soil type in the area, with some stony, sandy loam till around the eastern borders, fine to medium sand found in the northern areas of higher elevation, some gravel and fine sand over gravel to the south.

- The banks of the Eramosa River and Blue Springs Creek are densely forested, except through the built-up residential areas of Rockwood, Eden Mills and Guelph. The Blue Springs Creek subwatershed at the edge of the Niagara Escarpment is mostly covered with a mix of agricultural and forested land, while the Eramosa River subwatersheds are predominantly agricultural. Based on a brief review of aerial photography and land cover mapping, the land use within the watershed is primarily forested wetland, forested upland and agricultural land with some small, rural residential communities nearby.

Environmentally Sensitive Features

- The Eramosa River-Blue Springs Creek watershed is ecologically rich. There are approximately eight wetlands identified in the Eramosa River-Blue Springs Creek Linear Corridor Initiative (Proctor & Redfern Ltd., 1995). At least three of these are provincially significant including Eramosa/Blue Springs Creek Wetland, Knatchbull Wetland and Arkell-Corwhin Wetland Complex.

- There are six Provincially and six Regionally Significant Life and Earth Science ANSIs (Proctor & Redfern Ltd., 1995). Some of these include the Paris and Galt Moraines, Arkell Meltwater Channel, Knatchbull Swamp, Blue Springs Creek Wetland and Eramosa River Valley.

- There are seven ESAs in the watershed (Beak et al., 1999), including Hillsburgh Sand Hills, Eramosa River Valley, Rockwood Limestone Cliffs, Knatchbull Swamp, Blue Springs Swamp, Blue Springs Creek Valley and Paris Moraine Complex.

- Upper Eramosa River from the headwaters to Rockwood and Blue Springs Creek are coldwater streams (Proctor & Redfern Ltd., 1995).

- Beak et al. (1999) indicate that the watershed is home to three types of aquatic communities as follows: an intolerant coldwater community, which includes mainly Brook trout; a sensitive cold/cool water community, which includes Brook trout, Brown trout, Northern Hogsuckers and Minnows; and a diverse cool/warm water community, which includes Brown trout, Northern Pike, Rock Bass, Smallmouth Bass, Darters, Northern Hogsuckers, Hornyhead Chub and Minnows.

Clythe Creek

A previous watershed study in the area includes:

- **Clythe Creek Subwatershed Overview** (Ecologistics and Blackport, 1998)

Hydrologic Setting

- Clythe Creek subwatershed is located both within and outside the northeast corner of the City of Guelph. The subwatershed is between the Eramosa River to the southeast and the Guelph Northeast Wetland Complex (a provincially significant wetland) to the northwest.

- Watson Creek and Hadati Creek are the main tributaries of Clythe Creek, both of which have headwaters in the northwestern end of the subwatershed and flow southward towards Clythe Creek. Clythe Creek is itself a tributary of the Eramosa River to the south.

- The subwatershed has a drainage area of approximately 21 km^2. Watson Creek drains an area of approximately 103 ha (5%) of Clythe Creek subwatershed and Hadati Creek drains an area of 390 ha (20%) of Clythe Creek subwatershed.

- The high points are at approximately 360 m in elevation in the northeastern and southwestern areas of subwatershed and the low point is located in a built-up area to the south at approximately 330 m elevation. The landscape of the area is mostly gentle, smooth slopes.

- The soil is well-drained Guelph loam, consisting of loam till and it covers much of the subwatershed, particularly in the areas of Watson creek and Hadati creek to the southwest as well as around the northern limits of the drainage basin. A portion of the southern area, upstream of where Clythe creek drains into the Eramosa River, is well-drained gravel soil. Much of the Clythe Creek valley and immediate surrounding is composed of fine sand over gravel and is well-drained. There is very poor drainage around the headwaters of the Watson and Hadati Creeks where there is a small wetland with organic soil near the Guelph landfill site.

- The land around Clythe Creek is urbanized to the southwest but is predominantly agricultural cropland covering most of the land to the east.

Environmentally Sensitive Features

- Wetlands are present, consisting of bands of vegetation along the watercourses and vegetation communities in the low lying areas between drumlins (Ecologistics and Blackport, 1997). The most significant wetland is the Clythe Creek Wetland. Some of the wetland in the area has been removed for residential housing development.

- Clythe Creek is cold water stream with a band of wetland vegetation along its length and the abundance of groundwater, near or at the ground surface, plays a key role in influencing the composition and distribution of vegetation (Ecologistics and Blackport, 1997). Ecologistics and Blackport (1997) also indicate that the upper reaches of the creek are fairly well vegetated and the channel is fairly natural and in the lower reaches the creek is altered by ponds, open sections of creek, weirs and dams.

- The subwatershed study (Ecologistics and Blackport, 1997) indicates that Clythe Creek provides habitat for wide range of fish including Brook stickleback, creek chub, blacknose dace, minnows, shiners and Brook trout. Numerous birds, mammals, reptiles and amphibians were also reported, including some provincially significant species.

Torrance Creek

Some previous watershed studies in the area include:

- **Impact Assessment Guidelines for the Torrance Creek Subwatershed** (ESG, 1999);

- **Torrance Creek Subwatershed Study – Management Strategy – Executive Summary and Recommendations** (Totten Sims Hubicki et al., 1999);

- **Torrance Creek Subwatershed Study - Management Strategy** (Totten Sims Hubicki, et al., 1998);

- **Torrance Creek Subwatershed Study – Phase I Characterization Report – Final** (Totten Sims Hubicki et al., 1997a); and
- **Torrance Creek Subwatershed Study – Management Strategy – Technical Appendix** (Totten Sims Hubicki et al., 1997b).

Hydrologic Setting

- Torrance Creek subwatershed is located on the east side of City of Guelph partly within the city limits and partly within the Township of Puslinch.
- The Torrance Creek subwatershed covers a small drainage area of Torrance Creek within the City of Guelph, which flows northward into the Eramosa River.
- Torrance Creek is a tributary of the lower end of Eramosa River with the subwatershed covering approximately 11 km^2. On-line ponds are located along the creek.
- The eastern portion of the land is composed of well-drained gravel soil while the western side is mainly sandy, stony till. The valley lands around Torrance Creek itself are poorly drained organic soil.
- At its highest point of land, the Torrance Creek subwatershed has an elevation of about 370 m to the southeast and it has a relatively flat topography, sloping gently northwards towards its discharge point at about 320 m in elevation.
- The headwaters of Torrance Creek are surrounded by a golf course as well as some dense forest to the south. There is some residential build-up around the western boundary of the subwatershed, and row crops and small grains are the dominant agricultural land use, covering most of the western area.

Environmentally Sensitive Features

- The significant wetlands include the Torrance Creek/Hamilton Corners Wetland Complex.
- The Paris Moraine, which is situated along the southeast part of the subwatershed is considered an ANSI. Totten Sims Hubicki et al. (1999) indicate that the Torrance Creek subwatershed contains two Category 1 Natural Heritage Features: significant wetlands and regulated floodplains.
- Category 2 Natural Heritage Features in the subwatershed include significant wildlife habitat, significant woodlands, fish habitat and steep slopes (Totten Sims Hubicki et al., 1999).
- The subwatershed study (Totten Sims Hubicki et al., 1998) suggests that anecdotal evidence and creek conditions at the time indicate that Torrance Creek may have once been a cold water stream system. The study also indicates that wide fluctuations in water temperatures, due to groundwater discharge areas and on-line ponds, have effects on aquatic life. Totten Sims Hubicki et al. (1998) indicate that only the headwaters of Torrance Creek and Barber Creek are considered cold water streams.

2.5.3 Speed River

The Speed River is a major tributary to the Grand River. The overall Speed River Watershed includes the Lutteral Creek, Hanlon Creek and Irish Creek Subwatersheds, in addition to the Upper, Middle and Lower Speed River Subwatersheds. Lutteral Creek, Hanlon Creek and Irish Creek all discharge into the Speed River. The watersheds are bounded by Swan Creek, Cox Creek and Hopewell Creek Watersheds to the west and Eramosa River Watershed and its subwatersheds to the east as well as Mill Creek Watershed to the southeast.

A brief description of the Speed River is discussed below followed by a discussion of Hanlon Creek, which is an important subwatershed in the Guelph area.

The headwaters of the Speed River are located near the Orangeville Moraine. The river generally flows south through Guelph where it is joined by the Eramosa River. The river then flows through northern Cambridge and discharges to the Grand River in Preston.

Upper Speed River

Hydrologic Setting

- The Upper Speed River flows southward from a high point of approximately 500 m in elevation down to the confluence with the Lutteral Creek tributary at 450 m in elevation. The total drainage area is 103 km^2.
- The soils in the area are well-drained, composed principally of fine to medium sand in the northern regions and changing to loam till in the lower area south of Belwood Lake. Some isolated areas of imperfectly drained sandy soils and gravels are evident in the central region of the drainage basin.
- Some of the land in this area is covered by forest and mature plantations, particularly around the headwaters in the north, and the remainder is covered by various agricultural land uses.
- Lutteral Creek is the most significant tributary of the Upper Speed River and has its confluence at the south end, where the Upper Speed River subwatershed becomes the Middle Speed River subwatershed.

Middle Speed River

Hydrologic Setting

- The Speed River flows between the Upper Speed River and the Middle Speed River subwatersheds, with the divide being at the confluence of the Speed River and one of its major tributaries, Lutteral Creek. Another significant tributary is Marden Creek, which flows into the Speed River north of the City of Guelph limits. The subwatershed drains an area of 114 km^2.
- The Speed River flows south through the subwatershed and passes through Guelph Lake towards the City of Guelph. The high point of 400 m is to the northeastern boundary of the subwatershed, while the low point where the river discharges is at 320 m in elevation.

- The area of the subwatershed to the south of Guelph Lake sees built-up residential and commercial land within the City of Guelph boundaries, while the majority of the subwatershed land is used for agricultural activities interspersed with some forested areas.
- To the east, loam soils dominate with good drainage seen in the areas of higher elevation and imperfect drainage in the lower lands, as well as in the western region of the subwatershed. Towards the City of Guelph in the south, the soil is dominated by well-drained gravel and some medium sand along the bed of the Speed River.

Lutteral Creek

- Lutteral Creek subwatershed is 450 m in elevation at its highest point to the north and it drains southward to the upper speed river where it discharges at an elevation of 360 m above sea level. The subwatershed has a total area of 70.1 km^2.
- The northern area of the subwatershed is dominated by fine to medium sand with good drainage. This is separated from the southern and central areas, where well-drained fine sand over gravel and some loam soils with are predominant, by a low area of poorly-drained wetland.
- Land in this area is mostly used for open agriculture or pasture, interspersed with some forested areas throughout.

Lower Speed River

- The northern boundary of the Lower Speed River subwatershed lies within the City of Guelph limits and the watershed extends southwest towards Cambridge, with a small range of elevations from approximately 320 m at its highest point in the north to 270 m above sea level at its southern boundary marked by its confluence with Mill Creek tributary.
- Much of the upstream section of the subwatershed, particularly along the Speed River bed, is composed of well-drained gravelly soils, surrounded by loam and changing to medium sand in the southern reaches with some poorly drained areas around the confluence with the Ellis Creek tributary.
- The Eramosa River drains into the Speed River within the City of Guelph and other major tributaries include Hanlon Creek, Irish Creek and Ellis Creek. The drainage area of the Lower Speed River is 91.3 km^2.
- Much of the land in the subwatershed is built-up to the north and south where the Speed River flows through Guelph and Cambridge, while the other dominant land use is open agricultural land with some forest bordering the river itself.

Irish Creek

- Highest land elevations are around the northern boundaries of the watershed with an elevation of 340 m above sea level. The topography of the area is characterized by gently sloping land, with a low point of 300 m where the creek discharges to the Speed River. This creek drains an area of 43.1 km^2.
- Well-drained soils in the area are mostly stony, sandy loam till to the east and south, gravel and medium sand around the northern and western areas. Some isolated wetlands can be found throughout the drainage basin with poorly drained soils of organic matter and till.
- The land in this subwatershed is mainly used for agriculture with some isolated patches of forest cover.

Chilligo/Ellis Creek

- The Chilligo/Ellis Creek subwatershed is oriented north-south, with its high land at an elevation of 340 m above sea level, sloping gently to the south at an elevation of 310 m where Ellis Creek discharges into the Speed River. The drainage area is approximately 56.6 km^2.
- Much of the land in this subwatershed is well-drained, composed of loam soils to the northeast and gravel or fine sand over gravel to the west of Ellis Creek. The southern portion of the subwatershed has sandy soils that are for the most part well-drained, with some patches of poorly drained soil around the Speed River.
- The Chilligo/Ellis Creek subwatershed is dominated by open agricultural land of various uses, with few patches of forest and a golf course in the southern end.

Hanlon Creek

Some previous watershed studies in the areas include:

- **Hanlon Creek State-of-the-Watershed Study** (PEIL et al, 2004)
- **Hanlon Creek Watershed Plan – Summary Report** (MMM, 1993)
- **Hanlon Creek Watershed Plan – Final Report** (MMM and LGL, 1993)
- **Hanlon Creek Watershed Plan – Assessment Tables** (MMM and LGL, 1993)
- **Hanlon Creek Watershed Study – Interim Report – Volume 1** (MMM and LGL, 1992)
- **Hanlon Creek Watershed Study – Interim Report – Volume 2 (Maps)** (MMM and LGL, 1992)
- **Hanlon Creek Watershed Study – Interim Report – Volume 3 (Appendix A)** (MMM and LGL, 1992)
- **Hanlon Creek Watershed Study – Interim Report – Volume 4 (Appendix B to E)** (MMM and LGL, 1992)
- **Hanlon Creek Watershed Study – Interim Report Appendices-Phase 2** (MMM, 1992)
- **Hanlon Creek Ecological Study – Phase A** (UG, 1971)

- **Hanlon Creek Ecological Study – Phase B** (UG, 1972)
- **Grand River Conservation Authority Preliminary Report on Hanlon's Creek Basin** (Kilborn, 1968)

Hydrologic Setting

- The highest points of land, at around 360 m in elevation, are at the northeastern boundary of the subwatershed, while the central wetland area has an elevation of approximately 320 m, forming the headwaters of the Hanlon Creek. The total drainage area is approximately 26.4 km^2 (PEIL et al., 2004).
- For the most part, soils are well-drained and composed of loam till to the southeast and stony, sandy loam till in the west. The exception is around the central wetland area, where poorly drained gravel soil can be found bordering the wetland to the north and south, while the wetland itself is organic matter with very poor drainage.
- The land in this subwatershed is principally covered by built-up residential and commercial areas, particularly to the north and west. The Hanlon Industrial Park is located within the subwatershed at Clair Road West and the Hanlon Expressway. A major conservation area protects wetland and dense forest around the headwaters of the creek. Much of the land otherwise is used for agricultural purposes, but some dense and sparse forest is located to the west end of the subwatershed.

Environmentally Sensitive Features

- There are two significant wetlands in the Hanlon Creek subwatershed, which are connected by a heavily vegetated corridor. The Hanlon Creek Swamp is regionally significant and the Hall's Pond Wetland is provincially significant. These wetlands provide habitat for some rare and uncommon bird and plant species, as well as for deer and other wildlife (PEIL et al., 2004).
- The Paris Moraine, which is situated in the southeast part of the subwatershed, is considered an ANSI.
- Most of Hanlon Creek is classified as a cold water stream. PEIL et al. (2004) indicate that the presence of on-line ponds and broad creek sections in the lower portion of Hanlon Creek, tend to offset the cooling potential of groundwater inflows in the area.
- Brook trout are present upstream of the Hanlon Parkway but not downstream and similarly, brook trout spawning locations were found in the upper reaches and central wetland area, but not in the lower reaches (PEIL et al., 2004).

2.5.4 Mill Creek

A previous watershed study in the area includes:

- **Mill Creek Subwatershed Plan** (CH2M Gore and Storrie Ltd. et al., 1996)

Hydrologic Setting

- The Mill Creek Subwatershed is fairly long and narrow with the headwaters located southeast of the City of Guelph and the mouth of the creek located in Cambridge where the creek discharges to the Grand River. The creek flows in a southwest direction for approximately 30 km passing through Aberfoyle and the Shades Mill Reservoir, located near the downstream end of the creek on the outskirts of Cambridge. Mill Creek subwatershed is approximately 104 km^2 and is bordered by Speed River tributaries to the north and west, by Halton Region to the east, and by Fairchild Creek headwaters to the south.
- Soils in the area are mostly stony, sandy loam till and loam till with good drainage, as well as some well-drained gravel in the center of the drainage basin, south of Victoria Road. The lands in the valley surrounding Mill Creek as well as to the south in the Cambridge area are composed of poorly drained till with organic matter found principally in the wetland area.
- The highest land point in this subwatershed is located on the Paris moraine in the north with an elevation of 360 m above sea level, while the lower areas around the Mill Creek valley in the center have an elevation of 300 m above sea level. Thus, the topography of the land is hummocky with some steep slopes and many natural pond areas and wetlands.
- This subwatershed encompasses a variety of land uses, including residential and commercial developments in the south around the City of Cambridge, several relatively large areas of dense forest and extensive open agricultural land. Numerous aggregate extraction activities also occur throughout the area.

Environmentally Sensitive Features

- There are two Provincially Significant Wetlands in the Mill Creek subwatershed including Mill Creek Swamp Wetland and Arkell-Corwhin Bog Wetland Complex.
- Mill Creek is a groundwater-fed stream resulting in cool to cold water over most of its length with the exception of warming influences of ponds such as Mill Pond, Shades Mills Reservoir and Aberfoyle Pond (CH2M Gore and Storrie Ltd. et al., 1996).
- There are four ANSIs within Mill Creek subwatershed including: Mill Creek and Forest; Paris, Galt and Moffat Moraines; and Galt End Moraine. CH2M Gore and Storrie Ltd. et al. (1996) also indicate that there are two ESAs including Mill Creek and Forest and Aberfoyle Woods.
- Aquatic species present in the subwatershed include brook trout and brown trout and some largemouth bass, smallmouth bass, minnows, sunfish, rock bass and yellow perch (CH2M Gore and Storrie Ltd. et al., 1996).

2.6 Physiography

The physiography of the Study Area is controlled largely by the distribution of Quaternary glacial and postglacial deposits. Quaternary deposits, comprised mainly of glacial tills, glaciofluvial deposits and ice-contact stratified deposits overlie the bedrock within most of the Study Area. The Study Area encompasses various physiographic regions as identified by Chapman and Putnam (1984), which are described as the Guelph drumlin field, the Horseshoe Moraines, the Flamborough Plain, the Waterloo Hills and the Hillsburgh Sandhills (see Figure 9).

The Horseshoe Moraines encompass the central eastern part of the Study Area, east of the Guelph Drumlin Field. The region covers a large horseshoe area within southern Ontario. Within the Study Area, the landscape is characterized by moraines (primarily including the Galt and Paris Moraines) and a system of old spillways with broad gravel and sand terraces and swampy floors (Chapman and Putnam, 1984).

The Guelph Drumlin Field is located in the western and central portion of the Study Area. The area is characterized by various sizes of broad oval shape till drumlins fringed by gravel terraces and separated by swampy valleys in which tributaries of the Grand River flow (Chapman and Putnam, 1984). There are also several eskers present in this area.

The Flamborough Plain encompasses a small portion of the southeastern part of the Study Area beyond the Horseshoe Moraines. The plain consists of limestone bedrock with little or no overburden cover and a few drumlins scattered over the area (Chapman and Putnam, 1984). The area is poorly drained and large swampy areas are common including the Beverly Swamp which is connected to Spencer Creek.

The Waterloo Hills encompass a small portion of the southwestern part of the Study Area outside of the Guelph drumlin field. The surface is composed of sandy hills, some of them being ridges of sandy till while others are kames or kame moraines, with outwash sands occupying the intervening hollows (Chapman and Putnam, 1984). These hilly areas are well drained.

The Hillsburgh Sandhills encompass the north tip of the Study Area. Chapman and Putnam (1984) characterize this region as being comprised of rough topography with sandy materials and a flat bottomed swampy valley running through the moraine. This region is at the highest elevation in the Study Area.

As previously discussed, within some of these physiographic regions are drumlin fields, eskers and moraines. These are further described below.

Drumlins are isolated elongated hills oriented parallel to the direction of glacial movement, and are formed beneath the advancing ice sheet. The drumlins in the Guelph Drumlin Field consist primarily of sandy silt till, and rest on a low relief surface covered by the same material. Glacial meltwater flowing through the low areas between the drumlins has deposited glaciofluvial sands and gravels, and in some areas these better sorted materials rest directly on the underlying bedrock.

Eskers are ridges of sand and gravel deposited in meltwater channels that existed beneath the retreating ice sheet. Some examples of eskers in the Study Area include the Guelph Esker, Ariss Esker and Eramosa Esker.

Moraines are ridges of glacial deposits oriented perpendicular to the direction of glacial movement. They often mark the point where the ice sheet halted for a period of time during its retreat at the end of the last glacial period. Moraines may be made up of almost any type of glacial deposit ranging from poorly-sorted tills to outwash sands and gravels. There are five moraines in the Study Area including the Paris, Galt, Breslau, Orangeville and Moffat Moraines, which generally trend northeast to southwest.

2.7 Regional Quaternary Geology

The Quaternary geology of the Study Area has been described in detail by Karrow (1987, 1968). The OGS surficial Quaternary geology mapping of the Study Area is included on Figure 9. Most of the area is covered by varying thicknesses of glacial deposits, with bedrock exposed in some areas primarily within the deeper river valleys (e.g., through Elora, Fergus, Rockwood, Eden Mills and Guelph) and along the eastern portion of the Study Area in Flamborough and Acton.

After a period of ice marginal retreat, a prominent ice-lobe formed in the Lake Ontario basin, periodically advancing westward over the Study Area and then retreating. These advances formed the most recent Quaternary deposits found in most of the Study Area. The surficial sediments are mainly till deposits with a significant area interspersed with ice-contact stratified deposits and glaciofluvial deposits.

Glacial till refers to the poorly sorted mixture of clay, silt, sand and gravel (in varying proportions) that is the principal deposit left behind by continental ice sheets.

The Paris Moraine and the Galt Moraine are the two most prominent moraines in the Study Area. Within some parts of the Guelph area, these Moraines are connected. The internal structure of the moraines is a complex mixture of till, stratified drift and discontinuous layers of more permeable material. Recently, a detailed review of the state of knowledge of these moraines was completed by Blackport and AquaResource (2009). The work was undertaken to better understand the hydrogeologic characteristics of the moraines and identify threats and impacts to the hydrologic functions of the moraines to protect groundwater and source water through provisions, policies and legislation.

The Port Stanley Till and the Wentworth Till are the two most prevalent till units present at surface in the Study Area. The Port Stanley Till is present in areas west of the Paris Moraine and the Wentworth Till is present in areas on and east of the Paris Moraine (McKenzie, 1990).

The main overburden units present in the Study Area are summarized as follows:

- **Catfish Creek Till:** The Catfish Creek Till was deposited by a major glacial advance from the north to northeast that covered all of southern Ontario. The Catfish Creek Till is a dense, stony, sandy silt to silty sand till with little clay content. It is the oldest main Quaternary unit in the Study Area. Although originally deposited over a large area, erosion, glaciations and meltwater events have removed areas of the Catfish Creek Till and it is now discontinuous. Where present, it is usually found immediately overlying bedrock and beneath clayey sediments and is preserved in a few outcrops along the Grand River (Karrow, 1968) and may also be present in deeper older bedrock valleys such as the Rockwood buried valley. It is often interbedded with sand and gravel. The lithology and degree of compaction and/or cementation of the Catfish Creek Till are variable.

- **Port Stanley Till and associated fine grained drift:** The Port Stanley Till is a sandy silt to silty sand till and is occasionally stony. The Port Stanley Till was deposited by ice advancing from the Erie-Ontario ice lobe. In the Grand River and Speed River valleys this unit has been largely removed by erosion. This unit is generally finer grained than the younger Wentworth Till. The surficial mapping of the Port Stanley Till is shown on Figure 9 and is represented by Unit 5b in areas west of the Paris Moraine.

- **Wentworth Till:** The Wentworth Till is a stony, sandy to sandy-silt till with a relatively low clay content. This till was deposited by the last glacier to advance in the area and is often interbedded with sand and gravel. This till has a coarse-grained and loose nature. The surficial mapping of the Wentworth Till is shown on Figure 9 and is represented by Unit 5b in areas on and east of the Paris Moraine.
- **Sand and gravel deposits:** This unit generally consists of outwash sand and gravel and surficial ice contact sand and gravels that are present throughout much of the Study Area. These deposits overlie till in some places and lay directly on the bedrock in other places. These deposits are mapped surficially by the OGS as Units 6 and 7 as shown on Figure 9.
- **Eskers, Drumlins, Kames:** These glacial features are found throughout the Study Area. Eskers are sharp crested ridges of sand and gravel; drumlins are elongate hills generally composed partly or entirely of glacial till; and kames are hummocky accumulations of sand and gravel.
- **Peat, Muck etc:** These organic accumulations are generally associated with swamps and bogs.

The Moffat Moraine is associated with the Galt Moraine and is formed of Wentworth Till. The Orangeville Moraine is comprised of ice-contact sand and gravel deposits and is generally not capped with till. The Breslau Moraine was formed during an earlier ice advance and is comprised of a clay till.

As the glaciers receded at the end of the last ice age, they produced large quantities of meltwater. These powerful meltwater flows often carved large channels through the previously deposited glacial tills (or even into the bedrock), and left behind extensive deposits of sand and gravel. The northern part of the Study Area (Orangeville Moraine) is comprised largely of outwash sand and gravel and ice contact stratified sands and gravels, extending from east of Hillsburgh west to Fergus. To the south, along the Eramosa River, are glaciofluvial sands and gravels deposited in a meltwater channel that paralleled the present course of the river into the Guelph area. Between the Galt and Paris moraines is the Aberfoyle outwash channel, now occupied by Mill Creek and its tributaries. These outwash deposits overlie till in some place and lay directly on the bedrock in other places.

In general, the greatest overburden thickness is found in the northern portion of the Study Area where up to 80 m of overburden is present. Thick overburden deposits are also found within the buried bedrock valleys and within the major moraines in the Study Area. In general, the variations in thickness are caused by erosional features of the underlying bedrock surface such as buried valleys, which are filled and concealed by overburden sediments, resulting in a thick overburden sequence; depositional features such as end moraines, drumlins and outwash plains, which also result in a thick overburden sequence; and erosional features of the surface deposits such as stream valleys, which result in a thinning of the overburden sequence (Karrow, 1968).

2.8 Regional Bedrock Geology

The Paleozoic bedrock formations underlying the City of Guelph comprise one of the most extensive bedrock aquifers in Ontario and are the main source of drinking water supplies for a number of nearby municipalities such as the City of Cambridge located about 10 km to the southwest of Guelph, Centre Wellington located to the north of Guelph and Rockwood located to the east of Guelph.

The bedrock formations in the Guelph area consist of Paleozoic sedimentary rocks, composed of limestone, dolostone and shale sequences that comprise an active groundwater flow system that generally ranges from about 40 m to 100 m in thickness. The bedrock formations exhibit a gentle regional dip (about 4 degrees) to the southwest. In the east moving toward the Niagara Escarpment, the younger formations have been eroded reducing the overall thickness of the system and exposing the deeper formations at surface. The escarpment represents the easternmost limit of the aquifer system. As described in Section 2.7, bedrock outcrops in the Study Area are limited to a few areas including primarily the deeper river valleys (e.g., through Elora, Fergus, Rockwood, Eden Mills and Guelph) and along the eastern portion of the Study Area in Flamborough and Acton.

The diagram shown on Figure 10 illustrates the revised stratigraphic framework described by the OGS (Brunton, 2009) for the Paleozoic bedrock formations present in the Study Area. The Ontario Geological Survey (OGS) is currently mapping the Silurian carbonate strata along the Niagara Escarpment region and has proposed this revised framework for stratigraphy of this area.

A brief description of each of these bedrock formations is provided below (from oldest to youngest).

- **Cabot Head Formation:** The Cabot Head Formation, readily distinguished by its grey-green colour, is a non-calcareous shale with thin interbeds of sandstone and limestone. This unit ranges from 10 to 39 m thick (Johnson et al. 1992).

- **Merritton Formation:** The Merritton Formation consists of a pinkish-brown, finely crystalline dolostone unit with dark shaley partings. This unit, where present in the area, is generally less than 1 m thick.

- **Rockway Formation:** The Rockway Formation is a greenish-grey fine crystalline argillaceous dolostone with shaley partings (Brunton, 2008). The thickness of the Formation is consistent and estimated to range 1 to 2 m across the Study Area.

- **Irondequoit Formation:** This Formation is a thickly to medium-bedded crinoidal grainstone (Brunton, 2008). The unit has a fairly consistent thickness of approximately 3 m throughout the Study Area.

- **Rochester Formation:** The Rochester Formation is a calcareous shale with carbonate interbeds and, where present in the Study Area (primarily in the Cambridge area), it is a thin unit (typically about 1 m thick) located several metres above the Irondequoit Formation.

- **Irondequoit Formation:** This Formation is a thickly to medium-bedded crinoidal grainstone (Brunton, 2008). The unit has a fairly consistent thickness of approximately 3 m throughout the Study Area.

- **Gasport Formation:** The Gasport Formation is a cross-bedded crinoidal grainstone-packstone with sequences of reef mound and coquina (shell bed) lithofacies. This unit has commonly been referred to as the Amabel Formation in previous studies in the area. In the Study Area, the Formation generally varies in thickness from about 25 to over 70 m, and the upper sections of the reef mounds, the crinoidal grainstones and the coquina shell beds make this formation highly transmissive, where they are present.

- **Goat Island Formation:** The Goat Island Formation consists of two members; the lower Niagara Falls Member and the upper Ancaster Member.

  - **Goat Island Formation – Niagara Falls Member:** The Niagara Falls Member is a finely crystalline and cross laminated crinoidal grainstone with small reef mounds. This unit is typically less than 10 m thick in the Study Area.
  - **Goat Island Formation – Ancaster Member:** The Ancaster Member is a chert rich, finely crystalline dolostone that is medium to ash grey in colour. This unit generally overlies the Niagara Falls Member although in some cases in the Cambridge and Guelph areas, these units are interfingered.
- **Eramosa Formation:** The Eramosa Formation consists of three members including, from oldest to youngest, the Vinemount Member, the Reformatory Quarry Member and the Stone Road Member.
  - **Eramosa Formation – Vinemount Member:** The Vinemount Member is comprised of thinly bedded, fine crystalline dolostone with shaley beds that give off a distinctive petroliferous odour when broken (Brunton, 2008). This dark grey to black dolostone unit was commonly identified in water well records as 'black shale' and mapped in previous studies in the City of Guelph as the Eramosa Member. The shaley beds of this Formation significantly reduce the vertical permeability across this unit relative to the other Formations.
  - **Eramosa Formation – Reformatory Quarry Member:** The Eramosa Formation above the Vinemount Member is described by Brunton (2008) as light brown to cream coloured, pseudonodular, thickly bedded and coarsely crystalline dolostone. This unit is susceptible to karstification due to its uniform fine dolomite crystallinity (Brunton, 2008). This unit also often contains mud-rich and microbial mat-bearing lithofacies that may act as aquitard materials, reducing the vertical permeability across this unit. This unit was logged as either the Guelph Formation or Eramosa Member in previous studies within the City of Guelph.
  - **Eramosa Formation – Stone Road Member:** This cream coloured coarsely crystalline Upper Eramosa unit is not present in most of the cores and outcrops in the Study Area and can be difficult to distinguish from the Guelph Formation.
- **Guelph Formation:** The Guelph Formation consists of two members; the lower Hanlon Member and the upper Wellington Member.
  - **Guelph Formation – Hanlon and Wellington Members:** The Guelph Formation consists of medium to thickly bedded crinoidal grainstones and wackestones and reefal complexes (Brunton, 2008). The Guelph Formation is cream-coloured and fossiliferous and where present in the Cambridge and Guelph area it is most often the uppermost bedrock unit.
- **Salina Formation:** The Salina Formation consists of interbedded brown dolostone and grey to green shale with lenses of gypsum and anhydrite. Typically, groundwater extracted from the Salina Formation is of poor quality due to high concentrations of calcium and sulphate resulting from the dissolution of gypsum and anhydrite minerals. This Formation underlies much of the Region of Waterloo from the urban areas of Kitchener- Waterloo to the west (Johnson et al., 1992). The Salina Formation is present in the westernmost parts of Cambridge in the Study Area. Recent investigations by Golder, as part of the Region's Integrated Urban System (IUS) Groundwater Supply Optimization and Expansion Project, have inferred the presence

of the Salina Formation in the Breslau area (westernmost portion of the Study Area) based primarily on the geophysical signature obtained from the downhole logging of test wells (Golder, 2009b).

2.9 Previous Regional Hydrogeological Conceptual Model

The regional hydrogeology of the Study Area was described in the Guelph-Puslinch Groundwater Study (Golder, 2006a). The extent of the model domain and starting point conceptual model for the Tier Three Project is largely based on the conceptual and numerical groundwater flow model that was developed for the Guelph-Puslinch Study. Figure 11 shows the regional conceptual hydrogeological model developed as part of the Guelph-Puslinch Study.

The Guelph-Puslinch study was based primarily on water well records and supported with little reliable sub-surface data and pre-dated the recent modifications to the bedrock stratigraphic framework made by the OGS (Brunton, 2009). Note that in the Study Area, the bedrock aquifer system has typically been referred to in the past as the Guelph-Amabel aquifer and the Eramosa was previously identified as a Member of the Amabel Formation. The Amabel Formation is now referred to in this area by the OGS as the Gasport Formation.

The Guelph-Puslinch Study conceptual model included eight hydrostratigraphic layers which from the bottom upward included the Lower Amabel Aquifer; the Production Zone Aquifer in the Amabel; an Upper Amabel Aquifer; the Eramosa Member Aquitard; the Guelph Formation Aquifer; a contact aquifer layer at the top of bedrock/base of overburden; a lower overburden layer comprised mostly of till; and an upper overburden layer comprised of both sand and gravel deposits as well as till. A more detailed description of each of these layers is provided in the Guelph-Puslinch Study Report (Golder, 2006a).

At the time of the Guelph-Puslinch Study, little high quality core and borehole geophysics data was available in the Guelph area to warrant the creation of variable surface elevations in three dimensions for the bedrock units (Eramosa and Amabel). In fact, only one core hole within the City of Guelph was then available for review. For the Guelph-Puslinch conceptual geological model, a constant slope parallel to the regional dip of the bedrock formations was assumed for the top and bottom of the Eramosa Formation (and top of Amabel Formation) with the position of the Eramosa unit inferred primarily from occurrences of ‘black shale’ indicated on numerous water well records. A constant thickness was then applied to the Eramosa unit (11 m), the Upper Amabel unit (12 m) and the Amabel Production Zone (12 m).

While providing a reasonable representation of much of the reported geologic information available at that time, this geological model provided a simplified representation of a complex stratigraphic system. It was recommended at that time that reliable stratigraphic data be developed from a series of core holes and piezometer installations. The results developed from such a program would provide the basis for the development of a reliable conceptual model to provide the framework for the City of Guelph to advance the development of additional groundwater supplies and the necessary protection measures to support the sustainable use of this aquifer over the long term. A regionalized approach to model parameterization was used for the Guelph-Puslinch Study, whereby parameter values are tied to regional hydrostratigraphic units and adjusted globally during the calibration process to best match the limited reliable water level data available at the time. This type of approach is the common industry practice for regional models of this scale and purpose. In this parameterization approach, although some spatial variations in material properties for a given hydrostratigraphic unit are considered to match regional trends in error statistics, small scale local variations (on the scale of an individual property for example) are not considered. With this type of approach, while the model can be effectively used to evaluate regional scale impacts, it may not be suitable for application at the local scale. This regionalized model parameterization approach is also used as part of the Tier Three model.

Given the three-dimensional nature of the bedrock aquifer system, parameters estimated through modelling including calibration to transient events (pumping tests), provide best estimates of regional aquifer parameters, This is particularly the case for the vertical hydraulic conductivity which is difficult to determine through testing at individual boreholes such as packer and slug testing.

The Guelph-Puslinch Model built on previous modelling studies in the area primarily including:

- **The Mill Creek Subwatershed (MODFLOW) Groundwater Model**. This model was developed to support the Mill Creek subwatershed management strategy (CH2M Gore and Storrie Ltd. et al., 1996).
- **The City of Guelph (MODFLOW) Groundwater Model**. This previous model was used and regularly updated by the City as part of the management of the municipal water supply. The last update of this model was made in 2003 as part of the Arkell Spring Grounds assessment of additional groundwater takings (Gartner Lee Ltd., 2003).
- **The GRCA (FEFLOW) Groundwater Model**. This model was constructed for the entire GRCA watershed (WHI, 2004).

The hydraulic conductivity values for the previous model regional hydrostratigraphic units are presented in Table 2.4, including the final calibrated values from the Guelph-Puslinch Model. The hydraulic properties of the main aquifer (Amabel Production unit) and the main aquitard (Eramosa unit) were the most critical and sensitive parameters controlling the modelled groundwater flow system. As part of the model calibration process, a series of hydraulic conductivity zones were delineated within the Amabel Production unit, ranging from 1.0 E-4 m/s to 1.7 E-3 m/s. These zones built on previous zone delineations completed as part of the City of Guelph MODFLOW Model (Gartner Lee Ltd, 2003). In addition to the Amabel Production unit, the Eramosa aquitard was a key sensitive parameter controlling leakage (recharge) to the deeper aquifer. The calibrated vertical hydraulic conductivity of the Eramosa aquitard in the Guelph-Puslinch model was 1E-09 m/s.

For additional description of the Guelph-Puslinch model parameterization refer to Golder (2006). In a similar manner as in the Guelph-Puslinch Study, the Tier Three Assessment model builds on previously estimated regional parameterizations, as is further discussed in Section 5.5.

3.0 DATA COMPILATION

3.1 Borehole Log PDF Compilation

Indexed copies of PDFs of borehole logs were compiled for key bedrock boreholes used to support the characterization work. This compilation included scanning of hard copy logs and assembling those logs already in PDF format. Approximately 100 borehole log PDFs were compiled. The compilation is included in Appendix A and the indexed PDF file is provided digitally.

3.2 Borehole Database

The following provides a general overview of the contents and format of the Tier Three Project Borehole Database.

The Tier Three Project Borehole Database is a standard relational database management system, compatible for use and manipulation in Oracle, SQL and MS Access. The primary key for the database is the borehole LOCID which relates the various tables and provides the spatial borehole location for the data. The database includes all of the Guelph-Puslinch Study database tables (Golder, 2006a). The Guelph-Puslinch Study database was expanded to include the following additional tables:

- **Key Borehole Detail Table:** Includes all locations identified as "Golden Spikes" in the Guelph-Puslinch Study, plus all locations with geologic picks or water level or pumping data in the Tier Three project data tables. This table provides links to Borehole IDs from other borehole database tables including the Guelph-Puslinch database, the Mill Creek database, the Arkell database, the Guelph-Eramosa database and the Region of Waterloo WRAS+ (Water Resource Analysis System) database. This table includes the key location and construction information for these higher quality boreholes. This table includes descriptions of the types of geophysical logging completed at the borehole, the drilling method and whether a pdf of the consultant borehole log was compiled as part of this project. This table also includes references to studies, which provide additional details and testing information related to the borehole.

- **Monitoring Interval Table:** This table provides information on all the monitoring wells. This table contains a link to the borehole details associated with the monitor and provides the details for each monitor installed within the borehole. Information in this table includes monitoring well construction information such as the screen depths, screened formation and the measuring point reference. Records are included for wells for which water level data was compiled.

- **Transducer and Manual Water Level Data Tables:** Includes a compilation of transducer and manually measured water level data compiled from a variety of sources. The City of Guelph monitoring network has expanded rapidly over the last five years resulting in collection of a large volume of transducer water level data. Water level data from about 200 wells were imported into these data tables.

- **Municipal Pumping Data Table:** Includes a compilation of municipal pumping data provided by the City of Guelph. This data includes daily volumes (in m^3) from 1997 until the end of 2008 for all City of Guelph Production Wells. In addition, daily volumes for some U of G wells are included for the period from 2004 to 2008 and monthly total volumes for the Guelph Dolime Quarry pumping are also included. A monthly average of the daily production totals has been calculated in a query from the daily values.

- **Geologic Picks Data Table:** Includes the formation top depths for all geological formations picked from borehole logs and core as part of this study. This table also includes a reliability ranking for the picks. For cases where picks were obtained from other studies (top of bedrock) the source of the picks information is noted.

The primary data sources included in the database compilation were the following:

- Guelph Monitoring System Project (Golder, 2009);
- Southwest Quadrant EA Project (Golder, 2011);
- City of Guelph Quadrant Reports (Jagger Hims Ltd. 1995 and 1998a,b,c);
- Arkell Spring Grounds Ground Supply Investigation (Gartner Lee Ltd., 2003);
- Arkell Spring Grounds Hydrogeologic Study (AECOM, 2009);
- Provincial Groundwater Monitoring Network;
- City of Guelph water level and pumping data;
- Township of Puslinch monitoring data; and
- Miscellaneous other available reports and data from consultants.

4.0 FIELD PROGRAM

4.1 Multi-level Monitoring Well Program

4.1.1 Monitoring Well Program Overview

In the last five years, since the Guelph-Puslinch Study groundwater flow model was developed, Golder and others have completed comprehensive drilling and testing programs in the City of Cambridge and City of Guelph areas that have yielded significant additional information on subsurface conditions locally and on the interactions with the surface water system. Information includes continuous water level records for wells isolated in the Gasport Formation, geophysical logs and hydraulic testing results which have improved the definition of the Eramosa Formation and the understanding of the distribution and continuity of the highly permeable producing zones within the Gasport and other Formations.

Figure 12 shows the locations of higher quality deep bedrock boreholes drilled prior to this project. Over large sections of the Study Area, primarily beyond the City of Guelph limits, prior to this project available subsurface data was essentially limited to water well records that frequently did not intersect (or identify) the Gasport Formation and did not provide adequate characterization of the Eramosa Formation aquitard. These were critical data gaps in the areas immediately upgradient from the City and to the south of the City between Guelph and Cambridge. As part of this project, a field monitoring well program was designed to address these data gaps.

The key objectives of the field program are summarized as follows:

- To obtain high quality information outside of the City of Guelph to assess the following key characteristics that strongly influence regional groundwater flow and water budget for the City of Guelph aquifer system:
    - The distribution of highly permeable producing zones within the bedrock formations; particularly the Gasport Formation;

  - The characteristics of the overlying Eramosa Formation aquitard and other overlying units that limit downward leakage to the Gasport Formation;
  - Water levels in each of the bedrock formations;
  - Regional groundwater flow directions in the Gasport Formation; and
  - Vertical hydraulic gradients.
- To establish a network of deep monitoring wells outside of the City of Guelph.

The Tier Three Project monitoring well program included drilling through the aquifer system to the Cabot Head Formation, geophysical logging, borehole hydraulic testing, monitoring well nest installation, water level monitoring and water quality sampling at a total of 11 sites. Table 4.1 summaries the field program components that were conducted at each of the 11 sites, which are further described in the below sections.

4.1.2 Drilling Locations

The locations of the Tier Three Project monitoring well sites are shown on Figure 13. The sites were selected to provide coverage outside of the City of Guelph where pertinent data were lacking.

A brief description of the sites is provided below:

- **MW08-T3-01 and MW08-T3-02:** These sites were selected to resolve data gaps immediately upgradient to the north of the City of Guelph within 5 km of the northernmost municipal wells. These sites are located on GRCA lands at the Marden Tract (MW08-T3-01) and Guelph Lake CA (MW08-T3-02).
- **MW08-T3-03, MW08-T3-04 and MW08-T3-05:** These three sites were selected to provide high quality data at sites located 10 to 20 km upgradient to the north of the City of Guelph in the area between Guelph and Fergus and Belwood Lake. These Sites are located on GRCA lands at the Hurkman Tract (MW08-T3-03), Highway 6 south of Fergus (MW08-T3-04) and the Johnson Tract (MW08-T3-05).
- **MW08-T3-06:** This site is located to the northeast of Guelph adjacent to the Eramosa River near the town of Everton. This site is located in the area where bedrock outcrops and the Gasport Formation is close to surface. This site is located on GRCA lands near the Everton Mill.
- **MW08-T3-07, MW08-T3-08, MW08-T3-09 and MW08-T3-10:** Sites MW08-T3-07 and MW08-T3-08 are located south of Guelph Lake approximately 5 km from the nearest City of Guelph municipal wells. The sites MW08-T3-09 and MW08-T3-10 are located south and southeast of Guelph also about 5 km from the nearest the City of Guelph municipal wells. The City of Guelph provided separate funding for the monitoring well program at these sites to provide valuable information for incorporation into the Tier Three program. The sites are located on GRCA lands in the Guelph Lake (MW08-T3-07, MW08-T3-08), Crawford Tract (MW08-T3-09) and the Vance Tract (MW08-T3-10) areas.

MW09-T3-01: This site was a late addition to the field program made possible through funding from the Ontario Geological Survey (OGS) provided in the spring of 2009. This site is located between Guelph and Cambridge on the Little Tract lands owned by Wellington County. The site is situated in an area of sparse deep bedrock data located midway between the Hespeler area of Cambridge and the southwestern most Tier Three program well MW08-T3-10. Additional funding was provided by the OGS to complete continuous coring of the bedrock at four of the 11 sites. The sites that were cored are indicated on Figure 13 and include MW08-T3-02, MW08-T3-05, MW08-T3-06 and MW09-T3-01.

4.1.3 Borehole Drilling

Table 4.2 outlines the borehole location and construction details for the 11 bedrock boreholes drilled as part of this project.

The drilling program was completed during the months of July through September, 2008 at the 10 sites located on GRCA lands. Golder retained the services of Gerrits Well Drilling Inc. (Gerrits) to drill the 10 boreholes on the GRCA lands. The boreholes were drilled by Gerrits using air rotary techniques. A 152 mm steel casing was advanced to bedrock at each location. Drilling was continued through the bedrock and approximately 1.5 to 3 m into the Cabot Head Formation at all locations. The contact of the top of the Cabot Head Formation ranged from 60 m below ground surface to 144 m below ground surface. For the sites where the bedrock was cored, Gerrits subcontracted Aardvark Drilling Inc. to complete the bedrock coring. Borehole development took place following drilling using air lifting techniques for periods of up to 8 hours.

In the boreholes completed by air rotary methods, borehole cuttings were collected at 3 m intervals and organized into rock chip trays. Three of the sites on GRCA lands (MW08-T3-02, MW08-T3-05 and MW08-T3-06) were completed using PQ coring techniques in the bedrock. Gerrits Well Drilling installed the 152-mm casings to bedrock and Aardvark Drilling Inc. was employed to PQ core from the bedrock surface to the Cabot Head Formation. Bedrock core was collected, photographed and logged.

An overburden step-out hole was drilled at seven of the 10 locations (see Table 4.1). These overburden wells were screened in shallow saturated soils and local overburden aquifers. The overburden step-out holes were not installed at sites where the overburden was very thin and/or no permeable horizons were encountered. The depths of the step-out overburden boreholes ranged from 10.7 to 36.9 metres below ground surface (mbgs).

In May and June of 2009, the additional cored borehole MW-09-T3-01 was completed at the Little Tract on Wellington County land. As mentioned above, this borehole was a late addition to the program funded by the OGS. This borehole was drilled by Aardvark Drilling Inc. using HQ coring techniques.

Completed borehole logs can be found in Appendix B. Water well records for each site can be found in Appendix C1. Photos of the collected core and chips are included in Appendix C2. The original well survey coordinate information is included in Appendix C3.

4.1.4 Geophysical Logging

Downhole geophysical logging of the boreholes, including natural gamma, apparent conductivity and optical televiewer, was completed by Golder prior to monitoring well installation. Video logging was completed at some of the holes under ambient conditions primarily to inspect the borehole conditions for the planning and design of the multi-level well installations. A summary of the geophysical logging completed at each borehole is provided in Table 4.1. The geophysical logs can be found on the borehole logs in Appendix B. Digital versions for the optical televiewer logs are provided at a 1:10 vertical scale and 1:200 scale versions are provided in Appendix C4. The geophysics completed by Golder provided valuable information for the interpretation of the borehole geology, particularly in the cases where the sites were not cored.

In addition to the downhole logging completed by Golder, the U of G conducted high resolution temperature profiling at some of the sites (see Table 4.1). This investigative technique, developed by the Universities of Waterloo and Guelph, involves collection of active and passive temperature logs within a blank FLUTe liner, which provides natural ambient thermal stratification within the borehole (Pehme et al 2007). Additional description of the FLUTe liners can be found in Section 4.1.7. This temperature profiling technique was used to help identify permeable zones that likely contribute flow under natural (not vertically cross-connected) conditions. This technique was used to locate permeable zones in the borehole and provide information for the design of the multi-level monitoring wells. A summary of the groundwater flow zones interpreted from the temperature logging was provided by the U of G and is included in Appendix C4.

4.1.5 Packer Testing

Packer testing was performed by Golder at nine of the Tier Three project boreholes during the months of November 2008 to January 2009. Packer testing was conducted at the Little Tract site (MW09-T3-01) during the month of June 2009. Packer tests were not performed at Hurkman Tract (MW08-T3-03) due to site conditions restricting accessibility at the time of the testing program.

At each site, three or four representative zones were selected for packer testing based on review of the geophysical logs. A double packer assembly was used to isolate bedrock sections 3 m to 10 m in length for hydraulic conductivity testing. The pneumatic packers were lowered on the wireline and were inflated with nitrogen to isolate the test interval. Pressure transducers for water level monitoring (dataloggers) were installed within the test interval outside of the drill rods, above the packers in the rods and above the packer in the open borehole.

Rising head slug tests and pumping tests were performed at all of the sites except for the HQ cored site at Little Tract (MW09-T3-01) where falling head and pumping tests were performed. The rising head slug tests were performed on the lower permeability packer zones, where a constant rate of pumping could not be maintained due to decline of water levels to the pump intake. Once a static water level was established following packer inflation, the interval was pumped for a maximum of 30 minutes. The recovery of water levels to static conditions was monitored following the pumping of water from the test interval. At the Little Tract site MW09-T3-01, falling head tests were conducted by injecting water into the borehole and monitoring the return of water levels to static conditions.

Table 4.3 provides a summary of the interval details for each packer test conducted. The estimated hydraulic conductivity values are presented in this table. For the rising head tests, the Hvorslev method was used to analyze the data. For the pumping tests, the Thiem/Dupuis equation was used to interpret the results. Plots of drawdown versus time are included in Appendix C5. The interpreted hydraulic conductivity results from the packer testing are plotted on the borehole logs in Appendix B.

The U of G collaborated on the packer testing program for this project coincident with their research objectives and performed packer testing at the cored sites MW08-T3-02, MW08-T3-05 and MW08-T3-06. The U of G performed both rising head slug tests and pumping tests at 5 to 8 intervals per site during the months of December to February, 2009. Detailed discussion of the results of this testing can be found in Pat Quinn's PhD thesis (Quinn, 2009). The U of G packer testing involved withdrawal pumping tests and slug tests at various hydraulic head displacements and pumping durations resulting in multiple interpreted hydraulic conductivity values per interval. The U of G interpretation results for this packer testing presented in Table 4.3, and on the borehole logs are from the rising head tests of the greatest head displacement calculated by U of G using the Hvorslev method.

4.1.6 Short-Term Specific Capacity Tests

Short-term pumping tests were conducted at all sites with pumping from the open boreholes. These tests were conducted to provide information on relative permeability and specific capacity of the boreholes when open to the entire bedrock aquifer. The tests ranged in duration from 60 to 270 minutes with 15 minutes to one hour time of recovery monitoring. Pumping rates were the maximum sustainable rate given the size of pump and ranged from 71 to 305 m^3/day (10.8 to 46.6 IGM). These tests were conducted without need to obtain a Permit To Take Water from the MOE since the pumped volume was less than 50 m^3/day.

Due to the short-term nature and low pumping rates, these pumping tests provide only basic information on the relative yields at the locations. Further testing would be needed to confirm hydraulic properties at these sites.

Table 4.4 provides a summary of this testing including the calculated values of specific capacity at each borehole and the estimated hydraulic conductivity and transmissivity. The transmissivity was estimated using the Thiem-Dupuis method. Plots of drawdown versus time for these tests are included in Appendix C6.

4.1.7 FLUTe Hydraulic Conductivity Profiling

FLUTe hydraulic conductivity profiling was performed on ten of the Tier Three project boreholes as part of an OGS funded collaboration with the U of G. The profiling was completed by FLUTe personnel between September and November 2008 with assistance from U of G and some assistance provided by Golder field staff.

The FLUTe profiling technique uses a flexible nylon fabric tube that is everted down the borehole with a constant hydraulic head maintained inside the liner. The liner descent rate, the driving hydraulic head and the back tension on the liner are monitored and are used to calculate the discrete transmissivity between each data point as the liner is lowered down the borehole. Data reduction and transmissivity calculations based on the Flute data were done by Carl Keller of FLUTe.

Results of the FLUTe profiling can be found on the borehole logs in Appendix B.

4.1.8 Multi-level Well Installations

The original work plan for the Tier Three program included installation of piezometer nests of three wells per borehole similar to the typical previous municipal monitoring well installations in the City of Guelph allowing measurements of water levels and gradients typically in the Gasport Formation, Eramosa and Guelph Formations. The original monitoring well installation program for this project was expanded based on a more elaborate OGS funded multi-level installation program at the Tier Three project boreholes that was completed in collaboration with the OGS, the U of G and Golder. The primary purpose of these installations is to allow hydraulic head measurement and water sampling from discrete intervals within the borehole with a greater resolution (more intervals) than the traditional piezometer design.

The expanded multi-level program involved custom designed experimental system installations from three different manufacturers as follows:

- **FLUTe: T**he FLUTe multi-level system uses a polyurethane coated nylon material to create sealed zones between mesh monitoring intervals. The mesh monitoring intervals have a port and tube extending to ground surface allowing water level and water quality sampling. There is no need for backfilling with these systems and the FLUTe system is removable and can be considered a temporary installation. These systems are not ideal for sites with large solution cavities or strong vertical hydraulic gradients due to the flexible nature of the construction materials. Larger diameter boreholes are preferable for installation of these systems. The FLUTe systems were designed with three larger diameter tubes that could accommodate Micro-Diver pressure transducers.
- **Solinst Waterloo:** The Solinst multi-level system Model 401 consists of a two-inch diameter PVC casing containing sampling tubes leading from individual ports to ground surface. Installations of these systems in rock typically include the use of packers to isolate the intervals, however in this project, standard backfilling with sand and bentonite was used to isolate the ports. These systems are best suited to locations with relatively shallow water tables (< 8 mbgs) due to issues obtaining water level measurement and water samples from this system if the water level depth is greater.
- **Westbay:** The Westbay multi-level system consists of a two inch diameter PVC casing with ports for head measurement and water sampling. The measurement of head and water sampling of these systems require specialized wireline tools that are lowered from ground surface to connect with the ports. These systems can accommodate a greater number of ports since there is no need for tubes from each port leading to ground surface inside the casing. Similarly to the Solinst multi-level system installations for this project, standard backfilling with sand and bentonite was used to isolate the ports.

The intervals were selected/designed based on the results of the geophysics, packer testing and FLUTe hydraulic conductivity profiling. The type of system installed at each Tier Three borehole site is shown in Table 4.1.

The multilevel installation program began in June 2009 and was completed in May 2010. Given the custom and experimental nature of these installation designs, representatives from each of the three manufacturers assisted on-site with the installations along with staff from the U of G, Golder and Gerrits.

The multi-level system construction details are summarized in Table 4.5 and are shown on the borehole logs in Appendix B. Note that at the Westbay and Solinst sites, a 1“ diameter PVC piezometer was also installed outside of the multi-level casing as the most shallow bedrock monitoring interval.

4.1.9 Water Level Monitoring

Water level dataloggers were installed in all larger diameter Tier Three Project monitoring wells. This included the overburden step-off holes, the 1” PVC bedrock monitors and the FLUTe system intervals with larger diameter tubes. In total, 16 pressure transducers with dataloggers were installed. Table 4.1 and Table 4.5 indicate which monitors have a transducer installed. A monthly round of manual water level measurements was taken at all of the intervals in each multi-level well nest. The majority of the monthly manual water level measurements were made by U of G personnel. Hydraulic head profiles taken approximately one month after system installation are shown on the borehole logs in Appendix B. The groundwater elevation monitoring results for each well nest are shown on the hydrographs presented in Appendix C7.

4.1.10 Water Quality Sampling

Water samples were collected in December 2009 from the multi-level bedrock intervals with larger diameter (19.1 mm and 24.1 mm) tubes in the following well nests: MW08-T3-01, MW08-T3-05, MW08-T3-06 and MW08-T3-08. These samples were submitted to Maxxam Analytics in Mississauga for RCAp – Comprehensive water quality analyses, including anions, dissolved metals, nutrients and dissolved organic carbon (DOC). The certificates of analysis for the sampling are included in Appendix C8.

The results from these analyses are presented in Table 4.6. Field measurements of pH, temperature and electrical conductivity (EC) were also taken. A peristaltic pump was used to sample from the Solinst wells (MW08-T3-01, MW08-T3-05 and MW08-T3-06). Prior to sampling, at least two well volumes were purged from each well. As the wells were being purged, pH and EC were monitored. Once pH and EC measurements reached a steady state, the wells were sampled. The dissolved metal sample was filtered using a GWV High Capacity 0.45 micron inline filter.

A FLUTe sampler was used to sample the monitoring intervals in MW08-T3-08. Nitrogen gas was injected into each of the monitoring wells to expel water through the port tube. Three to four well volumes were purged from each interval prior to sampling. The dissolved metal samples were filtered using a 0.45 micron filter fitted on the end of a syringe. Samples were stored in a cooler at temperatures less than 5^0C until they were delivered to the laboratory for analysis.

The remaining Westbay and FLUTe well nests (MW08-T3-02, MW08-T3-03, MW08-T3-04, MW08-T3-07, MW08-T3-09, MW08-T3-10) were not sampled as part of the Tier Three Project since the U of G plans to sample these wells as part of an M.Sc. student thesis project.

4.1.11 Discussion of Monitoring Well Program Results

The following summarizes the key findings from the Tier Three project drilling sites:

Stratigraphy

A summary of the geologic formations encountered at each drilling site is provided in Table 4.7. The following provides an overview of the stratigraphy encountered at the drilling sites:

- **Cabot Head Formation:** The Cabot Head Formation was encountered at depths ranging from 54 to 141 mbgs.
- **Rochester, Irondequoit, Rockway and Merritton:** These Formations were about 2 to 5 m thick in total. Merritton was absent at the easternmost location MW08-T3-06. The Rochester Formation was not encountered in any of the boreholes.
- **Gasport Formation:** The Gasport Formation ranged in thickness from 16 to 51 m. The thickest sequence of Gasport Formation of 51 m was encountered at MW08-T3-02 located north of Guelph Lake.
- **Goat Island Formation:** The Goat Island Formation was encountered in all boreholes except at MW08-T3-02, where the Gasport Formation was the thickest. An exceptionally thick sequence (40 m) of the Niagara Falls Member of the Goat Island was observed at MW08-T3-04.
- **Eramosa Vinemount Member:** The Vinemount Member was generally less than 10 m thick, with the exception of Site 7 where it was 15 m thick. The Vinemount was absent at MW08-T3-04, where the Guelph directly overlies a thick Goat Island Formation. The Vinemount is also absent at MW08-T3-06, where the Goat Island is the uppermost Formation and has likely been eroded. At MW08-T3-09 and MW08-T3-10, south of the City of Guelph, the Vinemount is absent, however the lower portion of the Ancaster Member contains shaley beds of a similar aquitard nature to the Vinemount Member as described further below. The Vinemount is also very thin (<1m) at MW08-T3-01.
- **Eramosa Reformatory Quarry Member:** This unit was observed at most of the sites except MW08-T3-06 and MW08-T3-09 to the east where it has likely been eroded away and the Goat Island is the uppermost unit. The Reformatory Quarry is also absent at MW08-T3-04, where the Guelph Formation directly overlies the Goat Island. Thickness of the Reformatory Quarry unit is generally less than 10 m other than at MW08-T3-01 where a very thick sequence (48 m) of Reformatory Quarry was observed; this is similar to areas in Breslau and Cambridge to the west where the Gasport is thinner and overlying Goat Island and Eramosa are relatively thick.
- **Eramosa Formation- Stone Road Member:** The Stone Road Member was observed in the core from MW08-T3-02 and MW08-T3-05 and was also encountered at MW08-T3-03. The Stone Road Member was not observed at the other sites.
- **Guelph Formation:** The Guelph Formation was absent at most of the sites except for MW08-T3-02, MW08-T3-04 and MW09-T3-01. The Guelph Formation was observed to be the thickest at MW08-T3-04, where it was about 30 m thick.

Hydraulic Characteristics

The following provides a summary of the key hydraulic characteristics observed from the Tier Three testing program.

Specific Capacity Testing

- The specific capacity calculated from the pumping tests on the open boreholes is presented in Table 4.4. The permeability at most of the boreholes was observed to be quite low with the exception of boreholes MW08-T3-07, MW08-T3-09, MW08-T3-10 and MW09-T3-01. At boreholes MW08-T3-07 and MW08-T3-09 a moderate permeability was observed. At boreholes MW08-T3-10 and MW09-T3-01 a relatively high permeability was observed. The estimated specific capacity and transmissivity values presented in Table 4.4 are based on pumping tests with relatively low rates and a short duration.

FLUTe Profiling

- The FLUTe profiling results provide a high resolution indication of the vertical variation in transmissivity within the boreholes and are presented on the borehole logs in Appendix B. The FLUTe discrete transmissivity profile, as calculated by Carl Keller of FLUTe, is presented on the borehole logs. Note that the discrete transmissivity profile is presented on a log scale and the majority of the transmissive zones identified represent very subtle relative increases in transmissivity rather than major flow producing intervals. These results are also indicative of horizontal rather than vertical permeability in the Formations.

- The boreholes with identified highly transmissive zones include MW08-T3-07 and MW08-T3-09. FLUTe testing was also attempted at the highly permeable borehole MW08-T3-10, however due to the strong downward gradients at this site; the FLUTe profiling method was not possible. These identified highly transmissive zones are described below:

    - At MW08-T3-07, a zone of high transmissivity was encountered between depths of 44 and 52 mbgs corresponding to solution cavities and fractures that can be observed in the optical televiewer log at the base of the Goat Island Formation near the contact with the Gasport Formation; and

    - At MW08-T3-09, a zone of high transmissivity was observed between about 67 to 76 mbgs in the Gasport Formation corresponding to a zone of vugs, solution cavities and fractures observed in the optical televiewer log.

- Other relatively minor transmissive zones were identified from the FLUTe testing at the other boreholes. These zones are summarized as follows:

    - Common minor transmissive zones throughout the Reformatory Quarry Formation usually occurring at karstified zones, lithological breaks or contacts with the overlying and underlying Formations.

    - Minor transmissive zones in the Upper and Middle Gasport Formation corresponding to minor fractures and solution cavities, the upper sections of the reef mounds, the crinoidal grainstones and coquina shell beds.

    - Infrequent minor transmissive zones in the Goat Island Formation usually occurring at lithological breaks or contacts with the overlying and underlying Formations. At MW08-T3-08, a minor transmissive zone was identified in the upper 10 m of the Niagara Falls Member.

Packer Testing

- As with the FLUTe profiling the packer testing results provide an indication of the horizontal permeability of the Formations immediately local to the borehole. The packer testing results are presented in Table 4.3 and are plotted on the borehole logs in Appendix B.

- The boreholes identified from the packer testing to have highly permeable zones include MW08-T3-07 and MW08-T3-09. These zones showed hydraulic conductivity ranging on the order of 10^{-4} m/s to 10^{-3} m/s as estimated from the packer testing results. These identified highly transmissive zones are summarized below:

  - At MW08-T3-09, the tested zone between 67 and 77 mbgs showed a high hydraulic conductivity based on the packer testing. This is the same highly transmissive zone in the middle of the Gasport Formation that was identified from the FLUTe profiling. The tested zone between 40 and 50 mbgs was also found to be highly permeable throughout the Niagara Falls Member of the Goat Island Formation and the contact with the Gasport Formation.

  - At MW08-T3-10, the tested zone between 89 and 99 mbgs showed a high hydraulic conductivity from the packer testing. This zone is located in the middle of the Gasport Formation. The packer testing showed another highly permeable zone in this borehole between 36 and 46 mbgs in the Reformatory Quarry Formation, which is the uppermost bedrock formation at this location. From the optical televiewer log, a large fracture and zones of karstification can be observed in the Reformatory Quarry Member at this location.

  - At MW09-T3-01, the tested zone between 97 and 100 mbgs showed a very high hydraulic conductivity. This zone is in the middle of the Gasport Formation where several large fracture zones can be observed in the optical televiewer log.

- With the exception of the highly permeable zones identified above, the estimated hydraulic conductivity of the packer tested intervals was generally on the order of 10^{-6} to 10^{-5} m/s with some lower permeability zones estimated closer to 5×10^{-7} m/s. The estimated values for the tested zones generally showed this range of variability within each of the Formations.

Water Levels and Vertical Hydraulic Gradients

- Significant downward gradients are observed at the multi-level monitors in MW08-T3-07, MW08-T3-08, MW08-T3-09, MW08-T3-10 and MW09-T3-01. These sites are all relatively close (within 5 km) of the City of Guelph municipal pumping and show higher permeability zones in the Gasport Formation.

  - The strongest downward gradients are observed at MW08-T3-09 and MW08-T3-10, where the multi-level monitors show a difference in head of 13 to 14 m over a thin (1 to 2 m) section of shaley beds at the base of the Ancaster Member of Goat Island Formation. This is illustrated in the head profile on the borehole logs in Appendix B.

  - Downward gradients are observed at MW08-T3-07 and MW08-T3-08, where the multi-level monitors show a difference in head of 7 to 8 m, primarily across the Vinemount Member.

  - At MW09-T3-01, downward gradients are also observed across the Vinemount Member as measured in the two piezometers installed at this location. A head difference of about 6 m is observed across the Vinemount Member at this location.

- Vertical gradients at the other sites are subtle in comparison to those mentioned above.

- At the sites with significant downward gradients, the hydraulic head measured in the open borehole (prior to packer testing or multi-level installations) was similar to the hydraulic head measured in the Gasport Formation, with the exception of site MW08-T3-10. At site MW08-T3-10, the measured hydraulic head in the open borehole was similar to the values in the upper Goat Island and Reformatory Quarry units. This suggests that at this site, the transmissivity of the shallow bedrock (Reformatory Quarry) is likely greater than the transmissivity of the Gasport Formation. The packer testing of the Reformatory Quarry unit showed a relatively high hydraulic conductivity at this location with an estimated value of 2.1E-4 m/s, which is similar to the relatively high value of 2.3 E-4 m/s estimated from packer testing of the Gasport Formation at this borehole.

Water Quality Results

The water quality sampling results are presented in Table 4.6 and a basic description of these results is provided below.

- In some of the monitoring wells screened in the Eramosa Formation, high concentrations of dissolved metals are observed. At MW-T3-08, concentrations of arsenic from the Eramosa Formation intervals range from 40-70 µg/L, concentrations of iron range from 3.9 to 7.7 mg/L and concentrations of zinc range from 26-40 µg/L. The concentration of iron in the Eramosa Formation interval at MW08-T3-01 ranges from 0.9 to 7.900 mg/L.

- At MW08-T3-05, a monitor screened in the Eramosa and two monitors screened in the Gasport Formation were sampled. Water sampled in all of these intervals has high concentrations of total dissolved solids, ranging from 1290 mg/L in the Eramosa to 2030 mg/L in the deep Gasport. High concentrations of sulphates (780-1300 mg/L) are found in these intervals, with the highest concentration in the deep Gasport.

- At MW08-T3-06, monitoring wells screening the Goat Island and Gasport Formations were sampled. At this location the shallow Gasport had lower concentrations of TDS, sulphate, dissolved iron and major cations than the concentrations found in the Goat Island and deeper Gasport monitoring wells.

4.2 Baseflow Monitoring Program

This section outlines the methodology and results of stream baseflow monitoring completed by Golder. Surface water flow measurements were obtained at various streams/rivers in the Study Area for use in the groundwater flow model calibration. Measurements were collected during “baseflow” conditions at a total of 32 locations on July 7, August 26 and October 22, 2008.

Monitoring locations were chosen based on the spatial extent of the Study Area, usefulness for groundwater model calibration and suitability for flow measurement and accessibility. The monitoring locations are presented on Figure 14.

The criterion adopted for identifying “baseflow” conditions was a minimum of four consecutive days without observed precipitation in the area. Based on a review of meteorological records from the Environment Canada weather station at the Region of Waterloo International Airport, two of the monitoring events were preceded by precipitation within the day of monitoring and the previous three days; however, the flow measurements that were collected during these campaigns were deemed acceptable for the purposes of this program as the observed rainfall was either minor (i.e., ≤2.0 mm in the four day period) or localized. All spot flow measurements for each monitoring event were completed within one day to maintain comparable results across all stations. Three field teams of two persons each were used to accommodate the large number of monitoring locations.

The majority of the spot flow measurements were estimated using the velocity-area method. Streamflow velocities and corresponding water depths were collected at various intervals along representative cross sections on the watercourses. Interval spacing varied based on cross section width and geometry. At each interval, velocities were recorded at 60% depth where water depths were less than or equal to 0.5 m and at both 20% and 80% depth where water depths were greater than 0.5 m. Most streamflow velocities were estimated using an electro-magnetic flow meter (Valeport Model 801) while some locations were measured using an impeller flow meter (Valeport Model BFM002).

The timed volume flow method (i.e., bucket and stopwatch) was employed at one monitoring location (i.e., EC_10) due to the shallow depth of flow at the culvert outlet, low flow rate and available drop height for bucket use.

Flow measurement method protocols are summarized in Table 4.8.

The estimated flow rates at each of the monitoring locations were an average of the mid-section method and mean-section method for all velocity-area method locations and are summarized in Table 4.9.

In-situ water chemistry parameters of pH, electrical-conductivity (EC) and temperature were recorded at the time of each flow measurement event using hand-held meters (Hanna Instruments; pH meter: HI 98128; EC meter: HI 98312). These field chemistry results are provided in Appendix C9.

5.0 HYDROGEOLOGIC CHARACTERIZATION AND CONCEPTUAL MODEL REFINEMENT

5.1 Water Taking Assessment

5.1.1 City of Guelph Municipal Water Takings

The City of Guelph owns and operates 23 wells and an infiltration gallery that make up part of the municipal water supply system. It should be noted that not all of the wells are in use, primarily due to water quality concerns. A summary of the municipal water takings is included in Table 2.1. The permitted rates for the wells are listed as per the City of Guelph Water Supply Master Plan (Earth Tech et al., 2006). Table 2.1 also shows the average rate that the wells were pumping in 2008 and the estimated capacity as presented in the City of Guelph Vulnerability Report (AquaResource, 2010).

The estimated capacity of the wells is approximately 89,910 m^3/day and the average day water demand in 2008 was approximately 48,492 m^3/day or 54% of the estimated capacity. AquaResource (2010) indicate that the estimated well capacities were based primarily on operational experience and monitoring data and do not include potential for well interference or consideration for impacts to ecological features. The estimate also includes wells with water quality concerns and required treatment and wells that are still in the approvals process. It should also be noted that the estimated capacity may be affected by climatic conditions such as drought. This was evident at the collector system from 1997 to 2003 when precipitation was below average for most of those years (Earth Tech et al., 2006). In addition, well interference and well efficiency may also reduce the estimated capacity of the wells.

5.1.2 Other Permitted Water Takings

The locations of other municipal wells near the City of Guelph are shown on Figure 15. The main adjacent municipalities that use groundwater for supply include Fergus/Elora, Acton, Rockwood, Maryhill and Cambridge.

In addition there are a number of communal water supplies in the area including Mini-Lakes, Irish Creek Estates, McClintock's Trailer Park and Mill Creek Camping and Country Club.

The non-municipal permitted water users in the Study Area are shown on Figure 15. The non-municipal Permit To Take Water information shown on Figure 15 was provided by the GRCA. Based on this data there are permits to take water for agriculture, commercial, dewatering, industrial and remediation.

More detailed discussion of permitted water takings and water demands is presented in the Tier Three Numerical Modelling Report.

5.2 Hydrostratigraphic Model Refinement

The previous conceptual hydrogeological model for the Study Area that was developed as part of the Guelph-Puslinch Study (Golder, 2006a) has been updated and improved as part of this study. The revised conceptual model used in this study is described in this section including discussion of the modifications and advancements made relative to the previous model. An update to the previous conceptual model was warranted based on the following key factors:

- Approximately 100 higher quality deep bedrock boreholes have been drilled since the Guelph-Puslinch Study in the Cities of Guelph and Cambridge. These boreholes have included continuous coring and/or high quality geophysical logging to better define bedrock geology. These boreholes now provide sufficient density of high quality information within these municipal well fields to begin to explicitly define the contact elevations of the various bedrock geologic formations with a higher degree of confidence. At the time of the Guelph-Puslinch Study, such information was not available and therefore simplifying assumptions of planar surfaces with constant slopes were used for many of the bedrock formations as described in Section 2.9.

- The drilling program for the Tier Three Study has provided deep bedrock hydrogeologic information outside of the core areas of the municipal well fields to begin to interpret a regional hydrogeological conceptual model based on some high quality bedrock information in these areas.

- Development of much of the above described recent borehole data and associated geologic interpretations have been possible due to funding contributions and input from the ongoing Ontario Geologic Survey (OGS) bedrock aquifer mapping program. The OGS is currently mapping the Silurian carbonate strata along the Niagara Escarpment region and has proposed revisions to the Silurian Stratigraphy of this area, as described in Section 2.8. The updated stratigraphic framework described by the OGS (Brunton, 2009) has formed the basis for and warranted the re-interpretation and revisions to the Guelph area conceptual hydrogeological model.

The revised hydrostratigraphic model framework used for the Tier Three study is illustrated on Figure 16.

The following key updates are made to the previous three dimensional conceptual model as part of the Tier Three project:

- Definition of variable three dimensional bedrock formation surface elevations based on current data and following OGS revised stratigraphic framework. In areas outside the City of Guelph where high quality borehole data is sparse, simplified constant slope and constant thickness approaches are used for the formations in a similar manner as in the Guelph-Puslinch Study.
- Improved delineation and separation of bedrock units primarily including:
    - Separation of the Eramosa Aquitard into the Vinemount Member and Reformatory Quarry Member, which have distinctly different hydraulic properties as described further below; and
    - Better definition of the top of the Gasport Formation (formerly Amabel) including delineation of the Goat Island Formation as a separate unit.

The overburden hydrogeologic conceptual model used in the Guelph-Puslinch Study is further described in Section 5.2.11. The revisions to the conceptual model completed as part of this project focused on improving delineation of the bedrock units, which have the most significant influence on the conceptualization of groundwater flow in the municipal aquifer system. The overburden conceptual model layer structure developed as part of the Guelph-Puslinch model was largely retained for this project. A key exception is in the Southwest Quadrant area of Guelph where in conjunction with the Southwest Quadrant Class EA project a more local scale review and refinement of the Guelph-Puslinch model overburden stratigraphy was completed (Golder, 2011). Minor revisions to the overburden layer structure were also made in the Torrance Creek and Arkell areas during the model calibration process as described in the Tier Three Modelling Report (AquaResource, 2011).

Additional details on the bedrock borehole geologic interpretation picks and surface generation methodology and results are provided below. The conceptual model surfaces form the basis for the FEFLOW model layers.

The borehole geologic interpretation picks developed as part of this study are described in Section 5.2.1 and the distribution of these picks are shown on Figure 17. The methodology used to create the surfaces is introduced in Section 5.2.2. Details on the methodology and results of the conceptual model surface development are described in detail for each layer in Sections 5.2.3 to 5.2.11. The surface and isopach maps developed for the units are provided in Appendix F. The thicknesses of the most significant aquifer and aquitard units (the Gasport and Vinemount) are presented on Figures 18 and 19, respectively. Several cross-sections were created to illustrate the key characteristics of these units. The locations of six cross-sections A-A’, B-B’, C-C’, D-D’, E-E’ and F-F’ are shown on Figure 20 and the sections are included as Figures 21 to 26.

5.2.1 Borehole Geological Interpretation Picks

Borehole logs within the Study Area were examined and ranked for quality of available information. Borehole logs were given a reliability designation of high, medium or low according to the following criteria:

- HIGH (H) - The geology was defined based on review of continuous core. Geophysical data may also be available. Bedrock boreholes with a high quality optical televiewer geophysical log are also included in this category.
- MEDIUM (M) - The geology was defined with the collection of grab samples (i.e., not continuous coring) and geophysical data such as gamma and apparent conductivity were the primary means for definition of the geology.
- LOW (L) – The geology was defined by grab samples, no/limited collection of geophysical data, or logged by the driller. Wells that did not have a borehole log available were also considered to have a low reliability.

A summary of the bedrock boreholes within the Study Area that were reviewed to determine subsurface conditions is provided in Appendix E (see Table E.1), including the quality ranking (H, M, L) assigned to each borehole. The available consultant borehole logs used to generate the formation picks are provided in Appendix A. The distribution of the deep bedrock boreholes where picks were made and the ranked borehole reliability is shown on Figure 17.

5.2.2 Surface Development Methodology

The surface generation was an iterative process including review and visualization of picks and surfaces in plan view, cross-section and three dimensional view.

The conceptual model surfaces were interpolated over a rectangular grid. The interpolation was based on the geologic formation picks that are described above, with additional interpretive controls as described in more detail below. The grids were interpolated using kriging methods with a 50 m grid resolution (Easting grid extents: 536000 to 589000, Northing grid extents 4796000 to 4859000 – NAD 83).

The conceptual model layer surfaces used in the numerical model were subsequently input into the FEFLOW software and the layer minimum thickness constraints needed for the numerical modelling were applied at that time. The methodology used to incorporate the conceptual model surface grids into FEFLOW model layers is described in the Tier Three Assessment Numerical Modelling Report (AquaResource, 2011).

All surfaces were constrained so that the layer elevation did not exceed the elevation of the overlying layers. This constraint is most important and relevant in the eastern portion of the Study Area where the deeper formations are closer to ground surface and where the upper bedrock formations are often non-existent and pinch out, particularly in areas of bedrock valleys.

Additional details on the development of the individual surfaces are provided in the following sections.

5.2.3 Cabot Head Formation

The Cabot Head Formation, readily distinguished by its grey-green colour, is a non-calcareous shale with thin interbeds of sandstone and limestone. This unit ranges from 10 to 39 m thick (Johnson et al. 1992). The Cabot Head shale forms the lower boundary of the active groundwater flow system in the Study Area and acts as a regional aquitard. The interpretation of this unit has not changed significantly since the Guelph-Puslinch Study, although there is considerably more borehole data available now to define contact pick elevations for the upper surface of this formation.

The top elevation of the Cabot Head Formation was delineated from borehole picks. In areas of sparse higher quality borehole data, control points were added to constrain the top surface elevation of this unit, assuming a regional dip of the formation to the southwest in a similar manner used in the Guelph-Puslinch model (Golder, 2006a). This surface is based on borehole picks for the top elevation of the Cabot Head Formation that were made at approximately 150 locations in the model domain.

This Formation forms the lower boundary of the active groundwater flow system in the Study Area and acts as a regional aquitard. The Cabot Head shale dips to the southwest at approximately 4 degrees across the Study Area. This formation is one of the most readily identifiable due to its pronounced gamma response and distinctive characteristics. The Cabot Head Formation top surface shows little variability in topography in comparison to the other formations.

5.2.4 Merritton, Rockway, Irondequoit and Rochester Formations

The following four bedrock units generally comprise a total cumulative thickness of about 3 to 5 m in the Study Area. These units have often been described as lower or undifferentiated dolostone and have not been previously defined in any detail with the exception of the Rochester Formation, which has been differentiated in Cambridge but is not present in Guelph. Although geologic picks for these Formations have been made as part of this study, these Formations are grouped with the Lower Gasport conceptual model unit in a similar manner as in the Guelph-Puslinch Study. These Formations have similar hydraulic properties to the lower portion of the Gasport Formation and do not represent a significant hydrostratigraphic unit to be represented separately in the regional model for this study. These formations include:

- ***Merritton Formation (Included with the Lower Gasport Hydrostratigraphic Unit):*** The Merritton Formation consists of a pinkish-brown, finely crystalline dolostone unit with dark shaley partings. This unit, where present in the area, is generally less than 1 m thick.

- ***Rockway Formation (Included with the Lower Gasport Hydrostratigraphic Unit):*** The Rockway Formation is a greenish-grey fine crystalline argillaceous dolostone with shaley partings (Brunton, 2008). The thickness of the Formation is consistent and generally ranges from 1 to 2 m across the Study Area.

- ***Irondequoit Formation (Included with the Lower Gasport Hydrostratigraphic Unit):*** This Formation is a thickly to medium-bedded crinoidal grainstone (Brunton, 2008). The unit has a fairly consistent thickness of approximately 3 m throughout the Study Area.

- ***Rochester Formation (Included with the Lower Gasport Hydrostratigraphic Unit):*** The Rochester Formation is a calcareous shale with carbonate interbeds and, where present in the Cambridge area, it is a thin unit (typically about 1 m thick) located above the Irondequoit Formation. This Formation is not present in the Guelph area.

Borehole picks were made for the Rockway, Merritton, Irondequoit and Rochester Formations where possible at the higher quality boreholes. These formations underlie the Gasport Formation and are above the Cabot Head Formation. Top surface elevations for these formations were not used in the numerical modelling.

5.2.5 Gasport Formation

The Gasport Formation is a cross-bedded crinoidal grainstone-packstone with sequences of reef mound and coquina (shell bed) lithofacies. This unit has commonly been referred to as the Amabel Formation in previous studies in the Study Area. In the Study Area, the Formation generally varies in thickness from about 25 to over 70 m. Zones of increased primary and secondary permeability in the upper sections of the reef mounds, the crinoidal grainstones and the coquina shell beds often make this formation highly transmissive, where such zones are present. This Formation has been divided into upper, middle and lower hydrostratigraphic units to allow for a generalized representation of the vertical variations in hydraulic properties and vertical distribution of the more transmissive reef mound and coquina shell bed lithofacies within this unit.

The thickness of the Gasport Formation influences the distribution of the overlying bedrock units. The thickness of the Gasport Formation is shown on Figure 18. A belt of composite reef mounds in the Gasport Formation that has been mapped to extend from the Middleton Well Field on the west side of Cambridge northeast to Guelph and further north to the Fergus area. The steep topography of the top of the thick Gasport composite reef mounds near the Guelph Dolime Quarry and in the northeast quadrant of Guelph is typical of such reef mound sequences and is similar to that seen in the Middleton Well Field area and at the Hespeler well fields and eastern Pinebush well field areas of Cambridge.

The top elevation of the Gasport Formation was delineated from borehole picks. In areas of sparse higher quality borehole data, control points were added to constrain the top surface elevation of this unit, assuming a regional dip of the formation to the southwest in a similar manner used in the Guelph-Puslinch Study model. This surface is based on borehole picks for the top elevation of the Gasport Formation that were made at approximately 150 locations in the model domain.

Cross-section A-A’ (see Figure 21) shows an area extending through the thickest part of the Gasport Formation extending from Middleton well field in Cambridge through Hespeler and through western Guelph. The areas of thickest Gasport generally show little “accommodation space” for the overlying Goat Island and Eramosa Formations. As discussed in the next section, the Vinemount layer is thin or absent over much of Cross-Section A-A’ in the areas where the Gasport Formation is thickest.

Cross-section B-B’ (see Figure 22) shows an area immediately east of Cross-section A-A’ where the Gasport is generally thinner. In this area, the Vinemount Member is consistently present as discussed in the next section.

The Gasport Formation has been separated into three hydrostratigraphic units as follows:

- **Lower Gasport Hydrostratigraphic Unit:** Generally across the Study Area, the lower 10 to 20 m of the Gasport Formation exhibits a much lower permeability than the middle and upper portions of the Formation and does not contain highly transmissive reef mound and coquina bed zones. As mentioned above, for this study the underlying Formations (Rochester, Irondequiot, Rockway and Merritton) have been grouped with this lower permeability Lower Gasport Hydrostratigraphic Unit. This unit is generally consistent with the previous Lower Amabel layer from the Guelph-Puslinch Study.

- **Middle Gasport Hydrostratigraphic Unit:** A key highly transmissive layer within the Gasport was represented in the Guelph-Puslinch Study as the Production Amabel layer. The Production Amabel layer in the Guelph-Puslinch Study was assigned a constant thickness of 12 m based on the average thickness of a zone of cavities, vugs and fracturing observed in geophysical logs and video surveys at 28 wells within the City of Guelph. The top and bottom surfaces of this layer were assumed to be planar in the Guelph-Puslinch Study with a constant dip to the southwest. The top and bottom elevations of the Guelph-Puslinch Study Amabel Production layer were used to delineate the top of the Middle Gasport and top of the Lower Gasport units in this study.

  Although high quality data regarding vertical variations in transmissivity within the Gasport (flow profiling, packer testing, Flute profiling etc.) are available for some boreholes in the Study Area, the distribution of this data across the City of Guelph and on the more regional scale was not considered sufficient at this stage to warrant moving beyond a three layer conceptual hydrostratigraphic representation of the Gasport Formation with a middle unit of constant slope and thickness. The use of a constant thickness middle Gasport unit, consistent with the Guelph-Puslinch model, has advantages for numerical model calibration as the insights from the previously calibrated model hydraulic conductivity zones can be more directly applied and the relation between hydraulic conductivity zones and transmissivity is simplified because of the constant layer thickness.

- **Upper Gasport Hydrostratigraphic Unit:** Although the base of the Upper Gasport Unit is consistent with the base of the Upper Amabel layer in the previous conceptual model, the top of the Upper Gasport unit differs from the previous top of the Upper Amabel. The Guelph-Puslinch Study Upper Amabel layer included the Goat Island Formation, which has now been represented as a separate unit as described below. The Upper Gasport unit is typically lower transmissivity relative to the underlying Middle Gasport unit.

5.2.6 Goat Island Formation

The Goat Island Formation consists of two members; the upper Ancaster Member and lower Niagara Falls Member. The Ancaster Member is a chert rich, finely crystalline dolostone that is medium to ash grey in colour. This Member generally overlies the Niagara Falls Member although in some cases in the Cambridge and Guelph areas, these units are interfingered. The Niagara Falls Member is a finely crystalline and cross laminated crinoidal grainstone with small reef mounds. The finely crystalline nature of these Members, typically results in a lower conductivity and transmissivity of this Formation compared to the underlying Gasport Formation. In some areas the Ancaster Member contains low permeability shaley beds similar to the Vinemount Member and acts as an aquitard. Conceptually the two members of the Goat Island are treated as a single hydrostratigraphic unit for this project. The Goat Island unit was not distinguished in the previous conceptual model and was previously included in the Upper Amabel layer.

The Goat Island Formation is generally thin (<5m) or absent in areas of thick Gasport reef mounds. Thick sequences of Goat Island (>30 m) are found further west in Cambridge where the Gasport Formation is thinner.

The top surface of the Goat Island Formation was developed by first creating an isopach layer using borehole pick locations where the top and bottom of this unit were interpreted. The isopach for this layer was then added to the top surface of the underlying Gasport Formation. Control points were added to constrain the thickness of this layer in areas where it is interpreted to be non-existent and in order to extend a constant thickness for this unit in areas of sparse higher quality data. The surface is based on borehole picks for the thickness of the Goat Island Formation that were made at approximately 100 locations in the model domain.

5.2.7 Eramosa Formation - Vinemount Member

The Vinemount Member is comprised of thinly bedded, fine crystalline dolostone with shaley beds that give off a distinctive petroliferous odour when broken (Brunton, 2008). This dark grey to black dolostone unit was commonly identified in water well records as ‘black shale’ and mapped in previous studies in the Study Area as the Eramosa Member of the Amabel Formation. This unit represents an aquitard where present within the Study Area. The distinction of the Vinemount Member of the Eramosa from the Reformatory Quarry Member is a key revision to the conceptual model as these units have different hydraulic properties.

The interpreted thickness of the Vinemount Member is shown on Figure 19. The Vinemount Member is not observed to the west of the thick Gasport reef mounds observed in the Hespeler and Pinebush areas of Cambridge and is not observed in Breslau to the west of Guelph. The Vinemount, where present in the Study Area, is less than 10 m thick and has a strong influence on vertical hydraulic connections and vertical gradients within the bedrock aquifer as described in Section 5.5.

In a similar manner to that used for the Goat Island unit, the top surface of this unit was developed by first creating an isopach layer for the Vinemount Member using borehole pick locations where the top and bottom of this unit were interpreted. The isopach for this layer was then added to the top surface of the underlying Goat Island Formation. This approach using the isopach of the layer allowed better control of the thickness of the layer and avoided inadvertent layer pinch outs resulting from the interpolation of elevations between higher quality data points. Control points were added to constrain the thickness of this layer in areas where it is interpreted to be non-existent and in order to extend a constant thickness for this unit in areas of sparse higher quality data, where it is interpreted to be present. The surface is based on borehole picks for the thickness of the Vinemount Member that were made at approximately 100 locations in the model domain.

The Vinemount layer is thin or absent over much of Cross-Section A-A’ in the areas where the Gasport Formation is thickest. Cross-section B-B’ shows an area immediately east of Cross-Section A-A’ where the Gasport is thinner. In this area, the Vinemount Member is consistently present. Cross-section E-E’ (Figure 25) extends from Breslau in the west to east of Arkell area in the east. This Cross-Section illustrates the absence of the Vinemount to the west in the Breslau area and illustrates the absence of the Vinemount in the bedrock valleys to the east where the Vinemount has been eroded and the Goat Island or Gasport Formations are at or near surface. Cross- Section C-C (Figure 23)', D-D' (Figure 24) and F-F' (Figure 26) also illustrate the absence of the Vinemount to the west and the bedrock valleys to the east that cut through the Vinemount.

5.2.8 Eramosa Formation - Reformatory Quarry Member

The Reformatory Quarry Member is described by Brunton (2008) as light brown to cream coloured, pseudonodular, thickly bedded and coarsely crystalline dolostone. This proposed Member of the Eramosa Formation generally represents a poor aquifer or poor aquitard. This unit is susceptible to karstification due to its uniform fine dolomite crystallinity (Brunton, 2008). This unit also often contains mud-rich and microbial mat-bearing lithofacies that may act as aquitard materials, reducing the vertical permeability across this unit. This unit was typically logged as either the Guelph Formation or Eramosa Member in previous investigations in the Study Area. More recently, the OGS has defined a third Member of the Eramosa Formation named the Stone Road Member (Brunton, 2009). The Stone Road Member generally has similar hydraulic properties to the Guelph Formation and has not been separately represented as a conceptual model layer in this Study.

The top elevation of the Reformatory Quarry Member was delineated from borehole picks. In areas of sparse higher quality borehole data, control points were added to constrain the top surface elevation of this unit, assuming a regional dip of the formation to the southwest in a similar manner used in the Guelph-Puslinch model (Golder, 2006a). This surface is based on borehole picks for the top elevation of the Reformatory Quarry Member that were made at approximately 100 locations in the model domain.

The thickness of the Reformatory Quarry Member is quite variable across the Study Area ranging up to about 50 m thick in some areas. In areas of thicker Gasport the Reformatory Quarry unit is thinner or often absent. Thick sequences of Reformatory Quarry are observed in western Cambridge, Breslau and to the north of Guelph.

5.2.9 Guelph Formation

The Guelph Formation consists of medium to thickly bedded crinoidal grainstones and wackestones and reefal complexes (Brunton, 2008). The Guelph Formation is a cream-coloured fossiliferous dolostone that represents an important aquifer in the Cambridge and Guelph area, where it is most often the uppermost bedrock unit. As part of this study, large portions of the Guelph Formation have been re-interpreted in borehole logs as the Reformatory Quarry Member.

Wherever present in the Study Area, the top of the Guelph Formation was assumed to be equivalent to the top of bedrock. The base of the Guelph Formation is defined by the top of the underlying Reformatory Quarry Member. Borehole picks for the Guelph Formation were made at approximately 100 locations in the model domain.

The thickness of the Guelph Formation in the Study Area is quite variable and in many boreholes the Guelph Formation is not present. Thick sequences of Guelph Formation of 25 to 40 m are observed in northwest Guelph and some areas of Cambridge.

5.2.10 Top of Bedrock

A set of picks for the top of bedrock surface were compiled from the following data sources:

- Guelph-Puslinch model top of bedrock picks (Golder, 2006a);
- OGS top of bedrock picks (Gao et al., 2007);
- Halton Region top of bedrock picks;
- Credit Valley Conservation top of bedrock picks; and
- Additional top of bedrock picks made as part of this study at recent high quality boreholes.

Included in this set of picks are control points for the surface elevation of mapped bedrock outcrops and the bottom elevation of “pushdown wells” used to ensure the bedrock surface is lower than boreholes completed in overburden. The top of bedrock control points include bedrock valley thalweg picks as incorporated in the Guelph-Puslinch model, with additional control points added to improve definition of known bedrock valleys. Obvious anomalous single data points (bulls-eyes) were removed by visually inspecting the generated bedrock surface grid. Note that the OGS top of bedrock data source is in metres below ground surface and these picks were converted to elevations using the ground surface DEM. As with the other surfaces, the bedrock surface was constrained to be lower than the overlying ground surface DEM.

The top and base of the bedrock contact aquifer were calculated as 2 m above and 2 m below the bedrock surface, respectively. This results in a layer thickness of 4 m for the contact aquifer unit. The upper weathered/fractured bedrock and overlying coarse materials typically form a thin (assumed thickness of 4 m) aquifer that is able to support domestic water wells. This unit includes the coarse granular materials overlying bedrock at the base of the Catfish Creek Till that are identified in many boreholes in the Cambridge East area.

- ***Bedrock Contact Layer:*** In order to account for the weathered and fractured uppermost bedrock (regardless of Formation), a bedrock contact aquifer has been included as a conceptual hydrostratigraphic unit. In some areas the weathered uppermost bedrock is hydraulically connected to and difficult to distinguish from overlying coarse granular deposits. The upper weathered/fractured bedrock and overlying coarse overburden materials typically form a thin (assumed thickness of 4 m) aquifer that is able to support domestic water wells. This unit includes the coarse granular materials overlying bedrock at the base of the lower overburden that are identified in many boreholes in the Study Area.

5.2.11 Overburden

The revisions to the conceptual model completed as part of this project focused improving delineation of the bedrock units, which have the most significant influence on the conceptualization of groundwater flow in the municipal aquifer system. The overburden conceptual model layer structure developed as part of the Guelph-Puslinch model was largely retained for this project. One key exception is in the Southwest Quadrant area of Guelph where in conjunction with the Southwest Quadrant Class EA project a more local scale review and refinement of the Guelph-Puslinch model overburden stratigraphy was completed (Golder, 2011). Minor revisions to the overburden layer structure were also made in the Torrance Creek and Arkell areas during the model calibration process as described in the Tier Three Modelling Report (AquaResource, 2011).

- ***Lower Overburden:*** A conceptual model unit consistent with the Guelph-Puslinch model was used to represent the overburden materials above the bedrock contact aquifer layer that are inferred throughout the Study Area to be predominantly glacial till. This layer represents the remaining overburden thickness after the base of the overlying Upper Sand and Gravel unit is delineated, as described below. Over much of the Study Area, this unit represents the sandy silt Port Stanley Till which is generally considered a lower permeability aquitard or poor aquifer, although this is not always the case. The area south of the Eramosa River is dominated by the Paris and Galt moraines, which are covered at surface by sandy to sandy-silt Wentworth Till. Internally the moraines have a complex structure consisting of silty to sandy till units, sand and silt lenses, as well as discontinuous lenses of coarser sand and gravel whose cumulative thickness may exceed 15 m. Delineating individual units within the moraines across the Study Area is not possible given the available data. Conceptually this Lower Overburden unit is generally considered to have a greater permeability in the area of the moraines where it represents the coarser grained Wentworth Till and underlying moraine sediments, relative to the areas where it represents the Port Stanley Till. This unit was constrained to a minimum thickness of 2 m.

- ***Upper Sand and Gravel:*** Consistent with the Guelph-Puslinch model, an Upper Sand and Gravel unit was inferred to be present where surficial sand and gravel deposits are shown on the surficial geology map. The base of this Upper Sand and Gravel was delineated in detail in the area of Mill Creek as part of the Guelph-Puslinch Study through review of cross-sections and well logs. Outside of the Mill Creek watershed, the thickness of the Upper Sand and Gravel was assumed to be 5 m or less within the mapped surficial sands and gravels, and zero thickness outside the mapped areas. As mentioned previously, the base of the Upper Sand and Gravel was refined in the Southwest Quadrant area of Guelph where, in conjunction with the Southwest Quadrant EA project, a more local scale review and refinement of the Guelph-Puslinch model overburden stratigraphy was completed (Golder, 2011).

5.3 Municipal Pumping and Water Level Monitoring Data Analysis

5.3.1 Municipal Pumping Data Analysis

The detailed pumping data for the City of Guelph municipal production wells is presented in Appendix D (see Figures D.1 through D.6). The pumping plots are grouped by quadrant, with separate graphs for each individual well. Each graph shows the daily pumping rates (m^3/day) of the production well as well as the monthly average of the daily production total. The lowermost graph on each figure presents the total daily production for all wells in the quadrant, including a monthly average.

Since 1997, the City of Guelph has maintained consistent records of daily pumping volumes for all production wells. This data was imported into the project database. Based on this data, monthly average production totals were queried out of the database for each well. The manual measurements of groundwater elevation data were provided by the City of Guelph and were imported into the project database. Dewatering from a sump at the Dolime Quarry in the southwest quadrant represents a major water taking in the area. Data for the Dolime Quarry Sump is from the Dolime Quarry Permit To Take Water Monitoring Reports (CRA, 2009).

Southwest Quadrant

- Between 1997 and mid 2000, the Membro Well was inactive. Since mid 2000, the Monthly Average of the Daily Production Total has ranged from 380 to 5000 m^3/day. During periods when the well is inactive the static water level is about 303 masl. During periods of maximum pumping, the water level in the well decreased to a minimum of 282 masl, very close to the minimum pumping elevation.
- The Edinburgh Well has been offline. Static water levels in this well range from 298 to 306 masl.
- Prior to the middle of 1997 and from 1998 to mid 2000, the Water Street well was inactive. In June 1997, the well was pumped and towards the end of the year, the monthly average of the daily production total was just under the permitted rate. After June 2000, the well was once again active, with a fluctuating pumping rate, the pumping average of the production total ranges from 0 to 2750 m^3/day. Groundwater elevations in this well range from a maximum of about 302.5 to 284 masl.
- Dewatering from Sump 3 at the Dolime Quarry is a major water taking in the southwest quadrant area of Guelph. Dewatering at this site is permitted for up to 13,750 m^3/day. Between 2000 and 2005, the rates of dewatering ranged from 6,000 to 7,000 m^3/day and since about 2005 have been about 8,000 m^3/day (CRA, 2008).
- Since 1997, Dean has typically been pumped at significantly less than its permitted rate of 2300 m^3/day. During several periods of 2000 through 2004, the well was either pumped at very low rates or inactive. Beginning in 2004 through to the end of 2008, the well has been pumped at a fairly constant rate ranging from about 1000 to 1500 m^3/day. Water level elevations range from approximately 302 masl when the well is inactive to 280 masl during pumping.
- Between 1997 and 2001, the Production Totals at the University Well fluctuated from 800 to 1750 m^3/day. After March 2001, the Production Totals, while fluctuating, were increased up to approximately 3000 m^3/day. The well was pumped at a more consistent pumping rate after 2004, with typical Production totals ranging from 1500 to 1800 m^3/day. There was more variation of daily production totals in 2007. Little historical water level data is available for this well. In 2008, the groundwater elevation ranged between 300 and 305 masl.
- Historically the Production Total at the Downey Well has ranged from about 3000 to 5000 m^3/day. In 2004 through 2006, the Daily Production Totals fluctuated greatly from 0 to 4500 m^3/day. Water levels range from a maximum of about 305 to a minimum of 282.5 masl.
- In the Southwest Quadrant, between 1997 and 2001, the Monthly Average of the Daily Production Total ranged from 6000 to 11000 m^3/day. After 2001, the production totals generally increased to less than 15000 m^3/day, but with a few periods of lower rates (as low as 6000 m^3/day) in 2001, 2004, 2005 and 2008.

Southeast Quadrant

- During the period of 1997 to mid 1999, the Burkes Well was typically pumped at rates around the maximum permitted rate of 6546 m^3/day. In late 1999 and mid 2000 through May 2001, the Production Total for this well was decreased to 5000 m^3/day or less. As of May 2001, the rate at which the Production well has been pumped has steadily declined from about 6000 to 5400 m^3/day. Beginning in early 2005, the well has been pumped at a more consistent rate without any periods of inactivity. The static water level in this well rises to up to 336 masl when the well is inactive. During pumping conditions, the water level varies from about 314 to 320 masl.

- Since 1997, the pumping rates have fluctuated greatly ranging from about 1000 to 8000 m^3/day. The Carter Wells were inactive during a number of periods during 2000 to 2001 and early 2008. In response to on and off times of the pumps in these wells, water level elevations range from lows of 312 masl to highs of about 325 masl.
- Of the Arkell wells, Arkell 1 (overburden well) is pumped at a consistently lower rate than Arkell 6, Arkell 7 and Arkell 8 (bedrock wells). Since 1997, the Monthly Average of Daily Production Totals have ranged from 100 to 3500 m^3/day. Arkell 1 has periodically had a few short periods of inactivity, including in 2000, 2002, 2003 and 2004. Water level elevations range from about 320 to 331 masl in this well.
- Since 1997, Arkell 6, Arkell 7 and Arkell 8 have typically been pumped at close to their permitted rates. Generally the Daily Production Totals of these three wells are similar at any given time. At certain periods during 1998, 2000 and 2001, the Monthly Average of the Daily Production Totals in each of these wells exceeded the maximum permitted rate. During periods in which all three of these wells were pumped at higher rates (2000 and 2001), the water levels measured in these production wells dropped to below 305 masl.
- Daily Total Production in the Southeast Quadrant is most greatly influenced by the Arkell Wells. Since 1997, the Monthly Average of the Total Daily Production Total for this quadrant has ranged from 15,000 to 39,000 m^3/day.

Northwest Quadrant

- Wells Paisley, Queensdale and Calico are typically pumped at rates from between 800 and 3000 m^3/day, well below their permitted rates. Smallfield and Sacco have been offline during the period of record.
- Paisley was pumped at low rates or offline from 1997 to 1999. In 2002, the pumping rate increased to a maximum of about 1500 m^3/day. During a few brief periods in mid 2004 and early 2008, the well was inactive. Static groundwater elevations during times when the well is off rise to approximately 305 masl. During pumping water levels are measured at approximately 295 masl.
- Queensdale was offline for 1997 and the first half of 1998. Between 1998 and 2003, Queensdale was pumped intermittently. As of 2003 this well has been pumped more consistently, but at a declining rate. During periods when the well is inactive, static water levels in the well rise significantly to approximately 325 masl.
- Since 1997, Calico has been pumped fairly consistently at rates ranging from 600 to 1700 m^3/day. Groundwater elevations in this well range from about 305 masl (while being pumped) to 315 masl (while inactive).
- Daily Total Production in this well field from 1997 to May 1998 was approximately 1000 m^3/day, after which time, the daily total production increased to a maximum of about 5300 m^3/day. From May 1998 to July 2002, the total pumping rate fluctuated from about 1000 to 5000 m^3/day. After July 2002, the well field was pumped more consistently, with a declining trend from about 4500 to a current 2700 m^3/day.

Northeast Quadrant

- During the period between 1997 and 2001, the Emma Well was typically pumped at rates of less than 1200 m^3/day. However, during this time, there were a number of extended periods of inactivity. After April 2001, the Production Total was increased in this well up to about 3000 m^3/day, with several periods of either lower Production Totals or inactivity in late 2001, 2002 and 2004. No water level elevation data is available for this well.
- The combined Park wells typically have higher Production Totals than any other wells in this Quadrant, but range from 0 to 9500 m^3/day. During the period from mid 2005 to 2008, the well was pumped a more consistent rate of about 5000 m^3/day, increasing to a maximum 6700 m^3/day in 2008. Groundwater elevations in the Park wells range from about 290 to 329 masl.
- The Production Total at the Helmar Well ranges from 0 to 2800 m^3/day. In 1997, and parts of 1998, 2000, 2004 and 2008, this well was inactive. Since the latter half of 2005, the Monthly Average Production Totals have been more consistent at approximately 1000 m^3/day. Groundwater elevations in the Helmar well generally range between 300 to 315 masl.
- Other than the first half of 1997 and brief period in 1998 and 1999 the Clythe Well has been offline. Groundwater elevations between 320 and 323 masl are typical.
- The Cumulative Production Totals for the Northeast Quadrant are heavily influenced by pumping at the Park Wells. The Monthly Average of the Daily Production Totals ranges from 1500 to 10600 m^3/day.

5.3.2 Water Level Monitoring Data Analysis

Key monitoring wells in the City of Guelph area are shown on Figure 27. The most complete time period of transient monitoring in the City has been recent years (2007 to present) since the initiation of the Guelph Monitoring System Project (Golder, 2009a) monitoring and the Arkell Spring Grounds Investigation (AECOM, 2009) monitoring.

A series of hydrographs were compiled over the 2007 to 2008 time period showing the transient monitoring record from key wells. At each monitoring well nest, representative values were selected from monitors isolated below the Eramosa Formation and above the Eramosa Formation to compile a groundwater flow map in the deep bedrock and to compile mapping of vertical gradients across the Eramosa Formation.

Monitoring data from key monitoring wells that have a transient record is presented for each quadrant on Figures D.7 to D.22. The end of May/early June 2007 was selected as a time representing average water level conditions. Values from this time period were selected as shown on the hydrographs. In cases where data was not available from this time period, June/July 2008 water levels were used as representative. Given the influences of many of these wells to nearby short term pumping fluctuations, calculations of annual average water levels can be skewed by spikes during well interference. A review of the hydrograph and manual selection of values provided a more representative and reliable value than the calculated averages. These representative water level values are flagged in the project borehole database and provide a set of high quality water bedrock hydraulic head and vertical gradient data for use in groundwater flow model calibration.

Further discussion of the water level information is provided in Section 5.5.

5.4 Summary of Aquifer Response Tests

The following provides a summary of key aquifer response tests conducted as part of hydrogeological investigations to support municipal pumping. In addition, a review of the City's pumping records indicated some shut down events and periods of reduced pumping for which the water level record from nearby monitoring wells was examined to gain further insights into the characteristics of the aquifer system.

5.4.1 Southwest Quadrant Class EA 32 Day Pumping Test

As part of the City of Guelph's ongoing SW Quadrant Class EA (Golder, 2011), a long-term (32 day) pumping test was completed in the SW Quadrant of Guelph in July 2008 at the Ironwood and Steffler test well locations (see Figure 28 for the location of these test wells, and the approximate influence area within the SW Quadrant of the city). The casings in these wells extend through the Guelph and into the Goat Island Formation such that all the pumped water is derived from the Gasport Formation. During the 32 day period of the test, pumping was staged with the maximum pumping from both wells totalling 10,400 m^3/day for a period of 12 days. An extensive monitoring network including locations in the Gasport Formation, in the shallower bedrock above the Vinemount, in the overburden and surface water locations was instrumented with a total of 85 dataloggers.

Reference should be made to the supporting documentation for the City of Guelph's SW Quadrant EA for a detailed discussion of the FEFLOW model refinements, transient calibration details and the resulting parameterization in this area of the model (Golder, 2011). The following are the key responses observed:

- In the Gasport Formation, the response to pumping was observed over an elongate area extending generally north-northwest south-southeast. The extent of the response was limited to the north by the operation of the Membro, Dean and Water municipal wells and quarry dewatering while to the south, responses were observed extending beyond the Downey production well. The 2 m drawdown contour was inferred to extend more than 4 km south from the test pumping wells. To the east and west, the effects of pumping were limited with the 2 m drawdown contour inferred extend about 1 km to the east and west of the test pumping wells. Further east in the City, no response was observed at monitoring wells completed in the Gasport Formation.
- Some response was observed in the Guelph Formation in the vicinity of the test pumping wells; indicating a small increase in vertical seepage rate during testing. The vertical hydraulic conductivity of the Vinemount was estimated at about 10^{-9} m/s from these results.
- No response to pumping was observed in shallow overburden and surface water monitoring locations and upward hydraulic gradients were maintained in the vicinity of the wetlands.

5.4.2 Sacco/Smallfield Test

In December 2008, a 13-day pumping test was performed on the Sacco and Smallfield production wells (Stantec, 2009a). Packers were placed in these wells so that the Gasport Formation was isolated and pumped during this test. The Smallfield well was turned on first and pumped at a rate of 16.3 L/s. After six days, pumping commenced at the Sacco well at a rate of 13.3 L/s. After a total of 13 days, both wells were shut off on December 22, 2008. During this test, water levels were monitored at five City-owned multilevel wells (Hauser, MW06-01, MW06-02, MW06-05 and SM5-3) as well as numerous wells located on nearby industrial/commercial properties. The following observations were made:

- Under static conditions, there is a slight downward vertical gradient from the Guelph to the Gasport Formation in this area.
- There was no response observed in the overburden due to pumping in the Sacco and Smallfield wells.
- A response to pumping of the wells was observed in the overlying Guelph Formation, with a stronger response observed in wells screened in the lower Guelph formation compared with those screened in the shallow Guelph formation. A zone of influence in the Guelph Formation of 1 km is attributed to pumping at the Sacco Well and a zone of influence of 2.5 km is attributed to pumping in the Smallfield Well.
- The zone of influence in the Gasport Formation attributed to pumping at Sacco is interpreted to be elongated in a northwest to southwest direction covering a 4 km by 3 km area.
- The zone of influence in the Gasport Formation attributed to pumping at Smallfield is elongated in a north to south direction over an area of 4.5 km by 3 km.
- The main source of water is interpreted to be from the lower Gasport formation.

5.4.3 Guelph Lime Rotating Shutdown Test

In October 2004, a Rotating Municipal Well Shutdown was conducted on seven municipal production wells located in the southwest quadrant of the City of Guelph (Golder, 2006b). Each shut down event consisted of the reduction in total municipal pumping of about 4,000 m^3/day, with each event separated by a period of at least 24 hours of normal operation of these wells. The Membro well was shut down for 16 hours, followed by a shutdown of both the Queensdale and Paisley wells for 8 hours, Downey for 16 hours and finally a group of three wells, Water, Dean and University, for 8 hours. Water levels in seven monitoring wells; Membro OW, Downey OW, OW05-92, MW04-01, TW04-01, TW04-02 and the off-line Edinburgh municipal well were monitored. With the exception of the Queensdale and Paisley production wells, all the production and monitoring wells are located to the south east of the Speed River. It should be noted that Dean, Water, Downey, Paisley and Queensdale wells are cased into top of rock and thus are open across both the Guelph and Gasport Formations while at the Membro and University production wells, the casing has been advanced through the Guelph Formation with the borehole open across the Gasport Formation only. Figure 29 provides a hydrograph of the water level responses in these monitoring wells to the Rotating Shutdowns of the four groups of production wells. Table G.1 in Appendix G summarizes the observed responses during the Membro, Downey and University/Dean/Water Shutdowns. As interpreted from Figure 29 and Table G.1, the following observations can be made:

- During the Membro shutdown, recovery was observed in the Gasport Formation with a water level rise after 16 hours of 1.4 m and 0.18 m observed at distances of 825 m and 1876 m respectively to the south. The continued operation of the Downey well masked any recovery response at monitoring wells located to the southeast. The transmissivity of 385 m^2/day was calculated for the Gasport and the radius of influence was inferred to extend 2 km. Essentially no response was observed in the Guelph Formation to the shutdown of the Membro well which is cased across the Guelph and open to the Gasport only.
- During the Queensdale and Paisley shutdown, no response was observed in either the Gasport or Guelph Formations. However it should be noted that no monitoring wells are present in the vicinity of these production wells. It is likely therefore that the recovery response is localized and/or masked by the effects of the continued operation of the remaining production wells located closer to the monitoring wells.
- During the Downey shutdown, recovery was observed in the Gasport Formation with a water level rise after 16 hours of 6.01 m and 1.67 m observed at distances of 1100 m and 1750 m respectively to the north-northwest. A direct hydraulic connection to TW04-01 is inferred from the rapid response to the shutdown of the Downey well and a transmissivity for this portion of the Gasport estimated at 1,600 m^2/day. For other monitoring wells, a more typical aquifer transmissivity of 210 m^2/day was estimated and the radius of influence was inferred to extend 2.3 km. In the Guelph Formation, a water level rise of as much as 0.5 m was observed at a distance of 1100 m. The Downey well is partially open to the Guelph and so this formation contributes water directly to the pumped well.
- During the University, Dean and Water shutdown, a water level recovery of 1.54 m was observed at TW04-01 located 1184 m to the south and 1.10 m at MW04-01 located 1086 m to the south-southwest. An aquifer transmissivity of 185-243 m^2/day was calculated from these responses. Groundwater levels in the Guelph Formation recovered during this shut down event with a rise of 0.44 m observed at TW04-01 located 1184 m to the south. It should be noted that two of these production wells, Dean and Water are open to both the Guelph and Gasport Formations while the University well is open to the Gasport only.

In the Gasport Formation, a strong hydraulic connection was observed between the Membro and Downey production wells; generally extending south-southeast north-northwest. These two wells are pumped at the highest rates of the production wells in the southwest quadrant of the City. More subdued responses were observed in response to the other shutdown events indicating some significant variation in the hydrogeological characteristics of the Gasport Formation locally. Smaller water level rises were observed in the overlying Guelph Formation in response to the shutdown of the Downey well.

5.4.4 Arkell Spring Grounds Testing 2000/2001

To develop additional groundwater supplies for the City of Guelph, two long term pumping test programs were conducted at the Arkell Spring Grounds located immediately southeast of the City, in August to October 2000 and again in July to September 2001. The following discussion pertains to the more comprehensive test conducted in 2001 with the information provided in the *Final Arkell Springs Grounds Groundwater Supply Investigation Report* prepared by Gartner Lee (Gartner Lee Ltd., 2003).

Testing for the 2001 program was conducted at Arkell 1 (PW1/66 an overburden well) and at the following wells completed in the Gasport Formation: Arkell 6 (PW6/63), Arkell 7 (PW7/63), Arkell 8 (PW8/63), Arkell 14

(TW14/00) and Arkell 15 (TW15/00). These wells were pumped at rates that totalled between about 18,000 and 28,000 m^3/day. An extensive network of monitoring wells included: 48 City-owned monitoring wells, 23 private wells, 21 flow stations and staff gauges and 23 mini-piezometers. The following is a summary of the responses observed:

- Water level declines were observed in the Gasport Formation with declines in excess of 4 m extending over a radius of about 1 km from the pumping centre. The drawdown cone stabilized and it was concluded that a total sustainable pumping rate of 28,800 m^3/day could be achieved from these wells with only a moderate (<10 m) drawdown observed in the bedrock.
- Some drawdown was observed in monitoring wells completed in the Guelph and/or Eramosa bedrock units. This was more varied and local to the pumping wells.
- Responses in the overburden and stream side mini-piezometers were dominated by precipitation events and seasonal water level declines. Near the Eramosa River, immediately adjacent to the Arkell Spring Grounds, an increase in downward gradients or a reversal from upward to downward gradients was observed from the shallow to deep wells during the testing.

5.4.5 Quadrant Study Aquifer Performance Testing (1993-1996)

In the 1990s, the City of Guelph began detailed aquifer performance evaluations, in order to better understand the hydrogeological conditions in each of the four Quadrants of the city. Jagger Hims Limited was contracted to complete this work (Jagger Hims Ltd., 1995, 1998a,b,c). Each of the four quadrant studies involved a compilation and assessment of available historical geologic and hydrogeologic data on all municipal production wells and some municipal test wells. This review included historical aquifer and performance testing of municipal wells, limited long term water level data and long term production records. Secondly, step pumping tests and constant rate pumping tests were performed on municipal production and test wells in each Quadrant. Finally a groundwater flow model was developed for each Quadrant.

The constant rate pumping tests were performed in a similar manner in all of the Quadrants. For each pumping test, there was a phased start-up of all of the active municipal production wells in the Quadrant. These wells were then pumped simultaneously for approximately one week, prior to a sequential shut-down of the wells. The wells were pumped either close to their capacities or at the rates specified in the PTTWs. An attempt was made by the City of Guelph to maintain constant pumping rates at the production wells in all of the other Quadrants during these tests. In the Southeast Quadrant, two separate performance tests were conducted, one for wells in the Arkell Spring Grounds and one for production wells in the Torrance Creek Area.

For discussion of the results of this testing refer to Jagger Hims Ltd. (1995, 1998a,b,c).

The following events were identified from a review of the City's pumping records. These events occurred during the normal course of water supply operations. It should be noted that the City's municipal wells normally cycle (periodically the well stops pumping) in response to variations in daily demand. However only longer shut down events were considered, where water levels would have approached a stable position. The effects of these events could be assessed only where monitoring wells equipped with data loggers were available nearby.

5.4.6 2008 Membro Well Shutdown Event

The Membro Well was shutdown for 42 hours from August 3, 2008 until August 5, 2008 while other nearby municipal wells continued to operate. The record obtained from seven nearby sites (Membro OW, MW04-01, MW06-04, MW06-05, MW08-02, TW04-02, Edinburgh) and one surface water station were monitored was examined to assess the response to this event. Prior to shutdown, the Membro Well was being pumped at an approximate rate of 3350 m^3/day. As shown on Figure 30, the following observations can be made:

- No response was observed in monitoring wells screened in the Guelph Formation;
- No response was observed in water level/flows at the Speed River station SS-1;
- Response was limited to wells screened in the Gasport Formation with the most obvious responses observed over an elongate zone extending south-southwest; and
- A response was observed across the Speed River to the north at MW06-05A (Gasport Formation).

5.4.7 Emma Well Shutdown

During the period of October and November 2008, the Emma Production Well was frequently turned on and off, with shutdown periods of up to 4 days. Figure 31 shows a series of these shutdown events along with groundwater elevations for nearby monitoring wells screened in the Gasport Formation. During this time, the pumping rates at the other Productions Wells in the Northeast Quadrant remained fairly constant with a rate of about 6500 m^3/day at the Park Wells. The Helmar Well was not being pumped during this period.

- A rise in water level of about 7.5 m was observed in MW06-03A (Gasport Formation) during each shutdown event;
- A more gentle rise in water level of up to about 0.8 m was observed in monitoring well Eastview A (Gasport Formation); and
- No change in water level elevation was observed at MW06-02A (Gasport Formation) during these shutdown events.

5.4.8 Park Well Pumping Reduction

At the end of April 2008, the pumping rate at the Park Wells was decreased from an average of about 6,500 m^3/day to approximately 4,500 m^3/day. During this time the pumping rates of the other Production Wells in the Northeast Quadrant remained constant with a rate of 2800 m^3/day at Emma and a rate of 800 m^3/day at

Helmar. Figure 32 shows the pumping rate at the Park Wells during the end of April 2008 as well as groundwater elevations of nearby monitoring wells screened in the Gasport Formation.

- With the decrease in pumping rate, a water level rise of about 3.5 m is observed in well MW06-02A (Gasport Formation);
- No change in water levels are observed at MW06-03A or OW11-06D (Gasport Formation) during this period;

5.5 Groundwater Flow System Characterization

Regional groundwater flow in the Gasport Formation is shown on Figure 33. The vertical gradients between the shallow (typically the Guelph Formation) and deep (Gasport Formation) bedrock groundwater flow system are shown on Figure 34 within the City of Guelph area. These maps were assembled using data specific to each of the bedrock units as compiled as part of this project (see Section 5.3.2).

Regionally, groundwater flow in the deeper Gasport Formation is south-southwest from highs of about 430 masl to the northeast of the City of Guelph to lows of about 270 masl on the southwestern boundary of the Study Area. Locally, flow directions are strongly modified by pumping at municipal wells in Guelph and Cambridge along with quarry dewatering immediately west of Guelph. Groundwater flow in the Gasport converges on the main pumping centres in Guelph along an elongate zone extending generally south-southwest through the City as is shown on Figure 33. This narrow elongate zone is indicative of a higher transmissivity feature that is bounded laterally by lesser transmissive rock of the Gasport Formation. This higher transmissive zone supports pumping from many of the large capacity municipal water wells which provide much of the City’s drinking water supplies. Dewatering at the Dolime Quarry also draws groundwater from this more transmissive zone of the Gasport Formation. The effects of municipal pumping at the Arkell Springs grounds to the southeast of Guelph are also evident from the localized area of flow convergence as shown on Figure 33. Elsewhere in City of Guelph, the yields from municipal wells are lower and the effects of pumping, as inferred from the regional flow mapping, are not obvious. The groundwater elevation data points used to plot Figure 33 are listed in Table G.2.

The three-dimensional groundwater flow modelling to be conducted in this study will provide a more comprehensive understanding of horizontal and vertical flow in the Study Area.

Over much of the area influenced by pumping, groundwater levels in the Gasport have been lowered below the elevation of the Speed River. As such, groundwater in the Gasport Formation does not discharge locally in this area.

South of the City, the few monitoring locations available indicate an extensive area of low horizontal hydraulic gradients suggesting that the effects of pumping in the southwest section of Guelph extend into the Township of Puslinch. This area of low horizontal gradients also may indicate an extension of the highly transmissive zone in the Gasport Formation south into Puslinch and towards Cambridge. Further downgradient, groundwater flow in the Gasport Formation is more southwesterly in response to municipal pumping at the east side of the City of Cambridge.

Groundwater flow directions in the overlying Guelph Formation are controlled by local topography with flow converging on the main rivers; the Eramosa, Speed and Blue Springs Creek. The effects of municipal groundwater pumping and quarry dewatering are not evident in the Guelph Formation.

Groundwater pumping from the Gasport Formation has strongly influenced flow directions and vertical hydraulic gradients in the vicinity of the pumping centres (see Figure 34). Where controlled by pumping, groundwater levels in the Gasport are as much as 20 to 30 m below those in the overlying Guelph Formation with groundwater elevations below the base of the Speed River. Locally in areas of higher elevation; e.g., on the Paris Moraine, strong downward vertical gradients are observed beyond the areas of municipal pumping, with groundwater levels in the Guelph Formation as much as 10 m above those in the Gasport Formation. Elsewhere observed vertical gradients are generally weakly downward or essentially non-existent.

The presence of the low permeability Vinemount Member accounts for the clear hydraulic separation between the Gasport Formation and the overlying Guelph Formation in the areas of strong downward hydraulic gradients and limits the quantity of vertical seepage reaching the Gasport Formation. The Vinemount is present in all areas where strong vertical gradients are measured. Some exceptions to this are at Tier Three project sites MW08-T3-09 and MW08-T3-10, where the multi-level monitors show a difference in head of 13 to 14 m over a thin (1 to 2 m) section of shaley beds at the base of the Ancaster Member of Goat Island Formation. At these locations this lower section of the Goat Island Formation behaves as an aquitard in a similar manner as the Vinemount Member.

In the northwest quadrant of the City of Guelph, the Vinemount Member is generally thin or absent. The absence of a competent Vinemount aquitard in this area is consistent with the Sacco/Smallfield testing (Stantec, 2009a), which showed a clear response in the Guelph Formation from pumping isolated in the Gasport Formation.

Seasonal groundwater levels fluctuations typically of about 1 to 3 m are observed in Gasport Formation piezometers where not influenced by large scale pumping with similar or lower fluctuations in the overlying Guelph Formation. However an unusually large and rapid water level rise was observed in some piezometers in January 2008. On January 4, 2008, the air temperature began to rise above zero degrees Celsius, reaching a maximum Mean Temperature of 11^{o}C and did not return to below freezing until January 12, 2008. In addition, there was a large rainfall event on January 8 and 9, 2008 (11.5 and 19 mm, respectively). As shown on Figure 35, groundwater levels in the Gasport Formation at TW04-01A rose about 10 m over a 2 day period consistent with the onset of above freezing temperatures; with a further rise a few days later consistent with the rainfall event. In total, groundwater levels rose by a total of about 12 m during this period and thereafter declined slowly as below freezing temperatures returned. Groundwater levels in the overlying Guelph Formation responded to a much lesser degree with a rise of about 2 m observed during this period.

As shown on Figure 36, the most pronounced water level rise was observed at monitoring locations completed within the elongate highly transmissive zone of the Gasport Formation. Away from this zone, the observed water level rise was typically less than 0.5 m with a similar rise in the both the Gasport and overlying Guelph Formations. The start and end times of the peaks in water level as presented on Figure 36 are included in Appendix G (see Table G.3). It should be noted that the City advised that there were no reductions/shutdowns at production wells during this time. The magnitude and distribution of this significant water level rise is indicative of the strong lateral hydraulic connection through the highly transmissive zone within the Gasport

Formation and the direct connection to a source of recharge where the Gasport is not confined by the Vinemount Member either to the northwest of the observed strong water level rise or further to the east of the City of Guelph.

A compilation of the hydraulic conductivity and transmissivity values estimated from aquifer test results, packer testing and single well response tests is provided in Table G.4 in Appendix G. This information was compiled from various key reports in the four well field quadrants of the City of Guelph. Table G.4 summarizes the well tested, the interval over which the testing was conducted, the formation tested and the estimated hydraulic conductivity (m/s), transmissivity (m^2/day) and storativity values. A reference to the source of the information is provided in the table. Table 5.0 presents a summary of aquifer parameter estimates for the model units from previous studies and from a compilation of results of bedrock hydraulic tests completed within individual formations at boreholes with a high level of geologic control/reliability.

Much of the testing has been conducted on open boreholes with pumping from multiple hydrostratigraphic units which can provide estimates of the bulk transmissivity of the bedrock aquifer system rather than values for individual formations. Packer testing and slug testing can provide information on the hydraulic conductivity and transmissivity of the discretely tested intervals and the individual formations, although the interpreted properties are representative of conditions local to the boreholes only and provide an estimate of the horizontal rather than vertical hydraulic conductivity. Test data developed on a borehole scale over a large area show a significant range of calculated values of aquifer transmissivity or hydraulic conductivity; reflecting variation of the rock properties at the borehole and the variable distribution of secondary permeability features such fractures and karst dissolution within the formations. Testing over a longer duration and where a greater quantity of water is moved, such as in a long term pumping test, provide a much more reliable estimate of the bulk properties of a more extensive portion of an aquifer. Given the three-dimensional variability of the bedrock aquifer system hydraulic characteristics, the parameters estimated through three-dimensional modelling, including calibration to transient pumping test data, provide the best estimates of aquifer parameters on a larger or regional scale.

As discussed in Section 2.4, a regionalized approach to model parameterization was used for the Guelph-Puslinch Study, whereby parameter values are tied to regional hydrostratigraphic units and adjusted globally during the calibration process to best match observed data. This regionalized model parameterization approach is also used as part of the Tier Three model. This type of approach is the common industry practice for regional models of this scale and purpose. In this parameterization approach, although some spatial variations in material properties for a given hydrostratigraphic unit are considered to match regional trends in error statistics, small scale local variations (on the scale of an individual property for example) are not considered. With this type of approach, while the model can be effectively used to evaluate regional scale impacts, it may not be as effective in its use at the local scale.

As was done with the Guelph-Puslinch Study modelling, the approach taken in this Tier Three Assessment was to build on the regional hydraulic property distributions developed in past modelling studies (see Table 2.4 and Golder, 2006a), making adjustments and refinements during the model calibration to match the updated hydraulic head and baseflow target data.

The following provides a discussion of the hydraulic parameter estimates for the regional hydrostratigraphic units:

- **Lower Gasport Unit:** The lower portion of the Gasport Formation including the underlying Rochester, Irondequoit, Rockway and Merritton Formations are interpreted as generally a low permeability poor aquifer in the Study Area. In the Guelph-Puslinch Study the calibrated hydraulic conductivity of this unit (formerly the Lower Amabel unit) was 1E-5 m/s with a vertical/horizontal hydraulic conductivity ratio of 0.5. Dynamic flow profiling, packer testing and FLUTe profiling of this unit typically has not shown any significant producing or permeable zones in this unit in the Guelph area.

- **Middle Gasport Unit:** A series of hydraulic conductivity zones were assigned to this unit as part of the Guelph-Puslinch modelling with calibrated hydraulic conductivity values ranging from 1E-4 m/s to 1.7E-3 m/s and a vertical/horizontal hydraulic conductivity ratio of 1. As part of the City of Guelph's ongoing SW Quadrant Class EA (Golder, 2011), the distribution of permeable zones in the Middle Gasport unit were adjusted during model calibration to the results of the 32-day pumping test that was performed in 2008. The response to pumping was observed over an elongate area extending generally north-northwest south-southeast. Reference should be made to the supporting documentation for the City of Guelph's SW Quadrant EA for a detailed discussion of the resulting parameterization in this area of the model (Golder, 2011). The parameterization of this unit in the east of the City and in the Arkell area is based on the zones developed as part of the Arkell Springs Grounds Investigation MODFLOW model calibration (Gartner Lee Ltd. 2003). Testing on the Tier Three project boreholes drilled as part of this Study has provided some information on the distribution of the highly permeable zones within the Gasport Formation beyond the City of Guelph where such information is sparse. The Tier Three borehole testing showed higher permeability zones within this unit to the south of the City of Guelph at MW08-T3-09 (test 1), MW08-T3-10 (test 1) and MW09-T3-01 (test 6), where horizontal hydraulic conductivity values ranged from 2E-4 to 9E-4 m/s, calculated based on the packer testing (see Table 4.3). Although high quality data regarding vertical variations in hydraulic conductivity within the Gasport (flow profiling, packer testing and FLUTe profiling) are available for some boreholes in the Study Area, the distribution of this data across the City of Guelph and on the more regional scale was not considered sufficient at this stage to warrant moving beyond a three layer conceptual hydrostratigraphic representation of the Gasport Formation with a middle unit of constant slope and thickness containing the higher permeability Gasport zones. Within the interpreted elongate zone of high permeability Gasport described above the horizontal hydraulic conductivity estimates, as summarized in Table 5.0, range from 2E-6 to 1E-2 m/s with a median value of 2E-4 m/s. Outside of the high permeability Gasport zone, the horizontal hydraulic conductivity estimates summarized in Table 5.0 range from 2E-8 to 5E-4 m/s with a median value of 5E-6 m/s.

- **Upper Gasport Unit:** This unit generally corresponds to the former Upper Amabel unit in the Guelph-Puslinch Model where the calibrated hydraulic conductivity of this unit was 1E-5 m/s with a vertical/horizontal hydraulic conductivity ratio of 0.5.

- **Goat Island Unit:** The Goat Island unit in the Guelph area is generally a poor low permeability aquifer. This unit was previously included within the Upper Amabel unit where the calibrated hydraulic conductivity of this unit was 1E-5 m/s with a vertical/horizontal hydraulic conductivity ratio of 0.5. The horizontal hydraulic conductivity estimates summarized in Table 5.0 for the Goat Island Formation range from 9E-8 to 4E-4 m/s with a median value of 5E-6 m/s. At borehole MW08-T3-10, the shaley beds of the lower Ancaster Member are interpreted to behave as a clear aquitard in a similar manner to the Vinemount unit supporting a head difference of over 13 m across the lower 2 m of the Goat Island.

- **Vinemount Unit:** The Vinemount vertical permeability is a key sensitive parameter controlling leakage to the deeper aquifer. The calibrated vertical hydraulic conductivity of the Vinemount from the Guelph-Puslinch Study was 1E-9 m/s with a vertical/horizontal hydraulic conductivity ratio of 0.02. A vertical hydraulic conductivity value of about 1E-9 m/s was also estimated from transient numerical model calibration to the results of the SW Quadrant 2008 pumping test (Golder, 2011). The horizontal hydraulic conductivity estimates summarized in Table 5.0 for the Vinemount Member range from 5E-7 to 3E-5 m/s with a median value of 5E-6 m/s.

- **Reformatory Quarry Unit:** This unit was not separately represented in the previous model as it was often previously interpreted as the Guelph Formation. This unit generally has similar variability and similar hydraulic properties as the Guelph Formation, although because of sequences of lower permeability shaley beds that may be present, the anisotropy for this unit is interpreted to be higher than the Guelph Formation. The horizontal hydraulic conductivity estimates summarized in Table 5.0 for the Reformatory Quarry Member range from 2E-7 to 2E-4 m/s with a median value of 3E-6 m/s.

- **Guelph Unit:** The calibrated Guelph-Puslinch model had a regionalized parameter estimate of 1E-5 m/s for this Formation with a vertical/horizontal hydraulic conductivity ratio of 1.0. The Guelph Formation shows a high degree of variability, although it is generally a poor aquifer except in some localized areas where it is highly transmissive. Where the Guelph Formation does behave as an aquifer capable of supporting municipal supplies, it is often the upper portion of the Formation including the contact aquifer that is the most transmissive. The horizontal hydraulic conductivity estimates summarized in Table 5.0 range from 4E-7 to 6E-4 m/s with a median value of 4E-6 m/s for the Guelph Formation.

- **Contact Aquifer:** The calibrated horizontal hydraulic conductivity value for the contact aquifer unit from the Guelph-Puslinch Study was 1E-4 m/s with a vertical/horizontal hydraulic conductivity ratio of 1.0. Other modelling based hydraulic conductivity estimates for this unit have ranged from 1E-4 to 1E-5 m/s (see Table 2.4). This unit is variable in hydraulic properties and locally some municipal wells have shown a high transmissivity from this zone including weathered and highly permeable portions of the upper bedrock formations. This is the case at the Burke and Carter wells in the Southeast Quadrant where the majority of water is drawn from the shallow rock and lower overburden. Some of the municipal wells in East Cambridge (wells H4 and G5, for example) also draw the majority of their water from a localized highly transmissive contact aquifer/shallow bedrock zone.

- **Overburden Till:** The hydraulic conductivity of the overburden till units in the Guelph-Puslinch Model was 1 E-6 to 1E-5 m/s, with a vertical/horizontal hydraulic conductivity ratio of 0.5. Locally there may be areas where the tills have a much lower permeability. The range of hydraulic conductivity values for these tills reported from the quadrant studies was 2E-9 to 1E-4 m/s (Jagger Hims Ltd., 1998b).

- **Overburden Sand and Gravel:** The hydraulic conductivity of the sand and gravel units in the Guelph-Puslinch Model was 2.5 E-4 to 5E-4 m/s, within the typical range of permeability for coarse-grained and gravel materials.

Dynamic flow profiling has been completed in numerous open rock boreholes in the City of Guelph area including production wells, test wells and monitoring wells. The majority of these tests have been performed by Lotowater Ltd. These flow profiles provide valuable information on the distribution of flow producing intervals vertically within the bedrock. Table G.4 provides a summary of the dynamic flow profiling completed at the municipal wells and some of the key monitoring wells and test wells.

6.0 CLOSURE

It has been our pleasure working on this challenging and important study. If you have any questions or require clarification, please contact the undersigned.

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TABLES

Table 2.1: City of Guelph Municipal Production Wells

Quadrant	Well Name	Easting	Northing	Depth (m)	Formation	Permitted Rate (m^3/day)	2008 Pumping Rate (m3/day)	Estimated Capacity[1] (m3/day)
Southeast	Arkell 1	567944	4822434	20.1	Overburden - Contact Zone	3,273	730	2,000
	Arkell 6	567934	4823061	41.2	Upper - Middle Gasport	6,546	3,774	6,500
	Arkell 7	567993	4822436	43.3	Upper - Middle Gasport	6,546	3,689	6,500
	Arkell 8	568055	4822971	42.1	Upper - Middle Gasport	6,546	3,694	6,500
	Arkell 14	568096	4823126	40.5	Upper - Middle Gasport	---	N/A	4,680 [2]
	Arkell 15	567440	4822878	30.5	Upper - Lower Gasport	---	N/A	4,680 [2]
	Burke	565157	4818701	79.6	Guelph - Middle Gasport	6,546	5,385	6,500
	Carter (In/Out)	564870	4820808	20.7	Guelph	7,856	2,004	5,500
	Arkell Infiltration Galleries				Overburden	25,000	6,500	6,900
Southwest	Dean Ave	560997	4819805	57.2	Upper - Middle Gasport	2,300	1,215	1,500
	Downey Road	561798	4817015	73.8	Upper - Middle Gasport	5,237	3,940	5,100
	Membro	560293	4819861	73.2	Upper - Middle Gasport	6,050	3,036	6,000
	University	561613	4819168	64.3	Upper Gasport	3,300	1,648	2,500
	Water Street	560773	4820356	60.0	Upper - Middle Gasport	3,400	1,184	2,700
	Edinburgh[3]	560594	4820066	69.5	Upper - Middle Gasport	---	0	0
Northeast	Clythe Creek	564031	4823927	58.9	Reformatory Quarry - Lower Gasport	---	N/A[4]	3,000 [2]
	Emma	559931	4823351	46.0	Upper - Middle Gasport	3,100	2,273	2,800
	Helmar	560357	4825777	79.6	Upper - Middle Gasport	3,273	500	1,500
	Park 1 & Park 2	560430	4823231	57.0	Upper - Middle Gasport	10,300	5,897	8,000
Northwest	Calico	554602	4819900	64.0	Upper Gasport	5,237	748	1,100
	Paisley	558126	4819636	80.2	Upper - Middle Gasport	3,200	762	1,400
	Queensdale	558482	4818297	74.4	Guelph - Upper Gasport	5,237	702	2,000
	Sacco	556416	4821929	95.7	Guelph - Middle Gasport	---	N/A[4]	1,150 [2]
	Smallfield	556748	4820866	102.1	Guelph - Lower Gasport	---	N/A[4]	1,400 [2]

NOTES:

1) Estimated Sustainable Rates from Water Supply Master Plan, Earth Tech et al., (2006)

2) Sustainable Rate estimated by City of Guelph Water Services Division

3) No current plans to use Edinburgh Well

4) Wells not pumped during 2008 due to water quality concerns

Table 2.2: Summary of Climate Normals (1971 to 2000) For The Study Area

Station Name	Elevation (MASL)	Mean Annual Temperature (°C)	Mean Annual Rainfall (mm)	Mean Annual Snowfall (cm)	Mean Annual Precipitation (mm)
Guelph Arboretum	327.7	6.5	771.4	160.6	923.3
Cambridge Galt MOE	268.2	7.2	787.2	127.2	912.9
Fergus Shand Dam	417.6	6.3	782.5	156	938.5
Waterloo Wellington A	317	6.7	765	159.5	907.9
Georgetown WWTP	221	6.8	743.8	141.5	885
Orangeville MOE	411.5	6	731.5	160.2	891.7
Mean[1]	n.a.	6.6	n.a.	n.a.	909.9

Notes:

1) Mean of station data is not necessarily representative of the spatial distribution of meteorological data over the Study Area.

Table 2.3: Summary of WSC And GRCA Hydrometric Data For The Study Area

Station Number	Station Name	Period of Record	Drainage Area (km^2)	Mean Annual Flow	
				m^3/s	mm/yr
02GA033	Lutteral Creek Near Oustic	1953-1991	64.8	0.731	356
02GA040	Speed River Near Armstrong Mills	1973-2005	167	2.12	400
02GA007[1]	Speed River Near Guelph	1913-1917	180	2.18	382
02GA031	Blue Springs Creek Near Eden Mills	1965-2005	44.5	0.568	403
02GA029	Eramosa River Above Guelph	1962-2005	236	2.47	330
02GA020[2]	Speed River Above Guelph	1953-1961	269	2.62	307
02GA032	O.A.C. Farm No.5 at Guelph	1966-1984	2.51	0.024	302
02GA015	Speed River Below Guelph	1950-2005	593	5.67	302
02GA008[3]	Speed River at Hespeler	1913-1949	707	6.39	285
02GA047	Speed River at Cambridge	2002-2005	NA	7.83	NA
2GAC19	Mill Creek at Sideroad 10	1990-2005	82.3	0.877	336

Notes:

1) Gauge 02GA007 has incomplete data for 1913 and 1917.
2) Gauge 02GA020 has incomplete data for 1953 and 1961.
3) Gauge 02GA008 is missing data sporadically from 1922 to 1947.

Table 2.4: Previous Hydraulic Conductivity Values for Regional Stratigraphic Units

Horizontal Hydraulic Conductivity (m/s)	Ratio of Vertical to Horizontal Hydraulic Conductivity	Data Source
Overburden (Sand and Gravel)		
2.5x10^{-4} to 5x10^{-4}	0.25	Arkell Spring Grounds MODFLOW Model
5x10^{-5} to 7x10^{-4}	0.10	Reid's Heritage Homes Groundwater Model
6x10^{-6} to 1x10^{-3}	-	City of Guelph Northwest Quadrant Report
1x10^{-4}	0.10	GRCA FEFLOW Model
9x10^{-4} to 1.2x10^{-4}	0.50	Mill Creek Groundwater Model
2.5x10^{-4} to 5x10^{-4}	**1.00**	**Guelph-Puslinch FEFLOW Model**
Overburden (Till)		
1x10^{-7}	0.25	Arkell Spring Grounds MODFLOW Model
5x10^{-8} to 8x10^{-7}	0.10	Reid's Heritage Homes Groundwater Model
2x10^{-9} to 9x10^{-5}	-	City of Guelph Northwest Quadrant Report
1x10^{-5}	0.10	GRCA FEFLOW Model
1.4x10^{-4}	0.50	Mill Creek Groundwater Model
1x10^{-6} to 1x10^{-5}	**0.50**	**Guelph-Puslinch FEFLOW Model**
Contact Aquifer		
1x10^{-5} to 7x10^{-5}		Reid's Heritage Homes Groundwater Model
1.2x10^{-4}	0.50	Mill Creek Groundwater Model (Upper bedrock)
1x10^{-4}	**1.00**	**Guelph-Puslinch FEFLOW Model**
Guelph Formation		
5x10^{-8} to 8x10^{-3}	0.50	Arkell Spring Grounds MODFLOW Model
7x10^{-9} to 8x10^{-5}	-	City of Guelph Northwest Quadrant Report
5x10^{-5}	0.10	GRCA FEFLOW Model (Represents combined Guelph, Eramosa and Amabel Formations)
1x10^{-5}	**1.00**	**Guelph-Puslinch FEFLOW Model**
Eramosa Member		
5x10^{-8} to 1x10^{-6}	0.10	Arkell Spring Grounds MODFLOW Model
7x10^{-9} to 1x10^{-6}	-	City of Guelph Northwest Quadrant Report
5x10^{-8}	**0.02**	**Guelph-Puslinch FEFLOW Model**
Upper/Lower Amabel Formation		
5x10^{-6} to 1x10^{-5}	0.25	
1x10^{-5}	**0.50**	**Guelph-Puslinch FEFLOW Model**
Production Amabel		
5x10^{-6} to 4x10^{-3}	1.00	Arkell Spring Grounds MODFLOW Model
up to 4x10^{-3}	-	City of Guelph Northwest Quadrant Report
Variable ranging from 1x10^{-4} to 1.7x10^{-3}	**1.00**	**Guelph-Puslinch FEFLOW Model**

Table 4.1: Monitoring Well Program Overview

WORK PROGRAM COMPONENT	**BOREHOLE NAME**										
	MW08-T3-01	MW08-T3-02	MW08-T3-03	MW08-T3-04	MW08-T3-05	MW08-T3-06	MW08-T3-07	MW08-T3-08	MW08-T3-09	MW08-T3-10	MW09-T3-01
Drilling											
Tri-coning		✓	✓	✓			✓	✓	✓	✓	
PQ Coring	✓				✓	✓					
HQ Coring											✓
Hydraulic Testing											
Short Pumping Test	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Packer Testing	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓
FLUTe K-Profiling	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Geophysics											
Natural Gamma	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Apparent Conductivity	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Optical Televiewer	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Borehole Video Logging	✓				✓	✓			✓	✓	
Temperature Logging		✓		✓	✓						
Multi-level Construction											
Flute Multi-level Installation							✓	✓			
Solinst Mulit-Level Installation	✓				✓	✓					
Westbay Multi-Level Installation		✓	✓	✓					✓	✓	
Shallow Bedrock 1" OD PVC Monitoring Well Installation	✓				✓	✓					✓
Deep Bedrock 1" OD PVC Monitoring Well Installation											✓
Number of Bedrock Monitoring Intervals	9	23	14	28	9	9	9	10	16	18	2
Step-off Overburden Well			✓	✓	✓		✓	✓	✓	✓	
Water Quality and Water Level Monitoring											
Number of Data Loggers Installed in Bedrock Intervals	1				1	1	3	3			2
Data Logger Installed in Overburden Interval			✓	✓	✓		✓	✓	✓	✓	
Monthly Manual Water Level Measurements	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Water Quality Sampling (metals, nutrients, general chemisty, DOC)	✓				✓	✓	✓	✓			

Table 4.2: Borehole Details

Borehole Name	Location	Easting	Northing	Ground Elevation (masl)	Boring Method	Drilling Completion Date	Casing Diameter (mm)	Casing Depth (mbgs)	Bedrock Borehole Diameter (mm)	Top of Bedrock (mbgs)	Bottom of Hole (mbgs)
MW08-T3-01	Marden Tract	555101.11	4824026.41	339.25	Air Rotary	08/07/2008	152.4	10.8	152.4	9.8	95.7
MW08-T3-02	Mill Road	559361.46	4830632.50	367.32	PQ Coring	09/09/2008	152.4	8.5	121.9	8.6	89.9
MW08-T3-03	Hurkman Tract	563028.55	4835572.20	399.46	Air Rotary	28/07/2008	152.4	43.9	152.4	30.5	97.2
MW08-T3-04	Hwy 6 - South of Fergus	552653.90	4836466.61	413.95	Air Rotary	06/08/2008	152.4	19.4	152.4	19.2	143.9
MW08-T3-05	Johnson Tract	562220.26	4845823.57	427.59	PQ Coring	15/09/2008	152.4	19.2	121.9	16.8	104.9
MW08-T3-06	Everton	568274.08	4834617.39	365.83	PQ Coring	19/09/2008	152.4	1.1	121.9	1.1	57.7
MW08-T3-07	County Road 29	564581.25	4828348.62	354.29	Air Rotary	30/09/2008	152.4	15.5	152.4	14.9	76.5
MW08-T3-08	Kaine Hill Drive	560948.78	4826604.45	345.33	Air Rotary	10/07/2008	152.4	16.9	152.4	16	76.2
MW08-T3-09	Crawford Tract	570645.12	4820064.57	346.47	Air Rotary	12/08/2008	152.4	28	152.4	25.6	84.7
MW08-T3-10	Vance Tract	563160.90	4812508.87	330.31	Air Rotary	17/07/2008	152.4	39	152.4	38.5	105.4
MW09-T3-01	Little Tract	560864.18	4810648.97	315.84	HQ Coring	05/06/2009	127	25.6	88.9	23.8	113.1

Step-Off Overburden Boreholes

Borehole Name	Location	Easting	Northing	Ground Elevation (masl)	Boring Method	Drilling Completion Date	Casing Diameter (mm)	Top of Screen (mbgs)	Bottom of Screen (mbgs)	Top of Sandpack (mbgs)	Bottom of Sandpack (mbgs)
MW08-T3-03-OB	Hurkman Tract	563029.51	4835573.58	399.45	Air Rotary	07-28-2008	38.1	35.4	36.9	34.8	36.9
MW08-T3-04-OB	Hwy 6 - South of Fergus	552651.43	4836461.87	413.70	Air Rotary	08-06-2008	38.1	15.2	16.8	13.1	16.8
MW08-T3-05-OB	Johnson Tract	562220.26	4845823.57	427.59	Air Rotary	09-15-2008	38.1	9.1	10.7	7.6	10.7
MW08-T3-07-OB	County Road 29	564581.25	4828348.62	354.29	Air Rotary	09-30-2008	38.1	12.2	13.4	10.4	13.4
MW08-T3-08-OB	Kaine Hill Drive	560948.78	4826604.45	345.33	Air Rotary	07-10-2008	38.1	14.3	15.9	13.7	15.9
MW08-T3-09-OB	Crawford Tract	570645.73	4820063.83	346.47	Air Rotary	08-12-2008	38.1	10.1	11.6	8.5	11.6
MW08-T3-10-OB	Vance Tract	563160.90	4812508.87	330.31	Air Rotary	07-17-2008	38.1	33.5	36.6	32.0	36.6

Table 4.3: Packer Testing Results

Site/Interval	Packer Test Interval (m)		Interval Length (m)	Pumping Rate (m^3/day)	Drawdown at End of Test (m)	Formation	Open Hole Static Water Level (mbtop)	Water Level in Packer Interval (mbtop)	Water Level above Packer (mbtop)	K (m/s)	Analysis Method
	Top	Bottom									
MW08-T3-01-1	65	75	10	92	15.24	Goat Island	2.55	2.68	-	5.4E-06	Thiem/Dupuis
MW08-T3-01-2	48	58	10	85	33.22	Reformatory Quarry / Vinemount	2.57	2.78	-	2.6E-06	Hvorslev
MW08-T3-01-3	35	45	10	92	4.68	Reformatory Quarry	2.57	2.00	-	1.8E-05	Thiem/Dupuis
MW08-T3-01-4	18	28	10	92	11.73	Reformatory Quarry	2.24	3.46	-	7.0E-06	Thiem/Dupuis
MW08-T3-02-1[1]	60.3	70.3	10			Gasport				1.3E-06	Hvorslev
MW08-T3-02-2[1]	50.3	60.3	10			Gasport				2.8E-06	Hvorslev
MW08-T3-02-3[1]	40.3	50.3	10			Gasport				1.1E-06	Hvorslev
MW08-T3-02-4[1]	29.3	39.3	10			Gasport				6.1E-07	Hvorslev
MW08-T3-02-5[1]	19.3	29.3	10			Stone Road / Reformatory Quarry / Vinemount				7.5E-06	Hvorslev
MW08-T3-04-1	114.7	124.7	10	89	1.90	Gasport	9.42	10.47	10.07	inconclusive	
MW08-T3-04-2	60	70	10	82	42.63	Goat Island	9.60	10.24	10.10	1.7E-06	Thiem/Dupuis
MW08-T3-04-3	26	36	10	85	13.45	Guelph	9.60	10.31	10.07	5.7E-06	Thiem/Dupuis
MW08-T3-05-1[1]	61.8	67.8	6			Gasport				6.0E-07	Hvorslev
MW08-T3-05-2[1]	55.8	61.8	6			Gasport				3.4E-05	Hvorslev
MW08-T3-05-3[1]	49.8	55.8	6			Goat Island / Gasport				1.5E-05	Hvorslev
MW08-T3-05-4[1]	43.8	49.8	6			Goat Island				7.5E-06	Hvorslev
MW08-T3-05-5[1]	37.8	43.8	6			Goat Island				6.0E-07	Hvorslev
MW08-T3-05-6[1]	31.8	37.8	6			Vinemount / Goat Island				6.7E-06	Hvorslev
MW08-T3-05-7[1]	25.8	31.8	6			Reformatory Quarry / Vinemount				2.2E-06	Hvorslev
MW08-T3-05-8[1]	19.8	25.8	6			Stone Road / Reformatory Quarry				3.0E-06	Hvorslev
MW08-T3-06-1[1]	39.6	45.6	6			Gasport				3.0E-06	Hvorslev
MW08-T3-06-2[1]	33.6	39.6	6			Gasport				3.0E-05	Hvorslev
MW08-T3-06-3[1]	23.6	29.6	6			Gasport				1.1E-06	Hvorslev
MW08-T3-06-4[1]	17.6	23.6	6			Gasport				5.2E-07	Hvorslev
MW08-T3-06-5[1]	11.6	17.6	6			Gasport				1.0E-06	Hvorslev
MW08-T3-06-6[1]	5.6	11.6	6			Goat Island / Gasport				2.3E-05	Hvorslev
MW08-T3-07-1	52	62	10	79	7.66	Goat Island / Gasport	11.05	11.54	11.05	9.2E-06	Thiem/Dupuis
MW08-T3-07-2	42	52	10	72	11.00	Goat Island	11.05	11.89	7.52	inconclusive	
MW08-T3-07-3	25	35	10	85	1.32	Vinemount	11.44	6.93	6.58	inconclusive	
MW08-T3-07-4	15	25	10	82	5.55	Reformatory Quarry / Vinemount	11.46	6.19	-	2.6E-06	Thiem/Dupuis

Table 4.3: Packer Testing Results

Site/Interval	Packer Test Interval (m)		Interval Length (m)	Pumping Rate (m^3/day)	Drawdown at End of Test (m)	Formation	Open Hole Static Water Level (mbtop)	Water Level in Packer Interval (mbtop)	Water Level above Packer (mbtop)	K (m/s)	Analysis Method
	Top	Bottom									
MW08-T3-08-1	52	62	10	92	4.57	Goat Island / Gasport	11.10	11.39	11.00	1.8E-05	Thiem/Dupuis
MW08-T3-08-2	41	51	10	92	2.87	Goat Island	11.10	11.56	10.42	2.9E-05	Thiem/Dupuis
MW08-T3-08-3	25	35	10	79	7.11	Vinemount / Goat Island	11.10	11.66	5.64	9.9E-06	Thiem/Dupuis
MW08-T3-08-4	15	25	10	79	9.01	Reformatory Quarry / Vinemount	11.12	4.99	11.13	2.0E-05	Hvorslev
MW08-T3-09-1	67	77	10	85	0.33	Gasport	17.94	18.48	9.19	2.3E-04	Thiem/Dupuis
MW08-T3-09-2	53	63	10	79	3.31	Gasport	17.94	19.29	8.03	2.1E-05	Thiem/Dupuis
MW08-T3-09-3	40	50	10	79	0.75	Goat Island / Gasport	18.31	19.62	6.90	9.4E-05	Thiem/Dupuis
MW08-T3-09-4	29	39	10	82	17.62	Goat Island	18.31	8.35	6.66	4.2E-06	Thiem/Dupuis
MW08-T3-10-1	89	99	10	79	0.31	Gasport	13.94	25.52	12.42	2.3E-04	Thiem/Dupuis
MW08-T3-10-2	70	80	10	72	3.49	Gasport	13.94	29.63	12.10	1.9E-05	Thiem/Dupuis
MW08-T3-10-3	46	56	10	72	30.00	Goat Island	-	13.24	11.91	5.1E-06	Hvorslev
MW08-T3-10-4	36	46	10	88	0.37	Reformatory Quarry	-	11.98	14.09	2.1E-04	Thiem/Dupuis
MW09-T3-01-1	25	28.1	3	79 [2]	6.94	Guelph	11.81	6.97	5.87	3.8E-06	Hvorslev
MW09-T3-01-2	43	46	3	151 [2]	5.87	Reformatory Quarry	11.09	7.29	5.58	1.4E-06	Hvorslev
MW09-T3-01-3	50	53	3	72 [2]	4.59	Vinemount	12.07	6.51	5.44	7.2E-07	Hvorslev
MW09-T3-01-4	58.5	61.5	3	169 [2]	12.00	Goat Island	12.60	12.58	6.27	2.8E-06	Hvorslev
MW09-T3-01-5	73	76	3	147 [2]	10.86	Gasport	12.03	12.05	7.55	6.4E-05	Hvorslev
MW09-T3-01-6	97	100	3	142 [2]	0.50	Gasport	12.38	12.375	10.86	9.3E-04	Thiem/Dupuis
MW09-T3-01-7	64	113	49	324 [2]	0.32	Gasport to Cabot Head	12.14	12.18	6.48	1.1E-05	Hvorslev

NOTES:

1) Packer testing at Sites MW08-T3-02, MW08-T3-05 and MW08-T3-06 was conducted by the University of Guelph.

2) Pumping rate of injection pumping for a falling head test.

Table 4.4: Open Borehole Specific Capacity Testing Results

Well ID	Casing Depth (m)	Bottom of Hole Depth (m)	Thickness (m)	Static Water Level (mbTOC)[1]	Pumping Rate (m^3/day)	Elapsed Time (min)	Drawdown at End of Test (m)	Specific Capacity (m^3/day/m DD)	K (m/s)	T (m^2/day)	Analysis Method
MW08-T3-01	10.8	95.7	84.9	2.66	281	120	13.7	21	4.2E-06	16	Thiem/Dupuis Solution
MW08-T3-02	8.5	89.9	77.5	12.38	180	120	17.9	10	3.3E-06	8	Thiem/Dupuis Solution
MW08-T3-03	43.9	97.2	53.3	24.45	74 [2]	60	21.0	4	7.7E-06	3	Thiem/Dupuis Solution
MW08-T3-04	19.4	143.9	124.5	10.19	273	240	9.1	30	2.3E-06	23	Thiem/Dupuis Solution
MW08-T3-05	19.2	104.9	85.7	0.67	305	60	8.8	35	5.3E-06	28	Thiem/Dupuis Solution
MW08-T3-06	1.1	57.7	56.6	0.96	206	60	26.9	8	4.4E-06	6	Thiem/Dupuis Solution
MW08-T3-07	15.5	76.5	61.0	11.23	295	240	0.7	398	3.5E-05	310	Thiem/Dupuis Solution
MW08-T3-08	16.9	76.2	59.3	11.81	272	240	6.8	40	5.4E-06	31	Thiem/Dupuis Solution
MW08-T3-09	28.0	84.1	56.1	18.06	281	270	0.6	440	2.8E-05	342	Thiem/Dupuis Solution
MW08-T3-10	39.0	105.4	66.4	12.91	290	240	0.4	763	1.3E-04	593	Thiem/Dupuis Solution
MW09-T3-01	25.6	113.1	87.5	11.86	71	30	0.08	885	1.6E-04	753	Thiem/Dupuis Solution

NOTES:

1) Static water level measured immediately prior to Test.
2) A higher pump rate was used for the first 20 minutes at MW08-T3-03.

Table 4.5: Monitoring Well Completion Details

Borehole Name	Ground Surface Elevation (masl)	Monitoring Well Installation Date	Interval ID	Tube Diameter (mm)	Top Screen (mbgs)	Bottom Screen (mbgs)	Top Sand Pack (mbgs)	Bottom Sand Pack (mbgs)	Formation Screened	Transducer Installed
MW08-T3-01	339.25	8-Jul-2008	CS	25.4	11.4	11.7	10.7	12.5	Eramosa - Reformatory Quarry	Yes
		23-Jun-2009	1	6.4	15.4	15.7	13.9	17.2	Eramosa - Reformatory Quarry	
			2	6.4	24.4	24.7	22.4	26.7	Eramosa - Reformatory Quarry	
			3	19.1	40.2	40.5	39.2	41.6	Eramosa - Reformatory Quarry	
			4	6.4	52.0	52.3	49.8	54.4	Eramosa - Reformatory Quarry	
			5	6.4	60.0	60.3	58.8	61.4	Goat Island - Ancaster	
			6	19.1	68.1	68.4	66.8	69.8	Goat Island - Ancaster	
			7	6.4	78.0	78.3	75.6	80.6	Gasport	
			8	6.4	92.3	92.6	91.0	94.0	Irondequoit and Rockway	
MW08-T3-02		8-Apr-2010	1	N/A	N/A	N/A	7.8	8.8	Guelph - Hanlon	
			2	N/A	N/A	N/A	9.8	11.6	Guelph - Hanlon	
			3	N/A	N/A	N/A	13.1	14.6	Guelph - Hanlon	
			4	N/A	N/A	N/A	16.2	17.7	Eramosa - Stone Road	
			5	N/A	N/A	N/A	19.2	20.7	Eramosa - Stone Road	
			6	N/A	N/A	N/A	23.5	25.1	Eramosa - Reformatory Quarry	
			7	N/A	N/A	N/A	26.7	28.5	Eramosa - Vinemount	
			8	N/A	N/A	N/A	30.0	31.7	Eramosa - Vinemount and Gasport	
			9	N/A	N/A	N/A	33.2	35.1	Gasport	
			10	N/A	N/A	N/A	36.6	38.1	Gasport	
			11	N/A	N/A	N/A	39.6	41.1	Gasport	
			12	N/A	N/A	N/A	43.4	45.4	Gasport	
			13	N/A	N/A	N/A	46.9	48.5	Gasport	
			14	N/A	N/A	N/A	50.0	51.5	Gasport	
			15	N/A	N/A	N/A	53.0	54.6	Gasport	
			16	N/A	N/A	N/A	56.4	58.2	Gasport	
			17	N/A	N/A	N/A	59.9	61.7	Gasport	
			18	N/A	N/A	N/A	63.4	65.4	Gasport	
			19	N/A	N/A	N/A	68.4	70.7	Gasport	
			20	N/A	N/A	N/A	73.6	76.0	Gasport	
			21	N/A	N/A	N/A	78.6	81.2	Gasport	
			22	N/A	N/A	N/A	82.8	84.3	Irondequoit	
			23	N/A	N/A	N/A	86.3	87.8	Cabot Head	
MW08-T3-03		28-Jul-2008	OB	50.8	35.4	36.9	34.8	36.9	Eramosa - Stone Road	Yes
		8-Apr-2010	1	N/A	N/A	N/A	43.9	45.4	Eramosa - Stone Road and Reformatory Quarry	
			2	N/A	N/A	N/A	46.6	48.2	Eramosa - Reformatory Quarry and Vinemount	
			3	N/A	N/A	N/A	49.7	51.2	Eramosa - Vinemount	
			4	N/A	N/A	N/A	53.3	55.0	Eramosa - Vinemount and Goat Island - Niagara Falls	
			5	N/A	N/A	N/A	56.5	58.8	Goat Island - Niagara Falls	
			6	N/A	N/A	N/A	60.8	62.9	Goat Island - Niagara Falls	
			7	N/A	N/A	N/A	64.8	66.8	Goat Island - Niagara Falls	
			8	N/A	N/A	N/A	71.0	73.8	Gasport	
			9	N/A	N/A	N/A	75.3	76.8	Gasport	
			10	N/A	N/A	N/A	78.6	81.1	Gasport	

Table 4.5: Monitoring Well Completion Details

Borehole Name	Ground Surface Elevation (masl)	Monitoring Well Installation Date	Interval ID	Tube Diameter (mm)	Top Screen (mbgs)	Bottom Screen (mbgs)	Top Sand Pack (mbgs)	Bottom Sand Pack (mbgs)	Formation Screened	Transducer Installed
MW08-T3-03		8-Apr-2010	11	N/A	N/A	N/A	83.7	85.8	Gasport	
			12	N/A	N/A	N/A	87.5	89.3	Gasport	
			13	N/A	N/A	N/A	90.8	92.8	Gasport	
			14	N/A	N/A	N/A	94.5	96.0	Irondequoit, Rockway and Cabot Head	
MW08-T3-04		6-Aug-2008	OB	50.8	15.24	16.76	13.1	16.76	Silty Sand and Gravel	Yes
		9-Apr-2010	1	N/A	N/A	N/A	19.2	22.1	Guelph - Hanlon	
			2	N/A	N/A	N/A	26.1	28.0	Guelph - Hanlon	
			3	N/A	N/A	N/A	30.0	33.7	Guelph - Hanlon	
			4	N/A	N/A	N/A	35.7	38.4	Guelph - Hanlon	
			5	N/A	N/A	N/A	41.6	44.2	Guelph - Hanlon	
			6	N/A	N/A	N/A	46.6	48.8	Guelph - Hanlon	
			7	N/A	N/A	N/A	50.3	52.4	Goat Island - Niagara Falls	
			8	N/A	N/A	N/A	53.9	55.9	Goat Island - Niagara Falls	
			9	N/A	N/A	N/A	57.6	59.3	Goat Island - Niagara Falls	
			10	N/A	N/A	N/A	60.8	63.1	Goat Island - Niagara Falls	
			11	N/A	N/A	N/A	65.2	67.5	Goat Island - Niagara Falls	
			12	N/A	N/A	N/A	69.6	71.9	Goat Island - Niagara Falls	
			13	N/A	N/A	N/A	75.0	76.8	Goat Island - Niagara Falls	
			14	N/A	N/A	N/A	78.5	80.5	Goat Island - Niagara Falls	
			15	N/A	N/A	N/A	83.8	86.3	Goat Island - Niagara Falls	
			16	N/A	N/A	N/A	87.8	91.0	Goat Island - Niagara Falls and Gasport	
			17	N/A	N/A	N/A	93.3	96.0	Gasport	
			18	N/A	N/A	N/A	97.5	99.2	Gasport	
			19	N/A	N/A	N/A	102.4	104.4	Gasport	
			20	N/A	N/A	N/A	105.9	107.4	Gasport	
			21	N/A	N/A	N/A	109.0	111.9	Gasport	
			22	N/A	N/A	N/A	113.7	115.7	Gasport	
			23	N/A	N/A	N/A	117.3	120.1	Gasport	
			24	N/A	N/A	N/A	121.8	125.0	Gasport	
			25	N/A	N/A	N/A	126.5	128.0	Gasport	
			26	N/A	N/A	N/A	130.5	133.4	Gasport	
			27	N/A	N/A	N/A	136.9	139.1	Gasport	
			28	N/A	N/A	N/A	141.0	143.3	Merritton and Cabot Head	
MW08-T3-05	427.59	15-Sep-2008	OB	50.8	9.1	10.7	7.6	10.7	Sand and Gravel	Yes
		3-Jul-2009	CS	25.4	23.80	25.3	21.3	25.6	Eramosa - Stone Road	Yes
			1	6.4	33.8	34.1	30.3	37.6	Eramosa - Reformatory Quarry and Vinemount, Goat Island - Niagara Falls	
			2	6.4	42.1	42.4	40.4	44.2	Goat Island - Niagara Falls	
			3	6.4	50.3	50.6	47.5	53.3	Goat Island - Niagara Falls	
			4	19.1	58.7	59.0	56.8	60.8	Gasport	
			5	6.4	67.2	67.5	65.7	69.0	Gasport	
			6	6.4	72.7	73.0	70.9	74.8	Gasport	
			7	19.1	90.1	90.4	85.3	95.1	Gasport	

Table 4.5: Monitoring Well Completion Details

Borehole Name	Ground Surface Elevation (masl)	Monitoring Well Installation Date	Interval ID	Tube Diameter (mm)	Top Screen (mbgs)	Bottom Screen (mbgs)	Top Sand Pack (mbgs)	Bottom Sand Pack (mbgs)	Formation Screened	Transducer Installed
MW08-T3-05			8	6.4	101.2	101.5	100.0	102.7	Irondequoit, Rockway, Merritton and Cabot Head	
MW08-T3-06	365.83	2-Jul-2009	CS	25.4	1.1	2.0	0.8	2.0	Goat Island - Ancaster and Niagara Falls	Yes
			1	6.4	4.0	4.3	3.4	4.9	Goat Island - Niagara Falls	
			2	6.4	6.5	6.8	5.9	7.3	Gasport	
			3	6.4	10.3	10.6	9.6	11.3	Gasport	
			4	19.1	19.8	20.1	17.1	22.9	Gasport	
			5	6.4	27.1	27.4	25.1	29.3	Gasport	
			6	19.1	36.7	37.0	35.4	38.4	Gasport	
			7	6.4	45.6	45.9	44.3	47.2	Gasport	
			8	6.4	56.3	56.6	55.6	57.3	Cabot Head	
MW08-T3-07	354.29	30-Sep-2008	OB	50.8	12.2	13.4	10.4	13.4	Silty Sand and Gravel	Yes
		1-Dec-2009	1	25.4	15.5	17.8	N/A	N/A	Eramosa - Reformatory Quarry	Yes
			2	9.5	20.4	22.4	N/A	N/A	Eramosa - Reformatory Quarry and Vinemount	
			3	25.4	30.0	32.3	N/A	N/A	Eramosa - Vinemount	Yes
			4	9.5	34.1	35.8	N/A	N/A	Eramosa - Vinemount and Goat Island - Ancaster	
			5	9.5	41.9	45.1	N/A	N/A	Goat Island - Ancaster	
			6	25.4	48.0	52.0	N/A	N/A	Goat Island - Ancaster	Yes
			7	9.5	54.7	57.8	N/A	N/A	Gasport	
			8	9.5	66.8	69.6	N/A	N/A	Gasport	
MW08-T3-08	345.33	10-Jul-2008	OB	50.8	14.3	15.9	13.7	15.9	Clayey Silt to Sand and Gravel	Yes
		8-Jul-2009	1	25.4	16.8	18.4	N/A	N/A	Eramosa - Reformatory Quarry	Yes
			2	9.5	20.4	22.4	N/A	N/A	Eramosa - Reformatory Quarry and Vinemount	
			3	25.4	26.4	30.3	N/A	N/A	Eramosa - Vinemount	Yes
			4	9.5	33.7	36.4	N/A	N/A	Goat Island - Ancaster	
			5	9.5	38.9	41.1	N/A	N/A	Goat Island - Niagara Falls	
			6	9.5	47.9	51.4	N/A	N/A	Goat Island - Niagara Falls	
			7	25.4	56.2	61.0	N/A	N/A	Gasport	Yes
			8	9.5	63.2	65.4	N/A	N/A	Gasport	
			9	9.5	73.6	76.2	N/A	N/A	Irondequoit, Rockway, Merritton and Cabot Head	
MW08-T3-09	346.47	12-Aug-2008	OB	50.8	10.1	11.6	8.5	11.6	Sand and Gravel	Yes
		10-Sep-2009	1	N/A	N/A	N/A	27.9	29.4	Goat Island - Ancaster	
			2	N/A	N/A	N/A	31.2	32.8	Goat Island - Ancaster	
			3	N/A	N/A	N/A	34.9	36.4	Goat Island - Ancaster	
			4	N/A	N/A	N/A	37.9	39.6	Goat Island - Ancaster	
			5	N/A	N/A	N/A	41.3	42.8	Goat Island - Niagara Falls	
			6	N/A	N/A	N/A	44.3	45.9	Goat Island - Niagara Falls	

Table 4.5: Monitoring Well Completion Details

Borehole Name	Ground Surface Elevation (masl)	Monitoring Well Installation Date	Interval ID	Tube Diameter (mm)	Top Screen (mbgs)	Bottom Screen (mbgs)	Top Sand Pack (mbgs)	Bottom Sand Pack (mbgs)	Formation Screened	Transducer Installed
MW08-T3-09			7	N/A	N/A	N/A	47.9	51.2	Goat Island - Niagara Falls and Gasport	
			8	N/A	N/A	N/A	52.7	54.3	Gasport	
			9	N/A	N/A	N/A	55.8	57.3	Gasport	
			10	N/A	N/A	N/A	58.8	61.3	Gasport	
			11	N/A	N/A	N/A	62.9	65.2	Gasport	
			12	N/A	N/A	N/A	66.8	69.5	Gasport	
			13	N/A	N/A	N/A	71.3	75.6	Gasport	
			14	N/A	N/A	N/A	77.7	79.7	Gasport	
			15	N/A	N/A	N/A	81.5	83.5	Rockway and Merritton	
MW08-T3-10	330.31	17-Jul-2008	OB	50.8	33.5	36.6	32.0	36.6	Sand and Gravel	Yes
		17-Sep-2009	1	N/A	N/A	N/A	39.2	40.8	Eramosa - Reformatory Quarry	
			2	N/A	N/A	N/A	42.4	44.7	Eramosa - Reformatory Quarry	
			3	N/A	N/A	N/A	46.2	47.7	Goat Island - Ancaster	
			4	N/A	N/A	N/A	49.4	51.1	Goat Island - Ancaster	
			5	N/A	N/A	N/A	52.6	54.1	Goat Island - Ancaster	
			6	N/A	N/A	N/A	55.6	57.6	Goat Island - Ancaster	
			7	N/A	N/A	N/A	59.3	61.0	Goat Island - Niagara Fallls	
			8	N/A	N/A	N/A	63.1	65.2	Goat Island - Niagara Fallls	
			9	N/A	N/A	N/A	66.8	68.6	Gasport	
			10	N/A	N/A	N/A	69.8	71.9	Gasport	
			11	N/A	N/A	N/A	73.5	75.1	Gasport	
			12	N/A	N/A	N/A	78.9	82.0	Gasport	
			13	N/A	N/A	N/A	84.7	87.6	Gasport	
			14	N/A	N/A	N/A	89.6	91.4	Gasport	
			15	N/A	N/A	N/A	93.3	96.8	Gasport	
			16	N/A	N/A	N/A	98.5	100.0	Gasport	
			17	N/A	N/A	N/A	102.7	104.5	Rockway and Merritton	
MW09-T3-01	315.84	5-Jun-2009	1	25.4	25.9	30.5	25.0	32.0	Guelph - Hanlon	Yes
			2	25.4	82.3	97.5	79.2	100.6	Gasport	Yes

Table 4.6: Water Quality Sampling Results

Well ID	Units	RDL	ODWS-MAC	ODWS-AO/OG	MW08-T3-01-CS	MW08-T3-01-3	MW08-T3-01-6	MW08-T3-02	MW08-T3-02	MW08-T3-02	MW08-T3-03	MW08-T3-03	MW08-T3-03	MW08-T3-04	MW08-T3-04	MW08-T3-04	MW08-T3-05-CS	MW08-T3-05-4	MW08-T3-05-7
Sampling Date					07-Dec-09	07-Dec-09	07-Dec-09										15-Dec-09	15-Dec-09	15-Dec-09
Formation Sampled					Eramosa-Reformatory Quarry	Eramosa-Reformatory Quarry	Goat Island - Ancaster										Eramosa - Stone Road	Gasport	Gasport
Inorganics																			
Total Ammonia-N	mg/L	0.05			0.29	0.79	0.35										0.20	0.23	0.26
Conductivity	umho/cm	1			996	804	951										1670	2180	2340
Dissolved Organic Carbon	mg/L	0.2		5	1.1	1.0	1.3										1.2	1.9	1.2
Orthophosphate (P)	mg/L	0.01			<0.01	<0.01	<0.01										<0.01	<0.01	<0.01
pH	pH				7.9	7.8	8.0										7.9	7.8	7.6
Dissolved Sulphate (SO_4)	mg/L	1		500	37	32	96										780	1200	1300
Alkalinity (Total as $CaCO_3$)	mg/L	1		30-500	271	333	261										166	174	156
Dissolved Chloride (Cl)	mg/L	1		250	140	49	94										9	15	16
Nitrite (N)	mg/L	0.01	1		<0.01	<0.01	<0.01										<0.01	<0.01	<0.01
Nitrate (N)	mg/L	0.1	10		<0.1	0.3	<0.1										<0.1	<0.1	<0.1
Nitrate + Nitrite	mg/L	0.1	10		<0.1	0.3	<0.1										<0.1	<0.1	<0.1
Calculated Parameters																			
Anion Sum	me/L	N/A			10.2	8.71	9.87										19.7	28.1	31.0
Bicarb. Alkalinity (calc. as $CaCO_3$)	mg/L	1			269	331	259										165	173	155
Calculated TDS	mg/L	1		500	543	464	537										1290	1840	2030
Carb. Alkalinity (calc. as $CaCO_3$)	mg/L	1			2	2	2										1	1	<1
Cation Sum	me/L	N/A			10.7	9.42	10.1										21.6	30.2	31.7
Hardness ($CaCO_3$)	mg/L	1		80-100	470	410	450										1000	1400	1500
Ion Balance (% Difference)	%	N/A			2.61	3.92	1.20										4.60	3.64	1.19
Langelier Index (@ 20C)	N/A				0.908	0.923	0.924										0.975	1.01	0.840
Langelier Index (@ 4C)	N/A				0.660	0.675	0.677										0.730	0.764	0.597
Saturation pH (@ 20C)	N/A			6.5-8.5	7.00	6.92	7.04										6.89	6.79	6.78
Saturation pH (@ 4C)	N/A			6.5-8.5	7.25	7.17	7.29										7.14	7.03	7.02
Metals																			
Dissolved Aluminum (Al)	ug/L	5		100	<5	<5	7										<5	<5	<5
Dissolved Antimony (Sb)	ug/L	0.5	6		0.7	1.0	0.6										<0.5	<0.5	<0.5
Dissolved Arsenic (As)	ug/L	1	25		1	<1	<1										5	2	1
Dissolved Barium (Ba)	ug/L	5	1000		20	30	68										8	8	7
Dissolved Beryllium (Be)	ug/L	0.5			<0.5	<0.5	<0.5										<0.5	<0.5	<0.5
Dissolved Bismuth (Bi)	ug/L	1			<1	<1	<1										<1	<1	<1
Dissolved Boron (B)	ug/L	10	5000		35	17	50										85	110	110
Dissolved Cadmium (Cd)	ug/L	0.1	5		<0.1	<0.1	<0.1										<0.1	<0.1	<0.1
Dissolved Calcium (Ca)	ug/L	200			110000	110000	110000										300000	400000	470000
Dissolved Chromium (Cr)	ug/L	5	50		<5	<5	<5										<5	<5	<5
Dissolved Cobalt (Co)	ug/L	0.5			2.0	4.3	3.7										0.7	<3[1]	<3[1]
Dissolved Copper (Cu)	ug/L	1		1000	<1	<1	<1										<1	<1	<1
Dissolved Iron (Fe)	ug/L	100		300	940	7900	350										1500	1800	1100
Dissolved Lead (Pb)	ug/L	0.5	10		<0.5	<0.5	<0.5										<0.5	<0.5	<0.5
Dissolved Magnesium (Mg)	ug/L	50			46000	36000	45000										65000	100000	81000
Dissolved Manganese (Mn)	ug/L	2		50	22	170	25										29	17	31
Dissolved Molybdenum (Mo)	ug/L	1			1	1	<1										3	5	4
Dissolved Nickel (Ni)	ug/L	1			<1	2	<1										<1	<5[1]	<5[1]
Dissolved Phosphorus (P)	ug/L	100			<100	<100	<100										<100	<100	<100
Dissolved Potassium (K)	ug/L	200			2100	1100	2200										2200	3000	3100
Dissolved Selenium (Se)	ug/L	2	10		<2	<2	<2										<2	<2	<2
Dissolved Silicon (Si)	ug/L	50			6100	5600	6000										5800	5600	5100
Dissolved Silver (Ag)	ug/L	0.1			<0.1	<0.1	<0.1										<0.1	<0.1	<0.1
Dissolved Sodium (Na)	ug/L	100		200000	30000	19000	25000										30000	35000	28000
Dissolved Strontium (Sr)	ug/L	1			2800	970	25000										4600	7600	8700
Dissolved Thallium (Tl)	ug/L	0.05			<0.05	<0.05	<0.05										<0.05	<0.05	<0.05
Dissolved Titanium (Ti)	ug/L	5			<5	<5	<5										<5	<5	<5
Dissolved Uranium (U)	ug/L	0.1	20		1.1	0.7	0.4										1.9	0.9	0.5
Dissolved Vanadium (V)	ug/L	1			<1	<1	<1										<1	<1	<1
Dissolved Zinc (Zn)	ug/L	5		5000	<5	<5	<5										<30[1]	<30[1]	<30[1]

NOTES: 1) Detection Limit was raised due to matrix interferences; 2) RDL = Reportable Detection Limit; 3) ODWS - Ontario Drinking Water Quality Standards, Objectives and Guidelines;

4) MAC - Maximum Acceptable Concentration; 5) AO/OG - Aesthetic Objective and/or Operational Guideline.

Table 4.6: Water Quality Sampling Results

Well ID	**Units**	**RDL**	**ODWS-MAC**	**ODWS-AO/OG**	**MW08-T3-06-CS**	**MW08-T3-06-4**	**MW08-T3-06-6**	**MW08-T3-07**	**MW08-T3-07**	**MW08-T3-07**	**MW08-T3-08-1**	**MW08-T3-08-3**	**MW08-T3-08-7**	**MW08-T3-09**	**MW08-T3-09**	**MW08-T3-09**	**MW08-T3-10**	**MW08-T3-10**	**MW08-T3-10**
Sampling Date					08-Dec-09	08-Dec-09	08-Dec-09				14-Dec-09	14-Dec-09	14-Dec-09						
Formation Sampled					Goat Island - Ancaster and Niagara Falls	Gasport	Gasport				Eramosa - Reformatory Quarry	Eramosa - Vinemount	Gasport						
Inorganics																			
Total Ammonia-N	mg/L	0.05			0.05	0.09	0.28				4.9	3.1	0.39						
Conductivity	umho/cm	1			1340	747	1890				614	555	658						
Dissolved Organic Carbon	mg/L	0.2		5	4.5	1.1	0.7				9.0	8.3	1.2						
Orthophosphate (P)	mg/L	0.01			<0.01	<0.01	<0.01				<0.01	<0.01	<0.01						
pH	pH				8.1	7.9	7.8				7.8	7.8	7.8						
Dissolved Sulphate (SO_4)	mg/L	1		500	350	140	900				<1	<1	58						
Alkalinity (Total as $CaCO_3$)	mg/L	1		30-500	295	259	177				296	268	266						
Dissolved Chloride (Cl)	mg/L	1		250	67	5	22				24	20	22						
Nitrite (N)	mg/L	0.01	1		0.01	<0.01	<0.01				<0.01	<0.01	<0.01						
Nitrate (N)	mg/L	0.1	10		1.4	<0.1	<0.1				<0.1	<0.1	<0.1						
Nitrate + Nitrite	mg/L	0.1	10		1.4	<0.1	<0.1				<0.1	<0.1	<0.1						
Calculated Parameters																			
Anion Sum	me/L	N/A			15.2	8.34	22.9				6.58	5.94	7.16						
Bicarb. Alkalinity (calc. as $CaCO_3$)	mg/L	1			291	257	176				294	267	264						
Calculated TDS	mg/L	1		500	916	466	1510				350	307	374						
Carb. Alkalinity (calc. as $CaCO_3$)	mg/L	1			3	2	1				2	2	2						
Cation Sum	me/L	N/A			15.6	8.92	25.1				7.09	6.01	7.02						
Hardness ($CaCO_3$)	mg/L	1		80-100	570	430	1200				300	260	320						
Ion Balance (% Difference)	%	N/A			1.15	3.36	4.63				3.78	0.550	0.990						
Langelier Index (@ 20C)	N/A				1.22	0.904	1.02				0.661	0.613	0.692						
Langelier Index (@ 4C)	N/A				0.973	0.656	0.779				0.412	0.364	0.443						
Saturation pH (@ 20C)	N/A			6.5-8.5	6.85	7.02	6.79				7.11	7.22	7.11						
Saturation pH (@ 4C)	N/A			6.5-8.5	7.10	7.27	7.03				7.36	7.47	7.36						
Metals																			
Dissolved Aluminum (Al)	ug/L	5		100	<5	<5	<5				<5	<5	<5						
Dissolved Antimony (Sb)	ug/L	0.5	6		0.6	<0.5	<0.5				<0.5	<0.5	<0.5						
Dissolved Arsenic (As)	ug/L	1	25		<1	<1	1				70	40	3						
Dissolved Barium (Ba)	ug/L	5	1000		29	36	21				100	83	110						
Dissolved Beryllium (Be)	ug/L	0.5			<0.5	<0.5	<0.5				<0.5	<0.5	<0.5						
Dissolved Bismuth (Bi)	ug/L	1			<1	<1	<1				<1	<1	<1						
Dissolved Boron (B)	ug/L	10	5000		130	33	110				16	26	35						
Dissolved Cadmium (Cd)	ug/L	0.1	5		<0.1	<0.1	<0.1				<0.1	<0.1	<0.1						
Dissolved Calcium (Ca)	ug/L	200			170000	110000	370000				70000	59000	80000						
Dissolved Chromium (Cr)	ug/L	5	50		<5	<5	<5				<5	<5	<5						
Dissolved Cobalt (Co)	ug/L	0.5			4.3	2.2	<3[1]				0.5	<0.5	<0.5						
Dissolved Copper (Cu)	ug/L	1		1000	3	<1	<1				4	1	<1						
Dissolved Iron (Fe)	ug/L	100		300	<100	310	2000				7700	3900	790						
Dissolved Lead (Pb)	ug/L	0.5	10		<0.5	<0.5	<0.5				0.6	0.6	<0.5						
Dissolved Magnesium (Mg)	ug/L	50			39000	39000	61000				30000	28000	30000						
Dissolved Manganese (Mn)	ug/L	2		50	200	11	25				42	21	6						
Dissolved Molybdenum (Mo)	ug/L	1			8	3	5				10	9	<1						
Dissolved Nickel (Ni)	ug/L	1			4	<1	<5[1]				3	2	<1						
Dissolved Phosphorus (P)	ug/L	100			<100	<100	<100				<100	<100	<100						
Dissolved Potassium (K)	ug/L	200			8200	1400	3500				2500	2100	1500						
Dissolved Selenium (Se)	ug/L	2	10		<2	<2	<2				<2	<2	<2						
Dissolved Silicon (Si)	ug/L	50			5100	2800	5600				11000	9800	4800						
Dissolved Silver (Ag)	ug/L	0.1			<0.1	<0.1	<0.1				<0.1	<0.1	<0.1						
Dissolved Sodium (Na)	ug/L	100		200000	91000	7300	29000				10000	8400	11000						
Dissolved Strontium (Sr)	ug/L	1			2200	1000	7400				230	160	9000						
Dissolved Thallium (Tl)	ug/L	0.05			<0.05	<0.05	<0.05				<0.05	<0.05	<0.05						
Dissolved Titanium (Ti)	ug/L	5			<5	<5	<5				<5	<5	<5						
Dissolved Uranium (U)	ug/L	0.1	20		0.9	0.2	0.2				<0.1	0.1	<0.1						
Dissolved Vanadium (V)	ug/L	1			<1	<1	<1				<1	<1	<1						
Dissolved Zinc (Zn)	ug/L	5		5000	8	<5	<30[1]				40	26	<5						

NOTES: 1) Detection Limit was raised due to matrix interferences; 2) RDL = Report

NOTES: 1) Detection Limit was raised due to matrix interferences; 2) RDL = Reportable Detection Limit; 3) ODWS - Ontario Drinking Water Quality Standards, Objectives and Guidelines;

4) MAC - Maximum Acceptable Concentration; 5) AO/OG - Aesthetic Objective and/

4) MAC - Maximum Acceptable Concentration; 5) AO/OG - Aesthetic Objective and/or Operational Guideline.

Table 4.7: Borehole Geological Summary

Formation	MW08-T3-01			MW08-T3-02			MW08-T3-03			MW08-T3-04			MW08-T3-05			MW08-T3-06		
	Top (mbgs)	Bottom (mbgs)	Thickness (m)	Top (mbgs)	Bottom (mbgs)	Thickness (m)	Top (mbgs)	Bottom (mbgs)	Thickness (m)	Top (mbgs)	Bottom (mbgs)	Thickness (m)	Top (mbgs)	Bottom (mbgs)	Thickness (m)	Top (mbgs)	Bottom (mbgs)	Thickness (m)
Overburden	0.0	9.8	9.8	0.0	8.5	8.5	0.0	44.1	44.1	0.0	19.2	19.2	0.0	19.2	19.2	0.0	1.1	1.1
Guelph Formation	not present			8.5	14.6	6.1	not present			19.2	50.0	30.8	not present			not present		
Eramosa Formation (Stone Road Member)	not present			14.6	20.6	6.0	30.5	44.1	13.6	not present			19.2	22.8	3.6	not present		
Eramosa Formation (Reformatory Quarry Member)	9.8	57.9	48.2	20.6	25.3	4.7	44.1	47.4	3.3	not present			22.8	31.4	8.6	not present		
Eramosa Formation (Vinemount Member)	57.9	58.5	0.6	25.3	31.4	6.1	47.4	54.3	6.9	not present			31.4	33.7	2.3	not present		
Goat Island Formation (Ancaster Member)	58.5	75.1	16.6	not present			not present			not present			not present			1.1	1.5	0.4
Goat Island Formation (Niagara Falls Member)	not present			not present			54.3	66.8	12.5	50.0	90.0	40.0	33.7	53.3	19.6	1.5	6.0	4.5
Gasport Formation	75.1	91.1	16.0	31.4	82.8	51.4	66.8	93.4	26.6	90.0	139.0	49.0	53.3	99.0	45.7	6.0	50.5	44.5
Irondequoit Formation	91.1	92.3	1.2	82.8	84.5	1.7	93.4	95.1	1.7	139.0	139.9	0.9	99.0	100.5	1.5	50.5	51.7	1.2
Rockway Formation	92.3	93.2	0.9	84.5	85.4	0.9	95.1	95.7	0.6	139.9	140.7	0.8	100.5	101.2	0.7	51.7	54.0	2.3
Merritton Formation	93.2	94.5	1.3	85.4	85.9	0.5	not present			140.7	141.4	0.7	101.2	101.7	0.5	not present		
Cabot Head Formation	94.5	95.7	1.2	85.9	89.9	4.0	95.7	97.2	1.5	141.4	143.9	2.5	101.7	104.9	3.2	54.0	57.7	3.7

Formation	MW08-T3-07			MW08-T3-08			MW08-T3-09			MW08-T3-10			MW09-T3-01		
	Top (mbgs)	Bottom (mbgs)	Thickness (m)	Top (mbgs)	Bottom (mbgs)	Thickness (m)	Top (mbgs)	Bottom (mbgs)	Thickness (m)	Top (mbgs)	Bottom (mbgs)	Thickness (m)	Top (mbgs)	Bottom (mbgs)	Thickness (m)
Overburden	0.0	14.9	14.9	0.0	16.0	16.0	0.0	25.6	25.6	0.0	38.5	38.5	0.0	23.8	23.8
Guelph Formation	not present			not present			not present			not present			23.8	38.6	14.8
Eramosa Formation (Stone Road Member)	not present			not present			not present			not present			not present		
Eramosa Formation (Reformatory Quarry Member)	14.9	20.0	5.1	16.0	21.7	5.7	not present			38.5	45.8	7.3	38.6	50.2	11.6
Eramosa Formation (Vinemount Member)	20.0	34.6	14.6	21.7	29.3	7.6	not present			not present			50.2	58.4	8.2
Goat Island Formation (Ancaster Member)	34.6	51.8	17.2	29.3	38.3	9.0	25.6	41.2	15.6	45.8	57.4	11.6	not present		
Goat Island Formation (Niagara Falls Member)	not present			38.3	55.8	17.5	41.2	48.4	7.2	57.4	66.7	9.3	58.4	61.6	3.2
Gasport Formation	51.8	69.8	18.0	55.8	72.8	17.0	48.4	79.1	30.7	66.7	100.9	34.2	61.6	105.2	43.6
Irondequoit Formation	69.8	72.0	2.2	72.8	74.0	1.2	79.1	81.6	2.5	100.9	102.9	2.1	105.2	107.0	1.8
Rockway Formation	72.0	73.2	1.2	74.0	74.5	0.5	81.6	83.2	1.6	102.9	103.5	0.6	107.0	108.0	1.0
Merritton Formation	73.2	75.0	1.8	74.5	75.2	0.7	83.2	84.1	0.9	103.5	105.2	1.7	108.0	109.2	1.2
Cabot Head Formation	75.0	76.5	1.5	75.2	76.2	1.0	84.1	84.7	0.6	105.2	105.4	0.2	109.2	113.1	3.9

Table 4.8: Summary of Stream Baseflow Measurement Methodology

Watercourse	Location ID	Road Crossing	Flow Meter/Method[1, 2]
Blue Springs Creek	BSC_10	5th Line	EM (Jul. 7, Oct. 22) [Golder], EM (Aug. 26) [McQuest]
	BSC_20 (Trib.)	28th Sideroad, between 1st and 2nd Lines	
	BSC_30a/ BSC_30b	1st Line	
Cox Creek	CC_10	6th Line E	EM (Aug. 26, Oct. 22) [Golder], Impeller (July 7) [Golder]
	CCT_20 (South Trib.)	6th Line E	
	CC_30	Cox Creek Road	
Ellis Creek	EC_10	Wellington Road 32	Bucket EM [Golder]
	EC_20	Maple Grove Road	
Eramosa River	ER_10	3rd Line	EM (Jul. 7, Oct. 22) [Golder], EM (Aug 26) [McQuest]
	ER_20	Wellington Road 125	
	ER_30	Evert Street	
	ER_40	Wellington Road 29 (1st Line)	
Guelph Lake Tributary	GLT_10	3rd Line	EM [Golder]
	GLT_20	Jones Baseline	
Hanlon Creek	HC_10	Highway 6 Hanlon	EM [Golder]
	HCT_20 (South Trib.)	Highway 6 Hanlon	
Hopewell Creek	HWC_10	3rd Township Road (Wellington Road 32)	EM [Golder]
	HWC_20	Greenhouse Road and Hopewell Creek Road	
Irish Creek	IC_10	Wellington Road 32	EM [Golder]
	IC_20	Townline Road	
Lutteral Creek	LC_10	Sideroad 20, between 5th and 6th Line	EM (Aug. 26, Oct. 22) [Golder], Impeller (July 7) [Golder]
	LCT_20 (Trib.)	6th Line	
	LC_30	3rd Line	
Marden Creek	MDC_10	Wellington Road 30	EM [Golder]
Mill Creek	MC_10	Victoria Road and Wellington Road 34	EM [Golder]
	MC_20	Wellington Road 35	
Swan Creek	SC_10	Sideroad 4 at Highway 23 (South River Road)	EM (Aug. 26, Oct. 22) [Golder], Impeller (July 7) [Golder]
Speed River	SR_10	Wellington Road 26	EM (Aug. 26, Oct. 22) [Golder], Impeller (July 7) [Golder]
	SR_20	6th Line	
	SR_30	3rd Line, between Wellington Road 22 and 29	
	SR_40	Jones Baseline and Wellington Road 22	
Torrance Creek	TC_10	Stone Road	EM (Jul. 7, Oct. 22) [Golder], EM (Aug 26) [McQuest]

Notes:

1) Methods correspond to the following: EM (Electro-magnetic flow meter – Valeport Model 801); Impeller (Impeller flow meter – Valeport Model BFM002); and Bucket (Bucket and stopwatch measurement).

2) [Golder] refers to equipment owned/maintained by Golder Associates Ltd.; [McQuest] refers to rental equipment from McQuest Marine Sciences Ltd., Burlington, ON.

Table 4.9: 2008 Stream Baseflow Monitoring Results

Watercourse	Location ID	Flow (m^3/s)		
		07-Jul-08	26-Aug-08	22-Oct-08
Blue Springs Creek	BSC_20	0.025	0.036	0.059
	BSC_10	0.281	0.238	0.132
	BSC_30a [1]	0.210	0.322	0.217
	BSC_30b [1]	NA	0.508	0.421
Cox Creek South Tributary	CCT_20	0.006	0.028	0.044
Cox Creek	CC_10	0.014	0.031	0.084
	CC_30	0.065	0.122	0.261
Ellis Creek	EC_10	0.005	0.002	0.015
	EC_20	0.117	0.215	0.141
Eramosa River	ER_10	0.319	0.353	0.399
	ER_20	0.376	0.392	0.372
	ER_30	0.413	0.551	0.765
	ER_40	1.005	1.179	1.151
Guelph Lake Tributary	GLT_10	0.037	0.033	0.051
	GLT_20	0.025	0.017	0.935 [2]
Hanlon Creek	HC_10	0.047	0.068	0.033
Hanlon Creek South Tributary	HCT_20	Dry	Dry	Dry
Hopewell Creek	HWC_10	0.023	0.019	0.055
	HWC_20	0.045	0.057	0.083
Irish Creek	IC_10	0.008	0.031	0.023
	IC_20	0.062	0.106	0.107
Lutteral Creek Trib	LCT_20	0.009	0.012	0.038
Lutteral Creek	LC_10	0.097	0.189	0.301
	LC_30	0.194	0.279	0.525
Marden Creek	MDC_10	0.022	0.067	0.052
Mill Creek	MC_10	0.018	0.022	0.016
	MC_20	0.384	0.383	0.408
Swan Creek	SC_10	0.077	0.122	0.233
Speed River	SR_10	0.061	0.151	0.296
	SR_20	0.083	0.116	0.325
	SR_30	0.141	0.279	0.676
	SR_40	0.127	0.202	0.612
Torrance Creek	TC_10	0.030	0.034	0.016

NOTES:

1) Blue Springs Creek forms two channels downstream of BSC_30b (i.e. a respective north and south branch), where BSC_30a is located at the south branch and represents a partial flow (relative to BSC_30b); BSC_30b not measured on July 7, 2008.

2) Flow measurement of Speed River at Jones Baseline downstream of Lutteral Creek.

Table 5.0: Summary of Hydraulic Conductivity Estimates

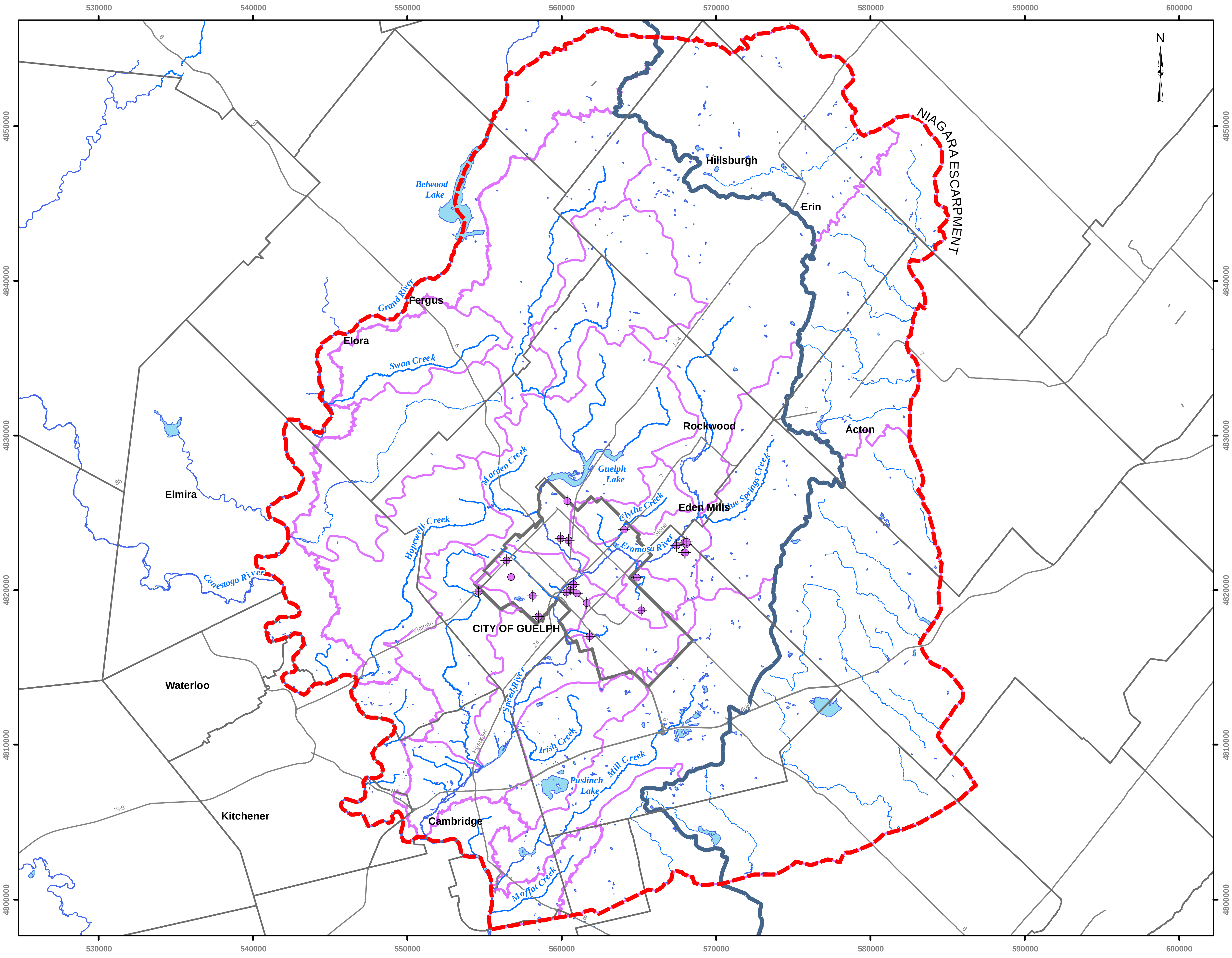
Unit	Previous Studies (see Table 2.4)	
	Horizontal Hydraulic Conductivity (m/s)	Ratio of Vertical to Horizontal Hydraulic Conductivity[4]
Overburden (Sand and Gravel)	6E-06 to 7E-04	0.1 to **1**
Overburden Till	2E-09 to 1E-04	0.1 to **0.5**
Contact Aquifer	1E-05 to 1E-04	0.5 to **1**
Guelph	7E-09 to 8E-03	0.1 to **1**
Reformatory Quarry	7E-09 to 1E-06 [1]	**0.02** to 0.1
Vinemount		
Goat Island	5E-06 to 1E-05 [2]	0.25 to **0.5**
Upper/Lower Gasport		
Middle Gasport[3]	5E-06 to 4E-03	**1**

High Quality Bedrock Borehole Test Results[5]						
Horizontal Hydraulic Conductivity (m/s)						
Unit	No. of Tests	Range		10th percentile	50th percentile	90th percentile
		Min	Max			
Guelph	13	4.E-07	6.E-04	7.E-07	4.E-06	2.E-05
Reformatory Quarry	15	2.E-07	2.E-04	6.E-07	3.E-06	6.E-05
Vinemount	7	5.E-07	3.E-05	6.E-07	5.E-06	2.E-05
Goat Island	13	9.E-08	4.E-04	3.E-07	5.E-06	2.E-05
Gasport (outside high permeability zones)[6]	45	2.E-08	5.E-04	6.E-07	5.E-06	2.E-04
Gasport - (within high permeability zones)[6]	26	2.E-06	1.E-02	2.E-05	2.E-04	8.E-04

Notes:

1) Previously Eramosa Unit
2) Previously Upper/Lower Amabel Unit
3) Previously Production Amabel Unit
4) Values shown in bold are those used in the Guelph-Puslinch Study Model
5) From hydraulic tests within individual formations at boreholes with high level of geologic control/reliability
6) Gasport hydraulic conductivity estimates are summarized separately for boreholes within the interpreted high permeability Gasport zones (model Kx/y > 1E-4 m/s)
These higher permeability zones are shown on the hydraulic conductivity distribution mapping in the Tier 3 Numerical Modelling Report

FIGURES



Tier Three Local Area Risk Assessment

LEGEND

- ⊕ City of Guelph Municipal Production Well
- — Major Roads / Highways
- — Rivers / Streams
- ▭ Open Water
- ▭ Guelph Tier III Model Boundary
- ▭ Subwatershed Boundary
- ▭ GRCA Watershed Boundary
- ▭ City of Guelph Boundary
- ▭ Municipal Boundaries

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Kilometers

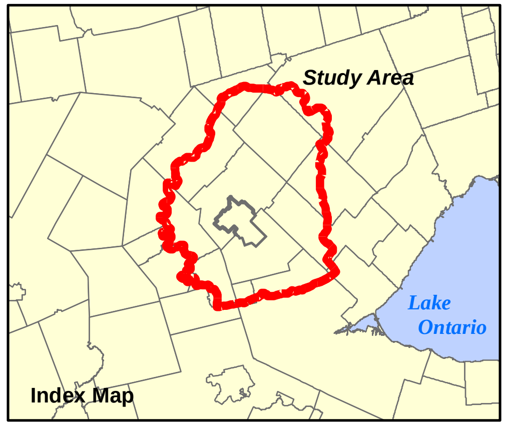

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FIGURE: 1

STUDY AREA

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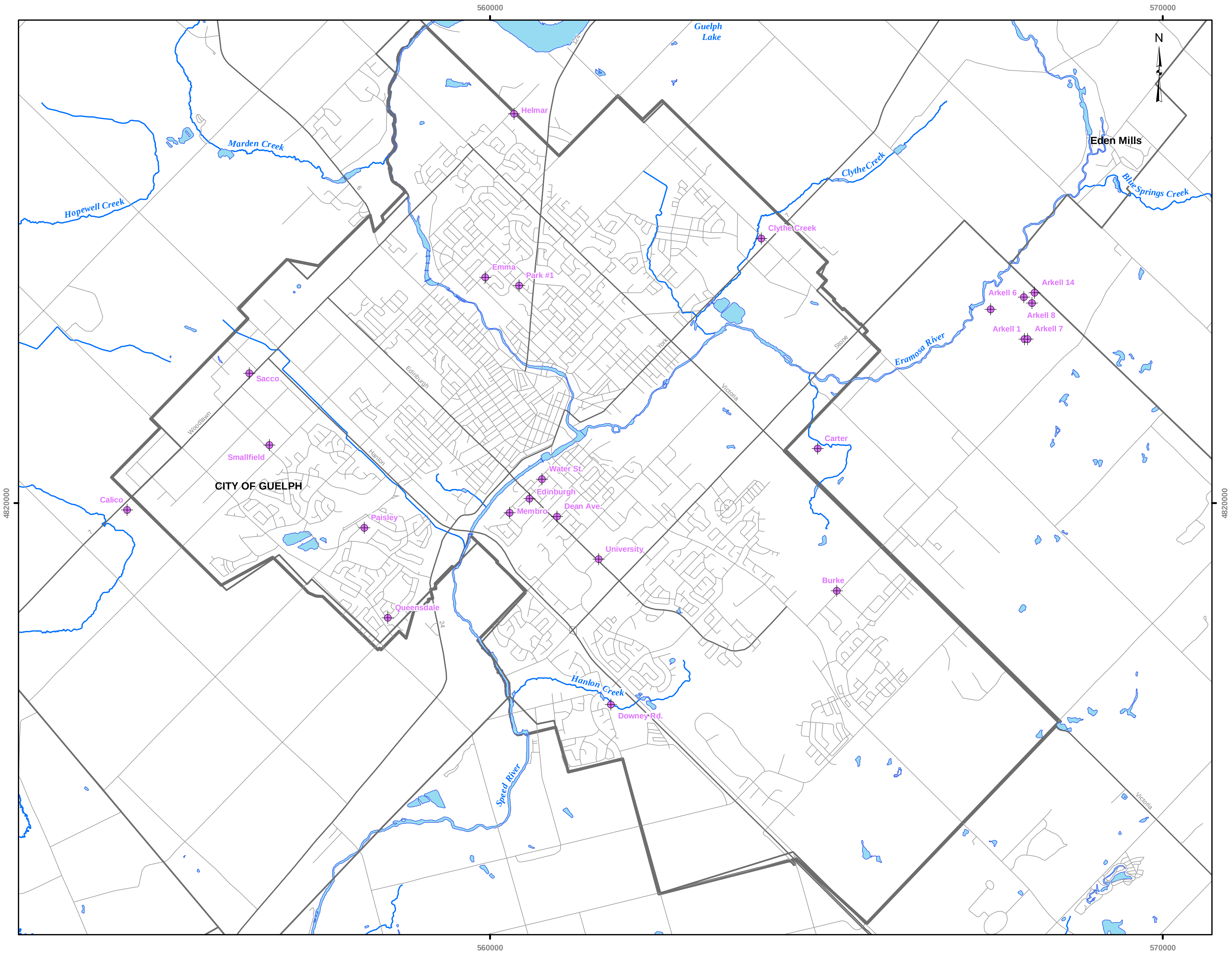
Project: 08-1112-0021_Guelph_Tier3

Tier Three Local Area Risk Assessment



LEGEND

- ⊕ City of Guelph Municipal Production Well
- — Collector Roads / Local Roads
- — Major Roads / Highways
- — Rivers / Streams
- ▭ Open Water
- ▭ GRCA Watershed Boundary
- ▭ City of Guelph Boundary
- ▭ Municipal Boundaries

Scale 1:55,000

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Kilometers

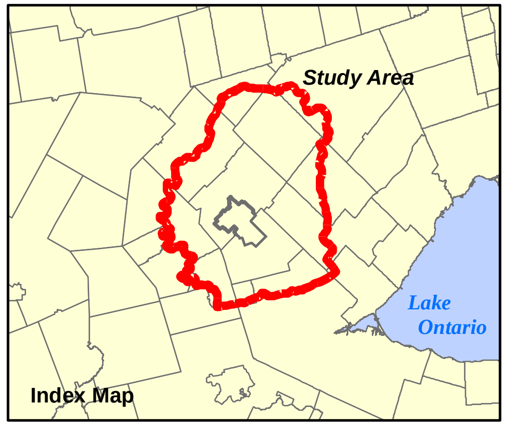

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FIGURE: 2

CITY OF GUELPH MUNICIPAL PRODUCTION WELL LOCATIONS

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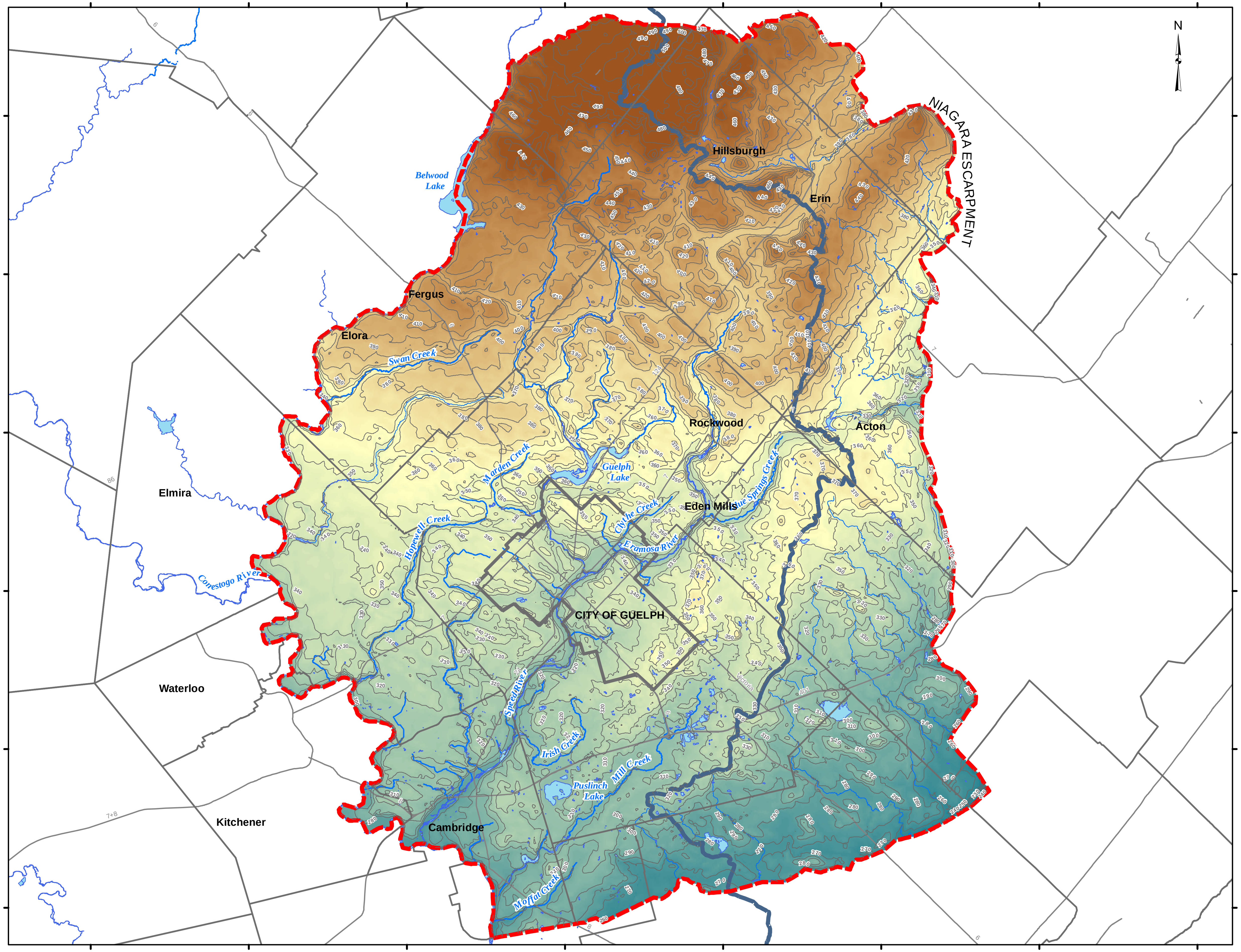
Project: 08-1112-0021_Guelph_Tier3



Tier Three Local Area Risk Assessment

LEGEND

Major Roads / Highways
Topographic Elevation Contour (masl)
Rivers / Streams
Open Water
Guelph Tier III Model Boundary
GRCA Watershed Boundary
City of Guelph Boundary
Municipal Boundaries
Elevation (masl)
High : 510
Low : 205

Scale 1:240,000
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Kilometers

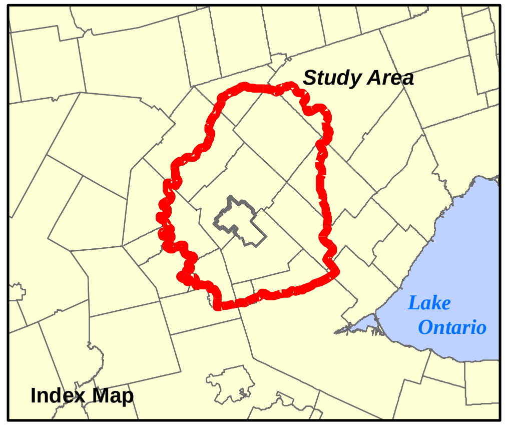

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FIGURE: 3

TOPOGRAPHY

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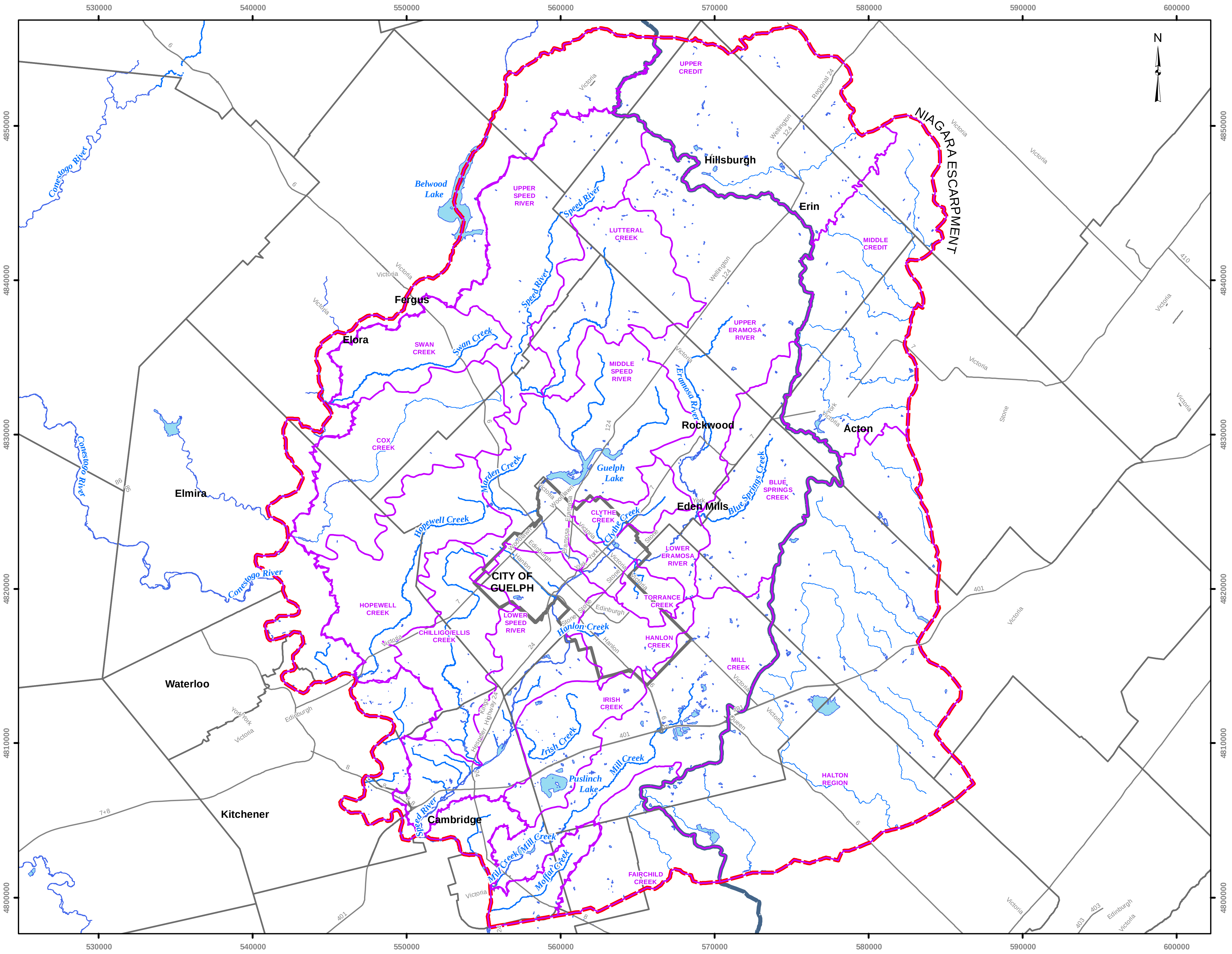
Project: 08-1112-0021_Guelph_Tier3

Tier Three Local Area Risk Assessment

Guelph

Making a Difference



LEGEND

- Major Roads / Highways
- Rivers / Streams
- 🟦 Open Water
- ▭ Guelph Tier III Model Boundary
- ▭ GRCA Watershed Boundary
- ▭ City of Guelph Boundary
- ▭ Municipal Boundaries
- ▭ Subwatershed Boundary

Scale 1:240,000

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Kilometers

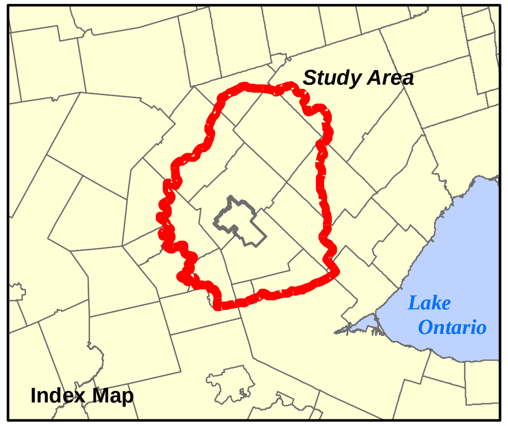

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FIGURE: 4

SUBWATERSHEDS

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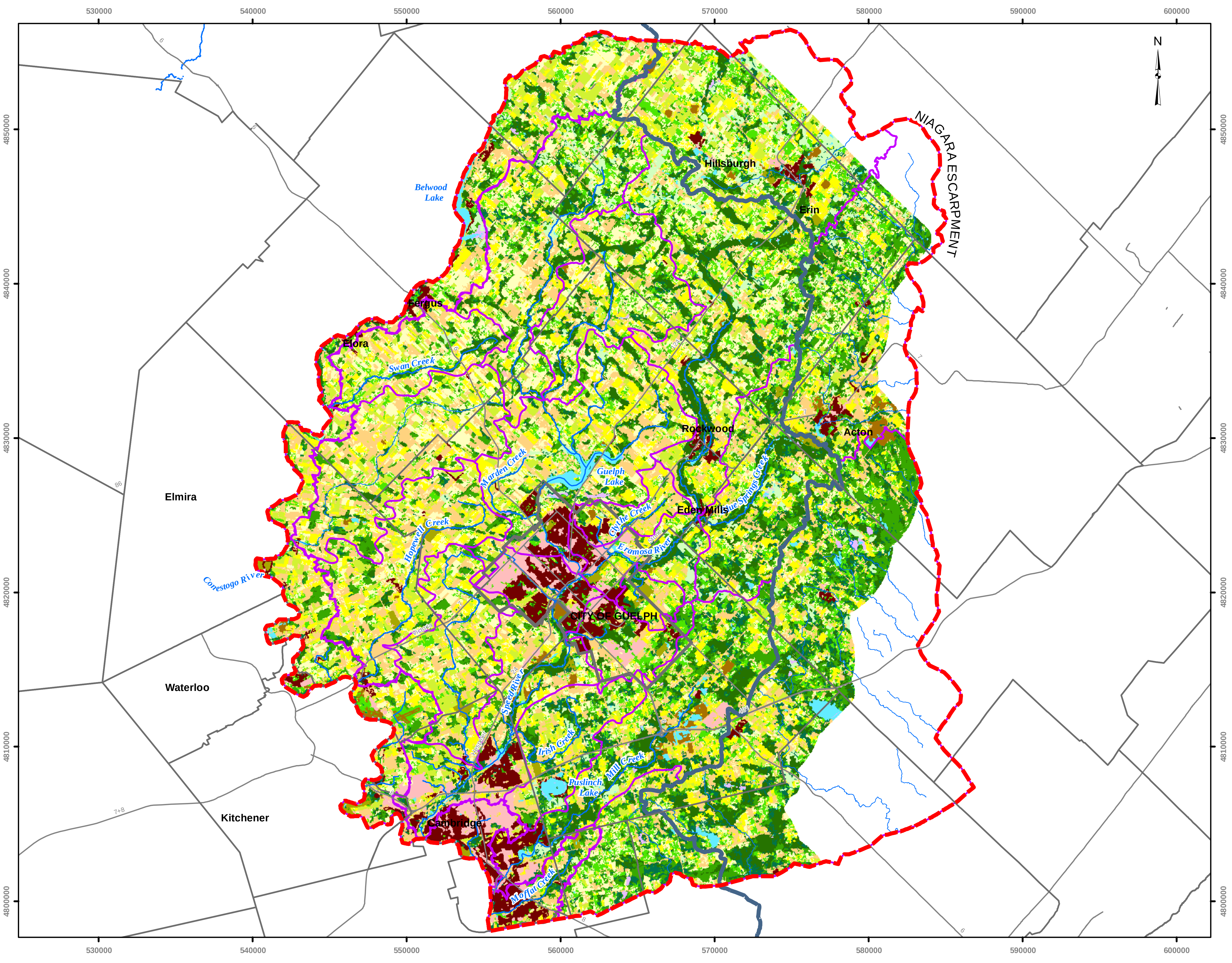
Project: 08-1112-0021_Guelph_Tier3



Tier Three Local Area Risk Assessment

LEGEND

- Major Roads / Highways
- Rivers / Streams
- Guelph Tier III Model Boundary
- Subwatershed Boundary
- GRCA Watershed Boundary
- City of Guelph Boundary
- Municipal Boundaries
- Builtup (residential)
- Builtup (commercial/industrial)
- Row crops
- Small grains
- Forage
- Pasture/sparse forest
- Dense forest (deciduous)
- Dense forest (conifer)
- Dense forest (mixed)
- Plantation (mature)
- Open water
- Wetlands
- Extraction/bedrock/roads/beaches
- Golf courses
- Bare agricultural fields

Scale 1:240,000

2.5 0 2.5 5

Kilometers

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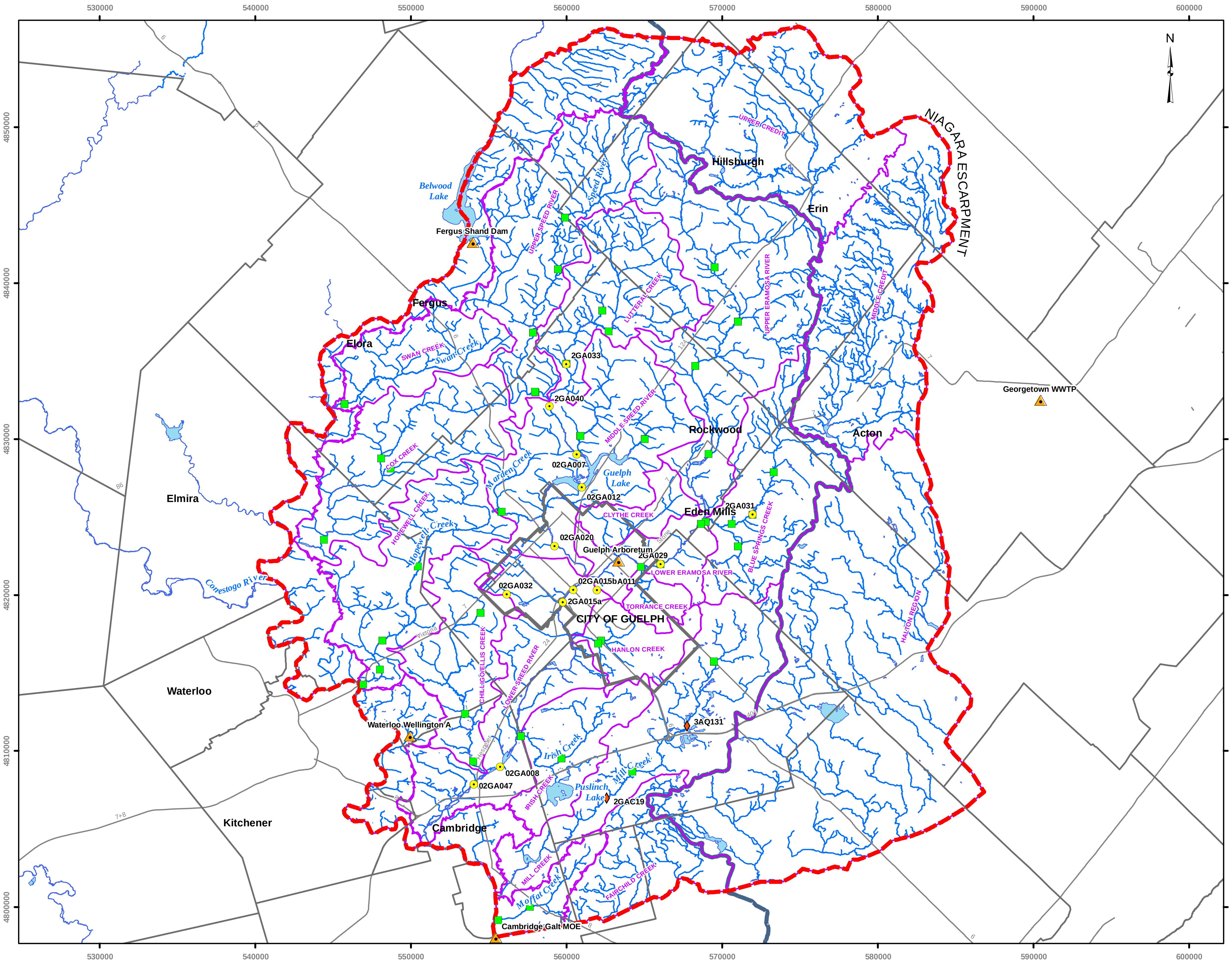
FIGURE: 5

LAND COVER

Tier Three Local Area Risk Assessment



LEGEND

- ▲ Climate Stations
- 🟩 Spotflow Measurements

Streamflow Gauges

- ◆ GRCA
- ● WSC
- — Major Roads / Highways
- — Rivers / Streams
- ▭ Open Water
- ▭ Guelph Tier III Model Boundary
- ▭ GRCA Watershed Boundary
- ▭ Subwatershed Boundary
- ▭ City of Guelph Boundary
- ▭ Municipal Boundaries

NOTE:
Figure to be read in conjuction with accompanying report.

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Kilometers

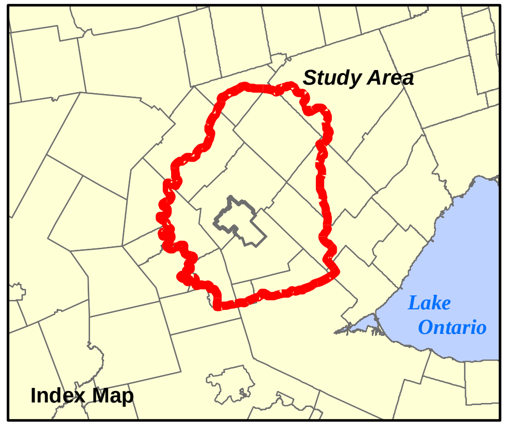

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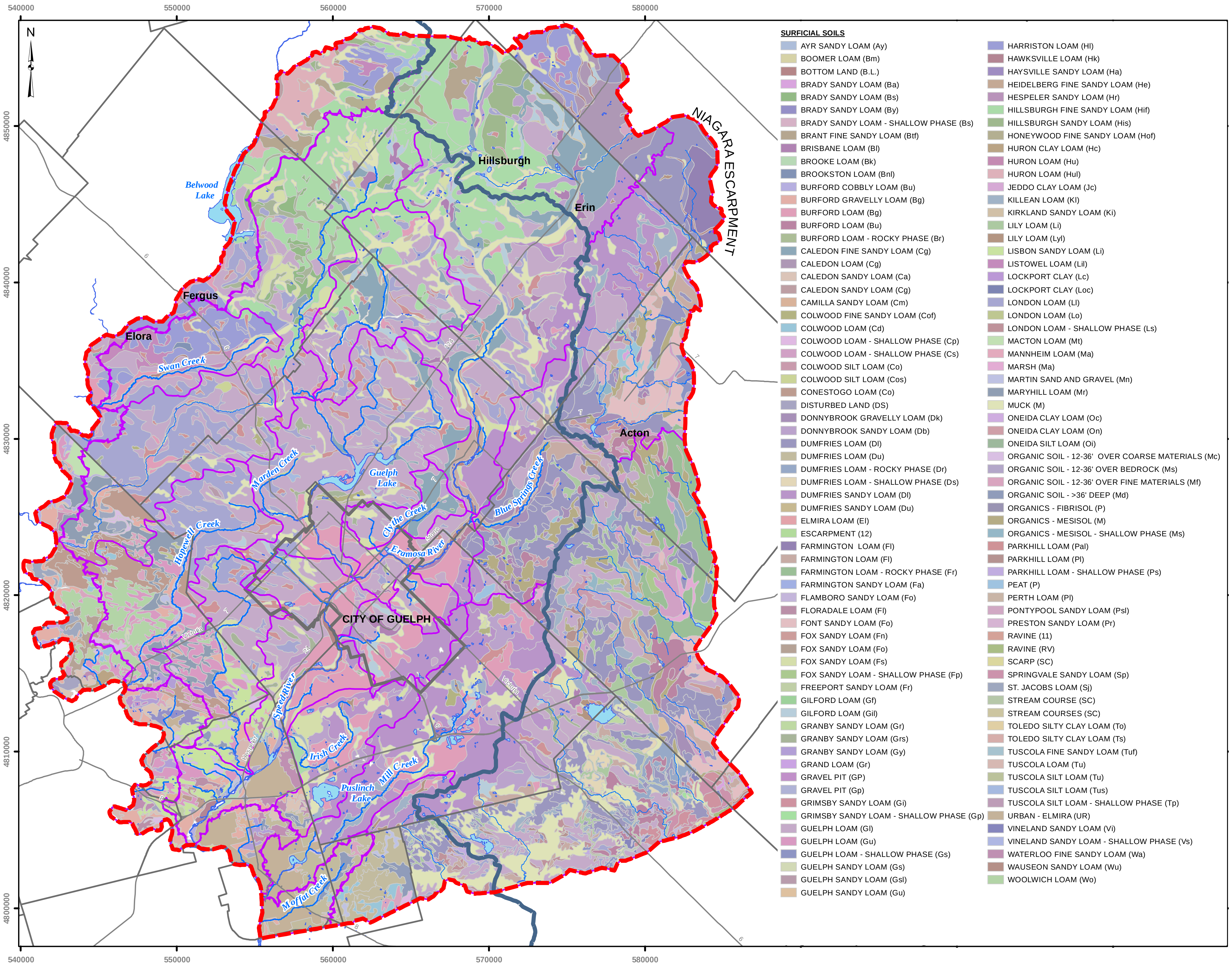
FIGURE: 6
CLIMATE AND SURFACE WATER MONITORING LOCATIONS

Tier Three Local Area Risk Assessment



Legend

- Major Roads / Highways
- Rivers / Streams
- Open Water
- GRCA Watershed Boundary
- Guelph Tier III Model Boundary
- Subwatershed Boundary
- City of Guelph Boundary
- Municipal Boundaries

Scale 1:240,000

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Kilometers

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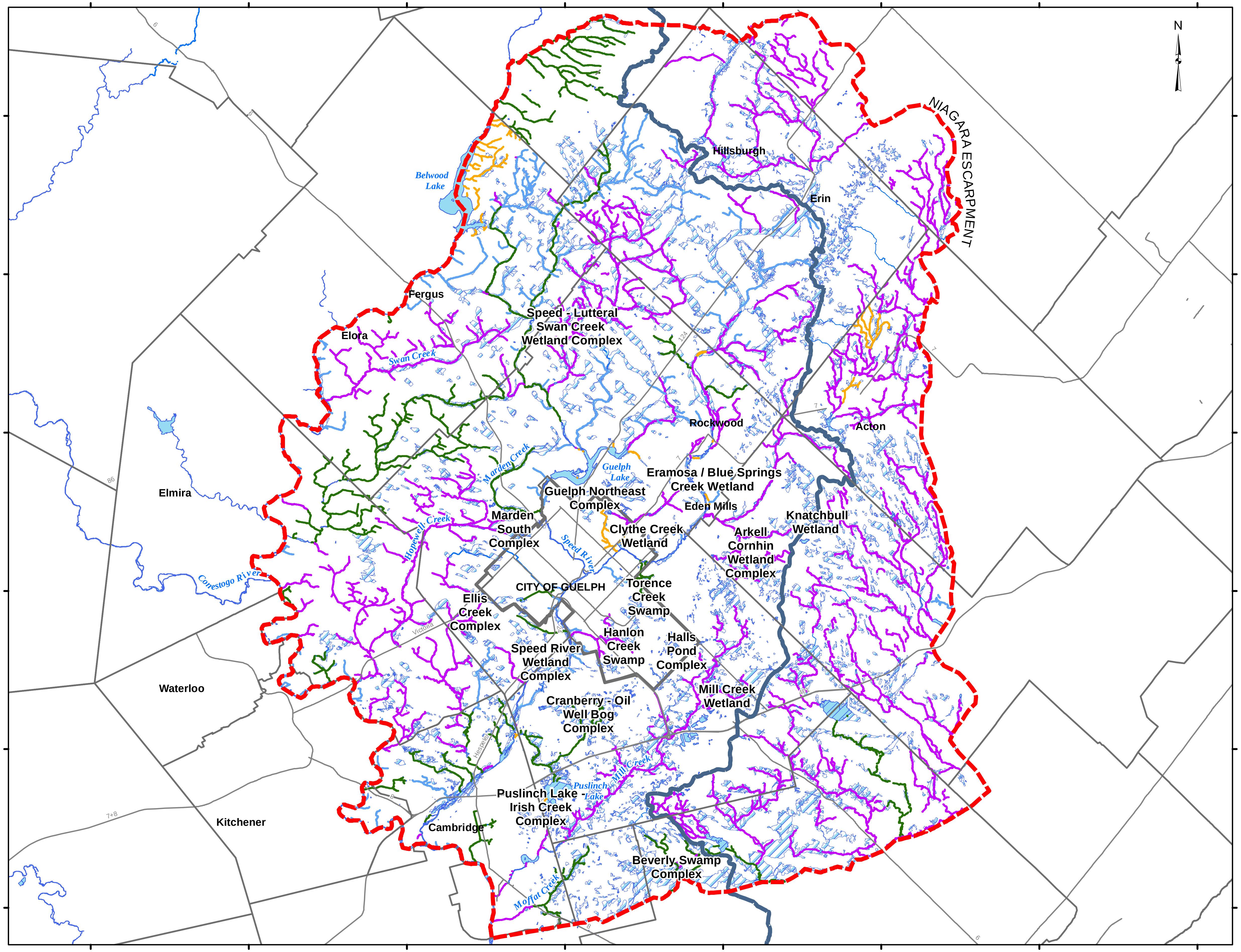
FIGURE: 7

SURFICIAL SOILS

Tier Three Local Area Risk Assessment



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Map Version: 1; Map Date: 15-Mar-10; Created By: CC/KD

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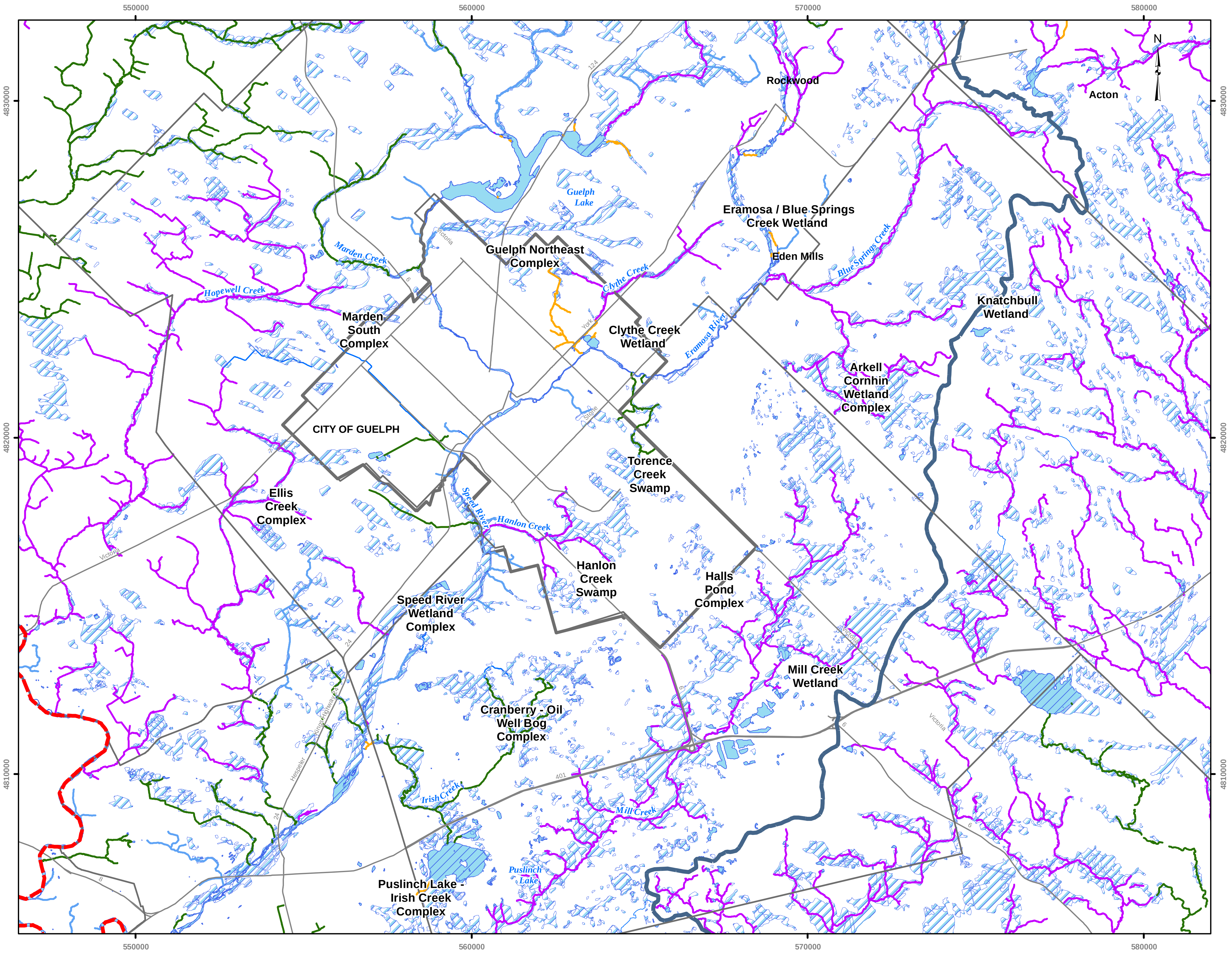
FIGURE: 8a
ENVIRONMENTALLY SENSITIVE FEATURES - STUDY AREA

G:\Projects\2008\08-1112-0021_Guelph_TierIII\GIS\MXDs\Final\May_2011_Report\Environmentally_Sensitive_Features_Study_Area.mxd

Project: 08-1112-0021_Guelph_Tier3



Tier Three Local Area Risk Assessment

Guelph
Making a Difference

LEGEND

—	Major Roads / Highways
—	Rivers / Streams

Watercourse Temperature Classification

—	Cool Water
—	Cold Water
—	Warm Water
—	Unknown
■	Open Water
▨	Wetland
☐	Guelph Tier III Model Boundary
☐	GRCA Watershed Boundary
☐	City of Guelph Boundary
☐	Municipal Boundaries

Scale 1:110,000

2.5 0 2.5 5

Kilometers

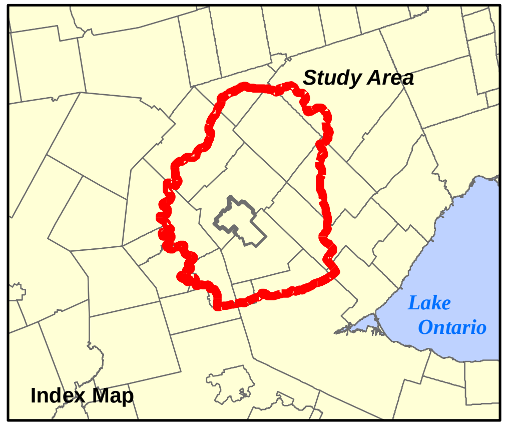


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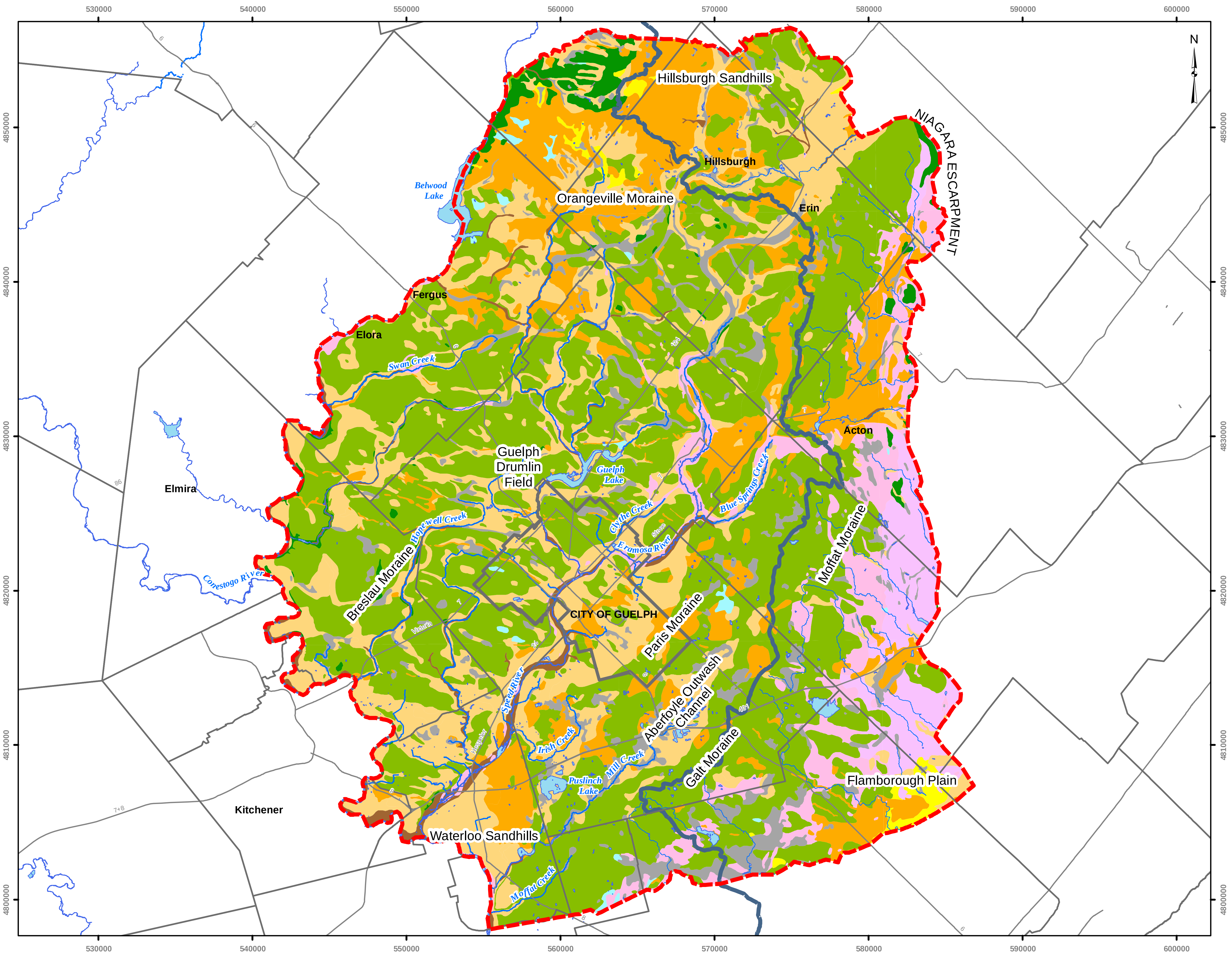
FIGURE: 8b

ENVIRONMENTALY SENSITIVE FEATURES - GUELPH AREA



Tier Three Local Area Risk Assessment

Guelph
Making a Difference

LEGEND

— Major Roads / Highways
— Rivers / Streams
■ Open Water
▭ Guelph Tier 3 Model Boundary
▭ GRCA Watershed Boundary
▭ City of Guelph Boundary
▭ Municipal Boundaries

Surficial Geology

■ 3: Paleozoic bedrock
■ 4: Paleozoic bedrock-drift complex
■ 4a: Mainly till veneer
■ 5a: Shield-derived silty to sandy till
■ 5b: Stone-poor, carbonate-derived silty to sandy till
■ 5d: Glaciolacustrine-derived silty to clayey till
■ 6: Ice-contact stratified deposits
■ 7: Glaciofluvial deposits
■ 7a: Sandy deposits
■ 7b: Gravelly deposits
■ 8: Fine-textured glaciolacustrine deposits
■ 8a: Massive-well laminated
■ 8b: Interbedded flow till, rainout deposits and silt and clay
■ 9: Coarse-textured glaciolacustrine deposits
■ 9c: Foreshore-basinal deposits
■ 19: Modern alluvial deposits
■ 20: Organic deposits

Scale 1:240,000
2.5 0 2.5 5
Kilometers

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FIGURE: 9

SURFICIAL GEOLOGY

G:\Projects\2008\08-1112-0021_Guelph_TierIII\GIS\MXDs\Final\May_2011_Report\Surficial_Geology.mxd

Project: 08-1112-0021_Guelph_Tier3

Preliminary Revisions to Silurian Stratigraphy

Lithology	Formation	Member
	Guelph	*Hanlon* *Wellington*
	Eramosa	*Stone Road* *Reformatory Quarry* *Vinemount*
	Goat Island	*Ancaster* Niagara Falls (=unsubdivided Amabel Fm)
	Gasport	*Gothic Hill* (Lions Head Mbr = Rochester Fm) (=previous unsubdivided Amabel Fm)
	Irondequoit	(=unsubdivided Amabel Fm)
	Rockway	
	Merritton	(=Fossil Hill Fm)
	Cabot Head	

PROJECT

Tier Three Local Area Risk Assessment

TITLE

REVISED BEDROCK STRATIGRAPHY
(Brunton, 2009)

Produced by
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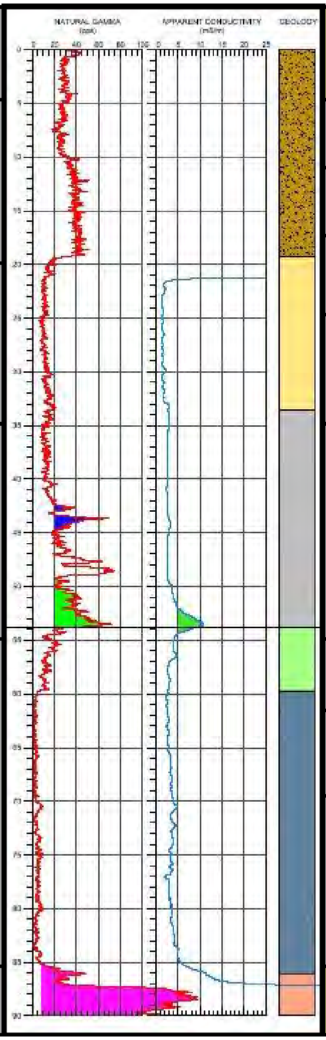
Golder Associates

PROJECT No.		08-1112-0021	FILE No. 0811120021DA00.dwg
DESIGN	KD	8/4/2009	SCALE AS SHOWN REV. A
CAD	KD	5/7/2010	Figure 10
CHECK	JP	5/7/2010	
REVIEW		5/7/2010	

PLOT DATE: May 18, 2010
FILENAME: T:\Projects\2008\08-1112-0021 (ARI, Guelph)\-DA- Modelling Report\0811120021DA00.dwg

PLOT DATE: November 18, 2010
FILENAME: T:\Projects\2008\08-1112-0021 (ARI, Guelph)\-DB- Modelling Report\0811120021DB11.dwg



Era	Period	Formation / Member		Conceptual Model Layer	Aquifer/Aquitard	Thickness (where present)
Cenozoic	Pleistocene			Upper Sand and Gravel	Aquifer	Variable, up to 40 m
				Till	Aquifer/Aquitard	Variable, up to 110 m
Palaeozoic	Middle Silurian	Guelph Formation		Contact Aquifer	Aquifer	4 m
				Guelph Formation	Aquifer	Variable, up to 75
		Amabel Formation	Eramosa Member	Eramosa Member	Aquitard	11 m
			Wiarton / Colpoy / Lions Head Member	Upper Amabel Formation	Aquifer	12 m
				Amabel Formation Production Zone	Aquifer	12 m
				Lower Amabel Formation	Aquifer	10 to 50 m
		Cabot Head / Reynales Formation		**Underlying Impermeable Bedrock**	**Aquitard**	

GEOPHYSICAL LOG LEGEND:

🟥	NATURAL GAMMA LOG
🟦	APPARENT CONDUCTIVITY LOG
—	LOG SIGNATURE REFERENCE LINE (BASE OF ERAMOSA MEMBER)
🟪	GEOPHYSICAL MARKER BED 1
🟩	GEOPHYSICAL MARKER BED 2
🟪	GEOPHYSICAL MARKER BED 3

PROJECT

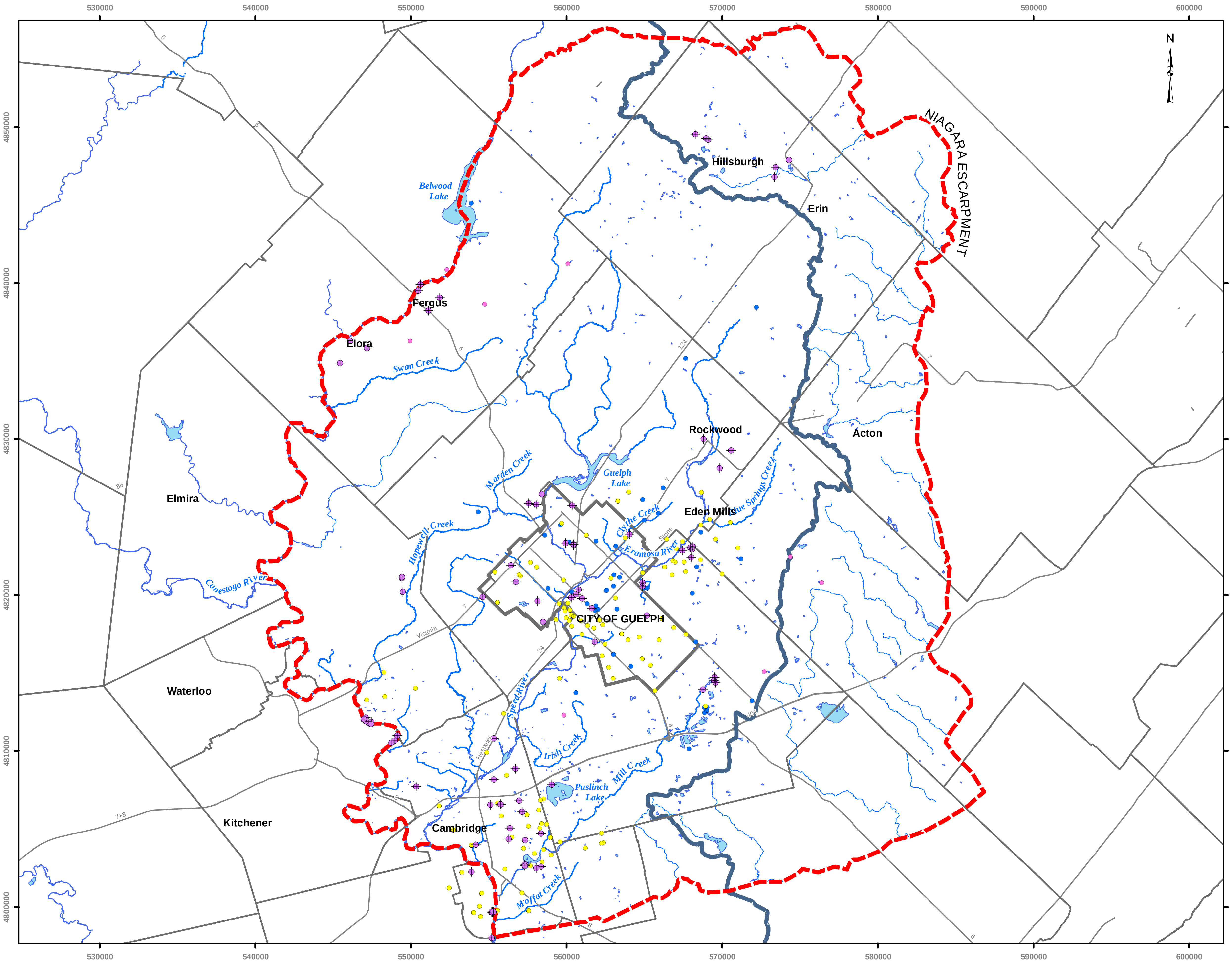
Tier Three Local Area Risk Assessment

TITLE

PREVIOUS HYDROGEOLOGICAL CONCEPTUAL MODEL (GOLDER, 2006)

Produced by Aquaresource Inc. and Golder Associates

PROJECT No.		08-1112-0021	FILE No. 0811120021DB11.dwg
DESIGN	KD	11/18/2010	SCALE AS SHOWN REV. 2
CAD	KD	11/18/2010	FIGURE:
CHECK	JH	11/18/2010	
REVIEW	JP	11/18/2010	11



Tier Three Local Area Risk Assessment

LEGEND

⌖	Municipal Production Well
●	Monitoring /Test Well
●	Non-Municipal Water Well
●	Oil and Gas Well
—	Major Roads / Highways
—	Rivers / Streams
▭	Open Water
▭	Guelph Tier III Model Boundary
▭	GRCA Watershed Boundary
▭	City of Guelph Boundary
▭	Municipal Boundaries

Scale 1:240,000

2.5 0 2.5 5

Kilometers

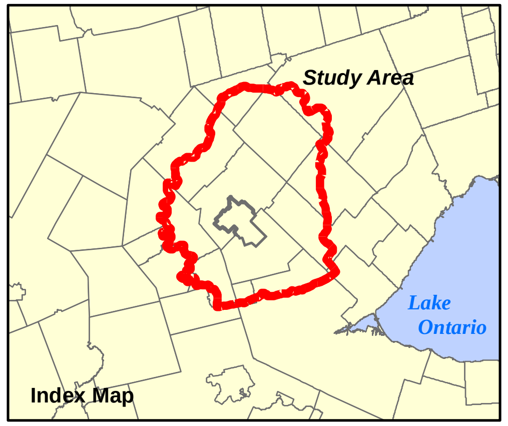


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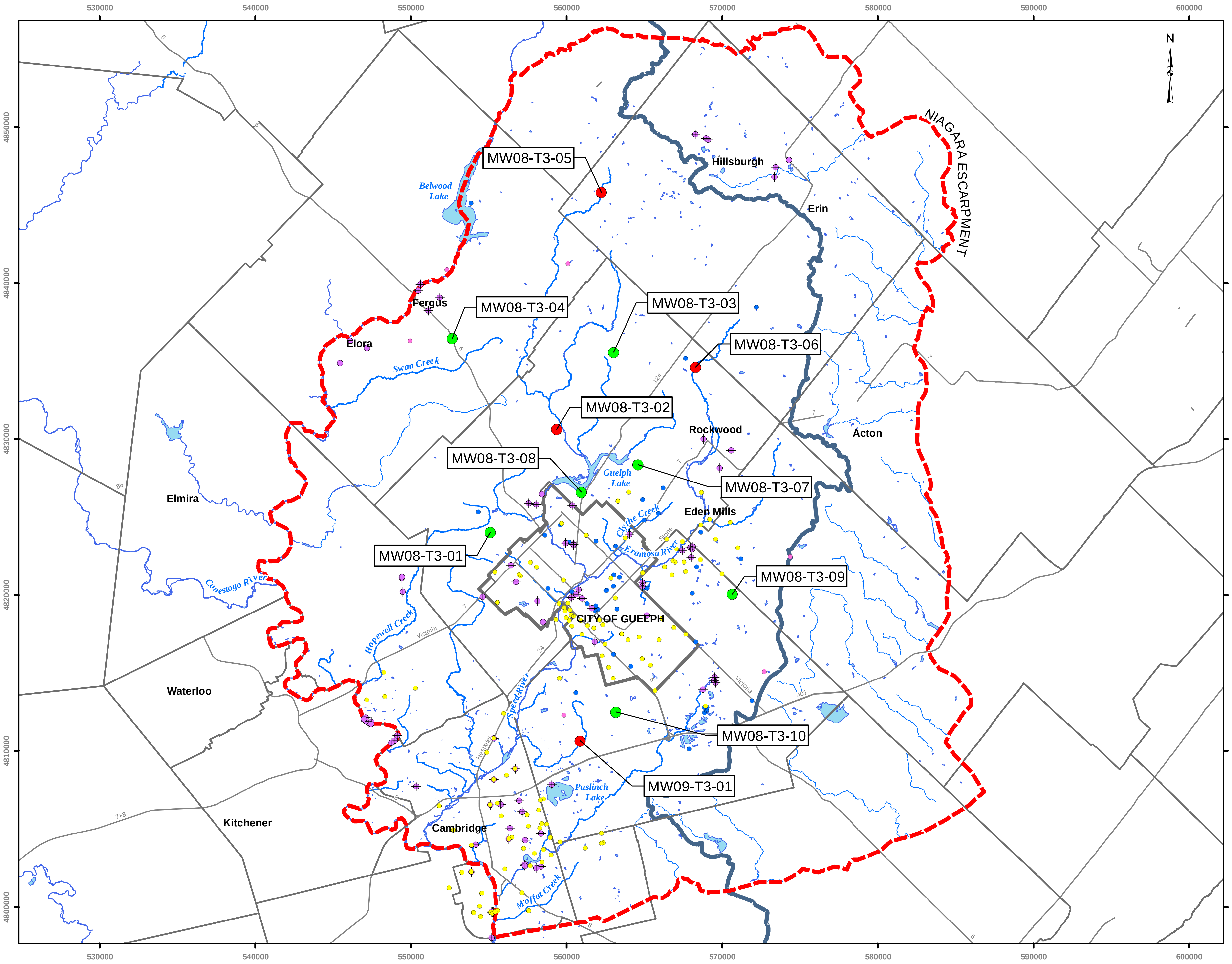
FIGURE: 12

KEY DEEP BEDROCK BOREHOLES

G:\Projects\2008\08-1112-0021_Guelph_TierIII\GIS\MXDs\Final\May_2011_Report\Key_bedrock_borehole_locations.mxd

Project: 08-1112-0021_Guelph_Tier3

Tier Three Local Area Risk Assessment



LEGEND

- 🟢 Tier 3 Project Borehole Location (tri-cone)
- 🔴 Tier 3 Project Borehole Location (cored)
- ⊕ Municipal Production Well
- ● Monitoring /Test Well
- ● Non-Municipal Water Well
- ● Oil and Gas Well
- — Major Roads / Highways
- — Rivers / Streams
- ▭ Open Water
- ▭ Guelph Tier III Model Boundary
- ▭ GRCA Watershed Boundary
- ▭ City of Guelph Boundary
- ▭ Municipal Boundaries

Scale 1:240,000

2.5 0 2.5 5

Kilometers

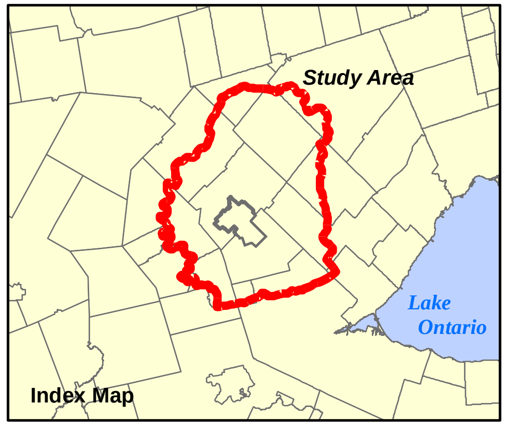


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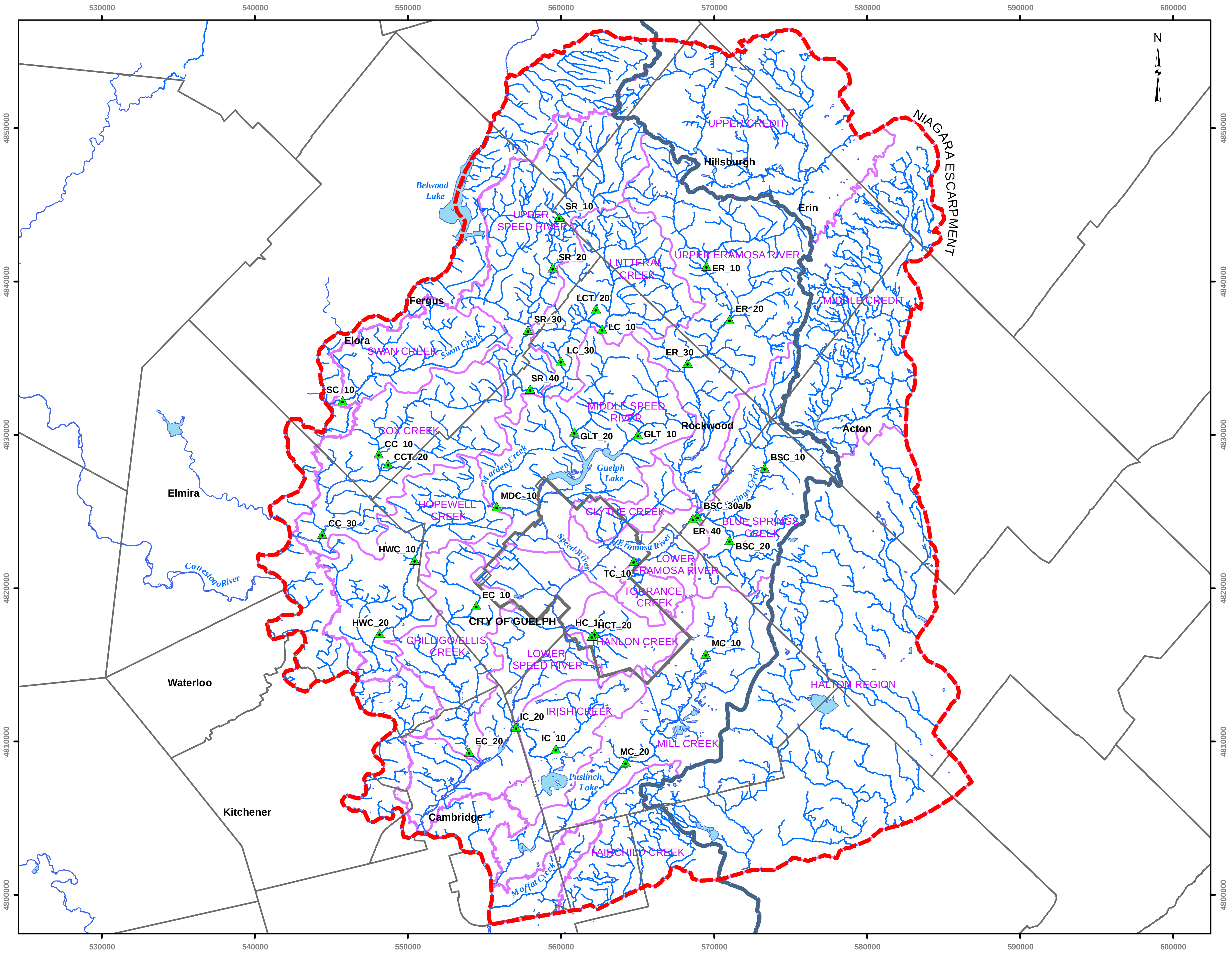
FIGURE: 13

TIER THREE ASSESSMENT
DRILLING LOCATIONS



Tier Three Local Area Risk Assessment

Guelph
Making a Difference

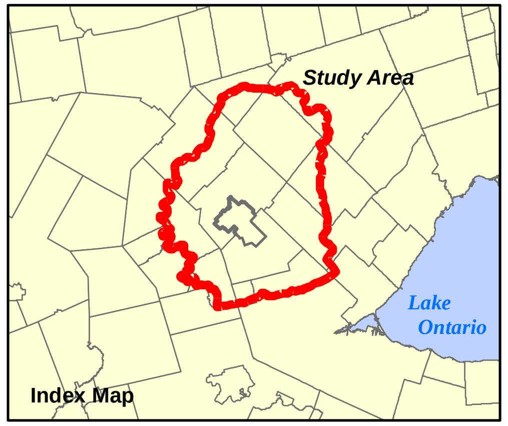
LEGEND

- ▲ Baseflow Monitoring Locations
- — Major Roads / Highways
- — Rivers / Streams
- ▭ Open Water
- ▭ Subwatershed Boundary
- ▭ Guelph Tier III Model Boundary
- ▭ GRCA Watershed Boundary
- ▭ City of Guelph Boundary
- ▭ Municipal Boundaries

Scale 1:241,503

2.5 0 2.5 5

Kilometers



Index Map

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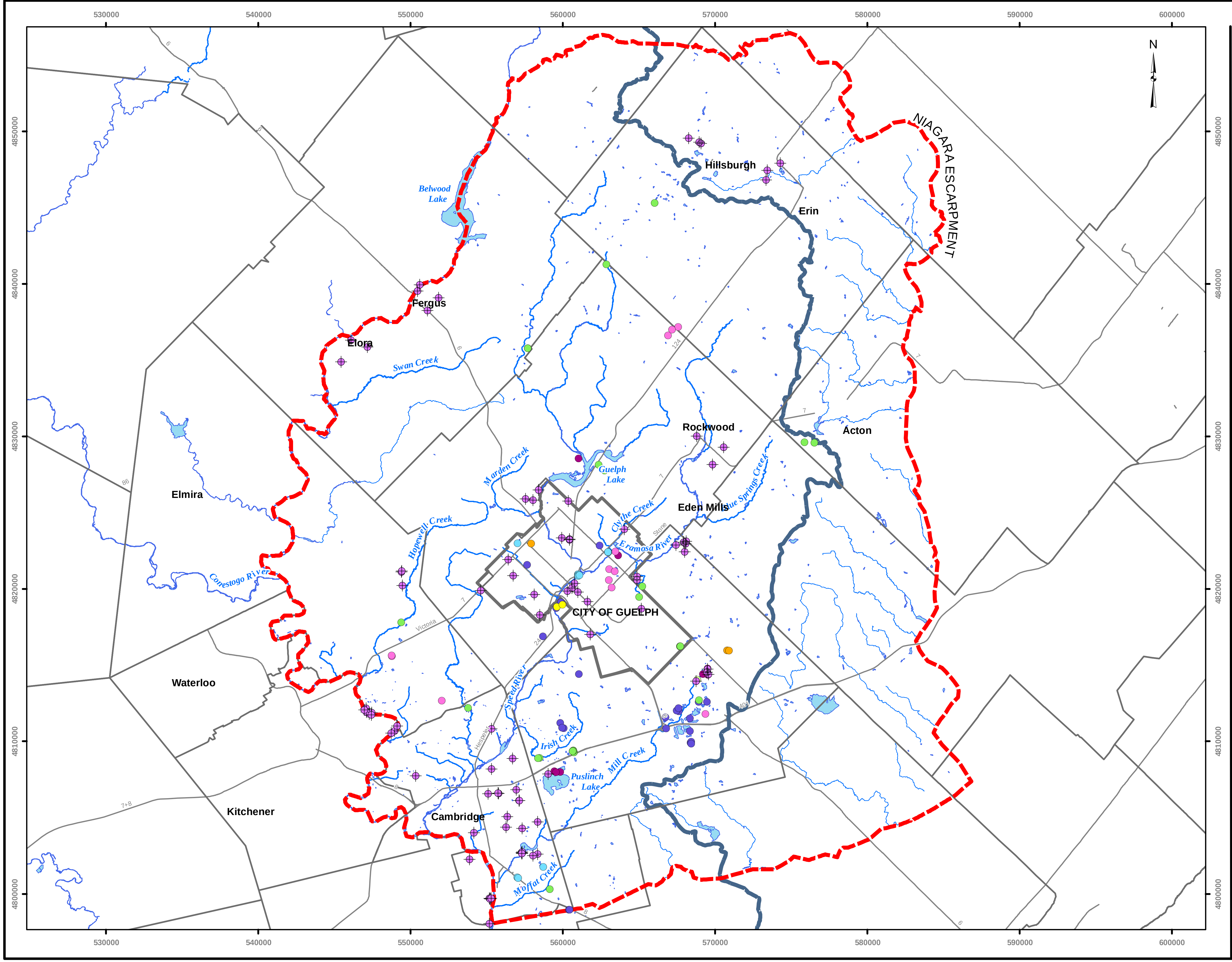
FIGURE: 14

TIER THREE PROJECT BASEFLOW MONITORING LOCATIONS

Tier Three Local Area Risk Assessment



LEGEND

- ▬ Major Roads / Highways
- ▬ Rivers / Streams
- ▭ Open Water
- ▭ Guelph Tier III Model Boundary
- ▭ GRCA Watershed Boundary
- ▭ City of Guelph Boundary
- ▭ Municipal Boundaries

Permit to Take Water Location

- ● Agricultural
- ● Commercial
- ● Dewatering
- ● Industrial
- ● Miscellaneous
- ● Remediation
- ● Water Supply, Campgrounds, Other
- ● Water Supply, Communal
- ⊕ Municipal Production Well

Scale 1:240,000
2.5 0 2.5 5
Kilometers

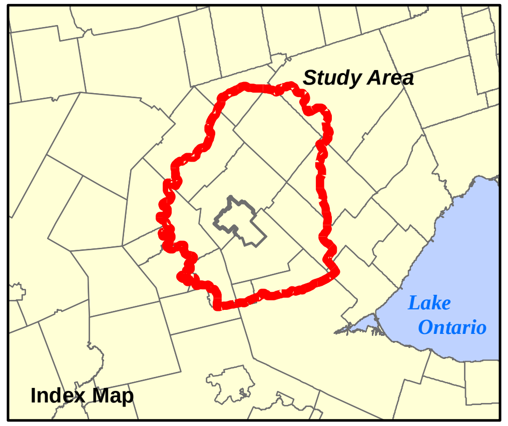


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FIGURE: 15

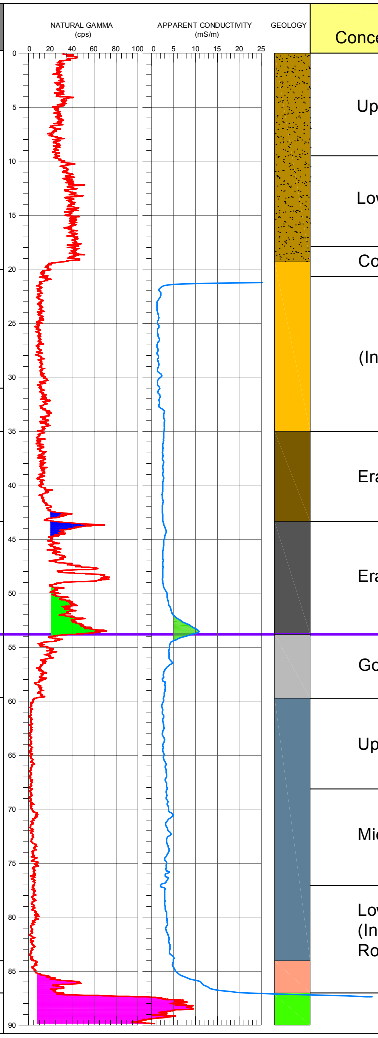
PERMIT TO TAKE
WATER LOCATIONS - GRCA

G:\Projects\2008\08-1112-0021_Guelph_TierIII\GIS\MXDs\Final\May_2011_Report\PTTW_Locations.mxd

Project: 08-1112-0021_Guelph_Tier3

PLOT DATE: November 18, 2010
FILENAME: T:\Projects\2008\08-1112-0021 (ARI, Guelph)\-DB- Modelling Report\0811120021DB16.dwg

Formation	Member
Overburden	
Guelph Formation	
Eramosa	Stone Road
	Reformatory Quarry
	Vinemount
Goat Island	Ancaster / Niagara Falls
Gasport Formation	
Rochester / Irondequoit / Rockway / Merritton	
Cabot Head	



Revised Conceptual Hydrostratigraphic Units	Aquifer / Aquitard	Thickness (Where Present)
Upper Sand and Gravel	Aquifer	Variable up to 40 m
Lower Till	Aquifer / Aquitard	Variable up to 110 m
Contact Aquifer	Aquifer	4 m
Guelph Formation (Including Stone Road Member of Eramosa Formation)	Aquifer	Variable up to 62 m
Eramosa - Reformatory Quarry	Aquifer / Aquitard	Variable up to 48 m
Eramosa - Vinemount	Aquitard	Variable up to 18 m
Goat Island	Aquifer / Aquitard	Variable up to 50 m
Upper Gasport	Aquifer	Variable up to 68 m
Middle Gasport	Aquifer	12 m
Lower Gasport (Including Roch. / Irond. / Rockway / Merritton Formations)	Aquifer	Variable up to 26 m
Underlying Impermeable Bedrock		

Revised bedrock stratigraphy
based on Brunton (2009)

GEOPHYSICAL LOG LEGEND:

NATURAL GAMMA LOG
APPARENT CONDUCTIVITY LOG
LOG SIGNATURE REFERENCE LINE
(BASE OF ERAMOSA MEMBER)
GEOPHYSICAL MARKER BED 1
GEOPHYSICAL MARKER BED 2
GEOPHYSICAL MARKER BED 3

PROJECT

Tier Three Local Area Risk Assessment

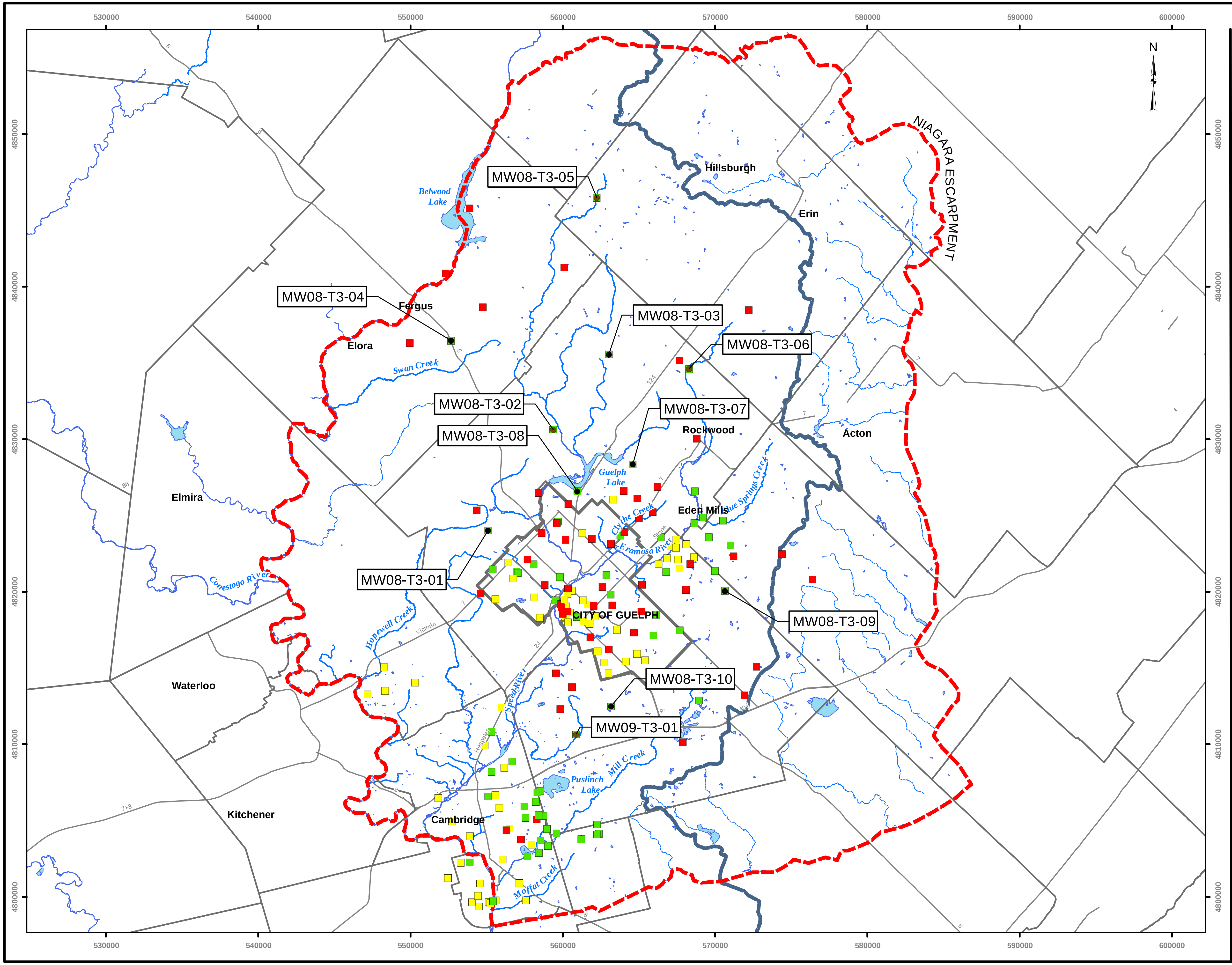
TITLE

CONCEPTUAL HYDROGEOLOGICAL MODEL

Produced by Aquaresource Inc. and Golder Associates

PROJECT No.		08-1112-0021
DESIGN	KD	11/18/2010
CAD	KD	11/18/2010
CHECK	JH	11/18/2010
REVIEW	JP	11/18/2010

FILE No. 0811120021DB16.dwg
SCALE AS SHOWN REV. 2
FIGURE:
16



Tier Three Local Area Risk Assessment

Guelph

LEGEND

- ● Tier 3 Project Borehole Location (not cored)
- ● Tier 3 Project Borehole Location (cored)
- 🟩 High Borehole Reliability
- 🟨 Medium Borehole Reliability
- 🟥 Low Borehole Reliability
- — Major Roads / Highways
- — Rivers / Streams
- ▭ Open Water
- ▭ Guelph Tier III Model Boundary
- ▭ GRCA Watershed Boundary
- ▭ City of Guelph Boundary
- ▭ Municipal Boundaries

Scale 1:240,000

2.5 0 2.5 5

Kilometers

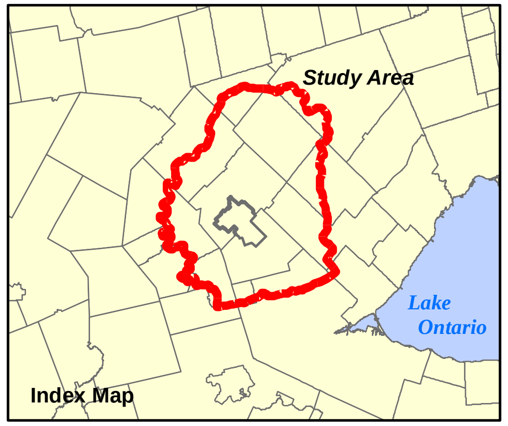


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FIGURE: 17

BEDROCK BOREHOLE RELIABILITY

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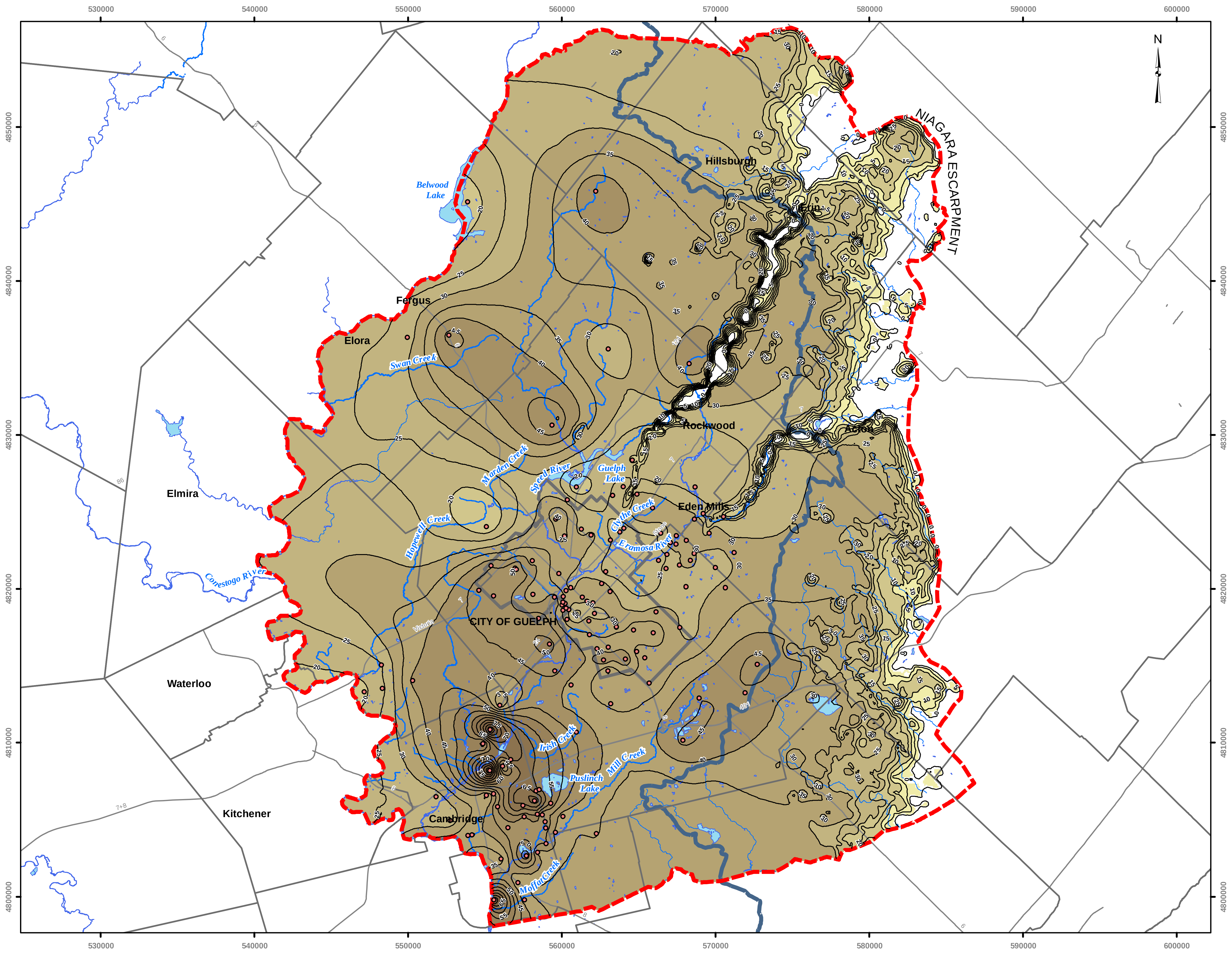
Project: 08-1112-0021_Guelph_Tier3



Tier Three Local Area Risk Assessment

LEGEND

● Data Point

Isopach Thickness Contour (m)

Major Roads / Highways

Rivers / Streams

Open Water

Guelph Tier III Model Boundary

GRCA Watershed Boundary

City of Guelph Boundary

Municipal Boundaries

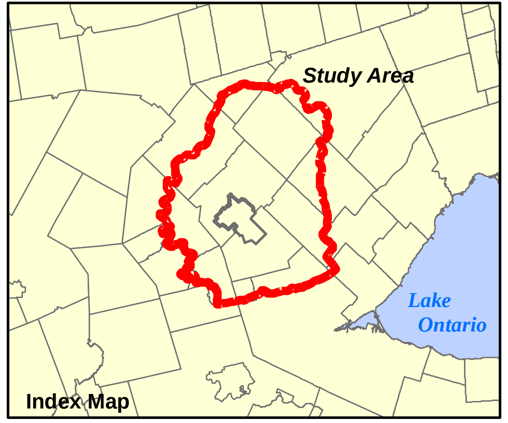
Thickness (m)

▨	90 - 100	▨	30 - 40
▨	80 - 90	▨	20 - 30
▨	70 - 80	▨	10 - 20
▨	60 - 70	▨	0 - 10
▨	50 - 60	☐	0
▨	40 - 50		

Scale 1:240,000

2.5 0 2.5 5

Kilometers



Index Map

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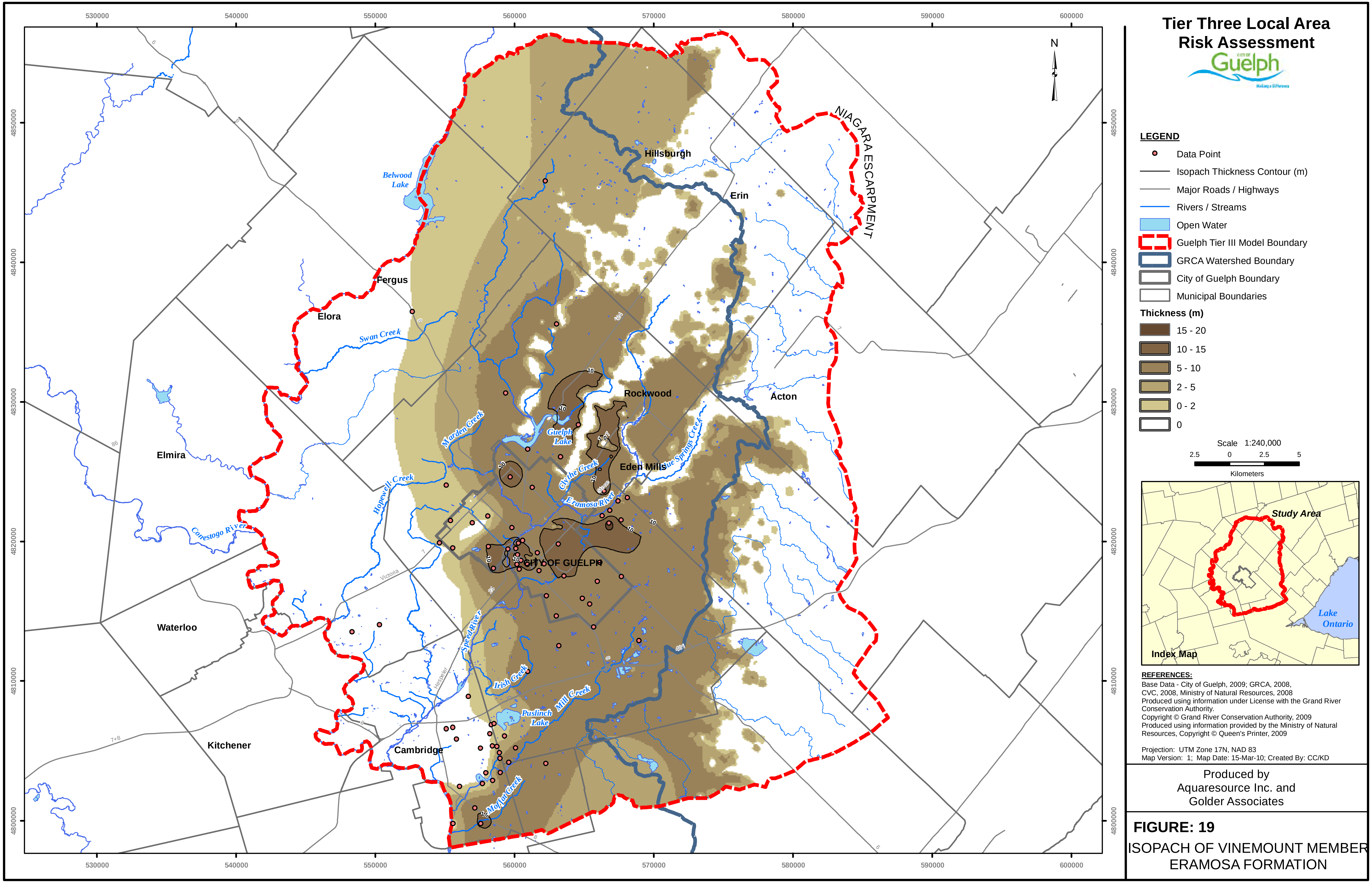
FIGURE: 18

ISOPACH OF GASPORT FORMATION

Tier Three Local Area Risk Assessment



LEGEND

- ● Data Point
- Isopach Thickness Contour (m)
- Major Roads / Highways
- Rivers / Streams
- Open Water
- Guelph Tier III Model Boundary
- GRCA Watershed Boundary
- City of Guelph Boundary
- Municipal Boundaries

Thickness (m)

- 15 - 20
- 10 - 15
- 5 - 10
- 2 - 5
- 0 - 2
- 0

Scale 1:240,000
2.5 0 2.5 5
Kilometers

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FIGURE: 19
ISOPACH OF VINEMOUNT MEMBER
ERAMOSA FORMATION

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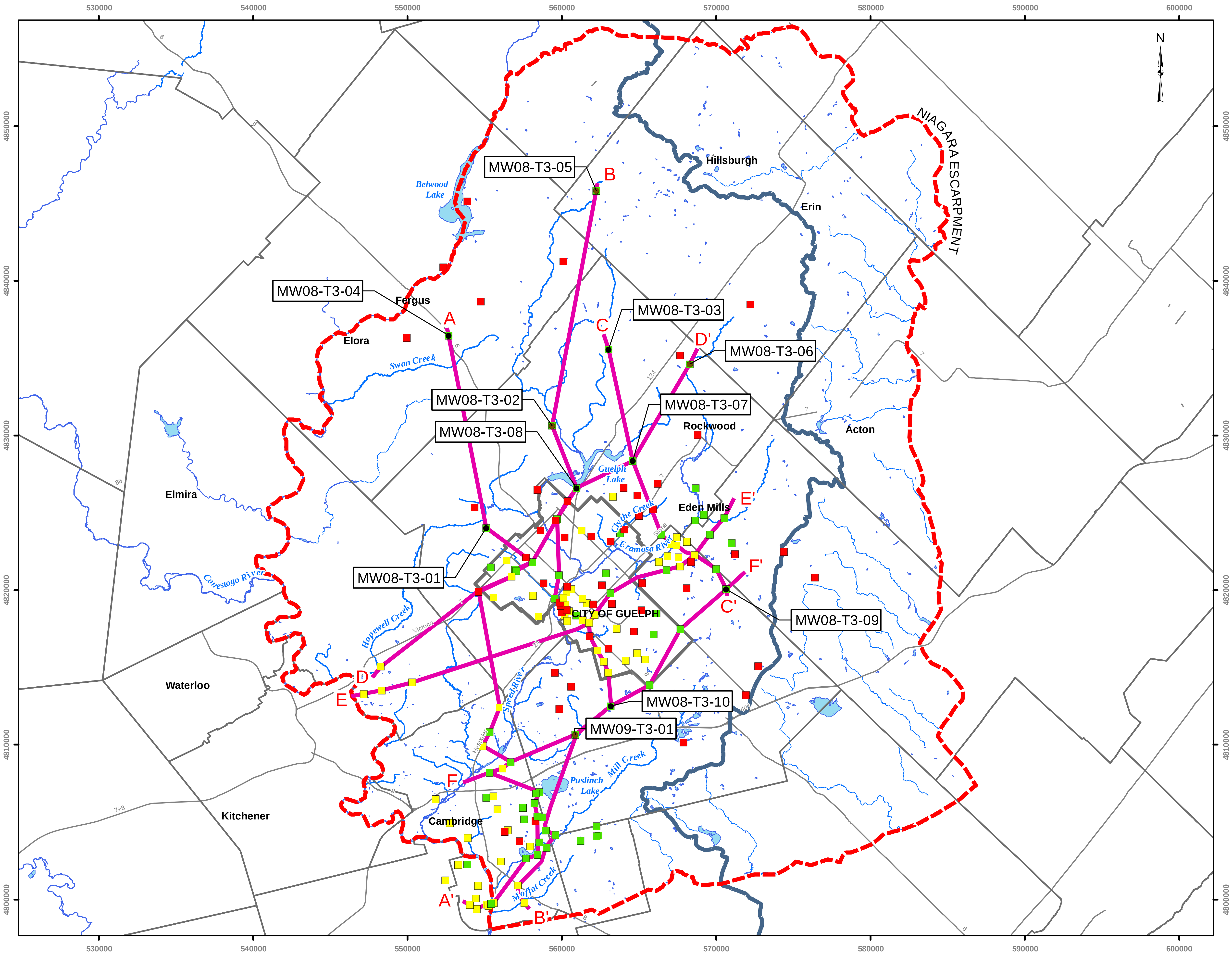
Project: 08-1112-0021_Guelph_Tier3



Tier Three Local Area Risk Assessment

Guelph
Making a Difference

LEGEND

- ● Tier 3 Project Borehole Location (not cored)
- ● Tier 3 Project Borehole Location (cored)
- 🟩 High Borehole Reliability
- 🟨 Medium Borehole Reliability
- 🟥 Low Borehole Reliability
- — Major Roads / Highways
- — Cross Section Location
- — Rivers / Streams
- ▭ Open Water
- ▭ Guelph Tier III Model Boundary
- ▭ GRCA Watershed Boundary
- ▭ City of Guelph Boundary
- ▭ Municipal Boundaries

Scale 1:240,000

2.5 0 2.5 5

Kilometers

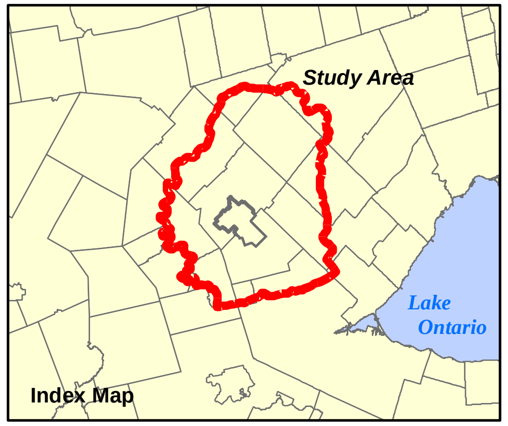


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FIGURE: 20

CROSS SECTION LOCATIONS

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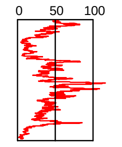
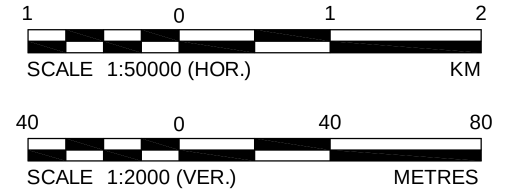
Project: 08-1112-0021_Guelph_Tier3

LEGEND:

OB	OVERBURDEN	GI	GOAT ISLAND FORMATION	MW08-T3-01	HIGH RELIABILITY BOREHOLE (CORED)
GU	GUELPH FORMATION	GP	GASPORT FORMATION	PBOW2-06	HIGH RELIABILITY BOREHOLE
RQ	ERAMOSA - REFORMATORY QUARRY		MIDDLE GASPORT LAYER	Calico-PW3/76	MEDIUM RELIABILITY BOREHOLE
VM	ERAMOSA - VINEMOUNT	CH	CABOT HEAD FORMATION	(-0.8)	HEAD DIFFERENCE (m) (SHALLOW MINUS DEEP BEDROCK) + = DOWNWARD GRADIENT - = UPWARD GRADIENT



NATURAL GAMMA (cps)



V.E. = 25X

PROJECT

GUELPH TIER THREE ASSESSMENT

TITLE

CROSS SECTION A-A'

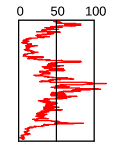
Mississauga, Ontario, Canada

PROJECT No.		08-1112-0021	FILE No. 0811120021BD0021.dwg	
DESIGN			SCALE AS SHOWN	REV.
CAD	RJ	5/16/2011	FIGURE No.	
CHECK	JP	5/16/2011	21	
REVIEW				

PLOT DATE: May 16, 2011
FILENAME: T:\Projects\2008\08-1112-0021 (ARI, Guelph)\-BD-\0811120021BD0021.dwg

LEGEND:

OB	OVERBURDEN	GI	GOAT ISLAND FORMATION	MW08-T3-01	HIGH RELIABILITY BOREHOLE (CORED)
GU	GUELPH FORMATION	GP	GASPORT FORMATION	PBOW2-06	HIGH RELIABILITY BOREHOLE
RQ	ERAMOSA - REFORMATORY QUARRY		MIDDLE GASPORT LAYER	Calico-PW3/76	MEDIUM RELIABILITY BOREHOLE
VM	ERAMOSA - VINEMOUNT	CH	CABOT HEAD FORMATION	(-0.2)	HEAD DIFFERENCE (m) (SHALLOW MINUS DEEP BEDROCK) + = DOWNWARD GRADIENT - = UPWARD GRADIENT



NATURAL GAMMA (cps)

1 0 1 2
SCALE 1:50000 (HOR.) KM

40 0 40 80
SCALE 1:2000 (VER.) METRES

V.E. = 25X

PROJECT
GUELPH TIER THREE ASSESSMENT

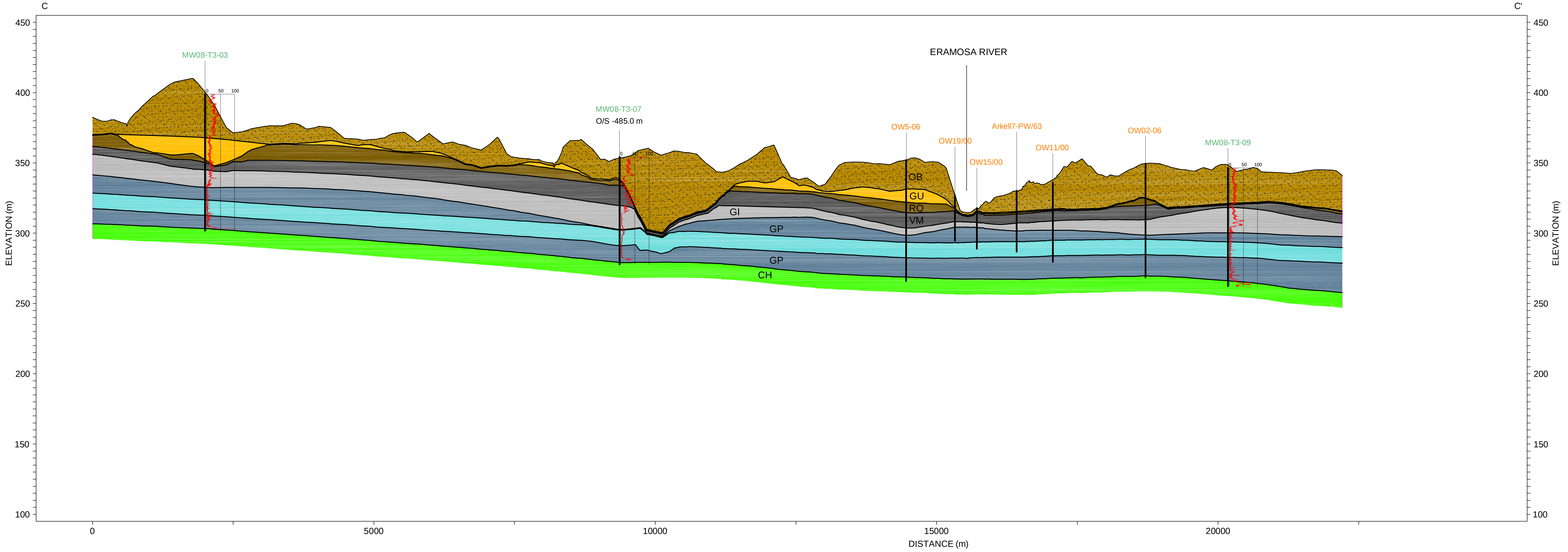
TITLE
CROSS SECTION B-B'

Golder Associates
Mississauga, Ontario, Canada

PROJECT No.		08-1112-0021
DESIGN		
CAD	RJ	5/6/2011
CHECK	JP	5/6/2011
REVIEW		

FILE No. 0811120021BD0022.dwg
SCALE AS SHOWN REV.
FIGURE No.
22

PLOT DATE: May 16, 2011
FILENAME: T:\Projects\2008\08-1112-0021 (ARI, Guelph)\-BD-\0811120021BD0022.dwg



LEGEND:

OB	OVERBURDEN	GI	GOAT ISLAND FORMATION	MW08-T3-01	HIGH RELIABILITY BOREHOLE (CORED)
GU	GUELPH FORMATION	GP	GASPORT FORMATION	PBOW2-06	HIGH RELIABILITY BOREHOLE
RQ	ERAMOSA - REFORMATORY QUARRY		MIDDLE GASPORT LAYER	Calico-PW3/76	MEDIUM RELIABILITY BOREHOLE
VM	ERAMOSA - VINEMOUNT	CH	CABOT HEAD FORMATION		

0 50 100
NATURAL GAMMA (cps)

1 0 1 2
SCALE 1:50000 (HOR.) KM

40 0 40 80
SCALE 1:2000 (VER.) METRES

V.E. = 25X

PROJECT
GUELPH TIER THREE ASSESSMENT

TITLE
CROSS SECTION C-C'

Golder Associates
Mississauga, Ontario, Canada

PROJECT No.		08-1112-0021
DESIGN		
CAD	RJ	5/16/2011
CHECK	JP	5/16/2011
REVIEW		

FILE No. 0811120021BD0023.dwg
SCALE AS SHOWN REV.
FIGURE No.
23

T:\Projects\2008\08-1112-0021 (ARI, Guelph)\-BD-\0811120021BD0023.dwg
PLOT DATE: May 16, 2011
FILENAME:

LEGEND:

OB	OVERBURDEN
SA	SALINA FORMATION
GU	GUELPH FORMATION
RQ	ERAMOSA - REFORMATORY QUARRY
VM	ERAMOSA - VINEMOUNT
GI	GOAT ISLAND FORMATION
GP	GASPORT FORMATION
	MIDDLE GASPORT LAYER
CH	CABOT HEAD FORMATION

MW06-6	HIGH RELIABILITY BOREHOLE (CORED)
MW08-01AB	HIGH RELIABILITY BOREHOLE
OW11/00	MEDIUM RELIABILITY BOREHOLE

0 50 100 NATURAL GAMMA (cps)

1 0 1 2
SCALE 1:50000 (HOR.) KM

40 0 40 80
SCALE 1:2000 (VER.) METRES

V.E. = 25X

PROJECT
GUELPH TIER THREE ASSESSMENT

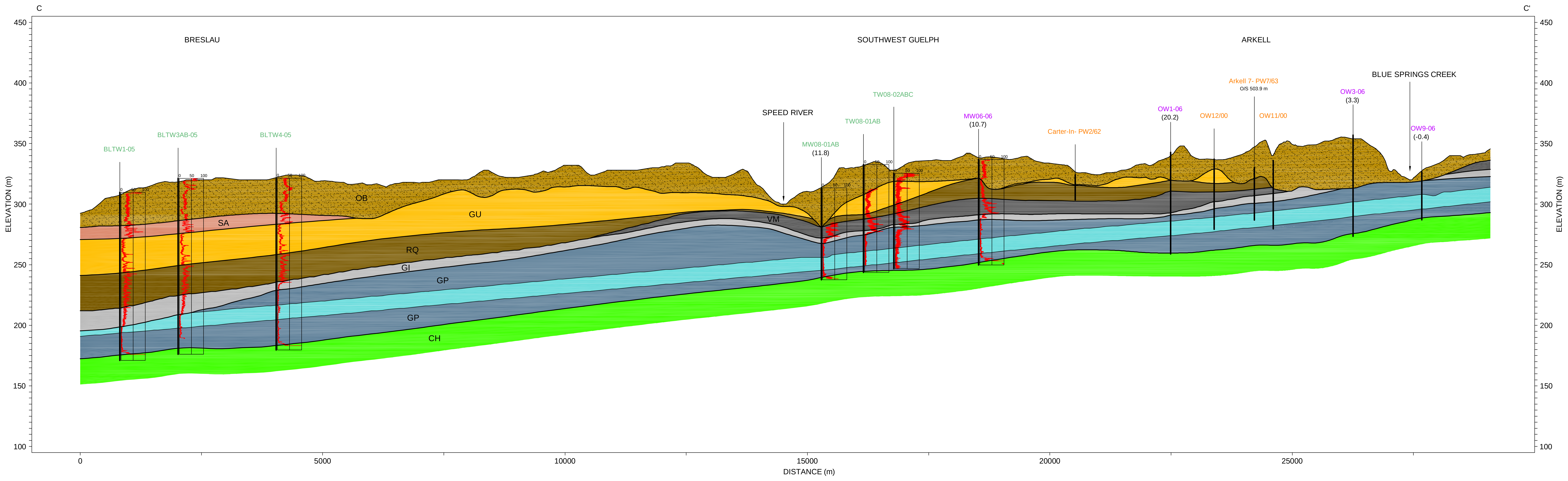
TITLE
CROSS SECTION D-D'

Golder Associates
Mississauga, Ontario, Canada

PROJECT No.		08-1112-0021
DESIGN		
CAD	JFC	5/16/2011
CHECK	JP	5/16/2011
REVIEW		

FILE No. 0811120021BD0024.dwg
SCALE AS SHOWN REV. A
FIGURE No.
24

PLOT DATE: May 16, 2011
FILENAME: T:\Projects\2008\08-1112-0021 (ARI, Guelph)\-BD-\0811120021BD0024.dwg



LEGEND:

OB	OVERBURDEN	GI	GOAT ISLAND FORMATION	MW06-6	HIGH RELIABILITY BOREHOLE (CORED)
SA	SALINA FORMATION	GP	GASPORT FORMATION	MW08-01AB	HIGH RELIABILITY BOREHOLE
GU	GUELPH FORMATION		MIDDLE GASPORT LAYER	OW11/00	MEDIUM RELIABILITY BOREHOLE
RQ	ERAMOSA - REFORMATORY QUARRY	CH	CABOT HEAD FORMATION	(11.8)	HEAD DIFFERENCE (m) (SHALLOW MINUS DEEP BEDROCK) + = DOWNWARD GRADIENT - = UPWARD GRADIENT
VM	ERAMOSA - VINEMOUNT				

0 50 100

NATURAL GAMMA (cps)

1 0 1 2

SCALE 1:50000 (HOR.) KM

40 0 40 80

SCALE 1:2000 (VER.) METRES

V.E. = 25X

PROJECT

GUELPH TIER THREE ASSESSMENT

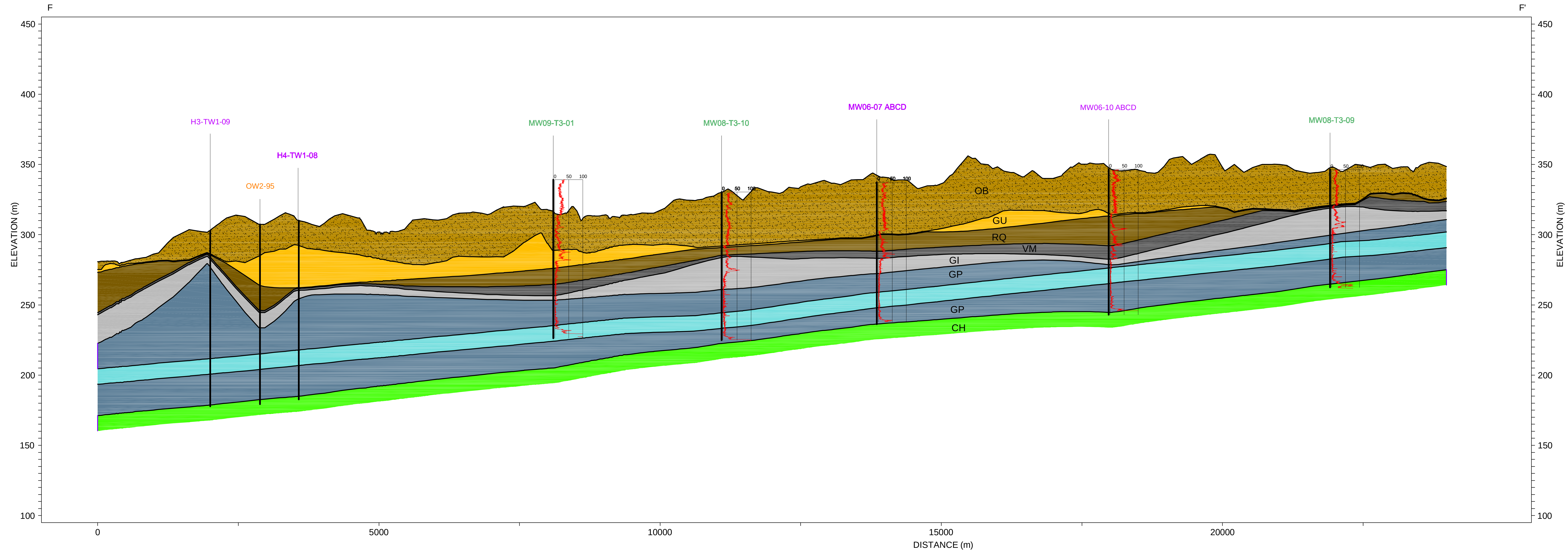
TITLE

CROSS SECTION E-E'

Mississauga, Ontario, Canada

PROJECT No.		08-1112-0021	FILE No. 0811120021BD0025.dwg	
DESIGN			SCALE AS SHOWN	REV.
CAD	RJ	5/6/2011	FIGURE No.	
CHECK	JP	5/6/2011	**25**	
REVIEW				

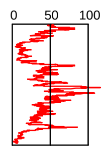
PLOT DATE: May 16, 2011
FILENAME: T:\Projects\2008\08-1112-0021 (ARI, Guelph)\-BD-\0811120021BD0025.dwg



LEGEND:

OB OVERBURDEN
SA SALINA FORMATION
GU GUELPH FORMATION
RQ ERAMOSA - REFORMATORY QUARRY
VM ERAMOSA - VINEMOUNT
GI GOAT ISLAND FORMATION
GP GASPORT FORMATION
MIDDLE GASPORT LAYER
CH CABOT HEAD FORMATION

MW06-6 HIGH RELIABILITY BOREHOLE (CORED)
MW08-01AB HIGH RELIABILITY BOREHOLE
OW11/00 MEDIUM RELIABILITY BOREHOLE



NATURAL GAMMA (cps)

1 0 1 2
SCALE 1:50000 (HOR.) KM

40 0 40 80
SCALE 1:2000 (VER.) METRES

V.E. = 25X

PROJECT
GUELPH TIER THREE ASSESSMENT

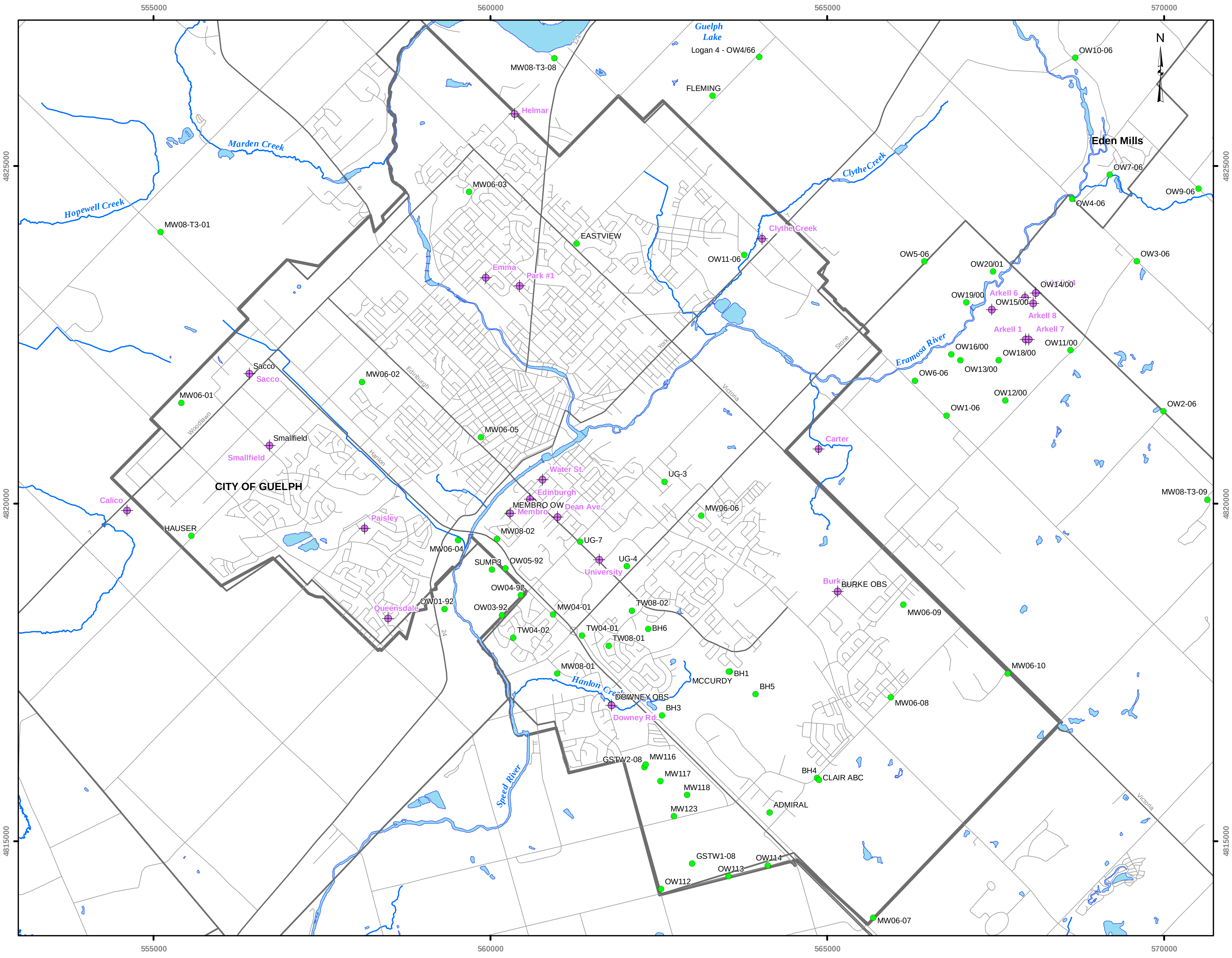
TITLE
CROSS SECTION F-F'

Golder Associates
Mississauga, Ontario, Canada

PROJECT No.		08-1112-0021
DESIGN		
CAD	JFC	5/16/2011
CHECK	JP	5/16/2011
REVIEW		

FILE No. 0811120021BD0026.dwg
SCALE AS SHOWN REV. A
FIGURE No.
26

PLOT DATE: May 16, 2011
FILENAME: T:\Projects\2008\08-1112-0021 (ARI, Guelph)\-BD-\0811120021BD0026.dwg



Tier Three Local Area Risk Assessment

Guelph

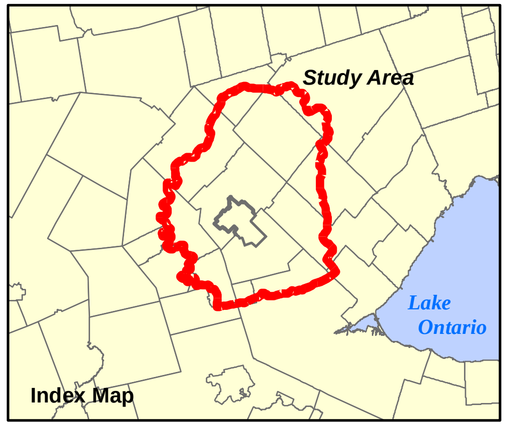
LEGEND

⌖	City of Guelph Municipal Production Well
●	Monitoring Well Location
—	Collector Roads / Local Roads
—	Major Roads / Highways
—	Rivers / Streams
▭	Open Water
▭	Guelph Tier III Model Boundary
▭	GRCA Watershed Boundary
▭	City of Guelph Boundary
▭	Municipal Boundaries

Scale 1:55,000

1 0 1 2

Kilometers



REFERENCES:

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Projection: UTM Zone 17N, NAD 83
Map Version: 1; Map Date: 15-Mar-10; Created By: CC/KD

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FIGURE: 27
CITY OF GUELPH KEY MONITORING WELL LOCATIONS

G:\Projects\2008\08-1112-0021_Guelph_TierIII\GIS\MXDs\Final\May_2011_Report\Key_Monitoring_Well_Locations.mxd

Project: 08-1112-0021_Guelph_Tier3

Tier Three Local Area Risk Assessment

Guelph

LEGEND

―	Watercourse
▭	Waterbody
▨	Wetland
🟥	Guelph City Limit

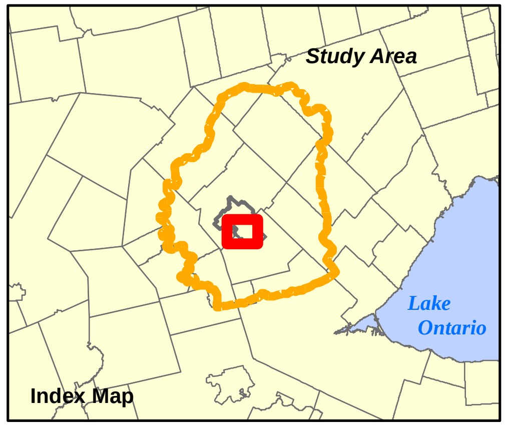
Municipal Test Well Locations

⊕	Municipal Test Well
⊕	Municipal Production Well
⊕	University of Guelph Production Wells
⊕	Municipal Monitoring Well
⊕	Guelph-Lime Quarry Monitoring Well
⊕	Hanlon Creek Watershed Study Monitoring Wells
⊕	Hanlon Creek Proposed Business Park Monitoring Well
⊙	Shallow Overburden Piezometer
▲	Surface Water Staff Gauge
☐	Surface Water Flow Monitoring Station

Scale 1:25,000

0.5 0 0.5 1

Kilometers



REFERENCES:

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Projection: UTM Zone 17N, NAD 83
Map Version: 1; Map Date: 03-May-03; Created By: KD

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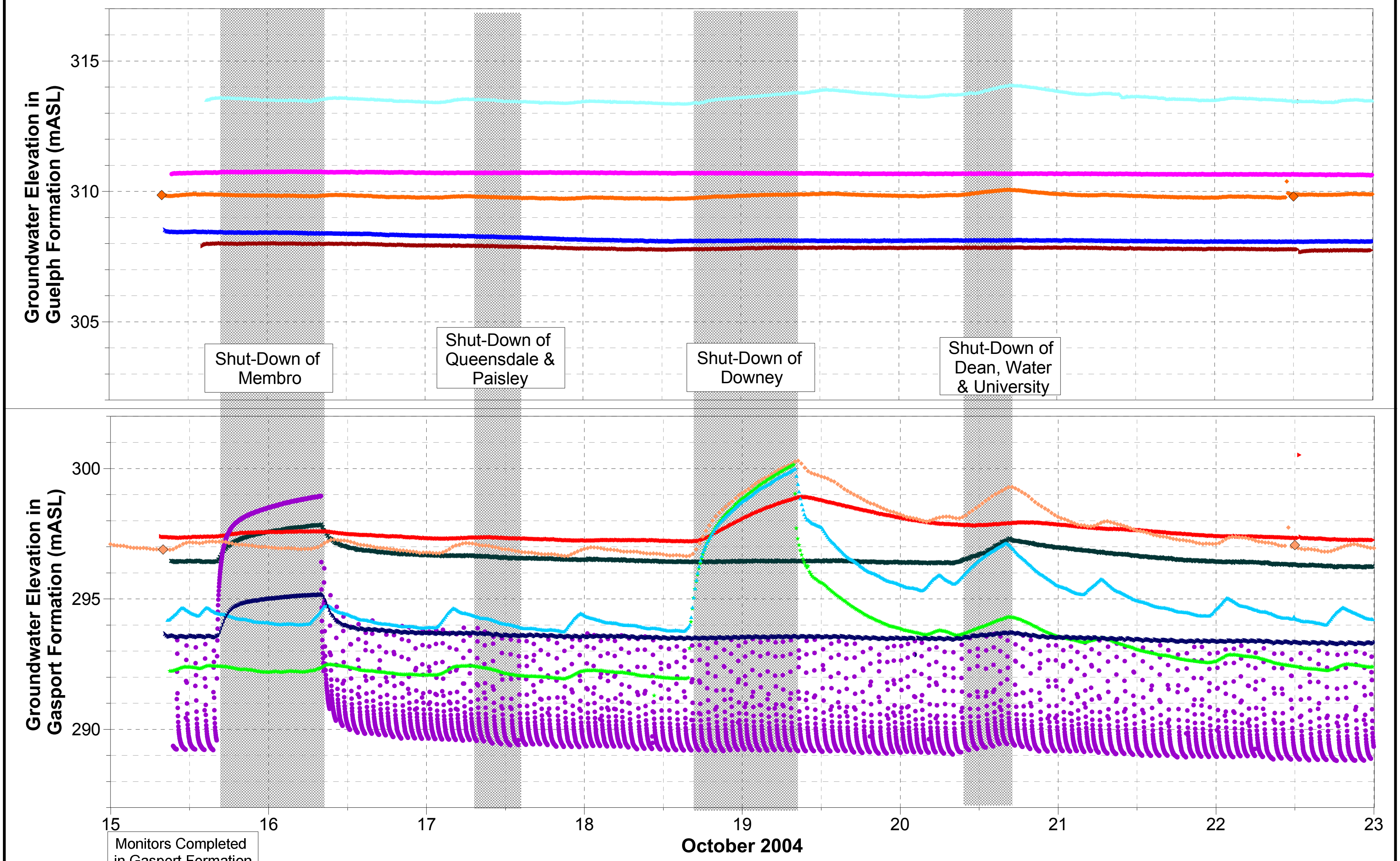
FIGURE: 28

SOUTHWEST QUADRANT PUMPING TEST - WELL LOCATIONS

G:\Projects\2008\08-1112-0021_Guelph_TierIII\GIS\MXDs\Final\May_2011_Report\SW_Quadrant_Pumping_Test_Wells.mxd

Project: 2008003_Guelph_Tier3

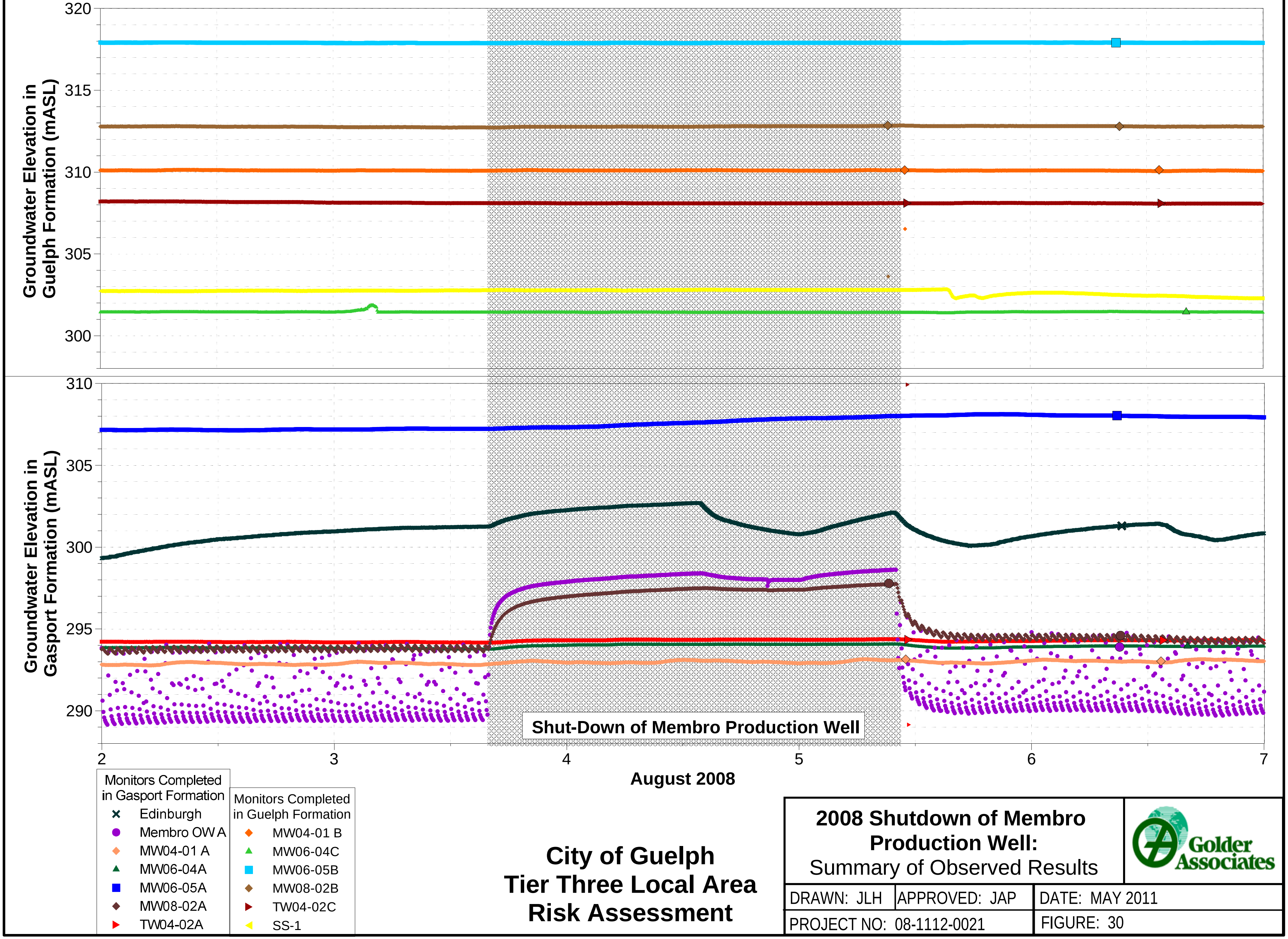


City of Guelph
Tier Three Local Area
Risk Assessment

2004 Guelph Lime Rotating
Shutdown of Production Wells:
Summary of Observed Results

Golder Associates

DRAWN: JLH
APPROVED: JAP
DATE: MAY 2011
PROJECT NO: 08-1112-0021
FIGURE: 29

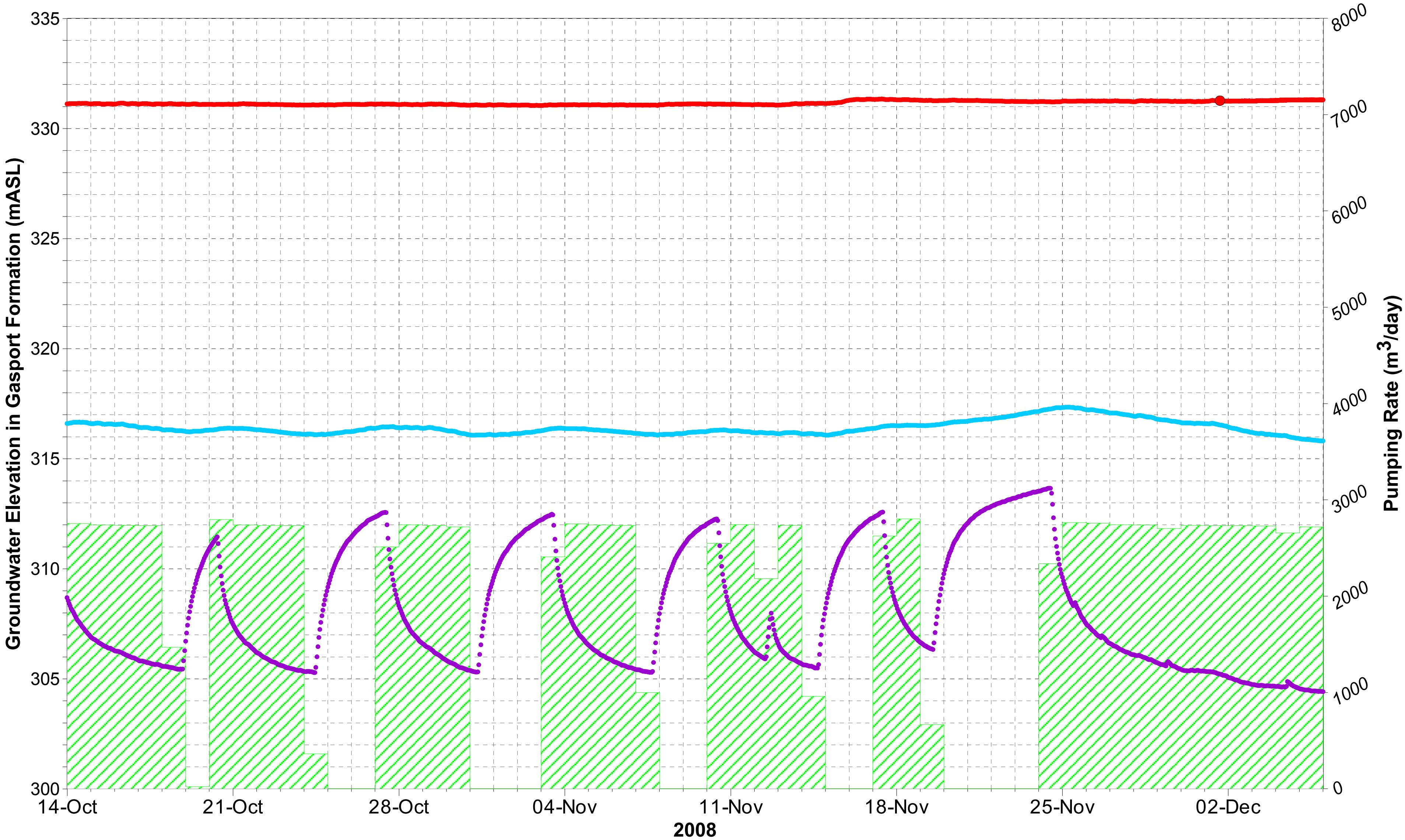


City of Guelph
Tier Three Local Area
Risk Assessment

2008 Shutdown of Membro Production Well:
Summary of Observed Results

Golder Associates

DRAWN: JLH
APPROVED: JAP
DATE: MAY 2011
PROJECT NO: 08-1112-0021
FIGURE: 30

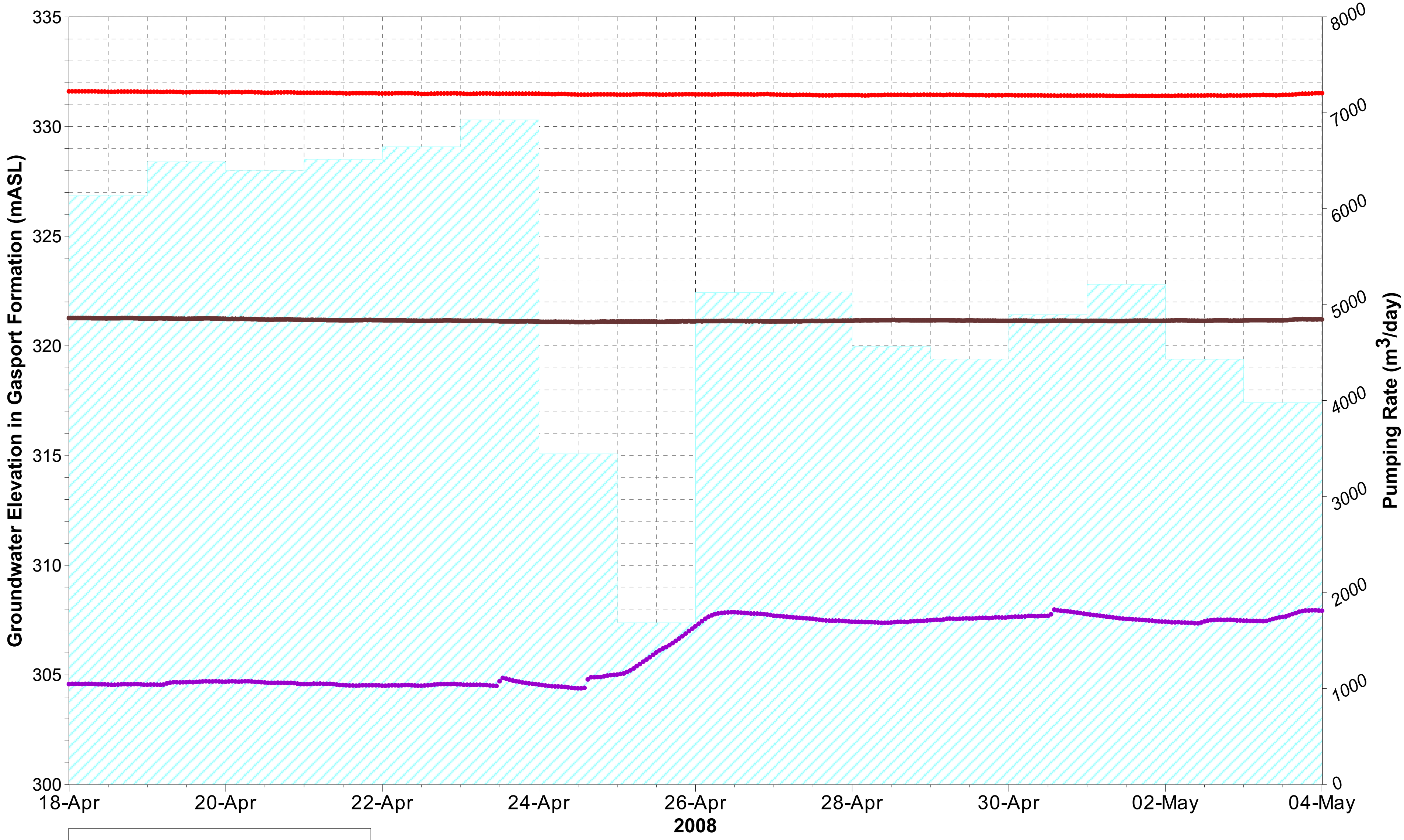


City of Guelph
Tier Three Local Area
Risk Assessment

2008 Shutdown of Emma Production Well:
Summary of Observed Results

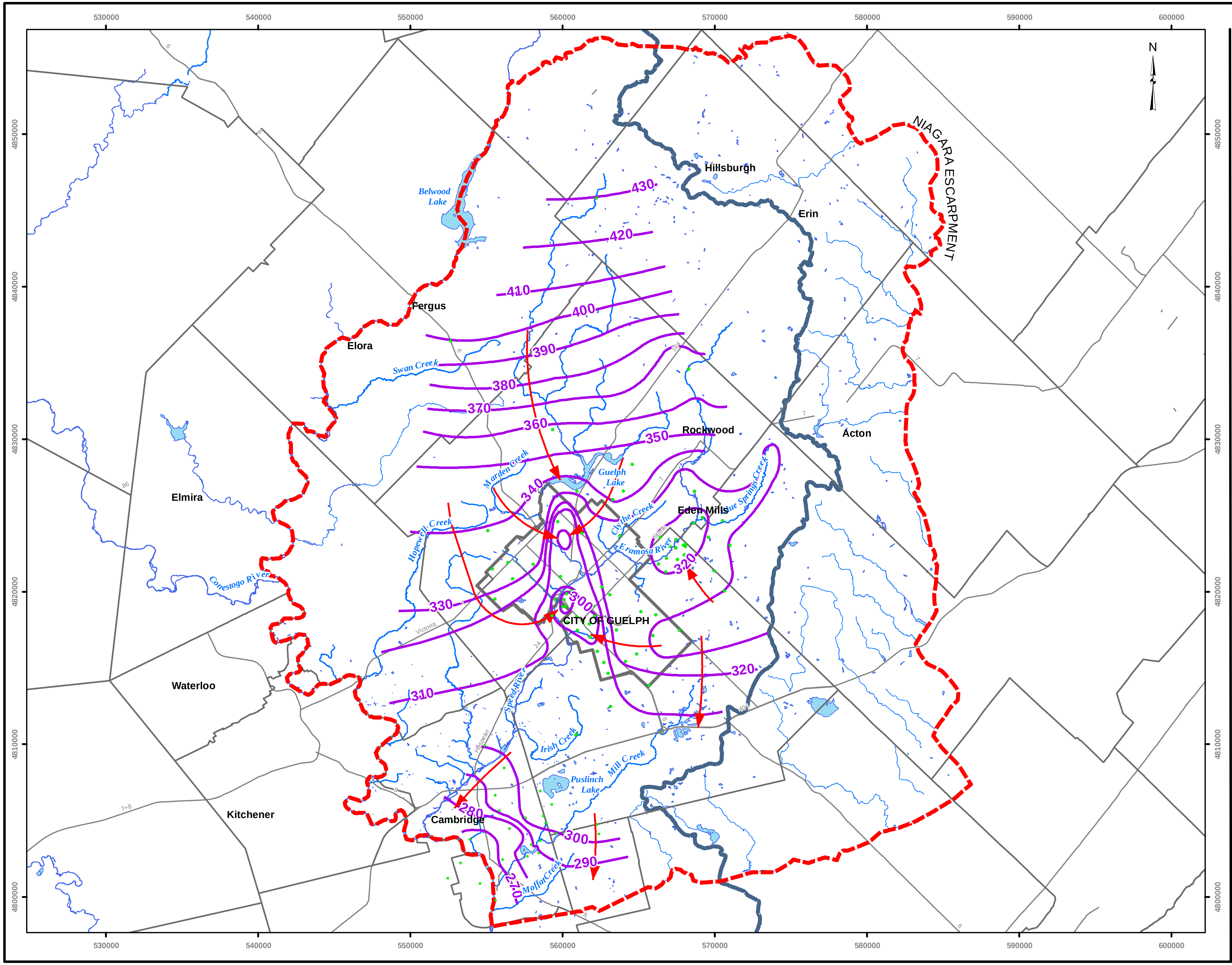
Golder Associates

DRAWN: JLH	APPROVED: JAP	DATE: MAY 2011
PROJECT NO: 08-1112-0021		FIGURE: 31



City of Guelph
Tier Three Local Area
Risk Assessment

2008 Decrease in Production Rate at Park Production Wells: Summary of Observed Results		Golder Associates
DRAWN: JLH	APPROVED: JAP	DATE: MAY 2011
PROJECT NO: 08-1112-0021		FIGURE: 32



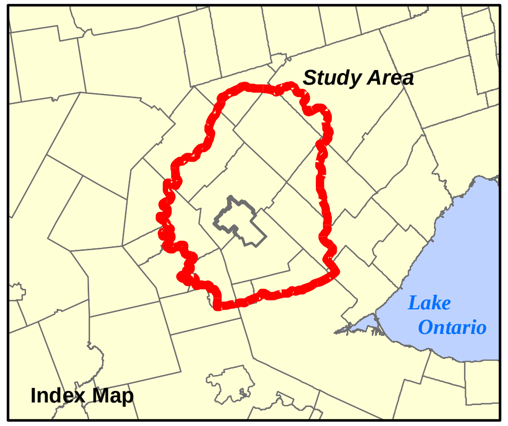
Tier Three Local Area Risk Assessment

Guelph
Making a Difference

LEGEND

- ● Data Point
- Groundwater Elevation Contour (10 m)
- Inferred Groundwater Flow Direction
- Major Roads / Highways
- Rivers / Streams
- Open Water
- Guelph Tier III Model Boundary
- GRCA Watershed Boundary
- City of Guelph Boundary
- Municipal Boundaries

Scale 1:240,000
2.5 0 2.5 5
Kilometers



Index Map

REFERENCES:
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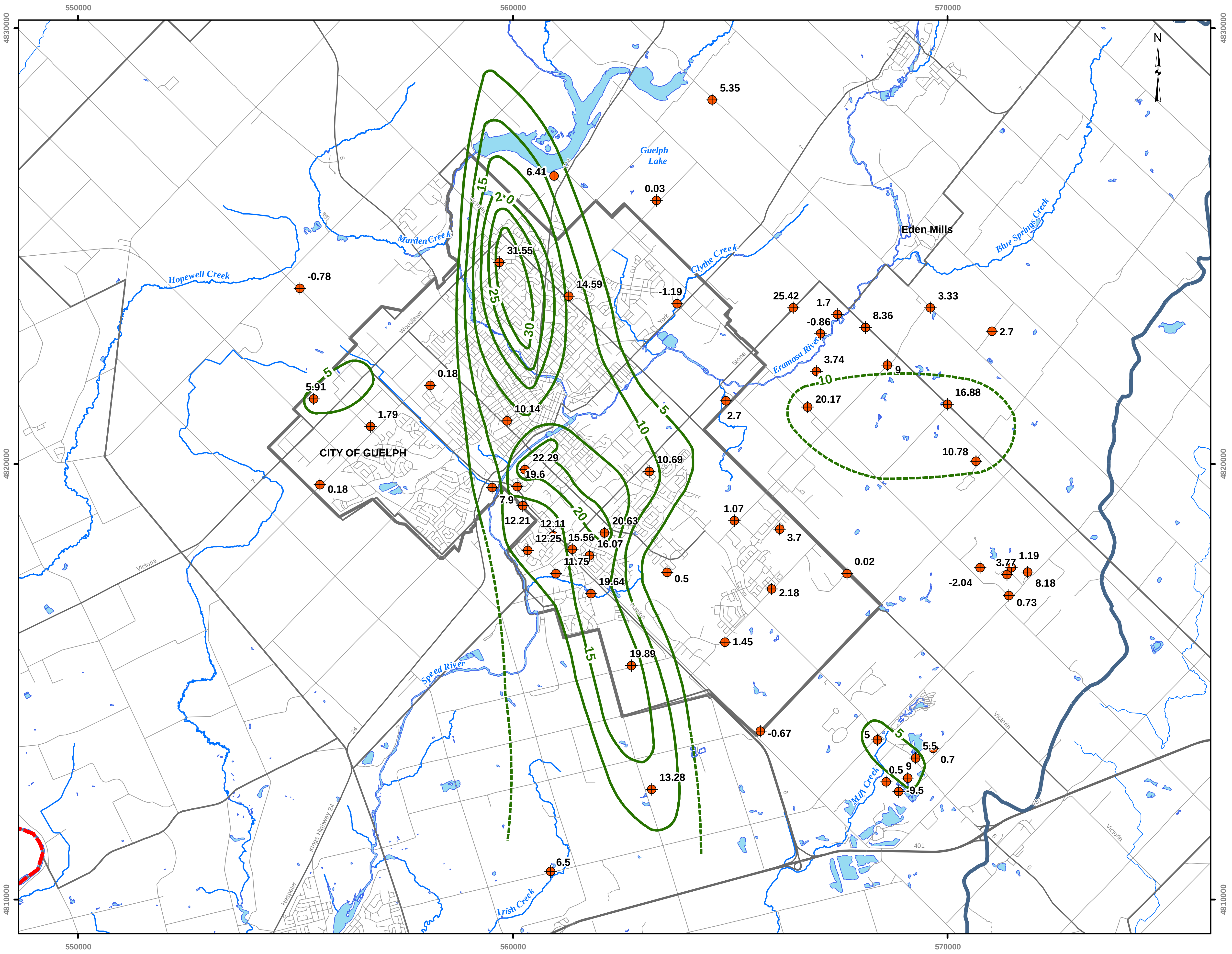
Projection: UTM Zone 17N, NAD 83
Map Version: 1; Map Date: 15-Mar-10; Created By: CC/KD

Produced by
Aquaresource Inc. and
Golder Associates

FIGURE: 33

DEEP AQUIFER POTENTIOMETRIC SURFACE (GASPORT FM)



Tier Three Local Area Risk Assessment

Guelph

Making a Difference

LEGEND

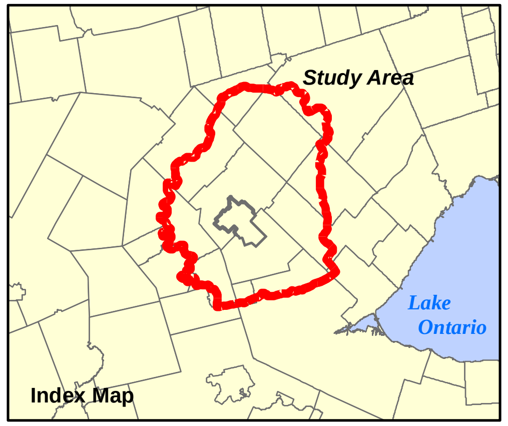
- Groundwater Contours Difference Gasport
- Inferred Groundwater Contours Difference Gasport
- Collector Roads / Local Roads
- Major Roads / Highways
- Rivers / Streams
- Open Water
- Guelph Tier III Model Boundary
- GRCA Watershed Boundary
- City of Guelph Boundary
- Municipal Boundaries

1.19 ⊕ = Head Difference Value (shallow minus deep bedrock hydraulic head (m)
+ = Downward gradient
- = Upward gradient

Scale 1:85,000

1.5 0 1.5 3

Kilometers



REFERENCES:

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Projection: UTM Zone 17N, NAD 83
Map Version: 1; Map Date: 15-Mar-10; Created By: CC/KD

Produced by
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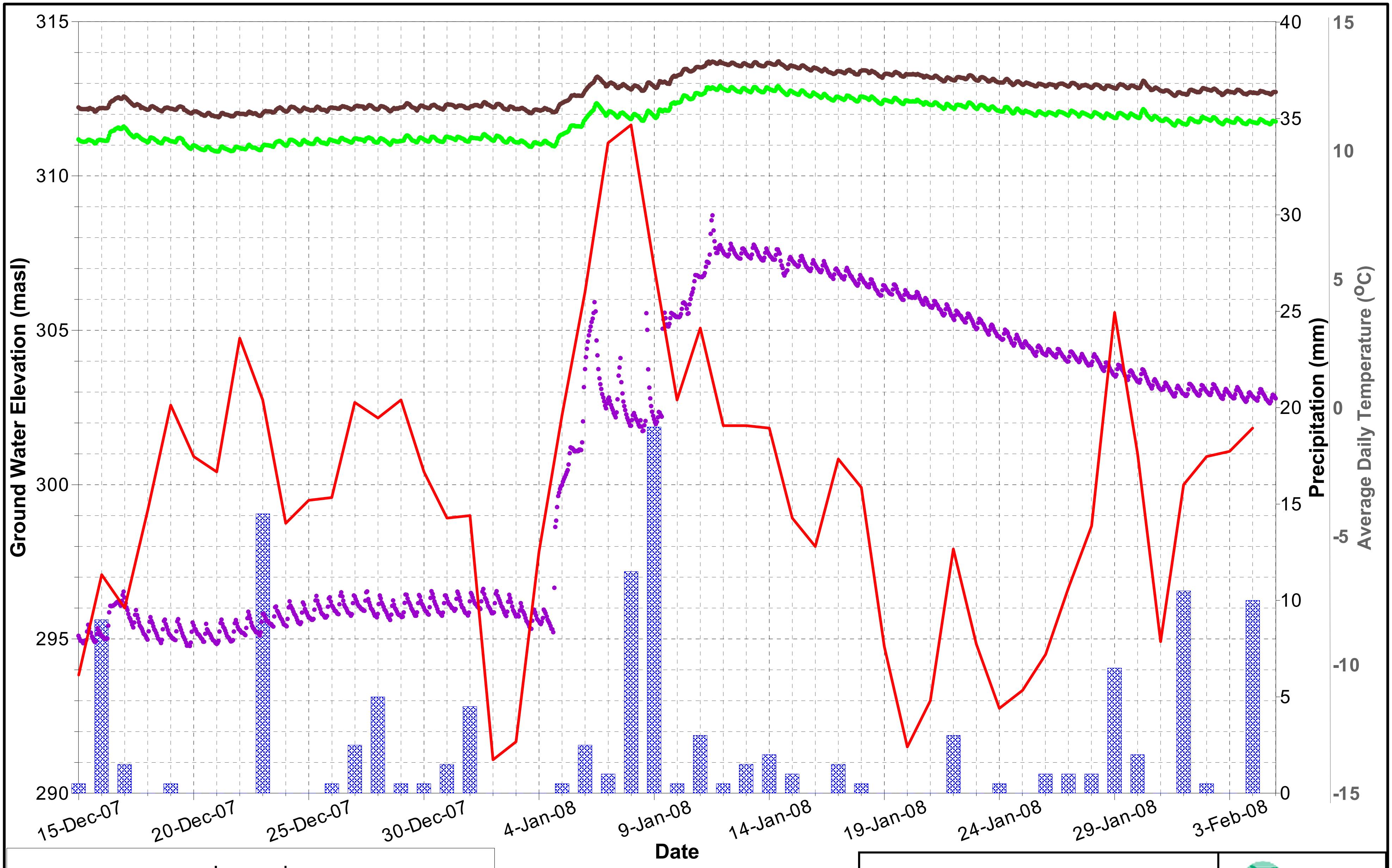
FIGURE: 34

HYDRAULIC HEAD DIFFERENCE BETWEEN SHALLOW AND DEEP BEDROCK

G:\Projects\2008\08-1112-0021_Guelph_TierIII\GIS\MXDs\Final\May_2011_Report\Hydraulic Head Difference Between Shallow and Deep Bedrock.mxd

Project: 08-1112-0021_Guelph_Tier3



Legend

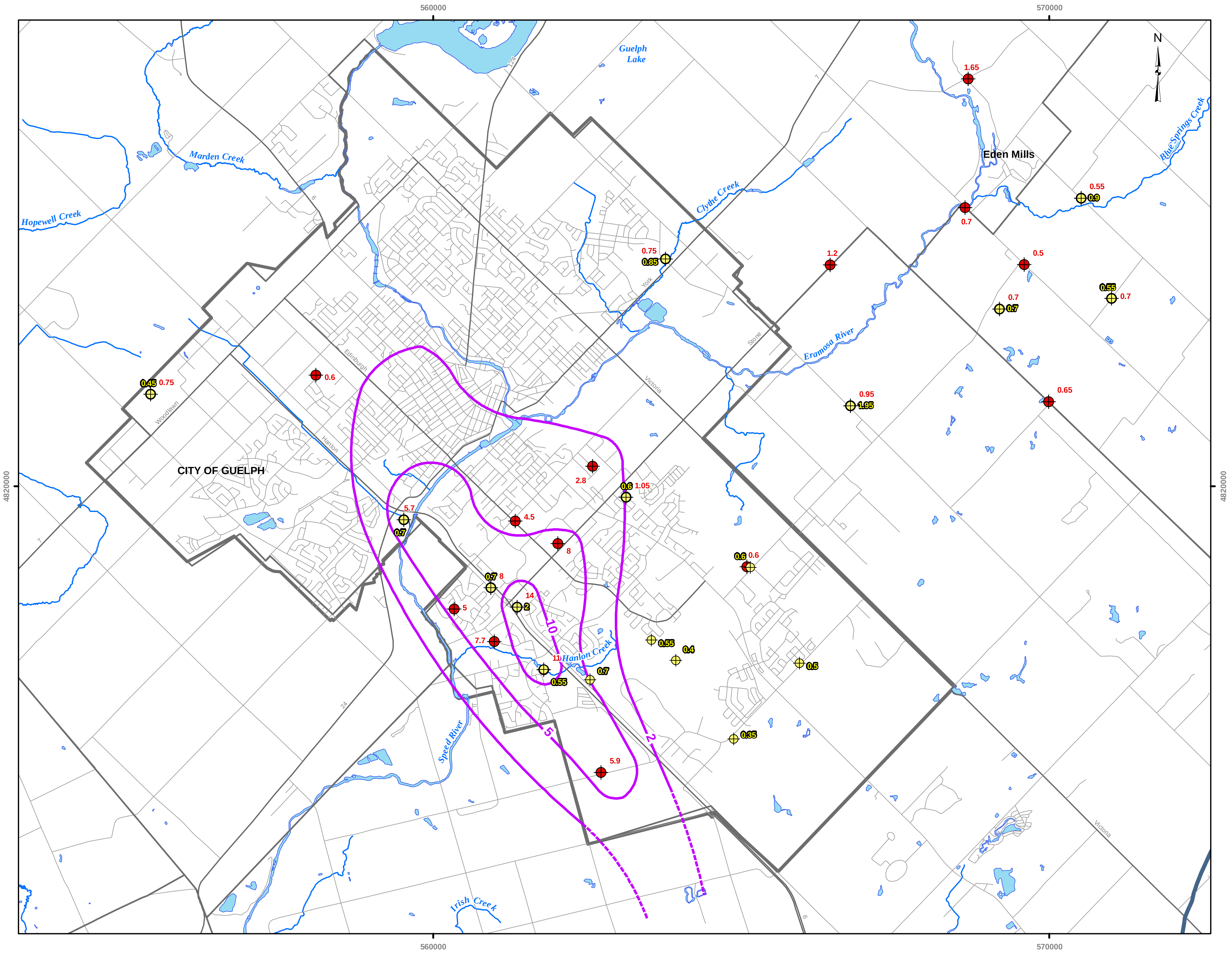
●	TW04-01A	—	Mean Temperature
●	TW04-01B	▨	Precipitation
●	TW04-01C		

City of Guelph
Tier Three Local Area
Risk Assessment

January 2008 Snowmelt Event -
Response at TW04-01

Golder Associates

DRAWN: JLH	APPROVED: JAP	DATE: MAY 2011
PROJECT NO: 08-1112-0021		FIGURE: 35



Tier Three Local Area Risk Assessment

Guelph
Making a Difference

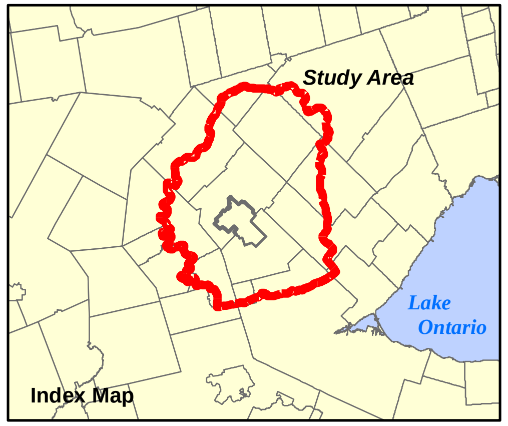
LEGEND

⊕	Shallow Response
⊕	Deep Response
—	Response Contour
—	Collector Roads / Local Roads
—	Major Roads / Highways
—	Rivers / Streams
▭	Open Water
▭	Guelph Tier III Model Boundary
▭	GRCA Watershed Boundary
▭	City of Guelph Boundary
▭	Municipal Boundaries

Scale 1:60,000

1 0 1 2

Kilometers



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Projection: UTM Zone 17N, NAD 83
Map Version: 1; Map Date: 15-Mar-10; Created By: CC/KD

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FIGURE: 36

WATER LEVEL RISE -
JANUARY 2008 MELT EVENT

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Europe	+ 356 21 42 30 20
North America	+ 1 800 275 3281
South America	+ 55 21 3095 9500

solutions@golder.com
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Golder Associates Ltd.
2390 Argentia Road
Mississauga, Ontario, L5N 5Z7
Canada
T: +1 (905) 567 4444

APPENDIX A

Existing Borehole Log Compilation

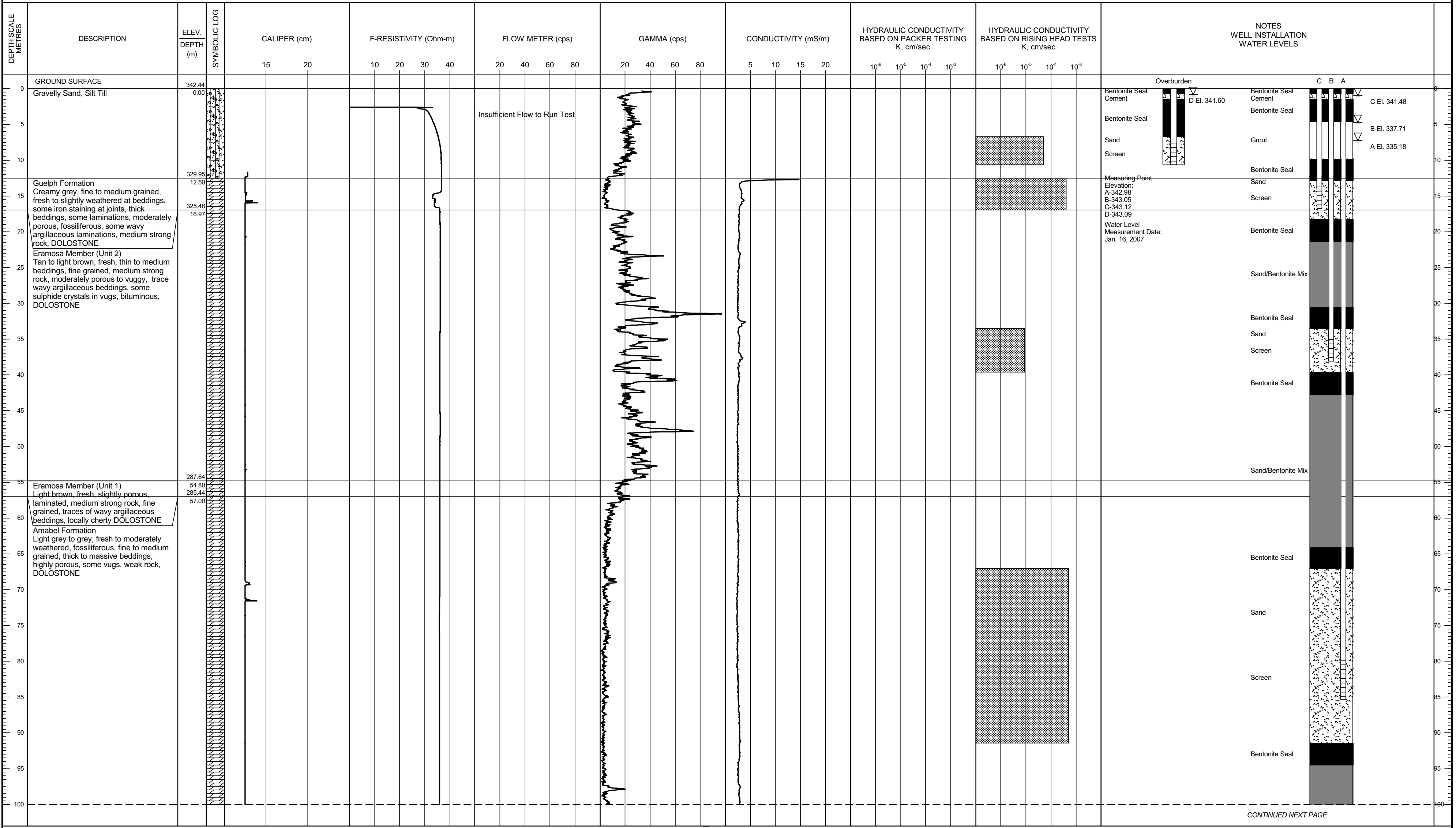
PROJECT: 06-1112-032

LOCATION: N 555406.0 ;E 4821490.0

RECORD OF DRILLHOLE: MW 06-01

SHEET 1 OF 2

DATUM: Geodetic



GROUND SURFACE — 342.44

Description	Elev. / Depth (m)
Gravelly Sand, Silt Till	342.44 0.00
Guelph Formation Creamy grey, fine to medium grained, fresh to slightly weathered at beddings, some iron staining at joints, thick beddings, some laminations, moderately porous, fossiliferous, some wavy argillaceous laminations, medium strong rock, DOLOSTONE	329.95 12.50
Eramosa Member (Unit 2) Tan to light brown, fresh, thin to medium beddings, fine grained, medium strong rock, moderately porous to vuggy, trace wavy argillaceous beddings, some sulphide crystals in vugs, bituminous, DOLOSTONE	325.48 16.97
Eramosa Member (Unit 1) Light brown, fresh, slightly porous, laminated, medium strong rock, fine grained, traces of wavy argillaceous beddings, locally cherty DOLOSTONE	287.64 54.80
Amabel Formation Light grey to grey, fresh to moderately weathered, fossiliferous, fine to medium grained, thick to massive beddings, highly porous, some vugs, weak rock, DOLOSTONE	285.44 57.00

Measuring Point Elevation:
A-342.98
B-343.05
C-343.12
D-343.09

Water Level Measurement Date:
Jan. 16, 2007

CONTINUED NEXT PAGE

DEPTH SCALE
1 : 500

Golder Associates

LOGGED: GY
CHECKED: SD

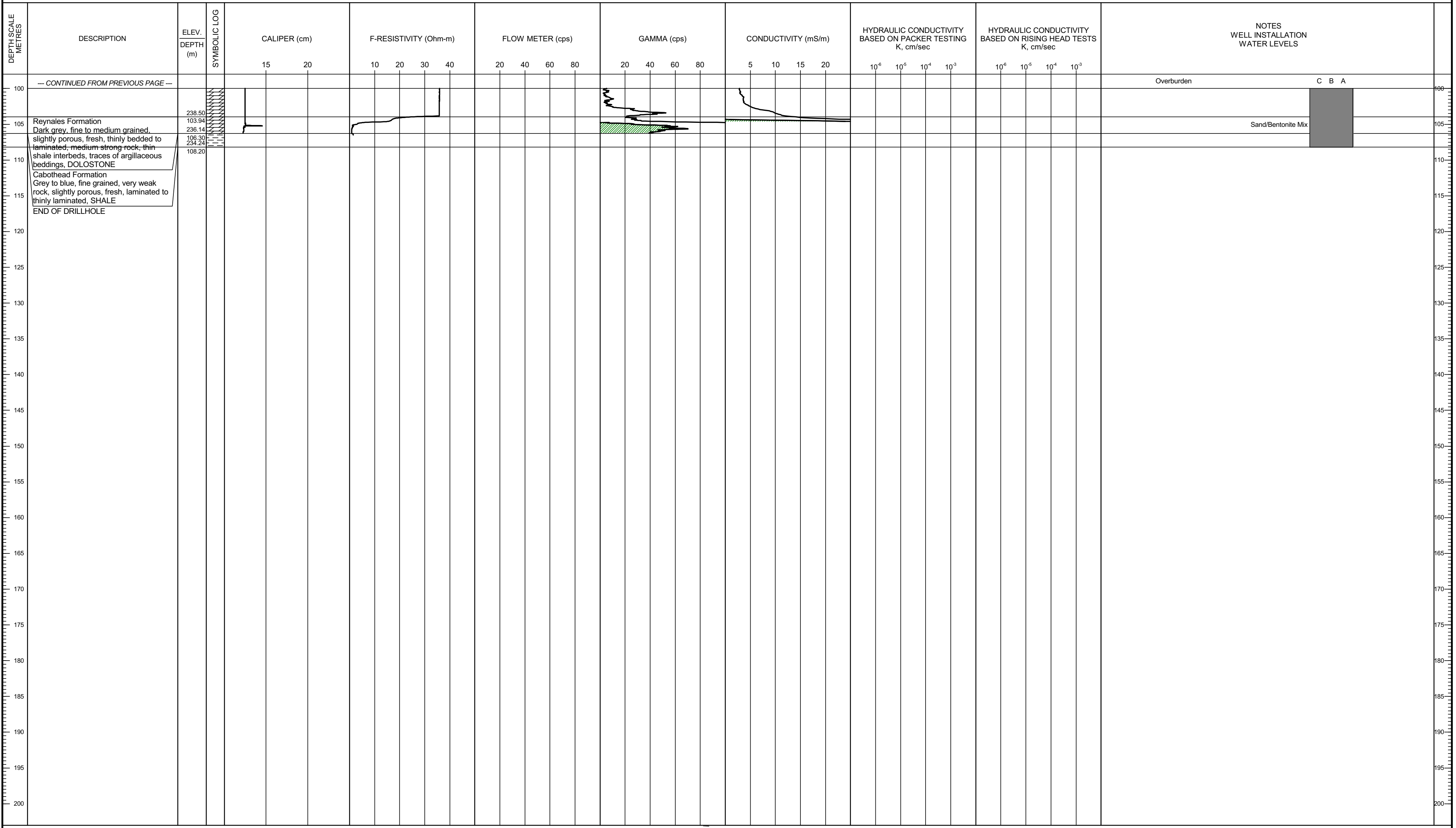
PROJECT: 06-1112-032

LOCATION: N 555406.0 ;E 4821490.0

RECORD OF DRILLHOLE: MW 06-01

SHEET 2 OF 2

DATUM: Geodetic



--- CONTINUED FROM PREVIOUS PAGE ---

DESCRIPTION	ELEV. / DEPTH (m)
Reynales Formation Dark grey, fine to medium grained, slightly porous, fresh, thinly bedded to laminated, medium strong rock, thin shale interbeds, traces of argillaceous beddings, DOLOSTONE	238.50 103.94
Cabothead Formation Grey to blue, fine grained, very weak rock, slightly porous, fresh, laminated to thinly laminated, SHALE	236.14 106.30
END OF DRILLHOLE	234.24 108.20

MIS-GEO 006 06-1112-032.GPJ GAL-MISS.GDT 6/9/08 MSM/RJ

DEPTH SCALE
1 : 500

LOGGED: GY
CHECKED: SD

PROJECT: 06-1112-032

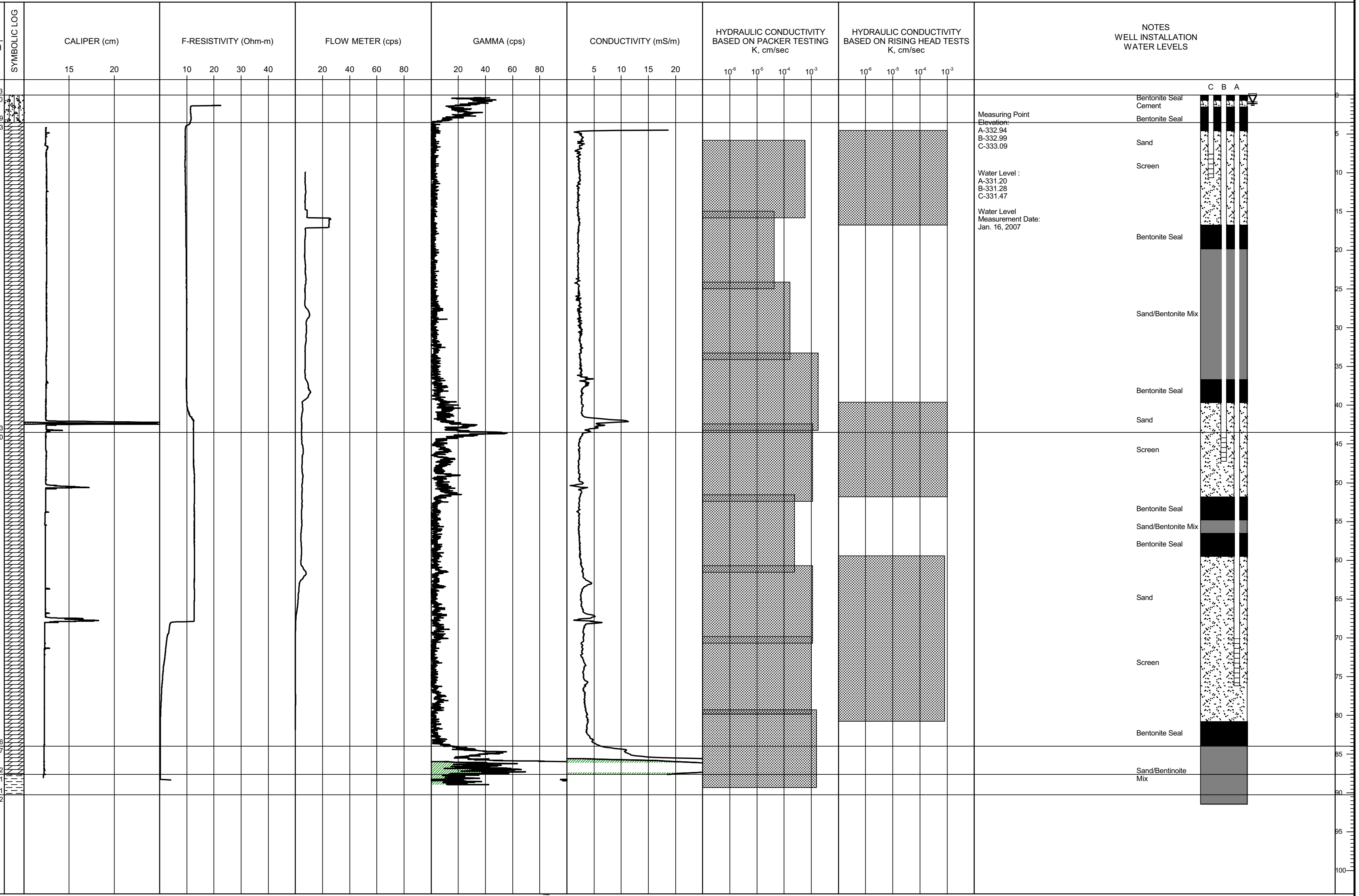
LOCATION: N 558089.8 ;E 4821803.9

RECORD OF DRILLHOLE: MW 06-02

SHEET 1 OF 1

DATUM: Geodetic

DEPTH SCALE METRES	DESCRIPTION	ELEV. / DEPTH (m)
	GROUND SURFACE	332.33
0	Sandy Silt Till	0.00
	Guelph Formation Creamy grey to grey, fresh, medium to thickly bedded, highly porous to vuggy iron staining on some joints, fossiliferous, trace wavy argillaceous beddings, moderately fractured throughout, medium strong rock, some sulphide crystals in vugs, DOLOSTONE	328.79 3.53
	Amabel Formation Dark grey to grey, fresh to moderately weathered, fossiliferous, fine to medium grained, thick to massive beddings, highly porous to vuggy, weak rock, DOLOSTONE - Large cavity encountered at approximately 42.5 m to 43 m - Highly weathered zone from 50.9m to 51.2m - Moderately to highly weathered zone from 67m to 73m	288.83 43.50
	Reynales Formation Dark grey, fine to medium grained, slightly porous, fresh, thinly bedded to laminated, medium strong rock, thin shale interbeds, trace wavy argillaceous beddings, DOLOSTONE	248.36 83.97
	Cabothead Formation Grey to blue, fine grained, very weak rock, slightly porous, fresh, laminated to thinly laminated, SHALE	244.72 87.61
	END OF DRILLHOLE	242.11 90.22



Measuring Point Elevation:
A-332.94
B-332.99
C-333.09

Water Level :
A-331.20
B-331.28
C-331.47

Water Level Measurement Date:
Jan. 16, 2007

DEPTH SCALE

1 : 500

Golder Associates

LOGGED: GY

CHECKED: SD

PROJECT: 06-1112-032

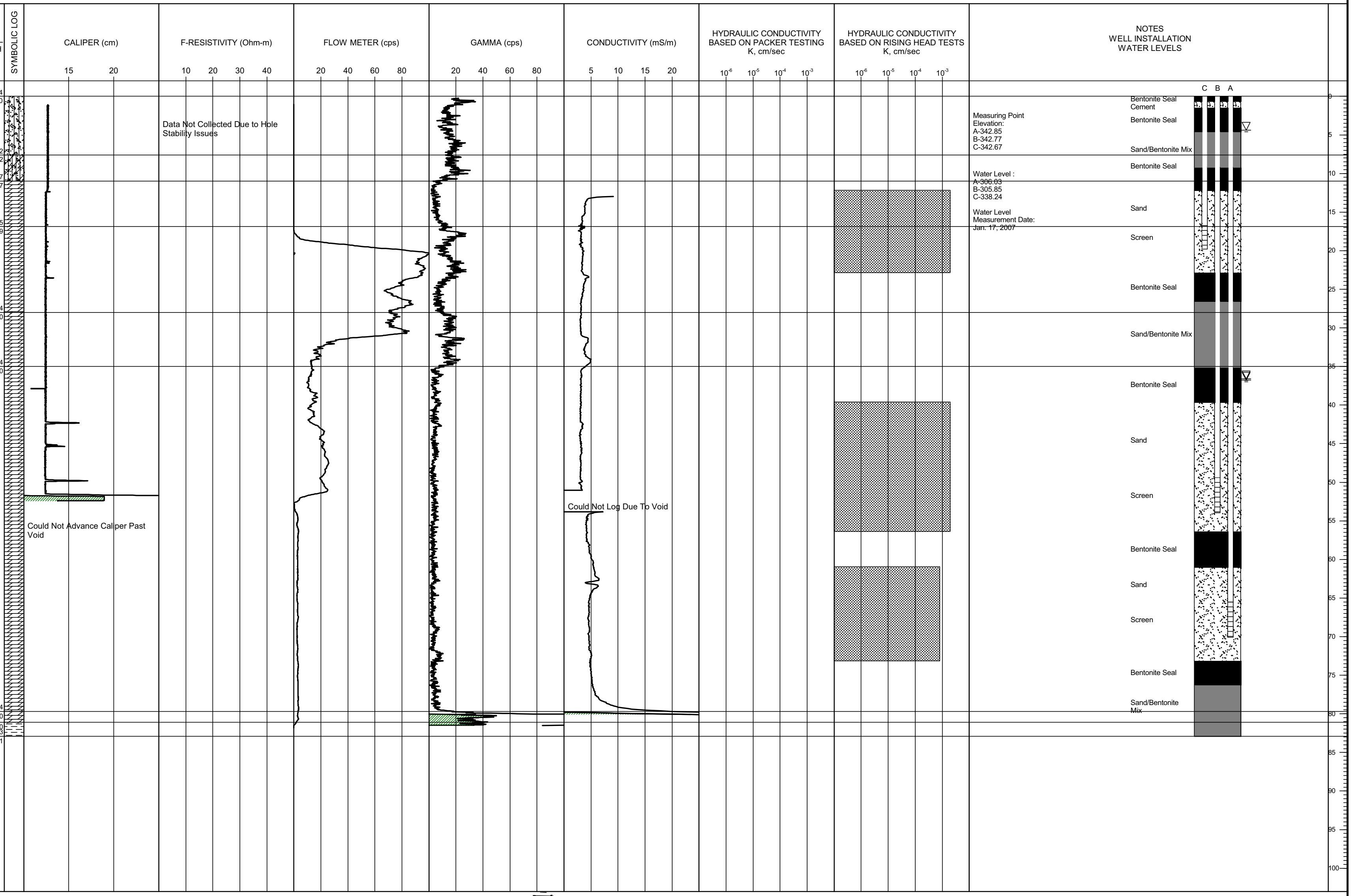
LOCATION: N 559688.0 ;E 4824618.6

RECORD OF DRILLHOLE: MW 06-03

SHEET 1 OF 1

DATUM: Geodetic

DEPTH SCALE METRES	DESCRIPTION	ELEV. DEPTH (m)
	GROUND SURFACE	342.64
0	Silty Sand Till	0.00
		335.02
	Clayey Silt Till	7.62
		331.67
10	Guelph Formation Creamy grey, fresh to slightly weathered at bedding, moderately porous, fine to medium grained, medium to thickly bedded, medium strong rock, trace laminations, some iron staining at joints, trace wavy argillaceous bedding, fossiliferous, DOLOSTONE -Vuggy zone from 18.9m to 22.55m	10.97
		325.75 16.89
	Eramosa Member (Unit 2) Tan to light brown, fresh, thin to medium beddings, fine grained, medium strong rock, moderately porous to vuggy, some wavy argillaceous beddings, trace sulphide crystals in vugs, some fossils, bituminous, DOLOSTONE	
		314.64 28.00
	Eramosa Member (Unit 1) Brown to grey, fresh, moderately porous, thinly bedded, medium strong rock, fine grained, traces of wavy argillaceous beddings, traces of vugs, some sulphide crystals in vugs, locally cherty DOLOSTONE	
		307.64 35.00
	Amabel Formation Dark grey to grey, fresh to moderately weathered, highly fossiliferous, trace wavy argillaceous beddings fine to medium grained, thick to massive beddings, highly porous to vuggy, weak rock, DOLOSTONE - Large Cavity encountered at approximately 52.6m to 53.5m - Moderately to highly weathered from 42.9m to 46.3m , 49.6m to 54m	
		262.94
80	Reynales Formation Grey to light brown, fine to medium grained, slightly porous, fresh, thinly bedded to laminated, trace wavy argillaceous beddings, medium strong rock, DOLOSTONE	79.70
		81.10
	Cabothead Formation grey, fine grained, very weak rock, slightly porous, fresh, laminated to thinly laminated, SHALE	259.73 82.91
	END OF DRILLHOLE	



NOTES
WELL INSTALLATION
WATER LEVELS

Measuring Point
Elevation:
A-342.85
B-342.77
C-342.67

Water Level :
A-306.03
B-305.85
C-338.24

Water Level
Measurement Date:
Jan. 17, 2007

DEPTH SCALE
1 : 500

Golder Associates

LOGGED: GY
CHECKED: SD

PROJECT: 06-1112-032

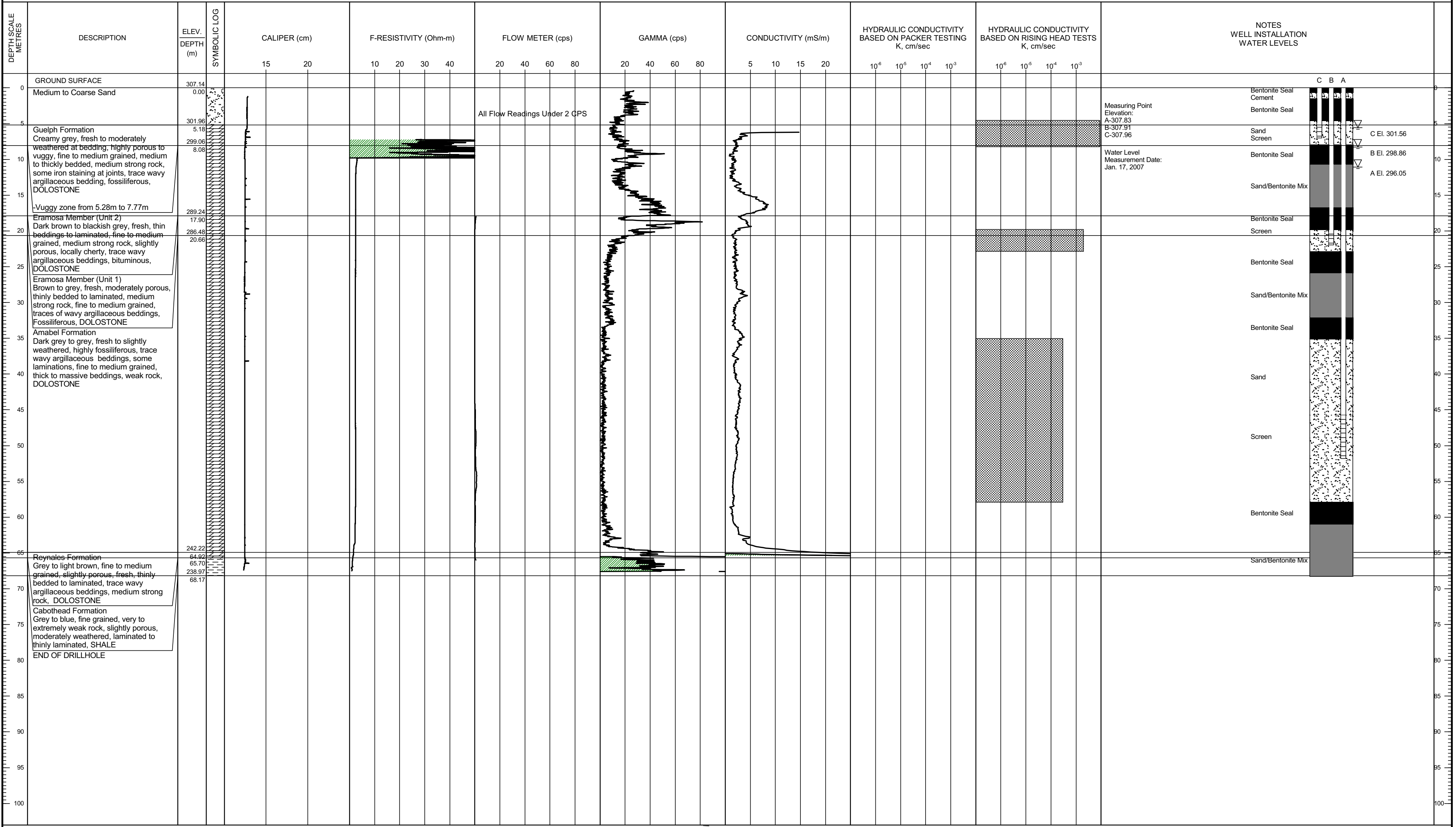
LOCATION: N 559517.6 ;E 4819459.7

RECORD OF DRILLHOLE: MW 06-04

SHEET 1 OF 1

DATUM: Geodetic

DESCRIPTION	ELEV. / DEPTH (m)
GROUND SURFACE	307.14
Medium to Coarse Sand	0.00
Guelph Formation Creamy grey, fresh to moderately weathered at bedding, highly porous to vuggy, fine to medium grained, medium to thickly bedded, medium strong rock, some iron staining at joints, trace wavy argillaceous bedding, fossiliferous, DOLOSTONE -Vuggy zone from 5.28m to 7.77m	301.96 5.18 299.06 8.08
Eramosa Member (Unit 2) Dark brown to blackish grey, fresh, thin beddings to laminated, fine to medium grained, medium strong rock, slightly porous, locally cherty, trace wavy argillaceous beddings, bituminous, DOLOSTONE	289.24 17.90 286.48 20.66
Eramosa Member (Unit 1) Brown to grey, fresh, moderately porous, thinly bedded to laminated, medium strong rock, fine to medium grained, traces of wavy argillaceous beddings, Fossiliferous, DOLOSTONE	
Amabel Formation Dark grey to grey, fresh to slightly weathered, highly fossiliferous, trace wavy argillaceous beddings, some laminations, fine to medium grained, thick to massive beddings, weak rock, DOLOSTONE	
Reynales Formation Grey to light brown, fine to medium grained, slightly porous, fresh, thinly bedded to laminated, trace wavy argillaceous beddings, medium strong rock, DOLOSTONE	242.22 64.92 65.70 238.97 68.17
Cabothead Formation Grey to blue, fine grained, very to extremely weak rock, slightly porous, moderately weathered, laminated to thinly laminated, SHALE	
END OF DRILLHOLE	



Measuring Point
Elevation:
A-307.83
B-307.91
C-307.96

Water Level
Measurement Date:
Jan. 17, 2007

DEPTH SCALE
1 : 500

Golder Associates

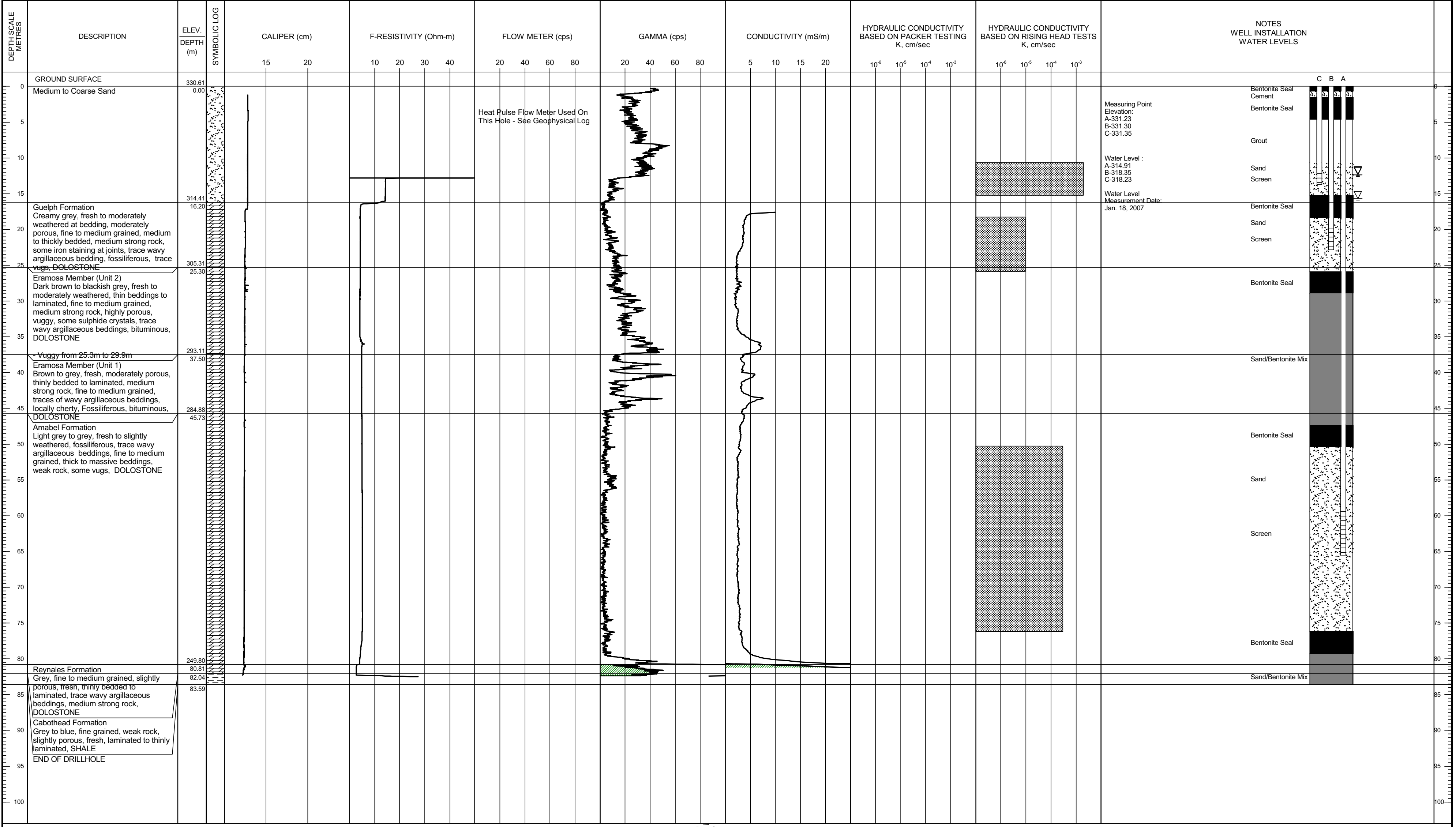
LOGGED: GY
CHECKED: SD

PROJECT: 06-1112-032
LOCATION: N 559803.9 ;E 4820984.9

RECORD OF DRILLHOLE: MW 06-05

SHEET 1 OF 1
DATUM: Geodetic

DEPTH SCALE METRES	DESCRIPTION	ELEV. DEPTH (m)
	GROUND SURFACE	330.61
0	Medium to Coarse Sand	0.00
		314.41
16.20	Guelph Formation Creamy grey, fresh to moderately weathered at bedding, moderately porous, fine to medium grained, medium to thickly bedded, medium strong rock, some iron staining at joints, trace wavy argillaceous bedding, fossiliferous, trace vugs, DOLOSTONE	16.20
		305.31
25.30	Eramosa Member (Unit 2) Dark brown to blackish grey, fresh to moderately weathered, thin beddings to laminated, fine to medium grained, medium strong rock, highly porous, vuggy, some sulphide crystals, trace wavy argillaceous beddings, bituminous, DOLOSTONE - Vuggy from 25.3m to 29.9m	25.30
		293.11
37.50	Eramosa Member (Unit 1) Brown to grey, fresh, moderately porous, thinly bedded to laminated, medium strong rock, fine to medium grained, traces of wavy argillaceous beddings, locally cherty, Fossiliferous, bituminous, DOLOSTONE	37.50
		284.88
45.73	Amabel Formation Light grey to grey, fresh to slightly weathered, fossiliferous, trace wavy argillaceous beddings, fine to medium grained, thick to massive beddings, weak rock, some vugs, DOLOSTONE	45.73
		249.80
80.81	Reynales Formation Grey, fine to medium grained, slightly porous, fresh, thinly bedded to laminated, trace wavy argillaceous beddings, medium strong rock, DOLOSTONE	80.81
82.04	Cabothead Formation Grey to blue, fine grained, weak rock, slightly porous, fresh, laminated to thinly laminated, SHALE	82.04
83.59	END OF DRILLHOLE	83.59



Heat Pulse Flow Meter Used On This Hole - See Geophysical Log

Measuring Point
Elevation:
A-331.23
B-331.30
C-331.35

Water Level :
A-314.91
B-318.35
C-318.23

Water Level
Measurement Date:
Jan. 18, 2007

DEPTH SCALE
1 : 500

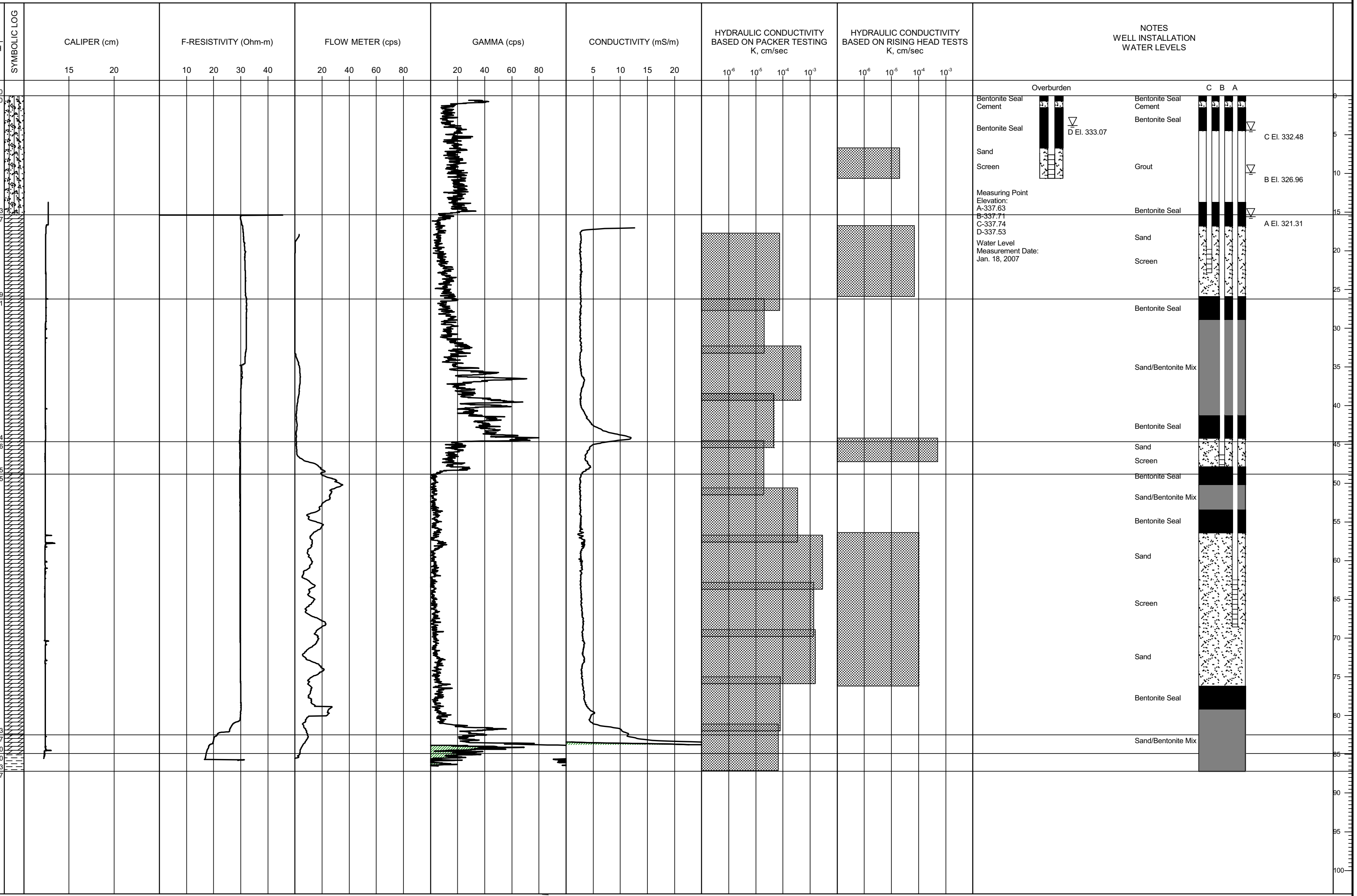
LOGGED: GY
CHECKED: SD

PROJECT: 06-1112-032
LOCATION: N 563132.0 ;E 4819826.5

RECORD OF DRILLHOLE: MW 06-06

SHEET 1 OF 1
DATUM: Geodetic

DEPTH SCALE METRES	DESCRIPTION	ELEV. DEPTH (m)
	GROUND SURFACE	336.90
0	Sandy Silt Till	0.00
15	Guelph Formation Creamy grey, fresh, moderately porous, fine to medium grained, medium to thickly bedded, medium strong rock, some iron staining at joints, trace wavy argillaceous bedding, fossiliferous, trace vugs, DOLOSTONE	321.53 15.37
26	Eramosa Member (Unit 2) Dark brown to blackish grey, fresh, thin beddings to laminated, fine to medium grained, medium strong rock, slightly porous, trace vugs, trace sulphide crystals, some wavy argillaceous beddings, bituminous, DOLOSTONE	310.69 26.21
45	Eramosa Member (Unit 1) Grey, fresh, slightly porous, thinly bedded to laminated, medium strong rock, fine to medium grained, traces of wavy argillaceous beddings, Fossiliferous, locally cherty, DOLOSTONE	292.24 44.66
49	Amabel Formation Light grey to grey, moderately to highly weathered, fossiliferous, trace wavy argillaceous beddings, fine to medium grained, thick to massive beddings, weak rock, some vugs, trace sulphide crystals, DOLOSTONE - Moderately to highly weathered zone from 56m to 61.3m	288.05 48.85
82	Reynales Formation Grey, fine to medium grained, slightly porous, fresh, thinly bedded to laminated, trace wavy argillaceous beddings, medium strong rock, DOLOSTONE	254.43 82.47
85	Cabothead Formation Grey, fine grained, weak rock, slightly porous, fresh to moderately weathered, laminated to thinly laminated, SHALE	252.00 84.90
87	END OF DRILLHOLE	249.73 87.17



Measuring Point
Elevation:
A-337.63
B-337.71
C-337.74
D-337.53

Water Level
Measurement Date:
Jan. 18, 2007

DEPTH SCALE
1 : 500

Golder Associates

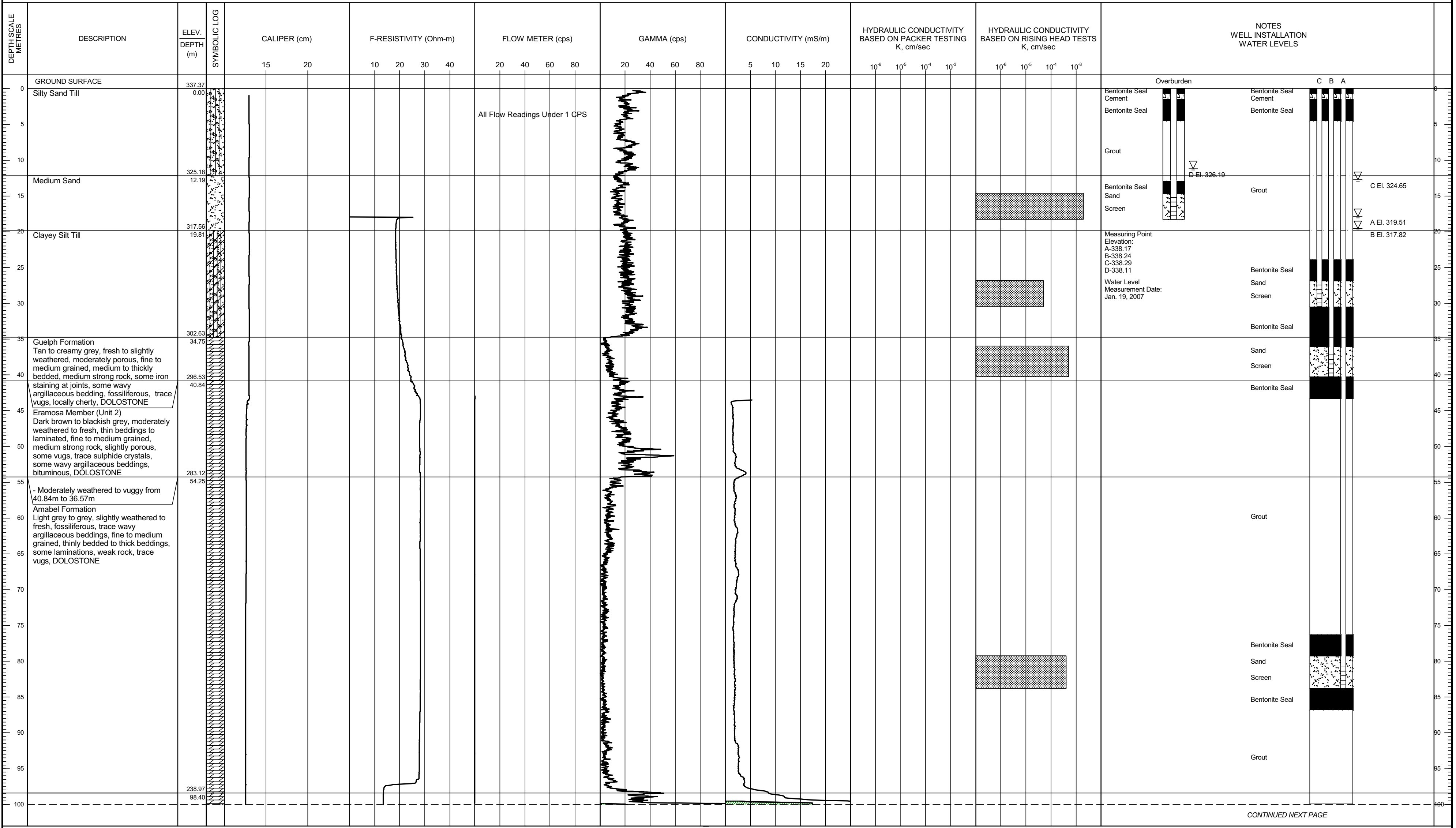
LOGGED: GY
CHECKED: SD

MIS-GEO 006 06-1112-032.GPJ GAL-MISS.GDT 6/9/08 MSM/RJ

PROJECT: 06-1112-032
LOCATION: N 565685.4 ;E 4813871.7

RECORD OF DRILLHOLE: MW 06-07

SHEET 1 OF 2
DATUM: Geodetic



GROUND SURFACE

Silty Sand Till

Medium Sand

Clayey Silt Till

Guelph Formation
Tan to creamy grey, fresh to slightly weathered, moderately porous, fine to medium grained, medium to thickly bedded, medium strong rock, some iron staining at joints, some wavy argillaceous bedding, fossiliferous, trace vugs, locally cherty, DOLOSTONE

Eramosa Member (Unit 2)
Dark brown to blackish grey, moderately weathered to fresh, thin beddings to laminated, fine to medium grained, medium strong rock, slightly porous, some vugs, trace sulphide crystals, some wavy argillaceous beddings, bituminous, DOLOSTONE

- Moderately weathered to vuggy from 40.84m to 36.57m

Amabel Formation
Light grey to grey, slightly weathered to fresh, fossiliferous, trace wavy argillaceous beddings, fine to medium grained, thinly bedded to thick beddings, some laminations, weak rock, trace vugs, DOLOSTONE

Measuring Point
Elevation:
A-338.17
B-338.24
C-338.29
D-338.11

Water Level
Measurement Date:
Jan. 19, 2007

CONTINUED NEXT PAGE

DEPTH SCALE
1 : 500

Golder Associates

LOGGED: GY
CHECKED: SD

PROJECT: 06-1112-032

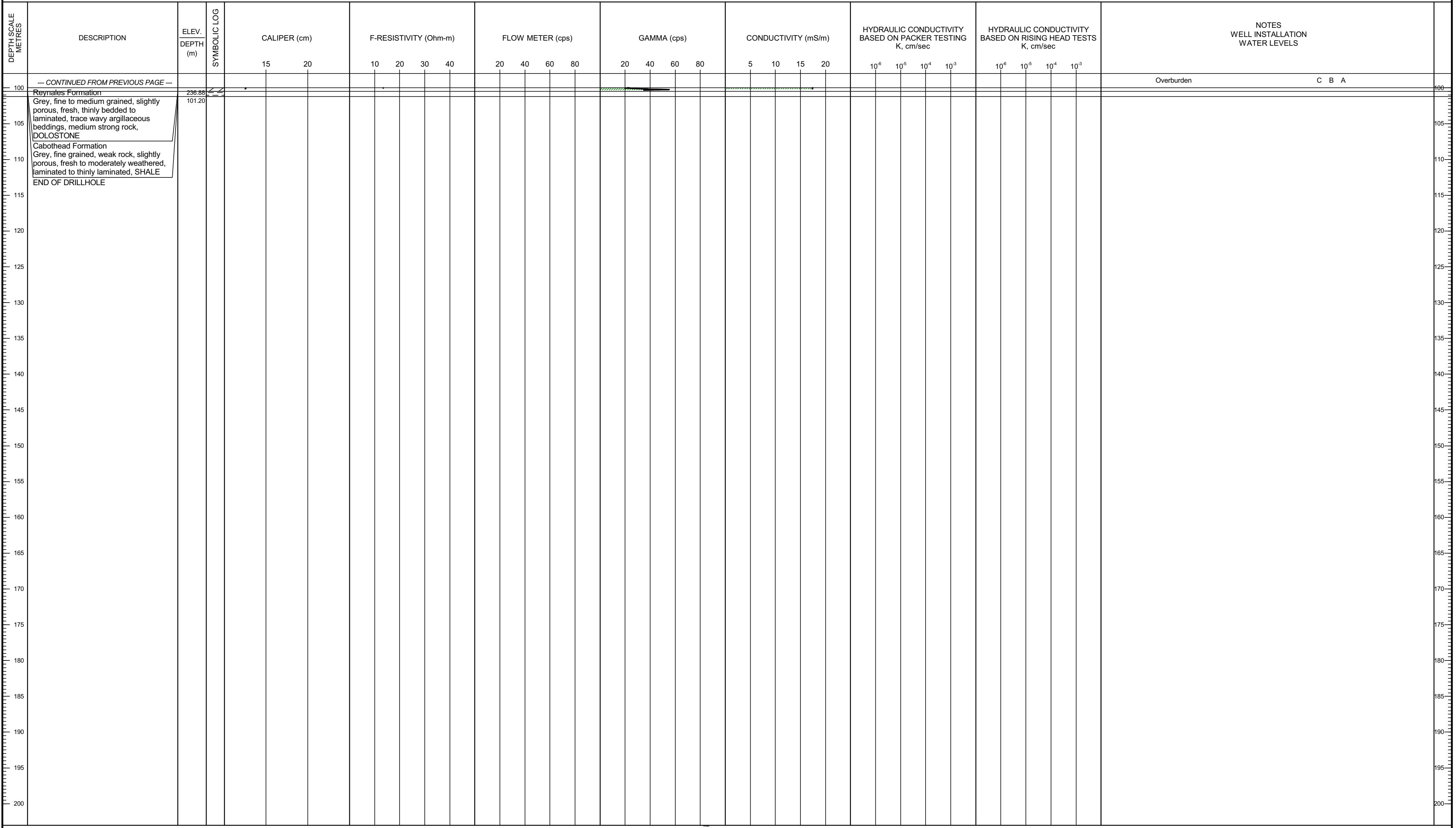
LOCATION: N 565685.4 ;E 4813871.7

RECORD OF DRILLHOLE: MW 06-07

SHEET 2 OF 2

DATUM: Geodetic

DEPTH SCALE METRES	DESCRIPTION	ELEV. / DEPTH (m)	SYMBOLIC LOG
	--- CONTINUED FROM PREVIOUS PAGE ---		
100	Reynales Formation Grey, fine to medium grained, slightly porous, fresh, thinly bedded to laminated, trace wavy argillaceous beddings, medium strong rock, DOLOSTONE	236.88 101.20	
	Cabothead Formation Grey, fine grained, weak rock, slightly porous, fresh to moderately weathered, laminated to thinly laminated, SHALE		
	END OF DRILLHOLE		



DEPTH SCALE

1 : 500

LOGGED: GY

CHECKED: SD

PROJECT: 06-1112-032

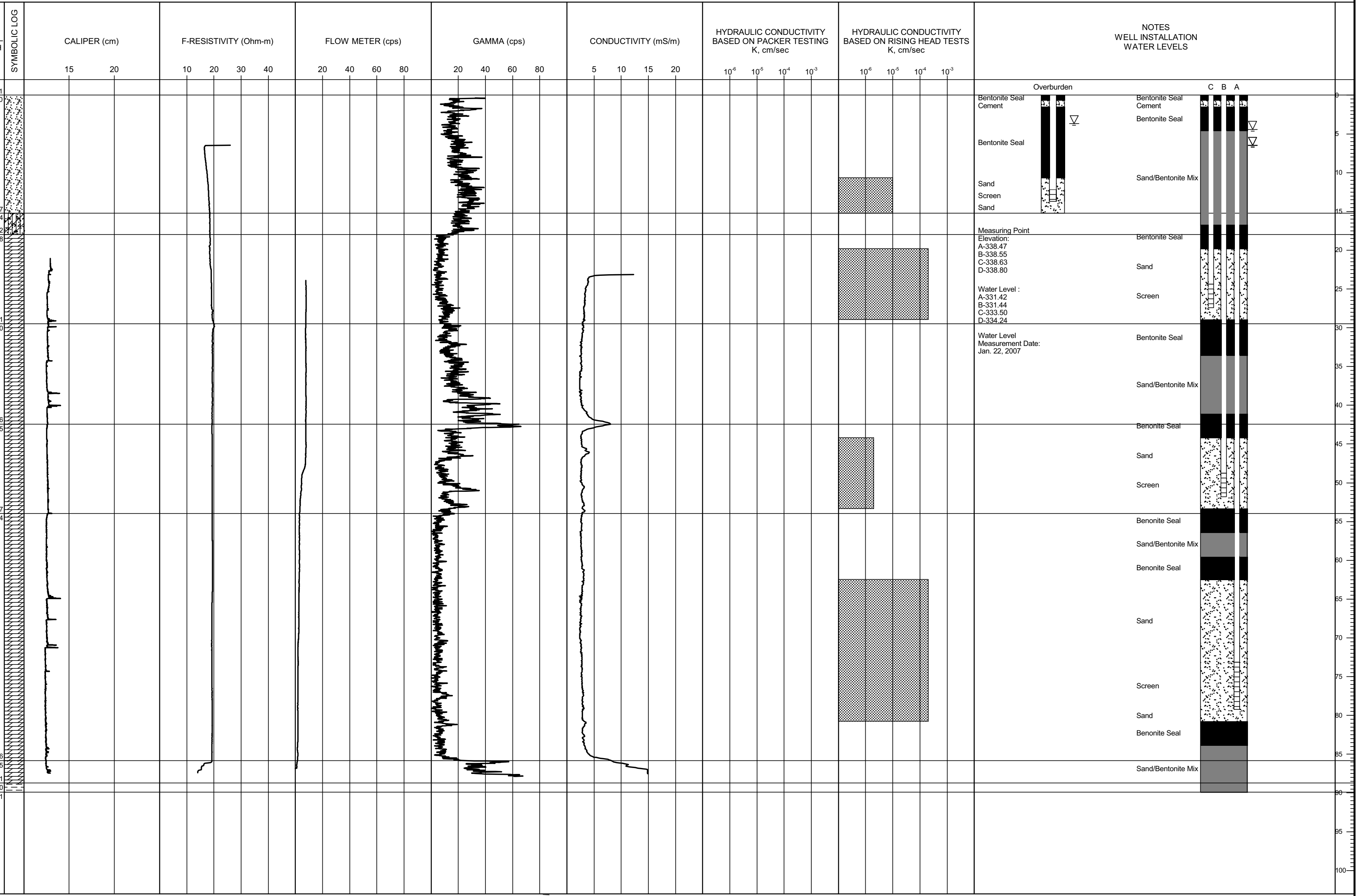
LOCATION: N 565946.2 ;E 4817134.5

RECORD OF DRILLHOLE: MW 06-08

SHEET 1 OF 1

DATUM: Geodetic

DESCRIPTION	ELEV.	DEPTH (m)
GROUND SURFACE	337.91	
Silty Sand and Gravel		0.00
Clayey Silt Till	322.67	15.24
Guelph Formation Tan to creamy grey, fresh to slightly weathered, moderately porous, fine to medium grained, medium to thickly bedded, medium strong rock, trace iron staining at joints, trace wavy argillaceous bedding, fossiliferous, trace vugs, locally cherty, DOLOSTONE	319.92	17.98
Eramosa Member (Unit 2) Dark brown to blackish grey, moderately weathered to fresh, thin beddings to laminated, fine to medium grained, medium strong rock, slightly porous, some vugs, trace sulphide crystals, trace wavy argillaceous beddings, fossiliferous, ituminous, DOLOSTONE - Moderate weathered zone from 33.5 to 35m - Highly weathered zone from 39.3m to 41.4m	308.41	29.50
Eramosa Member (Unit 1) Grey, fresh, slightly porous, thinly bedded to laminated, medium strong rock, fine to medium grained, traces of wavy argillaceous beddings, fossiliferous, locally cherty, traces of stylolites, DOLOSTONE	295.46	42.45
Amabel Formation Light grey to grey, slightly weathered to fresh, fossiliferous, trace wavy argillaceous beddings, fine to medium grained,thick beddings to massive, some laminations, trace stylolites, weak rock, trace vugs, DOLOSTONE - Highly to moderately weathered zone from 74.7m to 80.8m	283.97	53.94
Reynales Formation Grey, fine to medium grained, slightly porous, fresh, thinly bedded to laminated, trace wavy argillaceous beddings, medium strong rock, DOLOSTONE	252.06	85.85
Cabothead Formation Grey, fine grained, weak rock, slightly porous, fresh to moderately weathered, laminated to thinly laminated, SHALE	249.21	88.70
END OF DRILLHOLE		89.91



Measuring Point
Elevation:
A-338.47
B-338.55
C-338.63
D-338.80

Water Level :
A-331.42
B-331.44
C-333.50
D-334.24

Water Level
Measurement Date:
Jan. 22, 2007

DEPTH SCALE
1 : 500

Golder Associates

LOGGED: GY
CHECKED: SD

PROJECT: 06-1112-032

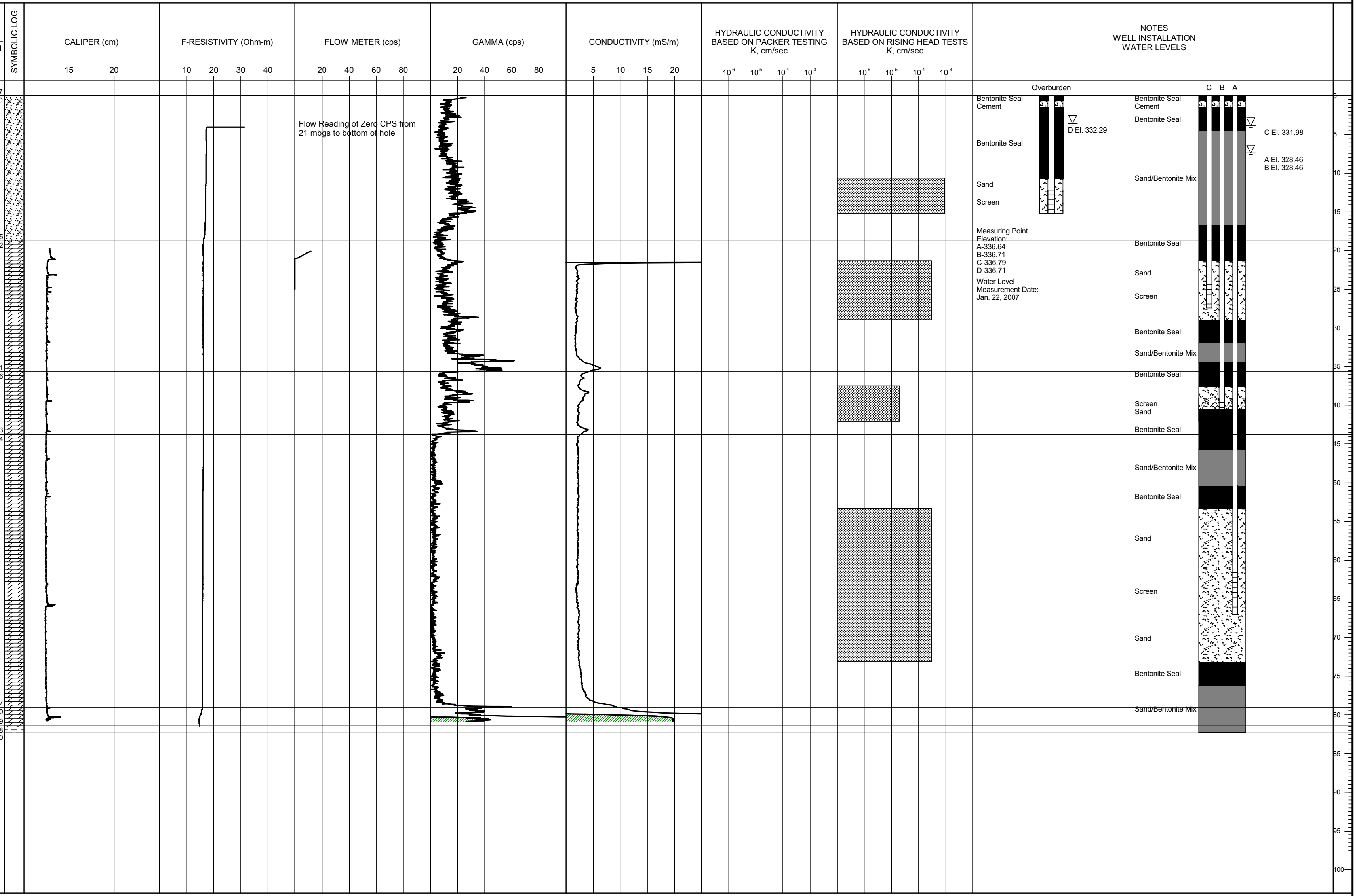
LOCATION: N 566130.2 ;E 4818503.0

RECORD OF DRILLHOLE: MW 06-09

SHEET 1 OF 1

DATUM: Geodetic

DEPTH SCALE METRES	DESCRIPTION	ELEV. / DEPTH (m)
	GROUND SURFACE	335.87
0	Silty Sand and Gravel	0.00
		317.15
20	Eramosa Member (Unit 2) Dark brown to blackish grey, moderately weathered to fresh, thin beddings to laminated, fine to medium grained, medium strong rock, slightly porous, some vugs, trace sulphide crystals, trace wavy argillaceous beddings, fossiliferous, locally cherty, bituminous, DOLOSTONE - Moderately to highly weathered zone with some vugs from 22.86m to 28m	18.72
		300.21
35	Eramosa Member (Unit 1) Grey to dark grey, fresh, slightly porous, thinly bedded to laminated, medium strong rock, fine to medium grained, traces of wavy argillaceous beddings, traces of fossils, locally cherty, traces of stylolites, DOLOSTONE	35.66
		292.13
45	Amabel Formation Light grey to grey, moderately weathered to fresh, fossiliferous, trace wavy argillaceous beddings, fine to medium grained, thick beddings to massive, some laminations, trace stylolites, weak rock, trace vugs, DOLOSTONE - Moderately weathered zone with vugs from 63.39m to 67.1m	43.74
		256.87
80	Reynales Formation Grey, fine to medium grained, slightly porous, fresh, thin beddings to laminated, trace wavy argillaceous beddings, medium strong rock, trace shale interbeds, DOLOSTONE	79.00
		254.49
	Cabothead Formation Grey, fine grained, weak rock, slightly porous, fresh to slightly weathered, laminated to thinly laminated, SHALE	81.38
	END OF DRILLHOLE	82.30



Measuring Point Elevation:
A-336.64
B-336.71
C-336.79
D-336.71

Water Level Measurement Date:
Jan. 22, 2007

DEPTH SCALE
1 : 500

Golder Associates

LOGGED: GY
CHECKED: SD

MIS-GEO 006 06-1112-032.GPJ GAL-MISS.GDT 6/9/08 MSM/RJ

PROJECT: 06-1112-032

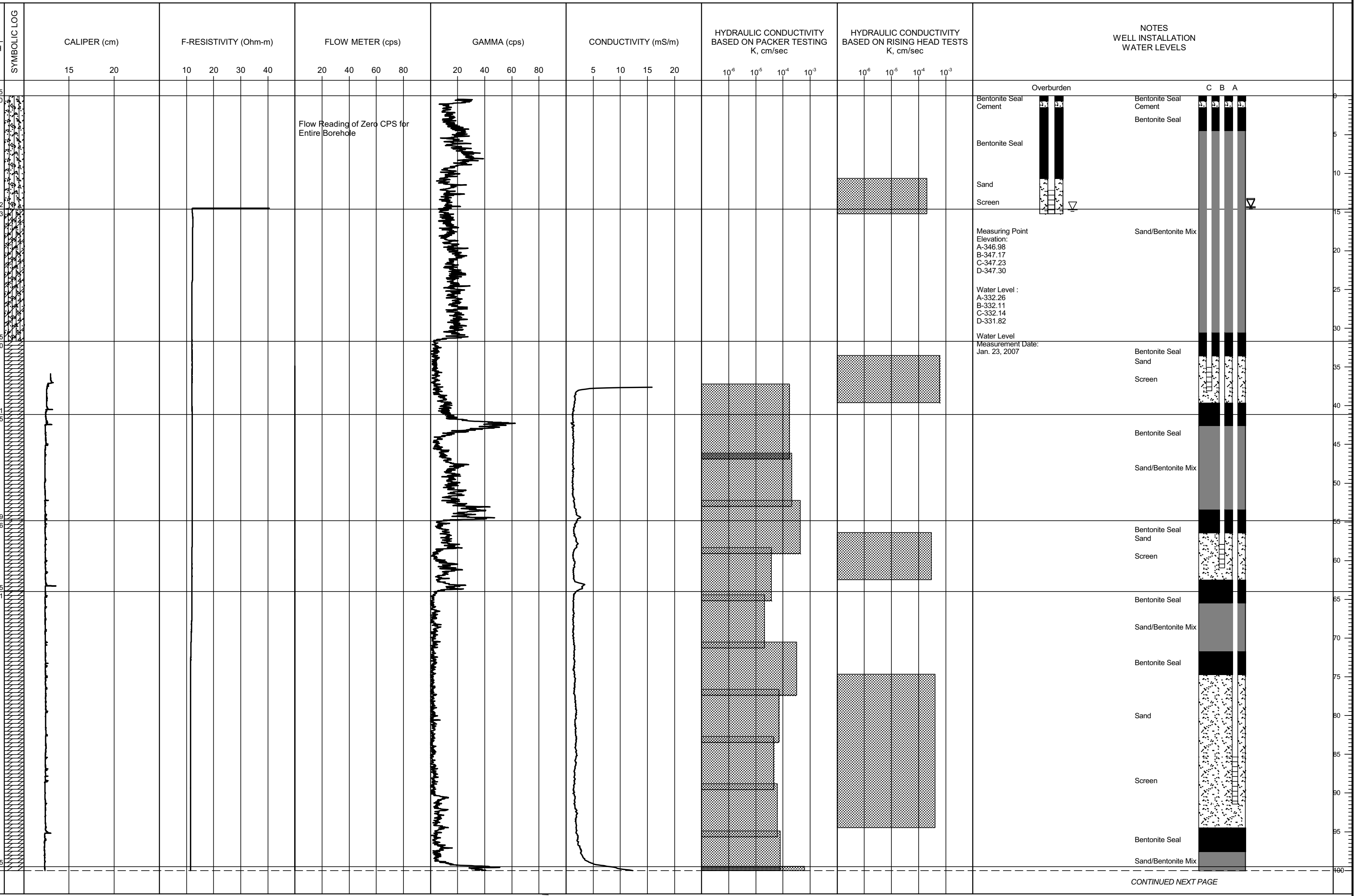
LOCATION: N 567678.8 ;E 4817480.8

RECORD OF DRILLHOLE: MW 06-10

SHEET 1 OF 2

DATUM: Geodetic

DEPTH SCALE METRES	DESCRIPTION	ELEV. / DEPTH (m)
	GROUND SURFACE	346.55
0	Silty Sand Till	0.00
15	Clayey Silt Till	331.92 14.63
31.70	Guelph Formation Tan to creamy grey, fresh to slightly weathered, moderately porous, fine to medium grained, medium to thickly bedded, medium strong rock, trace iron staining at joints, trace wavy argillaceous bedding, fossiliferous, trace vugs, trace sulphide crystals in vugs, traces of stylolites, DOLOSTONE	314.85 31.70
41.15	Eramosa Member (Unit 2) Dark brown to blackish grey, slightly weathered to fresh, thin beddings to laminated, fine to medium grained, medium strong rock, slightly porous, some vugs, trace sulphide crystals, trace wavy argillaceous beddings, fossiliferous, locally cherty, bituminous, DOLOSTONE	305.41 41.15
54.86	Eramosa Member (Unit 1) Grey to dark grey, fresh, slightly porous, thinly bedded to laminated, medium strong rock, fine to medium grained, traces of wavy argillaceous beddings, occassional fossils, traces of stylolites, DOLOSTONE	291.69 54.86
64.01	Amabel Formation Light grey to grey, slightly weathered to fresh, fossiliferous, trace wavy argillaceous beddings, fine to medium grained, thick beddings to massive, some laminations, trace stylolites, weak rock, trace vugs, locally cherty, DOLOSTONE	282.55 64.01
100		247.05



Flow Reading of Zero CPS for Entire Borehole

Measuring Point
Elevation:
A-346.98
B-347.17
C-347.23
D-347.30

Water Level :
A-332.26
B-332.11
C-332.14
D-331.82

Water Level
Measurement Date:
Jan. 23, 2007

CONTINUED NEXT PAGE

DEPTH SCALE
1 : 500

Golder Associates

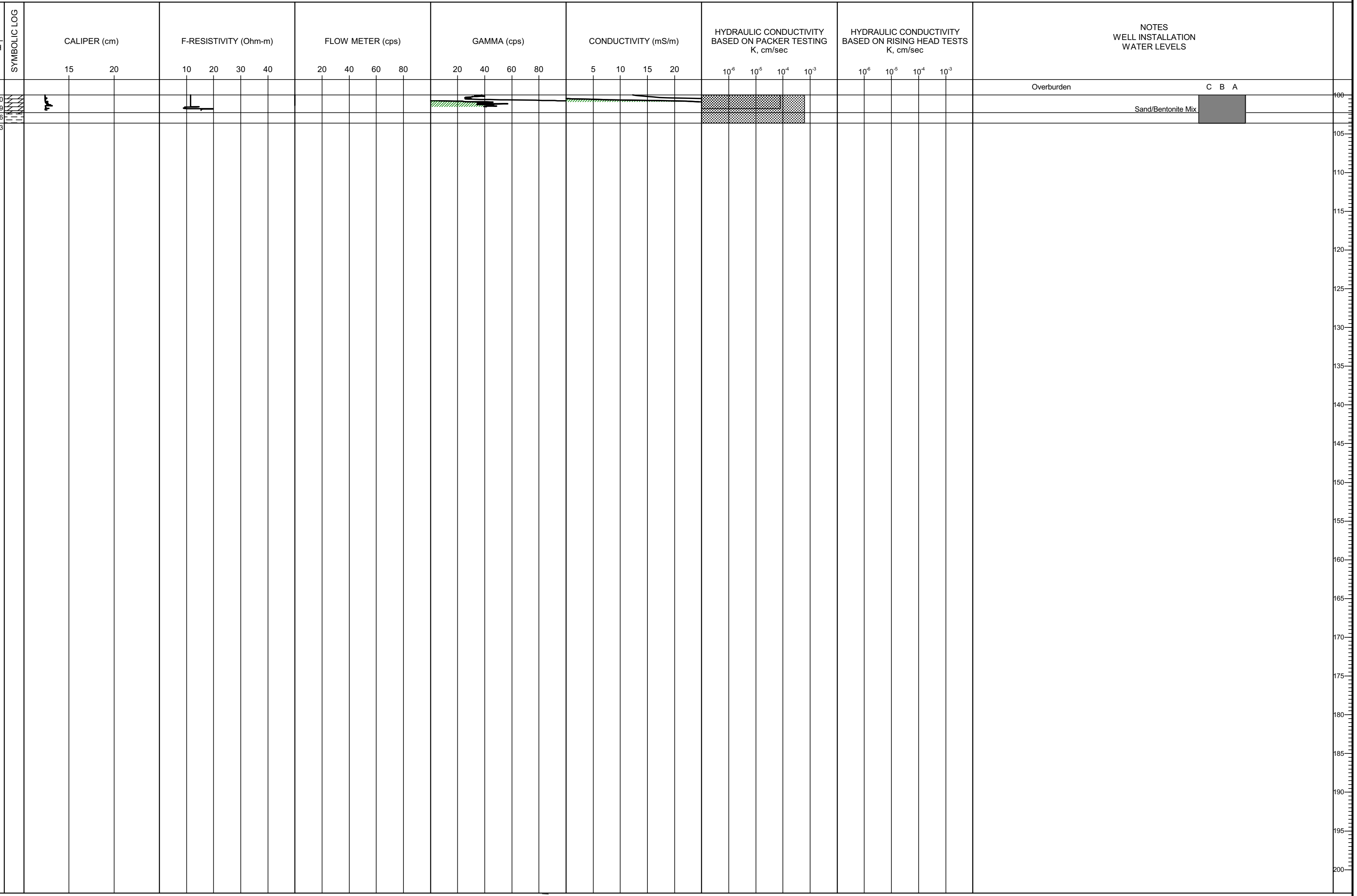
LOGGED: GY
CHECKED: SD

PROJECT: 06-1112-032
LOCATION: N 567678.8 ;E 4817480.8

RECORD OF DRILLHOLE: MW 06-10

SHEET 2 OF 2
DATUM: Geodetic

DEPTH SCALE METRES	DESCRIPTION	ELEV. / DEPTH (m)
	--- CONTINUED FROM PREVIOUS PAGE ---	
100	Reynales Formation Grey, fine to medium grained, slightly porous, fresh, thin beddings to laminated, trace wavy argillaceous beddings, medium strong rock, locally cherty, trace shale interbeds, DOLOSTONE	99.50 244.29
	Cabothead Formation Grey, fine grained, weak rock, slightly porous, fresh to slightly weathered, laminated to thinly laminated, SHALE	102.26
	END OF DRILLHOLE	103.63



DEPTH SCALE
1 : 500

Golder Associates

LOGGED: GY
CHECKED: SD

PROJECT: 06-1112-032

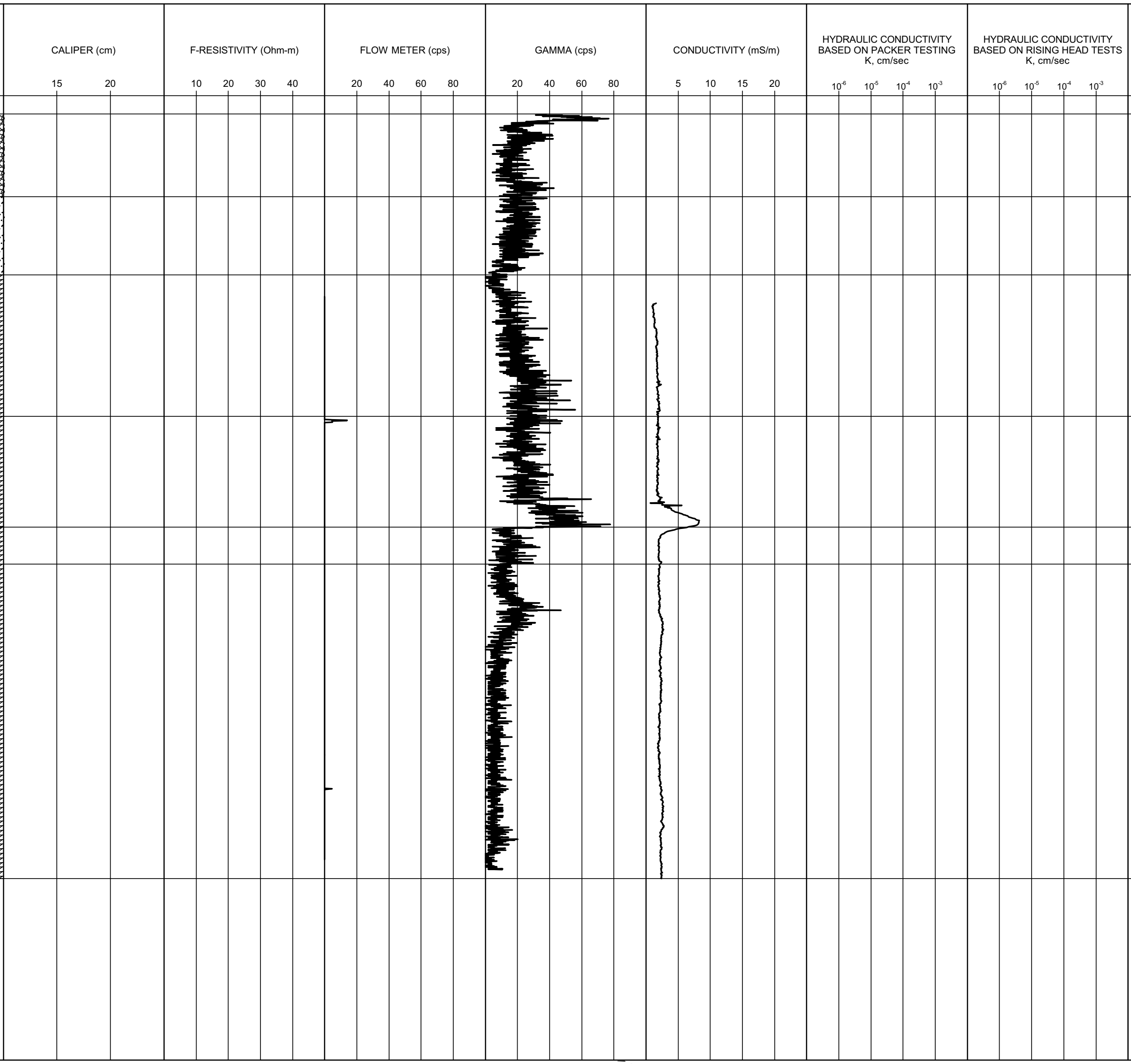
LOCATION: N 564875.6 ;E 4815908.6

RECORD OF DRILLHOLE: Clair Well

SHEET 1 OF 1

DATUM: Geodetic

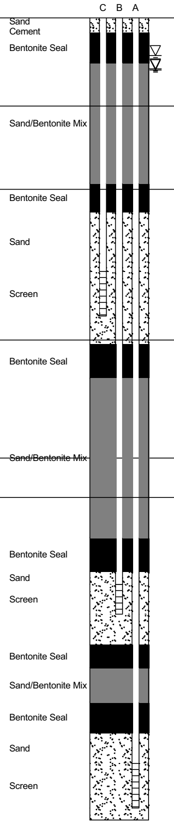
DEPTH SCALE METRES	DESCRIPTION	ELEV. DEPTH (m)
	GROUND SURFACE	333.71
0	Gravel, Cobbles and Boulders	0.00
		324.71
10	Sandy Silt Till	9.00
		316.21
17.5	Guelph Formation Light brown, rock, DOLOSTONE - Water bearing zone at 19.8m, 29m, 32.61m, and 37.19m	17.50
		300.81
32.9	Eramosa Member (Unit 2) Dark brown, rock, DOLOSTONE	32.90
		288.71
45	Eramosa Member (Unit 1) Dark grey, rock, DOLOSTONE	45.00
		284.71
49	Amabel Formation Light grey, DOLOSTONE - Water bearing zone at 57.91m, 63.7m, and 76.2m	49.00
		250.45
83.26	END OF DRILLHOLE Note: 1. Well log based on description provided in MOE Well Record No. 670-0932	83.26



NOTES
WELL INSTALLATION
WATER LEVELS

Measuring Point
Elevation:
A-334.36
B-334.23
C-334.19

Water Level :
A-328.41
B-328.51
C-329.86
Water Level
Measurement Date:
Apr. 25, 2007



DEPTH SCALE
1 : 500

Golder Associates

LOGGED: KS
CHECKED: SMD

PROJECT: 06-1112-032

LOCATION: N 561281.9 ;E 4823857.3

RECORD OF DRILLHOLE: Eastview Well

SHEET 1 OF 1

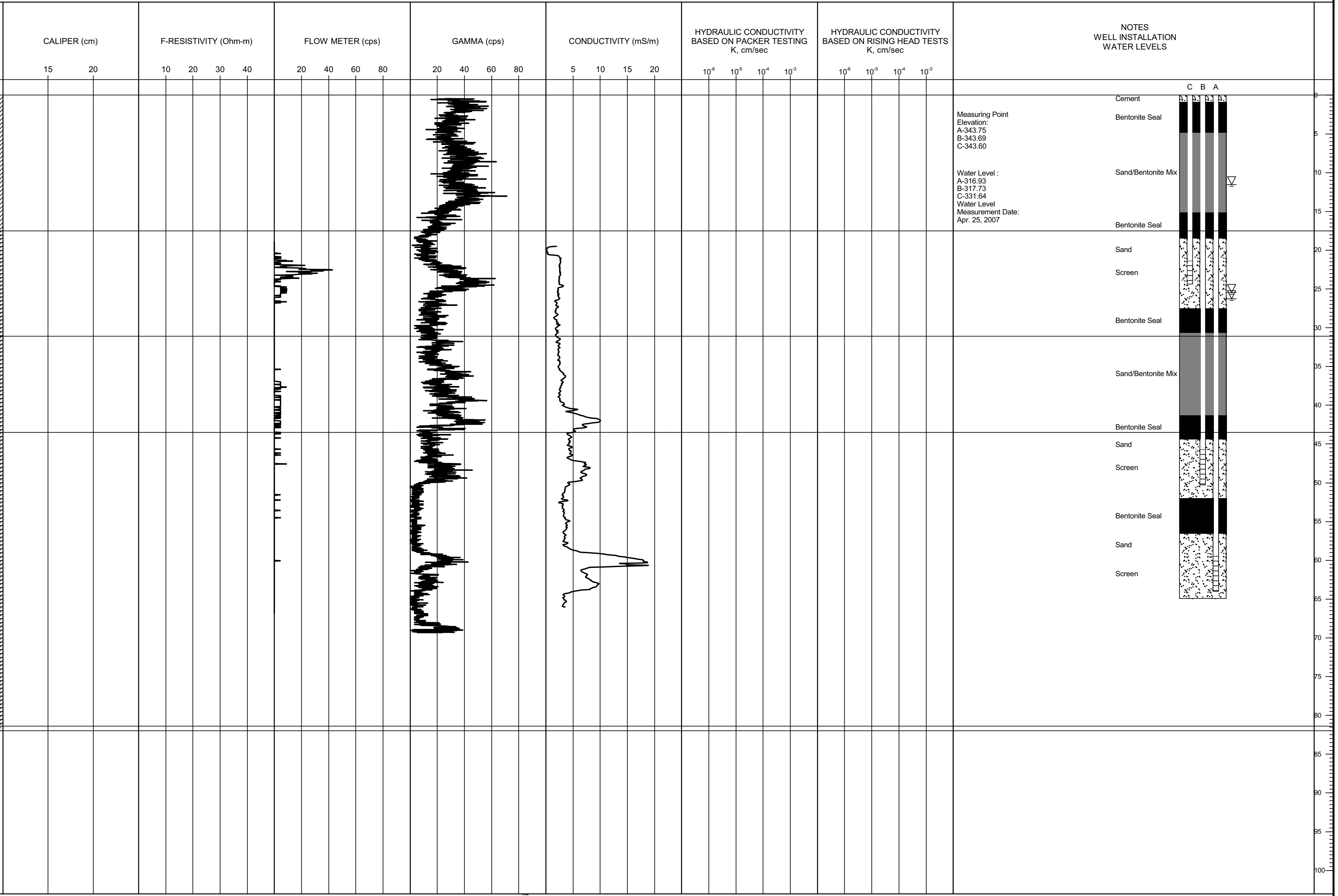
DATUM: Geodetic

DEPTH SCALE METRES	DESCRIPTION	ELEV. / DEPTH (m)	SYMBOLIC LOG
	GROUND SURFACE	343.19	
0	Clay Till	0.00	▨
		325.69	
17.50	Guelph Formation Light brown, rock, DOLOSTONE	17.50	▨
		312.09	
31.10	Eramosa Member Black, rock, DOLOSTONE - Significant fracture at 40.1m	31.10	▨
		299.70	
43.49	Amabel Formation Grey, rock, DOLOSTONE	43.49	▨
		261.79	
82.00	Cabothead Formation Blueish grey, rock, SHALE	82.00	

END OF DRILLHOLE

Note:

1. Well log based on description provided in MOE Well Record No. 670-0888



Measuring Point
Elevation:
A-343.75
B-343.69
C-343.60

Water Level :
A-316.93
B-317.73
C-331.64
Water Level
Measurement Date:
Apr. 25, 2007

DEPTH SCALE

1 : 500

Golder Associates

LOGGED: KS

CHECKED: SMD

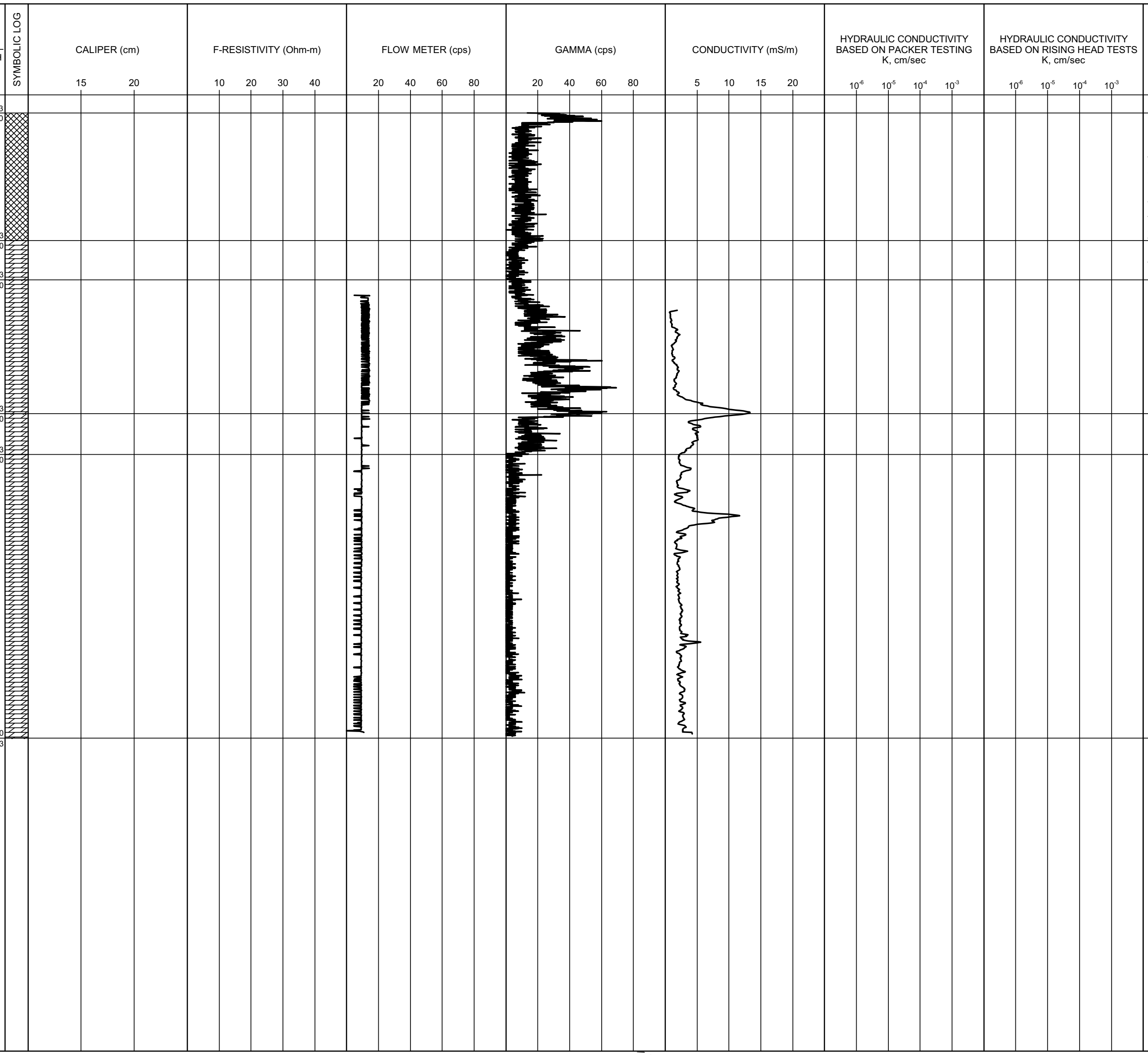
MIS-GEO 006 06-1112-032.GPJ GAL-MISS.GDT 6/9/08 MSM/RJ

PROJECT: 06-1112-032
LOCATION: N 563298.6 ;E 4826047.0

RECORD OF DRILLHOLE: Fleming Well

SHEET 1 OF 1
DATUM: Geodetic

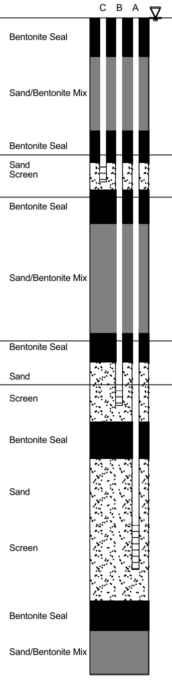
DEPTH SCALE METRES	DESCRIPTION	ELEV. / DEPTH (m)
	GROUND SURFACE	343.93
0	OVERBURDEN	0.00
		329.93
15	Guelph Formation Brown, rock, DOLOSTONE	14.00
		325.63
20	Eramosa Member (Unit 2) Black, rock, DOLOSTONE - Significant fracture at 28.3m, 30.5m and 31.2m	18.30
		310.93
35	Eramosa Member (Unit 1) Grey, rock, DOLOSTONE	33.00
		306.43
40	Amabel Formation Grey, rock, DOLOSTONE - Major fractures 38.3m, 38.7m, 40.2m, 45.2m, 47.1m, 56.5m, 56.8m, and 57.2m - Significant fractures at 45.8m, 47.8m, and 60.7m	37.50
		275.30
70	END OF DRILLHOLE Note: 1. Well log based on description provided in MOE Well Record No. 670-1127	68.63



NOTES
WELL INSTALLATION
WATER LEVELS

Measuring Point
Elevation:
A-344.78
B-344.74
C-344.70

Water Level :
A-344.00
B-343.99
C-343.86
Water Level
Measurement Date:
Apr. 25, 2007



DEPTH SCALE
1 : 500

Golder Associates

LOGGED: KS
CHECKED: SMD

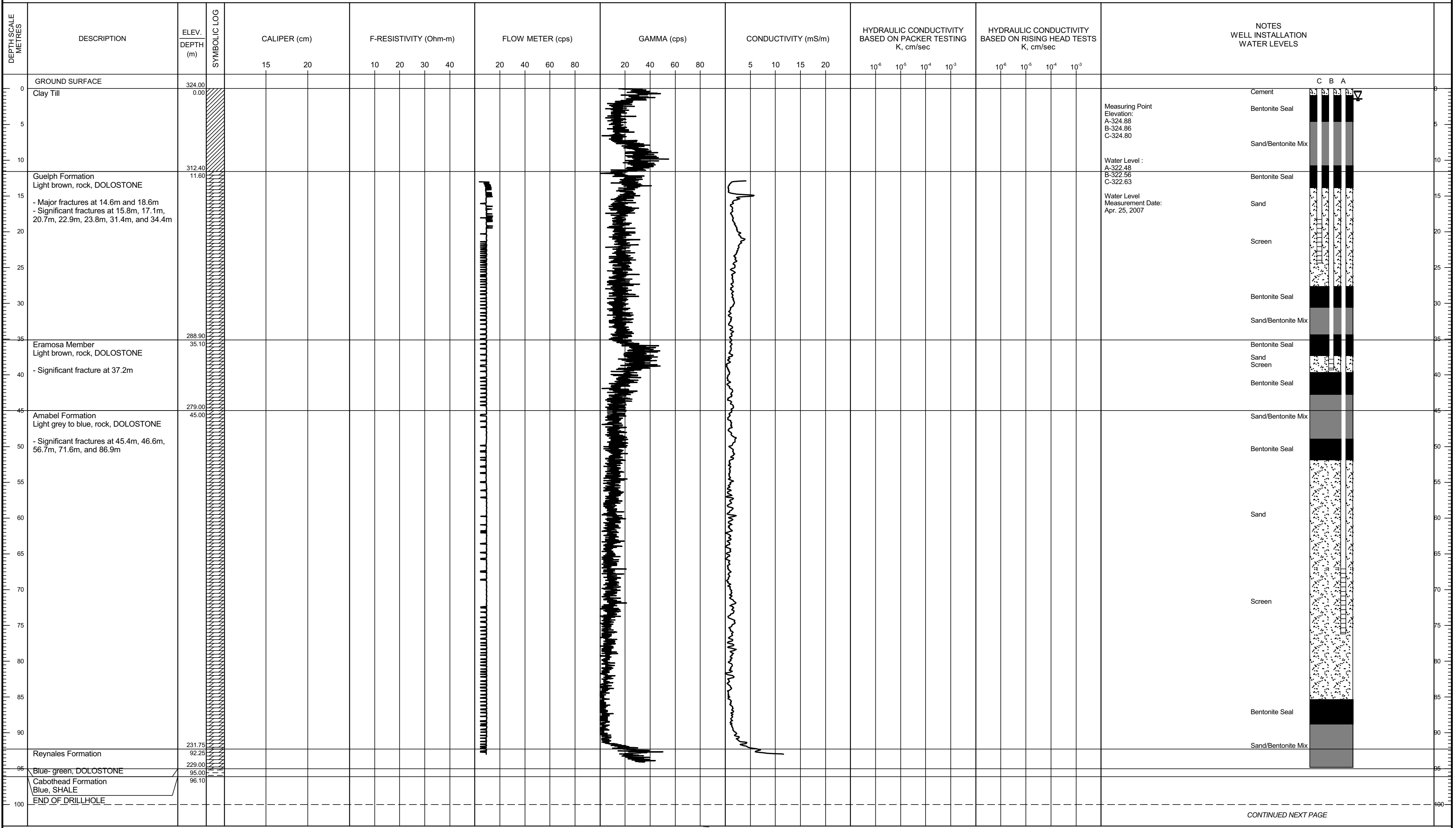
PROJECT: 06-1112-032

LOCATION: N 555554.8 ;E 4819528.3

RECORD OF DRILLHOLE: Hauser Well

SHEET 1 OF 2

DATUM: Geodetic



DESCRIPTION	ELEV. / DEPTH (m)
GROUND SURFACE	324.00
Clay Till	0.00
	312.40
Guelph Formation Light brown, rock, DOLOSTONE - Major fractures at 14.6m and 18.6m - Significant fractures at 15.8m, 17.1m, 20.7m, 22.9m, 23.8m, 31.4m, and 34.4m	11.60
	288.90
Eramosa Member Light brown, rock, DOLOSTONE - Significant fracture at 37.2m	35.10
	279.00
Amabel Formation Light grey to blue, rock, DOLOSTONE - Significant fractures at 45.4m, 46.6m, 56.7m, 71.6m, and 86.9m	45.00
	231.75
Reynales Formation	92.25
	229.00
Blue- green, DOLOSTONE	95.00
Cabothead Formation Blue, SHALE	96.10
END OF DRILLHOLE	

Measuring Point
Elevation:
A-324.88
B-324.86
C-324.80

Water Level :
A-322.48
B-322.56
C-322.63

Water Level
Measurement Date:
Apr. 25, 2007

CONTINUED NEXT PAGE

DEPTH SCALE
1 : 500

Golder Associates

LOGGED: KS
CHECKED: SMD

PROJECT: 06-1112-032

LOCATION: N 555554.8 ;E 4819528.3

RECORD OF DRILLHOLE: Hauser Well

SHEET 2 OF 2

DATUM: Geodetic

DEPTH SCALE METRES	DESCRIPTION	ELEV. / DEPTH (m)	SYMBOLIC LOG	CALIPER (cm) 15 20	F-RESISTIVITY (Ohm-m) 10 20 30 40	FLOW METER (cps) 20 40 60 80	GAMMA (cps) 20 40 60 80	CONDUCTIVITY (mS/m) 5 10 15 20	HYDRAULIC CONDUCTIVITY BASED ON PACKER TESTING K, cm/sec 10^{-6} 10^{-5} 10^{-4} 10^{-3}	HYDRAULIC CONDUCTIVITY BASED ON RISING HEAD TESTS K, cm/sec 10^{-6} 10^{-5} 10^{-4} 10^{-3}	NOTES WELL INSTALLATION WATER LEVELS
	--- CONTINUED FROM PREVIOUS PAGE ---										C B A
100	Note: 1. Well log based on description provided in MOE Well Record No. 670-0954										
105											
110											
115											
120											
125											
130											
135											
140											
145											
150											
155											
160											
165											
170											
175											
180											
185											
190											
195											
200											

DEPTH SCALE
1 : 500

Golder Associates

LOGGED: KS
CHECKED: SMD

MIS-GEO 006 06-1112-032.GPJ GAL-MISS.GDT 6/9/08 MSM/RJ

PROJECT: 06-1112-032

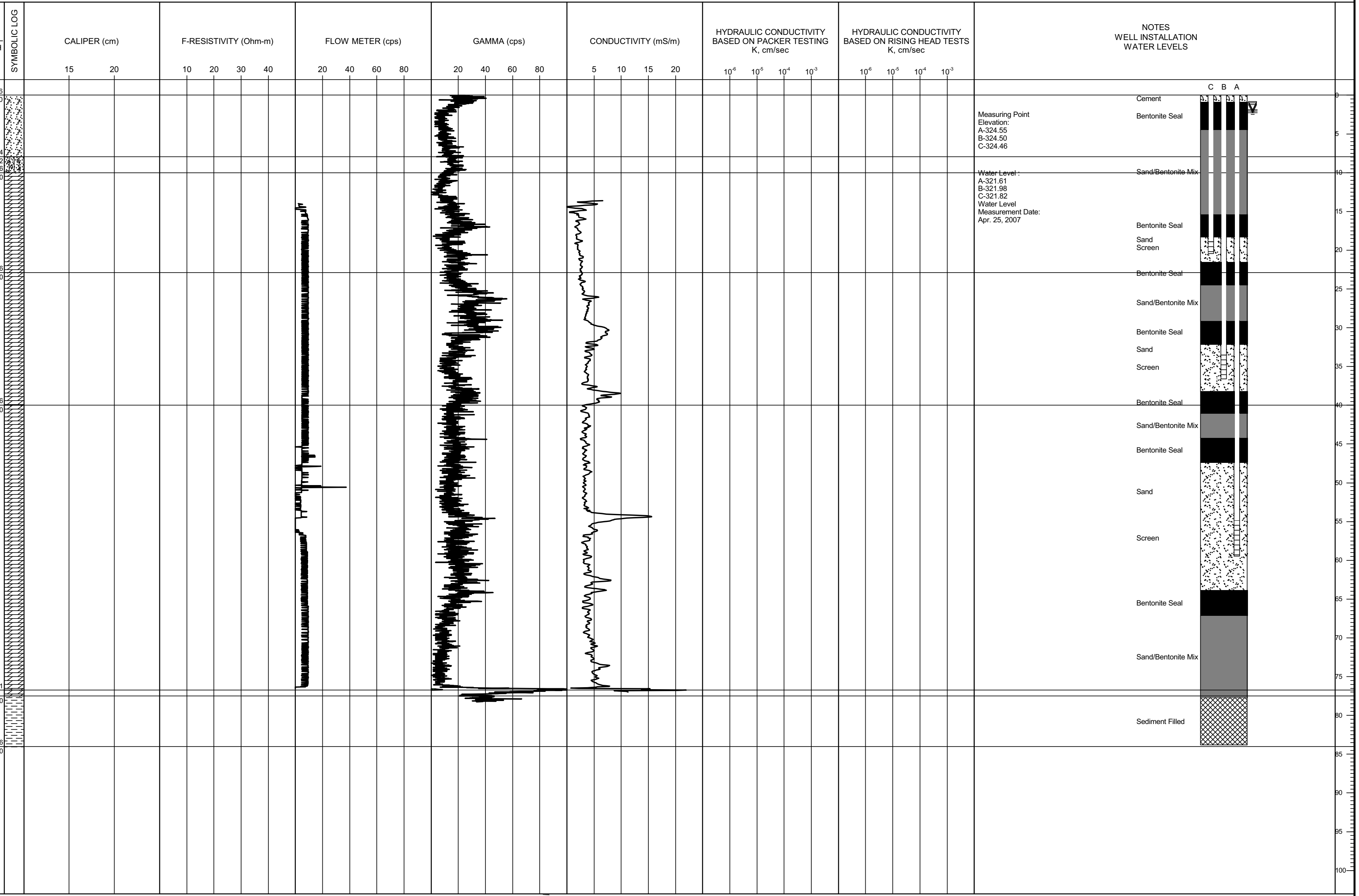
LOCATION: N 563539.4 ;E 4817510.2

RECORD OF DRILLHOLE: McCurdy Well

SHEET 1 OF 1

DATUM: Geodetic

DEPTH SCALE METRES	DESCRIPTION	ELEV. / DEPTH (m)
	GROUND SURFACE	323.86
0	Gravelly Sand	0.00
		315.94
	Silt Till	7.92 313.86
10	Guelph Formation Creamy grey, rock, DOLOSTONE	10.00
		300.96
	Eramosa Member Black, rock, DOLOSTONE - Water bearing zone from 30.18m to 31.09m	22.90
		283.86
40	Amabel Formation Dark grey, rock, DOLOSTONE - Water bearing zone from 48.16m, 54.86m to 55.17m, 60.66m to 64.01m	40.00
		247.11
	Blue-green, DOLOSTONE	
	Cabothead Formation Grey, rock, SHALE	77.50
		239.86
85	END OF DRILLHOLE Note: 1. Well log based on description provided in MOE Well Record No. 670-2434	84.00



Measuring Point
Elevation:
A-324.55
B-324.50
C-324.46

Water Level :
A-321.61
B-321.98
C-321.82
Water Level
Measurement Date:
Apr. 25, 2007

DEPTH SCALE
1 : 500

LOGGED: KS
CHECKED: SMD

PROJECT: 04-1112-032

RECORD OF DRILLHOLE: CH

LOCATION: Hanlon Rd., opposite #727

INCLINATION: -90° AZIMUTH: ---

DRILLING DATE: June 15 - 19, 2004

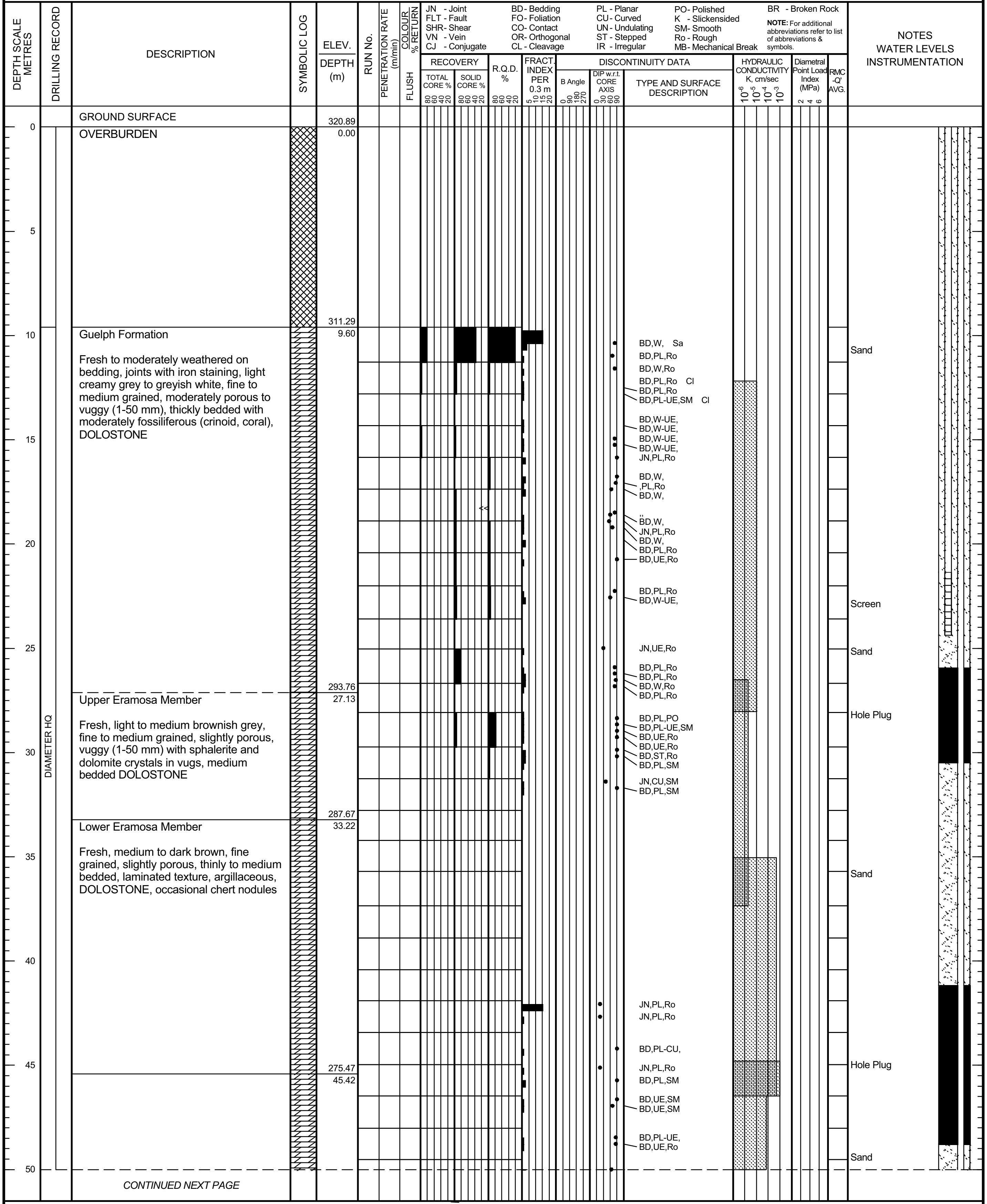
DRILL RIG: MOBIL B57

DRILLING CONTRACTOR: LANTECH

DATUM: Ground

JN - Joint	BD - Bedding	PL - Planar	PO - Polished	BR - Broken Rock
FLT - Fault	FO - Foliation	CU - Curved	K - Slickensided	
SHR - Shear	CO - Contact	UN - Undulating	SM - Smooth	
VN - Vein	OR - Orthogonal	ST - Stepped	Ro - Rough	
CJ - Conjugate	CL - Cleavage	IR - Irregular	MB - Mechanical Break	

NOTE: For additional abbreviations refer to list of abbreviations & symbols.



DESCRIPTION	ELEV. / DEPTH (m)
GROUND SURFACE	320.89
OVERBURDEN	0.00
Guelph Formation Fresh to moderately weathered on bedding, joints with iron staining, light creamy grey to greyish white, fine to medium grained, moderately porous to vuggy (1-50 mm), thickly bedded with moderately fossiliferous (crinoid, coral), DOLOSTONE	311.29 9.60
Upper Eramosa Member Fresh, light to medium brownish grey, fine to medium grained, slightly porous, vuggy (1-50 mm) with sphalerite and dolomite crystals in vugs, medium bedded DOLOSTONE	293.76 27.13
Lower Eramosa Member Fresh, medium to dark brown, fine grained, slightly porous, thinly to medium bedded, laminated texture, argillaceous, DOLOSTONE, occasional chert nodules	287.67 33.22
	275.47 45.42

TYPE AND SURFACE DESCRIPTION:

BD,W, Sa
BD,PL,Ro
BD,W,Ro
BD,PL,Ro Cl
BD,PL,Ro
BD,PL-UE,SM Cl
BD,W-UE,
BD,W-UE,
BD,W-UE,
BD,W-UE,
JN,PL,Ro
BD,W,
,PL,Ro
BD,W,
,,
BD,W,
JN,PL,Ro
BD,W,
BD,PL,Ro
BD,UE,Ro
BD,PL,Ro
BD,W-UE,
JN,UE,Ro
BD,PL,Ro
BD,PL,Ro
BD,W,Ro
BD,PL,Ro
BD,PL,PO
BD,PL-UE,SM
BD,UE,Ro
BD,UE,Ro
BD,ST,Ro
BD,PL,SM
JN,CU,SM
BD,PL,SM
JN,PL,Ro
JN,PL,Ro
BD,PL-CU,
JN,PL,Ro
BD,PL,SM
BD,UE,SM
BD,UE,SM
BD,PL-UE,
BD,UE,Ro

NOTES / WATER LEVELS / INSTRUMENTATION:

Sand
Screen
Sand
Hole Plug
Sand
Hole Plug
Sand

CONTINUED NEXT PAGE

DEPTH SCALE
1 : 250

LOGGED: MR
CHECKED:

PROJECT: 04-1112-032

RECORD OF DRILLHOLE: CH

SHEET 2 OF 2

LOCATION: Hanlon Rd., opposite #727

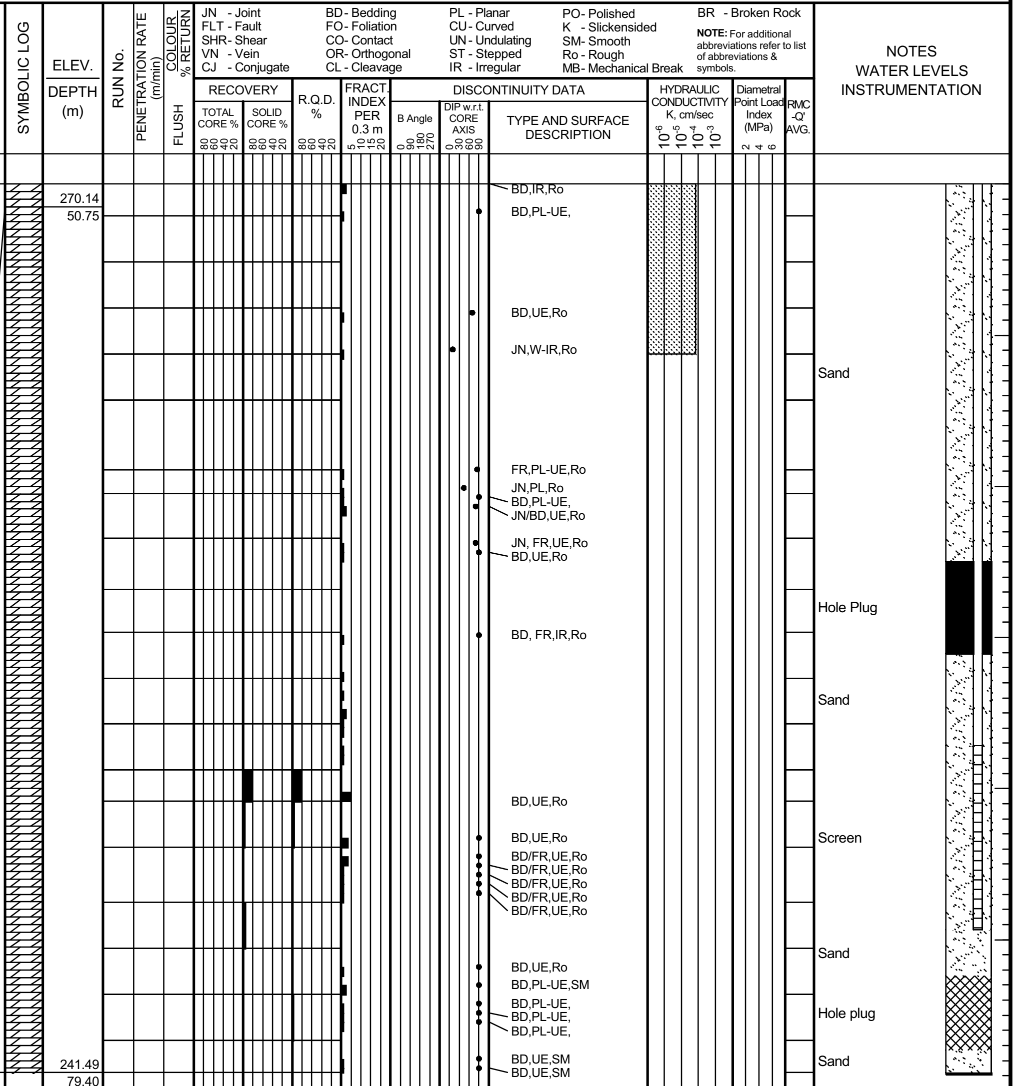
INCLINATION: -90° AZIMUTH: ---

DRILLING DATE: June 15 - 19, 2004
DRILL RIG: MOBIL B57
DRILLING CONTRACTOR: LANTECH

DATUM: Ground

JN - Joint	BD - Bedding	PL - Planar	PO - Polished	BR - Broken Rock
FLT - Fault	FO - Foliation	CU - Curved	K - Slickensided	**NOTE:** For additional abbreviations refer to list of abbreviations & symbols.
SHR - Shear	CO - Contact	UN - Undulating	SM - Smooth	
VN - Vein	OR - Orthogonal	ST - Stepped	Ro - Rough	
CJ - Conjugate	CL - Cleavage	IR - Irregular	MB - Mechanical Break	

DEPTH SCALE METRES	DRILLING RECORD	DESCRIPTION	ELEV. DEPTH (m)
		--- CONTINUED FROM PREVIOUS PAGE ---	
50	DIAMETER HQ	Lateral equivalent to Goat Island Member Fresh, light to moderately grey, fine grained, moderately porous, thin to medium bedded argillaceous DOLOSTONE with numerous chert nodules (5-40 mm), wavy argillaceous bedding partings, occasional vugs with dolomite crystals	270.14 50.75
55		Unsubdivided Amabel Formation Fresh to moderately weathered, light grey, fine to medium grained, partly crystalline, very porous and vuggy, highly fossiliferous (crinoids), occasional stylolite, thickly bedded to massive DOLOSTONE	
60			
65			
70			
75		Less vuggy First appearance of gypsum in fillings fossils	
			241.49 79.40
80		End of Drillhole	
85			
90			
95			
100			



TYPE AND SURFACE DESCRIPTION:

BD,IR,Ro
BD,PL-UE,
BD,UE,Ro
JN,W-IR,Ro
FR,PL-UE,Ro
JN,PL,Ro
BD,PL-UE,
JN/BD,UE,Ro
JN, FR,UE,Ro
BD,UE,Ro
BD, FR,IR,Ro
BD,UE,Ro
BD,UE,Ro
BD/FR,UE,Ro
BD/FR,UE,Ro
BD/FR,UE,Ro
BD/FR,UE,Ro
BD/FR,UE,Ro
BD,UE,Ro
BD,PL-UE,SM
BD,PL-UE,
BD,PL-UE,
BD,PL-UE,
BD,UE,SM
BD,UE,SM

NOTES WATER LEVELS INSTRUMENTATION:

Sand
Hole Plug
Sand
Screen
Sand
Hole plug
Sand

DEPTH SCALE
1 : 250

Golder Associates

LOGGED: MR
CHECKED:

PROJECT: 04-1112-032

RECORD OF DRILLHOLE: TW 1

SHEET 1 OF 2

LOCATION: N 4818044.9 ;E 561360.0

INCLINATION: -90° AZIMUTH: ---

DRILLING DATE: August 9 -10, 2004

DRILL RIG: Air Rotary

DRILLING CONTRACTOR: Gerrits Well Drilling

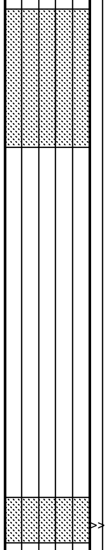
DATUM: Ground

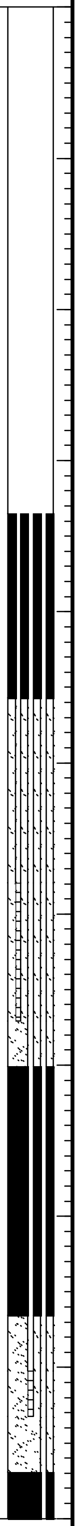
JN - Joint	BD- Bedding	PL - Planar	PO- Polished
FLT - Fault	FO- Foliation	CU- Curved	K - Slickensided
SHR- Shear	CO- Contact	UN - Undulating	SM- Smooth
VN - Vein	OR- Orthogonal	ST - Stepped	Ro - Rough
CJ - Conjugate	CL - Cleavage	IR - Irregular	MB- Mechanical Break

BR - Broken Rock

NOTE: For additional abbreviations refer to list of abbreviations & symbols.

DEPTH SCALE METRES	DRILLING RECORD	DESCRIPTION	SYMBOLIC LOG	ELEV. / DEPTH (m)	RUN No.	PENETRATION RATE (m/min)	FLUSH	COLOUR / % RETURN	RECOVERY TOTAL CORE % (80 60 40 20)	RECOVERY SOLID CORE % (80 60 40 20)	R.Q.D. % (80 60 40 20)	FRACT. INDEX PER 0.3 m (5 10 15 20)	DISCONTINUITY DATA B Angle (0 90 180 270)	DISCONTINUITY DATA DIP w.r.t. CORE AXIS (0 30 60 90)	DISCONTINUITY DATA TYPE AND SURFACE DESCRIPTION	HYDRAULIC CONDUCTIVITY K, cm/sec (10^{-6} 10^{-5} 10^{-4} 10^{-3})	Diametral Point Load Index (MPa) (2 4 6)	RMC -Q' AVG.	NOTES WATER LEVELS INSTRUMENTATION
		GROUND SURFACE		328.24															
0		Brown CLAY, matrix brown gravel and cobbles		0.00															
		Brown sandy CLAY, matrix gravel and boulders		326.44 1.80															
5		Brown CLAY, some gravel		322.74 5.50															
		Brown CLAY, matrix gravel and cobbles		321.54 6.70															
		Grey CLAY TILL, large angular stones		320.34 7.90															
10		Dark grey CLAY, massive, some small stones, rounded		317.54 10.70															
15		Grey silty CLAY, soft some small rounded gravel		312.74 15.50															
20		Light brown DOLOSTONE, soft, fractured, traces of white gypsum (GUELPH FORMATION)		308.74 19.50															Seal
25																			Sand
30																			Screen
		Black DOLOSTONE, strong petroliferous odour (ERAMOSA MEMBER)		295.00 33.24															Sand
35																			
40																			Seal
45																			Sand Screen Sand Seal
50																			





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DEPTH SCALE

1 : 250

Golder Associates

LOGGED:

CHECKED:

PROJECT: 04-1112-032

RECORD OF DRILLHOLE: TW 1

SHEET 2 OF 2

LOCATION: N 4818044.9 ;E 561360.0

INCLINATION: -90° AZIMUTH: ---

DRILLING DATE: August 9 -10, 2004

DRILL RIG: Air Rotary

DRILLING CONTRACTOR: Gerrits Well Drilling

DATUM: Ground

JN - Joint
FLT - Fault
SHR- Shear
VN - Vein
CJ - Conjugate

BD- Bedding
FO- Foliation
CO- Contact
OR- Orthogonal
CL - Cleavage

PL - Planar
CU- Curved
UN - Undulating
ST - Stepped
IR - Irregular

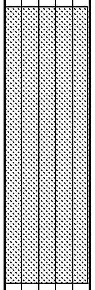
PO- Polished
K - Slickensided
SM- Smooth
Ro - Rough
MB- Mechanical Break

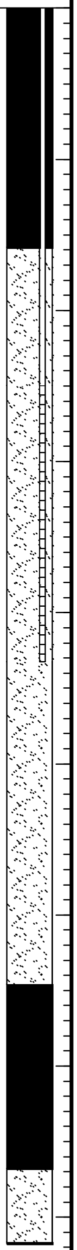
BR - Broken Rock

NOTE: For additional abbreviations refer to list of abbreviations & symbols.

RUN No. | PENETRATION RATE (m/min) | FLUSH | COLOUR % RETURN | RECOVERY: TOTAL CORE % (80 60 40 20), SOLID CORE % (80 60 40 20) | R.Q.D. % (80 60 40 20) | FRACT. INDEX PER 0.3 m (5 10 15 20) | DISCONTINUITY DATA: B Angle (0 90 180 270), DIP w.r.t. CORE AXIS (0 30 60 90), TYPE AND SURFACE DESCRIPTION | HYDRAULIC CONDUCTIVITY K, cm/sec (10^{-6} 10^{-5} 10^{-4} 10^{-3}) | Diametral Point Load Index (MPa) (2 4 6) | RMC -Q' AVG.

DEPTH SCALE METRES	DESCRIPTION	ELEV. DEPTH (m)	NOTES WATER LEVELS INSTRUMENTATION
	--- CONTINUED FROM PREVIOUS PAGE ---		
50	Black DOLOSTONE, strong petroliferous odour (ERAMOSA MEMBER)		
55	Grey DOLOSTONE (Lateral equivalent to Goat Island Member)	274.50 53.74	Seal
60 65 70 75 80	Grey DOLOSTONE (AMABEL LIMESTONE) Productions zone identified by 6' fracture at 66.3 m depth Production zone from 66.3 m to 71.2 m depth	268.04 60.20	Sand Screen Sand
85 90	Light blue LIMESTONE, fractured and broken (REYNALES FORMATION)	245.94 82.30	Seal Sand
95 100	End of Borehole	237.44 90.80	





DEPTH SCALE

1 : 250

Golder Associates

LOGGED:

CHECKED:

PROJECT: 04-1112-032

RECORD OF DRILLHOLE: TW 2

SHEET 1 OF 2

LOCATION: N 4818015.9 ;E 560339.4

INCLINATION: -90° AZIMUTH: ---

DRILLING DATE: August 11 -12, 2004

DRILL RIG: Air Rotary

DRILLING CONTRACTOR: Gerrits Well Drilling

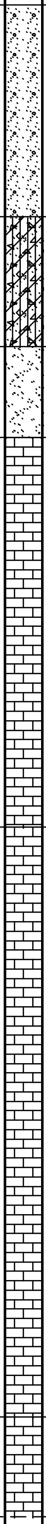
DATUM: Ground

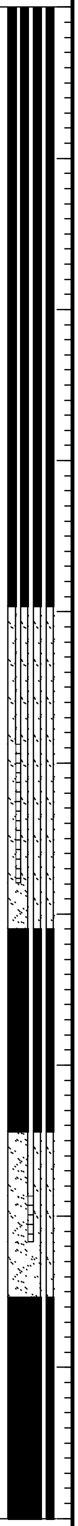
JN - Joint
FLT - Fault
SHR - Shear
VN - Vein
CJ - Conjugate
BD - Bedding
FO - Foliation
CO - Contact
OR - Orthogonal
CL - Cleavage
PL - Planar
CU - Curved
UN - Undulating
ST - Stepped
IR - Irregular
PO - Polished
K - Slickensided
SM - Smooth
Ro - Rough
MB - Mechanical Break
BR - Broken Rock

NOTE: For additional abbreviations refer to list of abbreviations & symbols.

DEPTH SCALE METRES	DESCRIPTION	ELEV. DEPTH (m)	NOTES WATER LEVELS INSTRUMENTATION
	GROUND SURFACE	325.08	
0	Brown, coarse SAND and GRAVEL, some white gypsum cemented	0.00	
7	Biege, CALY TILL, angular stones, lots of stoney	318.08 7.00	Seal
11.3	Stratified SAND and CLAY	313.78 11.30	
14.3	Biege DOLOSTONE, fractured and broken in top 2 m (GUELPH FORMATION)	310.78 14.30	Sand Screen
27.2	Black DOLOSTONE (ERAMOSA MEMBER)	297.88 27.20	Sand Seal Sand Screen Sand Seal
46.7	Grey DOLOSTONE (Lateral equivalent to Goat Island Member) Grey from 49.7 m to 53.4 m	278.38 46.70	

Other column headings: DRILLING RECORD; SYMBOLIC LOG; RUN No.; PENETRATION RATE (m/min); FLUSH; COLOUR % RETURN; RECOVERY: TOTAL CORE %, SOLID CORE % (80 60 40 20); R.Q.D. % (80 60 40 20); FRACT. INDEX PER 0.3 m (5 10 15 20); DISCONTINUITY DATA: B Angle (0 90 180 270), DIP w.r.t. CORE AXIS (0 30 60 90), TYPE AND SURFACE DESCRIPTION; HYDRAULIC CONDUCTIVITY K, cm/sec (10^{-6} 10^{-5} 10^{-4} 10^{-3}); Diametral Point Load Index (MPa) (2 4 6); RMC -Q' AVG.





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DEPTH SCALE
1 : 250

Golder Associates

LOGGED:

CHECKED:

PROJECT: 04-1112-032

RECORD OF DRILLHOLE: TW 2

SHEET 2 OF 2

LOCATION: N 4818015.9 ;E 560339.4

INCLINATION: -90° AZIMUTH: ---

DRILLING DATE: August 11 -12, 2004

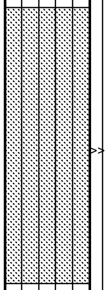
DRILL RIG: Air Rotary

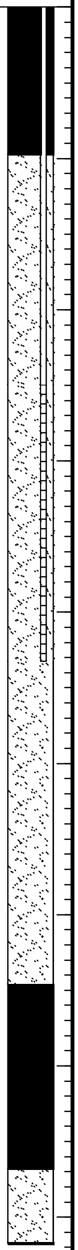
DRILLING CONTRACTOR: Gerrits Well Drilling

DATUM: Ground

JN - Joint	BD - Bedding	PL - Planar	PO - Polished	BR - Broken Rock
FLT - Fault	FO - Foliation	CU - Curved	K - Slickensided	**NOTE:** For additional abbreviations refer to list of abbreviations & symbols.
SHR - Shear	CO - Contact	UN - Undulating	SM - Smooth	
VN - Vein	OR - Orthogonal	ST - Stepped	Ro - Rough	
CJ - Conjugate	CL - Cleavage	IR - Irregular	MB - Mechanical Break	

DEPTH SCALE METRES	DRILLING RECORD	DESCRIPTION	SYMBOLIC LOG	ELEV. DEPTH (m)	RUN No.	PENETRATION RATE (m/min)	COLOUR % RETURN	FLUSH	RECOVERY TOTAL CORE % 80 60 40 20	RECOVERY SOLID CORE % 80 60 40 20	R.Q.D. % 80 60 40 20	FRACT. INDEX PER 0.3 m 5 10 15 20	DISCONTINUITY DATA B Angle 0 90 180 270	DISCONTINUITY DATA DIP w.r.t. CORE AXIS 0 30 60 90	DISCONTINUITY DATA TYPE AND SURFACE DESCRIPTION	HYDRAULIC CONDUCTIVITY K, cm/sec 10^{-6} 10^{-5} 10^{-4} 10^{-3}	Diametral Point Load Index (MPa) 2 4 6	RMC -Q' AVG.	NOTES WATER LEVELS INSTRUMENTATION
		--- CONTINUED FROM PREVIOUS PAGE ---																	
50				274.00 51.08															
		LIMESTONE (AMABEL FORMATION)																	Seal
		Light grey to white from 53.4 to 57.6 m																	
55																			
		Blue-grey hard from 57.6 m to 64 m																	Sand
60																			
65		Grey soft and production zone from 64.0 m to 70.4 m																	
																			Screen
70		Brownish grey medium hard from 70.4 m to 82.0 m																	
75																			Sand
80																			
85																			Seal
		Blue-grey medium to hard hard LIMESTONE (REYNALES FORMATION)		238.08 87.00															
90																			Sand
		End of Borehole		234.08 91.00															
95																			
100																			





DEPTH SCALE

1 : 250

Golder Associates

LOGGED:

CHECKED:

PROJECT: 04-1112-032

RECORD OF DRILLHOLE: OW05-92

SHEET 1 OF 2

LOCATION: N 4819044.7 ;E 560223.1

INCLINATION: -90° AZIMUTH: ---

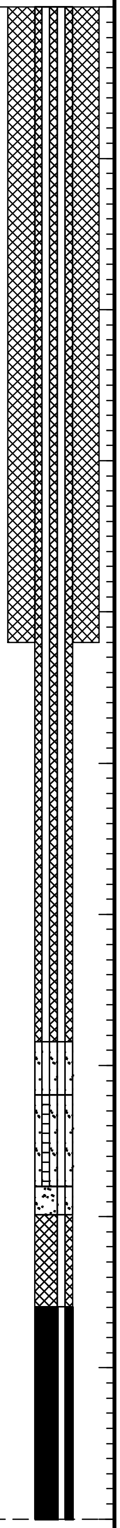
DRILLING DATE: December 15, 1992
DRILL RIG:
DRILLING CONTRACTOR:

DATUM: Ground

JN - Joint
FLT - Fault
SHR- Shear
VN - Vein
CJ - Conjugate
BD- Bedding
FO- Foliation
CO- Contact
OR- Orthogonal
CL - Cleavage
PL - Planar
CU- Curved
UN - Undulating
ST - Stepped
IR - Irregular
PO- Polished
K - Slickensided
SM- Smooth
Ro - Rough
MB- Mechanical Break
BR - Broken Rock

NOTE: For additional abbreviations refer to list of abbreviations & symbols.

DEPTH SCALE METRES	DRILLING RECORD	DESCRIPTION	SYMBOLIC LOG	ELEV. DEPTH (m)	RUN No.	PENETRATION RATE (m/min)	FLUSH COLOUR % RETURN	RECOVERY TOTAL CORE % 80 60 40 20	RECOVERY SOLID CORE % 80 60 40 20	R.Q.D. % 80 60 40 20	FRACT. INDEX PER 0.3 m 5 10 15 20	DISCONTINUITY DATA B Angle 0 90 180 270	DISCONTINUITY DATA DIP w.r.t. CORE AXIS 0 30 60 90	DISCONTINUITY DATA TYPE AND SURFACE DESCRIPTION	HYDRAULIC CONDUCTIVITY K, cm/sec 10^{-6} 10^{-5} 10^{-4} 10^{-3}	Diametral Point Load Index (MPa) 2 4 6	RMC -Q' AVG.	NOTES WATER LEVELS INSTRUMENTATION
		GROUND SURFACE		331.39														
0		Loose, brown SAND, fine gravel and some cobbles		0.00														
5																		
10				321.33														
		Loose, grey CLAY, fine gravel		10.06														
15																		Backfill
				312.49														
		Hard, white ROCK		18.90														
20																		
25																		
30				297.56														
		Hard, black ROCK		33.83														
35																		Sand
																		Screen
40																		Sand
																		Grout
45																		Bentonite
50																		



CONTINUED NEXT PAGE

DEPTH SCALE
1 : 250

Golder Associates

LOGGED:
CHECKED:

PROJECT: 04-1112-032

RECORD OF DRILLHOLE: OW05-92

SHEET 2 OF 2

LOCATION: N 4819044.7 ;E 560223.1

INCLINATION: -90° AZIMUTH: ---

DRILLING DATE: December 15, 1992

DRILL RIG:

DRILLING CONTRACTOR:

DATUM: Ground

JN - Joint
FLT - Fault
SHR- Shear
VN - Vein
CJ - Conjugate

BD- Bedding
FO- Foliation
CO- Contact
OR- Orthogonal
CL - Cleavage

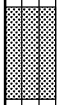
PL - Planar
CU- Curved
UN - Undulating
ST - Stepped
IR - Irregular

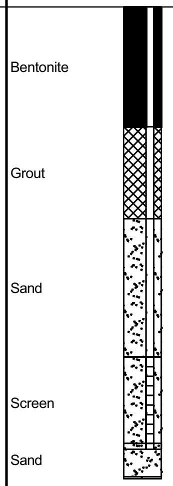
PO- Polished
K - Slickensided
SM- Smooth
Ro - Rough
MB- Mechanical Break

BR - Broken Rock

NOTE: For additional abbreviations refer to list of abbreviations & symbols.

DEPTH SCALE METRES	DRILLING RECORD	DESCRIPTION	SYMBOLIC LOG	ELEV. DEPTH (m)	RUN No.	PENETRATION RATE (m/min)	FLUSH COLOUR % RETURN	RECOVERY TOTAL CORE % 80 60 40 20	RECOVERY SOLID CORE % 80 60 40 20	R.Q.D. % 80 60 40 20	FRACT. INDEX PER 0.3 m 5 10 15 20	DISCONTINUITY DATA B Angle 0 90 180 270	DISCONTINUITY DATA DIP w.r.t. CORE AXIS 0 30 60 90	DISCONTINUITY DATA TYPE AND SURFACE DESCRIPTION	HYDRAULIC CONDUCTIVITY K, cm/sec 10^{-6} 10^{-5} 10^{-4} 10^{-3}	Diametral Point Load Index (MPa) 2 4 6	RMC -Q' AVG.	NOTES WATER LEVELS INSTRUMENTATION
		--- CONTINUED FROM PREVIOUS PAGE ---																
50		Hard, black ROCK																Bentonite
		Hard, grey ROCK		279.57 51.82														
55																		Grout
60																		Sand
																		Screen
		End of Borehole		267.38 64.01														
65																		Sand
70																		
75																		
80																		
85																		
90																		
95																		
100																		





DEPTH SCALE

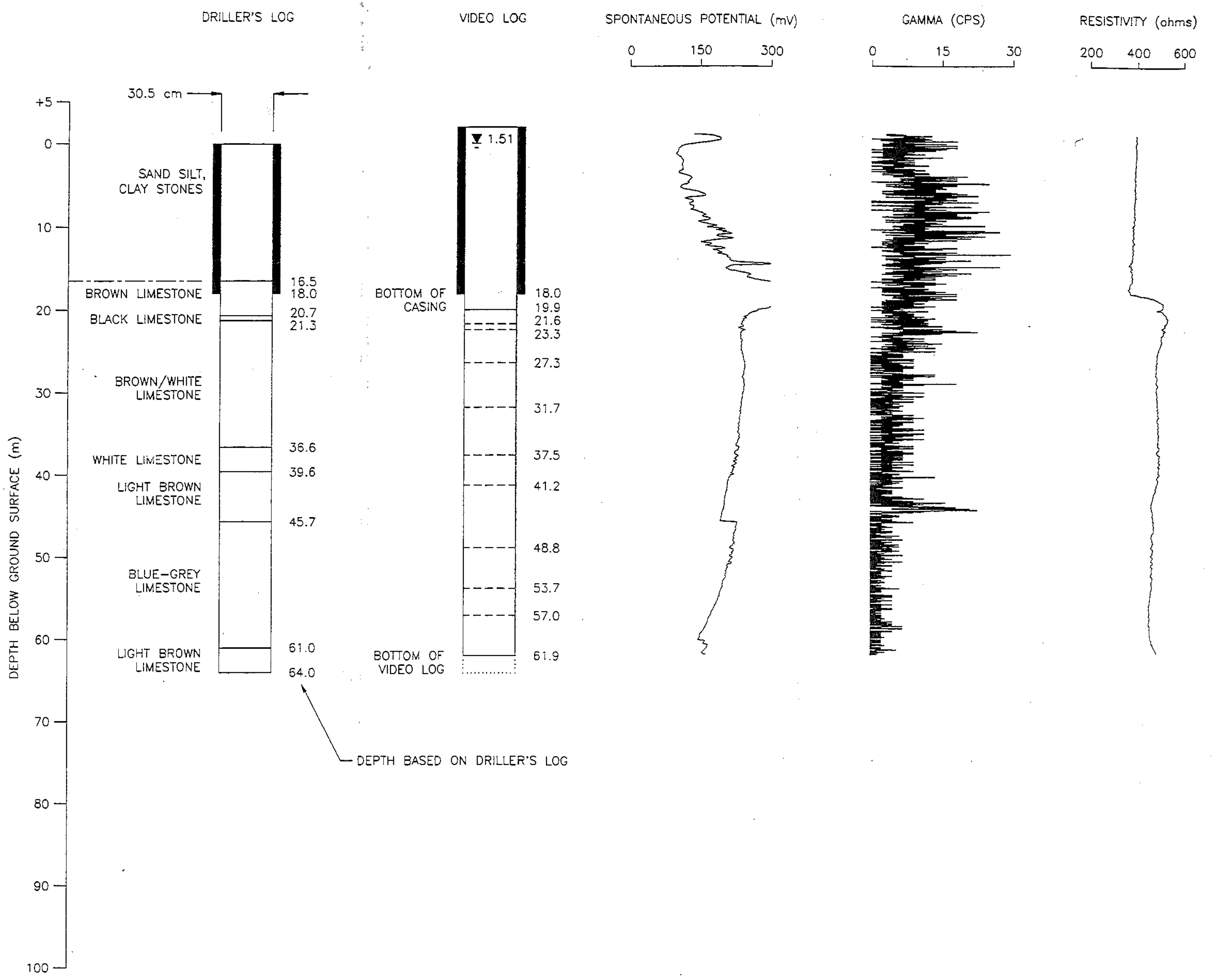
1 : 250

Golder Associates

LOGGED:

CHECKED:

MISS-ROCK-2 041112032AARCK.GPJ GAL-CANADA.GDT 12/8/05



LEGEND

-·-·-·- OVERBURDEN/BEDROCK CONTACT

- - - - - SIGNIFICANT FRACTURE/SOLUTION CAVITY

——— MAJOR FRACTURE/FRACTURE ZONE/ SOLUTION CAVITY

▼ WATER LEVEL

NOTES

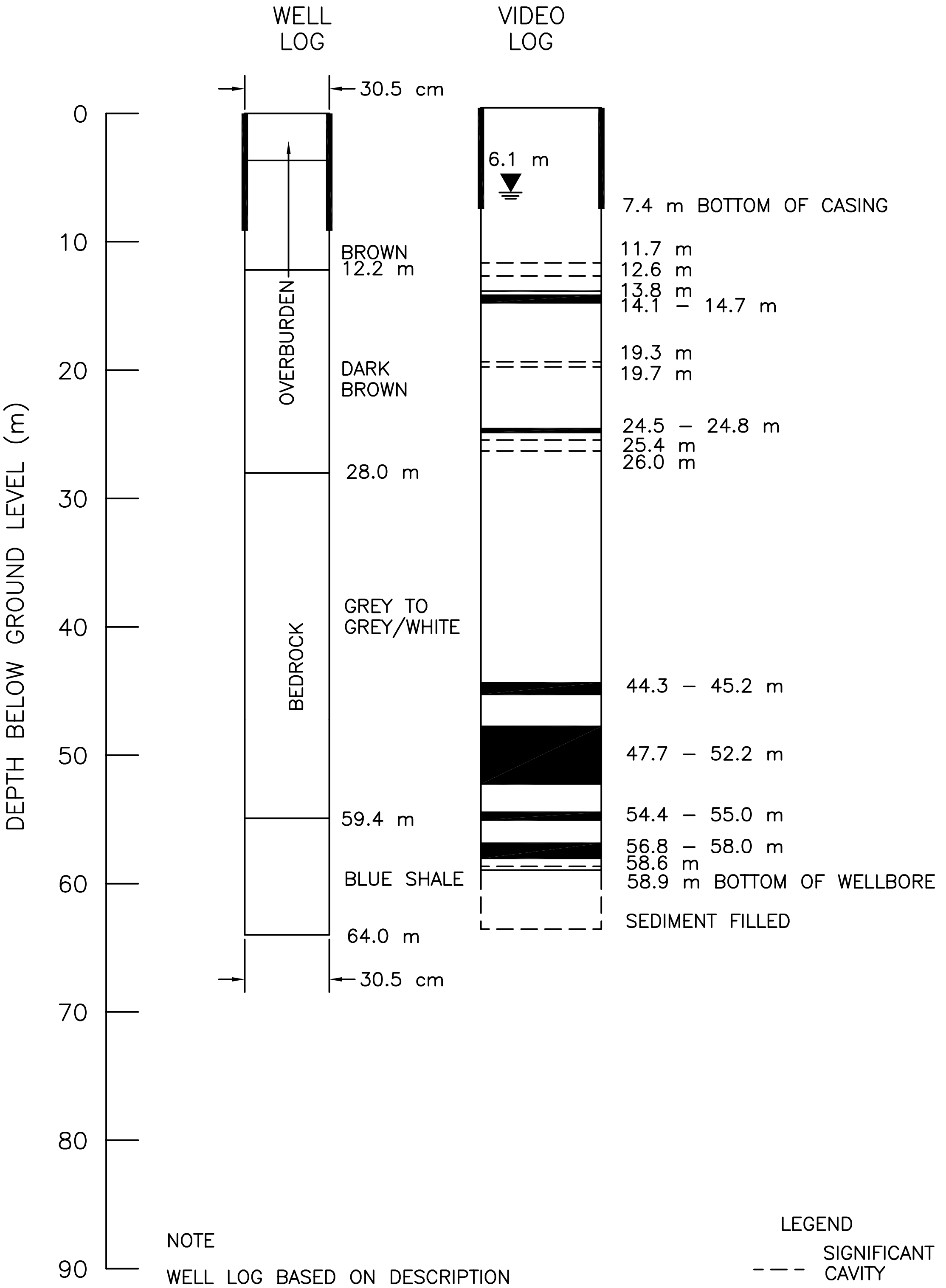
1. DRILLER'S LOG BASED ON DESCRIPTION PROVIDED IN WATER WELL RECORD No. LOG 67-6298.
2. WATER FOUND AT 18.3 m, 20.7 m, AND 21.3 m AS REPORTED IN WELL LOG.
3. WELL FLOWED AT 4.6 m^3 ON COMPLETION.
4. GEOPHYSICAL LOG OF SPONTANEOUS POTENTIAL, GAMMA, AND RESISTIVITY HAVE BEEN PROVIDED BY INTERNATIONAL WATER SUPPLY LIMITED, APRIL 25, 1994.
5. VIDEO LOG DERIVED FROM DOWNHOLE CAMERA WORK COMPLETED BY INTERNATIONAL WATER SUPPLY LIMITED, APRIL 25, 1994.
6. INITIAL ELEVATION 322.50 m.
   FLOOR ELEVATION 324.14 m.
   MEASURING POINT ELEVATION 325.32 m.

CALICO PRODUCTION WELL

AQUIFER PERFORMANCE EVALUATION
NORTHWEST QUADRANT
CITY OF GUELPH

DATE: OCTOBER 23, 1995	SCALE: AS SHOWN
PROJECT: 194061	FILE NO.: B061-1950234
JAGGER HIMS LIMITED Environmental Consulting Engineers · Braun Consulting Engineers	FIGURE B1-2

VIDEO LOG REFERENCE ELEVATION 326.75 m a.s.l.
FLOOR ELEVATION 326.30 m a.s.l.



NOTE

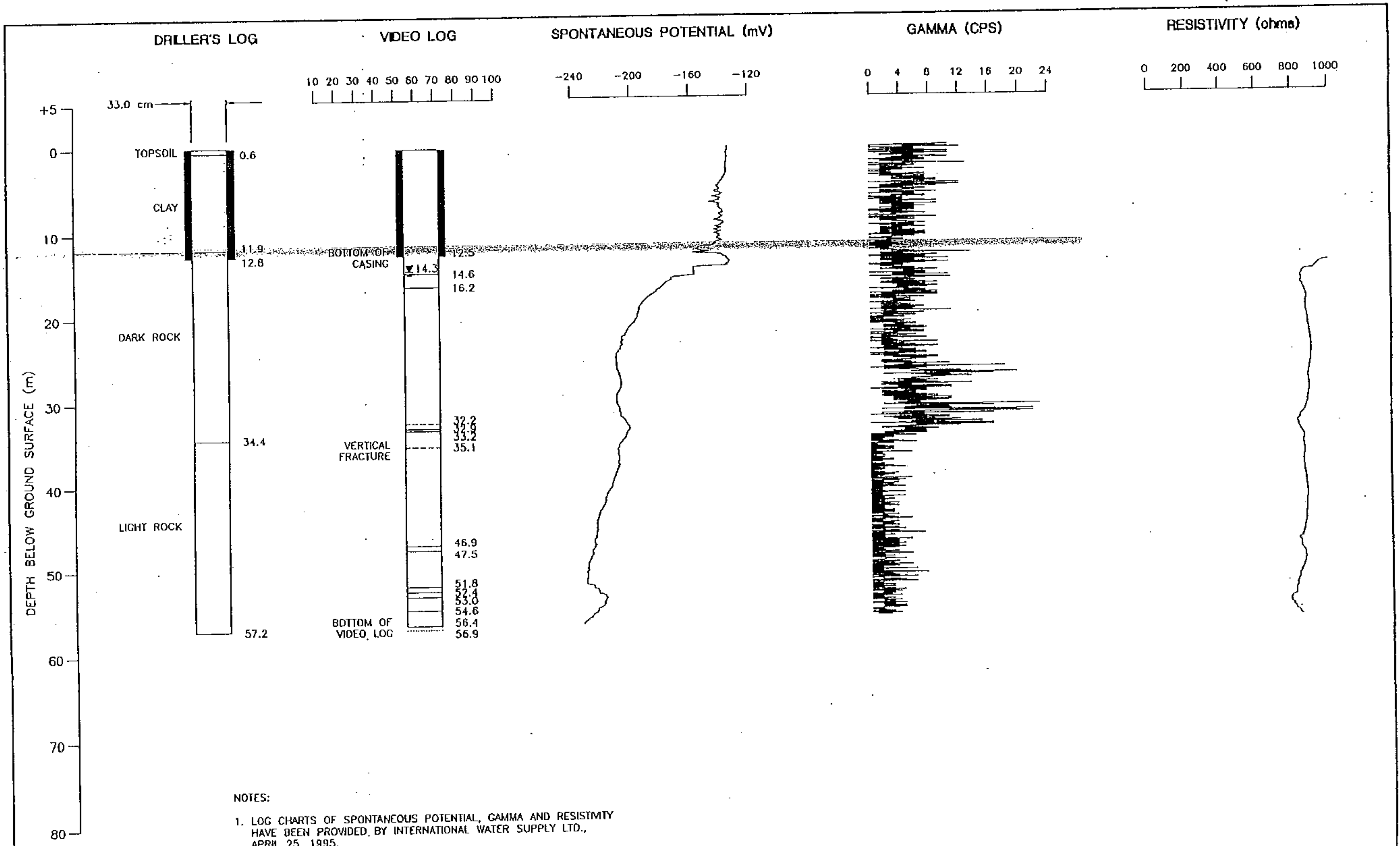
WELL LOG BASED ON DESCRIPTION PROVIDED IN DRILLER'S LOG 67–6103. VIDEO LOG DERIVED FROM DOWNHOLE CAMERA WORK COMPLETED BY INTERNATIONAL WATER SUPPLY LIMITED, AUG 16, 1993.

LEGEND

- - - SIGNIFICANT FRACTURE/SOLUTION CAVITY
— MAJOR FRACTURE/FRACTURE ZONE/SOLUTION CAVITY

JAGGER HIMS LIMITED
Environmental Consulting Engineers

FIGURE 5–6
CLYTHE CREEK PRODUCTION WELL
CITY OF GUELPH – NORTHEAST QUADRANT



NOTES:

1. LOG CHARTS OF SPONTANEOUS POTENTIAL, GAMMA AND RESISTIVITY HAVE BEEN PROVIDED BY INTERNATIONAL WATER SUPPLY LTD., APRIL 25, 1995.
2. WELL LOG BASED ON DESCRIPTION PROVIDED IN DRILLER'S LOG 67−1429.
3. VIDEO LOG DERIVED FROM DOWNHOLE CAMERA WORK COMPLETED BY INTERNATIONAL WATER SUPPLY LTD., APRIL 25, 1995.
4. WATER FOUND FROM 51.2 m TO 51.8 m AS REPORTED ON DRILLER'S LOG.
5. STATIC WATER LEVEL AT COMPLETION WAS 12.9 m.
6. MEASURING POINT ELEVATION 323.73 m.
FLOOR ELEVATION 323.33 m.
7. VIDEO AND GEOPHYSICAL LOGS ALIGNED WITH DRILLER'S LOG ON THE BOTTOM OF CASING.
8. DEPTH SCALE ALIGNED WITH DRILLER'S LOG

LEGEND

−·−·−	OVERBURDEN/BEDROCK CONTACT
- - - -	SIGNIFICANT FRACTURE/ SOLUTION CAVITY
——	MAJOR FRACTURE/FRACTURE ZONE/SOLUTION CAVITY
▼	WATER LEVEL (m B.G.S.)

SCALE: AS SHOWN

REF. NO.: A076−1960167

DATE: FEBRUARY 25, 1997

PROJECT: 195076

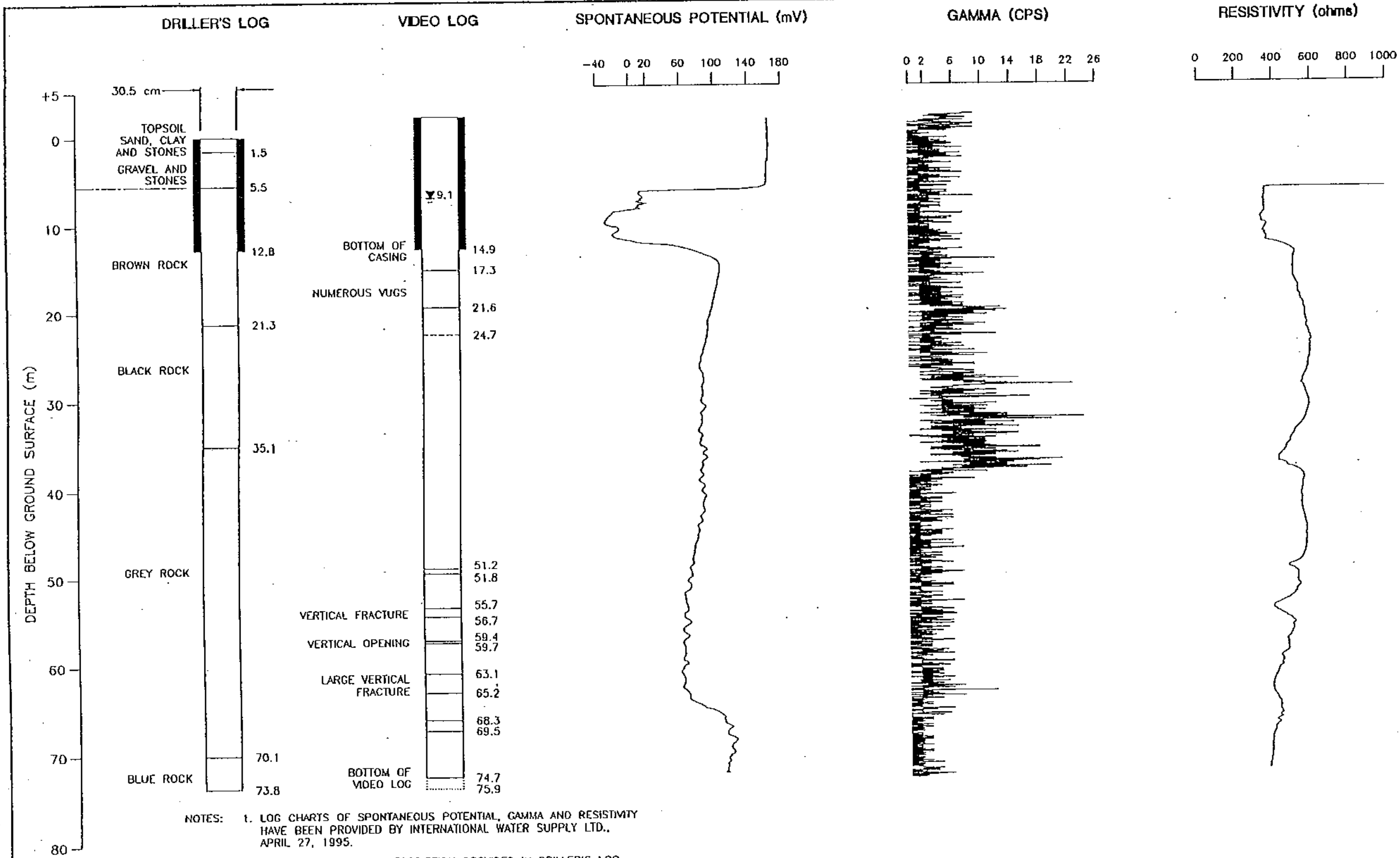
JAGGER HIMS LIMITED
Environmental Consulting Engineers

Braun Consulting Engineers

DEAN AVENUE PRODUCTION WELL

AQUIFER PERFORMANCE EVALUATION
SOUTHWEST QUADRANT
CITY OF GUELPH

FIGURE
B1-3



NOTES:

1. LOG CHARTS OF SPONTANEOUS POTENTIAL, GAMMA AND RESISTIVITY HAVE BEEN PROVIDED BY INTERNATIONAL WATER SUPPLY LTD., APRIL 27, 1995.
2. WELL LOG BASED ON DESCRIPTION PROVIDED IN DRILLER'S LOG 67-946.
3. VIDEO LOG DERIVED FROM DOWNHOLE CAMERA WORK COMPLETED BY INTERNATIONAL WATER SUPPLY LTD., APRIL 27, 1995.
4. VIDEO LOG SHOWED NUMEROUS CALCITE DEPOSITS.
5. WATER FOUND FROM 53.0 m TO 66.8 m AS REPORTED IN DRILLER'S LOG.
6. STATIC WATER LEVEL AT COMPLETION WAS 4.4 m.
7. MEASURING POINT ELEVATION 317.76 m. FLOOR ELEVATION 317.35 m.
8. VIDEO AND GEOPHYSICAL LOGS ALIGNED WITH DRILLER'S LOG ON THE BOTTOM OF CASING.
9. DEPTH SCALE ALIGNED WITH DRILLER'S LOG

LEGEND

-·- OVERBURDEN/BEDROCK CONTACT

---- SIGNIFICANT FRACTURE/SOLUTION CAVITY

— MAJOR FRACTURE/FRACTURE ZONE/SOLUTION CAVITY

▼ WATER LEVEL (m B.G.S.)

SCALE: AS SHOWN

REF. NO.: A076-1960163

DATE: FEBRUARY 25, 1997

PROJECT: 195076

JAGGER HIMS LIMITED
Environmental Consulting Engineers

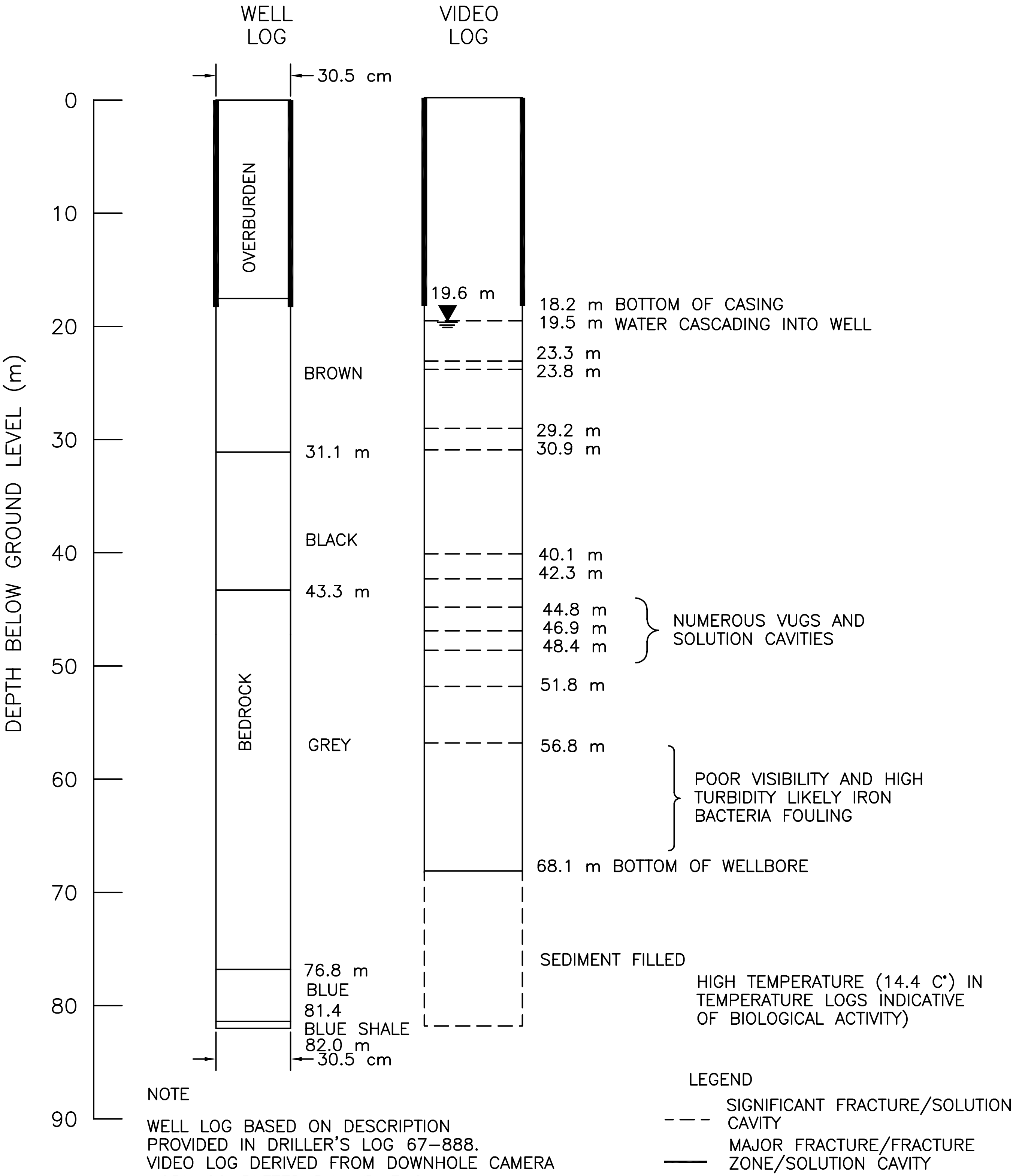
Braun Consulting Engineers

DOWNEY ROAD PRODUCTION WELL

AQUIFER PERFORMANCE EVALUATION
SOUTHWEST QUADRANT
CITY OF GUELPH

FIGURE
B1-5

VIDEO LOG REFERENCE ELEVATION 343.16 m a.s.l.
FLOOR ELEVATION 342.96 m a.s.l.

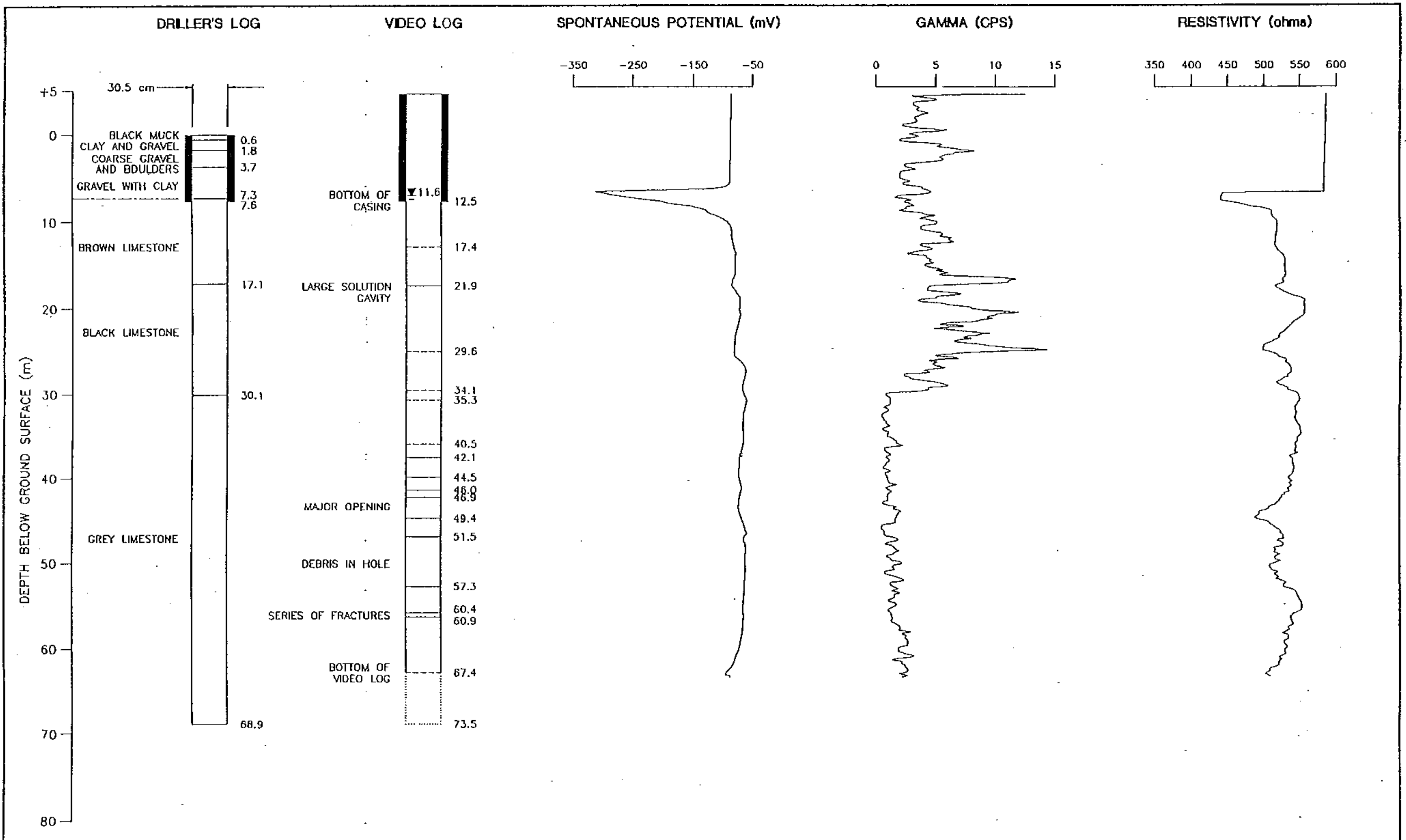


NOTE

WELL LOG BASED ON DESCRIPTION PROVIDED IN DRILLER'S LOG 67-888.
VIDEO LOG DERIVED FROM DOWNHOLE CAMERA WORK COMPLETED BY HYD-ENG GEOPHYSICS INC, MAY 4, 1993.

JAGGER HIMS LIMITED
Environmental Consulting Engineers

FIGURE 5-7
EASTVIEW ROAD PRODUCTION WELL
CITY OF GUELPH – NORTHEAST QUADRANT



LEGEND

- ——— OVERBURDEN/BEDROCK CONTACT
- - - - - SIGNIFICANT FRACTURE/ SOLUTION CAVITY
- ——— MAJOR FRACTURE/FRACTURE ZONE/SOLUTION CAVITY
- ▼ WATER LEVEL (m B.G.S.)

NOTES:

1. WELL LOG BASED ON DESCRIPTION PROVIDED IN DRILLER'S LOG 67-873.
2. VIDEO LOG DERIVED FROM DOWNHOLE CAMERA WORK COMPLETED BY INTERNATIONAL WATER SUPPLY LTD., APRIL 28, 1995.
3. STATIC WATER LEVEL AT COMPLETION WAS 5.6 m.
4. MEASURING POINT ELEVATION 315.98 m. FLOOR ELEVATION 315.64 m.
5. VIDEO AND GEOPHYSICAL LOGS ALIGNED WITH DRILLER'S LOG ON THE BOTTOM OF CASING.
6. DEPTH SCALE ALIGNED WITH DRILLER'S LOG.

SCALE: AS SHOWN

REF. NO.: A076-1960168

DATE: FEBRUARY 25, 1997

PROJECT: 195076

JAGGER HIMS LIMITED
Environmental Consulting Engineers

Braun Consulting Engineers

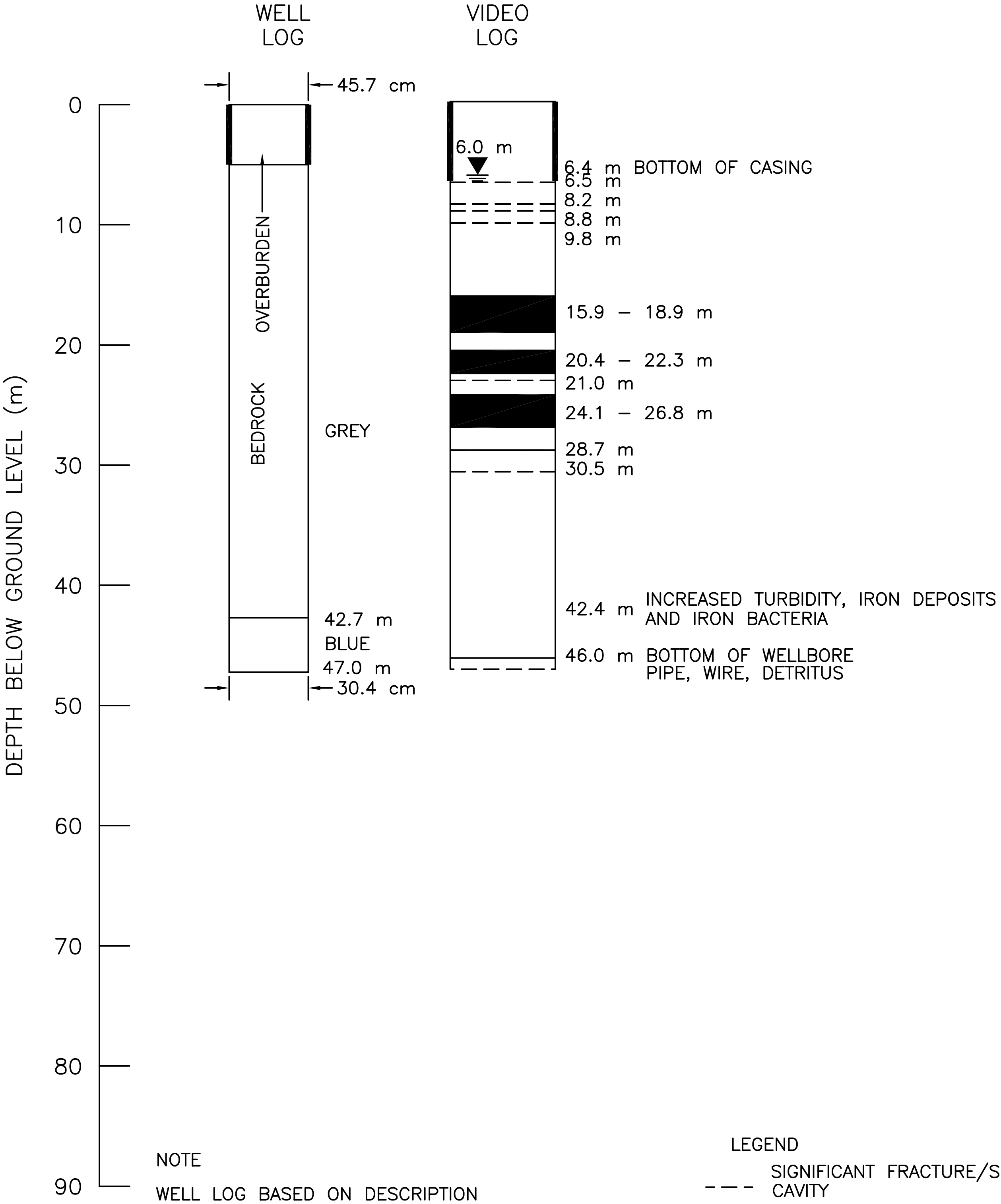
EDINBURGH ROAD PRODUCTION WELL

AQUIFER PERFORMANCE EVALUATION
SOUTHWEST QUADRANT
CITY OF GUELPH

FIGURE

B1-2

VIDEO LOG REFERENCE ELEVATION 328.41 m a.s.l.
FLOOR ELEVATION 328.16 m a.s.l.



NOTE

WELL LOG BASED ON DESCRIPTION
PROVIDED IN DRILLER'S LOG
VIDEO LOG DERIVED FROM DOWNHOLE CAMERA
WORK COMPLETED BY INTERNATIONAL
WATER SUPPLY LIMITED, AUG 16, 1993.

LEGEND

- - - SIGNIFICANT FRACTURE/SOLUTION CAVITY
— MAJOR FRACTURE/FRACTURE ZONE/SOLUTION CAVITY

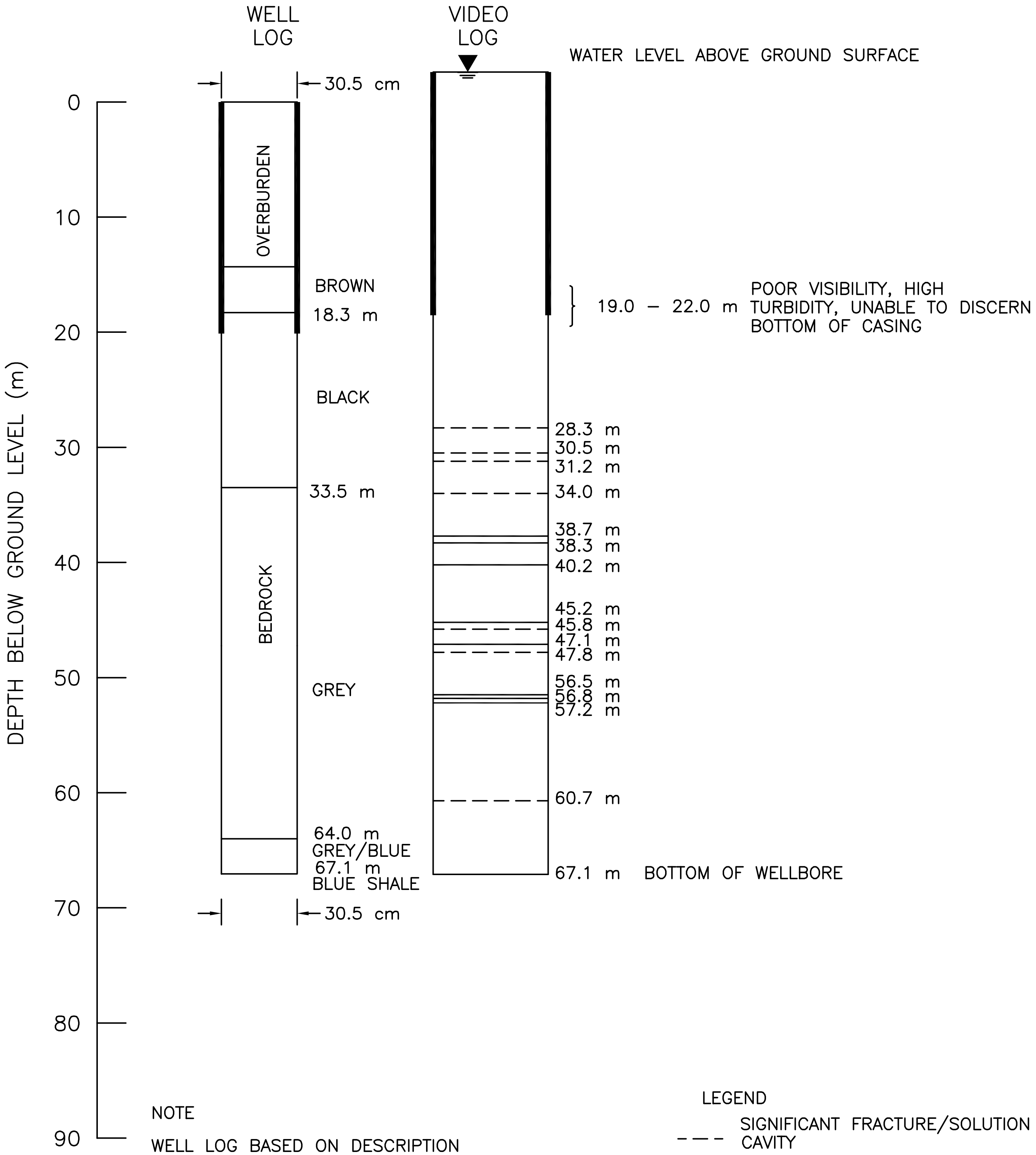
JAGGER HIMS LIMITED
Environmental Consulting Engineers

FIGURE 5–3

EMMA STREET PRODUCTION WELL

CITY OF GUELPH – NORTHEAST QUADRANT

VIDEO LOG REFERENCE ELEVATION 344.69 m a.s.l.
GROUND LEVEL ELEVATION 343.08 m a.s.l.



NOTE

WELL LOG BASED ON DESCRIPTION
PROVIDED IN DRILLER'S LOG 67–1127
VIDEO LOG DERIVED FROM DOWNHOLE CAMERA
WORK COMPLETED BY HYD–ENG
GEOPHYSICS INC, MAY 4, 1993.

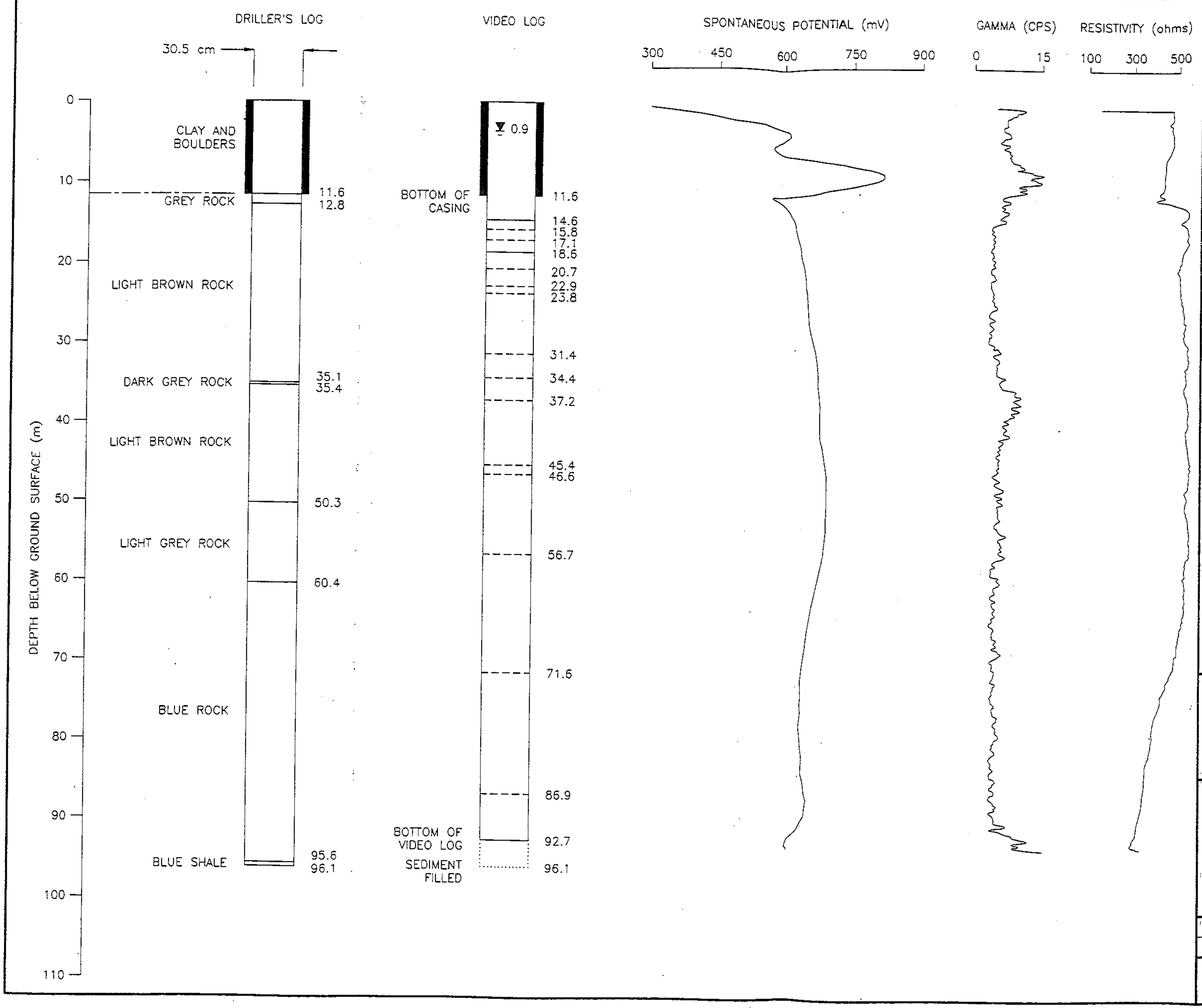
LEGEND

--- SIGNIFICANT FRACTURE/SOLUTION CAVITY
— MAJOR FRACTURE/FRACTURE ZONE/SOLUTION CAVITY

JAGGER HIMS LIMITED
Environmental Consulting Engineers

FIGURE 5–8

FLEMING TEST WELL
CITY OF GUELPH – NORTHEAST QUADRANT



LEGEND

- —·—·— OVERBURDEN/BEDROCK CONTACT
- – – – – – SIGNIFICANT FRACTURE/SOLUTION CAVITY
- ——— MAJOR FRACTURE/FRACTURE ZONE/ SOLUTION CAVITY
- ▼ WATER LEVEL

NOTE:

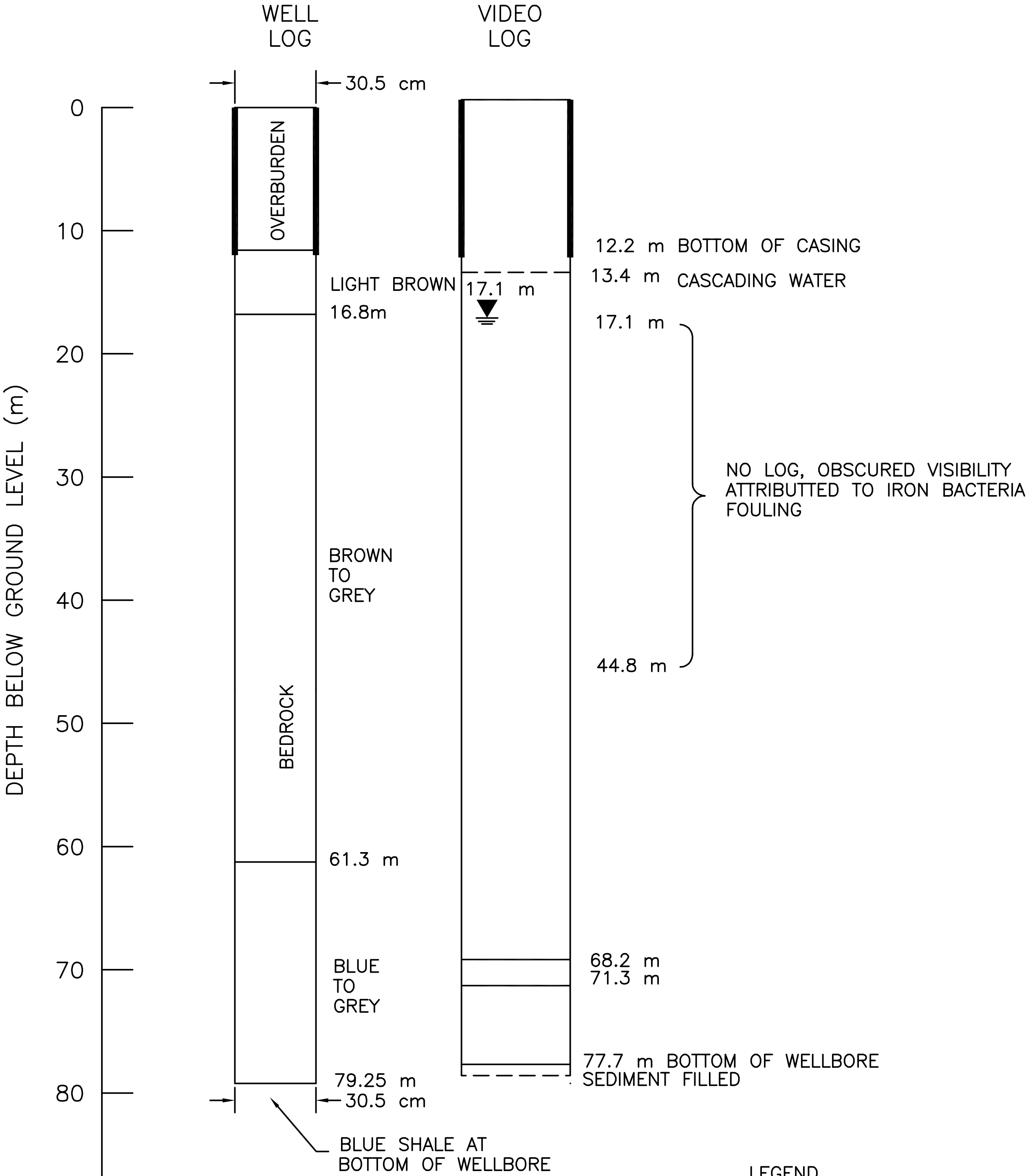
1. DRILLER'S LOG BASED ON DESCRIPTION PROVIDED IN WATER WELL RECORD No. 67-954.
2. GEOPHYSICAL LOG OF SPONTANEOUS POTENTIAL, GAMMA, AND RESISTIVITY HAVE BEEN PROVIDED BY INTERNATIONAL WATER SUPPLY LIMITED, APRIL 28, 1994.
3. VIDEO LOG DERIVED FROM DOWNHOLE CAMERA WORK COMPLETED BY INTERNATIONAL WATER SUPPLY LIMITED, APRIL 28, 1994.
4. MEASURING POINT ELEVATION 324.20 m.

HAUSER MUNICIPAL TEST WELL

AQUIFER PERFORMANCE EVALUATION
NORTHWEST QUADRANT
CITY OF GUELPH

DATE: OCTOBER 30, 1995	SCALE: AS SHOWN
PROJECT: 194061	FILE NO.: B061-1950240
JAGGER HIMS LIMITED Environmental Consulting Engineers / Braun Consulting Engineers	FIGURE B1-9

VIDEO LOG REFERENCE ELEVATION 345.16 m a.s.l.
FLOOR ELEVATION 344.54 m a.s.l.



NOTE

WELL LOG BASED ON DESCRIPTION PROVIDED IN DRILLER'S LOG 67-1132. VIDEO LOG DERIVED FROM DOWNHOLE CAMERA WORK COMPLETED BY INTERNATIONAL WATER SUPPLY LIMITED, AUG 12, 1993.

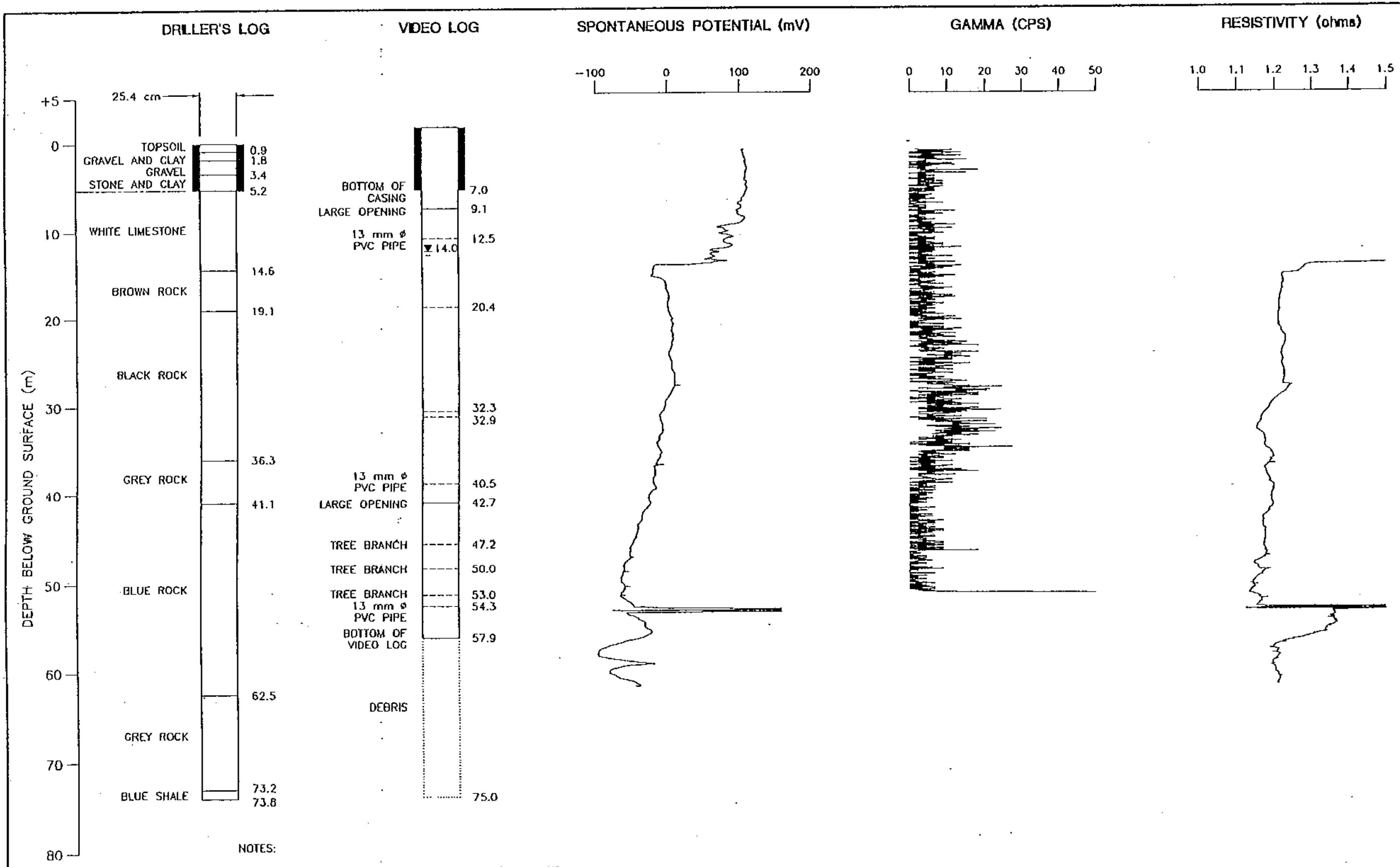
LEGEND

– – –	SIGNIFICANT FRACTURE/SOLUTION CAVITY
——	MAJOR FRACTURE/FRACTURE ZONE/SOLUTION CAVITY

JAGGER HIMS LIMITED
Environmental Consulting Engineers

FIGURE 5–4

HELMAR PRODUCTION WELL
CITY OF GUELPH – NORTHEAST QUADRANT



NOTES:

1. LOG CHART OF SPONTANEOUS POTENTIAL, GAMMA AND RESISTIVITY HAVE BEEN PROVIDED BY INTERNATIONAL WATER SUPPLY LTD., SEPTEMBER 8, 1994.
2. WELL LOG BASED ON DESCRIPTION PROVIDED IN DRILLER'S LOG 67-870.
3. VIDEO LOG DERIVED FROM DOWNHOLE CAMERA WORK COMPLETED BY INTERNATIONAL WATER SUPPLY LTD., SEPTEMBER 8, 1994.
4. STATIC WATER LEVEL AT COMPLETION WAS 14.0 m.
5. MEASURING POINT ELEVATION 315.08 m.
6. VIDEO AND GEOPHYSICAL LOGS ALIGNED WITH DRILLER'S LOG THE BOTTOM OF CASING.
7. DEPTH SCALE ALIGNED WITH DRILLER'S LOG.

LEGEND

—·— OVERBURDEN/BEDROCK CONTACT
- - - - SIGNIFICANT FRACTURE/SOLUTION CAVITY
——— MAJOR FRACTURE/FRACTURE ZONE/SOLUTION CAVITY
▼ WATER LEVEL (m B.G.S.)

SCALE: AS SHOWN
REF. NO.: A076-1960018
DATE: FEBRUARY 25, 1997
PROJECT: 195076

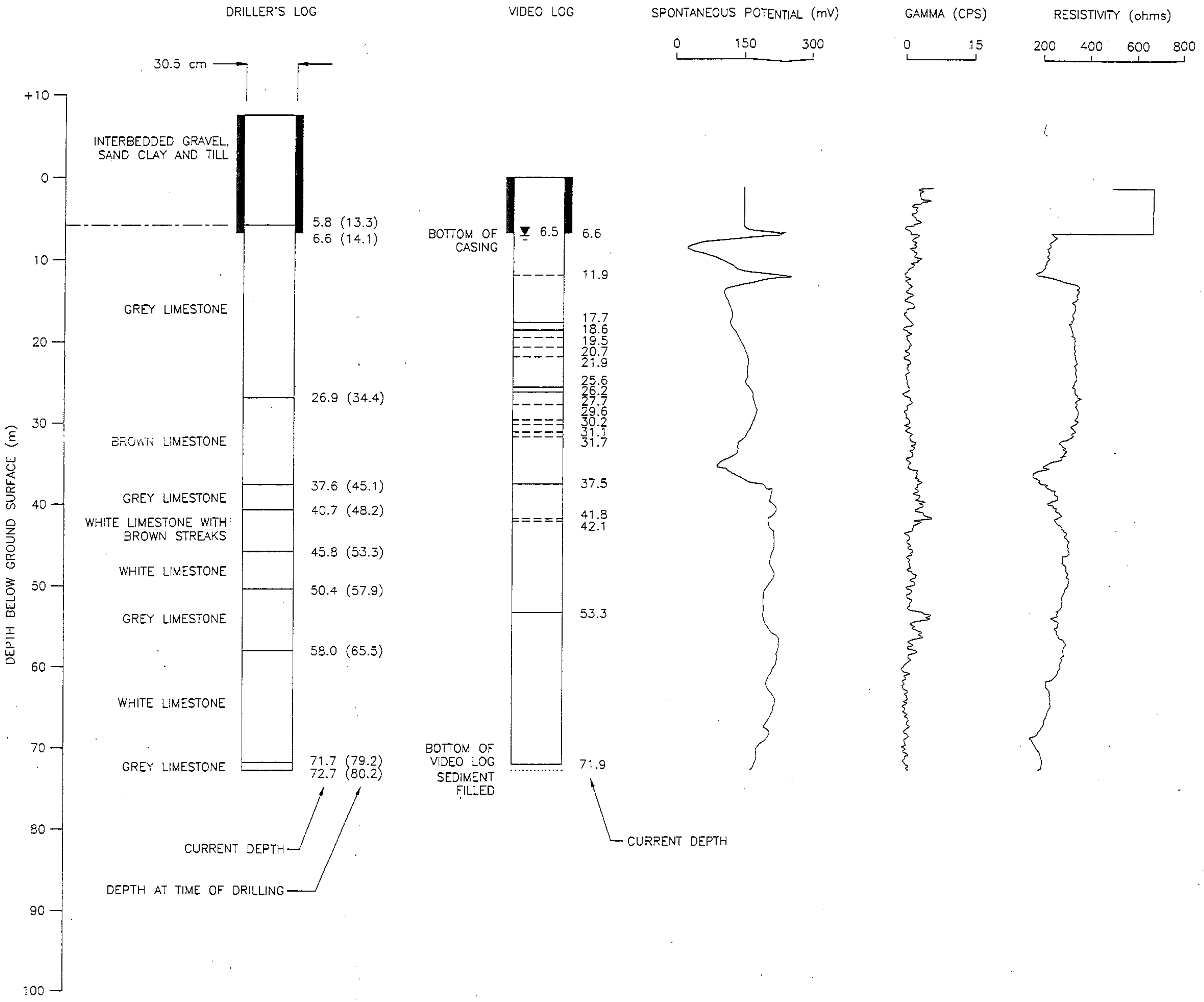
JAGGER HIMS LIMITED
Environmental Consulting Engineers

Braun Consulting Engineers.

MEMBRO PRODUCTION WELL

AQUIFER PERFORMANCE EVALUATION
SOUTHWEST QUADRANT
CITY OF GUELPH

FIGURE
B1-6



LEGEND

–·–·–· OVERBURDEN/BEDROCK CONTACT

– – – – SIGNIFICANT FRACTURE/SOLUTION CAVITY

——— MAJOR FRACTURE/FRACTURE ZONE/ SOLUTION CAVITY

▼ WATER LEVEL

NOTES:

1. DRILLER'S LOG BASED ON DESCRIPTION PROVIDED IN WATER WELL RECORD No. 67–1380.
2. POOR DRILLING RETURNS BETWEEN 37.8 m – 44.5 m. WATER PRODUCED FROM THIS ZONE.
3. 7.5 m OF CASING CUT OFF IN 1966. STATIC LEVEL AT 0.05 m BELOW TOP OF PIPE.
4. GEOPHYSICAL LOG OF SPONTANEOUS POTENTIAL, GAMMA, AND RESISTIVITY PROVIDED BY INTERNATIONAL WATER SUPPLY LIMITED, APRIL 26, 1994.
5. VIDEO LOG DERIVED FROM DOWNHOLE CAMERA WORK COMPLETED BY INTERNATIONAL WATER SUPPLY LIMITED, APRIL 26, 1994.
6. GENERALLY POOR VISIBILITY DUE TO HIGH SEDIMENT LOAD.
7. DEBRIS AT 31.7 m – 71.9 m (PIPE).
8. FLOOR ELEVATION 322.18 m. MEASURING POINT ELEVATION 322.67 m.

PAISLEY ROAD PRODUCTION WELL

AQUIFER PERFORMANCE EVALUATION
NORTHWEST QUADRANT
CITY OF GUELPH

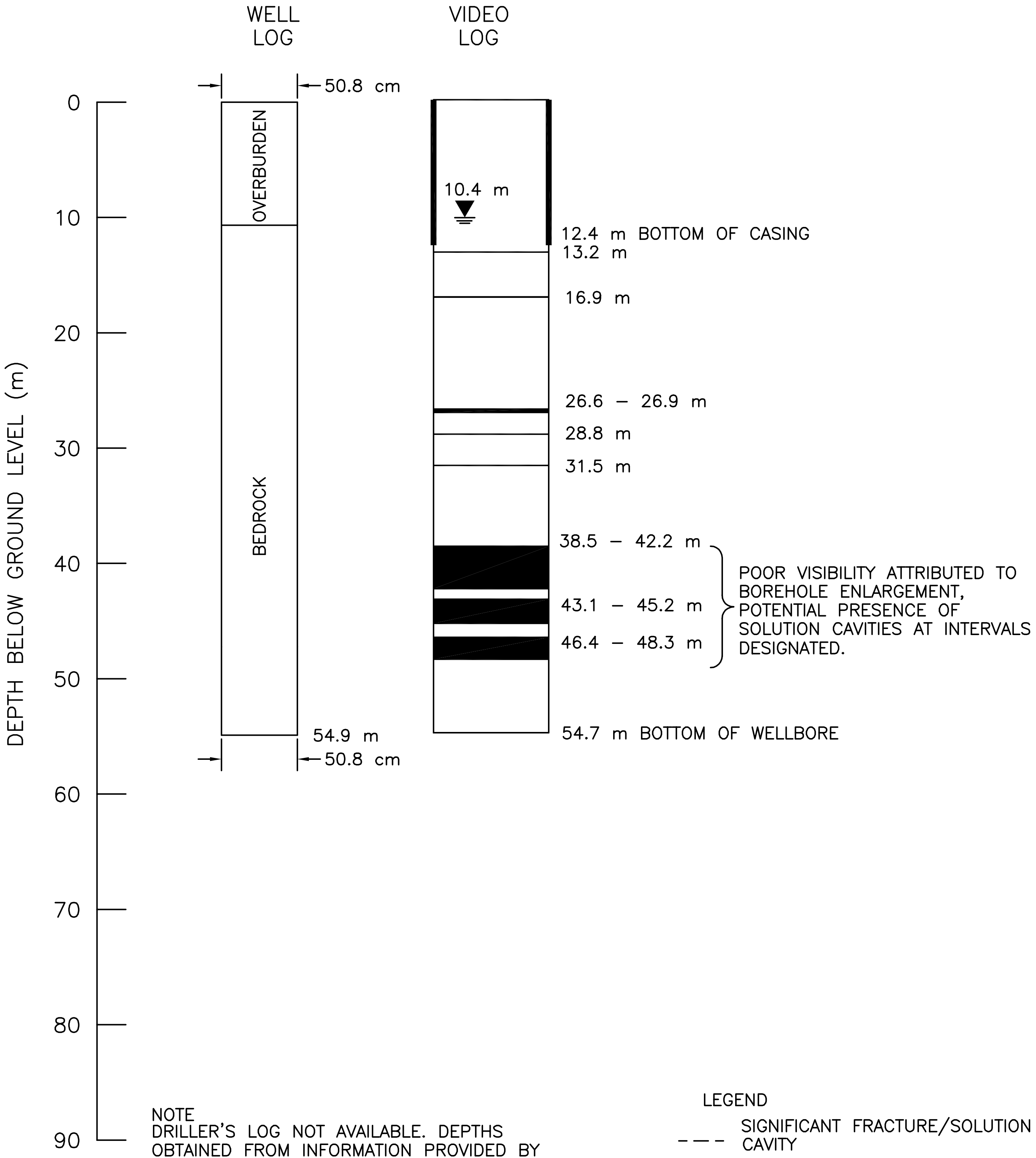
DATE: OCTOBER 30, 1995	SCALE: AS SHOWN
PROJECT: 194061	FILE NO.: B061–1950236

JAGGER HIMS LIMITED
Environmental Consulting Engineers

Braun Consulting Engineers

FIGURE
B1-4

VIDEO LOG REFERENCE ELEVATION 328.48 m a.s.l.
FLOOR ELEVATION 328.26 m a.s.l.



NOTE
DRILLER'S LOG NOT AVAILABLE. DEPTHS OBTAINED FROM INFORMATION PROVIDED BY THE CITY OF GUELPH.
VIDEO LOG DERIVED FROM DOWNHOLE CAMERA WORK COMPLETED BY INTERNATIONAL WATER SUPPLY LTD., AUG 13, 1993.

LEGEND

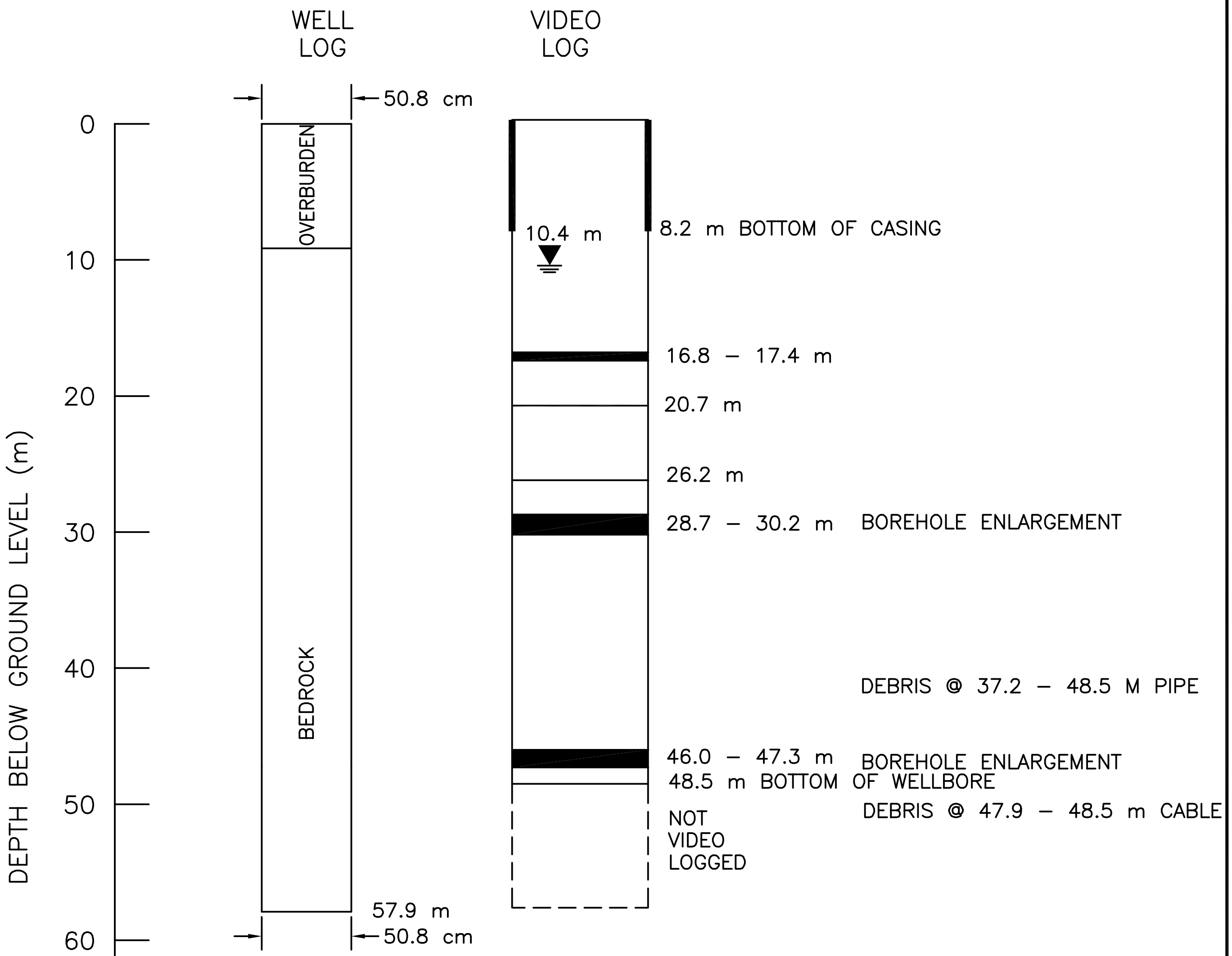
– – –	SIGNIFICANT FRACTURE/SOLUTION CAVITY
——	MAJOR FRACTURE/FRACTURE ZONE/SOLUTION CAVITY

JAGGER HIMS LIMITED
Environmental Consulting Engineers

FIGURE 5–1

PARK #1 MUNICIPAL PRODUCTION WELL
CITY OF GUELPH – NORTHEAST QUADRANT

VIDEO LOG REFERENCE ELEVATION 328.55 m a.s.l.
FLOOR ELEVATION 328.26 m a.s.l.



DRILLER'S LOG NOT AVAILABLE. DEPTH TO BEDROCK 9.14 m OBTAINED FROM INFORMATION PROVIDED BY THE CITY OF GUELPH

NOTE
DRILLER'S LOG NOT AVAILABLE. DEPTHS OBTAINED FROM INFORMATION PROVIDED BY THE CITY OF GUELPH.
VIDEO LOG DERIVED FROM DOWNHOLE CAMERA WORK COMPLETED BY INTERNATIONAL WATER SUPPLY LIMITED, AUG 12, 1993.

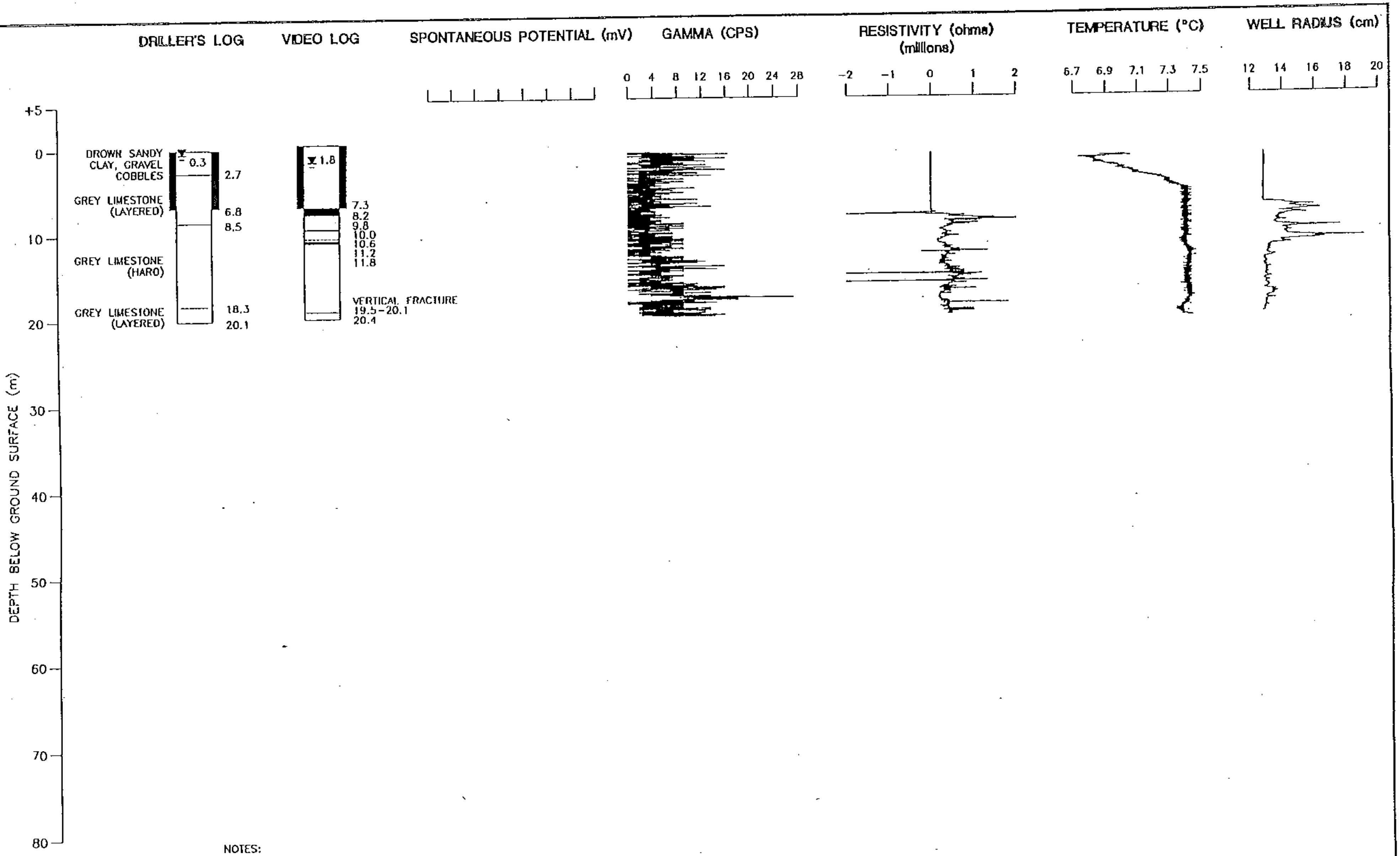
LEGEND

- – – – SIGNIFICANT FRACTURE/SOLUTION CAVITY
- —— MAJOR FRACTURE/FRACTURE ZONE/SOLUTION CAVITY

JAGGER HIMS LIMITED
Environmental Consulting Engineers

FIGURE 5–2

PARK #2 MUNICIPAL PRODUCTION WELL
CITY OF GUELPH – NORTHEAST QUADRANT



NOTES:

1. WELL LOG BASED ON DESCRIPTION PROVIDED IN DRILLER'S LOG.
2. VIDEO AND GEOPHYSICAL LOGS DERIVED FROM WORK COMPLETED BY INTERNATIONAL WATER SUPPLY LTD., FEBRUARY 19, 1996.
3. MEASURING POINT ELEVATION 324.15 m ASL. FLOOR ELEVATION NOT APPLICABLE
4. WATER FOUND AT 8.8 m AND 10.1 m ACCORDING TO DRILLER'S LOG.
5. VIDEO AND GEOPHYSICAL LOGS ALIGNED WITH DRILLER'S LOG AT BOTTOM OF CASING.
6. DEPTH SCALE ALIGNED WITH DRILLER'S LOG.

LEGEND

- ‒·‒·‒ OVERBUROEN/BEDROCK CONTACT
- - - - - SIGNIFICANT FRACTURE/ SOLUTION CAVITY
- ——— MAJOR FRACTURE/FRACTURE ZONE/SOLUTION CAVITY
- ▼ WATER LEVEL (m B.G.S.)

SCALE: AS SHOWN
REF. NO.: A00-086A2-02
DATE: FEBRUARY 3, 1998
PROJECT: 196086

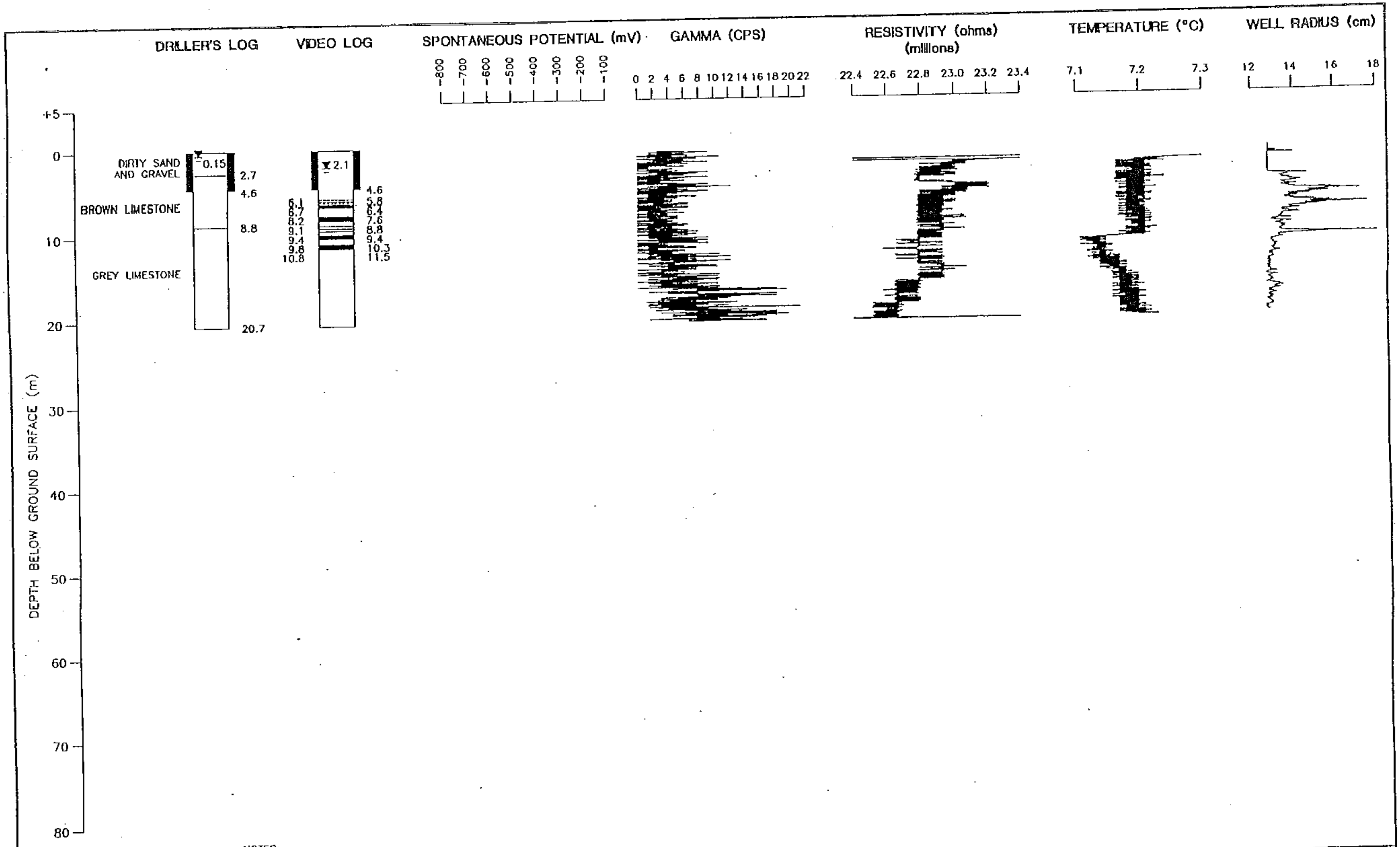
JAGGER HIMS LIMITED
Environmental Consulting Engineers

Braun Consulting Engineers

CARTER-OUT [PW1/89(COG)]

AQUIFER PERFORMANCE EVALUATION
SOUTHEAST QUADRANT
CITY OF GUELPH

FIGURE
A1.2-2



LEGEND

- —·— OVERBURDEN/BEDROCK CONTACT
- ----- SIGNIFICANT FRACTURE/SOLUTION CAVITY
- —— MAJOR FRACTURE/FRACTURE ZONE/SOLUTION CAVITY
- ▼ WATER LEVEL (m B.C.S.)

NOTES:

1. WELL LOG BASED ON DESCRIPTION PROVIDED IN DRILLER'S LOG 67-2696.
2. VIDEO AND GEOPHYSICAL LOGS DERIVED FROM WORK COMPLETED BY INTERNATIONAL WATER SUPPLY LTD., FEBRUARY 19, 1996.
3. MEASURING POINT ELEVATION 324.73 m ASL. FLOOR ELEVATION 323.97 m ASL.
4. WATER FOUND AT 3.3 m ACCORDING TO DRILLER'S LOG.
5. VIDEO AND GEOPHYSICAL LOGS ALIGNED WITH DRILLER'S LOG AT BOTTOM OF CASING.
6. DEPTH SCALE ALIGNED WITH DRILLER'S LOG.

SCALE: AS SHOWN

REF. NO.: A00-086A2-01

DATE: FEBRUARY 3, 1998

PROJECT: 196086

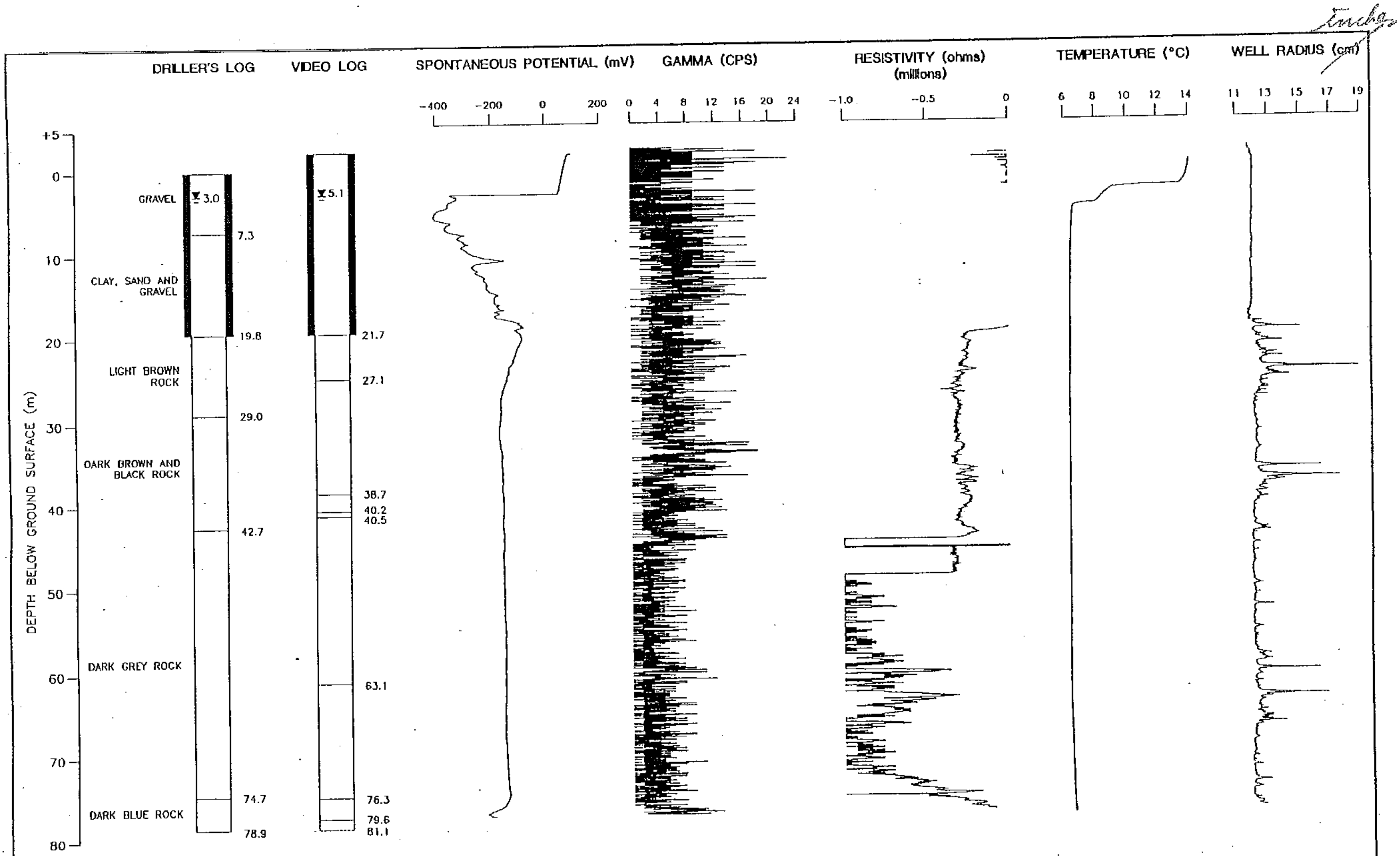
JAGGER HIMS LIMITED
Environmental Consulting Engineers

Braun Consulting Engineers

CARTER-IN [PW2/62(COG)]

AQUIFER PERFORMANCE EVALUATION
SOUTHEAST QUADRANT
CITY OF GUELPH

FIGURE
A1.2-1



NOTES:

1. WELL LOG BASED ON DESCRIPTION PROVIDED IN DRILLER'S LOG 67-933.
2. VIDEO AND GEOPHYSICAL LOGS DERIVED FROM WORK COMPLETED BY INTERNATIONAL WATER SUPPLY LTD., OCTOBER 17, 1966.
3. MEASURING POINT ELEVATION 336.37 m ASL. FLOOR ELEVATION 335.61 m ASL.
4. WATER FOUND AT 41.4 m ACCORDING TO DRILLER'S LOG.
5. VIDEO AND GEOPHYSICAL LOGS ALIGNED WITH DRILLER'S LOG AT BOTTOM OF CASING.
6. DEPTH SCALE ALIGNED WITH DRILLER'S LOG.

LEGEND

——	OVERBURDEN/BEDROCK CONTACT
- - - -	SIGNIFICANT FRACTURE/ SOLUTION CAVITY
———	MAJOR FRACTURE/FRACTURE ZONE/SOLUTION CAVITY
▼	WATER LEVEL (m B.G.S.)

SCALE: AS SHOWN

REF. NO.: A00-086A2-03

DATE: FEBRUARY 3, 1998

PROJECT: 196086

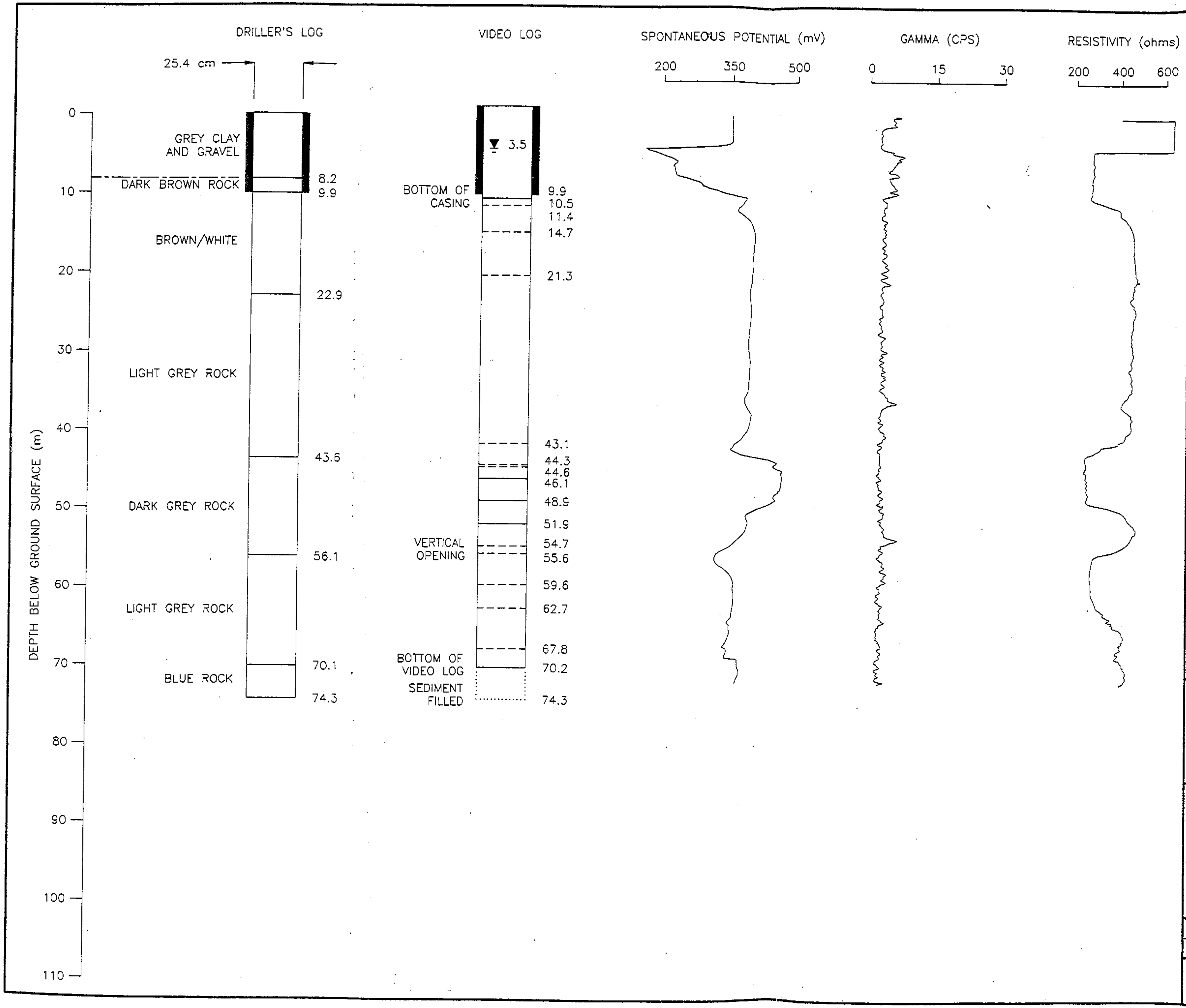
JAGGER HIMS LIMITED
Environmental Consulting Engineers

Braun Consulting Engineers

BURKE WELL [PW2/66(COG)]

AQUIFER PERFORMANCE EVALUATION
SOUTHEAST QUADRANT
CITY OF GUELPH

FIGURE
A1.2-4



LEGEND

-·-·- OVERBURDEN/BEDROCK CONTACT

- - - - SIGNIFICANT FRACTURE/SOLUTION CAVITY

—— MAJOR FRACTURE/FRACTURE ZONE/ SOLUTION CAVITY

▼ WATER LEVEL

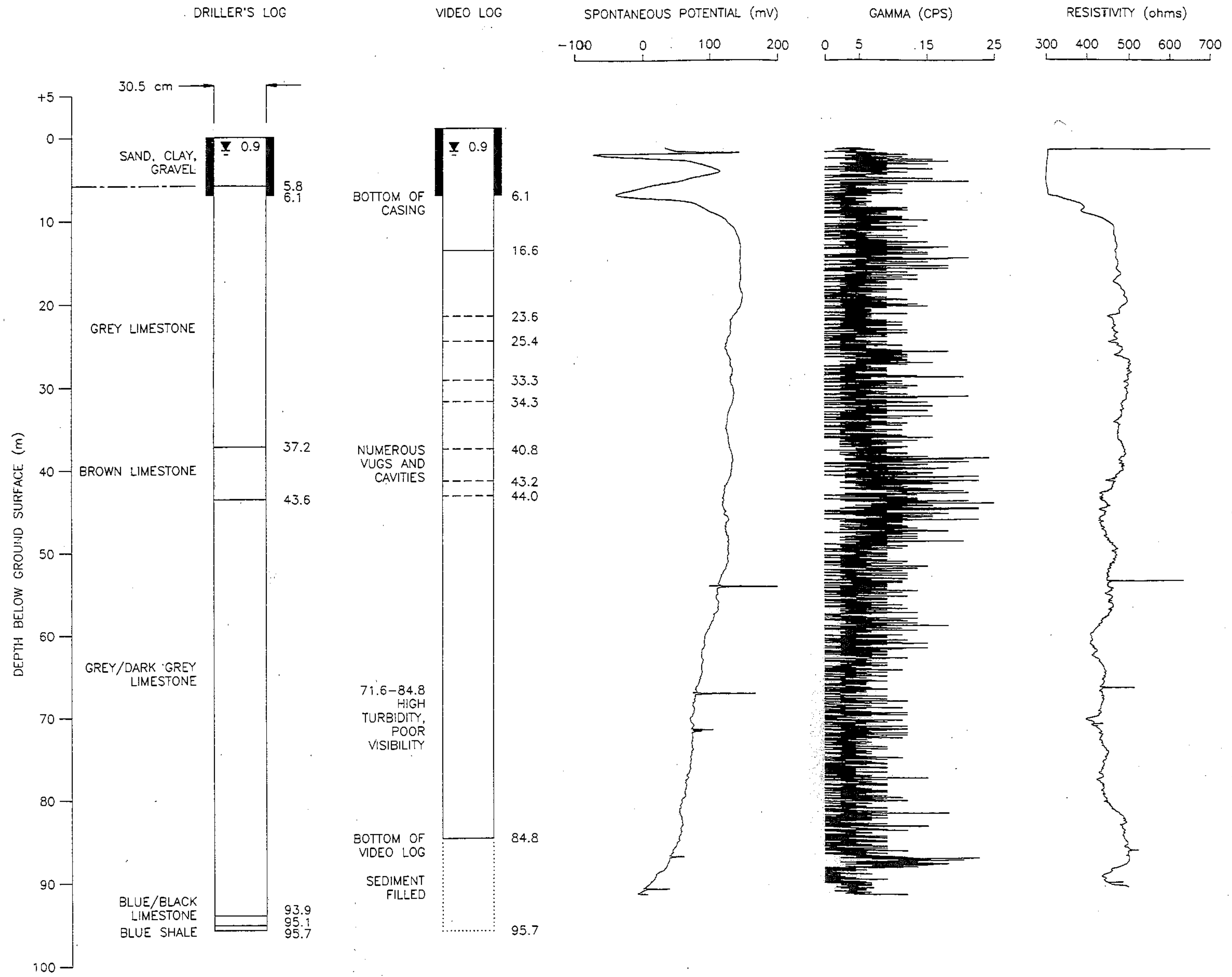
NOTES:

1. DRILLER'S LOG BASED ON DESCRIPTION PROVIDED IN WATER WELL RECORD No. 67-3649.
2. LOOSE BROKEN ROCK AND LARGE HOLES NOTED BETWEEN 70.1 m AND 74.3 m IN WELL LOG.
3. GEOPHYSICAL LOG OF SPONTANEOUS POTENTIAL, GAMMA, AND RESISTIVITY PROVIDED BY INTERNATIONAL WATER SUPPLY LIMITED, APRIL 27, 1994.
4. VIDEO LOG DERIVED FROM DOWNHOLE CAMERA WORK COMPLETED BY INTERNATIONAL WATER SUPPLY LIMITED, APRIL 27, 1994.
5. FLOOR ELEVATION 325.93 m. MEASURING POINT ELEVATION 326.43 m.
6. GENERALLY POOR VISIBILITY WITH DOWNHOLE CAMERA DUE TO TURBIDITY AND PARTICULATE LOAD IN WATER.

QUEENSDALE PRODUCTION WELL

AQUIFER PERFORMANCE EVALUATION
NORTHWEST QUADRANT
CITY OF GUELPH

DATE: OCTOBER 30, 1995	SCALE: AS SHOWN
PROJECT: 194061	FILE NO.: B061-1950237
JAGGER HIMS LIMITED Environmental Consulting Engineers Braun Consulting Engineers	FIGURE B1-5



LEGEND

- · - · - OVERBURDEN/BEDROCK CONTACT

------ SIGNIFICANT FRACTURE/SOLUTION CAVITY

——— MAJOR FRACTURE/FRACTURE ZONE/SOLUTION CAVITY

▼ WATER LEVEL (m B.G.S.)

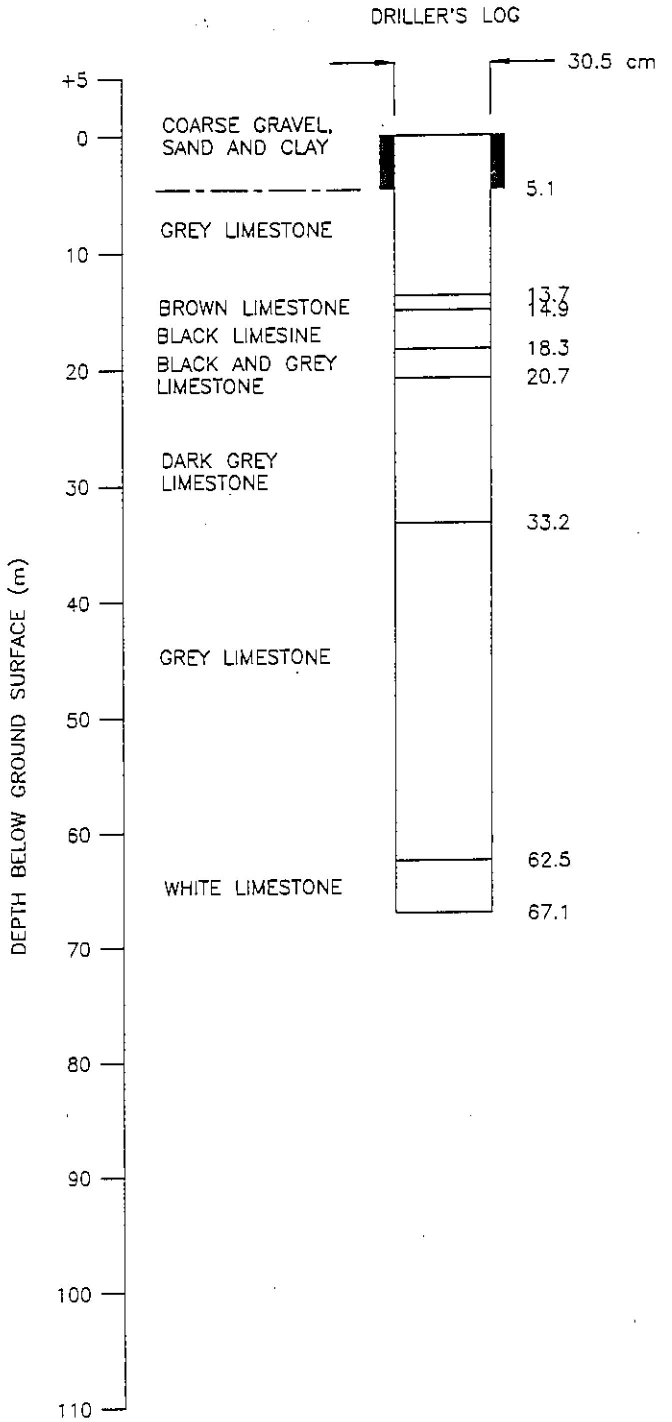
NOTES:

1. DRILLER'S LOG BASED ON DESCRIPTION PROVIDED IN WATER WELL RECORD No. 67–1333.
2. STATIC LEVEL AT WELL COMPLETION WAS 0.9 m.
3. GEOPHYSICAL LOG OF SPONTANEOUS POTENTIAL, GAMMA, AND RESISTIVITY HAVE BEEN PROVIDED BY INTERNATIONAL WATER SUPPLY LIMITED, APRIL 28, 1994.
4. VIDEO LOG DERIVED FROM DOWNHOLE CAMERA WORK COMPLETED BY INTERNATIONAL WATER SUPPLY LIMITED, APRIL 28, 1994.
5. FLOOR ELEVATION 339.15 m.
MEASURING POINT ELEVATION 339.79 m.

SACCO PRODUCTION WELL

AQUIFER PERFORMANCE EVALUATION
NORTHWEST QUADRANT
CITY OF GUELPH

DATE: OCTOBER 30, 1995	SCALE: AS SHOWN
PROJECT: 194061	FILE NO.: B061–1950233
JAGGER HIMS LIMITED Environmental Consulting Engineers Braun Consulting Engineers	FIGURE B1-1



VIDEO LOG OF
SILVERCREEK PARKWAY WELL
NOT OBTAINED (SEE
TEXT FOR EXPLANATION)

LEGEND

— — — OVERBURDEN/BEDROCK CONTACT

▼ WATER LEVEL

NOTES:
1. DRILLER'S LOG BASED ON DESCRIPTION PROVIDED IN WATER WELL RECORD No. 67–1377.
2. WATER FOUND AT 46.33 m AS REPORTED IN WELL LOG. ORIGINAL STATIC LEVEL REPORTED AS 1.4 m.
3. FLOOR ELEVATION 318.31 m. MEASURING POINT ELEVATION 318.50 m.

SILVERCREEK PARKWAY WELL

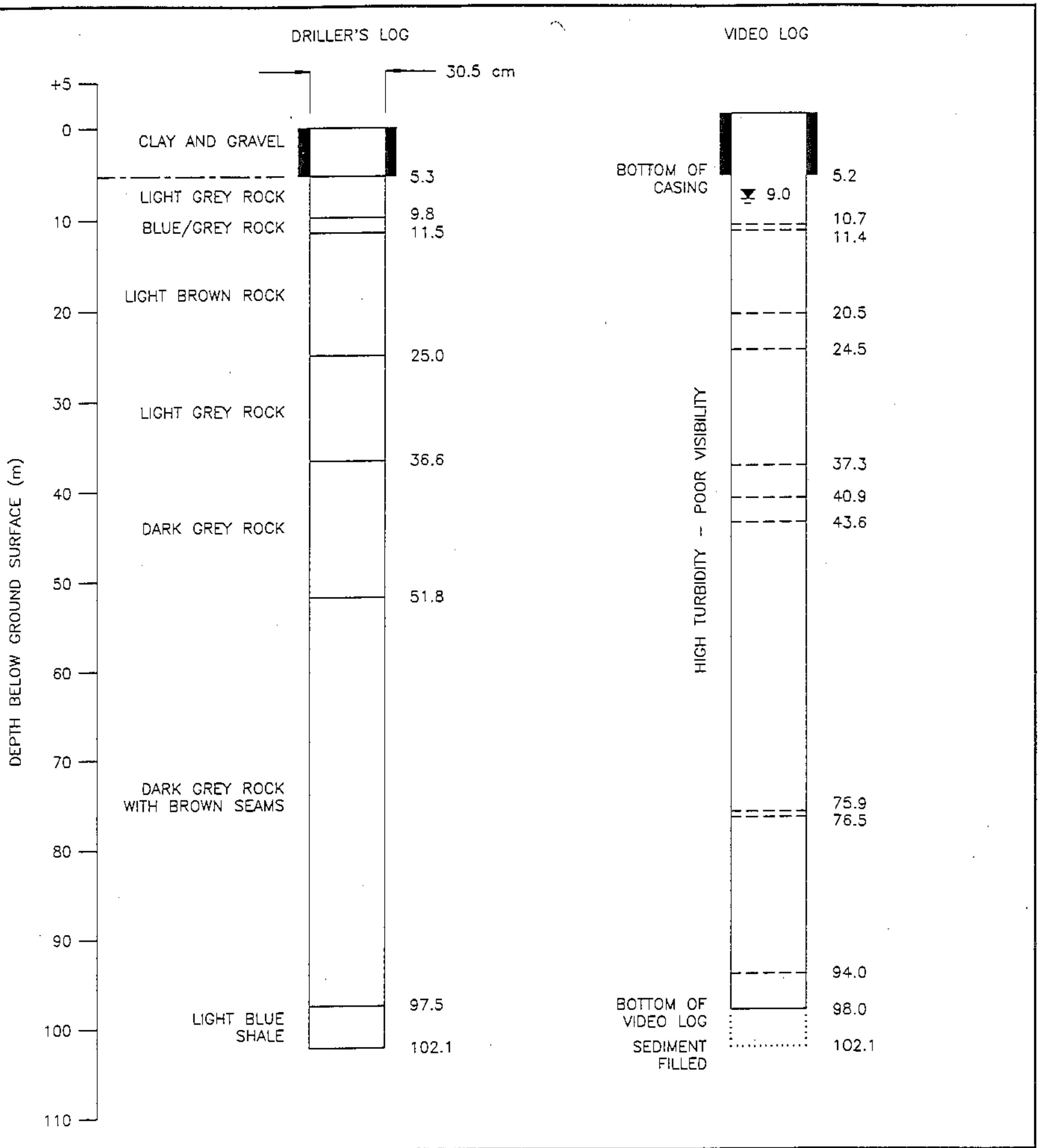
AQUIFER PERFORMANCE EVALUATION
NORTHWEST QUADRANT
CITY OF GUELPH

DATE: OCTOBER 30, 1995	SCALE: AS SHOWN
PROJECT: 194061	REF. NO.: A061–1950522

JAGGER HIMS LIMITED
Environmental Consulting Engineers

Braun Consulting Engineers

FIGURE
B1-8



LEGEND

— · — OVERBURDEN/BEDROCK CONTACT

- - - - - SIGNIFICANT FRACTURE/SOLUTION CAVITY

——— MAJOR FRACTURE/FRACTURE ZONE/SOLUTION CAVITY

▼ WATER LEVEL

NOTES:
1. DRILLER'S LOG BASED ON DESCRIPTION PROVIDED IN WATER WELL RECORD No. 67-1414.
2. WATER FOUND AT 24.7 AND 73.2 m AS REPORTED IN WELL LOG. ORIGINAL STATIC LEVEL REPORTED AS 7.3 m.
3. VIDEO LOG DERIVED FROM DOWNHOLE CAMERA WORK COMPLETED BY HYD-ENG GEOPHYSICS MAY 4, 1994.
4. INITIAL ELEVATION 342.90 m.
FLOOR ELEVATION 343.98 m.
MEASURING POINT ELEVATION 344.23 m.

SMALLFIELD PRODUCTION WELL

AQUIFER PERFORMANCE EVALUATION NORTHWEST QUADRANT CITY OF GUELPH

DATE: OCTOBER 30, 1995

SCALE: AS SHOWN

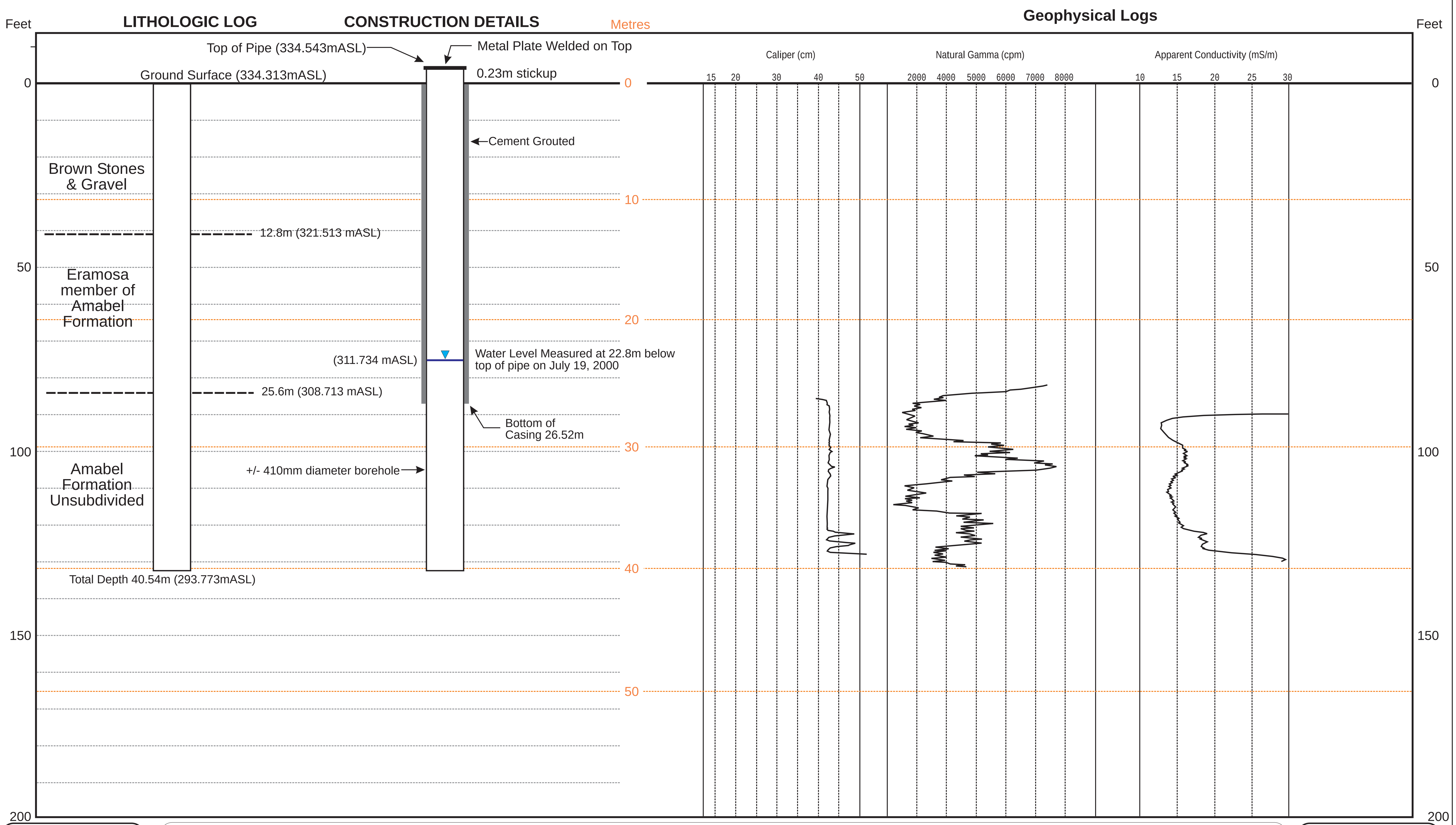
PROJECT: 194061

REF. NO.: A061-1950239

JAGGER HIMS LIMITED
Environmental Consulting Engineers

Braun Consulting Engineers

FIGURE B1-7



Gartner Lee

(Revised Feb 26/03)

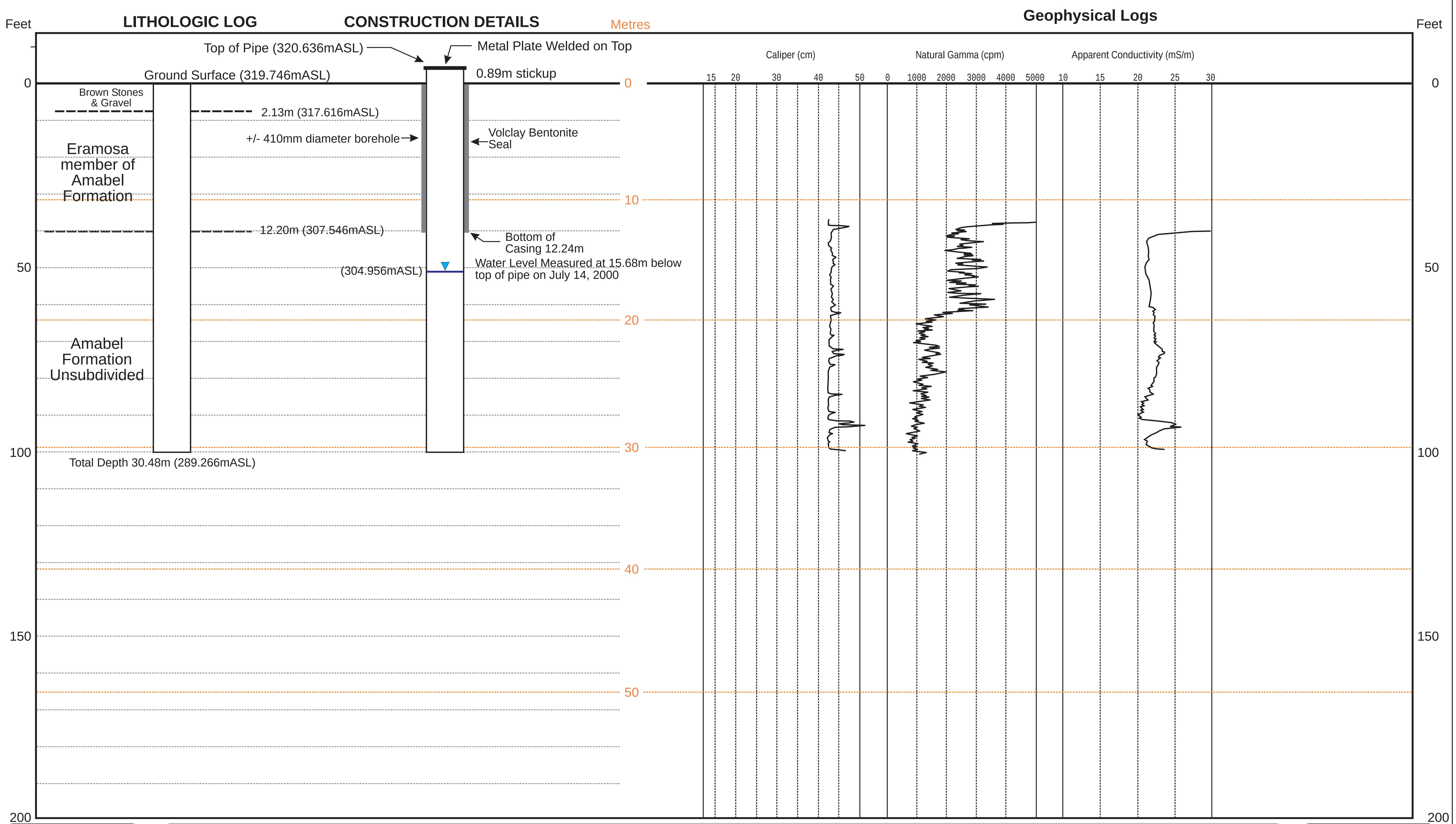
BOREHOLE # PW14a (Deep)

Lithologic Log, Construction Details, Geophysical Logs

Arkell Spring Grounds
Groundwater Supply Investigation

Map ID#
10

Project 99-415.9
(99\415\415-9\A.3-7.cdr)



Gartner Lee

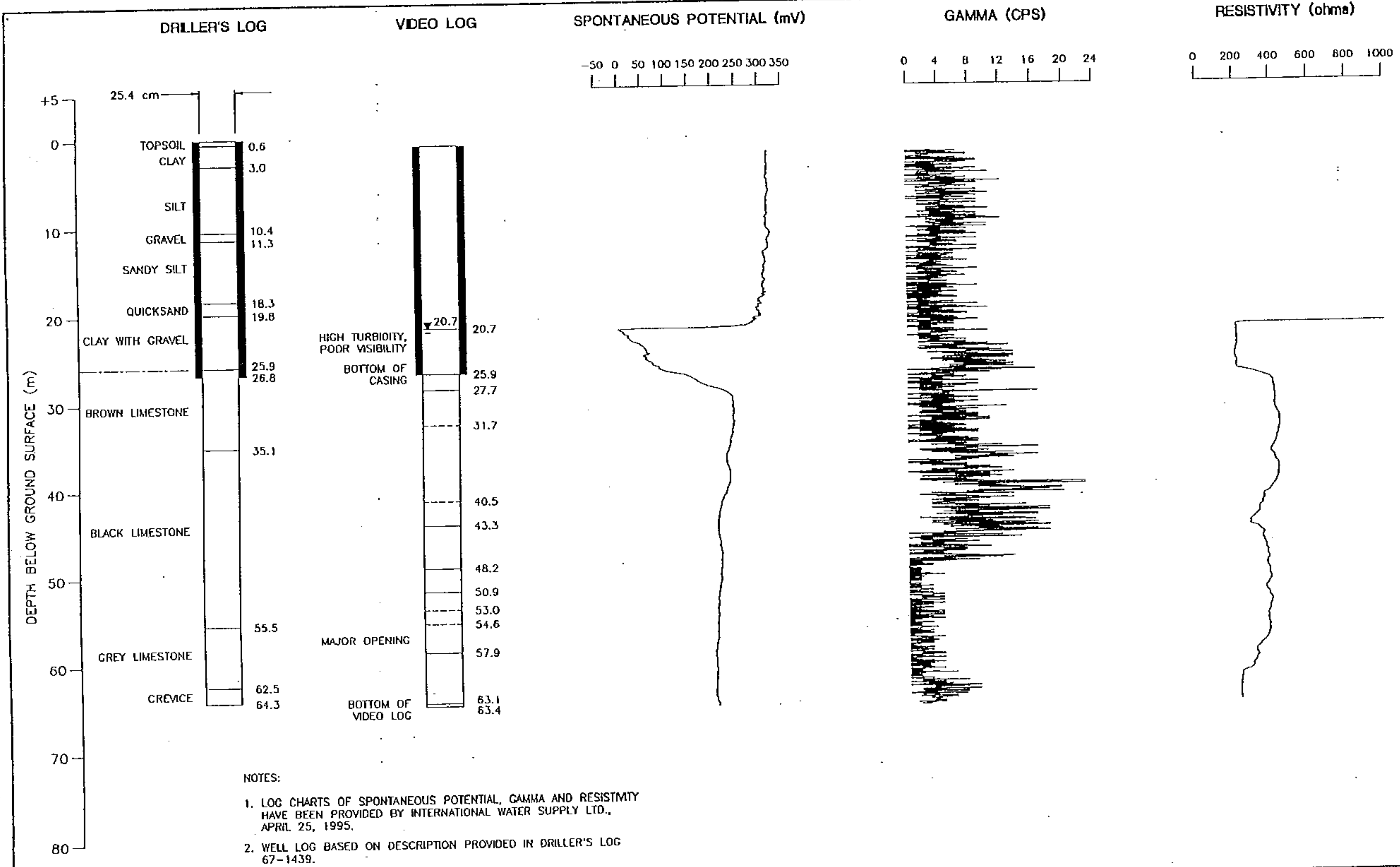
BOREHOLE # PW15a (Deep)

Lithologic Log, Construction Details, Geophysical Logs

Arkell Spring Grounds
Groundwater Supply Investigation

Map ID#
9

Project 99-415.2
(99\415\415-2\A-9.cdr)



NOTES:

1. LOG CHARTS OF SPONTANEOUS POTENTIAL, GAMMA AND RESISTIVITY HAVE BEEN PROVIDED BY INTERNATIONAL WATER SUPPLY LTD., APRIL 25, 1995.
2. WELL LOG BASED ON DESCRIPTION PROVIDED IN DRILLER'S LOG 67-1439.
3. VIDEO LOG DERIVED FROM DOWNHOLE CAMERA WORK COMPLETED BY INTERNATIONAL WATER SUPPLY LTD., APRIL 25, 1995.
4. POOR VISIBILITY FROM 20.7 m TO 25.9 m DUE TO IRON BACTERIA.
5. WATER FOUND AT 27.4 m AND 62.5 m AS REPORTED IN DRILLER'S LOG.
6. STATIC WATER LEVEL AT COMPLETION WAS 22.6 m.
7. MEASURING POINT ELEVATION 330.01 m. FLOOR ELEVATION 329.45 m.
8. VIDEO AND GEOPHYSICAL LOGS ALIGNED WITH DRILLER'S LOG ON THE BOTTOM OF CASING.
9. DEPTH SCALE ALIGNED WITH DRILLER'S LOG.

LEGEND

—·—·—	OVERBURDEN/BEDROCK CONTACT
-----	SIGNIFICANT FRACTURE/ SOLUTION CAVITY
———	MAJOR FRACTURE/FRACTURE ZONE/SOLUTION CAVITY
▼	WATER LEVEL (m B.G.S.)

SCALE: AS SHOWN

REF. NO.: A076-1960166

DATE: FEBRUARY 25, 1997

PROJECT: 195076

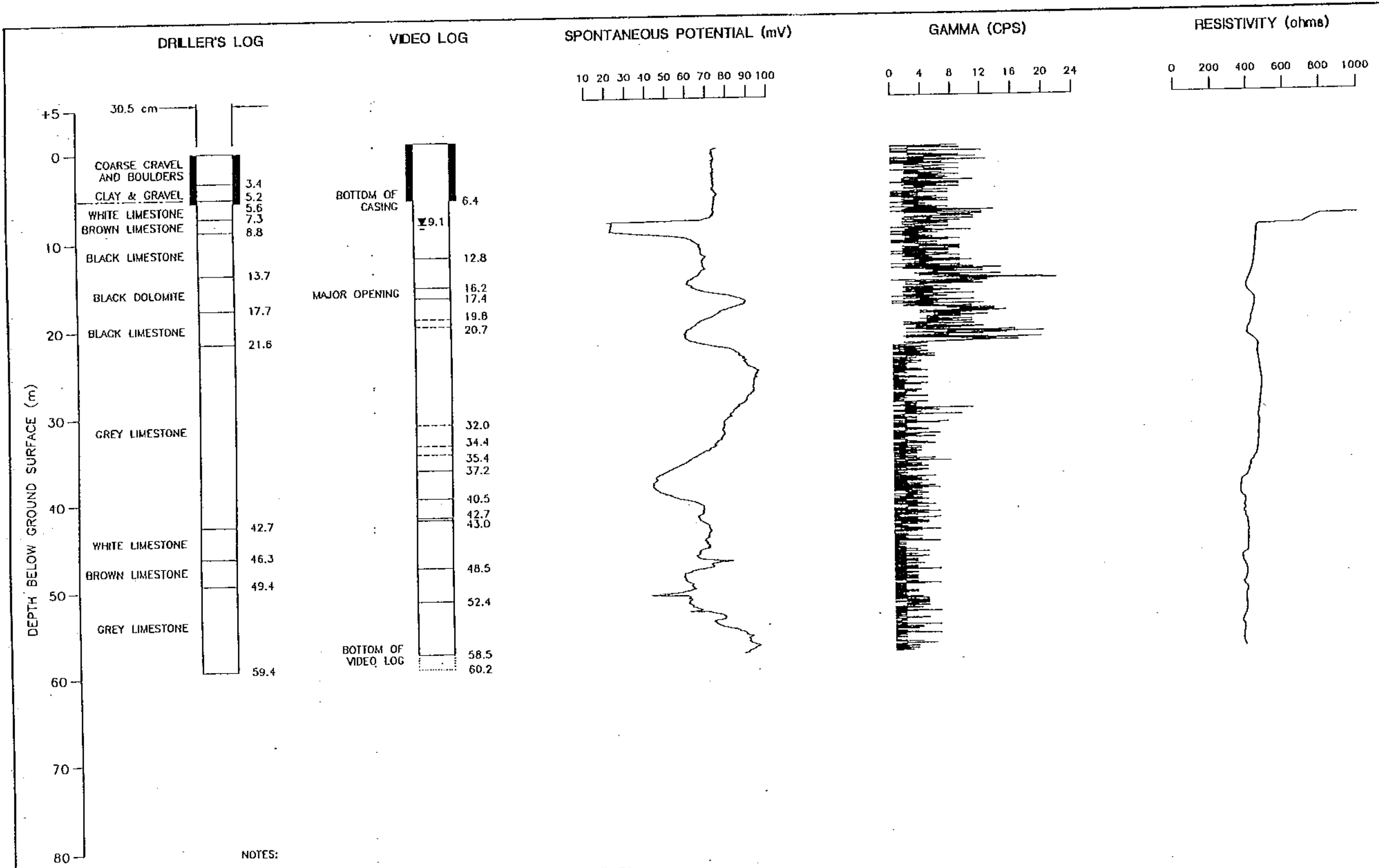
JAGGER HIMS LIMITED
Environmental Consulting Engineers

Braun Consulting Engineers

UNIVERSITY OF GUELPH
PRODUCTION WELL

AQUIFER PERFORMANCE EVALUATION
SOUTHWEST QUADRANT
CITY OF GUELPH

FIGURE
B1-4



NOTES:

1. LOG CHARTS OF SPONTANEOUS POTENTIAL, GAMMA AND RESISTIVITY HAVE BEEN PROVIDED BY INTERNATIONAL WATER SUPPLY LTD., APRIL 24, 1995.
2. WELL LOG BASED ON DESCRIPTION PROVIDED IN DRILLER'S LOG 67-875.
3. VIDEO LOG DERIVED FROM DOWNHOLE CAMERA WORK COMPLETED BY INTERNATIONAL WATER SUPPLY LTD., APRIL 24, 1995.
4. STATIC WATER LEVEL AT COMPLETION WAS 5.8 m.
5. MEASURING POINT ELEVATION 315.42 m. FLOOR ELEVATION 315.02 m.
6. VIDEO AND GEOPHYSICAL LOGS ALIGNED WITH DRILLER'S LOG ON THE BOTTOM OF CASING.

LEGEND

—·—·—	OVERBURDEN/BEDROCK CONTACT
- - - -	SIGNIFICANT FRACTURE/ SOLUTION CAVITY
———	MAJOR FRACTURE/FRACTURE ZONE/SOLUTION CAVITY
▼	WATER LEVEL (m B.G.S.)

SCALE: AS SHOWN

REF. NO.: A076-1960165

DATE: FEBRUARY 25, 1997

PROJECT: 195076

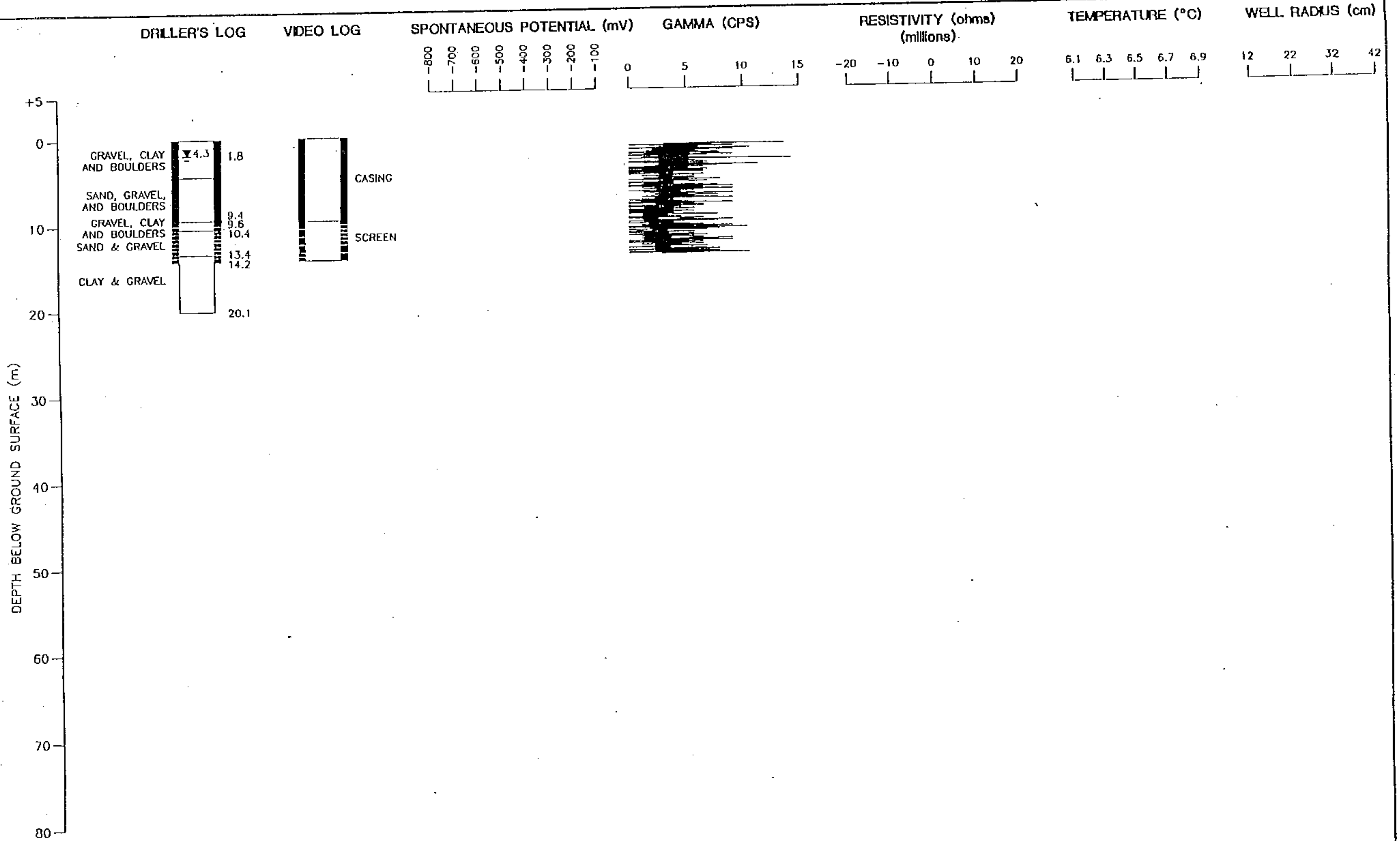
JAGGER HIMS LIMITED

Braun Consulting Engineers

WATER STREET PRODUCTION WELL

AQUIFER PERFORMANCE EVALUATION
SOUTHWEST QUADRANT
CITY OF GUELPH

FIGURE
B1-1



NOTES:

1. WELL LOG BASED ON DESCRIPTION PROVIDED IN DRILLER'S LOG 67-2769.
2. VIDEO AND GEOPHYSICAL LOGS DERIVED FROM WORK COMPLETED BY INTERNATIONAL WATER SUPPLY LTD., OCTOBER 11, 1996.
3. MEASURING POINT ELEVATION 330.79 m ASL.
   FLOOR ELEVATION 330.24 m ASL.
4. WATER FOUND AT 3.96 m ACCORDING TO DRILLER'S LOG.
6. VIDEO AND GEOPHYSICAL LOGS ALIGNED WITH DRILLER'S LOG AT BOTTOM OF CASING.
7. DEPTH SCALE ALIGNED WITH DRILLER'S LOG.

LEGEND

‐‐‐‐‐	OVERBURDEN/BEDROCK CONTACT
-----	SIGNIFICANT FRACTURE/SOLUTION CAVITY
———	MAJOR FRACTURE/FRACTURE ZONE/SOLUTION CAVITY
▼	WATER LEVEL (m B.G.S.)

SCALE: AS SHOWN

REF. NO.: A00-086A1-01

DATE: MAY 2, 1997

PROJECT: 196086

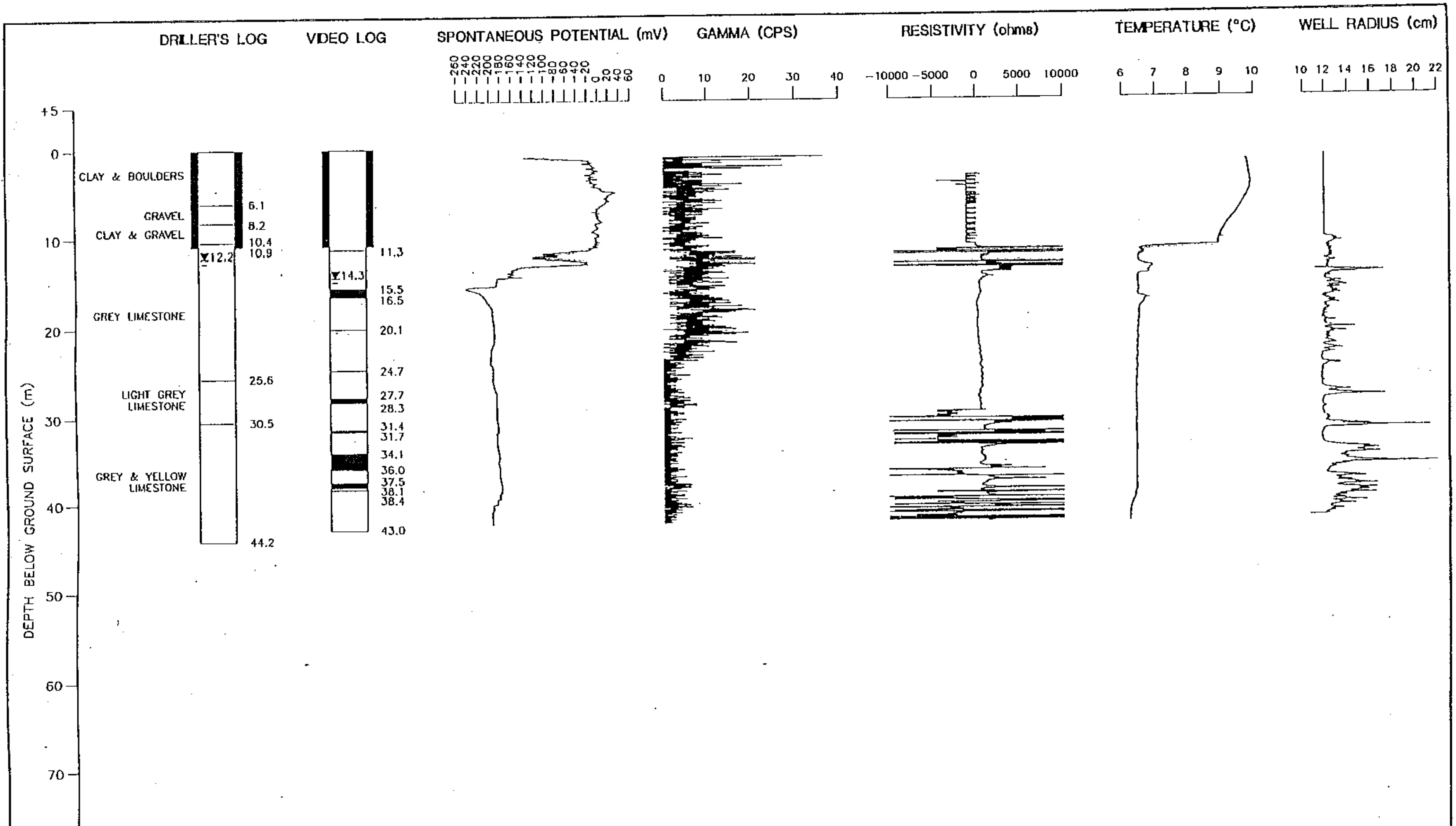
JAGGER HIMS LIMITED
Environmental Consulting Engineers

Braun Consulting Engineers

PW1/66(COG)

AQUIFER PERFORMANCE EVALUATION
SOUTHEAST QUADRANT
CITY OF GUELPH

FIGURE
A1.1-4



NOTES:

1. WELL LOG BASED ON DESCRIPTION PROVIDED IN DRILLER'S LOG 67-2808.
2. VIDEO AND GEOPHYSICAL LOGS DERIVED FROM WORK COMPLETED BY INTERNATIONAL WATER SUPPLY LTD., OCTOBER 9, 1996.
3. MEASURING POINT ELEVATION 330.70 m ASL. FLOOR ELEVATION 330.27 m ASL.
4. WATER FOUND FROM 30.5 m TO 44.2 m ACCORDING TO DRILLER'S LOG.
5. DRILLER'S REPORTED A LOSS OF CUTTING AND A RAPID DECLINE IN WATER LEVEL BETWEEN 33.2 m AND 34.7 m.
6. VIDEO AND GEOPHYSICAL LOGS ALIGNED WITH DRILLER'S LOG AT BOTTOM OF CASING.
7. DEPTH SCALE ALIGNED WITH DRILLER'S LOG.

LEGEND

-·-·- OVERBURDEN/BEDROCK CONTACT
- - - - SIGNIFICANT FRACTURE/SOLUTION CAVITY
—— MAJOR FRACTURE/FRACTURE ZONE/SOLUTION CAVITY
▼ WATER LEVEL (m B.G.S.)

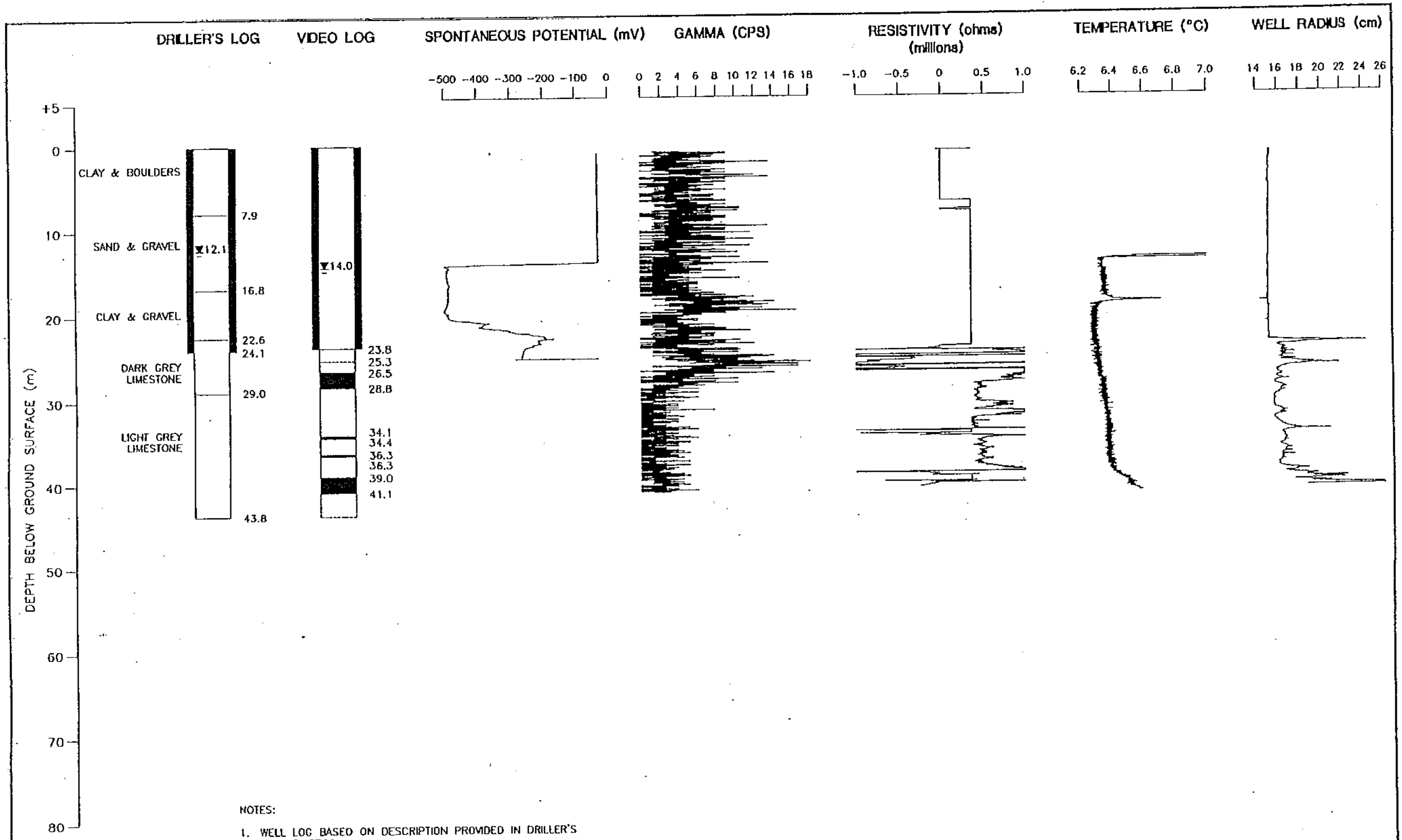
SCALE: AS SHOWN
REF. NO.: A00-086A1-02
DATE: MAY 2, 1997
PROJECT: 196086

JAGGER HIMS LIMITED
Environmental Consulting Engineers
Braun Consulting Engineers

PW6/63(COG)

AQUIFER PERFORMANCE EVALUATION
SOUTHEAST QUADRANT
CITY OF GUELPH

FIGURE
A1.1-1



NOTES:

1. WELL LOG BASED ON DESCRIPTION PROVIDED IN DRILLER'S LOG 67-2766.
2. VIDEO AND GEOPHYSICAL LOGS DERIVED FROM WORK COMPLETED BY INTERNATIONAL WATER SUPPLY LTD., OCTOBER 15, 1996.
3. MEASURING POINT ELEVATION 330.79 m ASL. FLOOR ELEVATION 330.21 m ASL.
4. WATER FOUND FROM 39.0 m ACCORDING TO DRILLER'S LOG.
5. DRILLER'S REPORTED A LOSS OF CUTTING AND A RAPID DECLINE IN WATER LEVEL BETWEEN 39.3 m AND 42.7 m.
6. VIDEO AND GEOPHYSICAL LOGS ALIGNED WITH DRILLER'S LOG AT BOTTOM OF CASING.
7. DEPTH SCALE ALIGNED WITH DRILLER'S LOG.

LEGEND

— - — OVERBURDEN/BEDROCK CONTACT
- - - - SIGNIFICANT FRACTURE/SOLUTION CAVITY
——— MAJOR FRACTURE/FRACTURE ZONE/SOLUTION CAVITY
▼ WATER LEVEL (m B.G.S.)

SCALE: AS SHOWN
REF. NO.: A00-086A1-03
DATE: MAY 2, 1997
PROJECT: 196086

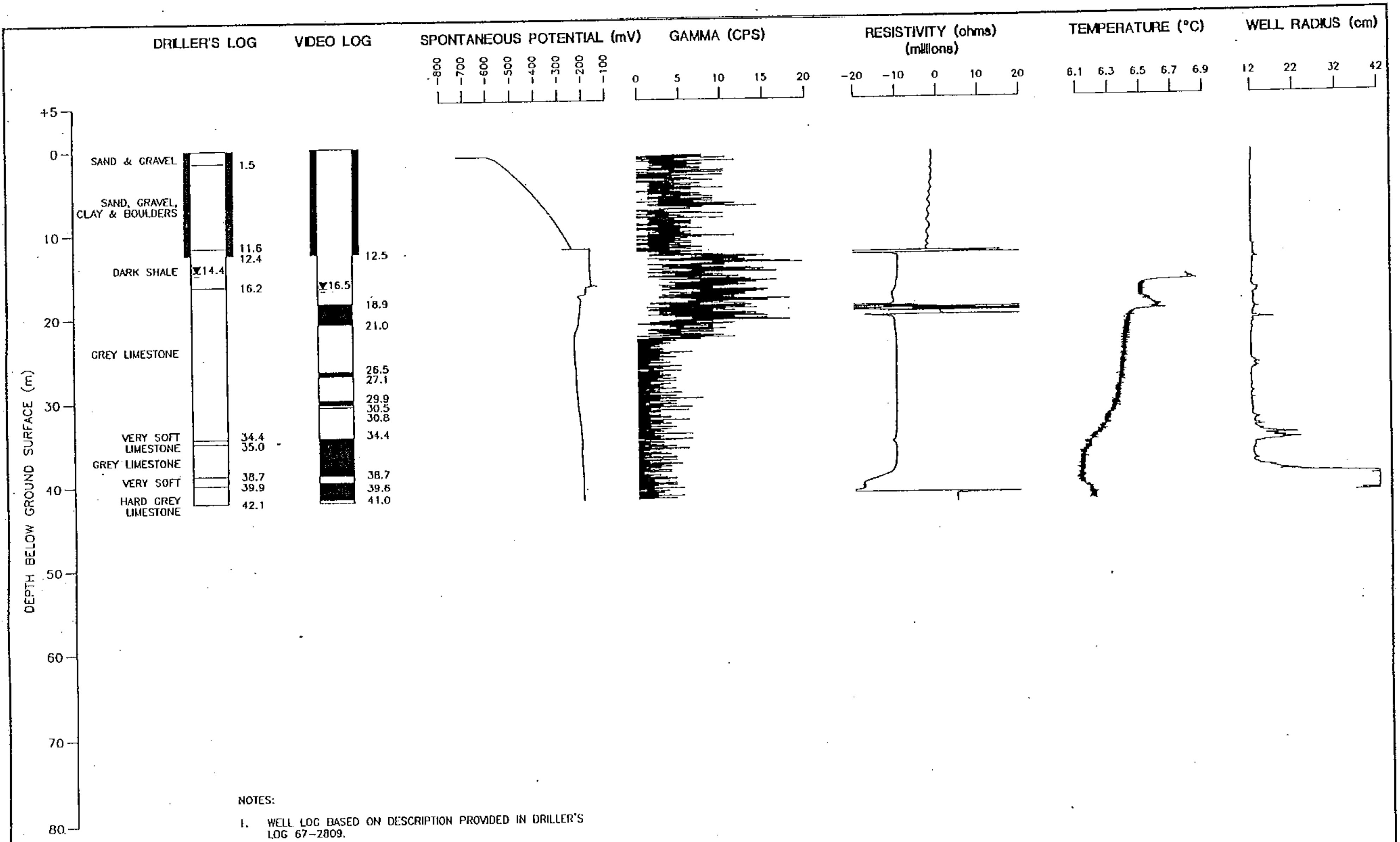
JAGGER HIMS LIMITED
Environmental Consulting Engineers

Braun Consulting Engineers

PW7/63(COG)

AQUIFER PERFORMANCE EVALUATION
SOUTHEAST QUADRANT
CITY OF GUELPH

FIGURE
A1.1-2



NOTES:

1. WELL LOG BASED ON DESCRIPTION PROVIDED IN DRILLER'S LOG 67–2809.
2. VIDEO AND GEOPHYSICAL LOGS DERIVED FROM WORK COMPLETED BY INTERNATIONAL WATER SUPPLY LTD., OCTOBER 10, 1996.
3. MEASURING POINT ELEVATION 332.87 m ASL. FLOOR ELEVATION 332.39 m ASL.
4. WATER FOUND FROM 8.2 m AND 34.4 m ACCORDING TO DRILLER'S LOG.
5. DRILLER'S REPORTED A LOSS OF CUTTING AND A RAPID DECLINE IN WATER LEVEL BETWEEN 34.4 m AND 38.7 m.
6. VIDEO AND GEOPHYSICAL LOGS ALIGNED WITH DRILLER'S LOG AT BOTTOM OF CASING.
7. DEPTH SCALE ALIGNED WITH DRILLER'S LOG.

LEGEND

—·—	OVERBURDEN/BEDROCK CONTACT
-----	SIGNIFICANT FRACTURE/ SOLUTION CAVITY
——	MAJOR FRACTURE/FRACTURE ZONE/SOLUTION CAVITY
▼	WATER LEVEL (m B.G.S.)

SCALE: AS SHOWN

REF. NO.: A00–086A1–04

DATE: MAY 2, 1997

PROJECT: 196086

JAGGER HIMS LIMITED
Environmental Consulting Engineers

Braun Consulting Engineers.

PW8/63(COG)

AQUIFER PERFORMANCE EVALUATION
SOUTHEAST QUADRANT
CITY OF GUELPH

FIGURE
A1.1-3

CASING
SET 1.7m INTO BEDROCK

GUELPH FORMATION
DOLOSTONE: MEDIUM BROWN TO GREYISH–BROWN; APHANITIC TO PHANERITIC; FOSSILIFEROUS; THICK BEDDED WITH OCCASIONAL SHALE LAMINATIONS; MEDIUM HARD; BROKEN; SLIGHTLY WEATHERED.

ERAMOSA MEMBER OF AMABEL FORMATION
DOLOSTONE: GREYISH–BROWN TO VERY DARK BROWN; ARGILLACEOUS; APHANITIC; MEDIUM–BEDDED WITH COMMON THINLY BEDDED TO THINLY LAMINATED SHALE; MEDIUM HARD; BROKEN TO BLOCKY; SLIGHTLY WEATHERED; OCCASIONAL CALCAREOUS BLEBS, PYRITE, GALENA– AND SPHALERITE–CRYSTALS.

UNSUBDIVIDED AMABEL
DOLOSTONE: LIGHT– TO MEDIUM–GREY; APHANITIC; FOSSILIFEROUS; MASSIVE WITH OCCASIONAL STYOLITES; MEDIUM HARD; BLOCKY; MODERATELY WEATHERED.

FOSSIL HILL / MERRITTON FORMATION
DOLOSTONE: GREY TO GREENISH–GREY, GREYISH–BROWN; ARGILLACEOUS; APHANITIC; MEDIUM–BEDDED WITH COMMON SHALE LAMINATIONS; MEDIUM HARD; BLOCKY TO BROKEN; SLIGHTLY WEATHERED.

CABOT HEAD FORMATION
SHALE: DARK GREEN; APHANITIC; MEDIUM SOFT; BROKEN TO VERY BROKEN; SLIGHTY WEATHERED; OCCASIONAL DISSEMINATED PYRITE.

LEGEND

▨	OVERBURDEN
▯	STEEL CASING
🟧	GUELPH FORMATION
🟫	ERAMOSA MEMBER OF AMABEL FORMATION
⬜	UNSUBDIVIDED AMABEL
🟩	FOSSIL HILL / MERRITTON FORMATION
🟩	CABOT HEAD FORMATION

——	TIGHT FRACTURE
- - - -	OPEN FRACTURE
～～～	BROKEN FRACTURE
🟦	VERTICAL OR SUBVERTICAL FRACTURE
░	#02 CLEAN SILICA SAND
▨	BENTONITE SEAL (⅜" BENTONITE PELLETS)
◁	GROUT

●	continuous
●	significant. with some partings
●	major, with partings
▲	undifferentiated rubbly zone

NOTE:
Provided in sets of two, showing top and bottom of opening.

NOTE:
GEOPHYSICS DATA PROVIDED BY DILLON CONSULTING (2006).

SCALES
5m 0 5m 10m 15m
Scale 1:200

Designed By: AZ/PJAM	Drawn By: JEP/TFB
Checked By: PJAM	Approved By: GHF
Date Issued: MAY 2007	Project No.: 60–346

Arkell Spring Grounds
Drilling Program

OW1-06

Gartner Lee

Drawing No.
1

LEGEND

▨	OVERBURDEN	───	TIGHT FRACTURE
▯	STEEL CASING	- - -	OPEN FRACTURE
🟧	GUELPH FORMATION	﹏	BROKEN FRACTURE
🟫	ERAMOSA MEMBER OF AMABEL FORMATION	🟦	VERTICAL OR SUBVERTICAL FRACTURE
⬜	UNSUBDIVIDED AMABEL	░	#02 CLEAN SILICA SAND
🟩	FOSSIL HILL / MERRITTON FORMATION	▨	BENTONITE SEAL ($\frac{3}{8}$" BENTONITE PELLETS)
🟩	CABOT HEAD FORMATION	⊿	GROUT

- ● continuous
- ● significant, with some partings
- ● major, with partings
- ▲ undifferentiated rubbly zone

NOTE:
Provided in sets of two, showing top and bottom of opening.

DRAFT

NOTE:
GEOPHYSICS DATA PROVIDED BY DILLON CONSULTING (2006).

SCALES
5m 0 5m 10m 15m
Scale 1:200

Designed By: AZ/PJAM	Drawn By: JEP/TFB
Checked By: PJAM	Approved By: GHF
Date Issued: MAY 2007	Project No.: 60–346

Arkell Spring Grounds
Drilling Program

OW2-06

Gartner Lee

Drawing No.
2

Jan 21, 2008 – 2:33pm H:\DATA\Guelph, City of\60346 Arkell Drilling Program\DRAWINGS\60346–F01–R2.dwg

CASING
SET 1.2m INTO BEDROCK

UNSUBDIVIDED AMABEL
DOLOSTONE: LIGHT– TO MEDIUM–GREY, OCCASIONALY LIGHT–BROWNISH–GREY; APHANITIC; FOSSILIFEROUS; MASSIVE WITH OCCASIONAL STYOLITES; MEDIUM HARD; BROKEN TO BLOCKY; SLIGHTY TO MODERATELY WEATHERED.

FOSSIL HILL / MERRITTON FORMATION
DOLOSTONE: GREENISH–GREY, GREYISH–BROWN; ARGILLACEOUS; APHANITIC; MEDIUM BEDDED WITH COMMON SHALE LAMINATIONS; MEDIUM HARD; SLIGHTLY WEATHERED.

CABOT HEAD FORMATION
SHALE: DARK GREEN, REDDISH–BROWN; APHANITIC; MEDIUM HARD; BROKEN; SLIGHTLY WEATHERED; COMMON DISSEMINATED PYRITE; COMMON CALCAREOUS BLEBS.

LEGEND

▨	OVERBURDEN
▯	STEEL CASING
🟧	GUELPH FORMATION
🟫	ERAMOSA MEMBER OF AMABEL FORMATION
⬜	UNSUBDIVIDED AMABEL
🟩	FOSSIL HILL / MERRITTON FORMATION
🟩	CABOT HEAD FORMATION

──	TIGHT FRACTURE
- - -	OPEN FRACTURE
∿∿∿	BROKEN FRACTURE
🟦	VERTICAL OR SUBVERTICAL FRACTURE
░	#02 CLEAN SILICA SAND
▨	BENTONITE SEAL (⅜" BENTONITE PELLETS)
△	GROUT

●	continuous
●	significant, with some partings
●	major, with partings
▲	undifferentiated rubbly zone

NOTE:
Provided in sets of two, showing top and bottom of opening.

DRAFT

NOTE:
GEOPHYSICS DATA PROVIDED BY DILLON CONSULTING (2006).

SCALES
5m 0 5m 10m 15m
Scale 1:200

Designed By: AZ/PJAM	Drawn By: JEP/TFB
Checked By: PJAM	Approved By: GHF
Date Issued: MAY 2007	Project No.: 60–346

Arkell Spring Grounds
Drilling Program

OW3-06

Gartner Lee

Drawing No.
3

Jan 21, 2008 – 2:47pm H:\DATA\Guelph, City of\60346 Arkell Drilling Program\DRAWINGS\60346–F01–R2.dwg

LEGEND

▨ OVERBURDEN
▯ STEEL CASING
🟧 GUELPH FORMATION
🟫 ERAMOSA MEMBER OF AMABEL FORMATION
⬜ UNSUBDIVIDED AMABEL
🟩 FOSSIL HILL / MERRITTON FORMATION
🟩 CABOT HEAD FORMATION

— TIGHT FRACTURE
- - - OPEN FRACTURE
〰 BROKEN FRACTURE
▬ VERTICAL OR SUBVERTICAL FRACTURE
░ #02 CLEAN SILICA SAND
▨ BENTONITE SEAL (⅜" BENTONITE PELLETS)
▵ GROUT

● continuous
● significant. with some partings
● major, with partings
▲ undifferentiated rubbly zone

NOTE:
Provided in sets of two, showing top and bottom of opening.

NOTE:
GEOPHYSICS DATA PROVIDED BY DILLON CONSULTING (2006).

SCALES
5m 0 5m 10m 15m
Scale 1:200

Designed By: AZ/PJAM
Drawn By: JEP/TFB
Checked By: PJAM
Approved By: GHF
Date Issued: MAY 2007
Project No.: 60–346

Arkell Spring Grounds
Drilling Program

OW4-06

Gartner Lee

Drawing No.
4

LEGEND

▨	OVERBURDEN	───	TIGHT FRACTURE
▯	STEEL CASING	- - -	OPEN FRACTURE
🟧	GUELPH FORMATION	﹏	BROKEN FRACTURE
🟫	ERAMOSA MEMBER OF AMABEL FORMATION	🟦	VERTICAL OR SUBVERTICAL FRACTURE
⬜	UNSUBDIVIDED AMABEL	░	#02 CLEAN SILICA SAND
🟩	FOSSIL HILL / MERRITTON FORMATION	▨	BENTONITE SEAL (⅜" BENTONITE PELLETS)
🟩	CABOT HEAD FORMATION	◁	GROUT

- ● continuous
- ● significant. with some partings
- ● major, with partings
- ▲ undifferentiated rubbly zone

NOTE:
Provided in sets of two, showing top and bottom of opening.

NOTE:
GEOPHYSICS DATA PROVIDED BY DILLON CONSULTING (2006).

SCALES

5m 0 5m 10m 15m

Scale 1:200

Designed By: AZ/PJAM	Drawn By: JEP/TFB
Checked By: PJAM	Approved By: GHF
Date Issued: MAY 2007	Project No.: 60−346

Arkell Spring Grounds
Drilling Program

OW5-06

Gartner Lee

Drawing No.
5

LEGEND

▨ OVERBURDEN
▯ STEEL CASING
🟧 GUELPH FORMATION
🟫 ERAMOSA MEMBER OF AMABEL FORMATION
⬜ UNSUBDIVIDED AMABEL
🟩 FOSSIL HILL / MERRITTON FORMATION
🟩 CABOT HEAD FORMATION

——— TIGHT FRACTURE
------ OPEN FRACTURE
〰〰 BROKEN FRACTURE
▬ VERTICAL OR SUBVERTICAL FRACTURE
░ #02 CLEAN SILICA SAND
▨ BENTONITE SEAL (⅜" BENTONITE PELLETS)
△ GROUT

● continuous
● significant. with some partings
● major, with partings
▲ undifferentiated rubbly zone

NOTE:
Provided in sets of two, showing top and bottom of opening.

NOTE:
GEOPHYSICS DATA PROVIDED BY DILLON CONSULTING (2006).

SCALES
5m 0 5m 10m 15m
Scale 1:200

Designed By: AZ/PJAM	Drawn By: JEP/TFB
Checked By: PJAM	Approved By: GHF
Date Issued: MAY 2007	Project No.: 60–346

Arkell Spring Grounds
Drilling Program

OW7-06

Gartner Lee

Drawing No.
6

LEGEND

▨ OVERBURDEN
▯ STEEL CASING
🟧 GUELPH FORMATION
🟫 ERAMOSA MEMBER OF AMABEL FORMATION
⬜ UNSUBDIVIDED AMABEL
🟩 FOSSIL HILL / MERRITTON FORMATION
🟩 CABOT HEAD FORMATION

— TIGHT FRACTURE
- - - OPEN FRACTURE
〰 BROKEN FRACTURE
▬ VERTICAL OR SUBVERTICAL FRACTURE
▩ #02 CLEAN SILICA SAND
▨ BENTONITE SEAL ($\frac{3}{8}$" BENTONITE PELLETS)
▫ GROUT

● continuous
● significant. with some partings
● major, with partings
▲ undifferentiated rubbly zone

NOTE:
Provided in sets of two, showing top and bottom of opening.

DRAFT

NOTE:
GEOPHYSICS DATA PROVIDED BY DILLON CONSULTING (2006).

SCALES
5m 0 5m 10m 15m
Scale 1:200

Designed By: AZ/PJAM	Drawn By: JEP/TFB
Checked By: PJAM	Approved By: GHF
Date Issued: MAY 2007	Project No.: 60–346

Arkell Spring Grounds
Drilling Program

OW8-06

Gartner Lee

Drawing No.
7

Jan 21, 2008 – 3:00pm H:\DATA\Guelph, City of\60346 Arkell Drilling Program\DRAWINGS\60346–F01–R2.dwg

GROUND SURFACE
(xxxxx mASL)

BEDROCK SURFACE
(xxxxx mASL)

CASING
SET 3.9m INTO BEDROCK

UNSUBDIVIDED AMABEL
DOLOSTONE: LIGHT– TO DARK–GREY; APHANITIC; FOSSILIFEROUS; THICK BEDDED WITH OCCASIONAL STYOLITES; MEDIUM HARD; BLOCKY TO BROKEN; SLIGHTY WEATHERED.

FOSSIL HILL / MERRITTON FORMATION
DOLOSTONE: GREY TO GREENISH GREY; ARGILLACEOUS; APHANITIC; MEDIUM BEDDED WITH COMMON SHALE LAMINATIONS; MEDIUM HARD; BROKEN; SLIGHTY WEATHERED; COMMON DISSEMINATED PYRITE; OCCASIONAL GYPSUM BLEBS.

CABOT HEAD FORMATION
SHALE: DARK GREEN; APHANITIC; SOFT; VERY BROKEN TO GRAVELLED; SLIGHTLY WEATHERED.

LEGEND

▨ OVERBURDEN
▯ STEEL CASING
🟧 GUELPH FORMATION
🟫 ERAMOSA MEMBER OF AMABEL FORMATION
⬜ UNSUBDIVIDED AMABEL
🟩 FOSSIL HILL / MERRITTON FORMATION
🟩 CABOT HEAD FORMATION

── TIGHT FRACTURE
– – – OPEN FRACTURE
〰 BROKEN FRACTURE
▬ VERTICAL OR SUBVERTICAL FRACTURE
░ #02 CLEAN SILICA SAND
▨ BENTONITE SEAL ($\frac{3}{8}$" BENTONITE PELLETS)
▫ GROUT

● continuous
● significant, with some partings
● major, with partings
▲ undifferentiated rubbly zone

NOTE:
Provided in sets of two, showing top and bottom of opening.

DRAFT

NOTE:
GEOPHYSICS DATA PROVIDED BY DILLON CONSULTING (2006).

SCALES

5m 0 5m 10m 15m

Scale 1:200

Designed By: AZ/PJAM	Drawn By: JEP/TFB
Checked By: PJAM	Approved By: GHF
Date Issued: MAY 2007	Project No.: 60–346

Arkell Spring Grounds
Drilling Program

OW9-06

Gartner Lee

Drawing No.
8

Jan 21, 2008 – 3:02pm H:\DATA\Guelph, City of\60346 Arkell Drilling Program\DRAWINGS\60346–F01–R2.dwg

LEGEND

▨	OVERBURDEN
▯	STEEL CASING
🟧	GUELPH FORMATION
🟫	ERAMOSA MEMBER OF AMABEL FORMATION
⬜	UNSUBDIVIDED AMABEL
🟩	FOSSIL HILL / MERRITTON FORMATION
🟩	CABOT HEAD FORMATION

—	TIGHT FRACTURE
- - -	OPEN FRACTURE
~~	BROKEN FRACTURE
🟦	VERTICAL OR SUBVERTICAL FRACTURE
░	#02 CLEAN SILICA SAND
▨	BENTONITE SEAL ($\frac{3}{8}$" BENTONITE PELLETS)
△	GROUT

●	continuous
●	significant. with some partings
●	major, with partings
▲	undifferentiated rubbly zone

NOTE:
Provided in sets of two, showing top and bottom of opening.

NOTE:
GEOPHYSICS DATA PROVIDED BY DILLON CONSULTING (2006).

SCALES

5m 0 5m 10m 15m

Scale 1:200

Designed By: AZ/PJAM	Drawn By: JEP/TFB
Checked By: PJAM	Approved By: GHF
Date Issued: MAY 2007	Project No.: 60–346

Arkell Spring Grounds
Drilling Program

OW10-06

Gartner Lee

Drawing No.
9

Jan 21, 2008 – 3:05pm H:\DATA\Guelph, City of\60346 Arkell Drilling Program\DRAWINGS\60346–F01–R2.dwg

LEGEND

- ▨ OVERBURDEN
- ▯ STEEL CASING
- 🟫 GUELPH FORMATION
- 🟫 ERAMOSA MEMBER OF AMABEL FORMATION
- ▩ UNSUBDIVIDED AMABEL
- 🟩 FOSSIL HILL / MERRITTON FORMATION
- 🟩 CABOT HEAD FORMATION

- ─── TIGHT FRACTURE
- - - - OPEN FRACTURE
- ∿∿∿ BROKEN FRACTURE
- ▬ VERTICAL OR SUBVERTICAL FRACTURE
- ▒ #02 CLEAN SILICA SAND
- ▨ BENTONITE SEAL (⅜" BENTONITE PELLETS)
- ▵ GROUT

- ● continuous
- ● significant. with some partings
- ● major, with partings
- ▲ undifferentiated rubbly zone

NOTE:
Provided in sets of two, showing top and bottom of opening.

NOTE:
GEOPHYSICS DATA PROVIDED BY DILLON CONSULTING (2006).

SCALES
5m 0 5m 10m 15m
Scale 1:200

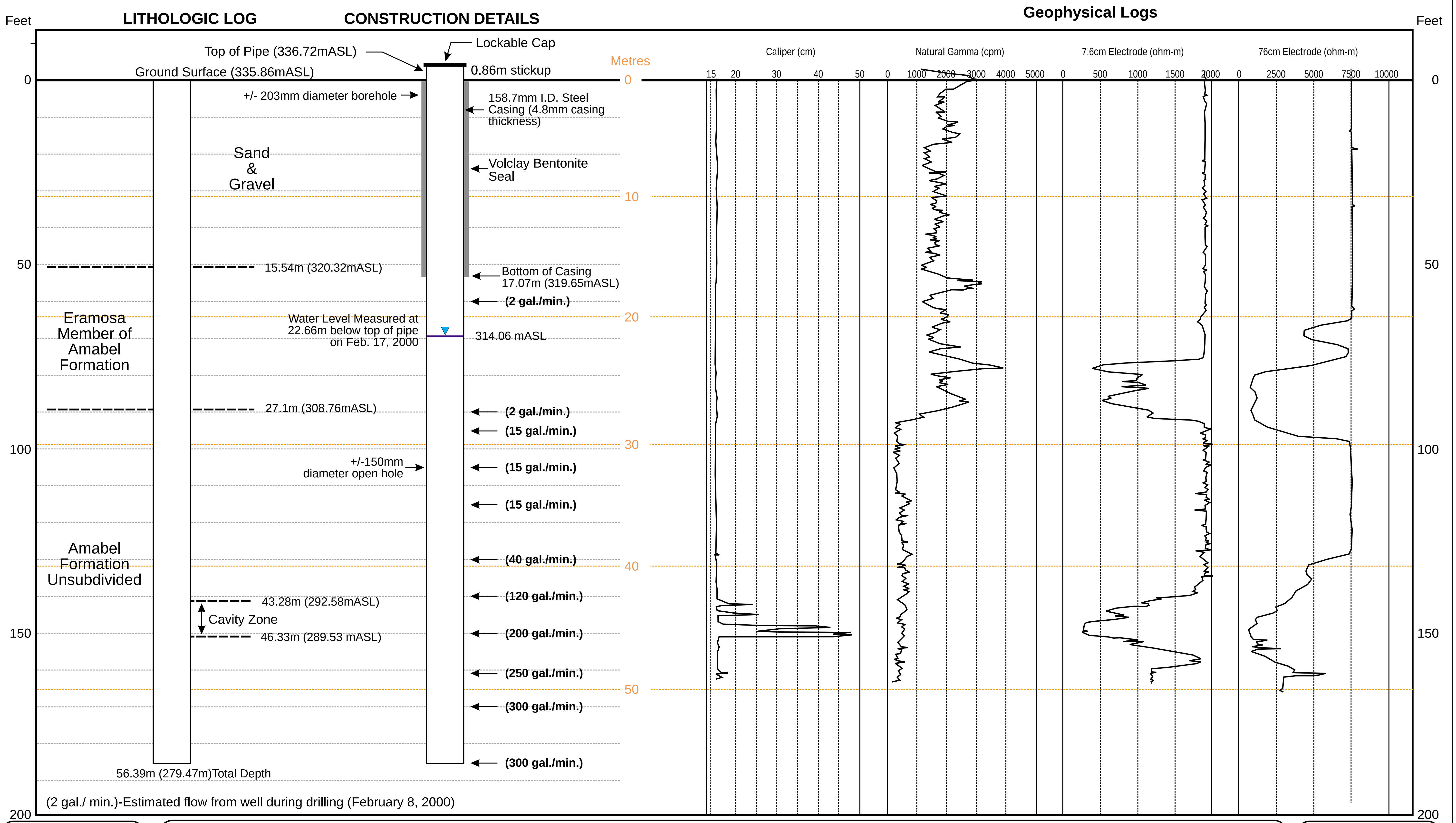
Designed By: AZ/PJAM	Drawn By: JEP/TFB
Checked By: PJAM	Approved By: GHF
Date Issued: MAY 2007	Project No.: 60–346

Arkell Spring Grounds
Drilling Program

OW11-06

Gartner Lee

Drawing No.
10



Gartner Lee

(Revised 26 Feb 03)

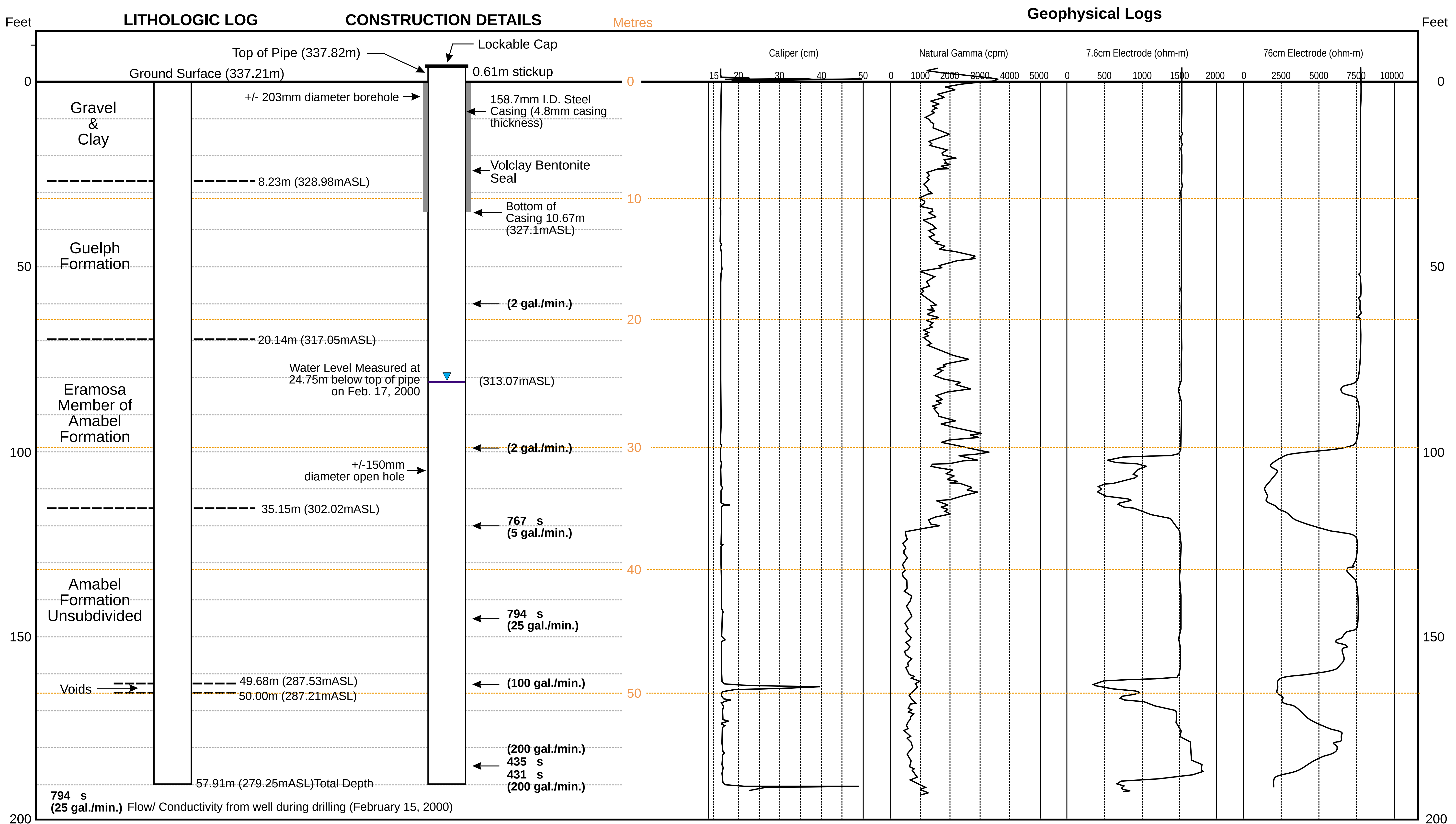
BOREHOLE # 11/2000 (Deep)

Lithologic Log & Construction Details, and Geophysical Logs

Arkell Spring Grounds
Groundwater Supply Investigation

Map ID# 19

Project 99-415.9
(99\415\415-9\A.3-1.cdr)



Gartner Lee

(Revised Feb 26/03)

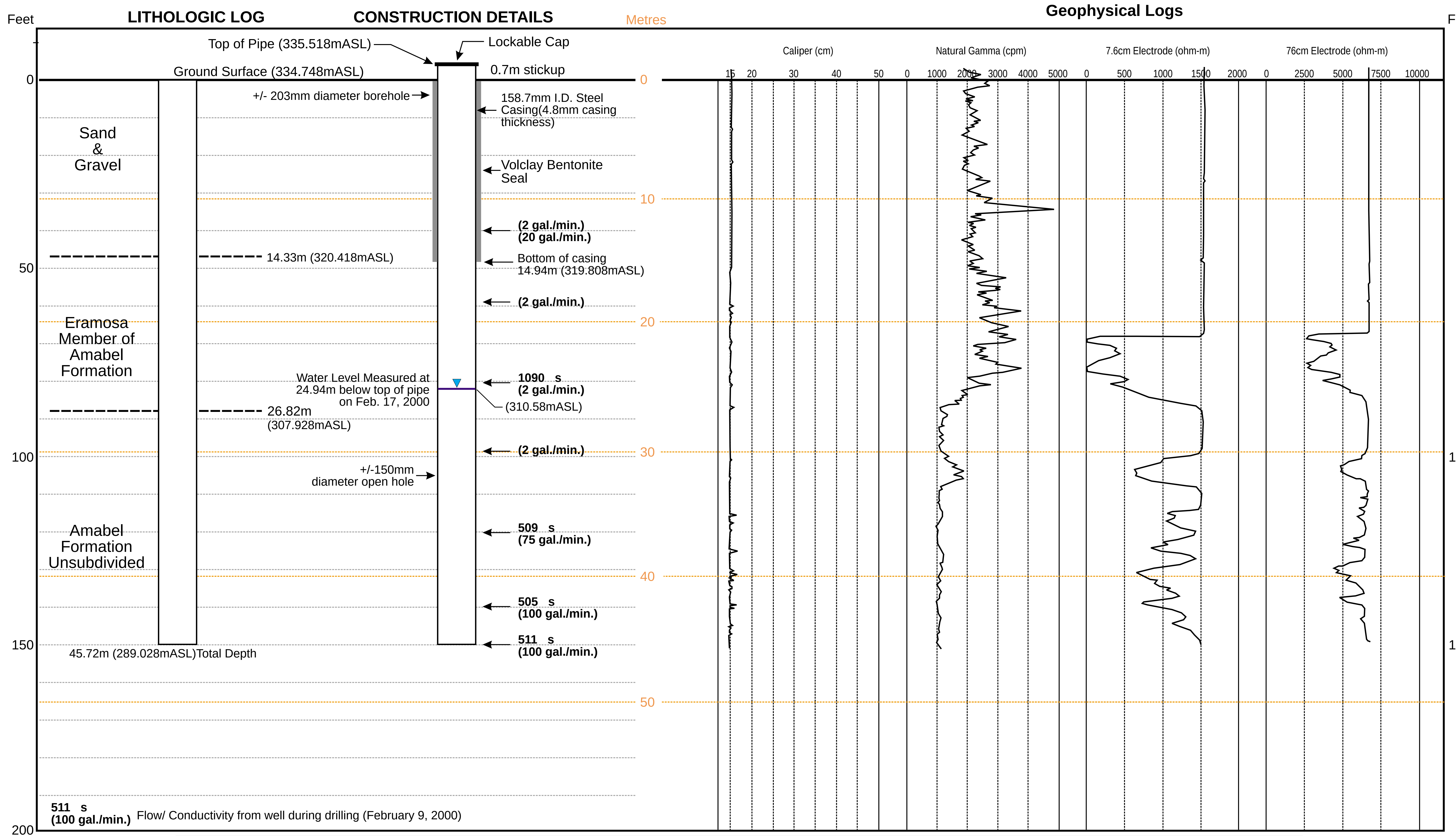
BOREHOLE # 12/2000 (Deep)

Lithologic Log & Construction Details, and Geophysical Logs

Arkell Spring Grounds
Groundwater Supply Investigation

Map ID# 22

Project 99-415.9
(99\415\415-9\A.3-3.cdr)



Gartner Lee

(Revised Feb 26/03)

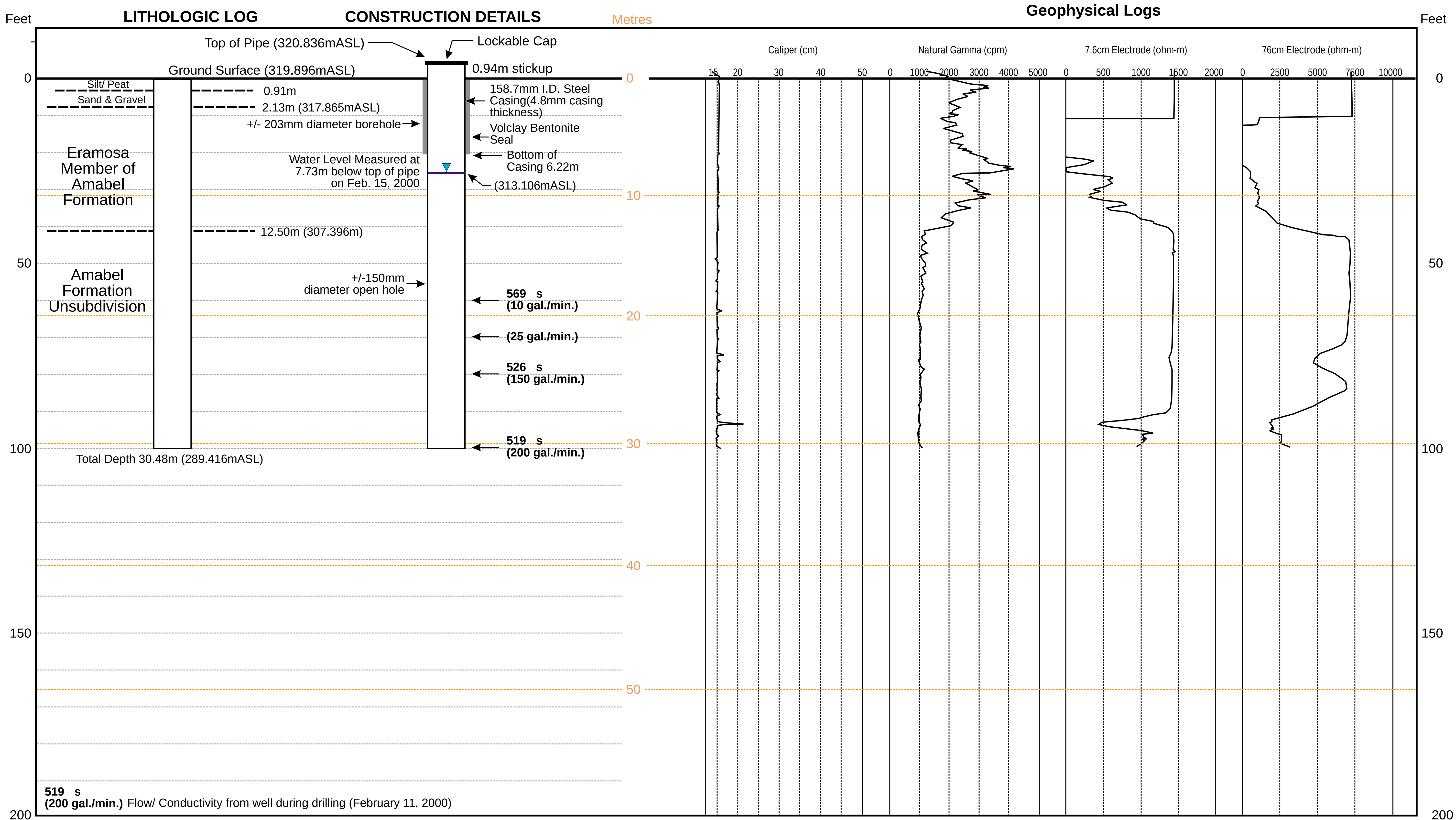
BOREHOLE # 14/2000 (Deep)

Lithologic Log, Construction Details, Geophysical Logs

Arkell Spring Grounds
Groundwater Supply Investigation

Map ID#
17

Project 99-415.9
(99\415\415-9\A.3-5.cdr)



519 s
(200 gal./min.) Flow/ Conductivity from well during drilling (February 11, 2000)

Gartner Lee

(Revised Feb 26/03)

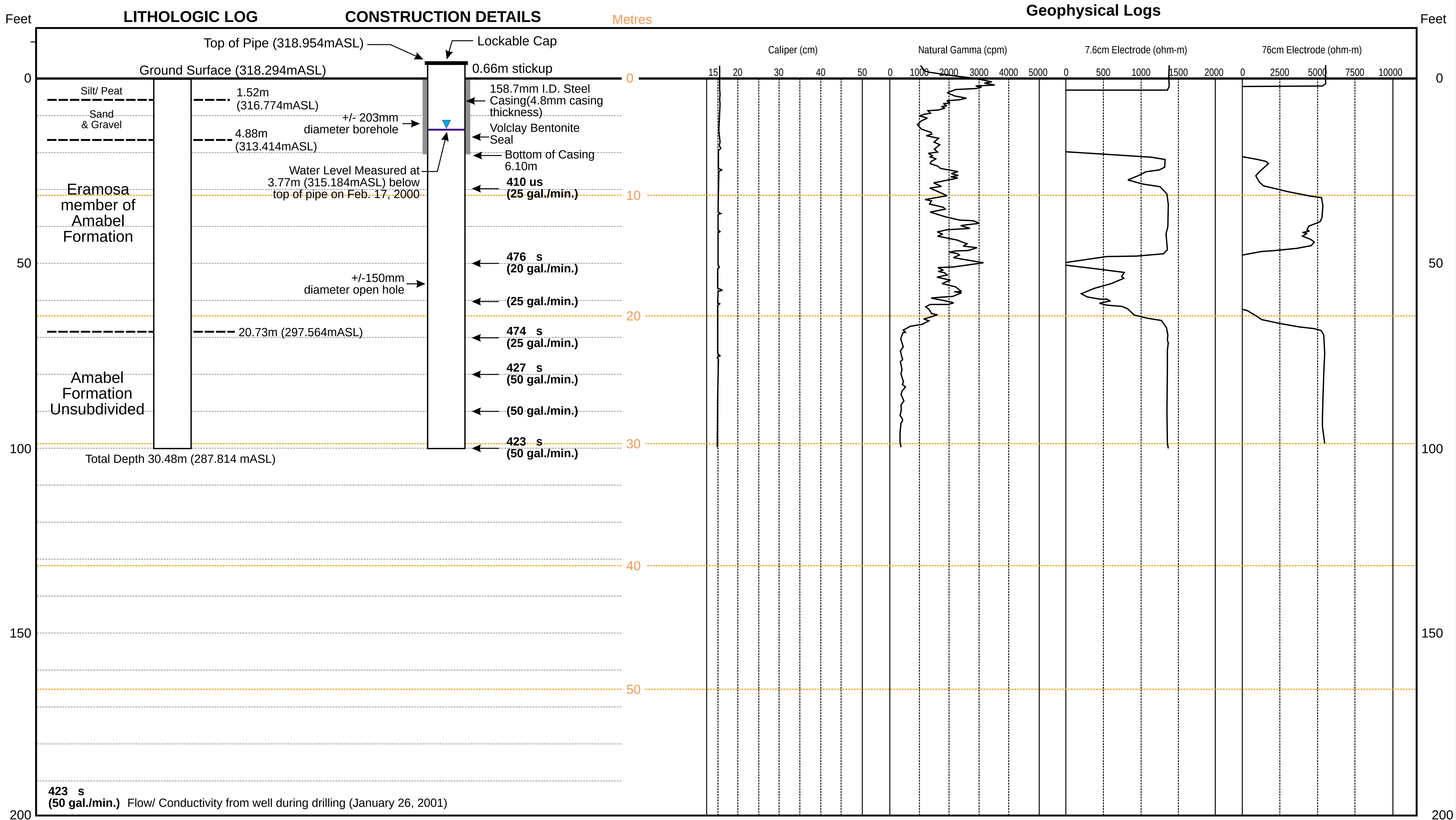
BOREHOLE # 15/2000 (Deep)

Lithologic Log, Construction Details, Geophysical Logs

Arkell Spring Grounds
Groundwater Supply Investigation

Map ID#
20

Project 99-415.9
(99\415\415-9\A.3-8.cdr)



Gartner
Lee

(Revised Feb 26/03)

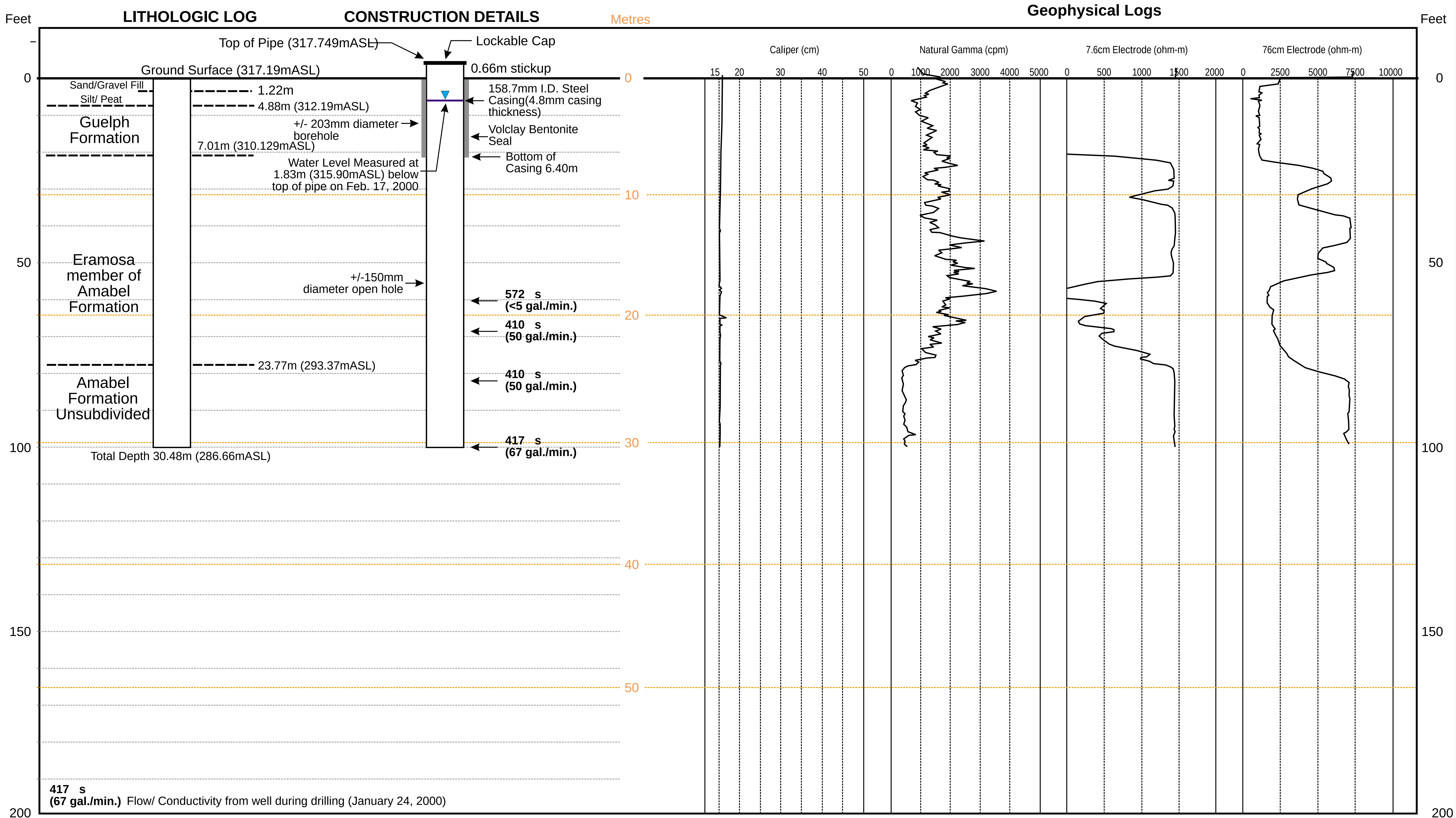
BOREHOLE # 16/2000 (Deep)

Lithologic Log, Construction Details, Geophysical Logs

Arkell Spring Grounds
Groundwater Supply Investigation

Map ID#
26

Project 99-415.9
(99\415\415-9\A.3-10.cdr)



417 s
(67 gal./min.) Flow/ Conductivity from well during drilling (January 24, 2000)

Gartner Lee

(Revised Feb 26/03)

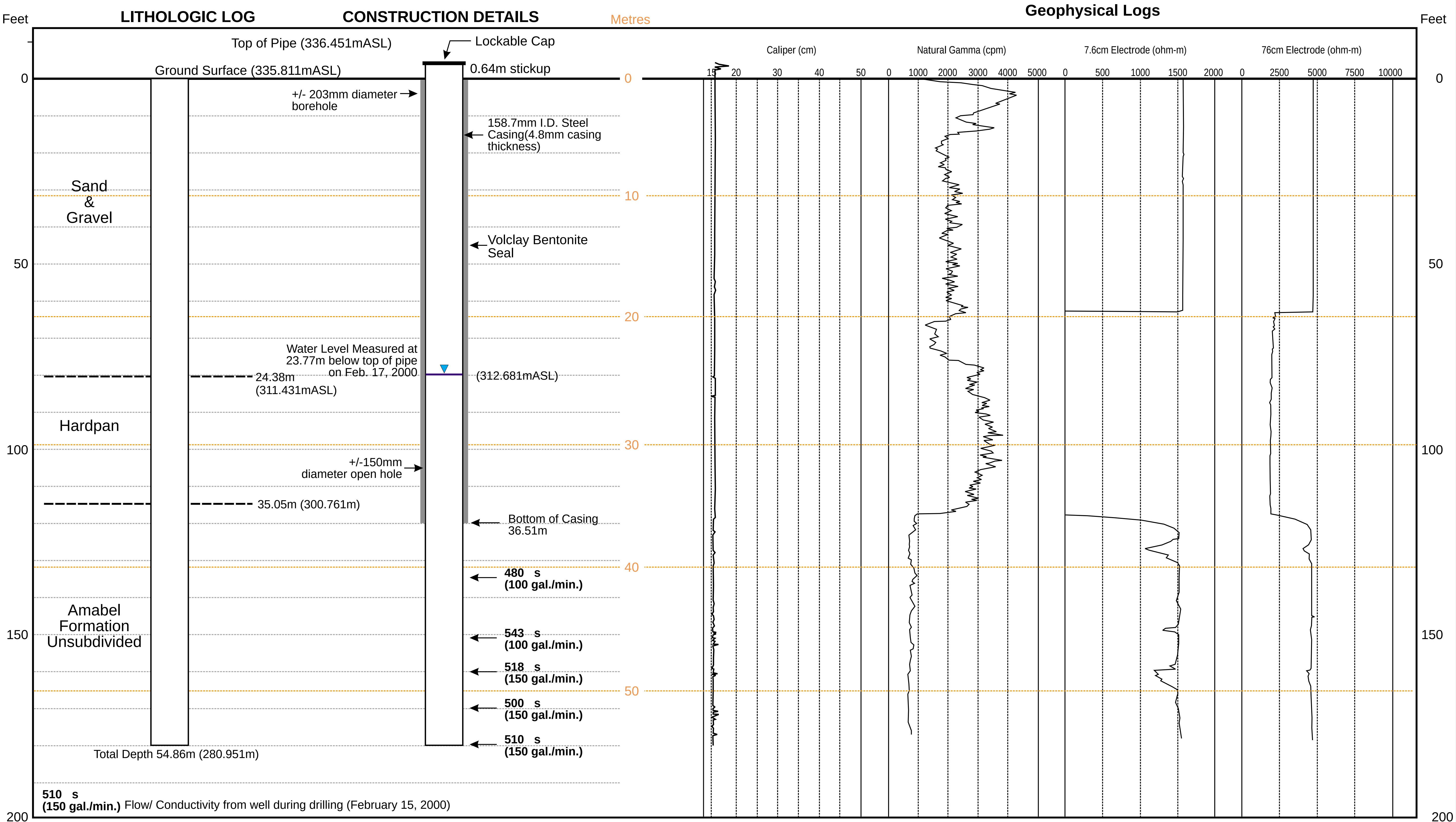
BOREHOLE # 17/2000 (Deep)

Lithologic Log, Construction Details, Geophysical Logs

Arkell Spring Grounds
Groundwater Supply Investigation

Map ID#
21

Project 99-415.9
(99\415\415-9\A.3-11.cdr)



Gartner
Lee

(Revised Feb 26/03)

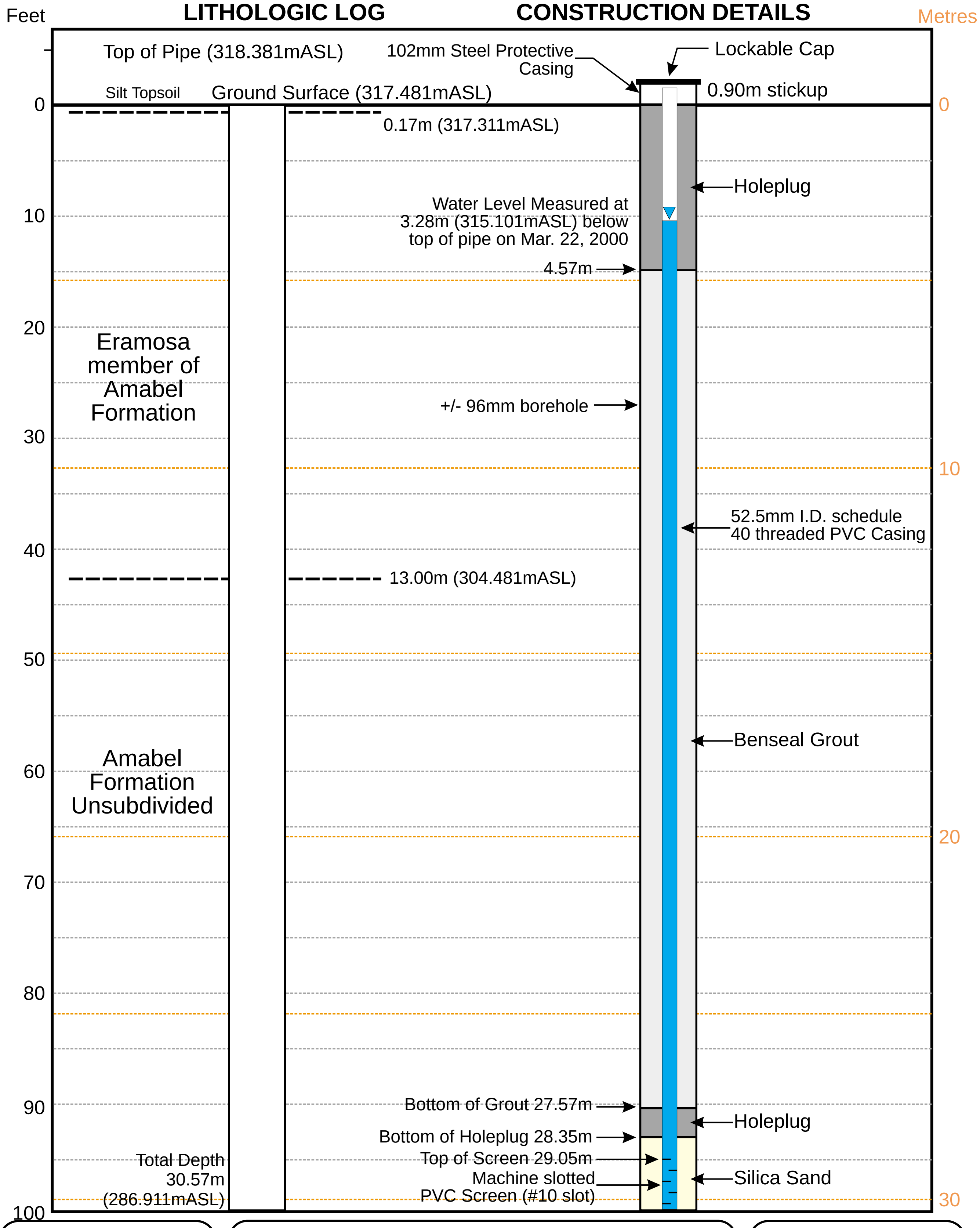
BOREHOLE # 18/2000 (Deep)

Lithologic Log, Construction Details, Geophysical Logs

Arkell Spring Grounds
Groundwater Supply Investigation

Map ID#
23

Project 99-415.9
(99\415\415-9\A.3-12.cdr)



Gartner Lee

(Revised Feb 26/03)

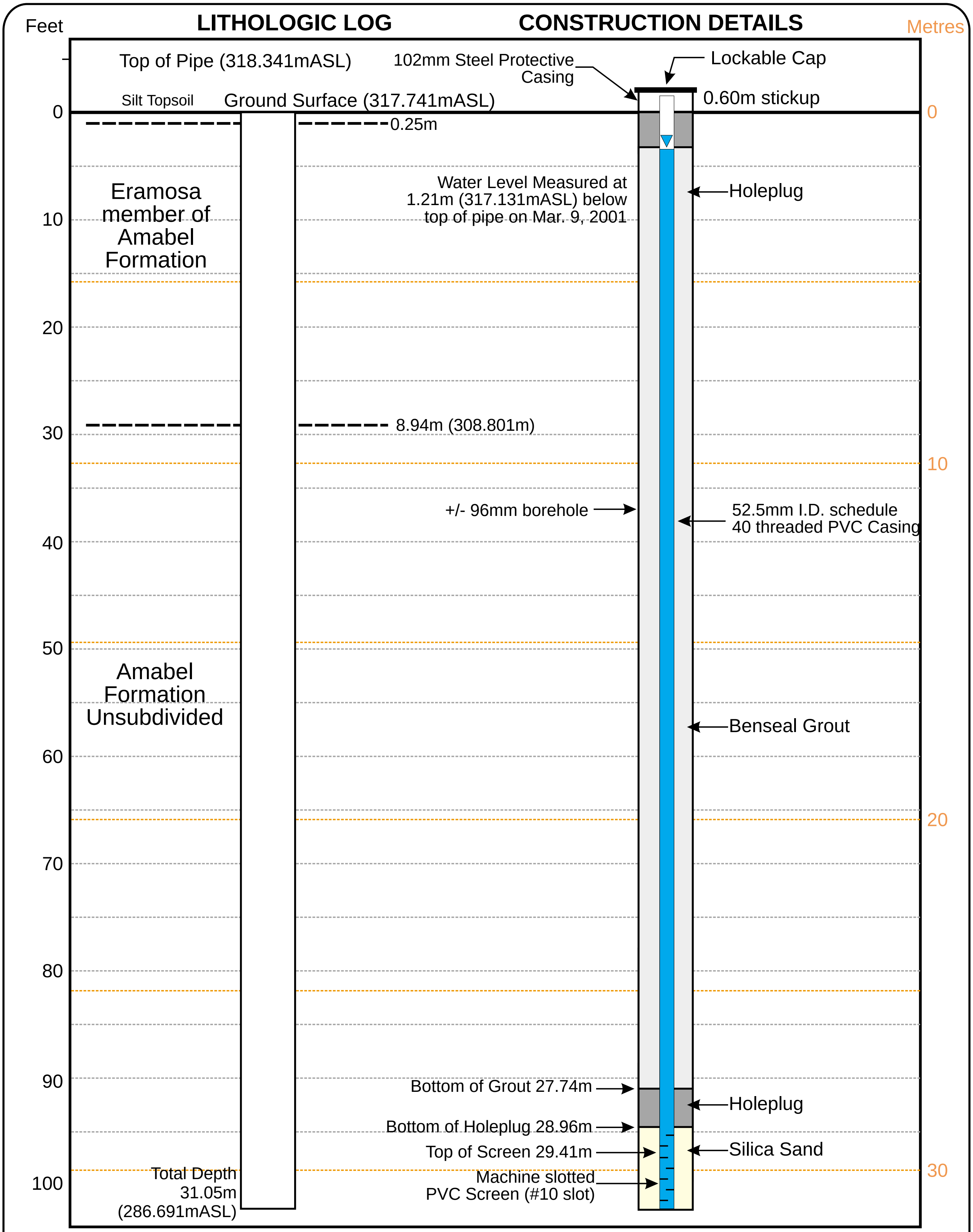
BOREHOLE # 19/2000 (Deep)

Lithologic Log & Construction Details

Arkell Spring Grounds
Groundwater Supply Investigation

**Map ID#
25**

Project 99-415.9
(99\415\415-9\A.3-13.cdr)



Gartner Lee

(Revised Feb 26/03)

BOREHOLE # 20/2001 (Deep)

Lithologic Log & Construction Details

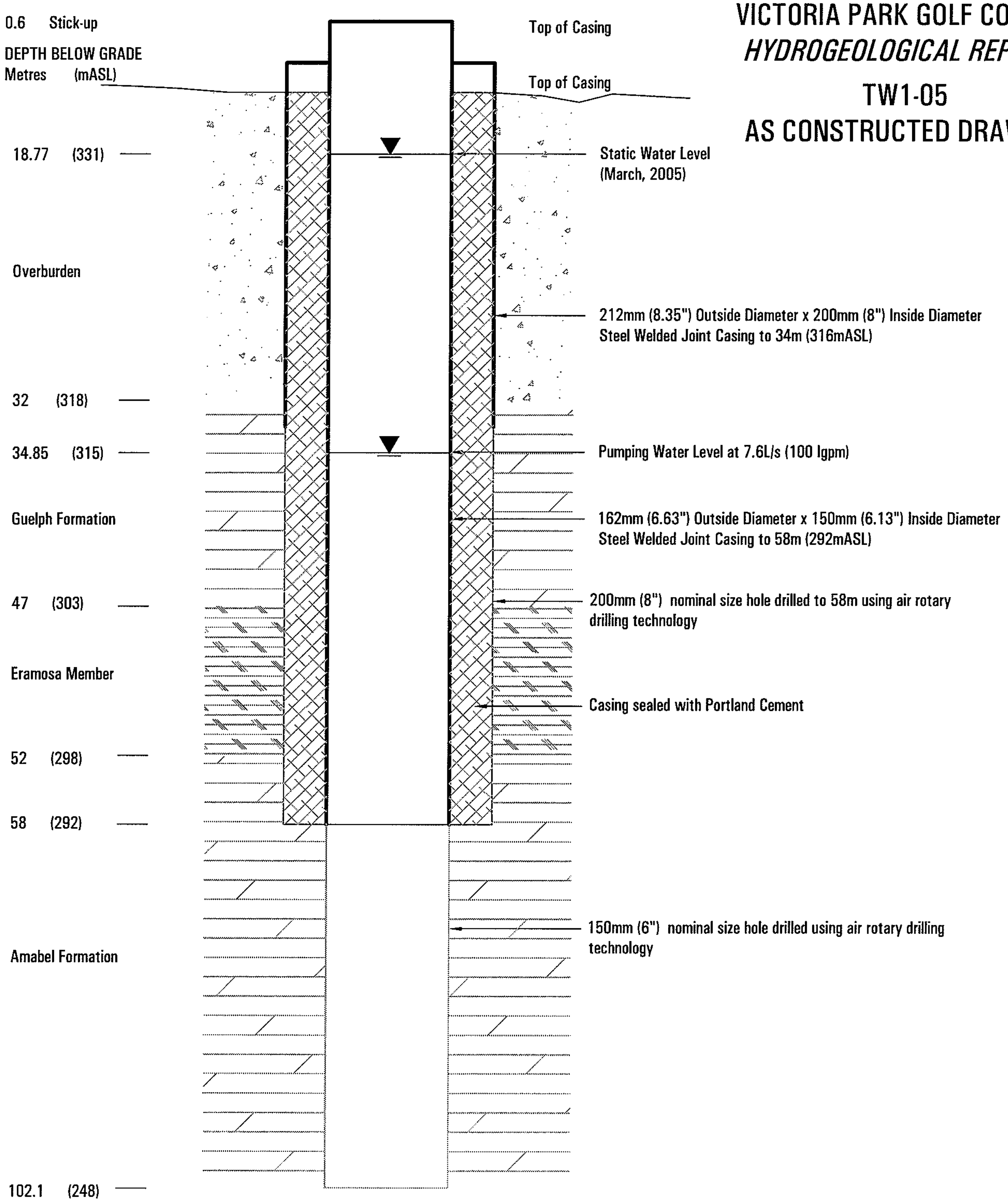
Arkell Spring Grounds
Groundwater Supply Investigation

Map ID#
28

Project 99-415.9
(99\415\415-9\A.3-15.cdr)

FIGURE 4

VICTORIA PARK GOLF COURSE
HYDROGEOLOGICAL REPORT
TW1-05
AS CONSTRUCTED DRAWING



May 2006
N.T.S.
FILE NO.: PGN 09069

BURNSIDE

PROJECT: 07-1112-0059

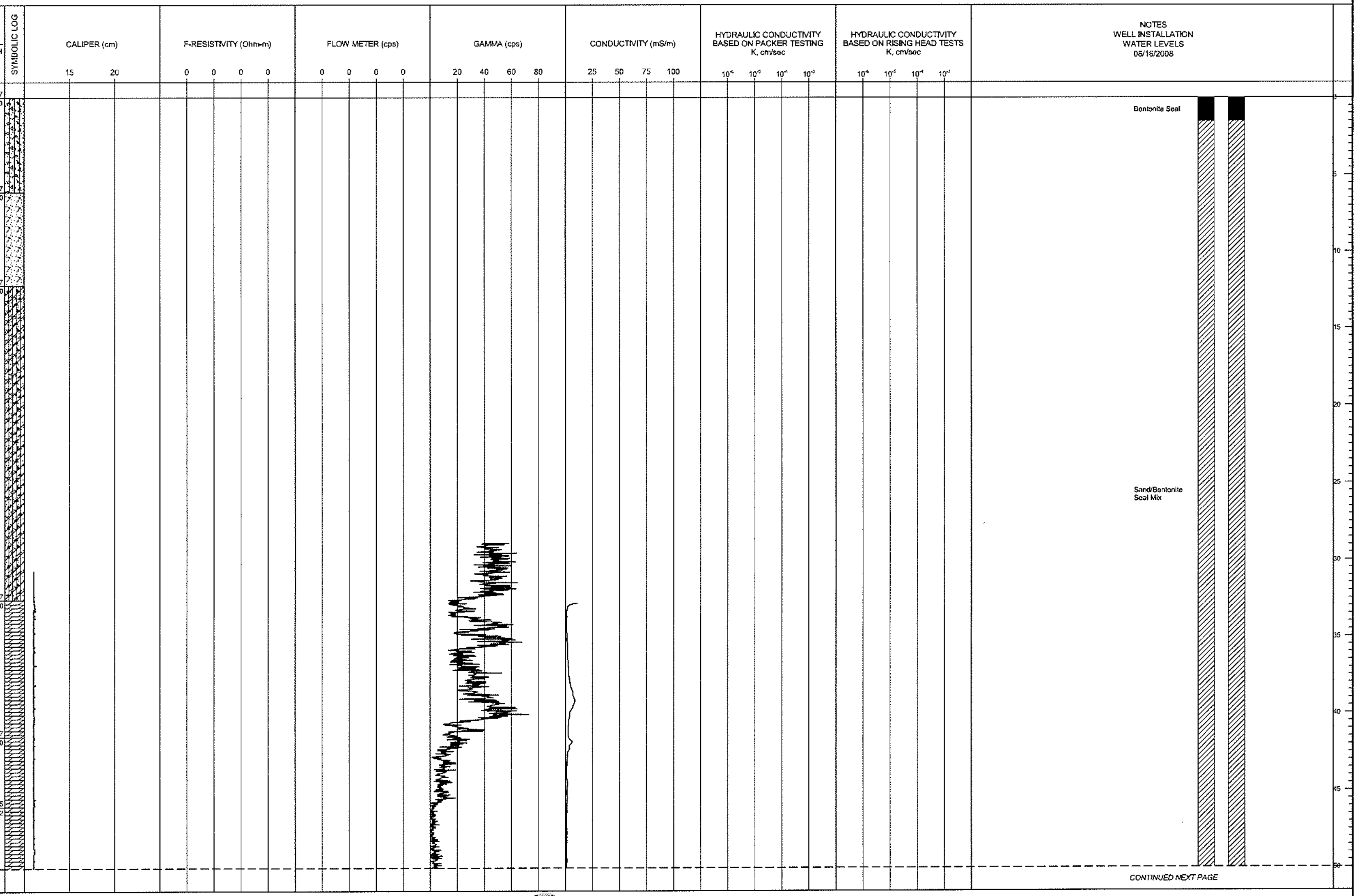
LOCATION: N 4817482.0 ;E 560990.0

RECORD OF DRILLHOLE: MW08-01A

SHEET 1 OF 2

DATUM: Geodetic

DEPTH SCALE METRES	DESCRIPTION	ELEV. / DEPTH (m)
	GROUND SURFACE	313.47
0	Loose, moist to wet, brown, silty fine to medium SAND, some gravel (TILL)	0.00
5		307.37
	Compact, saturated, brown, medium to very coarse SAND and GRAVEL	6.10
10		301.27
	Stiff to very hard, saturated, grey/brown, CLAYEY SILT, some gravel (TILL)	12.20
15		
20		
25		
30		280.87
	ERAMOSA FORMATION (Vinemount member) Black to dark brown, medium hardness, slightly weathered, odourous, DOLOSTONE	32.60
35		
40		271.97
	GOAT ISLAND FORMATION Brown to grey, medium hardness, slightly weathered, DOLOSTONE	41.50
45		267.45
	GASPORT FORMATION Grey to white, soft to medium hardness, moderately weathered, porous, DOLOSTONE	46.02
50		



CONTINUED NEXT PAGE

DEPTH SCALE
1 : 250

Golder Associates

LOGGED: KS
CHECKED:

MIS-GEO 003 07111220059.GPJ GAL-MISS.GDT 2/12/09 JFC

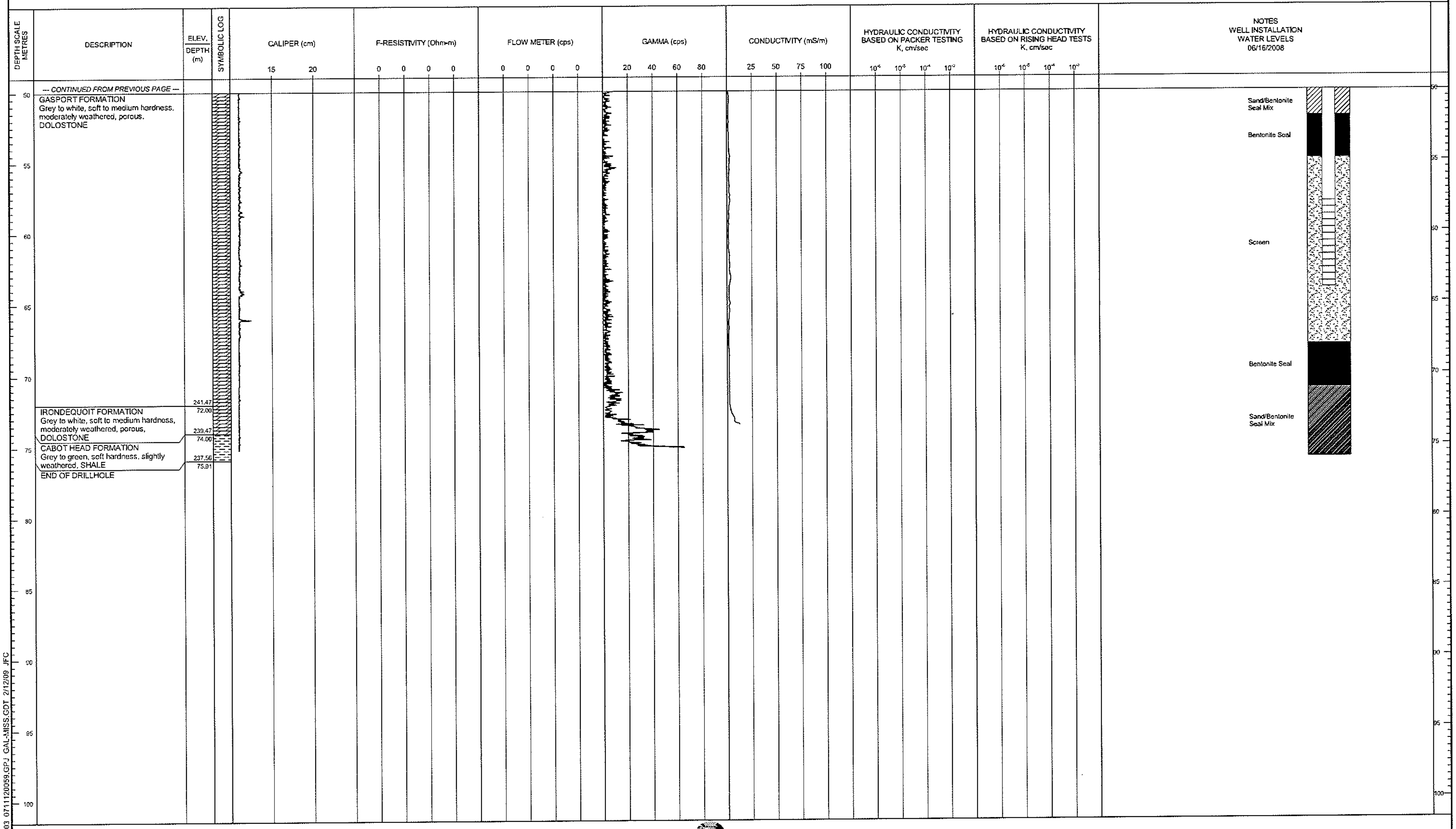
PROJECT: 07-1112-0059

LOCATION: N 4817482.0 ;E 560990.0

RECORD OF DRILLHOLE: MW08-01A

SHEET 2 OF 2

DATUM: Geodetic



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GASPORT FORMATION
Grey to white, soft to medium hardness, moderately weathered, porous. DOLOSTONE

IRONDEQUOIT FORMATION
Grey to white, soft to medium hardness, moderately weathered, porous, DOLOSTONE

CABOT HEAD FORMATION
Grey to green, soft hardness, slightly weathered, SHALE

END OF DRILLHOLE

DEPTH SCALE
1 : 250

Golder Associates

LOGGED: KS
CHECKED:

PROJECT: 08-1112-0098

RECORD OF DRILLHOLE: MW08-02

SHEET 1 OF 2

LOCATION: N 4819482.9 ;E 560096.3

INCLINATION: -90°   AZIMUTH: ---

DRILLING DATE: July, 2008

DRILL RIG: Dual Rotary

DRILLING CONTRACTOR: Gerrits Drilling Ltd.

DATUM: Geodetic

DEPTH SCALE METRES	DESCRIPTION	ELEV. DEPTH (m)	NOTES WATER LEVELS INSTRUMENTATION
	GROUND SURFACE	324.89	
0	Loose, moist, brown, SAND and GRAVEL	0.00	Bentonite Seal Cement
5			
	Stiff, moist, brown, silty SAND, trace gravel (TILL)	317.57 7.32	Bentonite Seal
10	Stiff, moist, grey, SILTY CLAY	313.92 10.97	07/18/2008 (B)
	GUELPH FORMATION Biege, DOLOTSTONE, platty chips, medium hardness	312.09 12.80	
15			Sand
20			Screen
25	ERAMOSA FORMATION Tan/ Black, DOLOTSONE, bituminuous, platty chips, medium hardness	300.51 24.38	Bentonite Seal
30			07/18/2008 (A)
35			
	GOAT ISLAND FORMATION Grey, DOLOTSONE, bituminuous, platty chips, medium hardness, cherty	286.04 38.85	Sand/Bentonite Seal Mix
40			
	GASPORT FORMATION Grey/White, DOLOSTONE, fossiliferous, platty chips, soft to medium hardnes	282.22 42.67	
45			
50			

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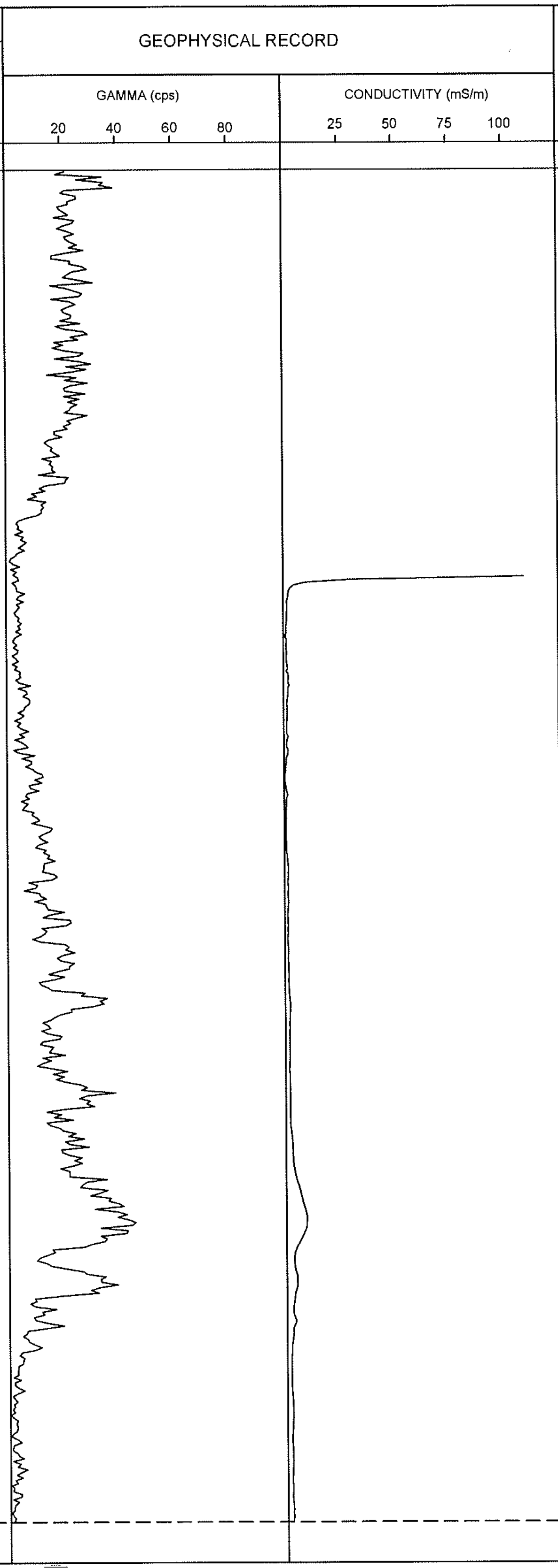
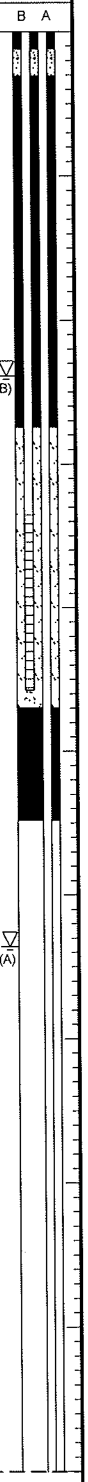




DEPTH SCALE
1 : 250

Golder Associates

LOGGED: KS

CHECKED: SMD

PROJECT: 08-1112-0098

RECORD OF DRILLHOLE: MW08-02

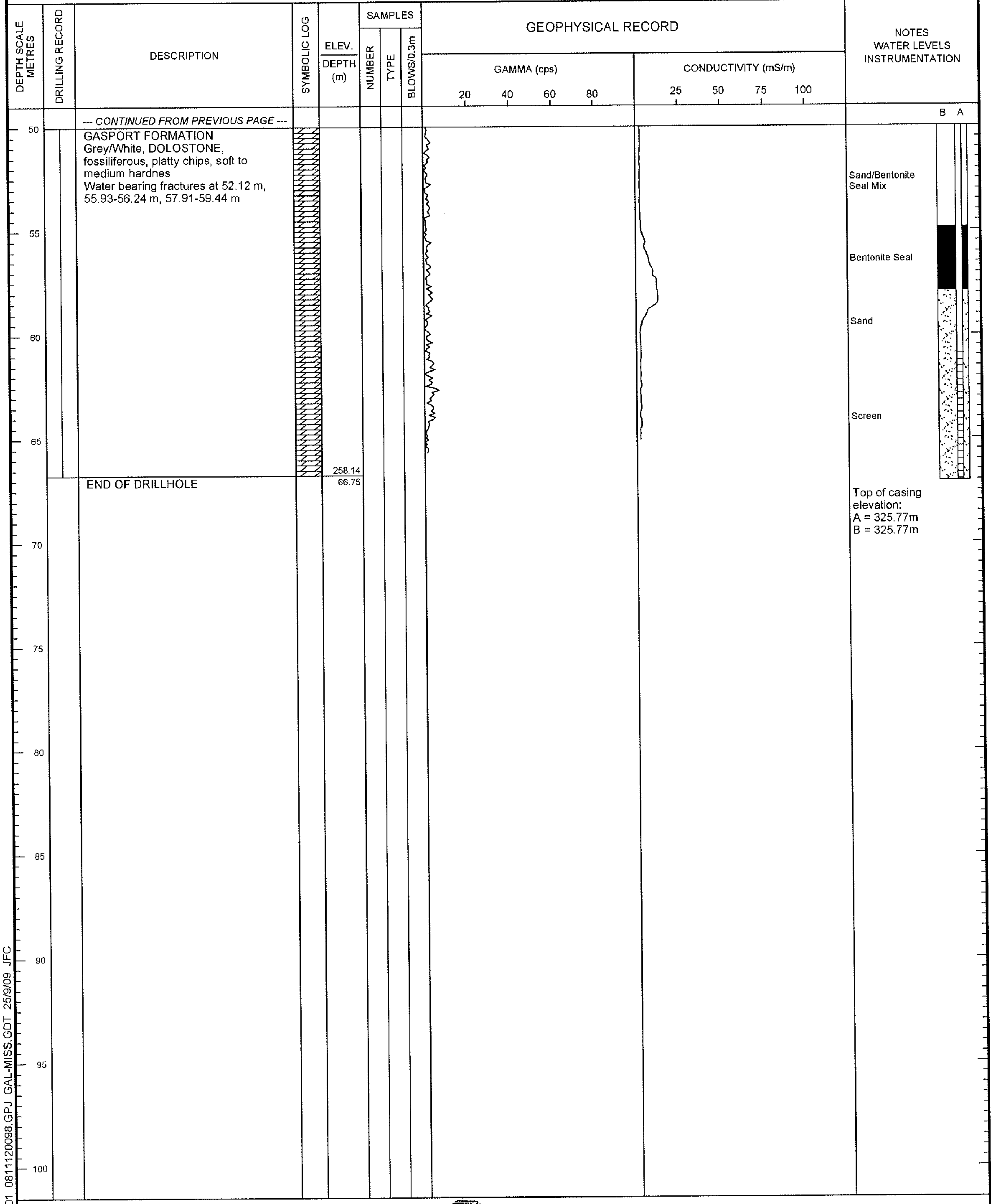
SHEET 2 OF 2

LOCATION: N 4819482.9 ;E 560096.3

INCLINATION: -90° AZIMUTH: ---

DRILLING DATE: July, 2008
DRILL RIG: Dual Rotary
DRILLING CONTRACTOR: Gerrits Drilling Ltd.

DATUM: Geodetic



--- CONTINUED FROM PREVIOUS PAGE ---

GASPORT FORMATION
Grey/White, DOLOSTONE, fossiliferous, platty chips, soft to medium hardnes
Water bearing fractures at 52.12 m, 55.93-56.24 m, 57.91-59.44 m

258.14
66.75

END OF DRILLHOLE

Sand/Bentonite Seal Mix

Bentonite Seal

Sand

Screen

Top of casing elevation:
A = 325.77m
B = 325.77m

DEPTH SCALE
1 : 250

Golder Associates

LOGGED: KS
CHECKED: SMD

PROJECT: 07-1112-0059

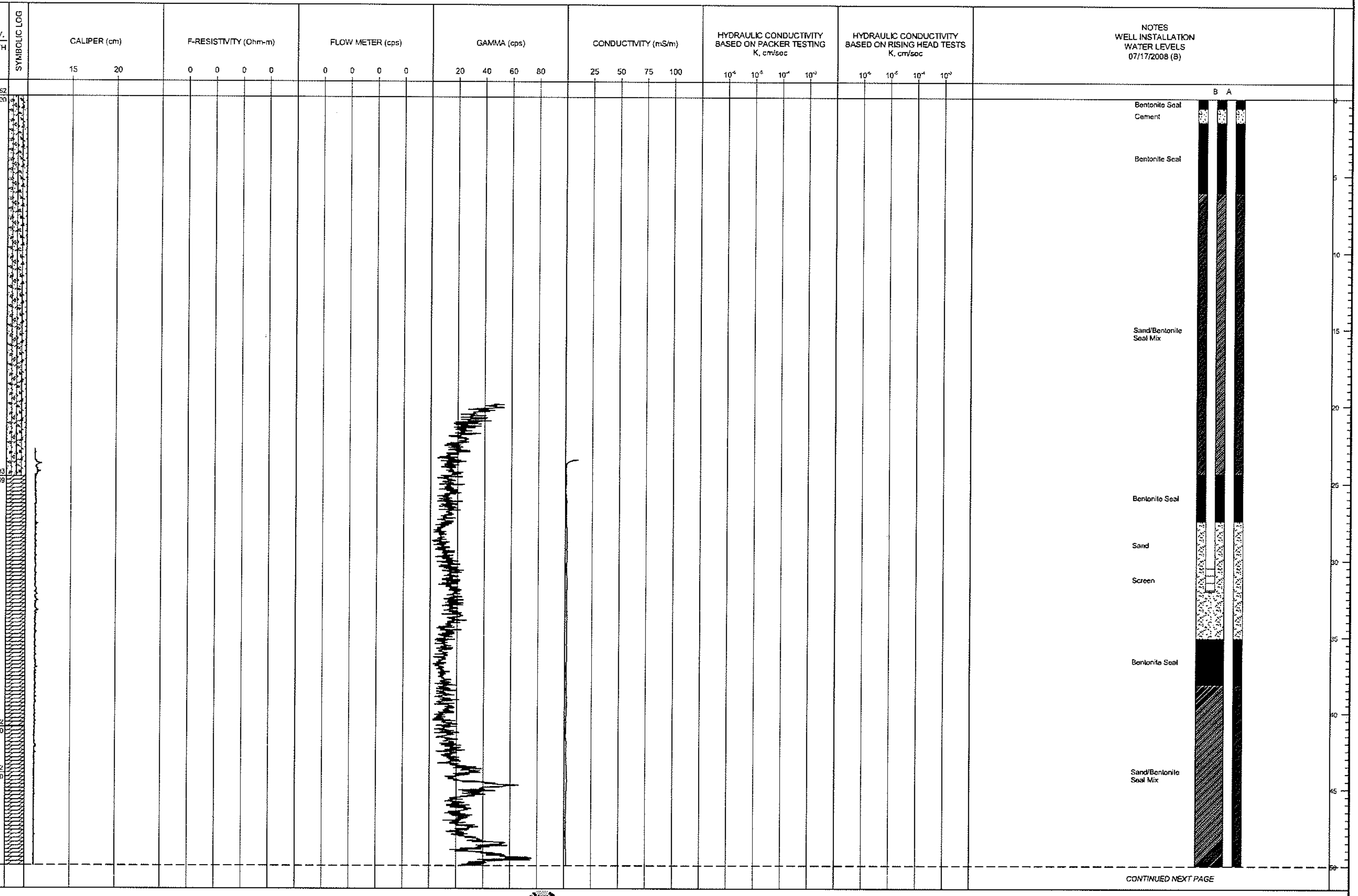
LOCATION: N 4817910.0 ;E 561758.0

RECORD OF DRILLHOLE: TW08-01(Davidson)

SHEET 1 OF 2

DATUM: Geodetic

DEPTH SCALE METRES	DESCRIPTION	ELEV. / DEPTH (m)
	GROUND SURFACE	332.62
0	Loose, moist to wet, brown, fine to medium sandy SILT, some gravel (TILL)	0.00
25	GUELPH FORMATION Biege, DOLOTSTONE, platty chips, medium hardness	307.93 24.69
41	ERAMOSA FORMATION (Reformatory member) Tan, DOLOTSONE, bituminuous, platty chips, medium hardness	291.62 41.00
44	ERAMOSA FORMATION (Vinemount member) Black to dark brown, medium hardness, slightly weathered, odourous, DOLOSTONE	288.62 44.00



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DEPTH SCALE

1 : 250

Golder Associates

LOGGED: KS

CHECKED:

PROJECT: 07-1112-0059

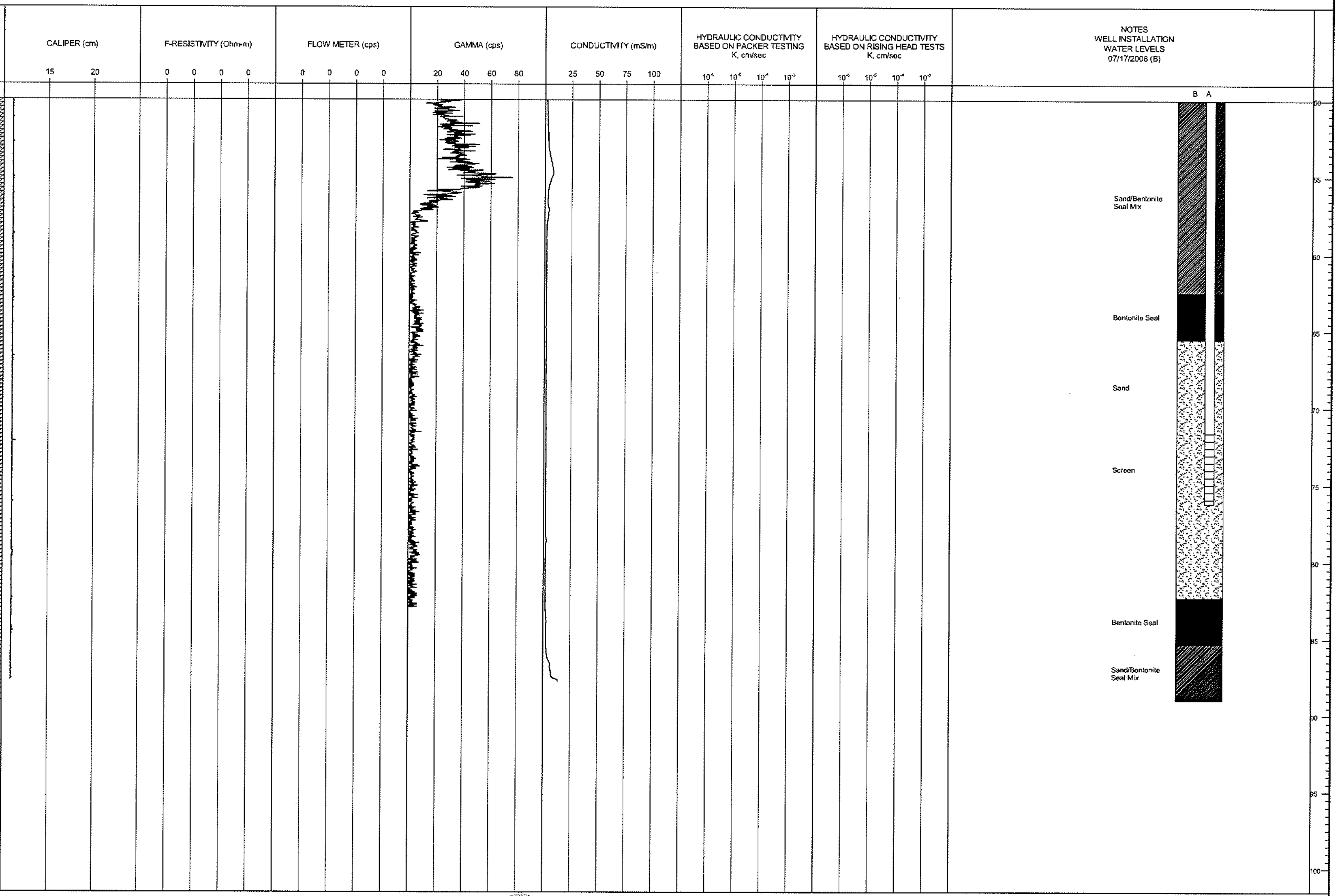
LOCATION: N 4817910.0 ;E 561758.0

RECORD OF DRILLHOLE: TW08-01(Davidson)

SHEET 2 OF 2

DATUM: Geodetic

DESCRIPTION	ELEV. / DEPTH (m)
--- CONTINUED FROM PREVIOUS PAGE ---	
ERAMOSA FORMATION (Vinemount member) Black to dark brown, medium hardness, slightly weathered, odourous, DOLOSTONE	
GOAT ISLAND FORMATION Brown to grey, medium hardness, slightly weathered, DOLOSTONE	278.12 54.50
GASPORT FORMATION Grey/White, DOLOSTONE, fossiliferous, platty chips, soft to medium hardnes	274.62 58.00
IRONDEQUOIT FORMATION Grey to white, soft to medium hardness, moderately weathered, porous, DOLOSTONE	246.62 86.00
CABOT HEAD FORMATION Grey to green, soft hardness, slightly weathered, SHALE	244.62 88.00
END OF DRILLHOLE	243.62 89.00



MIS-GEO 003 0711120059.GPJ GAL-MISS.GDT 2/12/09 JFC

DEPTH SCALE
1 : 250

Golder Associates

LOGGED: KS
CHECKED:

PROJECT: 07-1112-0059

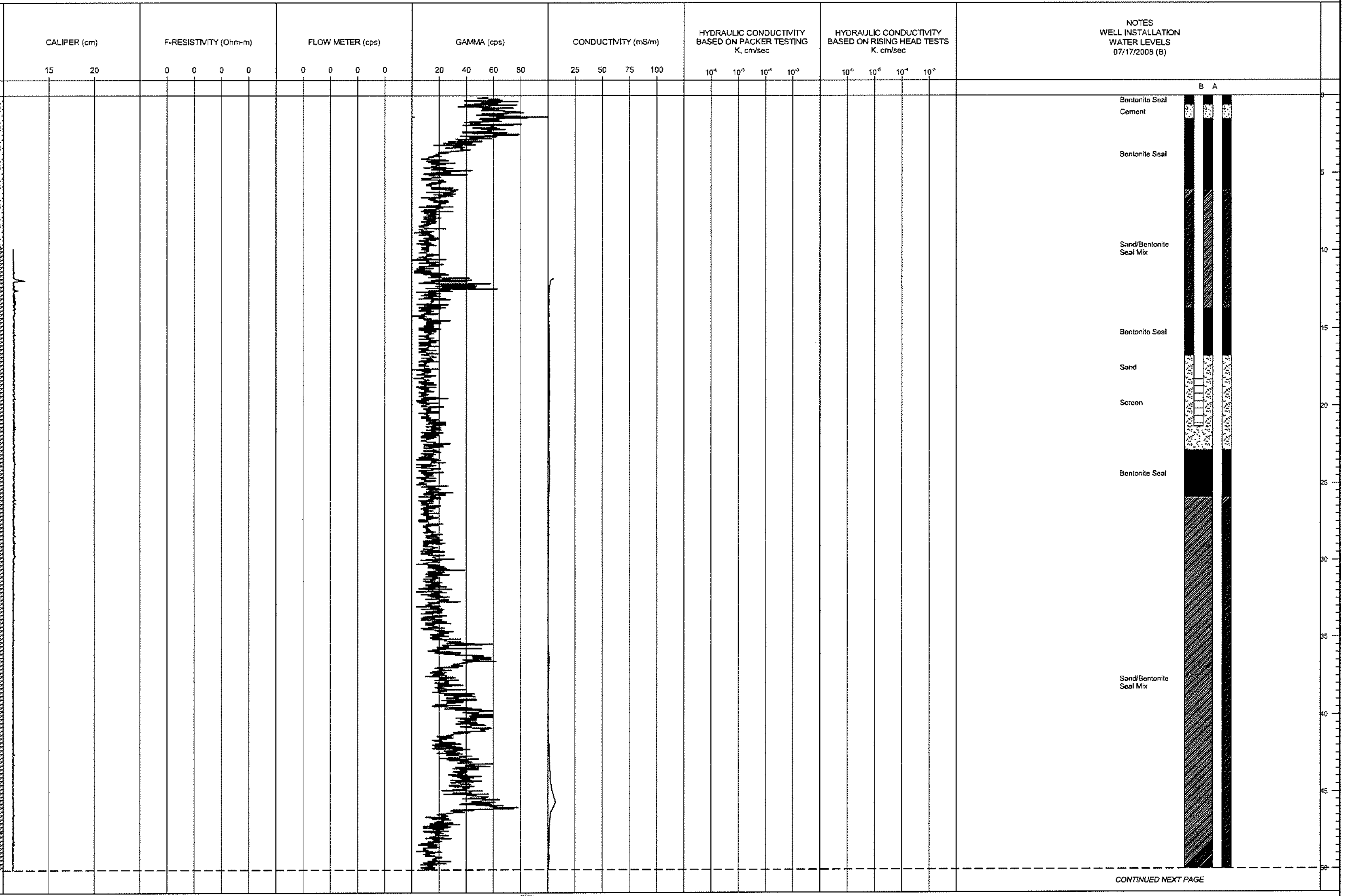
LOCATION: N 4818420.0 ;E 562092.0

RECORD OF DRILLHOLE: TW08-02

SHEET 1 OF 2

DATUM: Geodetic

DEPTH SCALE METRES	DESCRIPTION	ELEV. DEPTH (m)
	GROUND SURFACE	325.39
0	loose, moist to wet, brown, fine to medium sandy SILT, some gravel (TILL)	0.00
10	GUELPH FORMATION Biege, DOLOTSTONE, platty chips, medium hardness	315.59 9.80
30	ERAMOSA FORMATION (Reformatory member) Tan, DOLOTSONE, bituminuous, platty chips, medium hardness	296.13 29.26
37	ERAMOSA FORMATION (Vinemount member) Black to dark brown, medium hardness, slightly weathered, odourous, DOLOSTONE	268.93 36.46
45	GOAT ISLAND FORMATION Brown to grey, medium hardness, slightly weathered, DOLOSTONE	279.97 45.42
48	GASPORT FORMATION Grey/White, DOLOSTONE, fossiliferous, platty chips, soft to medium hardnes	277.84 47.55



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DEPTH SCALE

1 : 250

Golder Associates

LOGGED: KS

CHECKED:

PROJECT: 07-1112-0059

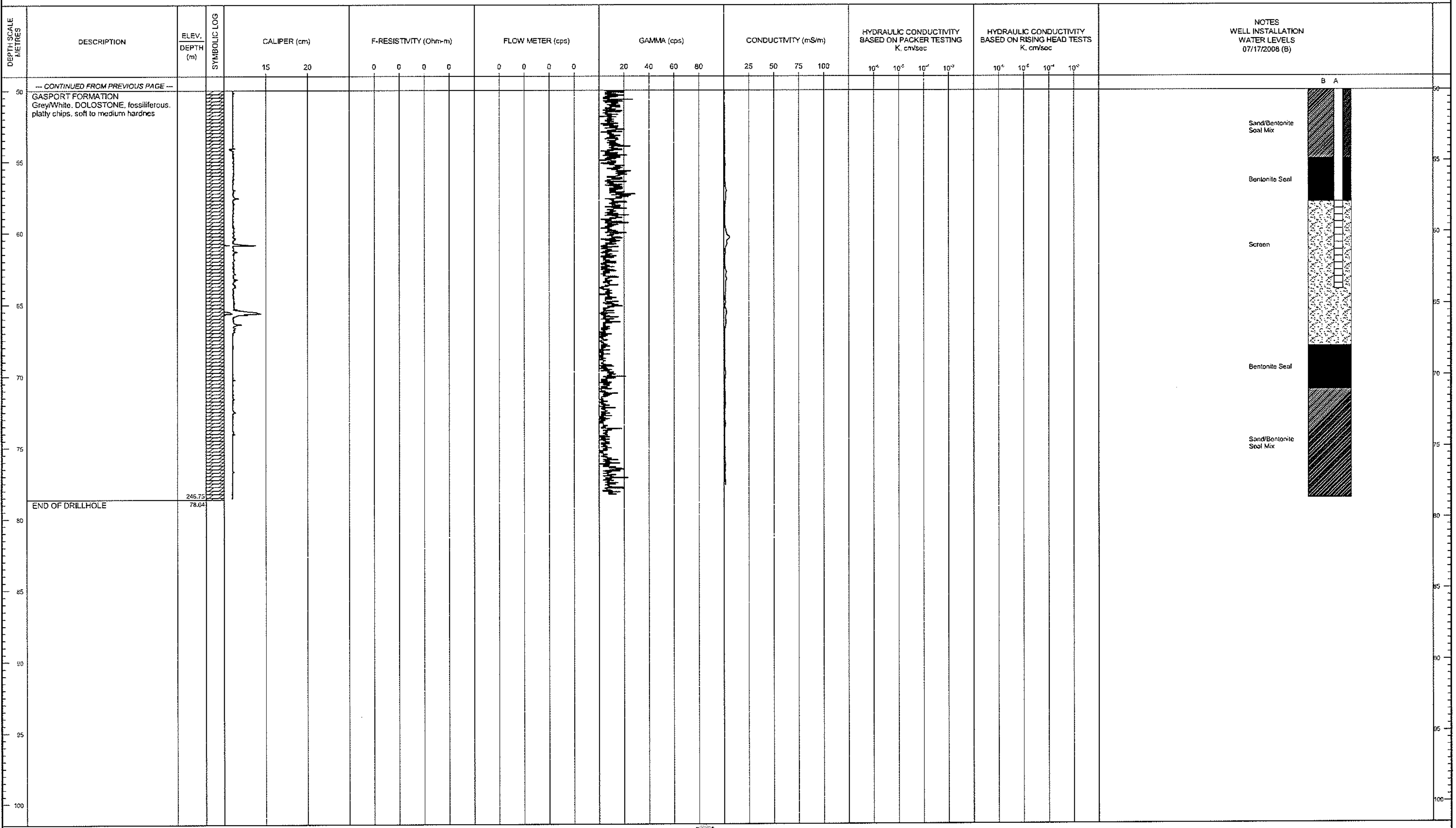
LOCATION: N 4818420.0 ;E 562092.0

RECORD OF DRILLHOLE: TW08-02

SHEET 2 OF 2

DATUM: Geodetic

DEPTH SCALE METRES	DESCRIPTION	ELEV. / DEPTH (m)
	--- CONTINUED FROM PREVIOUS PAGE ---	
50	GASPORT FORMATION Grey/White, DOLOSTONE, fossiliferous, platty chips, soft to medium hardnes	
	END OF DRILLHOLE	246.75 78.04



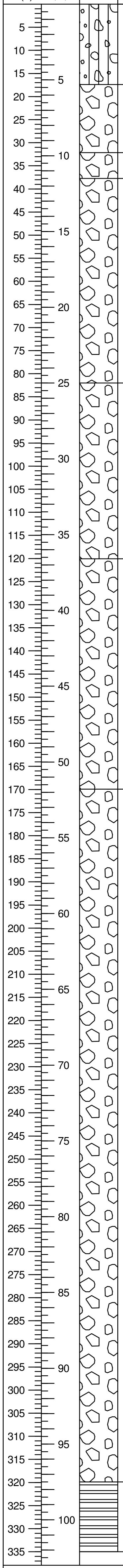
DEPTH SCALE
1 : 250

Golder Associates

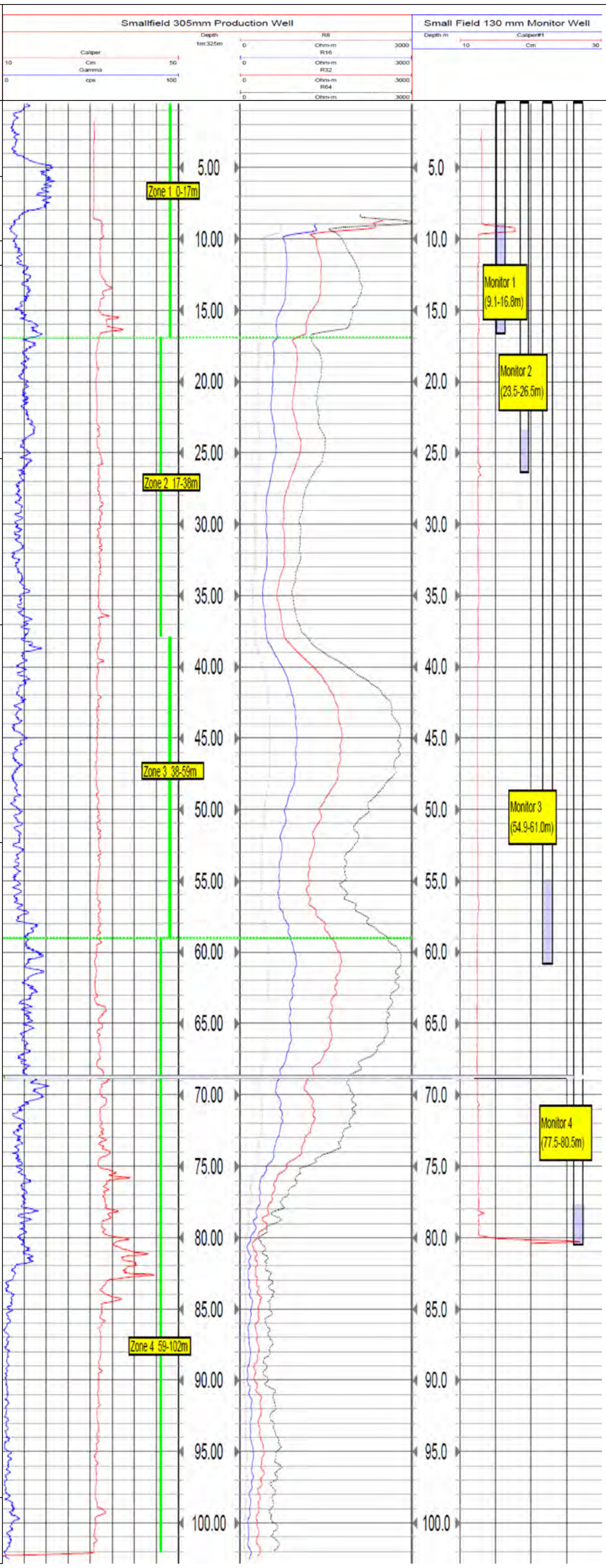
LOGGED: KS
CHECKED:

Production Well: Smallfield

Project:	Clyth Sacco & Smallfield Wells	**Drilling method:**	
Client:	Lotowater Technical Services	**Date started/completed:**	Oct-30-1995
Location:	Guelph, Ontario	**Ground surface elevaiton:**	343.98 m AMSL
Number:	160900504	**Top of casing elevation:**	344.23 m AMSL
Field investigator:		**Easting:**	556776.2
Contractor:		**Northing:**	4820865.2



Lithologic Description	Elevation (m AMSL) Depth (m BGS)
Ground Surface	
CLAY AND GRAVEL	343.98 0.00
ROCK light grey	338.68 5.30
ROCK blue grey	334.18 9.80
ROCK light brown	332.48 11.50
ROCK light grey	318.98 25.00
ROCK dark grey	307.38 36.60
ROCK dark grey with brown seams	292.18 51.80
SHALE light blue	246.48 97.50
End of Borehole	241.88 102.10



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Lotowater
TECHNICAL SERVICES INC.

CITY OF
Guelph

Client/Project
SMALLFIELD AND SACCO PRODUCTION WELLS
WELL REHABILITATION AND HYDROGEOLOGIC ASSESSMENT
PROGRESS REPORT FOR THE PERIOD DECEMBER 2008 TO MARCH 2009

Figure
4

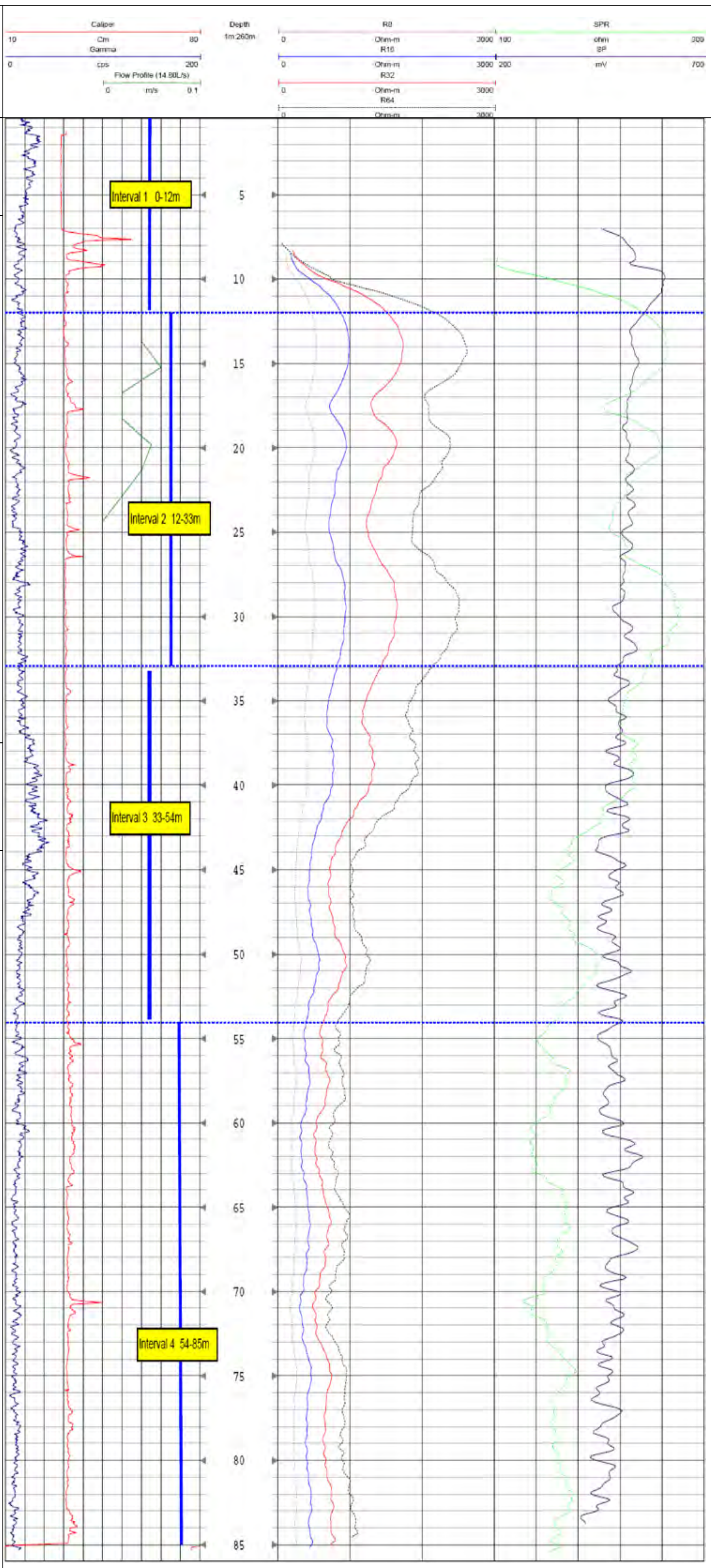
Title
Well Logging Results - Smallfield Well

Sheet 1 of 1

Production Well: Sacco

Project:	Clyth Sacco & Smallfield Wells	**Drilling method:**	
Client:	Lotowater Technical Services	**Date started/completed:**	Oct-30-1995
Location:	Guelph, Ontario	**Ground surface elevaiton:**	339.15 m AMSL
Number:	160900504	**Top of casing elevation:**	339.79 m AMSL
Field investigator:		**Easting:**	556466.1
Contractor:		**Northing:**	4821931.7

Depth (ft)	Depth (m)	Lithologic Description	Elevation (m AMSL) Depth (m BGS)
		Ground Surface	
0	0	SAND, CLAY AND GRAVEL	339.15 0.00
		LIMESTONE grey	333.35 5.80
		LIMESTONE brown	301.95 37.20
		LIMESTONE grey, dark grey	295.55 43.60
		LIMESTONE blue	245.25 93.90
		LIMESTONE	244.05 95.10
		SHALE	243.45 95.70
		End of Borehole	243.25 95.90



Client/Project
SMALLFIELD AND SACCO PRODUCTION WELLS
WELL REHABILITATION AND HYDROGEOLOGIC ASSESSMENT
PROGRESS REPORT FOR THE PERIOD DECEMBER 2008 TO MARCH 2009

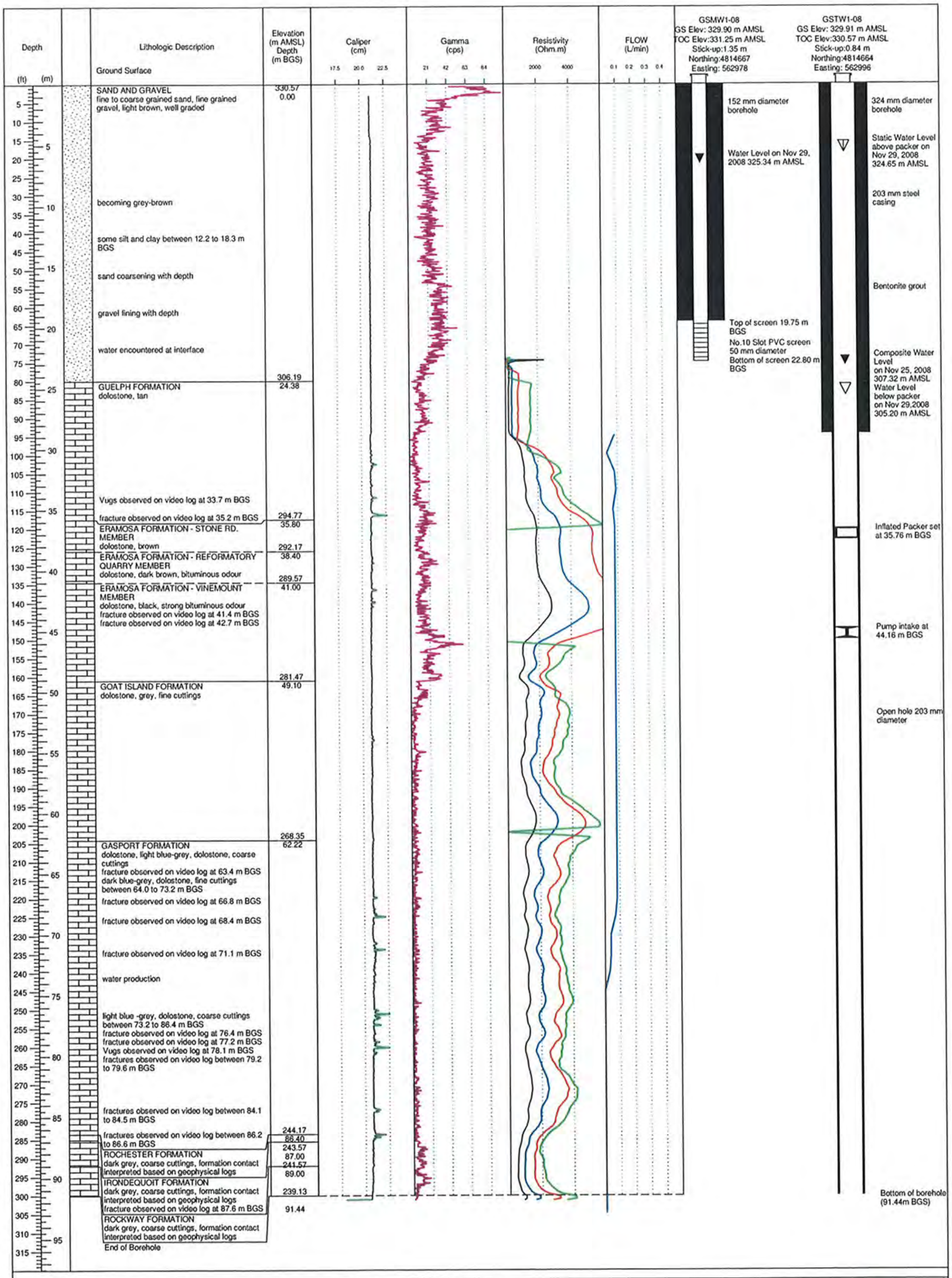
Figure
5

Title
Well Logging Results - Sacco Well

Sheet 1 of 1

Test Well: GSTW1-08 and GSMW1-08

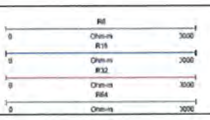
Project:	Guelph South Groundwater Investigation	**Drilling method:**	Air rotary
Client:	City of Guelph	**Date started/completed:**	Jun-11-2008 / Jun-17-2008
Location:	West Hanlon Business Park		
Number:	1609-00499		
Field investigator:	L.Kennell		
Contractor:	Davidson Drilling Ltd.		



NOTES:

mAMSL - metres above mean sea level

mBGS - metres below ground surface



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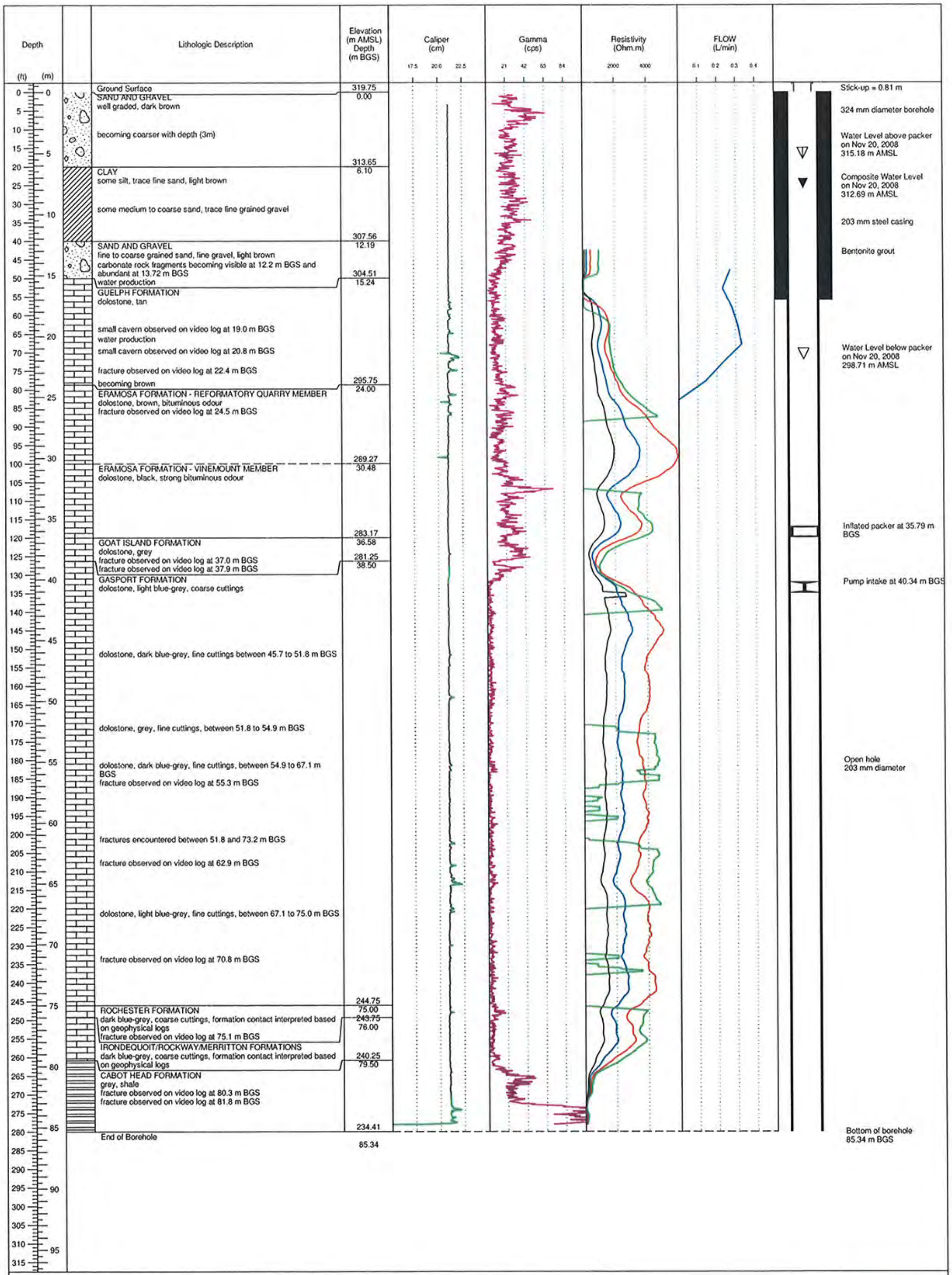
Sheet 1 of 1

Test Well: GSTW2-08

Project:	Guelph South Groundwater Investigation	**Drilling method:**	Air rotary
Client:	City of Guelph	**Date started/completed:**	Jun-24-2008 / Jun-27-2008
Location:	West Hanlon Business Park	**Ground surface elevaiton:**	319.75 m AMSL
Number:	1609-00499	**Top of casing elevation:**	320.65 m AMSL
Field investigator:	L.Kennell	**Easting:**	562286
Contractor:	Davidson Drilling Ltd.	**Northing:**	4816097

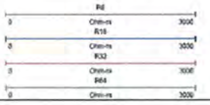


Lithologic Description	Elevation (m AMSL) Depth (m BGS)
Ground Surface	319.75
SAND AND GRAVEL well graded, dark brown becoming coarser with depth (3m)	0.00 313.65
CLAY some silt, trace fine sand, light brown some medium to coarse sand, trace fine grained gravel	6.10 307.56
SAND AND GRAVEL fine to coarse grained sand, fine gravel, light brown carbonate rock fragments becoming visible at 12.2 m BGS and abundant at 13.72 m BGS water production	12.19 304.51
GUELPH FORMATION dolostone, tan small cavern observed on video log at 19.0 m BGS water production small cavern observed on video log at 20.8 m BGS fracture observed on video log at 22.4 m BGS becoming brown	15.24 295.75
ERAMOSA FORMATION - REFORMATORY QUARRY MEMBER dolostone, brown, bituminous odour fracture observed on video log at 24.5 m BGS	24.00 289.27
ERAMOSA FORMATION - VINEMOUNT MEMBER dolostone, black, strong bituminous odour	30.48 283.17
GOAT ISLAND FORMATION dolostone, grey fracture observed on video log at 37.0 m BGS fracture observed on video log at 37.9 m BGS	36.58 281.25
GASPORT FORMATION dolostone, light blue-grey, coarse cuttings dolostone, dark blue-grey, fine cuttings between 45.7 to 51.8 m BGS dolostone, grey, fine cuttings, between 51.8 to 54.9 m BGS dolostone, dark blue-grey, fine cuttings, between 54.9 to 67.1 m BGS fracture observed on video log at 55.3 m BGS fractures encountered between 51.8 and 73.2 m BGS fracture observed on video log at 62.9 m BGS dolostone, light blue-grey, fine cuttings, between 67.1 to 75.0 m BGS fracture observed on video log at 70.8 m BGS	38.50 244.75
ROCHESTER FORMATION dark blue-grey, coarse cuttings, formation contact interpreted based on geophysical logs fracture observed on video log at 75.1 m BGS	75.00 243.75
IRONDEQUOIT/ROCKWAY/MERRITTON FORMATIONS dark blue-grey, coarse cuttings, formation contact interpreted based on geophysical logs	76.00 240.25
CABOT HEAD FORMATION grey, shale fracture observed on video log at 80.3 m BGS fracture observed on video log at 81.8 m BGS	79.50 234.41
End of Borehole	85.34

NOTES:

mAMSL - metres above mean sea level

mBGS - metres below ground surface



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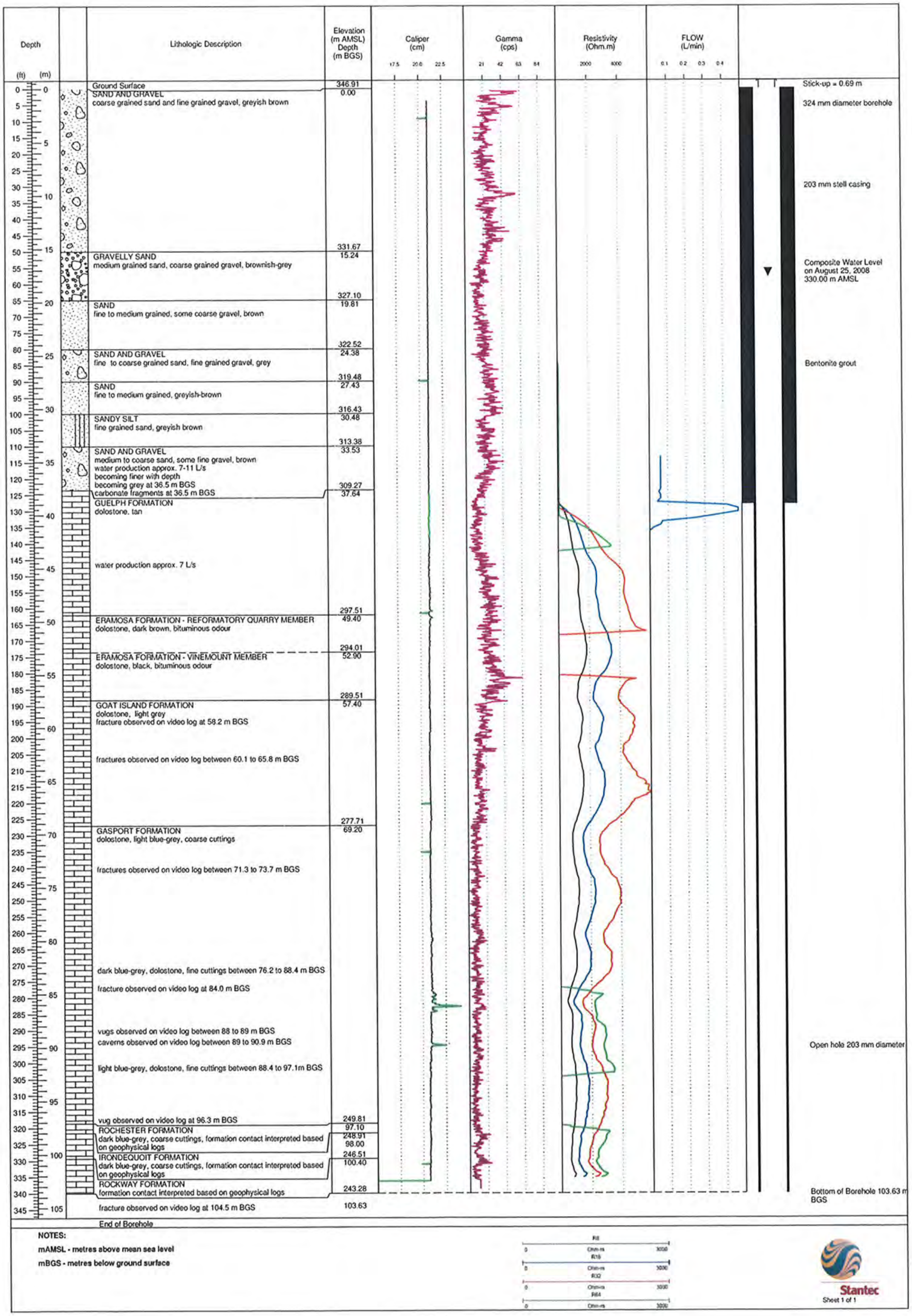
Sheet 1 of 1

Test Well: GSTW3-08

Project:	Guelph South Groundwater Investigation	**Drilling method:**	Air rotary
Client:	City of Guelph	**Date started/completed:**	May-27-2008 / May-29-2008
Location:	West Hanlon Business Park	**Ground surface elevaiton:**	346.91 m AMSL
Number:	1609-00499	**Top of casing elevation:**	347.57 m AMSL
Field investigator:	L.Kennell	**Easting:**	565403
Contractor:	Davidson Drilling Ltd.	**Northing:**	4815503



Lithologic Description	Elevation (m AMSL) Depth (m BGS)
Ground Surface	346.91
SAND AND GRAVEL coarse grained sand and fine grained gravel, greyish brown	0.00
GRAVELLY SAND medium grained sand, coarse grained gravel, brownish-grey	331.67 15.24
SAND fine to medium grained, some coarse gravel, brown	327.10 19.81
SAND AND GRAVEL fine to coarse grained sand, fine grained gravel, grey	322.52 24.38
SAND fine to medium grained, greyish-brown	319.48 27.43
SANDY SILT fine grained sand, greyish brown	316.43 30.48
SAND AND GRAVEL medium to coarse sand, some fine gravel, brown water production approx. 7-11 L/s becoming finer with depth becoming grey at 36.5 m BGS carbonate fragments at 36.5 m BGS	313.38 33.53
GUELPH FORMATION dolostone, tan water production approx. 7 L/s	309.27 37.64
ERAMOSA FORMATION - REFORMATORY QUARRY MEMBER dolostone, dark brown, bituminous odour	297.51 49.40
ERAMOSA FORMATION - VINEMOUNT MEMBER dolostone, black, bituminous odour	294.01 52.90
GOAT ISLAND FORMATION dolostone, light grey fracture observed on video log at 58.2 m BGS fractures observed on video log between 60.1 to 65.8 m BGS	289.51 57.40
GASPORT FORMATION dolostone, light blue-grey, coarse cuttings fractures observed on video log between 71.3 to 73.7 m BGS dark blue-grey, dolostone, fine cuttings between 76.2 to 88.4 m BGS fracture observed on video log at 84.0 m BGS vugs observed on video log between 88 to 89 m BGS caverns observed on video log between 89 to 90.9 m BGS light blue-grey, dolostone, fine cuttings between 88.4 to 97.1m BGS vug observed on video log at 96.3 m BGS	277.71 69.20
ROCHESTER FORMATION dark blue-grey, coarse cuttings, formation contact interpreted based on geophysical logs	249.81 97.10
IRONDEQUOIT FORMATION dark blue-grey, coarse cuttings, formation contact interpreted based on geophysical logs	248.91 98.00
ROCKWAY FORMATION formation contact interpreted based on geophysical logs	246.51 100.40
fracture observed on video log at 104.5 m BGS	243.28 103.63
End of Borehole	

NOTES:

mAMSL - metres above mean sea level

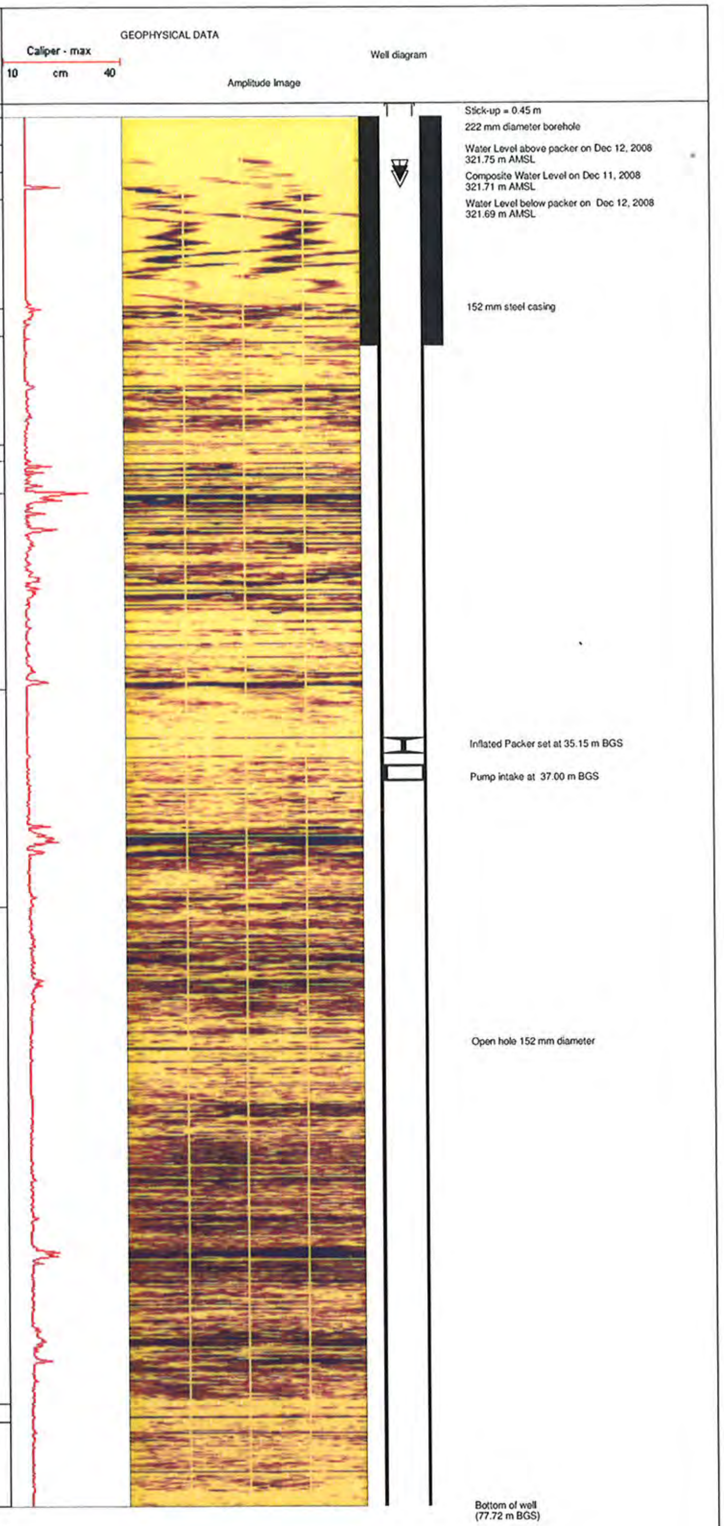
mBGS - metres below ground surface

Sheet 1 of 1

Test Well: GSTW4-08 (McCurdy)

Project:	Guelph South Groundwater Investigation	**Drilling method:**	Mud rotary
Client:	City of Guelph	**Date started/completed:**	Nov-21-2008
Location:	West Hanlon Business Park	**Ground surface elevaiton:**	324.09 m AMSL
Number:	1609-00499	**Top of casing elevation:**	324.54 m AMSL
Field investigator:	L.Kennell	**Easting:**	563539
Contractor:	Davidson Drilling Ltd.	**Northing:**	4817511

Lithologic Description	Elevation (m AMSL) Depth (m BGS)
Ground Surface	324.09 0.00
GRAVEL FILL	322.57 1.52
GRAVEL AND SAND fine grained gravel, medium to fine grained sand, some silt, brownish grey	321.04 3.05
SILTY SAND AND GRAVEL brown	319.52 4.57
GRAVEL AND SAND brown, fine grained gravel, medium to fine grained sand	313.42 10.67
SAND fine to medium grained, greyish brown	311.90 12.19
GUELPH FORMATION dolostone, tan fracture observed on video log at 14.9 m BGS fracture with flow into borehole observed on video log at 16.2 m BGS fracture observed on video log at 17.5 m BGS	305.80 18.29
ERAMOSA FORMATION - STONE RD. MEMBER dolostone, brown, fine cuttings	304.89 19.20
ERAMOSA FORMATION - REFORMATORY QUARRY MEMBER dolostone, brown black, bituminous odour	303.09 21.00
ERAMOSA FORMATION - VINEMOUNT MEMBER dolostone, black, strong bituminous odour, coarse cuttings with shaley pieces unit was observed in video log to be vuggy, highly fractured, with caverns at 22.9, 23.8, 24.1, 25.9 and 31.7 m BGS	292.09 32.00
GOAT ISLAND FORMATION grey, dolostone, fine cuttings fractures were limited near the top of the unit, from 38.1 m BGS to base of unit fractures increased and a small cavern noted at 40.5 m BGS as observed on video log	279.89 44.20
GASPORT FORMATION dolostone, light blue grey, fine cuttings, cuttings becoming coarser and lighter with depth fracture observed on video log at 45.7 m BGS fractures observed on video log between 47.6 to 48.5 m BGS fractures observed on video log between 50.0 to 50.6 m BGS fracture observed on video log at 53.3 m BGS dolostone, light grey to white, coarse cuttings between 57.9 to 62.5 m BGS fracture observed on video log between 62.5 m BGS large cavern observed on video log at 64.0 m BGS dolostone, dark blue-grey, fine cuttings between 62.5 to 71.6 m BGS caverns and fractures observed on video log between 68.9 to 70.1 m BGS	252.09 72.00
ROCHESTER FORMATION dark blue-grey, shale, coarse cuttings, formation contact based on geophysical logs from GSTW4-08 and McCurdy Multilevel	251.09 73.00
IRONDEQUOIT FORMATION formation contact based on geophysical logs from GSTW4-08 and McCurdy Multilevel	246.37
End of Borehole	77.72



NOTES:

mAMSL - metres above mean sea level

mBGS - metres below ground surface

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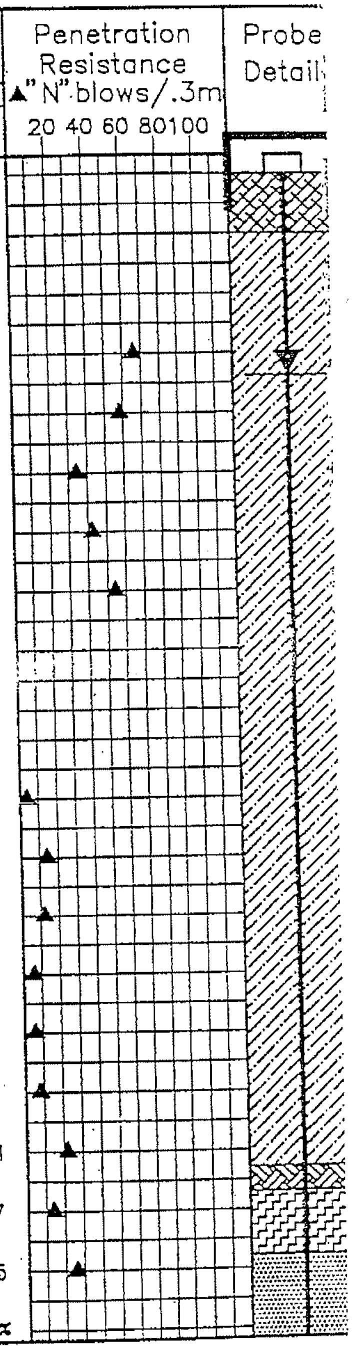
Sheet 1 of 1

MARSHALL MACKLIN MONAGHAN LIMITED
LOG OF BOREHOLE No.: 1-1 Observation Well 1

Project Number : 14-91008-103
Project Description : HANLON CREEK
Location : McCurdy Road
Installation Date(s) : October 22, 1991
Field Inspector : S. Mo

Prepared by : S. Mo
Checked by : A. Zilans
Rig Type : CME 75 TRACK MOUNTED
Drilling Equipment : SEE ATTACHED DRILLING METHODOLOGY FOR DETAILS
Piezometer Size : 2" I.D. SCH 40 PVC PIPE

Elev. m	Depth m	Soil Description	Strata Plot	Samples % Rec.	Samples Type	Samples Lab. Sa.	Samples K cm/s / No.&size of core pieces	Samples "N" / RQD
323.77	0.00	Poorly sorted, sand, gravel, cobbles, (Fill).						
	0.50							
	1.00							
	1.50			70%	SS1			66
321.79	1.98	GRAVELLY SAND trace of silt, poorly to moderately sorted, some cobble size clasts						
	2.50			87%	SS2			58
	3.00			79%	SS3			32
	3.50			100%	SS4	5	10^{-2}	41
	4.00			83%	SS5			54
	4.50							
	5.00							
	5.50							
317.68	6.09	Fine SAND, some silt, moderately well sorted, non-stratified		100%	SS6	4	10^{-3}	4
317.22	6.55	Silt, traces of sand and clay well sorted, non-stratified				3	10^{-5}	
316.76	7.01	Medium SAND, well sorted, non-stratified		50%	SS7			13
	7.50			37%	SS8			11
315.85	7.92	SILT with traces of sand and clay, non-stratified to weakly laminated, reddish brown, wet, (Lacustrine)		100%	SS9	2	10^{-5}	5
	8.50			100%	SS10			6
314.63	9.14	SANDY SILT, some clay, a trace of gravel, non-sorted, non-stratified (Till)						
	9.50			100%	SS11			9
313.74	10.03	Very porous, highly fractured white grey DOLOSTONE		50%	SS12	1	10^{-6}	21
	10.50			4%	SS13			17
	11.00			8%	SS14			25
312.19	11.58			84%	HQ1			59%



NOTES:

1. LOG OF BOREHOLE No. 1-1 CONTINUED ON FOLLOWING PAGE
2. WATER LEVEL ELEVATION 321.704m MEASURED ON FEBRUARY 06, 1992

MARSHALL MACKLIN MONAGHAN LIMITED
LOG OF BOREHOLE No.: 1-1

Project Number : 14-91008-103
Project Description : HANLON, CREEK
Location : McCurdy Road
Installation Date(s) : October 22, 1991
Field Inspector : S. Mo

Prepared by : S. Mo
Checked by : A. Zilans
Rig Type : CME 75 TRACK MOUNTED
Drilling Equipment : SEE ATTACHED DRILLING METHODOLOGY FOR DETAILS
Piezometer Size : 2"I.D. SCH 40 PVC PIPE

Elev.	Depth	Soil Description	Strata Plot	Samples					Penetration Resistance ▲"N" blows/.3m	Probe Detail
							K cm/s	"N"		
m	m			% Rec.	Type	Lab. Sa.	No.&size of core pieces	RQD	20 40 60 80 100	
	12.50	Greyish-white, porous, DOLOSTONE, highly fossiliferous, abundant vugs with calcite crystals; highly fractured, becoming grey towards bottom as shale content increases		93%	HQ1		2x5.05cm 1x7.62cm 1x10.16cm 1x48.26cm			
	13.00 13.50 14.00			99%	HQ2		1x55.5cm 1x21cm 1x11cm 1x21cm 1x11cm 1x21.5cm 1x2cm 1x9cm	92%		
	14.50 15.00 15.50			85%	HQ3		1x47cm 1x4.5cm 1x40cm 1x38.5cm	85%		
	16.00 16.50 17.00			89%	HQ4		2x1cm 1x9cm 1x22.5cm 1x4cm 1x1cm 1x21cm 1x16cm 1x2cm 1x1cm 1x23.5cm 1x3cm 1x17cm 1x14.5cm	75%		
	17.50 18.00 18.50			90%	HQ5		1x13.5cm 1x14.5cm 1x14.5cm 1x15cm 1x22cm 1x3.5cm 1x1.5cm 1x14.5cm 1x15cm 1x7cm	81%		
	19.00 19.50 20.00			90%	HQ6		1x5.5cm 1x11cm 1x6cm 1x20cm 3x1cm 1x10cm 1x19.5cm 1x1cm 1x23.5cm 1x7cm 1x3cm 1x20cm 1x6cm	61%		
	20.50 21.00 21.50			78%	HQ7		1x2.5cm 1x6.5cm 4x2cm 1x7.5cm 1x6cm 2x2cm 1x14cm 1x13.5cm 1x7.5cm 1x6cm 1x14.5cm	40%		
	22.00 23.50 23.00	Grey, DOLOSTONE with shale laminae increasing in abundance downward; vugs and fractures become fewer; no fossils		91%	HQ8		1x17cm 1x6.5cm 1x13cm 1x18.5cm 1x37cm 1x6cm 1x24cm 1x12cm	83%		
	23.50			96%	HQ9		1x18.5cm 1x3.5cm 1x1.5cm 1x2.5cm 1x15cm 1x1.5cm 1x5cm 1x28cm	77%		

NOTES:

1. LOG OF BOREHOLE No. 1-1 CONTINUED ON FOLLOWING PAGE

MARSHALL MACKLIN MONAGHAN LIMITED
LOG OF BOREHOLE No.: 1-1

Project Number	: 14-91008-103	Prepared by	: S. Mo
Project Description	: HANLON CREEK	Checked by	: A. Zilans
Location	: McCurdy Road	Rig Type	: CME 75 TRACK MOUNTED
Installation Date(s)	: October 22, 1991	Drilling Equipment	: SEE ATTACHED DRILLING METHODOLOGY FOR DETAILS
Field Inspector	: S. Mo	Piezometer Size	: 2"I.D SCH 40 PVC PIPE

Elev. m	Depth m	Soil Description	Strata Plot	Samples % Rec.	Samples Type	Samples Lab. Sa.	K cm/s No.&size of core pieces	"N" RQD	Penetration Resistance ▲"N" blows/.3m 20 40 60 80 100	Probe Detai
	24.50			96%	HQ9		1x3.5cm 1x13cm 1x12cm 1x14.5cm 1x3.5cm 1x15.5cm 1x7cm	77%		
	25.00									
	25.50			94%	HQ10		1x24cm 1x14cm 1x21cm 1x14.5cm 1x12cm 1x17.5cm 1x20.5cm 1x21.5cm	94%		
	26.00									
	26.50									
	27.00			97%	HQ11		1x3.5cm 1x21.5cm 1x3.5cm 1x25cm 1x18cm 1x1cm 1x33cm 1x12.5cm 1x20cm 1x11cm	92%		
	27.50									
	28.00									
	28.50			94%	HQ12		1x24cm 1x11cm 1x31.5cm 1x28cm 1x0.5cm 1x16cm 1x25.5cm 1x5cm	91%		
	29.00									
	29.50									
	30.00			90%	HQ13		1x1cm 1x10.5cm 1x5.5cm 1x18.5cm 1x27cm 1x19.5cm 1x5cm 1x6cm 1x12.5cm 1x3cm 2x14cm 1x16cm	77%		
	30.50									
	31.00									
	31.50			93%	HQ14		1x47.5cm 1x4cm 2x2cm 1x4.3cm 1x20.5cm 1x23cm	88%		
	32.00									
	32.50									
	33.00			98%	HQ15		1x29cm 1x17.5cm 1x11.5cm 1x2cm 1x16cm 1x2cm 1x42cm 1x14cm 1x18.5cm	96%		
	33.53	END OF BOREHOLE								
	34.00									
	34.50									
	35.00									
	35.50									

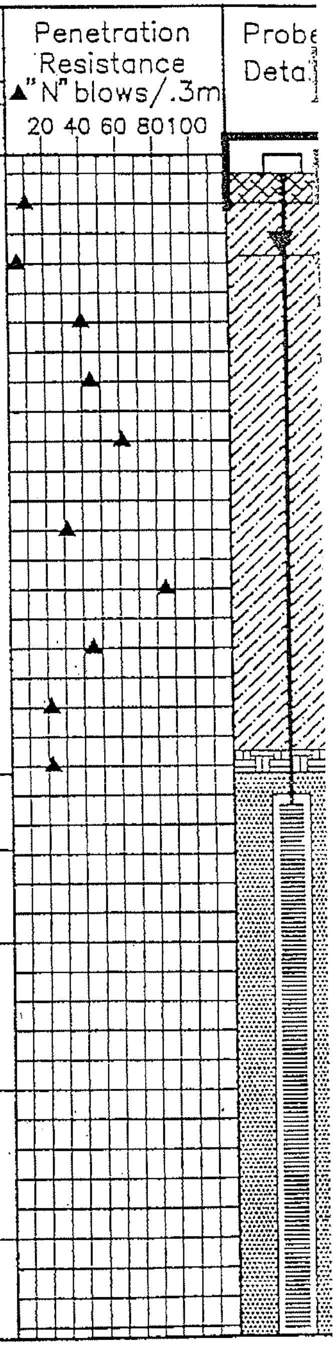
MARSHALL MACKLIN MONAGHAN LIMITED
LOG OF BOREHOLE No.: 3-1

Observation Well 7

Project Number	: 14-91008-103	Prepared by	: S. Mo
Project Description	: HANLON CREEK	Checked by	: A. Zilans
Location	: OLD HANLON ROAD	Rig Type	: CME 75 TRACK MOUNTED
Installation Date(s)	: November 04, 1991	Drilling Equipment	: SEE ATTACHED DRILLING METHODOLOGY FOR DETAILS
Field Inspector	: S. Mo	Piezometer Size	: 2"I.D. PVC PIPE

Elev. m	Depth m	Soil Description	Samples % Rec.	Type	Lab. Sa.	K cm/s / No.&size of core pieces	"N" / RQD
318.34	0.00						
		Gravelly sand, organic rich TOPSOIL	54%	SS1			10
317.73	0.61	GRAVEL with some sand and cobbles; most cobbles dolomite, few granitic; at 3.65 to 3.75m infilling of pore space between gravel by silty sand mud					
	1.00		46%	SS2			5
	1.50		75%	SS3			40
	2.00		87%	SS4			45
	2.50		100%	SS5			62
	3.00						
	3.50		68%	SS6			31
	4.00		71%	SS7	▨	1	84
	4.50		33%	SS8			43
	5.00						
	5.50		100%	SS9			21
312.37	5.97	SILTY SAND, with traces of clay and gravel clasts, non-sorted, non-stratified, moist, beige brown, (Till)			▨	10^{-5}	24
312.17	6.17	DOLOSTONE — Greyish white with some vugs with calcite crystals; few fossilis, becoming muddy (shale) at 24.7m					
	6.50		99%	HQ1		1x7cm 1x6cm 1x12.5cm 1x11.5cm 1x4cm 1x12.5cm 1x10cm 1x9.5cm	50%
	7.00						
	7.50		99%	HQ2		1x46cm 1x1cm 1x19.5cm 1x24cm	98%
	8.00						
	8.50		100%	HQ3		1x15.5cm 1x8.5cm 1x65cm 1x37.5cm 1x25.5cm	99%
	9.00						
	9.50						
	10.00		95%	HQ4		1x27cm 1x6cm 1x40cm 1x36cm 1x1.5cm 1x17cm 1x16cm	91%
	10.50						
	11.00						
	11.50		99%	HQ5		1x26cm 1x39cm 1x3cm 1x26.5cm 1x9.5cm 1x39cm 1x3.5cm	87%

Strata Plot



NOTES:

1. LOG OF BOREHOLE No. 3-1 CONTINUED ON FOLLOWING PAGE
2. WATER LEVEL ELEVATION 317.507m MEASURED ON FEBRUARY 06, 1992

MARSHALL MACKLIN MONAGHAN LIMITED
LOG OF BOREHOLE No.: 3-1

Project Number : 14-91008-103
Project Description : HANLON CREEK
Location : OLD HANLON ROAD
Installation Date(s) : November 04, 1991
Field Inspector : S. Mo

Prepared by : S. Mo
Checked by : A. Zilans
Rig Type : CME 75 TRACK MOUNTED
Drilling Equipment : SEE ATTACHED DRILLING METHODOLOGY FOR DETAILS

Piezometer Size : 2"I.D. PVC PIPE

Elev. m	Depth m	Soil Description	Strata Plot	Samples % Rec.	Samples Type	Samples Lab. Sa.	K cm/s No.&size of core pieces	"N" RQD	Penetration Resistance ▲"N" blows/.3m 20 40 60 80 100	Probe Detail
	12.50									
	13.00			100%	HQ6		1x16cm 1x54cm 1x30cm 1x19cm 1x8.5cm 1x24.5cm	94%		
	13.50									
	14.00									
	14.50			100%	HQ7		1x75.5cm 1x20cm 1x43.5cm 1x5cm 1x8.5cm	91%		
	15.00									
	15.50									
	16.00			97%	HQ8		1x46cm 1x15.5cm 1x18cm 1x9.5cm 1x20cm 1x3cm 1x3cm 1x21cm 1x3.5cm 2x2cm	78%		
	16.50									
	17.00									
	17.50			100%	HQ9		1x16.5cm 1x22cm 1x54.5cm 1x42.5cm 1x9.5cm 1x7.5cm	89%		
	18.00									
	18.50									
	19.00									
	19.50			90%	HQ10		1x53cm 1x29cm 1x62.5cm 1x2cm 1x5.5cm	61%		
	20.00									
	20.50									
	21.00			99%	HQ11		1X23.5cm 1x41cm 1x6cm 1x26cm 1x54.5cm	95%		
	21.50									
	22.00									
	23.50			100%	HQ12		1x36.5cm 1x6.5cm 1x30cm 1x21cm 1x31.5cm 1x4cm 1x23cm	93%		
	23.00									
	23.50			97%	HQ13		1x3.5cm 1x16cm 1x27cm 1x15cm 1x2cm 1x11cm	76%		

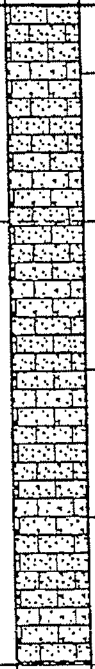
NOTES:

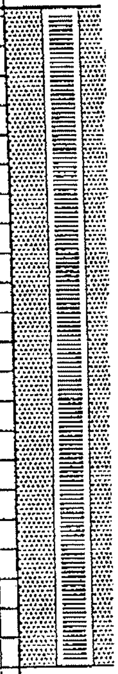
1. LOG OF BOREHOLE No. 3-1 CONTINUED ON FOLLOWING PAGE

MARSHALL MACKLIN MONAGHAN LIMITED
LOG OF BOREHOLE No.: 3–1

Project Number : 14–91008–103
Project Description : HANLON CREEK
Location : OLD HANLON ROAD
Installation Date(s) : November 04, 1991
Field Inspector : S. Mo

Prepared by : S. Mo
Checked by : A. Zilans
Rig Type : CME 75 TRACK MOUNTED
Drilling Equipment : SEE ATTACHED DRILLING METHODOLOGY FOR DETAILS
Piezometer Size : 2" I.D. PVC PIPE





Elev. m	Depth m	Soil Description	Samples % Rec.	Samples Type	Samples Lab. Sa.	K cm/s / No.&size of core pieces	"N" / RQD	Penetration Resistance ▲"N" blows/.3m 20 40 60 80 100	Probe Detail
						1x25cm 1x9cm 1x9.5cm 1x7cm 1x23cm			
	24.50								
	25.00								
	25.50		100%	HQ14		1x16cm 1x10.5cm 1x34cm 1x5.5cm 1x17.5cm 1x4cm 1x1.5cm 1x17cm 1x17.5cm 1x20.5cm 1x6cm	87%		
	26.00								
292.13	26.21								
	26.50								
	27.00	DOLOSTONE – Grey, shaley, laminated with few large vugs containing abundant calcite crystals	96%	HQ15		1x13cm 1x1.5cm 1x10.5cm 1x13.5cm 1x32cm 1x1.5cm 1x18.5cm 1x3.5cm 1x21.5cm 1x15cm 1x9cm 1x4.5cm 1x1cm	83%		
	27.50								
	28.00								
	28.50		99%	HQ16		1x15cm 1x25cm 1x23.5cm 1x15cm 1x5.5cm 1x23cm 1x3cm 1x22cm 1x16cm	93%		
	29.00								
	29.50								
	30.00		100%	HQ17		1x4.5cm 1x13.5cm 1x14cm 1x13.5cm 1x30cm 1x12.5cm 1x5.5cm 1x13.5cm 1x10cm 1x15.5cm 1x11cm 1x6.5cm	82%		
	30.50								
287.56	30.78	END OF BOREHOLE							
	31.00								
	31.50								
	32.00								
	32.50								
	33.00								
	33.50								
	34.00								
	34.50								
	35.00								
	35.50								

MARSHALL MACKLIN MONAGHAN LIMITED

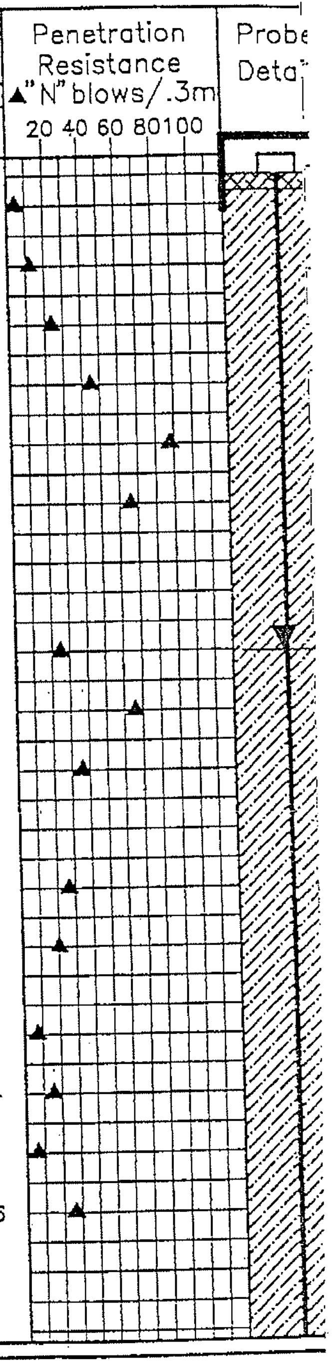
LOG OF BOREHOLE No.: 4–1 Observation Well 9

Project Number : 14–91008–103
Project Description : HANLON CREEK
Location : CLAIR ROAD
Installation Date(s) : November 08, 1991
Field Inspector : S. Mo

Prepared by : S. Mo
Checked by : A. Zilans
Rig Type : CME 75 TRACK MOUNTED
Drilling Equipment : SEE ATTACHED DRILLING METHODOLOGY FOR DETAILS
Piezometer Size : 2" I.D. PVC PIPE

Elev. m	Depth m	Soil Description	% Rec.	Type	Lab. Sa.	K cm/s No.&size of core pieces	"N" RQD
333.67	0.00	Organic rich dark brown TOPSOIL	58%	SS1			6
333.06	0.61	SAND, trace gravel, orange brown, generally massive (Fill)	58%	SS2			11
			75%	SS3			22
			87%	SS4			47
331.24	2.43	GRAVEL, COBBLES and BOULDERS, poorly sorted, some sand	100%	SS5			87
			21%	SS6			67
			66%	SS7			34
			83%	SS8			66
327.68	5.99	Fine to medium SAND, moderately sorted, generally non–stratified, wet; coarsening upward	75%	SS9			37
			100%	SS10	3	10^{-2}	
			100%	SS11			28
326.16	7.51	SILT with some fine sand and trace clay, well sorted, weakly stratified; gradational lower contact with till–like sediment and gradational upper contact with gravelly coarse sand	100%	SS12	2	10^{-4}	20
325.60	8.07	SAND with trace silt, few granule and gravel clasts (Till–like)	50%	SS13			
325.14	8.53	SILTY SAND, with some gravel; non–sorted, non–stratified (Till)	100%	SS14			7
324.53	9.14	SANDY SILT with trace clay and gravel; some cobble clasts; non–sorted, non–stratified (Till)	25%	SS15			14
			75%	SS16			7
			70%	SS17	1	10^{-5}	26

Depth scale (m): 0.00, 0.61, 1.00, 1.50, 2.00, 2.43, 3.00, 3.50, 4.00, 4.50, 5.00, 5.50, 5.99, 6.50, 7.00, 7.51, 8.07, 8.53, 9.14, 9.50, 10.00, 10.50, 11.00



NOTES:

1. LOG OF BOREHOLE No. 4–1 CONTINUED ON FOLLOWING PAGE
2. WATER LEVEL ELEVATION 328.783m MEASURED ON FEBRUARY 06, 1992

MARSHALL MACKLIN MONAGHAN LIMITED
LOG OF BOREHOLE No.: 4-1

Project Number : 14-91008-I03
Project Description : HANLON CREEK
Location : CLAIR ROAD
Installation Date(s) : November 08, 1991
Field Inspector : S. Mo

Prepared by : S. Mo
Checked by : A. Zilans
Rig Type : CME 75 TRACK MOUNTED
Drilling Equipment : SEE ATTACHED DRILLING METHODOLOGY FOR DETAILS
Piezometer Size : 2" I.D. PVC PIPE

Elev. m	Depth m	Soil Description	Strata Plot	Samples % Rec.	Samples Type	Samples Lab. Sa.	K cm/s / No.&size of core pieces	"N" / RQD	Penetration Resistance ▲"N" blows/.3m 20 40 60 80 100	Probe Detail
	12.50									
	13.00									
	13.50									
	14.00									
	14.50									
	15.00									
	15.50									
	16.00									
	16.50									
	17.00			98%	HQ1		1x12cm 1x1.3cm 1x6cm 1x5.5cm 1x5cm 1x6cm 1x3cm 1x2.5cm 1x38cm 1x22.5cm 1x18.5cm 1x18.5cm 1x17cm	83%		
316.25	17.42	DOLOSTONE – Grey white, moderately abundant vugs with calcite crystals, few fossils; mud content increasing downward								
	18.00									
	18.50			99%	HQ2		1x18.5cm 1x10.5cm 1x2.5cm 1x12.5cm 1x2.5cm 1x9cm 1x2.5cm 1x12.5cm 1x5cm 1x61.5cm 1x16.5cm	86%		
	19.00									
	19.50									
	20.00			99%	HQ3		1x39.5cm 1x31cm 1x25cm 1x33cm 1x1cm 1x16cm 1x6cm	95%		
	20.50									
	21.00									
	21.50			98%	HQ4		1x6.5cm 1x11cm 1x6cm 1x20cm 3x1cm 1x10cm 1x19.5cm 1x1cm 1x23.5cm 1x7cm 1x3cm 1x20cm 1x8cm	95%		
	22.00									
	23.50									
	23.00			98%	HQ5		1x22.5cm 1x63cm 1x47.5cm 1x11cm 1x6cm	95%		
	23.50									

NOTES:

1. LOG OF BOREHOLE No. 4-1 CONTINUED ON FOLLOWING PAGE

MARSHALL MACKLIN MONAGHAN LIMITED
LOG OF BOREHOLE No.: 4-1

Project Number : 14-91008-103
Project Description : HANLON CREEK
Location : CLAIR ROAD
Installation Date(s) : November 08, 1991
Field Inspector : S. Mo

Prepared by : S. Mo
Checked by : A. Zilans
Rig Type : CME 75 TRACK MOUNTED
Drilling Equipment : SEE ATTACHED DRILLING METHODOLOGY FOR DETAILS
Piezometer Size : 2"I.D. PVC PIPE

Elev. m	Depth m	Soil Description	Samples % Rec.	Samples Type	Samples Lab. Sa.	K cm/s No.&size of core pieces	"N" RQD
	24.50						
	25.00						
	25.50		98%	HQ6		1x42.5cm 1x27.5cm 1x77cm	98%
	26.00						
	26.50						
	27.00		99%	HQ7		1x21.5cm 1x51.5cm 1x4.5cm 1x7.5cm 1x28cm	94%
	27.50						
	28.00						
	28.50		98%	HQ8		1x11.5cm 1x5cm 1x51cm 1x30cm 1x15cm 1x5.5cm 1x29cm	89%
	29.00						
	29.50						
	30.00		100%	HQ9		1x71cm 1x1cm 1x11.5cm 1x35.5cm 1x33cm	89%
	30.50						
	31.00						
	31.50		100%	HQ10		1x18.5cm 1x101.5cm 1x32cm	100%
	32.00						
301.36	32.31						
	32.50						
	33.00		97%	HQ11		1x9cm 1x35cm 1x6cm 1x6.5cm 1x16cm 1x6.5cm 1x16cm 1x6.5cm 1x14.5cm 1x8.5cm 1x6.5cm 1x27.5cm 1x4.5cm 1x4cm	83%
	33.50	DOLOSTONE – Grey finely laminated with laminae of shale; few large (3cm) vugs with calcite crystals					
	34.00						
	34.50		98%	HQ12		1x3.5cm 1x20.5cm 1x19cm 1x15.5cm 1x24.5cm 1x25.5cm 1x24cm 1x13.5cm	95%
	35.00						
	35.50		89%	HQ13		1x12cm 1x28cm 1x7.5cm 1x15cm 1x12.5cm	71%

Strata Plot

Penetration Resistance "N" blows/.3m
20 40 60 80 100

Probe Detai

NOTES:

1. LOG OF BOREHOLE No. 4-1 CONTINUED ON FOLLOWING PAGE

MARSHALL MACKLIN MONAGHAN LIMITED
LOG OF BOREHOLE No.: 4–1

Project Number : 14–91008–103
Project Description : HANLON CREEK
Location : CLAIR ROAD
Installation Date(s) : November 08, 1991
Field Inspector : S. Mo

Prepared by : S. Mo
Checked by : A. Zilans
Rig Type : CME 75 TRACK MOUNTED
Drilling Equipment : SEE ATTACHED DRILLING METHODOLOGY FOR DETAILS
Piezometer Size : 2" I.D. PVC PIPE

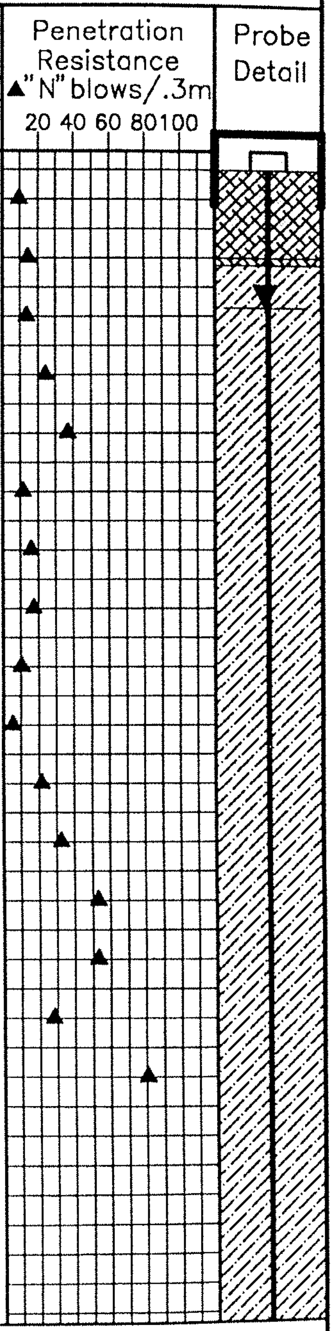
Elev. m	Depth m	Soil Description	Samples % Rec.	Samples Type	Samples Lab. Sa.	K cm/s No.&size of core pieces	"N" RQD	Penetration Resistance ▲"N" blows/.3m 20 40 60 80 100	Probe Detail
						1x22cm 1x40cm 1x7.5cm 1x7cm			
	36.50								
	37.00								
	37.50		99%	HQ14		1x31cm 1x85cm 1x2cm 1x9.5cm 1x10cm 1x11cm 1x14.5cm 1x9.5cm 1x3.5cm 1x38.5cm 1x13cm	70%		
	38.00								
	38.50								
	39.00		99%	HQ15		1x6cm 1x5cm 1x9cm 1x13.5cm 1x22.5cm 1x6.5cm 1x23.5cm 1x34cm 1x29cm	80%		
	39.50								
293.86	39.81	END OF BOREHOLE							
	40.50								
	41.00								
	41.50								
	42.00								
	42.50								
	43.00								
	43.50								
	44.00								
	44.50								
	45.00								
	45.50								
	46.00								
	46.50								
	47.00								
	47.50								

MARSHALL MACKLIN MONAGHAN LIMITED
LOG OF BOREHOLE No.: 5-1

Project Number : 14-91008-103
Project Description : HANLON CREEK
Location : CENTRAL WETLAND
Installation Date(s) : November 15, 1991
Field Inspector : S. Mo

Prepared by : S. Mo
Checked by : A. Zilans
Rig Type : CME 75 TRACK MOUNTED
Drilling Equipment : SEE ATTACHED DRILLING METHODOLOGY FOR DETAILS
Piezometer Size : 2"I.D. PVC PIPE

Elev. m	Depth m	Soil Description	Samples % Rec.	Samples Type	Samples Lab. Sa.	Samples K cm/s No.&size of core pieces	Samples "N" RQD
324.36	0.00	Organic rich sand, trace gravel, TOPSOIL	50%	SS1			10
323.75	0.61	GRAVEL and COBBLES with some sand; poorly sorted; some sand and silt mud in matrix between 1.98 to 2.13m depth					
	1.00		33%	SS2			17
	1.50		50%	SS3			14
	2.00		58%	SS4			26
	2.44	Fine to coarse SAND, some gravel and a trace of silt, moderately sorted, few cobbles, moist to wet	92%	SS5	3	10^{-2}	35
	3.00		83%	SS6			13
320.70	3.66	Well sorted fine SAND with some silt, orange brown					
	4.00		100%	SS7	2	10^{-3}	18
320.10	4.26	Moderately sorted SAND and some fine gravel, wet	75%	SS8			19
319.28	5.08	SANDY SILT some clay, trace gravel and cobble clasts, non-stratified, non-sorted; grey brown, moist (Till) 5.08 to 5.25m gradational from till to moderately sorted sand and fine gravel	92%	SS9			11
	5.50						
	6.00		83%	SS10			4
	6.50		66%	SS11			23
	7.00		75%	SS12			32
	7.50		83%	SS13			52
	8.00		100%	SS14			55
	8.50						
	9.00		96%	SS15			38
	9.50		50%	SS16	1	10^{-6}	80
	10.00						
	10.50		25%	SS17			
	11.00						
	11.50		70%	SS18			



NOTES:

1. LOG OF BOREHOLE No. 5-1 CONTINUED ON FOLLOWING PAGE
2. WATER LEVEL ELEVATION 322.969m MEASURED ON FEBRUARY 06, 1992

MARSHALL MACKLIN MONAGHAN LIMITED
LOG OF BOREHOLE No.: 5-1

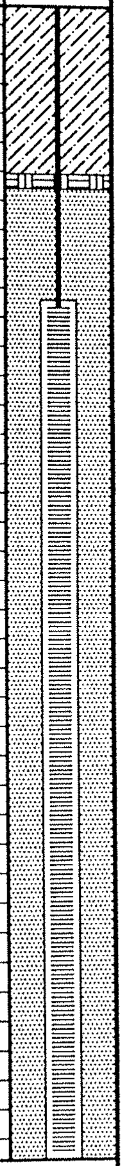
Project Number : 14-91008-103
Project Description : HANLON CREEK
Location : CENTRAL WETLAND
Installation Date(s) : November 15, 1991
Field Inspector : S. Mo

Prepared by : S. Mo
Checked by : A. Zilans
Rig Type : CME 75 TRACK MOUNTED
Drilling Equipment : SEE ATTACHED DRILLING METHODOLOGY FOR DETAILS

Piezometer Size : 2" I.D. PVC PIPE

Elev. m	Depth m	Soil Description	Samples: % Rec.	Samples: Type	Samples: Lab. Sa.	Samples: K cm/s / No.&size of core pieces	Samples: "N" / RQD	Penetration Resistance ▲"N" blows/.3m 20 40 60 80 100
	12.50							
	13.00							
	13.50							
310.47	13.89	DOLOSTONE – Grey white, abundant small (<1cm) vugs with calcite crystals; few fossils in upper part; mud content increasing at 26.1m						
	14.50		75%	HQ1		4x1cm 1x5cm 1x3cm 1x4cm 1x3.5cm 1x2.5cm 1x2cm 1x2.5cm 1x5cm 3x2cm 1x4cm 1x1cm 1x72cm	47%	
	15.00							
	15.50							
	16.00		100%	HQ2		1x10cm 1x1.5cm 1x50.5cm 1x90cm	92%	
	16.50							
	17.00							
	17.50		97%	HQ3		1x61.5cm 1x5.5cm 1x2cm 1x52cm 1x26.5cm	83%	
	18.00							
	18.50							
	19.00		99%	HQ4		1x27cm 1x20cm 1x3.5cm 1x23cm 1x12cm 1x11.5cm 1x6.5cm	95%	
	19.50							
	20.00							
	20.50		98%	HQ5		1x17.5cm 1x4.5cm 1x83.5cm 1x2cm 1x42cm	94%	
	21.00							
	21.50							
	22.00		98%	HQ6		1x27cm 1x44.5cm 1x64.5cm 1x14cm	98%	
	23.50							
	23.00							
	23.50		98%	HQ7		1x73cm 1x20cm 1x3.5cm 1x23cm 1x12cm 1x11.5cm 1x6.5cm	92%	

Probe Detail



NOTES:

1. LOG OF BOREHOLE No. 5-1 CONTINUED ON FOLLOWING PAGE

MARSHALL MACKLIN MONAGHAN LIMITED
LOG OF BOREHOLE No.: 5-1

Project Number : 14-91008-103
Project Description : HANLON CREEK
Location : CENTRAL WETLAND
Installation Date(s) : November 15, 1991
Field Inspector : S. Mo

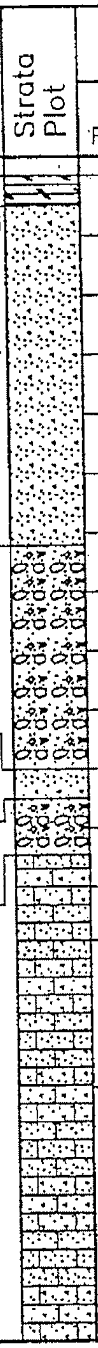
Prepared by : S. Mo
Checked by : A. Zilans
Rig Type : CME 75 TRACK MOUNTED
Drilling Equipment : SEE ATTACHED DRILLING METHODOLOGY FOR DETAILS
Piezometer Size : 2" I.D. PVC PIPE

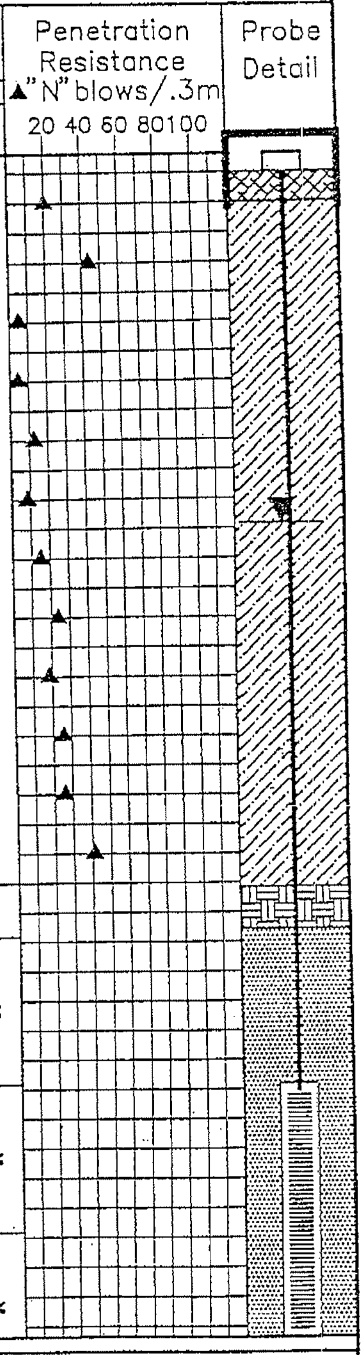
Elev. m	Depth m	Soil Description	Strata Plot	Samples					Penetration Resistance ▲"N" blows/.3m 20 40 60 80 100	Probe Detail
				% Rec.	Type	Lab. Sa.	K cm/s No.&size of core pieces	"N" RQD		
	24.50			97%	HQ8		1.7.5cm 1x31.5cm 1x28cm 1x17cm 1x3.5cm 1x5cm 1x2cm 1x21cm 1x12.5cm 1x3cm 1x16.5cm	83%		
	25.00									
	25.50									
	26.00			90%	HQ9		1x4.5cm 1x2cm 1x8cm 1x9cm 1x18cm 1x33.5cm 1x12cm 1x18cm 1x5.5cm	61%		
	26.50									
	27.00									
	27.50			98%	HQ10		1x22.5cm 1x10.5cm 1x5cm 1x20cm 1x29cm 1x6cm 1x21.5cm 1x10cm 1x25cm	84%		
	28.00									
	28.50									
295.22	29.14			98%	HQ11		1x9cm 1x18.5cm 1x29.5cm 1x8cm 1x36cm 1x23.5cm 1x15.5cm 1x10cm	81%		
	29.50									
	30.00									
	30.50	DOLOSTONE – Laminated with shaley laminae; some vugs with calcite crystals; no fossils		99%	HQ12		1x5.5cm 1x11cm 1x6cm 1x20cm 3x1cm 1x10cm 1x19.5cm 1x1cm 1x23.5cm 1x7cm 1x3cm 1x20cm 1x8cm	89%		
	31.00									
	31.50									
	32.00			90%	HQ13		1x5.5cm 1x11cm 1x6cm 1x20cm 3x1cm 1x10cm 1x19.5cm 1x1cm 1x23.5cm 1x7cm 1x3cm 1x20cm 1x8cm	61%		
	32.50									
	33.00									
290.83	33.53	END OF BOREHOLE								
	34.00									
	34.50									
	35.00									
	35.50									

MARSHALL MACKLIN MONAGHAN LIMITED
LOG OF BOREHOLE No.: 6-1 Observation Well 12

Project Number : 14-91008-103
Project Description : HANLON CREEK
Location : KORTRIGHT
Installation Date(s) : November 21, 1991
Field Inspector : S. Mo

Prepared by : S. Mo
Checked by : A. Zilans
Rig Type : CME 75 TRACK MOUNTED
Drilling Equipment : SEE ATTACHED DRILLING METHODOLOGY FOR DETAILS
Piezometer Size : 2" I.D. PVC PIPE





Elev. m	Depth m	Soil Description	% Rec.	Type	Lab. Sa.	K cm/s No.&size of core pieces	"N" RQD
323.33 323.03	0.00 0.30 0.50	Organic rich silty sand, trace gravel; TOPSOIL	50%	SS1			21
	1.00	Orange brown oxidized silty SAND with traces of clay and gravel, non-sorted, non-stratified, damp to moist	50%	SS2			44
	1.50		75%	SS3			7
	2.00		79%	SS4			5
	2.50		71%	SS5			11
	3.00		58%	SS6	▨	10^{-4}	8
319.55	3.50 3.78	GRAVEL and COBBLES, poorly sorted, with sand and silt mud, wet	92%	SS7			15
	4.00 4.50		50%	SS8			25
	5.00		75%	SS9			18
	5.50		75%	SS10			26
317.24 316.93	6.09 6.40	Fine to coarse SAND, some gravel, and a trace of silt; generally well sorted, wet	58%	SS11	▨	10^{-2}	26
316.35	6.98	GRAVEL and COBBLE, boulder size dolostone clasts; weathered dolostone bedrock, wet	46%	SS12			41
	7.50		87%	HQ1		1x45cm 1x4cm 1x22.5cm 1x2cm 1x15.5cm	68%
	8.00 8.50 9.00	DOLOSTONE – Grey white abundant vugs with calcite crystals; abundant fossils; laminae of mud begin at 24.7m	94%	HQ2		1x47cm 1x35.5cm 1x10cm 1x4.8cm 1x1.5cm 2x1cm 1x7cm 1x32cm 1x4cm	75%
	9.50 10.00 10.50		94%	HQ3		1x17cm 1x1cm 1x34cm 1x11cm 1x1cm 1x26cm 1x9.5cm 1x2.5cm 1x12cm 1x26cm 1x11.5cm	90%
	11.00 11.50		96%	HQ4		1x52.5cm 1x37cm 1x14cm 1x20cm 1x1.5cm 1x1cm 1x11cm 1x2cm	61%

NOTES:

1. LOG OF BOREHOLE No. 6-1 CONTINUED ON FOLLOWING PAGE
2. WATER LEVEL ELEVATION 319.720m MEASURED ON FEBRUARY 06, 1992

MARSHALL MACKLIN MONAGHAN LIMITED
LOG OF BOREHOLE No.: 6–1

Project Number : 14–91008–103
Project Description : HANLON CREEK
Location : KORTRIGHT
Installation Date(s) : November 21, 1991
Field Inspector : S. Mo

Prepared by : S. Mo
Checked by : A. Zilans
Rig Type : CME 75 TRACK MOUNTED
Drilling Equipment : SEE ATTACHED DRILLING METHODOLOGY FOR DETAILS
Piezometer Size : 2" I.D. PVC PIPE

Elev. m	Depth m	Soil Description	Strata Plot	Samples % Rec.	Samples Type	Samples Lab. Sa.	K cm/s No.&size of core pieces	"N" RQD	Penetration Resistance ▲"N" blows/.3m 20 40 60 80100	Probe Detail
							1x10cm 1x7cm			
	12.50									
	13.00			96%	HQ5		1x5cm 1x37cm 1x14cm 1x20cm 1x1.5cm 1x1cm 1x11cm 1x2cm 1x7.5cm 1x1cm 1x2cm 1x44cm	83%		
	13.50									
	14.00									
	14.50			94%	HQ6		1x2.5cm 1x25.5cm 1x12cm 1x32cm 1x31.5cm 1x1cm 1x3cm 1x11.5cm 1x13cm 1x10cm 1x1cm	82%		
	15.00									
	15.50									
	16.00			97%	HQ7		1x38.5cm 1x7.5cm 1x3.3cm 1x12.5cm 1x30.5cm 1x1cm 1x1.5cm 1x10cm 1x25.5cm 1x7cm 1x1.5cm 1x7cm 1x2cm	70%		
	16.50									
	17.00									
	17.50			90%	HQ8		1x29.5cm 1x2.5cm 1x49cm 1x21cm 1x29cm 1x16cm 1x9.5cm	81%		
	18.00									
	18.50									
	19.00			93%	HQ9		1x5cm 1x24cm 1x6cm 1x5.5cm 1x17cm 1x13.5cm 1x19cm 1x9cm 1x10cm 1x9cm 1x4.5cm 1x18.5cm	80%		
	19.50									
	20.00									
	20.50			91%	HQ10		1x23cm 1x57cm 1x50.5cm 1x7.5cm	97%		
	21.00									
	21.50									
	22.00			99%	HQ11		1x43.5cm 1x20cm 1x44cm 1x1.5cm 1x36cm 1x5cm	97%		
	23.50									
	23.00									
	23.50						1x43.5cm 1x20cm 1x44cm 1x1.5cm 1x36cm 1x5cm			
				90%	HQ12			94%		

NOTES:

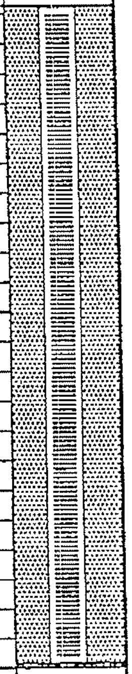
1. LOG OF BOREHOLE No. 6–1 CONTINUED ON FOLLOWING PAGE

MARSHALL MACKLIN MONAGHAN LIMITED
LOG OF BOREHOLE No.: 6-1

Project Number : 14-91008-103
Project Description : HANLON CREEK
Location : KORTRIGHT
Installation Date(s) : November 21, 1991
Field Inspector : S. Mo

Prepared by : S. Mo
Checked by : A. Zilans
Rig Type : CME 75 TRACK MOUNTED
Drilling Equipment : SEE ATTACHED DRILLING METHODOLOGY FOR DETAILS
Piezometer Size : 2" I.D. PVC PIPE

Elev. m	Depth m	Soil Description	Strata Plot	Samples % Rec.	Samples Type	Samples Lab. Sa.	K cm/s No.&size of core pieces	"N" RQD	Penetration Resistance ▲"N" blows/.3m 20 40 60 80 100	Probe Detail
	24.50		▨							
	25.00		▨							
	25.50		▨	99%	HQ13		1x24cm 1x37cm 1x30cm 1x4.5cm 1x26cm 1x10.5cm 1x13cm 1x5.5cm	92%		
	26.00		▨							
	26.50		▨							
	27.00		▨	97%	HQ14		1x25.5cm 1x30.5cm 1x33cm 1x6.5cm 1x16.5cm 1x32.5cm 1x2.5cm	83%		
	27.50		▨							
295.63	27.70		▨							
	28.00	DOLOSTONE – Grey, laminated with shaley laminae; vugs with calcite crystals	▨							
	28.50		▨	98%	HQ15		1x27.5cm 1x17cm 1x28.5cm 1x26cm 1x9.5cm 1x40.5cm 1x1cm 1x1cm	92%		
	29.00		▨							
	29.50		▨							
	30.00		▨	99%	HQ16		1x28.5cm 1x17cm 1x28.5cm 1x26cm 1x9.5cm 1x40.5cm	92%		
	30.50		▨							
292.55	30.78	END OF BOREHOLE								
	31.00									
	31.50									
	32.00									
	32.50									
	33.00									
	33.50									
	34.00									
	34.50									
	35.00									
	35.50									



MARSHALL MACKLIN MONAGHAN LIMITED
LOG OF BOREHOLE No.: 8–1

MW8–1/91(MMM)

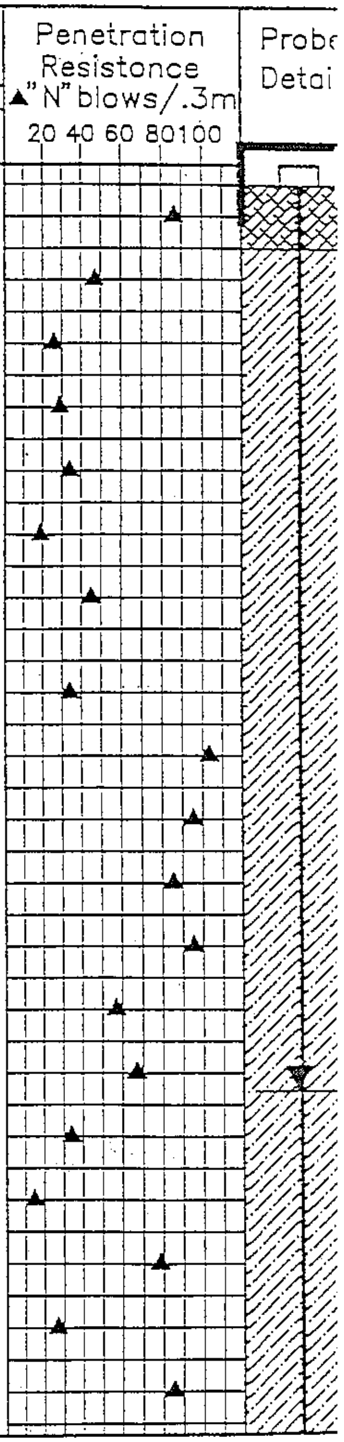
Project Number : 14–91008–103
Project Description : HANLON CREEK
Location : VICTORIA AND CLAIR
Installation Date(s) : December 24, 1991
Field Inspector : S. Mo

Prepared by : S. Mo
Checked by : A. Zilans
Rig Type : CME 75 TRACK MOUNTED
Drilling Equipment : SEE ATTACHED DRILLING METHODOLOGY FOR DETAILS
Piezometer Size : 2" I.D. PVC PIPE

Elev. m	Depth m	Soil Description
340.27	0.00	Organic rich sand and gravel TOPSOIL
339.61	0.61	GRAVEL and COBBLES, some sand, poorly sorted
	1.00	
	1.50	
	2.00	
	2.50	
	3.00	
	3.50	
	4.00	
	4.50	
	5.00	
	5.50	
	6.00	
	6.50	
	7.00	
	7.50	
	8.00	
332.04	8.23	GRAVELLY SAND with trace of silt, poorly sorted, occasional cobble size clasts, wet
	8.50	
	9.00	
330.97	9.30	Fine SAND with some silt, well sorted, orange beige brown, non–stratified, non–sorted, wet; some fine gravel with sand from 10 to 10.36m depth
	9.50	
	10.00	
329.60	10.67	SILT, trace of sand and clay, massive, moderately well sorted, gradational with overlying sand
	11.00	
	11.50	

Samples

% Rec.	Type	Lab. Sa.	K cm/s No.&size of core pieces	"N" ROD
16%	SS1			89
75%	SS2			48
46%	SS3			24
75%	SS4			26
50%	SS5			34
75%	SS6			20
71%	SS7			44
83%	SS8			35
100%	SS9			102
83%	SS10			94
71%	SS11			83
100%	SS12			94
83%	SS13			59
71%	SS14			68
75%	SS15	▨	10^{-2}	36
66%	SS16			18
100%	SS17	▨	10^{-3}	77
25%	SS18			25
63%	SS19			86



NOTES:

1. LOG OF BOREHOLE No. 8–1 CONTINUED ON FOLLOWING PAGE
2. WATER LEVEL ELEVATION 331.650m MEASURED ON FEBRUARY 06, 1992

MARSHALL MACKLIN MONAGHAN LIMITED
LOG OF BOREHOLE No.: 8-1

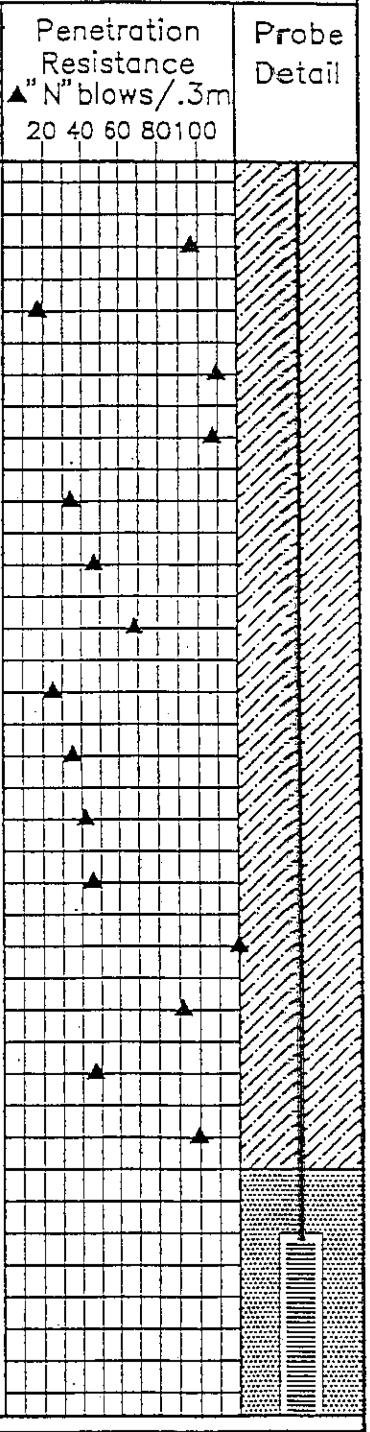
roject Number	: 14-91008-103	Prepared by	: S. Mo
r ect Description	: HANLON CREEK	Checked by	: A. Zilans
ocation	: VICTORIA AND CLAIR	Rig Type	: CME 75 TRACK MOUNTED
nstallation Date(s)	: December 24, 1991	Drilling Equipment	: SEE ATTACHED DRILLING METHODOLOGY FOR DETAILS
ie Inspector	: S. Mo		
		Piezometer Size	: 2" I.D. PVC PIPE

lev. m	Depth m	Soil Description
	12.50 13.00	
7.	13.21 13.50 14.00 14.50 15.00 15.50 16.00 16.50	Silty fine SAND, moderately to well sorted, gradational with overlying silt
3.51	16.76 17.00 17.50	SAND, fine, with some silt, well sorted, orange brown
2.	17.98 18.50 19.00 19.50 20.00 20.50 21.00	SILTY SAND, abundant gravel and cobble size clasts; non-sorted, non-stratified (Till) From 17.98m to 19.53m looser till with more water-deposited appearance to sediment Compact till between 19.81m to 20.39m;
	21.64 22.00 23.50 23.00 23.50	DOLOSTONE – Grey white, massive, few vugs, no fossils; mud content increases and becomes dark grey at 26.93m

Samples				
% Rec.	Type	Lab. Sa.	K cm/s / No.&size of core pieces	"N" / RQD
62%	SS20	3	10^{-5}	97
42%	SS21			18
58%	SS22			110
100%	SS23			107
87%	SS24	2	10^{-3}	33
100%	SS25			49
75%	SS26			69
100%	SS27			26
75%	SS28			38
54%	SS29			42
54%	SS30			46
54%	SS31			>120
96%	SS32	▨	10^{-4}	92
75%	SS33			49
8%	SS34			100

Penetration Resistance ▲"N" blows/.3m

Probe Detail



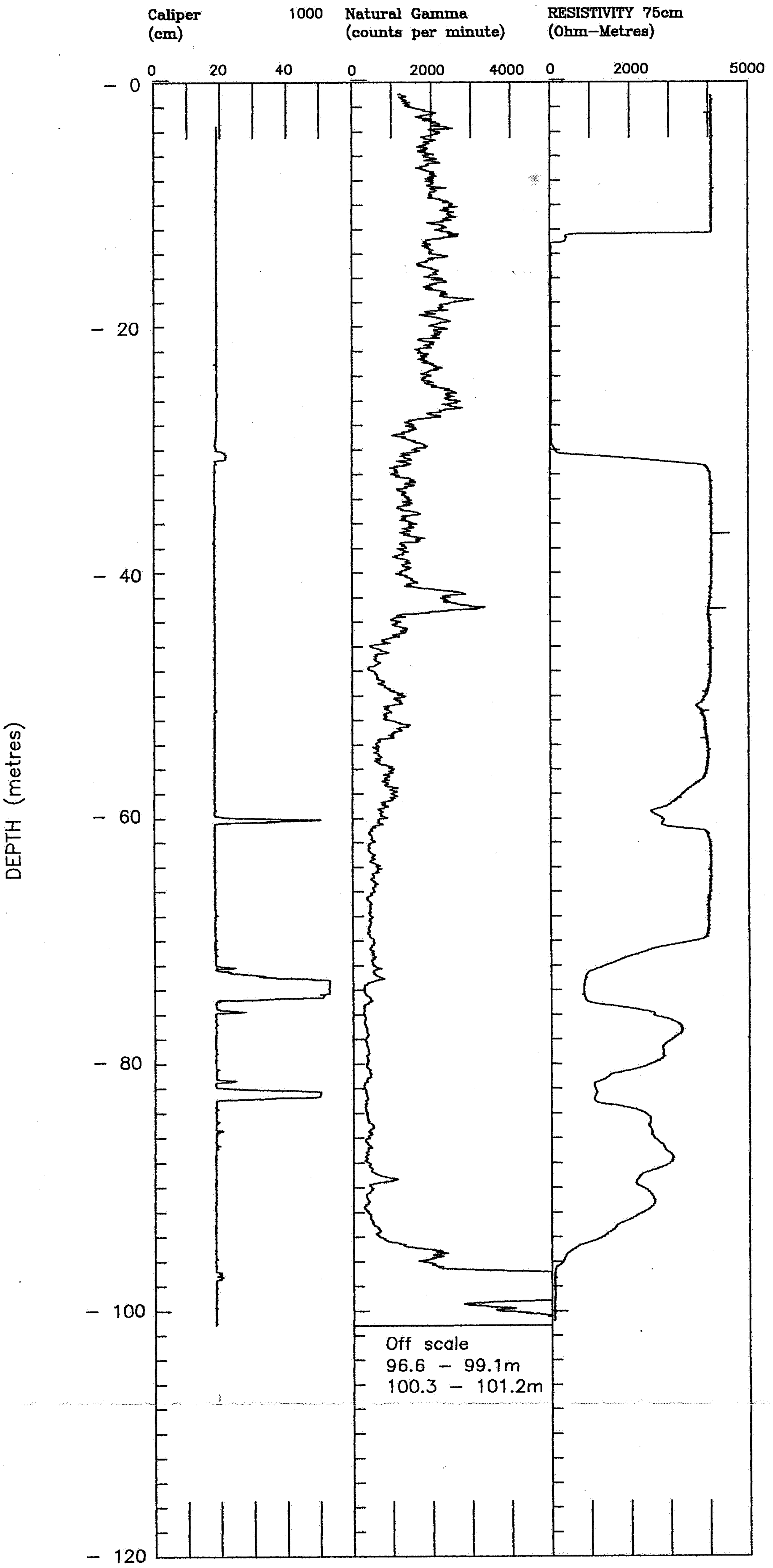
NOTES:

1. LOG OF BOREHOLE No. 8-1 CONTINUED ON FOLLOWING PAGE

MARSHALL MACKLIN MONAGHAN LIMITED
LOG OF BOREHOLE No.: 8-1

Project Number	: 14-91008-103	Prepared by	: S. Mo
Project Description	: HANLON CREEK	Checked by	: A. Zilans
Location	: VICTORIA AND CLAIR	Rig Type	: CME 75 TRACK MOUNTED
Installation Date(s)	: December 24, 1991	Drilling Equipment	: SEE ATTACHED DRILLING METHODOLOGY FOR DETAILS
Field Inspector	: S. Mo		
		Piezometer Size	: 2" I.D. PVC PIPE

Elev. m	Depth m	Soil Description	Strata Plot	Samples % Rec.	Samples Type	Samples Lab. Sa.	Samples K cm/s No.&size of core pieces	Samples "N" RQD	Penetration Resistance ▲"N" blows/.3m 20 40 60 80 100	Probe Detail
	24.50									
	25.00			90%	HQ1		1x75cm 1x6cm 1x13.5cm 2x2cm 1x6cm 1x10cm 1x1cm 1x8cm 1x9.5cm 1x34cm 1x17.5cm	81%		
	25.50									
	26.00									
	26.50			90%	HQ2		1x18cm 1x3cm 1x1cm 1x2cm 1x40cm 1x39cm 1x3cm 1x43cm 1x9.5cm	81%		
	27.00									
	27.50									
	28.00			90%	HQ3		1x19cm 1x18.5cm 1x8cm 1x12cm 1x3.5cm 1x19.5cm 1x10cm 1x19cm 1x12.5cm 1x24cm	81%		
	28.50									
311.30	28.97									
	29.50			90%	HQ4		1x25cm 1x15cm 1x4cm 1x6cm 1x33.5cm 1x17cm 1x3cm 1x14cm 1x25cm 1x6cm	61%		
	30.00	DOLOSTONE – Laminated, with shaley laminae, moderate number of vugs (1–3cm) with calcite crystals								
	30.50									
	31.00			90%	HQ5		1x4.5cm 1x11cm 1x6cm 1x20cm 2x1cm 1x10cm 1x19.5cm 1x1cm 1x23.5cm 1x7cm 1x3cm 1x20cm 1x8cm	61%		
	31.50									
	32.00									
	32.50			90%	HQ6		1x15.5cm 1x23.5cm 1x3.5cm 1x12.5cm 1x10.5cm 1x19cm 1x4cm 1x11.5cm 1x13.5cm 1x14.5cm 1x5.5cm 1x9cm 1x3.5cm	61%		
	33.00									
	33.50									
	34.00			90%	HQ7		1x8cm 1x1.5cm 1x4cm 1x5.5cm 1x2cm 1x6cm 1x9cm 2x2cm 1x6.5cm 1x8cm 1x11cm 1x2.5cm 1x3cm 1x3.5cm	81%		
	34.50									
305.22	35.05	END OF BOREHOLE								
	35.50									



Note: Logging completed before installation of liner.

CITY OF GUELPH

ADMIRAL WELL AT SLEEMAN BREWERY

Bedrock Geophysical Logs

Lotowater LTD.
Reference: 033–011

FIGURE 2
99/03/09

Ministry of Environment and Energy
Ontario 98-63-164

The Ontario Water Resources Act
WATER WELL RECORD

Print only in spaces provided.
Mark correct box with a checkmark, where applicable.

ADMIRAL WELL

County or District WELLINGTON	Township/Borough/City/Town/Village CITY OF GUELPH	Con block tract survey, etc.	Lot
Owner's surname CITY OF GUELPH First name	Address CITY HALL 59 CARDEN ST GUELPH ONT	Date completed 24 day 11 month 98 year	

LOG OF OVERBURDEN AND BEDROCK MATERIALS (see instructions)

General colour	Most common material	Other materials	General description	Depth – feet From	To
BROWN	GRAVEL	SAND, ROCKS		0	22
BROWN	GRAVEL		FINE	22	45
BROWN	GRAVEL		COURSE	45	49
GREY	GRAVEL	CLAY		49	90
DARK BROWN	LIMESTONE			90	137
LIGHT & DARK GREY	LIMESTONE			137	143
GREY & BROWN	LIMESTONE			143	155
LIGHT & DARK GREY	LIMESTONE			155	168
DARK GREY	LIMESTONE			168	196
LIGHT & DARK GREY	LIMESTONE			196	317
RED & GREEN	SHALE		LAYERED	317	334

WATER RECORD

Water found at – feet	Kind of water	
TEST BY	☐ Fresh ☐ Salty	☐ Sulphur ☐ Minerals ☐ Gas
OTHERS	☐ Fresh ☐ Salty	☐ Sulphur ☐ Minerals ☐ Gas
	☐ Fresh ☐ Salty	☐ Sulphur ☐ Minerals ☐ Gas
	☐ Fresh ☐ Salty	☐ Sulphur ☐ Minerals ☐ Gas
	☐ Fresh ☐ Salty	☐ Sulphur ☐ Minerals ☐ Gas

CASING & OPEN HOLE RECORD

Inside diam inches	Material	Wall thickness inches	Depth – feet From	To
8.125	☑ Steel ☐ Galvanized ☐ Concrete ☐ Open hole ☐ Plastic	.250	+2'	98'
7.875	☐ Steel ☐ Galvanized ☐ Concrete ☑ Open hole ☐ Plastic		98'	334'
	☐ Steel ☐ Galvanized ☐ Concrete ☐ Open hole ☐ Plastic			

SCREEN

Sizes of opening (Slot No.)	Diameter inches	Length feet
Material and type	Depth at top of screen feet	

PLUGGING & SEALING RECORD

☑ Annular space ☐ Abandonment

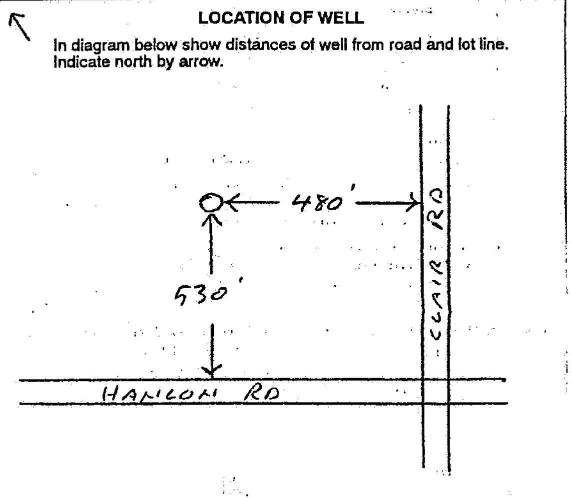
Depth set at – feet From	To	Material and type (Cement grout, bentonite, etc.)
0	98'	CEMENT GROUT

PUMPING TEST

Pumping test method ☐ Pump TIME ☒ Bailer 16	Pumping rate BY OT GPM	Duration of pumping R..S. Hours .... Mins		
Static level 52' 6" feet	Water level end of pumping feet	Water levels during ☐ Pumping ☐ Recovery 15 minutes feet	30 minutes feet	45 minutes feet / 60 minutes feet
If flowing give rate GPM	Pump intake set at feet	Water at end of test ☐ Clear ☐ Cloudy		
Recommended pump type ☐ Shallow ☐ Deep	Recommended pump setting feet	Recommended pump rate GPM		

LOCATION OF WELL

In diagram below show distances of well from road and lot line. Indicate north by arrow.



199088

FINAL STATUS OF WELL

- ☑ Water supply
- ☐ Observation well
- ☐ Test hole
- ☒ Recharge well
- ☐ Abandoned, insufficient supply
- ☐ Abandoned, poor quality
- ☐ Abandoned (Other)
- ☐ Dewatering
- ☐ Unfinished
- ☐ Replacement well

WATER USE

- ☐ Domestic
- ☐ Stock
- ☐ Irrigation
- ☐ Industrial
- ☑ Commercial
- ☐ Municipal
- ☐ Public supply
- ☐ Cooling & air conditioning
- ☐ Not used
- ☐ Other ....

METHOD OF CONSTRUCTION

- ☐ Cable tool
- ☑ Rotary (conventional)
- ☐ Rotary (reverse)
- ☐ Rotary (air)
- ☐ Air percussion
- ☐ Boring
- ☐ Diamond
- ☐ Jetting
- ☐ Driving
- ☐ Digging
- ☐ Other ....

Name of Well Contractor MEADOWBANK DRILLING SERVICES	Well Contractor's Licence No. 6865
Address BOX 416 ELORA ONT N0B 1S0	
Name of Well Technician JIM BROADFOOT	Well Technician's Licence No. T 0 3 70
Signature of Technician/Contractor Jim Broadfoot	Submission date day mo yr

MINISTRY USE ONLY

0506 (07/94) Front Form 9

PROJECT: 0508

GD1

Page 1 OF 3

LOCATION: Guelph Dolime Quarry

BORING DATE: May 9, 2005 DATUM: 295.328 m AMSL DIP: 90 LOGGED: SD / AW

DEPTH SCALE — METRES: 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15

FEET: 0, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30, 32, 34, 36, 38, 40, 42, 44, 46, 48, 50

BORING METHOD: HQ CORE

SOIL PROFILE

DESCRIPTION	DEPTH B.G.S. (m)
285.328 m AMSL	
DOLOSTONE, (Guelph Formation), tan/light grey, vuggy, some vugs lined with calcite crystals.	0.00
DOLOSTONE, (Upper Transition Zone), grey, stylolites with 4 to 20 cm separation, colour darkens with depth, large open vugs, possible void at 1.5 metres and loss of return water at 1.5 metres, crinoid stem fossils common, core breaks occur at stylolites or vugs.	0.914
DOLOSTONE, (Eramosa Member), black, layered, layers are 5 to 10 centimeters thick, horizontal bedding, numerous thinly separated, stylolites, fine grained. - 50 centimeter layer of fossils,some pyrite mineralization. - sulphurous odour - large calcite filled vug - stylolite banding 5 to 8 centimeter wide -some crinoid stem fossils	7.77

Continued on next page

SAMPLES

ID	TYPE	RECOVERY (%)	RQD
Run1	Core	85	67
Run2	Core	100	81
Run3	Core	100	73
Run4	Core	88	68
Run5	Core	100	77
Run6	Core	100	92
Run7	Core	98	95
Run8	Core	100	94
Run9	Core	100	100
Rn10	Core	100	100

CONCENTRATION (%)

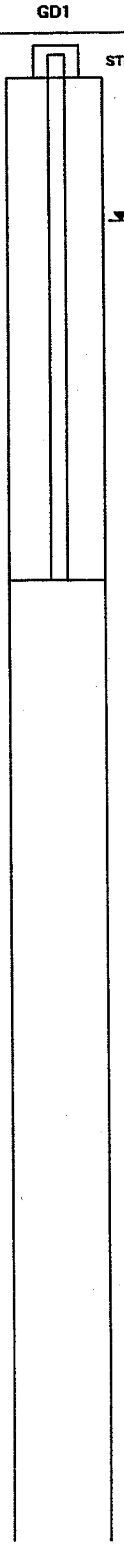
LEL ◆

MOISTURE CONTENT ●

GAS CONCENTRATION ■

0 20 40 60 80 100

INSTALLATION INFORMATION



STICKUP 0m to 1.98m

▼ 1.46m, May 20, 2005

Note: No final installation. 15 cm casing installed to 5.5 metres. Remainder is open hole. Depending on conditions, well may be flowing artesian.

DRAWN: AW Harden Env. CHECKED: SD

PROJECT: 0508

GD1

LOCATION: Guelph Dolime Quarry

BORING DATE: May 9, 2005 **DATUM:** 295.328 m AMSL **DIP:** 90 **LOGGED:** SD / AW

BORING METHOD: HQ CORE

CONCENTRATION (%): LEL ◆ MOISTURE CONTENT ● GAS CONCENTRATION ■ (0 20 40 60 80 100)

INSTALLATION INFORMATION: GD1

DEPTH SCALE METRES	DESCRIPTION	DEPTH B.G.S. (m)
15–17.83	DOLOSTONE, (Eramosa Member), black, layered, layers are 5 to 10 centimeters thick, horizontal bedding, numerous thinly separated, stylolites, fine grained. - vuggy	
17.83–19.81	DOLOSTONE, (Lower Transition Zone), grey, alternating grey and brown rock. Grey rock is medium to coarse grained whereas brown rock is finer. 15 cm silt-filled opening in rock.	17.83
19.81–30	DOLOSTONE, (Un-subdivided Amabel Formation), blue/grey alternating to white, heavily fossilized, varies from coarse to fine grained, vuggy.	19.81

ID	TYPE	RECOVERY (%)	RQD
Rn10	Core	100	100
Rn11	Core	97	67
Rn12	Core	95	100
Rn13	Core	100	80
Rn14	Core	100	92
Rn15	Core	100	100
Rn16	Core	100	100
Rn17	Core	100	100
Rn18	Core	100	100
Rn19	Core	97	93
Rn20	Core	100	100

Continued on next page

PROJECT: 0508

GD1

Page 3 OF 3

LOCATION: Guelph Dolime Quarry

BORING DATE: May 9, 2005 DATUM: 295.328 m AMSL DIP: 90 LOGGED: SD / AW

DEPTH SCALE METRES	DEPTH SCALE FEET	BORING METHOD	SOIL PROFILE DESCRIPTION	STRATA PLOT	DEPTH B.G.S. (m)	SAMPLES ID	TYPE	RECOVERY (%)	RQD	CONCENTRATION (%) LEL ◆ MOISTURE CONTENT ● GAS CONCENTRATION ■ 0 20 40 60 80 100	INSTALLATION INFORMATION GD1
30	100	HQ CORE	DOLOSTONE, (Un-subdivided Amabel Formation), blue/grey alternating to white, heavily fossilized, varies from coarse to fine grained, vuggy.	▨		Rn20	Core	100	100		
31	102			▨		Rn21	Core	97	91		
	104										
32	106		END OF HOLE @ 32.00m		32.00						END OF HOLE
33	108										
	110										
34	112										
	114										
35	116										
36	118										
	120										
37	122										
	124										
38	126										
39	128										
	130										
40	132										
	134										
41	136										
42	138										
	140										
43	142										
	144										
44	146										
45	148										

DRAWN: AW

Harden Env.

CHECKED: SD

PROJECT: 0508

GD2

LOCATION: Guelph

BORING DATE: May 11, 2005 **DATUM:** GROUND SURFACE **DIP:** 90 **LOGGED:** SD / AW

BORING METHOD: HQ CORE

DEPTH B.G.S. (m)	SOIL PROFILE – DESCRIPTION
	297.18 m AMSL
0	DOLOSTONE, (Guelph Formation), tan/light grey, vuggy, some vugs lined with calcite crystals. Minor stylolites, core breaks occur at stylolites or vugs. Vertical fractures occur between 1.5 m and 3 m. No major fossilized zones although large (2 cm) brachiopod impression at 3 metres. Some sphalerite infilling of vugs.
4.57	DOLOSTONE, (Upper Transition Zone), grey, stylolites with 4 to 20 cm separation, colour darkens with depth, large open vugs, crinoid stem fossils common, core breaks occur at stylolites or vugs.
7.62	DOLOSTONE, (Eramosa Member), black, layered, layers are 5 to 10 centimeters thick, horizontal bedding, numerous thinly separated, stylolites, fine grained. Some angled bedding. Bituminous, large coral fossil at 8.5 metres. Generally fossiliferous throughout and few vugs. Silt filled fracture at 11.8 metres. Vertical fracture containing calcite and sphalerite crystals

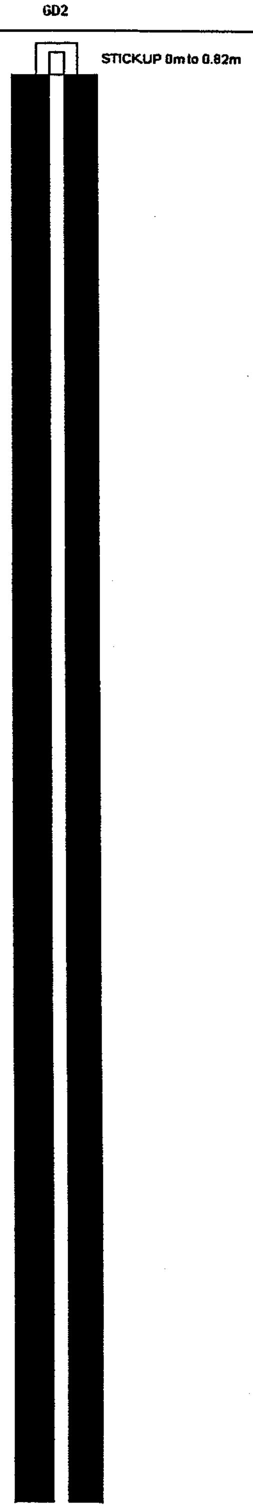
ID	TYPE	RECOVERY (%)	RQD
Run1	Core	95	67
Run2	Core	100	33
Run3	Core	98	53
Run4	Core	98	88
Run5	Core	100	77
Run6	Core	100	100
Run7	Core	100	93
Run8	Core	100	82
Run9	Core	100	95
Rn10	Core	100	100

CONCENTRATION (%)

LEL ◆
MOISTURE CONTENT ●
GAS CONCENTRATION ■

0 20 40 60 80 100

INSTALLATION INFORMATION



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Harden Env.

CHECKED: SD

PROJECT: 0588

LOCATION: Guelph

BORING DATE: May 11, 2005 **DATUM:** GROUND SURFACE **DIP:** 90 **LOGGED:** SD / AW

GD2

Page 2 OF 2

DEPTH SCALE: METRES 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30; FEET 50, 52, 54, 56, 58, 60, 62, 64, 66, 68, 70, 72, 74, 76, 78, 80, 82, 84, 86, 88, 90, 92, 94, 96, 98

BORING METHOD: HQ CORE

SOIL PROFILE: DESCRIPTION	DEPTH B.G.S. (m)	SAMPLES: ID	TYPE	RECOVERY (%)	RQD
DOLOSTONE, (Eramosa Member), black, layered, layers are 5 to 10 centimeters thick, horizontal bedding, numerous thinly separated stylolites, fine grained. Some angled bedding. Bituminous, Generally fossiliferous throughout and some vugs.		Rn10 Rn11	Core Core	100 100	100 100
DOLOSTONE, (Lower Transition Zone), alternating brown and blue grey, fossiliferous, vuggy, Silt-filled fracture at 20.5 metres, Silt is sulphurous.	17.00	Rn12 Rn13	Core Core	100 100	100 100
DOLOSTONE, (Un-subdivided Amabel Formation), blue/grey alternating to white, heavily fossilized, varies from coarse to fine grained, vuggy.	19.96	Rn14 Rn15	Core Core	100 100	94 97
END OF HOLE @ 22.86m	22.86				

CONCENTRATION (%)

LEL ◆

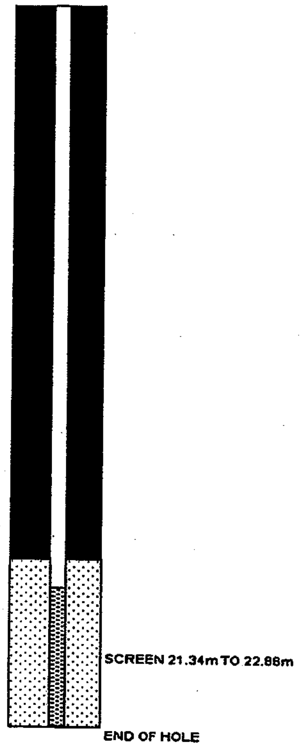
MOISTURE CONTENT ●

GAS CONCENTRATION ■

0 20 40 60 80 100

INSTALLATION INFORMATION

GD2



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Harden Env.

CHECKED: SD

GD3

PROJECT: 0588

LOCATION: Guelph Dolime Quarry

BORING DATE: May 12, 2005 **DATUM:** GROUND SURFACE **DIP:** 90 **LOGGED:** SD / AW

Page 1 OF 5

DEPTH SCALE — METRES: 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15

DEPTH SCALE — FEET: 0, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30, 32, 34, 36, 38, 40, 42, 44, 46, 48, 50

BORING METHOD: HQ CORE

CONCENTRATION (%): LEL ◆ MOISTURE CONTENT ● GAS CONCENTRATION ■ (0, 20, 40, 60, 80, 100)

SOIL PROFILE — DESCRIPTION	DEPTH B.G.S. (m)	SAMPLES — ID	TYPE	RECOVERY (%)	RQD
302.293					
FILL, sand and gravel	0.00				
DOLOSTONE, (Guelph Formation), tan/light grey, vuggy, some vugs lined with calcite crystals, minor stylolites.	1.37	Run1	Core	88	53
DOLOSTONE, (Upper Transition Zone), grey, stylolites with 4 to 20 cm separation, colour darkens with depth, large open vugs. Some vugs calcite lined.	2.73	Run2	Core	100	63
Fossiliferous, numerous crinoid stems.		Run3	Core	100	60
2 mm fracture filled with silt at 7.6 m.		Run4	Core	100	63
Becoming bituminous below 9.14 m, iron staining at 9.19 m.		Run5	Core	100	55
DOLOSTONE, (Eramosa Member), black, bituminous, some iron staining, argillaceous, finely spaced stylolites, thinly bedded, bedding at 70 ° from horizontal.	9.45	Run6	Core	100	55
		Run7	Core	100	82
		Run8	Core	98	85
25 mm fracture filled with silt at 14.3 m		Run9	Core	93	54
		Rn10	Core	100	75

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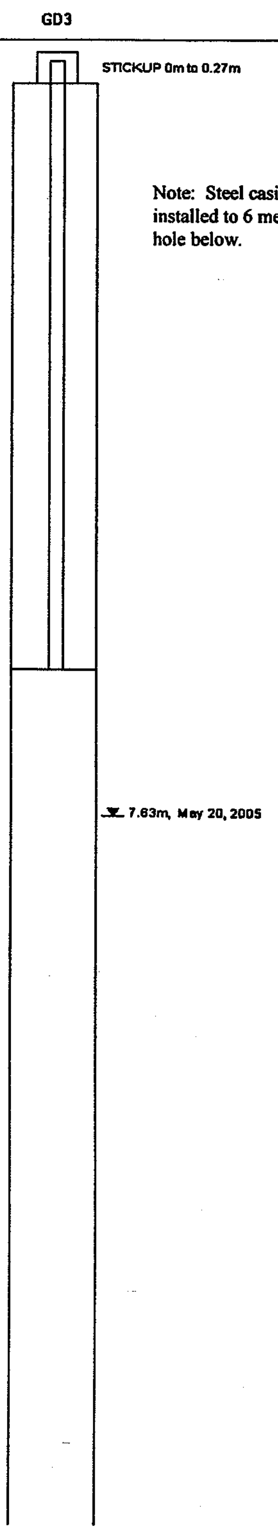
INSTALLATION INFORMATION



Note: Steel casing installed to 6 metres. Open hole below.

DRAWN: AW

Harden Env.

CHECKED: SD

PROJECT: 0508

GD3

LOCATION: Guelph Dolime Quarry

BORING DATE: May 12, 2005 **DATUM:** GROUND SURFACE **DIP:** 90 **LOGGED:** SD / AW

DEPTH SCALE — METRES: 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30

FEET: 50, 52, 54, 56, 58, 60, 62, 64, 66, 68, 70, 72, 74, 76, 78, 80, 82, 84, 86, 88, 90, 92, 94, 96, 98

BORING METHOD: HQ CORE

SOIL PROFILE

DESCRIPTION	DEPTH B.G.S. (m)
DOLOSTONE, (Eramosa Member), black, bituminous, some iron staining, argillaceous, finely spaced stylolites, thinly bedded, bedding at 70 ° from horizontal. Fossiliferous 50 mm fracture filled with silt at 17.1 m. Three smaller silt-filled fractures to 18.5 metres.	
DOLOSTONE, (Lower Transition Zone), alternating brown and blue grey, fossiliferous, vuggy. Bedding at 30 ° from horizontal,	18.693
DOLOSTONE, (Un-subdivided Amabel Formation), blue/grey alternating to white, heavily fossilized, varies from coarse to fine grained, vuggy. Core breaks mainly at vugs. Vertical fracture at 23.75 m Very fossiliferous at 24.3 m Very competent core between 24.4 and 25. 8 metres (no core breaks). Notable change in porosity at 24.5 metres. Core exhibits open porosity possibly co-incident with increase in coarseness. Rock is very porous, can blow through core. Very fossiliferous. 1 cm to 3 cm long crinoid stems. Porous rock. Porous and large crinoid stem traces and fossils. Where lighter colour, less porous and finer grained.	20.73

Continued on next page

SAMPLES

ID	TYPE	RECOVERY (%)	RQD
Rn10	Core	100	75
Rn11	Core	100	100
Rn12	Core	100	75
Rn13	Core	100	100
Rn14	Core	97	95
Rn15	Core	100	100
Rn16	Core	100	100
Rn17	Core	100	100
Rn18	Core	95	100
Rn19	Core	100	95
Rn20	Core	100	97

CONCENTRATION (%)

LEL ◆
MOISTURE CONTENT ●
GAS CONCENTRATION ■

0 20 40 60 80 100

INSTALLATION INFORMATION

GD3

PROJECT: 0508

GD3

LOCATION: Guelph Dolime Quarry

BORING DATE: May 12, 2005

DATUM: GROUND SURFACE

DIP: 90

LOGGED: SD / AW

CONCENTRATION (%): LEL ◆ MOISTURE CONTENT ● GAS CONCENTRATION ■ 0 20 40 60 80 100

INSTALLATION INFORMATION: GD3

Depth Scale Metres	Depth Scale Feet	Boring Method	Soil Profile Description	Depth B.G.S. (m)	Samples ID	Samples Type	Recovery (%)	RQD
30			DOLOSTONE, (Un-subdivided Amabel Formation), blue/grey alternating to white, heavily fossilized, varies from coarse to fine grained, vuggy. Core breaks mainly at vugs.		Rn20	Core	100	97
	100							
31	102				Rn21	Core	100	95
	104		Closed vertical fracture at 32 m.					
32	106		Large crinoid fossils. Porous.					
33	108				Rn22	Core	100	100
	110							
34	112				Rn23	Core	100	100
	114							
35	116		Very porous, vuggy and fossiliferous.					
36	118		8 cm void at 36.3 m.		Rn24	Core	100	92
	120							
37	122	NO CORE	Some closed vertical fractures. Becoming less porous. Decreasing coarseness and fewer fossils.		Rn25	Core	100	82
38	124							
	126							
39	128				Rn26	Core	100	95
	130		Large calcite lined vug. Increased porosity and fossils.					
40	132				Rn27	Core	100	100
41	134							
	136							
42	138		Transition to darker grey, fine grained dolostone at 42.3 m.		Rn28	Core	100	100
	140							
43	142		Alternating dark and light grey dolostone. Fossiliferous		Rn29	Core	100	98
44	144							
	146		Crinoid fossils. Coarse grained. Small vugs.		Rn30	Core	100	100
45	148							

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DRAWN: AW

CHECKED: SD

PROJECT: 0508

LOCATION: Guelph Dolime Quarry

BORING DATE: May 12, 2005 **DATUM:** GROUND SURFACE **DIP:** 90 **LOGGED:** SD / AW

GD3

Metres	Feet	Boring Method	Description	ID	Type	Recovery (%)	RQD
45	148 150	HQ CORE	DOLOSTONE, (Unsubdivided Amabel Formation), blue/grey alternating to white, heavily fossilized, varies from coarse to fine grained, vuggy. Core breaks mainly at vugs.	Rn30	Core	100	100
46	152 154			Rn31	Core	100	99
47	156		Gypsum filled vug. Light grey dolostone with pink hue.				
48	158 160		Small gypsum filled vugs.	Rn32	Core	100	87
49	162		Alternating between coarse grained an fossiliferous and medium grained with fewer fossils.	Rn33	Core	100	97
50	164 166		Competent core between 50.5 and 52 m. No breaks. Gypsum filled vugs.				
51	168 170			Rn34	Core	100	100
52	172			Rn35	Core	100	95
53	174 176						
54	178 180		Competent core between 53.5 and 56.5 m. Grey ;rock with pinkish hue. Few stylolites.	Rn36	Core	100	100
55	182		Stylolite spacing 0.30 m or more.	Rn37	Core	92	100
56	184 186						
57	188 190			Rn38	Core	100	78
58	192		Fossiliferous, colour variations from dark grey to light grey in distinct layers, regular stylolite occurrences, some vugs,	Rn39	Core	95	45
59	194 196			Rn40	Core	87	76
60							

CONCENTRATION (%): LEL ◆ MOISTURE CONTENT ● GAS CONCENTRATION ■ (0 20 40 60 80 100)

INSTALLATION INFORMATION: GD3

Continued on next page

DRAWN: AW

CHECKED: SD

PROJECT: 0508

GD3

Page 5 OF 5

LOCATION: Guelph Dolime Quarry

BORING DATE: May 12, 2005 **DATUM:** GROUND SURFACE **DIP:** 90 **LOGGED:** SD / AW

DEPTH SCALE METRES	DEPTH SCALE FEET	BORING METHOD	SOIL PROFILE DESCRIPTION	STRATA PLOT	DEPTH B.G.S. (m)	SAMPLES ID	SAMPLES TYPE	SAMPLES RECOVERY (%)	RQD
60	198	HQ CORE	DOLOSTONE, (Un-subdivided Amabel Formation), blue/grey, heavily fossilized, varies from coarse to fine grained, vuggy.	▨		Rn40	Core	87	76
61	200 202								
62	204		DOLSTONE, (Fossil Hill / Reynales), green/grey, pyrite mineralization, some red banding.	▨	61.72	Rn41	Core	100	23
			END OF HOLE @ 62.48m		62.48				
63	206 208								
64	210 212								
65	214 216								
66	218								
67	220 222								
68	224 226								
69	228								
70	230 232								
71	234 236								
72	238								
73	240 242								
74	244								
75	246								

CONCENTRATION (%)

LEL ◆

MOISTURE CONTENT ●

GAS CONCENTRATION ■

0 20 40 60 80 100

INSTALLATION INFORMATION

GD3

END OF HOLE

DRAWN: AW

Harden Env.

CHECKED: SD

PROJECT: 0508

GD4

Page 1 OF 4

LOCATION: Guelph Dolime Quarry

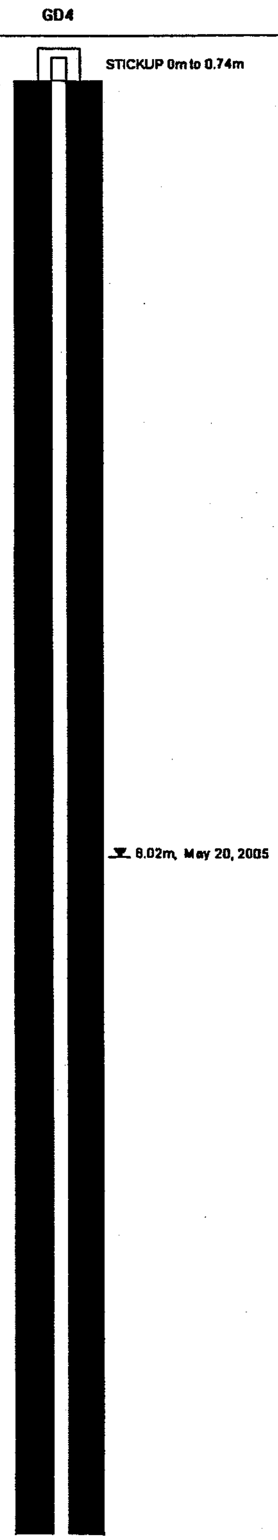
BORING DATE: May 19, 2005 DATUM: GROUND SURFACE DIP: 90 LOGGED: SD / AW

BORING METHOD	DEPTH B.G.S. (m)	SOIL PROFILE DESCRIPTION	ID	TYPE	RECOVERY (%)	RQD
		303.403 m AMSL				
	0	FILL, sand and gravel				
HQ CORE	3.81	DOLOSTONE, (Guelph Formation), tan/light grey, vuggy, some vugs lined with calcite crystals, minor stylolites. Some crinoid stems visible. Stylolite spacing generally less than 30 cm.	Run1	Core	87	75
			Run2	Core	100	94
			Run3	Core	98	90
	7.01	DOLOSTONE, (Upper Transition Zone), vuggy, vugs are often calcite lined, not bituminous, bedding 5 to 15 cm thick.	Run4	Core	100	88
			Run5	Core	100	79
		Fossiliferous, some large vugs.				
			Run6	Core	100	82
		Colour transition to black, numerous stylolites.				
	12.50	DOLOSTONE, (Eramosa Member), black, bituminous, some iron staining, argillaceous, finely spaced stylolites, thinly bedded.	Run7	Core	100	92
		Fossiliferous	Run8	Core	97	100

DEPTH SCALE: METRES 0–15; FEET 0–50

CONCENTRATION (%): LEL ◆ MOISTURE CONTENT ● GAS CONCENTRATION ■ (0 20 40 60 80 100)

INSTALLATION INFORMATION



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GD4

PROJECT: 0508

LOCATION: Guelph Dolime Quarry

BORING DATE: May 19, 2005 **DATUM:** GROUND SURFACE **DIP:** 90 **LOGGED:** SD / AW

DEPTH SCALE METRES	FEET	BORING METHOD	SOIL PROFILE DESCRIPTION	DEPTH B.G.S. (m)	SAMPLES ID	TYPE	RECOVERY (%)	RQD
15	50	HQ CORE	DOLOSTONE, (Eramosa Member), black, bituminous, some iron staining, argillaceous, finely spaced stylolites, thinly bedded. Fossiliferous.		Run8	Core	97	100
16	52				Run9	Core	100	95
17	54 56		Vertical fracture with calcite and pyrite mineralization at 15.5 metres.		Rn10	Core	100	95
18	58 60		Some layers of thinly spaced stylolites. Some large vugs.					
19	62 64		Void at 19.5 metres. Approximately 5 cm thick. Loss of return water.		Rn11	Core	100	100
20	66 68				Rn12	Core	100	93
21	70							
22	72 74				Rn13	Core	100	93
23	76 78		DOLOSTONE, (Lower Transition Zone), alternating grey and brown rock layers, vuggy, generally argillaceous, some gypsum filled vugs.	22.86	Rn14	Core	100	89
24	80							
25	82 84		DOLOSTONE, (Un-subdivided Amabel Formation), blue/grey, fossiliferous.	25.22	Rn15	Core	100	89
26	86							
27	88 90		Increased open porosity at 26.8 m.		Rn16	Core	100	88
28	92		Numerous stylolites. Increased crinoid stem fossilization.		Rn17	Core	98	95
29	94 96		Dark grey and light blue/grey colouring in distinct layers.					
30	98		Increasing open porosity.		Rn18	Core	100	93

CONCENTRATION (%): LEL ◆ MOISTURE CONTENT ● GAS CONCENTRATION ■ — 0 20 40 60 80 100

INSTALLATION INFORMATION

Continued on next page

GD4

Page 3 OF 4

PROJECT: 0508

LOCATION: Guelph Dolime Quarry

BORING DATE: May 19, 2005 **DATUM:** GROUND SURFACE **DIP:** 90 **LOGGED:** SD / AW

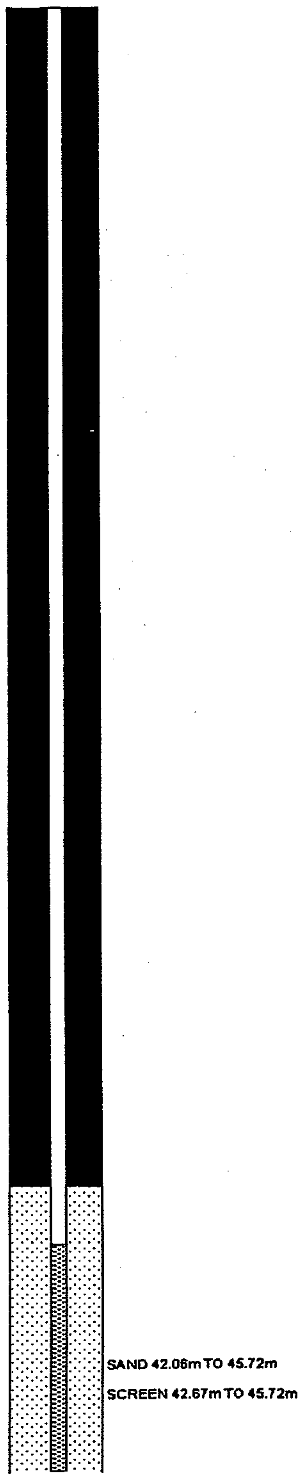
BORING METHOD: HQ CORE

DEPTH SCALE METRES	DEPTH SCALE FEET	SOIL PROFILE DESCRIPTION	SAMPLES ID	TYPE	RECOVERY (%)	RQD
30	100	DOLOSTONE, (Un-subdivided Amabel Formation), blue/grey, fossiliferous.	Rn18	Core	100	93
31	102	Openly porous. Coarse grained.	Rn19	Core	100	100
32	104 106	Competent core between 32 and 33.5 m. Distinct colour layering between light and dark grey.				
33	108	Some large vugs.	Rn20	Core	100	100
34	110 112		Rn21	Core	100	87
35	114 116					
36	118	7 cm void at 36 metres.	Rn22	Core	93	93
37	120 122	Porous, fossilized.	Rn23	Core	100	72
38	124 126	Vuggy. Some transition to fine-grained low-open-porosity dolostone. Some colour variability to light grey/white.				
39	128		Rn24	Core	100	92
40	130 132		Rn25	Core	100	93
41	134					
42	136 138	Coarse grained, crinoid fossils, vuggy and openly porous.	Rn26	Core	100	90
43	140 142		Rn27	Core	98	93
44	144					
45	146 148		Rn28	Core	100	88

CONCENTRATION (%): LEL ◆ MOISTURE CONTENT ● GAS CONCENTRATION ■ 0 20 40 60 80 100

INSTALLATION INFORMATION

GD4



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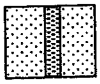
PROJECT: 0588

GD4

LOCATION: Guelph Dolime Quarry

BORING DATE: May 19, 2005 **DATUM:** GROUND SURFACE **DIP:** 90 **LOGGED:** SD / AW

DEPTH SCALE		BORING METHOD	SOIL PROFILE			SAMPLES				CONCENTRATION (%) LEL ◆ MOISTURE CONTENT ● GAS CONCENTRATION ■ 0 20 40 60 80 100	INSTALLATION INFORMATION GD4
METRES	FEET		DESCRIPTION	STRATA PLOT	DEPTH B.G.S. (m)	ID	TYPE	RECOVERY (%)	RQD		
45	148		DOLOSTONE, (Un-subdivided Amabel Formation), blue/grey, fossiliferous. Openly porous.	▦		Rn28	Core	100	88		
	150		END OF HOLE @ 45.72m		45.72						END OF HOLE
46	152										
47	154										
	156										
48	158										
	160										
49	162										
50	164										
	166										
51	168										
	170										
52	172										
53	174	HQ CORE									
	176										
54	178										
	180										
55	182										
56	184										
	186										
57	188										
58	190										
	192										
59	194										
	196										
60											

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