REPORT

March 2012

REPORT ON

Groundwater Vulnerability Study Richmond Village Well System Richmond, Ontario

Submitted to:
Mr. Frank Cairo
Richmond Village (South) Limited
3894 Prince of Wales Drive
Ottawa, ON
K2C 3H2

Report Number: 11-1127-0134

Distribution:

1 Copy - Richmond Village (South)
1 Copy - Golder Associates
7 Copies - City of Ottawa

Golder Associates

EXECUTIVE SUMMARY

The Village of Richmond (Village) is located approximately 35 km southwest of downtown Ottawa, along the Jock River. Water demand from the Village is currently met by a combination of individual private wells and two communal supply systems, referred to herein as the King's Park and Hyde Park systems. Groundwater vulnerability assessments were completed previously for these existing well systems, which involved construction and calibration of a groundwater flow model that was used to define the Well Head Protection Areas (WHPAs) associated with these well systems (Golder, 2009 and 2010a).

In 2008, Mattamy Homes Limited (Mattamy) initiated a Water and Sewer Master Servicing Study for lands located on the western portions of the Village, which recommended communal groundwater supply wells as the preferred option for new development on these lands (Stantec, 2009). A drilling and testing program was subsequently undertaken, where a number of wells were completed in the Nepean Formation aquifer. Portions of the development lands were acquired in 2010 by Richmond Village (South) Limited and Richmond Village (North) Limited, together referred to as RV. Golder Associates Ltd. (Golder) was retained by RV to complete a groundwater vulnerability study for the proposed municipal wells PW08-1, PW09-1 and PW09-2.

The groundwater flow model used in the King's Park and Hyde Park studies was used as the starting point for development of time-of-travel capture zones for the RV wells. The model parameterization was found to be consistent with data collected subsequent to its original development (i.e. hydraulic testing of the RV wells indicated an aquifer transmissivity that fell within the range used in the previous studies). Adjustments to the finite difference grid were required in order to properly include the RV wells. The pumping rate used in the capture zone delineation was based on the calculated average water demand for the Richmond development at full build-out (1,630 m^3/d) and was assumed to be shared evenly between PW09-1 and PW08-1.

Groundwater vulnerability mapping was performed over the area of the model domain using the Intrinsic Susceptibility Index (ISI) method, and intrinsic vulnerability scores were calculated based on the results of the groundwater vulnerability mapping and WHPA zone delineation. A threats assessment for the existing King's Park and Munster wells was previously undertaken by Dillon Consulting on behalf of the Mississippi-Rideau Source Protection Region, and was used as the basis for the threats assessment for the RV wells. In accordance with direction from the Source Protection Office of the Ministry of the Environment, only threats that could be considered significant according to the established methodology require evaluation.

WHPAs for the RV wells were similar to those developed previously for the King's Park wells; the capture zones extended in two directions, extending approximately 14 km towards the west-northwest, and approximately 6 km towards the south. Following the application of the ISI method, an aquifer vulnerability score of "low" was defined throughout the WHPA zones, which resulted from the extensive thickness of overlying geological materials found in the study area. Calculated vulnerability score ranged from 10 (limited to WHPA Zone A), to 2 in WHPA Zone D. For dense non-aqueous phase liquids (DNAPLs), the intrinsic vulnerability scoring value is 10 for any area within WHPA zone C

The uncertainty associated with the vulnerability scores within the WHPA was determined in accordance with Draft Guidance Module 3; the areas encompassed within WHPA Zone B were categorized as "low uncertainty", where the remaining areas within the overall WHPA were categorized as "high uncertainty".

Based on the results of the vulnerability scoring, significant threats to the RV wells, exclusive of DNAPL's, can only occur within WHPA Zone A. The current land use on the site is agricultural, but this will change to residential/parkland

as development proceeds. Based on the current methodology, sewage connections and laterals are defined as wastewater collection facilities and are considered significant threats in areas, such as WHPA Zone A, with an intrinsic vulnerability score of 10. It is understood that the MOE has determined that the provision of additional safeguards, such as double lined sewer pipes and more frequent inspections, will be sufficient to mitigate threats from sewage collection infrastructure.

The storage and handling of DNAPL's is considered a significant threat within WHPA Zones A, B and C (within a 5 year time-of-travel). The current WHPAs were reviewed and compared to those of the Richmond King's Park assessments. Both computer and on-ground surveys were used to verify that no additional sources, such as dry cleaners, manufacturing facilities or wood product manufacturers are found within the relevant WHPAs.

Significant data gaps identified in this study relate to the characterization of the porosity of the hydrostratigraphic units and the bedrock fracture network. Additional data relating to these parameters would provide a better estimate of the groundwater travel times and could be used to improve the delineation of the WHPAs. Additional data gaps for the current study relate to the threats identified within areas of overlap between the current WHPA Zone C and those of the King's Park assessment. These areas should be re-assessed during the next source protection iteration. Additionally, although the best data available at the time of this assessment were used to define the rates of groundwater pumping from other groundwater users found within the study area, these data could be refined to improve the overall WHPA delineation.

The groundwater vulnerability study has confirmed that risk to the proposed new supply wells is minimal due to the low vulnerability of the supply aquifer and the absence of significant threats to the water supply. Extraordinary aquifer protection measures are not anticipated for the proposed system.

Table of Contents

TABLES

FIGURES

APPENDICES

1.0 INTRODUCTION

1.1 Background

The Village of Richmond (Village) is located approximately 35 km southwest of downtown Ottawa, along the Jock River (Figure 1). Water demand from the Village is currently met by a combination of individual private wells and two communal supply systems, referred to herein as the King's Park, and Hyde Park systems. King's Park is a municipally owned and operated system, while Hyde Park is privately owned and operated. The King's Park and Hyde Park systems are currently comprised of two supply wells each, and service approximately 151 and 94 properties respectively within the Village (Stantec, 2011, Golder 2010a). A third well was constructed in 2010 and will be incorporated into the Hyde Park system to meet increasing system demands. Waste water within the Village is provided by the central municipal sanitary collection and treatment system.

A vulnerability assessment of the King's Park communal well system was completed by Golder Associates Ltd. (Golder) in 2003 as a part of a study for the Mississippi-Rideau Source Protection Region (MRSPR), and subsequently updated in 2009 (Golder, 2003 and 2009). This work involved the construction and calibration of a groundwater flow model, which was used to estimate the wellhead protection areas (WHPAs) for the wells. The model was used again to develop the WHPAs associated with the Hyde Park wells (Golder, 2010a).

In 2008, Mattamy Homes Limited (Mattamy) initiated a Water and Sewer Master Servicing Study (MSS) for lands located on the western portions of the Village, which recommended groundwater supply wells as the preferred option for new development on these lands (Stantec, 2009). Groundwater wells were subsequently installed and tested at the locations shown on Figure 2. Portions of the development lands were purchased in 2010 by Richmond Village (South) Limited and Richmond Village (North) Limited, together referred to as RV in this report. These lands included the wells PW09-1, PW09-2, and PW08-1. Golder was retained by RV to complete a groundwater vulnerability study for these wells.

1.2 Scope of Work

The technical requirements, study approach and methodology for groundwater vulnerability studies are set out within the Ontario Clean Water Act, 2006, Technical Rules: Assessment Report (November, 2009), as well as the draft Guidance Module 3 (October, 2006) prepared by the MOE in advance of the development of regulations, rules and final guidance documents under the Clean Water Act.

The objective of the study was to identify wellhead protection areas (WHPAs) for the proposed communal well system, to map the relative vulnerability of the supply aquifer within the identified WHPAs as high, medium or low, and to assign intrinsic vulnerability scores within the WHPAs.

The scope of work included:

- Reviewing the existing conceptual and numerical groundwater flow models that were developed as a part of the 2003 wellhead protection study;
- Reviewing hydrogeological data collected subsequent to completion of the 2003 study, including aquifer characteristics (thickness, transmissivity and storage properties) and additional nearby permitted water takings;
- Updating the groundwater flow model as necessary based on the review of data noted above;

- Using results of the recalibrated numerical groundwater flow model to assist in delineation of the WHPA zones A, B, C, and D using the forecasted pumping rates as defined in the MOE Guidance Module 3;
- Assessing the vulnerability of the supply aquifer based on a calculation of the Intrinsic Susceptibility Index (ISI), using the available hydrogeological data and the results of the numerical groundwater modelling;
- Using the results of the ISI calculation to categorize the relative vulnerability within the WHPAs as high, medium or low using Table 4.1 in Draft Guidance Module 3;
- Assigning intrinsic vulnerability scores within the WHPAs based on the delineated WHPA zones and results of the ISI vulnerability assessment; and,
- Completing an assessment of the uncertainty of the vulnerability scoring and categorizing the uncertainty as either high or low.

1.3 Proposed Water Supply System

The Mattamy Richmond well system is comprised of three wells, referred to as PW08-1, PW09-1, and PW09-2. PW08-1 was constructed in October 2009 and was completed at a depth of 137.16 m at the location shown on Figure 2. This well is completed with casing installed to a depth of 45.72 mbgs, and is open below this depth. In December 2009, a 0.254 m diameter production well (PW09-1) was drilled to a depth of 70 mbgs. PW09-1 is located near the eastern property boundary, approximately 650 m south of Perth St (Figure 2). The production well was completed with 45.72 m of steel well casing that was grouted in place. The steel casing was installed through the upper portion of the Oxford Formation, and groundwater flow to the well is expected to occur primarily from the lower aquifer (a description of the hydrostratigraphy of the site is provided in Section 2.4). In January, 2010, a third well (PW09-2, 0.254 m diameter) was installed less than 5 m from PW09-1. Similar to well PW09-1, PW09-2 is completed to a depth of 77.72 mbgs, with steel well casing installed to a depth of 45.72 mbgs. Further details of the Richmond wells are provided in Table 1 and well records are provided in Appendix A.

Forecast water demands on the Richmond well system were calculated based on a projection of the population growth for the development. The number of planned housing units and assumed water demand requirements for the Richmond development was provided by representatives of Mattamy and RV, summarized as follows:

- The RV lands will contain 1,000 units, including 650 single homes and 350 town homes;
- The Mattamy lands will contain 1,000 single homes;
- The average water demand is 835 L/d/unit for single homes and 720 L/d/unit for town homes (Stantec, 2011);

Therefore, the average water demand for the Richmond development at full build-out is 1,630 m^3/d (1,132 L/min).

2.0 REGIONAL SETTING

2.1 Physiography

Figure 1 illustrates the extent of the study area, which covers approximately 880 km^2, extending from Mississippi Lake in the west to the Rideau River in the east. A number of smaller creeks, streams, ponds, and tributaries to the larger rivers occur throughout the area, including the Jock River, a tributary to the Rideau River that flows through the Village of Richmond.

Topography within the study area generally slopes towards the east (Rideau River), with elevations ranging from approximately 145 masl along the western portions of the study area to approximately 85 masl along the eastern portions of the study area. Ground elevations are approximately 90 masl within the Village. Local topographic variations beyond the above noted range occur in isolated areas within the overall study area.

2.2 Surficial Geology

The surficial geology of the study area is illustrated on Figure 3. Surficial deposits found throughout the study area consist of glacial till, sandy and coarser stratified ice contact sediments, sandy and coarser nearshore sediments, a dense marine clay unit and modern fluvial deposits. The glacial till unit outcrops mainly in the western part of the study area where its thickness varies from centimetres to several metres. Many of the till outcrop areas are covered by large (several km^2) marshes and wetlands. An ice contact stratified deposit is reported 5 km northeast of Richmond. In the eastern part of the study area (including Richmond) these units are overlain by a marine clay material which increases in thickness towards the east. In the Richmond area, the overburden deposits mainly consist of the marine clay, underlain by the glacial till unit. Modern fluvial deposits are present along the Jock River.

2.3 Bedrock Geology

The bedrock geology of the study area is illustrated on Figure 4. In general, the surficial deposits within the study area are underlain by sedimentary rocks of Paleozoic age composed of sandstones, dolostones, limestones and shales. This sedimentary sequence unconformably overlies the Precambrian basement which underlies all of the study area and only outcrops west of it (near Mississippi Lake).

The Precambrian basement consists of highly deformed metasedimentary rocks. The Precambrian basement is overlain by the Nepean Formation sandstones which outcrop in the western area of the study, along the eastern shore of Mississippi Lake. The Nepean Formation, which is the upper unit of the Potsdam Group, underlies all of the study area. The lower member of the Potsdam Group, the Covey Hill Formation, is not represented in the study area. The Nepean Formation is composed of alternating beds of calcareous sandstone and quartz arenite. Its thickness, as reported by previous authors and estimated in the scope of the present study, would reach 45 m in the Richmond area. It is considered the most transmissive aquifer within the study area. Flow in this aquifer is controlled predominantly by fractures, as the primary porosity of the sandstones has been reduced by cementation. The Mattamy Richmond wells are completed in this formation.

Except where it outcrops, the Nepean Formation is overlain by the March and Oxford Formations of the Beekmantown Group. The March Formation consists of interbedded quartz sandstone, sandy dolostone/dolostone, and shale partings are present through the formation. Thicknesses up to 6.6 m have been documented for the March Formation in the study area. The Oxford Formation is mainly composed of dolostone with commonly occurring shale interbeds, and thicknesses up to 60 m have been reported in the study area.

Both the March and Oxford Formations are considered as good carbonate rock type aquifers, though their capacities are lesser than that of the Nepean Formation.

The Rockcliffe Formation, of the Chazy Group, is found mostly in the western part of the modelled area. It consists mainly of interbedded quartz sandstone and shale. Previous authors have estimated its thickness to be in the order of 10 m. The Rockcliffe Formation is typically not considered a significant water producing aquifer.

The Gull River and Bobcaygeon Formations, of the Ottawa Group, are also found mostly in the western part of the study area. The Gull River Formation is made of interbedded limestone and silty dolostone at the bottom and of finely crystalline limestone at the top. The Bobcaygeon Formation is described as an interbedded lithographic to coarsely crystalline limestone with shale parting. The Ottawa Group formations are referred to as marginal and variable water producing aquifers, although often able to provide enough water for an individual residence.

The March, Oxford, Rockcliffe, Gull River and Bobcaygeon outcrops are numerous and cover large areas west of Richmond. Several faults and joint sets have been mapped in these units. The faults in this area form part of a major tectonic feature, the Ottawa-Bonnechere Graben. Faults are steeply dipping and generally strike in an east to southeast direction. Vertical displacements reported along these faults generally vary between 5 and 50 m in the study area. Specific information on the hydraulic characteristics of the faults in the bedrock was not available local to the Richmond wells. It is not known whether the faults represent barriers or conduits for groundwater flow in this area. However, available information pertaining to the dissolved contaminant plume in the Blacks Corners area (approximately 25 km west of Richmond) suggests that groundwater flow occurs across faults in this area. The Paleozoic rocks are also intersected by steeply dipping (near vertical) joints which form four sets (N015°, N055°, N100° and N145°). Joint spacing typically varies from 30 to 100 cm and the N100° joint set is reported to be the most dominant (Golder, 2003).

2.4 Hydrogeology

2.4.1 Hydrostratigraphy

There are two primary bedrock aquifer systems that are identified within the study area. The upper aquifer is typically defined within the upper 35 m of the Oxford Formation. The majority of the private residential wells within Richmond are completed within and obtain water from this aquifer. The lower aquifer is defined within the lower portion of the March formation and the upper portion of the Nepean Formation. In general, the lower aquifer is considered to be more transmissive compared to the upper aquifer. Currently operating communal wells in the area (the King's Park and Hyde Park wells in Richmond, in addition to wells in Almonte, Munster, Kemptville, and Merrickville) draw water from the lower aquifer. In some areas the two aquifers are separated by a bedrock aquitard consisting of limestone of the lower Oxford Formation and interbedded limestone and sandstone of the March Formation. The presence of this aquitard is often indicated by strong upward vertical gradients between the aquifers. The potentiometric surface of the lower aquifer is typically above ground surface, and wells completed in this aquifer often flow.

The overburden within the study area consists of glacial till and marine clay deposits which are not considered suitable for water supply (only one of 893 water supply wells in the Village of Richmond was completed in the overburden (Golder, 2008a)). The Nepean formation is underlain by highly deformed Precambrian-aged metasedimentary rock, which is generally used as a supply aquifer only where neither the Paleozoic bedrock aquifers nor overburden aquifers are present.

2.4.2 Groundwater Flow

Observed groundwater flow characteristics within the study area are shown on Figure 5. Groundwater within the study area is generally interpreted to flow from the Mississippi River and Mississippi Lake in the west towards the Rideau River in the east. Upward gradients from the Nepean to the Oxford formation have been observed in Black's Corners and Manotick, as wells completed at the Site (Golder, 2011). Upward gradients are also expected where the Jock River flows over outcrops of the Oxford formation to the south of Munster (Golder, 2003). Shallow groundwater flow in the overburden units is expected to vary as a function of bedrock topography (Golder, 2010a).

2.4.3 Groundwater Quality

The lower sandstone aquifer (Nepean Formation) underlying the site is regionally extensive, and is utilized by the King's Park and Hyde Park communal wells in Richmond, as wells as the communal wells systems in Almonte, Munster, Kemptville and Merrickville. The groundwater in the lower aquifer is hard (typical for groundwater sources, particularly those that have a substantial carbonate composition) and occasionally exceeds the non-health related aesthetic criteria for iron. The exceedances of the aesthetic criteria for iron in the lower aquifer are generally treatable using conventional water softening. Where both aquifers are present, the shallower Oxford formation is typically used for residential supply purposes and tends to be of somewhat lower quality than the deeper aquifer. The groundwater in the upper aquifer is quite hard and occasionally exceeds the non-health related aesthetic criteria for iron. Low concentrations of hydrogen sulphide are often present. Overall, wells completed in either supply aquifer are expected to produce groundwater that is safe and aesthetically suitable for human consumption (Golder, 2008a).

3.0 SUMMARY OF PREVIOUS STUDIES

3.1 Hydrogeological Evaluations

Hydraulic testing data were collected for the overburden, Oxford, March, and Nepean bedrock formations as a part of previous hydrogeological investigations completed by Golder and others within the study area. These data are summarized in Table 2. The following describes the results of this testing. Tests completed in the Oxford Formation (Golder 2006), which are included in the Table for completeness, were not included in the following discussion, as the focus of the current study is on the Nepean Formation.

The hydraulic conductivity of the silty clay and fine sand overburden materials was estimated based on hydraulic response testing (rising head tests) of monitoring wells located on the Richmond property to range between approximately $1x10^{-6}$ m/s and $1x10^{-5}$ m/s (Golder, 2010b). This range is representative of the conditions local to the site, which is not necessarily representative of conditions across the full study area.

As a component of the Wellhead Protection Study for the King's Park wells completed by Golder in 2003, a 6-hour pumping test was completed on King's Park well KP2 on July 10, 2002. The well was completed as an open hole through the Oxford and March formations, and into the Nepean formation. It is interpreted that the majority of the water supplying the communal wells comes from the Nepean formation. The well was pumped at a rate of 1,100 m^3/day for the 6-hour period. Based on the results of the pumping test, the transmissivity and storage coefficient of the aquifer were estimated to be 605 m^2/day and 1.9×10^{-5}, respectively (Golder, 2008a).

Pumping tests were completed on three wells in the Hyde Park area of Richmond Village as a component of various hydrogeological studies completed for that development (Golder, 2010a). The wells varied in depth from 83 to 94 m, and were completed as open holes throughout the Nepean, March, and Oxford formations. Each well was pumped for a period of 24-hours. Analysis of these tests resulted in a range of transmissivity from 21 to 130 m^2/day. It is noted that although these wells were completed across several hydrostratigraphic units it is assumed that the majority of the flow was derived from the Nepean formation.

In November 2009, a 48-hour pumping test was conducted on PW08-1 (located within Richmond Village, see Figure 2, and well description in Section 1.3) using a pumping rate of 1,273 Litres per minute (L/min). The transmissivity and storativity values generated by the analysis of drawdown data from the pumping test range from 328 metres squared per day (m^2/day) to 700 m^2/day and from 9×10^{-4} to 1×10^{-2}, respectively. Based on the results of the pumping test, the sustainable yield of the well was estimated to be 2,600 L/min (Golder, 2011).

A 72-hour pumping test was conducted on well PW09-1 (located within Richmond Village, see Figure 2, and well description in Section 1.3) between September 27 and September 30, 2011. Recovery measurements were collected until October 3, 2011. The pumping test was started at a rate of 2,690 L/min. After the first day of pumping, the rate decreased slightly due to a loss of pump efficiency. The remainder of the test was completed at a rate that ranged from 2,690 L/min to 2,410 L/min. During the pumping test, water level data was collected from the pumping well (PW09-1) and four observation wells screened within the Nepean formation (PW09-2, PW08-1, MW08-1A, MW08-1B), as well as five additional wells screened in the upper aquifer. Based on analysis of pumping and recovery data the transmissivity of the lower sandstone aquifer was estimated to range from 500 m^2/day to 800 m^2/day. The pumping test results indicated that the sustainable yield for well PW09-1 is at least the minimum pumping rate of 2,410 L/min and is likely greater.

Hydraulic conductivity of the Precambrian unit underlying the Nepean formations is estimated to range from $1x10^{-8}$ to $1x10^{-7}$ m/s based on values reported in surrounding areas (Golder, 2003). Information on the hydraulic characteristics of the Precambrian unit within the study area was not available.

3.2 Groundwater Vulnerability Studies

A Wellhead Protection Study (WHPS) was completed by Golder for the communal wells in the King's Park Subdivision in April 2003 (Golder, 2003). A 3-dimensionsal numerical model (MODFLOW) was developed for the study area, and a modeling exercise was completed to define the time-related groundwater capture zones for the King's Park wells. Capture zones were determined using MODPATH to release particles over the open intervals of the wells, from within the lower aquifer and the upper aquifer, for the "base-case" model and for 21 additional modelling scenarios employed in a sensitivity analysis. The capture zones were therefore "composite" areas, combining the particle tracking results for the 22 modelling scenarios. Due to the significant depth of the lower aquifer below ground surface and the nature of the overlying bedrock formations, the aquifer vulnerability was classified as low throughout the Munster and King's Park WHPAs (Golder, 2003). A recommended well-head protection strategy was proposed as a part of that study.

In October 2006, a series of draft guidance modules were provided by the MOE as part of the Clean Water Act. Draft Module 3 – Groundwater Vulnerability Analysis provided new technical requirements and methodologies for defining WHPAs (MOE, 2006). In May 2008, Golder produced 5-year time of travel (ToT) capture zones for the Munster and Kings Park municipal wells using the previously constructed MODFLOW model (Golder, 2008b). The capture zones were determined using the same methodology followed in 2003.

In May 2009 capture zone modelling and an aquifer vulnerability assessment (Golder, 2009) was completed for the upper (Oxford Formation) aquifer using the previously constructed Munster-Kings Park model. For that study, the model was revised in order to relocate the municipal wells (using co-ordinates provided by MRSPR) and to subdivide the upper aquifer layer into three layers. A vulnerability assessment for the upper aquifer was then completed using Intrinsic Susceptibility Index approach (ISI).

In 2010 the Munster-Kings Park Model was used to develop a Well Head Protection Area Plan (WHPAP) for future phases of the Hyde Park development in Richmond (Golder, 2010a). The pumping tests discussed above were a component of that study. Based on the results of that study, the modelled supply rate for the Hyde Park well was increased to 265 m^3/day.

4.0 STUDY METHODOLOGY

4.1 Groundwater Flow Modelling

A groundwater flow model encompassing the study area was constructed previously as a part of the 2003 groundwater vulnerability study for the Munster and King's Park well systems (Golder, 2003). Upon review of the hydrogeological data that has become available since the completion of the 2003 study (described in Section 3.0 above), including data from borehole drilling, aquifer testing, and groundwater level monitoring, it was determined that these data are generally consistent with the original hydrogeological conceptualization. Therefore, the original groundwater flow model developed for the 2003 study is considered appropriate for use in the current study.

The groundwater flow model is described in the sections below. In general, this text follows that which was included in the 2003 assessment report to describe the groundwater flow model, though additional discussion is included herein to document the minor changes that were made to the model to incorporate the Richmond pumping wells.

The overall objective of the groundwater flow modelling was to delineate time-of-travel capture zones for the Richmond supply wells based on forecast pumping rates. These capture zones are subsequently used in the generation of WHPAs for the wells, forming the basis for the groundwater vulnerability assessment.

4.1.1 Modelling Scope

A numerical groundwater flow model was used to assess the time of travel capture zones, as per the *Clean Water Act, 2006* Technical Rules: Assessment Report (November 16, 2009), as well as other applicable MOE guidance, such as the draft Guidance Module: Groundwater Vulnerability Analysis (MOE, 2009 and 2006). Specifically, to meet the above objectives, the following tasks were completed:

- Review of geological and hydrogeological data that has become available since the time of the original groundwater vulnerability assessment;
- Determine the suitability of the above-noted data within the context of the existing conceptual model;
- Update the existing groundwater flow model to account for potential refinement of the conceptual model (as required);
- Verify the location and forecasted water usage for the Richmond Wells, and incorporate these wells into the existing groundwater flow model;
- Verify the calibration of the groundwater flow model using available water elevation data (MOE water well data, and site-specific observation well data), including data collected since the time of the original assessment; and
- Delineate capture zones using forecasted pumping rates.

4.1.2 Modelling Approach

The objective of the groundwater modelling for the Richmond area was the determination of time-related capture zones for the groundwater supply wells. As per the MOE guidance, the time-related capture zones of interest include the zero to 2 year time of travel (ToT), the 2 to 5 year ToT; and the 5 to 25 year ToT.

The MOE (under the Clean Water Act; MOE, 2009) requires subdivision of the WHPAs into four zones as follows:

1) Area WHPA-A, the surface and subsurface area centred on the well with an outer boundary identified by a radius of 100 m;
2) Area WHPA-B, the surface and subsurface areas within which the time of travel to the well is less than or equal to two years but excluding WHPA-A;
3) Area WHPA-C, the surface and subsurface areas within which the time of travel to the well is less than or equal to five years but greater than two years; and,
4) Area WHPA-D, the surface and subsurface areas within which the time of travel to the well is less than or equal to twenty-five years but greater than five years.

A 3D numerical (MODFLOW) groundwater model was constructed and calibrated with available hydrogeological data to estimate the time-related capture zones for the **King's Park and Munster** water supply wells (Golder, 2003). This model was subsequently adapted in order to estimate the time-related capture zones for the Richmond water supply wells. Data used to develop the model included information from the MOE Water Well Information System (MOE WWIS) as well as information from geological and hydrogeological investigations completed within the study area (inclusive of studies at Beckwith/Blacks Corners, and Manotick). MOE WWIS data from 2003 through 2011 were incorporated into the groundwater flow model to check for reasonableness of calibration using the most recent available data. Similarly, information from hydrogeological investigations completed subsequent to the 2003 assessment (summarized in Section 3.0 of this report) was evaluated to ensure a reasonable fit was maintained between these data and the existing conceptual model.

Following construction and calibration of the groundwater model under current conditions, predictive computer simulations were completed using the forecasted pumping rates to delineate capture zones. The forecasted pumping rates reflect the future average rates based on the total water demands projected for the supply wells at full buildout of the Mattamy/RV lands.

To delineate the capture zones under forecasted rates, groundwater particles were simulated in the numerical model at the pumping wells, backward-tracked using MODPATH, and the resulting particle traces were projected in plan view to ground surface. The time-related capture zones that are subsequently derived from this analysis represent a two-dimensional (2D) projection of the particle outlines to ground surface.

4.1.3 Code Selection and Description

MODFLOW-2000 (USGS, 2000) and MODPATH were used to estimate the time-related capture zones. MODFLOW is a multi-purpose three dimensional groundwater flow code developed by the United States Geological Survey. It is modular in nature and uses the finite difference formulation of the groundwater flow equation in its solution. Visual MODFLOW® (Version 4.3.0.154) was used as the numeric flow engine for the simulations presented in this report. MODPATH (Pollock, 1989), a companion code to MODFLOW, was used to complete the particle tracking analyses necessary for the capture zone delineation.

4.1.4 General Modelling Assumptions

The use of the MODFLOW/MODPATH groundwater model infers that the groundwater flow system in the Richmond area can be simulated as an "equivalent porous media" at the scale of the time-related capture zones under consideration (i.e., 0 to 2-year ToT; 2 to 5-year ToT; and 5 to 25-year ToT). Under this assumption, the rate of groundwater flow towards a pumping well occurs as a function of the hydraulic gradient, the hydraulic conductivity, and the porosity of the aquifer. While groundwater flow in bedrock aquifers is controlled primarily by fractures, an equivalent porous media approach is usually used to represent groundwater flow in these aquifer systems. This is considered reasonable provided the scale of the observation (i.e., in this case the extent of the capture zone) is much greater than the scale of the individual fractures, and consideration is given to the selection of a reasonable effective porosity for the bedrock.

Modelling calculations were completed at "steady-state". Under this assumption, the predictions reflect long-term average conditions. Therefore, the potential effects of short-term conditions (floods, severe rainfalls, etc.), seasonal fluctuations and long-term climate changes were not considered.

Table 3 provides a summary of the general modelling assumptions used in the groundwater flow model.

4.1.5 Conceptual Model

The conceptual model developed for the 2003 assessment was reviewed in light of new data collected since the previous study. The major aspects of the conceptual model remain unchanged. These include the topography and drainage conditions across the study area, hydrostratigraphic layering, geological material properties, groundwater and surface water flow directions and magnitudes, assumed flow boundaries. Based on the review it was determined that the conceptual model used previously was appropriate as the basis for the current assessment. The reader is referred to the 2003 report for a detailed description of the development of the conceptual model.

4.1.6 Grid Discretization

The model domain is horizontally discretized into 127 rows and 178 columns per layer. Horizontal grid spacing is specified as 500 m near the outer edges of the model domain, transitioning to 5 m in the vicinity of the pumping wells. It should be noted that horizontal grid refinement was required to accommodate the inclusion of the Richmond wells within the existing groundwater flow model. The total number of cells within the model domain is 158,242, inclusive of all 7 numerical layers, as discussed below.

4.1.7 Model Layering and Surfaces

Figure 6 shows the model layering and hydrostratigraphic conceptualization. The groundwater flow model was constructed using one overburden layer and six bedrock layers, defined as follows:

- **Overburden (Model Layer 1) –** The overburden material found within the study area, which is mainly composed of glacial till (overlain by clayey material in the eastern part of the model area) was conceptualized as a "moderate-low" permeability layer of variable thickness. The upper surface of this unit was defined by topographic data (25 m digital elevation model);

- **Upper Bedrock (Model Layer 2) –** The upper bedrock unit, which includes the Paleozoic dolomites, limestones, and shales of the March, Oxford, Rockcliffe, Gull River, and Bobcaygeon Formations, was conceptualized as a "moderate-low" permeability upper bedrock layer of variable thickness. The surface defining the top of the bedrock was constructed using the bedrock depth information from the MOE WWIS and other available borehole data, and subtracting this depth from the ground surface across the study area. Outliers in the data were identified by plotting the residual elevation (i.e. the difference of the input bedrock surface elevations and the interpolated results). Points having a residual elevation greater than 10 m were removed. The interpolated bedrock surface was corrected to the ground surface elevation where the bedrock surface was interpolated to be above ground surface. The resulting bedrock surface elevation and overburden isopach maps are shown on Figure 7 and Figure 8 respectively;

- **Nepean Aquifer (Model Layers 3 through 5) –** Below the upper bedrock layer lies a relatively high to very high conductivity bedrock layer representing the Nepean aquifer. The Nepean Formation surface was constructed as follows: a preliminary surface was constructed using only the wells, boreholes, and bedrock outcrops having clearly identified the Nepean top contact. The MOE WWIS data was filtered to retain only the wells presenting a sandstone bedrock contact elevation at a logical location in the stratigraphic sequence (e.g. any well having limestone or sand and gravel below the sandstone contact depth was removed). The MOE WWIS data were compared against the preliminary surface, and any point from the MOE WWIS dataset having a residual elevation of 20 m or greater was removed. A final surface (illustrated on Figure 9) and thickness of the overlying "upper bedrock" (illustrated on Figure 10) was created using the filtered MOE WWIS data combined with the data used to create the preliminary surface. In order to better match the available data, the Nepean aquifer was discretized into three separate layers, where:
  - The top Nepean layer (model layer 3) is one metre thick and represents fractured sandstones of relatively high hydraulic conductivity. This layer has the same hydraulic properties (hydraulic conductivity, storativity, and porosity) throughout the model area;
  - The middle Nepean layer (model layer 4) represents, depending on the location, either fractured sandstones of relatively very high hydraulic conductivity (same as model layer 3) or sandstones of relatively high hydraulic conductivity. This layer has a constant thickness of 4 m through all of the model area, but its conductivity is lower in the Munster area compared to the overall model area in order to match the lower transmissivity values obtained from the Munster area wells. Boundaries of the lower-conductivity zone were derived from the adjacent geological faults and contacts mapping;
  - The bottom Nepean layer (model layer 5) represents sandstones of relatively high hydraulic conductivity (same as Layer #4 in the Munster area) at the remaining thickness of the unit. The thickness of this layer varies across the model domain.
- **Precambrian Bedrock (Model Layers 6 and 7) –** Below the Nepean layers, the Precambrian metasedimentary rocks were discretized into two layers, where the top layer (model layer 6) represents a moderate-low hydraulic conductivity layer, and the bottom layer (model layer 7) represents a 50 m thick zone of low hydraulic conductivity bedrock. The Precambrian surface (illustrated on Figure 11) and Nepean Formation thickness (illustrated on Figure 12) was interpolated using data from a limited number of boreholes (mainly from the Blacks Corners, Munster, and Manotick areas) and outcrop areas on the outer edges of the model domain.

4.1.8 Groundwater Flow Boundaries

Figure 13 illustrates the flow boundaries used in the groundwater flow model. The eastern boundary follows the Rideau River and is specified in model layer 1 as a constant head boundary at an elevation ranging from 80 masl to 85.5 masl (corresponding to the river elevation along the boundary). Similarly, the western model boundary follows the eastern shore of Mississippi Lake (134.5 masl) and the Mississippi River. Along the Mississippi River, the assigned hydraulic head ranged from 122 masl to 134.5 masl. These boundaries were also assigned as constant head within the layers in contact with the water body (layers 1, 2, or 3 depending on the location). The northern and southern boundaries were also defined as constant head boundaries using values obtained from the groundwater elevations in the bedrock aquifer map (Figure 5).

The Jock River flows through the central area of the model in a southwest to northeast direction. A river boundary was assigned to the Jock River based on its elevation and using a conductance value of 200,000 m^2/d.

Four large marshes and wetland areas found within the study area were specified as constant head boundaries. Unique constant head values representing the mean water level elevations (derived from topographic mapping) or non-unique constant head values selected based on topography and on the inferred slope of the Jock River were used to simulate the wetland areas.

The base of the model (the Precambrian rock below model layer 7) is defined as a "no flow" boundary.

4.1.9 Pumping Wells and Water Takings

Water demand is primarily a function of population and predicting future demand requires making assumptions about the rate of growth. The average water demand for the Richmond development was assumed to be 1,630 m^3/d. A detailed calculation of the forecast water demands for the Richmond well system is provided in Section 1.3. For the purposes of the groundwater flow model it was assumed that the forecasted average demand would be supplied evenly between PW08-01 and PW09-01. It should be noted that due to their close proximity (< 3m), wells PW09-01 and PW09-02 were considered as a single well for the purpose of the modelling exercise.

In addition to the Richmond wells, the PTTW database contains other significant water takings within the study area. The Kings Park communal well system is located in the northeastern portion of the Village, approximately 1.5 km northwest of the Richmond wells. This system consists of two wells, RW1 (66 m deep and cased to 19.2 m) and RW2 (61 m deep and cased to 19.5 m). The wells penetrate limestone and dolomite and are completed as open holes in the upper portion of the underlying Nepean Formation sandstone. The permitted capacities of RW1 and RW2 are each 1,310 m^3/d. Actual pumping rates from these wells are much lower than the maximum permitted rate; historical water use data indicates the average pumping rate is 210 m^3/d for the Kings Park system. Based on information provided by the City of Ottawa, which projects a zero-percent increase in population for Kings Park, current water demands for the Kings Park system are expected to continue within the time frame considered as a part of the current study.

The Hyde Park communal well system is located approximately 1.0 km north of the Richmond wells. This system is comprised of two wells referred to as TW1 (the supply well) and TW2 (the backup well). TW1 and TW2 are completed to depths of 83.8 mbgs and 92 mbgs, respectively, and are completed as open holes through the Oxford, March, and Nepean Formations. The permitted pumping rate for the system is 576 m^3/d, though the typical current groundwater usage for this system is approximately 30 m^3/d based on 2010 usage data. The forecast estimation of average day groundwater usage for the system at full build out is 265 m^3/d.

The community of Munster, located approximately 8 km west-southwest of the Richmond wells, is serviced by two wells (MW1 and MW2). MW1 and MW2 are respectively 116 m and 122 m deep, and are cased to a depth of 29 m below ground surface. The permitted capacities of wells MW1 and MW2 are 980 and 1,181 m^3/d, respectively. Over the 1998-1999 period, groundwater extraction for this system averaged 422 m^3/d. The projected increases in pumping rates for these wells based on population growth estimates amount to 5 % above the average rates. For the purposes of this study, the forecast pumping rates used in the 2003 assessment (277 m^3/d at MW1 and 187 m^3/d at MW2) were maintained.

A PTTW was identified for a golf course located approximately 14 km west-northwest of the Richmond wells. No usage data was obtained, however, given the location of this well relative to the RV well system, it is anticipated that simulating this usage would not affect the results for the areas of interest of this study. In the absence of actual pumping data, numerical simulations were completed using an assumed pumping rate for the golf course well to confirm that this is the case.

4.1.10 Recharge

Figure 14 illustrates the distribution of recharge used in the groundwater flow model. Three separate recharge zones were defined to reflect the variability in surficial materials in the model area. Clayey overburden material east of the Richmond area was assigned an infiltration rate of 5 mm/y, till and rock outcrop areas west of Richmond were assigned an infiltration rate of 15 mm/y, and a stratified ice contact deposit located northeast of Richmond was assigned an infiltration rate of 200 mm/y. These values were estimated from professional judgement and through the model calibration process. Alternate infiltration configurations were also tested during the parameter variation simulations.

4.1.11 Model Parameterization

Figure 15 illustrates the model hydraulic conductivity distribution, as defined below.

Overburden (Layer 1)

The overburden material in the model area is comprised primarily of till with some sand and clay areas. There is no detailed differentiation of the overburden materials in areas of the model, and as such the hydraulic parameters are defined globally for the entire overburden layer. Except for bedrock outcropping areas, a unique value of $5x10^{-7}$ m/s was used in the model. In bedrock outcropping areas, a minimum thickness of 1 m was used and the hydraulic conductivity value of the underlying bedrock layer (based on geological maps) was manually assigned. The effective porosity of the overburden layer was conservatively assigned at 0.25, typical of a sandy silt to silty sand till.

Hydrogeological investigation of the overburden materials local to the Mattamy/RV area was completed previously (Golder, 2010b). Results from hydraulic testing of the silty clay and fine sand overburden materials identified a range in hydraulic conductivity between approximately $1x10^{-6}$ m/s and $1x10^{-5}$ m/s. It should be noted that these data were not available at the time of the 2003 assessment, and as such were not used in the original model development. The range in measured hydraulic conductivity for the overburden local to the Richmond development is higher than the simulated hydraulic conductivity for this unit, though the original simulated value was maintained, as the measured data represent only a small portion of the modelled area.

Upper Paleozoic Formations (Layer 2)

The hydraulic conductivity of the dolostones, limestones and shales (Bobcaygeon, Gull River, Rockcliffe, Oxford and March Formations) which overlie the Nepean aquifer range from $2x10^{-11}$ m/s to $9x10^{-4}$ m/s based on the results of hydraulic testing of these units. Except for the Nepean bedrock outcropping areas, a unique value of $5x10^{-7}$ m/s was used in the model. In the Nepean bedrock outcropping areas (based on geological maps), a minimum thickness of 1 m was used and the hydraulic conductivity value of the underlying Nepean bedrock layer was manually assigned. Based on the reported joint spacing and on the bulk hydraulic conductivity used in the model, an effective porosity of 0.001 was estimated and assigned to this layer. These values were varied during the sensitivity analysis.

Nepean Formation (Layers 3, 4 and 5)

Based on the results of pumping tests completed on the Richmond wells (PW08-1, and PW09-1), the estimated transmissivity of the Nepean formation at this location is estimated to be between 500 m^2/d and 800 m^2/d (Golder, 2011). Assuming that the thickness of the Nepean Formation in this area is approximately 45 m, this corresponds to a range in hydraulic conductivity of $1x10^{-4}$ m/s to $2x10^{-4}$ m/s.

Pumping tests completed at wells MW1 and MW2 in Munster indicate bulk bedrock transmissivities in the range of 4 to 370 m^2/d, with an arithmetic mean of 81 m^2/d and a geometric mean of 24 m^2/d. Assuming that the Nepean Formation is the principal contributing aquifer and that its thickness in the Munster area is in the order of 40 metres, this corresponds to a range in hydraulic conductivity of $1.3x10^{-6}$ m/s to $1x10^{-4}$ m/s. Also, Packer testing performed in Munster municipal well MW1 indicated a very high hydraulic conductivity (on the order of $1x10^{-4}$ m/s) in the uppermost portion of this formation.

Pumping tests completed at RW1, RW2 and HP1 (Kings Park/Hyde Park) indicate bulk bedrock transmissivities in the range of 30 to 658 m^2/d (see Table 2) with an arithmetic mean of 304 m^2/d and a geometric mean of 216 m^2/d. Again, assuming that the Nepean Formation is the principal contributing aquifer and that its thickness in the Richmond area is in the order of 45 metres, this corresponds to a range in hydraulic conductivity of $7.8x10^{-6}$ m/s to $1.7x10^{-4}$ m/s.

Transmissivity values from pumping tests performed in the Nepean Formation in the Blacks Corners area vary from 148 to 397 m^2/d with an arithmetic mean of 204 m^2/d and a geometric mean of 188 m^2/d. Again, assuming that the Nepean Formation is the principal contributing aquifer and considering a recorded thickness of 50 m in the Blacks Corners area, this corresponds to a range in hydraulic conductivity of $3.4x10^{-5}$ m/s to $9.2x10^{-5}$ m/s.

As indicated previously, the Nepean aquifer was discretized into three separate layers in order to better match the site/aquifer specific data and knowledge. Therefore, a hydraulic conductivity value of $4x10^{-4}$ m/s and a thickness of 1 m were assigned to the Nepean top layer (model layer 3) which is conceptualised as fractured sandstones of relatively very high conductivity. The Nepean middle layer (mode layer 4) was given a hydraulic conductivity value of $4x10^{-4}$ m/s and a constant thickness of 4 m through all of the model area except for the Munster area where a value of $1x10^{-5}$ m/s was assigned in order to match the Munster lower transmissivity values; boundaries of this "lower conductivity" zone are derived from the adjacent geological/faults contacts. The bottom Nepean layer (model layer 5) was assigned a hydraulic conductivity value of $1x10^{-5}$ m/s and the remaining thickness of the unit. The effective porosity was assumed to be related to the hydraulic conductivity. Therefore, based on an assumed fracture density of 100/m, any Nepean layer or portion of layer with a hydraulic conductivity value of $4x10^{-4}$ m/s was given an effective porosity value of 0.017. The rest of the Nepean material ($1x10^{-5}$ m/s) was considered less fractured and was accordingly given an effective porosity value of 0.001. These values were varied during the sensitivity analysis.

Precambrian (Layers 6 and 7)

Information on the hydraulic characteristics of the Precambrian metasedimentary rocks was not available in the study area. Based on values reported in surrounding areas, the upper Precambrian layer (model layer 6) was given a K value of $1x10^{-7}$ m/s and an effective porosity of 0.001. The lower Precambrian layer (model layer 7), which was considered as less conductive and less fractured, was given a K value of $1x10^{-8}$ m/s with an effective porosity of 0.0001.

Faults

Information on the hydraulic characteristics of the faults in the bedrock was not available in the study area. It is not known whether the faults represent barriers or conduits for groundwater flow. However, and as indicated earlier, available information pertaining to the dissolved contaminant plume in the Beckwith/Blacks Corners area suggests that faults in this sector would be transparent to groundwater migration. The bedrock faults have therefore not been represented as independent hydrostratigraphic units in the groundwater model.

The anisotropy ratio of all hydrostratigraphic units was assumed to be 1:1 (i.e. the vertical hydraulic conductivity is assumed to be equal to the horizontal hydraulic conductivity).

4.1.12 Parameter Variation Simulations

It should be recognized that there is inherently some uncertainty associated with the capture zones forecast by a calibrated groundwater model. These uncertainties stem from limitations in the available subsurface information and can be related to variability in the aquifer properties (e.g., hydraulic conductivity; porosity) or uncertainties with the conceptual model (e.g., groundwater-surface water interactions; location of flow boundaries; recharge rates; continuity in aquitards; direction of regional groundwater flow; simplification of fracture flow systems into bulk hydraulic conductivity (EPM) approaches). To gain some understanding of the potential impact of this uncertainty in the groundwater model forecasts, a sensitivity analysis was completed; the compilation of which when overlaid effectively increases the spatial coverage of each time-of-travel capture zone from those generated using the calibrated model parameters.

The sensitivity analysis was comprised of a series of 21 steady-state groundwater flow simulations, as summarized in Table 4. These simulations considered variability in: the hydraulic conductivity of the upper Paleozoic Formations (model layer 2), the hydraulic conductivity of the Nepean Formation model layers, recharge rates, the effective porosity of the upper Paleozoic Formations, and combinations of these parameter changes.

4.1.13 Capture Zone Delineation

As described earlier, the capture zones for the Richmond supply wells were determined using MODPATH by releasing groundwater particles at the pumping wells and backwards tracking them to their source. The time-related capture zones are subsequently derived from this analysis represent a two-dimensional projection of the particle outlines to ground surface. The final capture zones reflect the combined area resulting from the calibrated model simulation and from the various sensitivity runs.

4.2 Groundwater Vulnerability Mapping

Groundwater vulnerability mapping was performed over the area of the model domain using the Intrinsic Susceptibility Index (ISI) method. The ISI method provides a quantitative measure of the degree of protection afforded by the overlying geological material: the higher the index, the greater the degree of protection. The index is calculated for each discrete geological unit by multiplying a "K" factor by the thickness of the layer. A table of K factor values for many geological materials was prepared as a part of the groundwater vulnerability guidance documentation.

As described previously, the Richmond wells are equipped with grouted steel casing to a depth of approximately 45 m and draw water from the Nepean Formation sandstone. Geological materials overlying (and therefore "protecting") this aquifer include the Paleozoic dolomites, limestones, and shales of the March, Oxford, Rockcliffe, Gull River, and Bobcaygeon Formations, and the overlying overburden. Thus, the ISI was evaluated as follows:

$$ISI = 3B_1 + 4B_2$$

where B_1 and B_2 represent the respective thicknesses of the overburden and Paleozoic formations. The K-factors of 3 for the overburden and 4 for the bedrock were chosen directly from Table 3.1 in Appendix 3 of the Draft Guidance Module 3; the overburden is conservatively represented as "silty sand", and the Paleozoic formations that overlie the Nepean Formation are represented as "limestone/dolostone".

4.3 Intrinsic Vulnerability Scoring

Intrinsic vulnerability scores were calculated based on the results of the groundwater vulnerability mapping and WHPA zone delineation, pursuant to the Technical Rules: Assessment Report Table 2a (ISI). The vulnerability within each of the WHPAs is categorized as high (<30), medium (30 to 80) or low (>80).

4.4 Uncertainty Assessment

The zones of uncertainty (i.e. high uncertainty/low confidence, low uncertainty / high confidence) associated with the WHPA delineation and vulnerability scoring were qualitatively evaluated in consideration of the quantity and quality of hydrogeological information, the reasonableness of model calibration compared to available data, and the consistency and repeatability of the parameter variation simulations. Ultimately, zones of uncertainty were delineated based on professional judgement.

4.5 Threats Assessment

A threats assessment for the existing King's Park and Munster wells was previously undertaken by Dillon Consulting on behalf of the Mississippi-Rideau Source Protection Region. In accordance with direction from the Source Protection Office of the Ministry of the Environment, only threats that could be considered significant according to the established methodology require evaluation. Significant threats can only occur in two general circumstances:

1) In an area where the intrinsic vulnerability score is 8 or 10, or

2) For dense non-aqueous phase liquids (DNAPL's) within WHPA Zones A, B and C.

Potential significant threats to the Mattamy/RV wells were assessed based on these circumstances

5.0 RESULTS

5.1 Groundwater Flow Modelling

Calibration of the groundwater flow model involved the adjustment of recharge rates to the different overburden and bedrock outcrop zones, the adjustment of the hydraulic conductivities of the various overburden and bedrock units, and the adjustment of the boundary conditions until the simulated groundwater elevations and flow directions compared reasonably well to the observed conditions. Figure 16 shows the simulated bedrock groundwater elevations following calibration of the model. The simulated groundwater elevations indicate the overall regional groundwater flow direction is towards the east (Rideau River). Local to the Richmond area, groundwater flow is affected by the presence of the Jock River. In general the simulated groundwater flow patterns are consistent with the inferred groundwater elevation map shown on Figure 5.

In addition to reviewing the regional groundwater flow patterns simulated by the model, the static water levels recorded in the MOE WWIS were utilized as discrete points of comparison for the steady-state calibration of the model. A total of 982 calibration points were used following a QA/QC process which removed spurious and/or suspect data from the database (i.e., as defined by wells with a location or elevation accuracy code of 6 or greater, or where reported groundwater elevations were unreasonably high or low compared to nearby data points). It should be noted that MOE WWIS data collected subsequent to the 2003 assessment were included in the calibration process. Figure 17 shows a plot of calibration and provides calibration statistics. Observations made with respect to this figure are summarized below:

- Generally, the simulated groundwater levels compare reasonably well with the measured groundwater levels. Following the "trial-and-error" calibration process, the residual mean was 0.53 m, the absolute residual mean was 3.5 m, and the normalized RMS error was 5.5%;
- There is not a strong bias in simulated groundwater elevations either above or below the historical measured values; and,
- The dense cluster of data points plotted at an observed elevation of 85 masl reflects observations densely clustered in the Manotick area, while the cluster of wells plotted at about 135 masl reflect monitoring locations near the Mississippi Lake and River. This trend is considered to be a result of underlying variability in the topographic data in the MOE WWIS database.

The horizontal hydraulic conductivities that provided the best fit during model calibration (described previously in Section 4.1.11) lie within, or close to, the boundaries of the range of estimates described in Section 3.0, and are considered reasonable estimates of hydraulic conductivity on a regional scale.

A 72-hour pumping test was conducted at PW09-1 between September 27 and September 30, 2011 (Golder, 2011), and the results from this test were assessed with the calibrated groundwater model as a means of independently verifying the model parameterization. The regional model used in this study over-predicts the drawdown that was observed during the 72-hour pumping test at PW09-1. The bulk transmissivity used in the model is more representative of values derived from the tests completed in the Nepean formation in other locations within the study area (summarized previously in Section 3.0). The transmissivity predicted by the test at PW09-1 is higher, and may be more representative of a localized high conductivity zone. Additional testing would be required to verify this interpretation.

As a part of the 2003 assessment, the groundwater flow model calibration was compared against additional pumping tests conducted at the Kings Park and Munster well systems. Further details can be found in the 2003 assessment report.

The calibrated groundwater flow model provides a reasonable understanding of the groundwater flow conditions within the study area. Through the calibration process it was found that the hydraulic conductivities of the geological units are in good agreement with the site-specific information. The calibrated model values therefore represent suitable estimates for the use in developing the theoretical capture zones for the Richmond wells under forecast pumping rates. Table 3 provides a summary of the input parameters and model details for the final calibrated model.

5.2 Wellhead Protection Areas and Vulnerability Mapping

As described earlier, the capture zones for the Richmond wells were determined by activating the pumping wells in the calibrated groundwater flow model (given the forecast pumping rates described in Section 1.3) and releasing groundwater particles (using MODPATH) at the pumping wells, which are backward-tracked in the direction of their simulated flow paths. The time-related capture zones that are subsequently derived from this analysis represent a two-dimensional projection of the particle outlines to ground surface. This process was completed for the calibrated groundwater flow model and for each of the parameter variation simulations (for a total of 22 simulations). The projected particle traces from all simulations were combined to form the capture zone areas. The 2-year (WHPA Zone B), 5-year (WHPA Zone C), and 25-year (WHPA Zone D) time of travel capture zones for wells PW-08 and PW-09 as predicted using this method are mapped against the calculated intrinsic vulnerability of the aquifer on Figure 18 (ISI method). Also shown on this figure is the Zone A Pathogen Security / Prohibition Zone (100 m radius around well). Review of the figure allows the following observations:

- Due to the proximity of the Jock River, which influences local groundwater flow patterns, the capture zones extend in two directions. The main arm of the capture zones extends towards the west-northwest, in a direction upgradient of regional groundwater flow, through the bedrock, and terminates approximately 14km from the wells in the area of a large wetland located on a topographic high. This arm is approximately 5.5 km in width. The second arm extends approximately 6 km towards the south, beneath the Jock River, and terminates under the large wetland area located south of Richmond. This arm reaches a maximum width of approximately 2 km; and,

- The application of the ISI vulnerability scoring, as described in Section 4.3, resulted in a low groundwater vulnerability score (>80) over the model domain. This occurs as a result of the assumptions made using the ISI evaluation method; the extensive thickness of the geological materials that overly the Nepean Formation (the horizon from which the Richmond wells extract groundwater) provides sufficient isolation to result in a "low" vulnerability score.

Through the parameter variation simulations it was determined that the parameters having the strongest influence on the capture zone splitting (i.e. the "two-arm" configuration) include: the contrast in hydraulic conductivity of the Nepean upper and lower hydrostratigraphic units, variations in hydraulic conductivity of the upper Paleozoic formations, and adjustments to the surface recharge parameter.

5.3 Intrinsic Vulnerability Scoring

Figure 19 illustrates the intrinsic vulnerability scoring within the WHPAs for the Richmond wells. As shown on the figure, the calculated vulnerability score ranges from 10 (limited to WHPA Zone A), to 2 in WHPA Zone D. It should be noted that for dense non-aqueous phase liquids (DNAPLs), the intrinsic vulnerability scoring value is 10 for any area within WHPA zone C, as described in Draft Guidance Module 3. A map showing the DNAPL intrinsic vulnerability scoring for the Richmond pumping wells is provided on Figure 20.

5.4 Uncertainty Analysis

The uncertainty associated with the vulnerability scores within the WHPA was determined in accordance with Draft Guidance Module 3, and is shown on Figure 21. Uncertainty was categorized as either high or low. Based on professional judgement, the areas encompassed within the 2 year WHPA were categorized as "low uncertainty", where the remaining areas within the overall WHPA were categorized as "high uncertainty".

5.5 Threats Assessment

The intrinsic vulnerability scores calculated in Section 5.3 and illustrated on Figure 20 are less than 8, with the exception of WHPA Zone A, the 100 metre zone around each well. Therefore significant threats to the Mattamy/RV wells, exclusive of DNAPL's, can only occur within WHPA Zone A.

The current land use on the site is agricultural, but this will change to residential/parkland as development proceeds. Based on the current methodology, sewage connections and laterals are defined as wastewater collection facilities and are considered significant threats in areas, such as WHPA Zone A, with an intrinsic vulnerability score of 10. It is our understanding that the MOE has determined that the provision of additional safeguards, such as double lined sewer pipes and more frequent inspections, will be sufficient to mitigate threats from sewage collection infrastructure.

No activities that may propose a significant threat will be permitted within WHPA- Zone A. As of the date of this report, the Source Protection Office has not confirmed that additional restrictions on land usage within WHPA Zone A are being contemplated.

The storage and handling of DNAPL's is considered a significant threat within WHPA Zones A, B and C (within a 5 year time-of-travel). The capture zones considered as a part of the current study were reviewed and compared to the similar capture zones for the Richmond King's Park model. Both computer and on-ground surveys were used to determine if any potential users of DNAPL's were within the additional 5 year TOT that was not included in the existing assessment report. No additional sources, such as dry cleaners, manufacturing facilities or wood product manufacturers were identified.

6.0 DATA GAPS

Significant data gaps identified in this study include:

- Characterization of the porosity of the hydrostratigraphic units. Assumed values for effective porosity of the overburden and bedrock units are used in estimating the groundwater velocity (and therefore travel time through a given formation) in the current analysis. Testing (isotope analysis) of groundwater samples from the Nepean Formation from the pumping wells would provide a better estimate of the groundwater travel time through the aquifer and could be used to improve the delineation of the WHPAs. The required testing is not covered under the current project scope;
- Characterization of the bedrock fracture network. Additional data relating to the orientation and extent of the bedrock fracture network identified during well drilling and on regional mapping would provide a better understanding of preferential flow pathways through the bedrock, and improve certainty with respect to the size and orientation of the WHPAs. However, a study of the bedrock fracture network would require significant effort, extending well beyond the scope of the current work;
- The threats assessment included the areas within the new WHPA Zone C, but excluded the areas of overlap between the King's Park capture zones and the new capture zones. These areas should be re-assessed during the next source protection iteration; and,
- Groundwater users within the model domain were identified based on the available information, including PTTW records, though pumping records were not always available. Incorporation of actual pumping rates into the groundwater model could improve overall delineation of the WHPAs.

7.0 LIMITATIONS

This report was prepared for the use of Richmond Village (South) Limited. The report, which specifically includes all tables, figures and appendices, is based on data gathered by Golder Associates Ltd., and information provided to Golder Associates Ltd. by others. The information provided by others has not been independently verified or otherwise examined by Golder Associates Ltd. to determine the accuracy or completeness. Golder Associates Ltd. has relied in good faith on this information and does not accept responsibility for any deficiency, misstatements, or inaccuracies contained in the information as a result of omissions, misinterpretation or fraudulent acts.

The assessment of environmental conditions and possible hazards at this site has been made using the results of physical measurements from a number of locations. The site conditions between testing locations have been inferred based on conditions observed at the testing locations. Actual conditions may deviate from the inferred values.

Hydrogeological investigations and groundwater modelling are dynamic and inexact sciences. They are dynamic in the sense that the state of any hydrological system is changing with time, and in the sense that the science is continually developing new techniques to evaluate these systems. They are inexact in the sense that groundwater systems are complicated beyond human capability to evaluate them comprehensively in detail, and we invariably do not have sufficient data to do so. A groundwater model uses the laws of science and mathematics to draw together the available data into a mathematical or computer-based representation of the essential features of an existing hydrogeological system. While the model itself obviously lacks the detailed reality of the existing hydrogeological system, the behaviour of a valid groundwater model reasonably approximates that of the real system. The validity and accuracy of the model depends on the amount of data available relative to the degree of complexity of the geologic formations, the site geochemistry, the fate and transport of the dissolved compounds, and on the quality and degree of accuracy of the data entered. Therefore, every groundwater model is a simplification of a reality and the model described in this report is not an exception.

The professional groundwater modelling services performed as described in this report were conducted in a manner consistent with that level of care and skill normally exercised by other members of the engineering and science professions currently practising under similar conditions, subject to the quality and quality of available data, the time limits and financial and physical constraints applicable to the services. Unless otherwise specified, the results of previous or simultaneous work provided by sources other than Golder Associates Ltd. and quoted and/or used herein are considered as having been obtained according to recognized and accepted professional rules and practices, and therefore deemed valid. This model provides a predictive scientific tool to evaluate the impacts on a real groundwater system of specified hydrological stresses and/or to compare various scenarios in a decision-making process. However and despite the professional care taken during the construction of the model and in conducting the simulations, its accuracy is bound to the normal uncertainty associated to groundwater modelling and no warranty, express or implied, is made.

Any use which a third party makes of this report, or any reliance on, or decisions to be made based on it, are the responsibilities of such third parties. Golder Associates Ltd. accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made, or actions taken based on this report.

8.0 CLOSURE

We trust the information presented in this report meets your requirements. Should you have any questions or concerns, please contact the undersigned.

Yours truly,

GOLDER ASSOCIATES LTD.

Nicholas Bishop, M.Sc., P.Eng.
Geological Engineer

PROFESSIONAL GEOSCIENTIST
March 13, 2012
STEPHEN R. WILSON
PRACTISING MEMBER
0122
ONTARIO

Stephen Wilson, P.Geo.
Senior Hydrogeologist/Associate

Melissa Bunn, Ph.D.
Groundwater Scientist

NFB/MIB/SRW/sg
n:\active\2011\1127 - geosciences\11-1127-0134 richmond village groundwater vulnerability\reporting\groundwater vulnerability report final.docx

REFERENCES

Geo-Analysis Inc., 1991. Hydrogeologic Evaluation – Potential for Village Expansion Based on Private Individual Services, Village of Richmond. May 1991.

Golder Associates Ltd., 2001. Hydrogeological Evaluation for Communal Water Supply in Support of the Groundwater Component Requirement for a Permit to Take Water and Water Works C of A. May 2001.

Golder Associates Ltd., 2003. Wellhead Protection Study, Munster Hamlet and Kings Park Communal Wells, City of Ottawa, MVCA Study Group. April 2003.

Golder Associates Ltd., 2004. Hydrogeological Evaluation for Communal Water Back-Up Supply Well in Support of the Groundwater Component Requirement for a Permit to Take Water, Hyde Park Townhome Project, Ottawa, Ontario. November 2004.

Golder Associates Ltd., 2006. Hydrogeological Investigation – Proposed Residential Subdivision, Lot 24 and 25, Concession III, Village of Richmond, Ottawa, Ontario.

Golder Associates Ltd., 2008a. Mattamy Richmond Lands, Preliminary Existing Conditions Analysis: Hydrogeology. May, 2008.

Golder Associates Ltd., 2008b. Wellhead Protection Area Maps – Carp, Munster and Kings Park, Ottawa, Ontario. May 2008.

Golder Associates Ltd., 2009. Vulnerability of the Upper Aquifer Wellhead Protection Areas of the Munster Hamlet and Kings Park Municipal Wells. May 2009. Report No. 09-1127-0035.

Golder Associates Ltd., 2010a. Wellhead Protection Area Plan, Hyde Park Development, City of Ottawa (Richmond), Ontario. January, 2010. Report No. 08-1122-0275.

Golder Associates Ltd., 2010b. Hydrogeological Investigation – Proposed Mattamy Homes Development – Richmond (Ottawa), Ontario. Technical Memorandum to Sue Murphy (Mattamy Homes) dated July 16, 2010. 08-1122-0078/9600.

Golder Associates Ltd., 2011. Summary of the Hydrogeological Investigation, Production Well PW09-1 – Western Development Lands, Village of Richmond, Ottawa, Ontario. Technical Memorandum to City of Ottawa dated November 10, 2011. 08-1122-0078.

Graham Berman & Associates, 1971. Groundwater Report Kings Park Subdivision – Richmond, Ontario. December 1971.

Jacques Whitford Limited, 1990. Hydrogeological Study Munster Hamlet.

Jacques Whitford Limited, 1991. Hydrogeological Study King's Park Subdivision, Richmond. March 1991.

Ontario Ministry of the Environment, 2006. Assessment Report: Draft Guidance Module 3 – Groundwater Vulnerability Analysis. October 2006.

Ontario Ministry of the Environment, 2009. Technical Rules: Assessment Report, Clean Water Act, 2006. Amended on November 16, 2009.

Pollock, David W., 1989. Documentation of Computer Programs to Compute and Display Pathlines using Results from the U.S. Geological Survey Modular Three-Dimensional Finite-Difference Ground-water Flow Model. USGS Open File Report 89-381.

Raven Beck Environmental Ltd., 1996. Supplementary Bedrock Hydrogeologic Investigation of PCE Contamination, Village of Manotick. Final Report prepared for the Ontario Ministry of the Environment and Energy.

Stantec Consulting Ltd. 2011. Village of Richmond Water & Sanitary Master Servicing Study.

USGS, 2000. The U.S. Geological Survey Modular Ground-Water Model – User Guide to Modularization Concepts and Ground-Water Flow Process. By A.W. Harbaugh, E.R. Banta, M.C. Hill and M.G. McDonald. U.S.G.S Open-File Report 00-92.

Table 1
Richmond Groundwater Vulnerability
Well Details

Well Name	UTM - Easting (m)	UTM - Northing (m)	Depth to Bedrock (m)	Casing Depth (m)	Total Depth (m)	Formation
PW08-1	433874	5003838	3.4	45.72	137.16	Upper Nepean
PW09-1	433898	5003808	0	45.72	70	Upper Nepean
PW09-2	433897	5003811	4.3	45.72	77.72	Upper Nepean

Created By: NFB
Checked By: SRW

Table 2
Richmond Groundwater Vulnerability
Summary of Previous Well Testing

Location	Geological Unit	Minimum Transmissivity (m^2/day)	Maximum Transmissivity (m^2/day)	Reference
Village of Richmond	Oxford	9	248	Golder (2006)
Village of Richmond	Oxford	5	100	GeoAnalysis (1991)
Village of Richmond	Oxford, March and Nepean	236	236	Golder (2001), Golder (2008a)
Village of Richmond	Oxford, March and Nepean	112	130	Golder (2004), Golder (2008a)
Village of Richmond	Oxford, March and Nepean	256	658	Graham Berman and Associates (1971)
Village of Richmond	Oxford, March and Nepean	279	642	Jacques Whitford (1991)
Munster	Oxford, March and Nepean	54	370	Jacques Whitford (1990)
Manotick	March and Upper Nepean	600	600	Raven Beck (1996)
Village of Richmond	Nepean	328	700	Golder (2011)
Village of Richmond	Nepean	500	800	Golder (2011)

Created By: MIB
Checked By: NFB

Table 3
Richmond Groundwater Vulnerbality Study
Summary of Base Case Modelling Parameterization

Basic Model Construction - MODFLOW Grid Details

Number of Cells	158242	
Number of Layers	7	
Model Top	variable	(defined by DEM)
Model Bottom	variable	(defined by geology)
Nodal Spacing	5 to 500 m	(variable range)

Hydraulic Properties of Model Hydrostratigraphic Units

	Horizontal Hydraulic Conductivity, K_h (m/s)	Vertical Hydraulic Conductivity, K_v (m/s)	Effective Porosity
Overburden	$5x10^{-7}$	$=K_h$	0.25
Upper Paleozoic Formations	$5x10^{-7}$	$=K_h$	0.001
Upper Nepean	$4x10^{-4}$	$=K_h$	0.017
Middle Nepean (except Munster area)	$4x10^{-4}$	$=K_h$	0.017
Middle Nepean (Munster area)	$1x10^{-5}$	$=K_h$	0.001
Lower Nepean	$1x10^{-5}$	$=K_h$	0.001
Upper Precambrian	$1x10^{-7}$	$=K_h$	0.001
Lower Precambrian	$1x10^{-8}$	$=K_h$	0.0001

Model Boundary Conditions

- Variable surficial recharge, ranging from 5 to 200 mm/yr (see Figure 14)
- Refer to Figure 13 for a summary of groundwater model flow boundaries

Model Assumptions

- The geological data used in the development of the model was derived from geological information depicted on governmental agency maps, presented in public reports and studies, and filtered from the MOE Water Well Information System.
- Flow is laminar and steady, and is governed by Darcy's Law.
- Regional groundwater flow is simulated using an "equivalent porous media" approach
- Hydraulic heads are vertically averaged within a given model layer.
- A 1:1 horizontal to vertical anisotropy ratio was assumed.
- Except for the middle Nepean layer (Layer #4), a homogeneous hydraulic conductivity was applied for each hydrostratigraphic unit. Spatial variation of material properties within Layer #4 was based on faulted geological contacts reported northeast and southwest of Munster.
- Modelling and capture zone calculations were done at steady-state and therefore the predictions reflect average long-term conditions based on historical data. The potential effects of short-term "out of the ordinary" conditions (floods, severe rainfalls, etc.) were not considered neither the potential effects of long-term climate changes.
- The capture zones that delineate the WHPAs were derived by using a forecast pumping rate based on the estimated build-out of the Richmond Development
- Results assume that no other major water takings occur in the aquifer system that would change the flow directions or water balance near the capture zone of the Kings Park and Munster wells
- There is no differentiation in the overburden units.
- Recharge estimates reflect deeper recharge and discharge characteristics of the groundwater flow system, and do not account for shallow infiltration and discharge to intermittent streams (i.e. interflow).
- Mapped faults and faulted geological contacts were considered to be transparent to groundwater migration and were not explicitly included in the model
- Major rivers and large wetland areas were considered to potentially influence the deep groundwater flow and were included in the model
- A "regionalized" approach to model calibration was employed, such that parameter values were established for the hydrostratigraphic units on a regional scale. Minor, local variations in hydraulic conductivity (which might locally appear to improve the calibration at specific monitoring wells and therefore reduce the overall statistical measure of the calibration error) were not simulated.
- The most recent groundwater elevation data available were used in the calibration process. These are assumed to approximate steady-state conditions.

Created by: NFB
Checked by: SRW

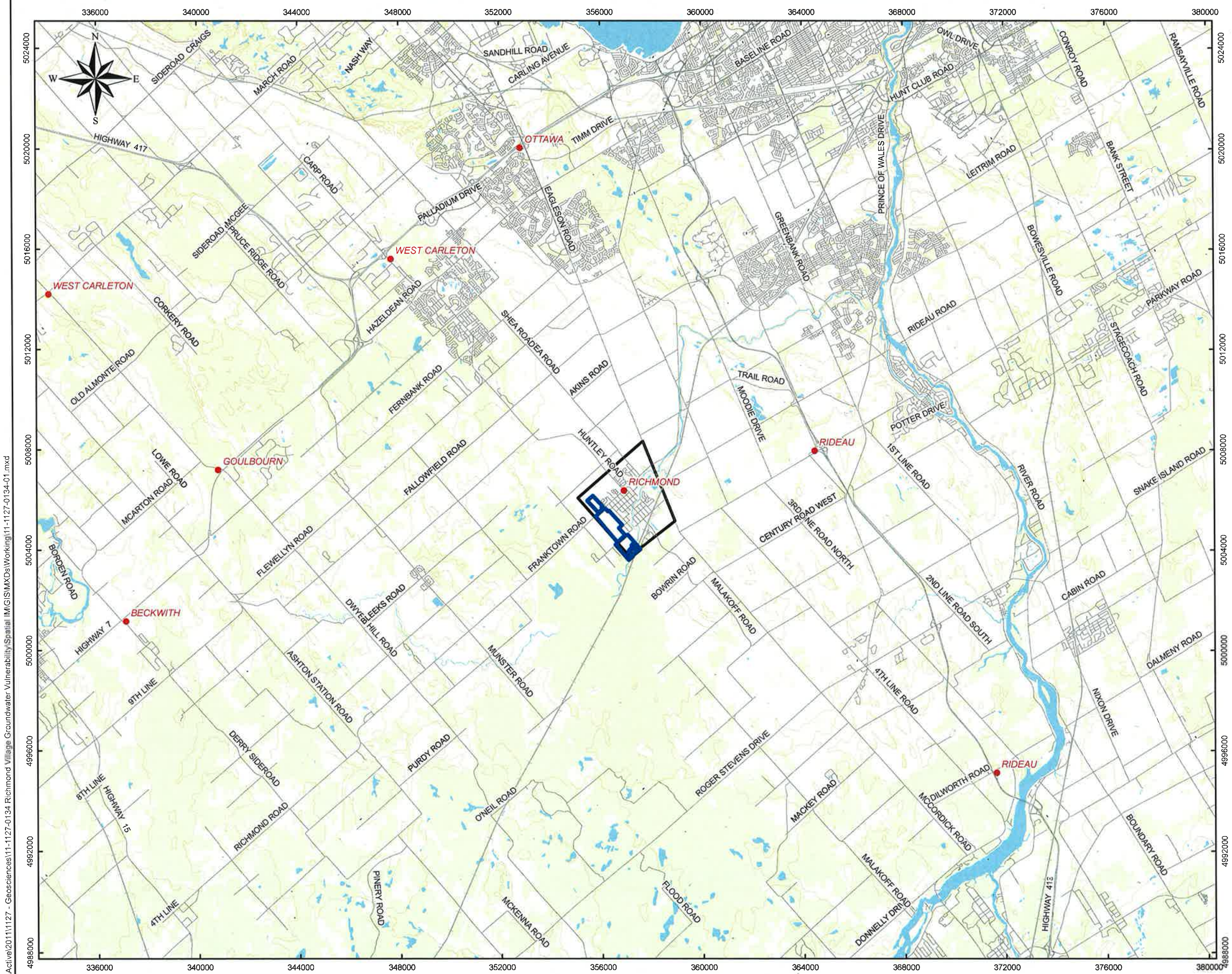
Table 4
Richmond Groundwater Vulnerbality Study
Summary of Modelling Scenarios

Run	Hydraulic Conductivity (m/s)			Recharge Rates (mm/yr)			Porosity (-)		
	Oxford Formation	Upper Nepean and Middle Nepean (Except Munster Area)	Lower Nepean and Middle Nepean (Munster Area)	Clayey Material	Till and Bedrock Outcrops	Stratified Ice Contact Sand and Gravel	Oxford Formation	Upper Nepean and Middle Nepean (except Munster Area)	Lower Nepean and Middle Nepean (Munster Area)
1	5.0E-07	4.0E-04	1.0E-05	5	15	200	0.001	0.017	0.001
2	2.5E-07	4.0E-04	1.0E-05	5	15	200	0.001	0.017	0.001
3	1.0E-07	4.0E-04	1.0E-05	5	15	200	0.001	0.017	0.001
4	1.0E-06	4.0E-04	1.0E-05	5	15	200	0.001	0.017	0.001
5	2.5E-06	4.0E-04	1.0E-05	5	15	200	0.001	0.017	0.001
6	5.0E-07	2.0E-04	1.0E-05	5	15	200	0.001	0.017	0.001
7	5.0E-07	4.0E-04	5.0E-06	5	15	200	0.001	0.017	0.001
8	5.0E-07	4.0E-04	2.0E-05	5	15	200	0.001	0.017	0.001
9	5.0E-07	4.0E-04	1.0E-05	2.5	15	200	0.001	0.017	0.001
10	5.0E-07	4.0E-04	1.0E-05	10	15	200	0.001	0.017	0.001
11	5.0E-07	4.0E-04	1.0E-05	5	7.5	200	0.001	0.017	0.001
12	5.0E-07	4.0E-04	1.0E-05	5	30	200	0.001	0.017	0.001
13	5.0E-07	4.0E-04	1.0E-05	5	15	50	0.001	0.017	0.001
14	2.5E-07	4.0E-04	1.0E-05	2.5	15	200	0.001	0.017	0.001
15	1.0E-06	4.0E-04	1.0E-05	10	15	200	0.001	0.017	0.001
16	2.5E-07	4.0E-04	1.0E-05	5	7.5	200	0.001	0.017	0.001
17	1.0E-06	4.0E-04	1.0E-05	5	30	200	0.001	0.017	0.001
18	5.0E-07	4.0E-04	1.0E-05	5	15	200	0.01	0.017	0.001
19	5.0E-07	4.0E-04	1.0E-05	5	15	200	0.001	0.017	0.017
20	5.0E-07	4.0E-04	1.0E-05	5	15	200	0.001	0.034	0.034
21	5.0E-07	2.0E-04	2.0E-05	5	7.5	200	0.001	0.017	0.001
22	5.0E-07	2.0E-04	2.0E-05	5	7.5	200	0.001	0.034	0.034

Notes:

- Only parameters varied in the sensitivity analysis have been included in the table
- Shaded values indicate a change from the base case simulation

Created By: MIB
Checked By: NFB



LEGEND

- POPULATED PLACE
- MATTAMY RICHMOND LANDS
- RAILWAY
- ROAD
- TOPOGRAPHIC CONTOUR 10m
- WATERBODY
- VEGETATION
- RICHMOND VILLAGE BOUNDARY

NOTE

THIS FIGURE IS TO BE READ IN CONJUNCTION WITH THE ACCOMPANYING GOLDER ASSOCIATES LIMITED REPORT NO. 11-1127-0134

REFERENCE

BASE DATA - CANVEC PROVIDED BY HER MAJESTY THE QUEEN IN RIGHT OF CANADA, DEPARTMENT OF NATURAL RESOURCES
PROJECTION: TRANSVERSE MERCATOR DATUM: NAD 83
COORDINATE SYSTEM: UTM ZONE 18

5 0 5

SCALE 1:150,000 KILOMETRES

PROJECT

RICHMOND VILLAGE
GROUNDWATER VULNERABILITY

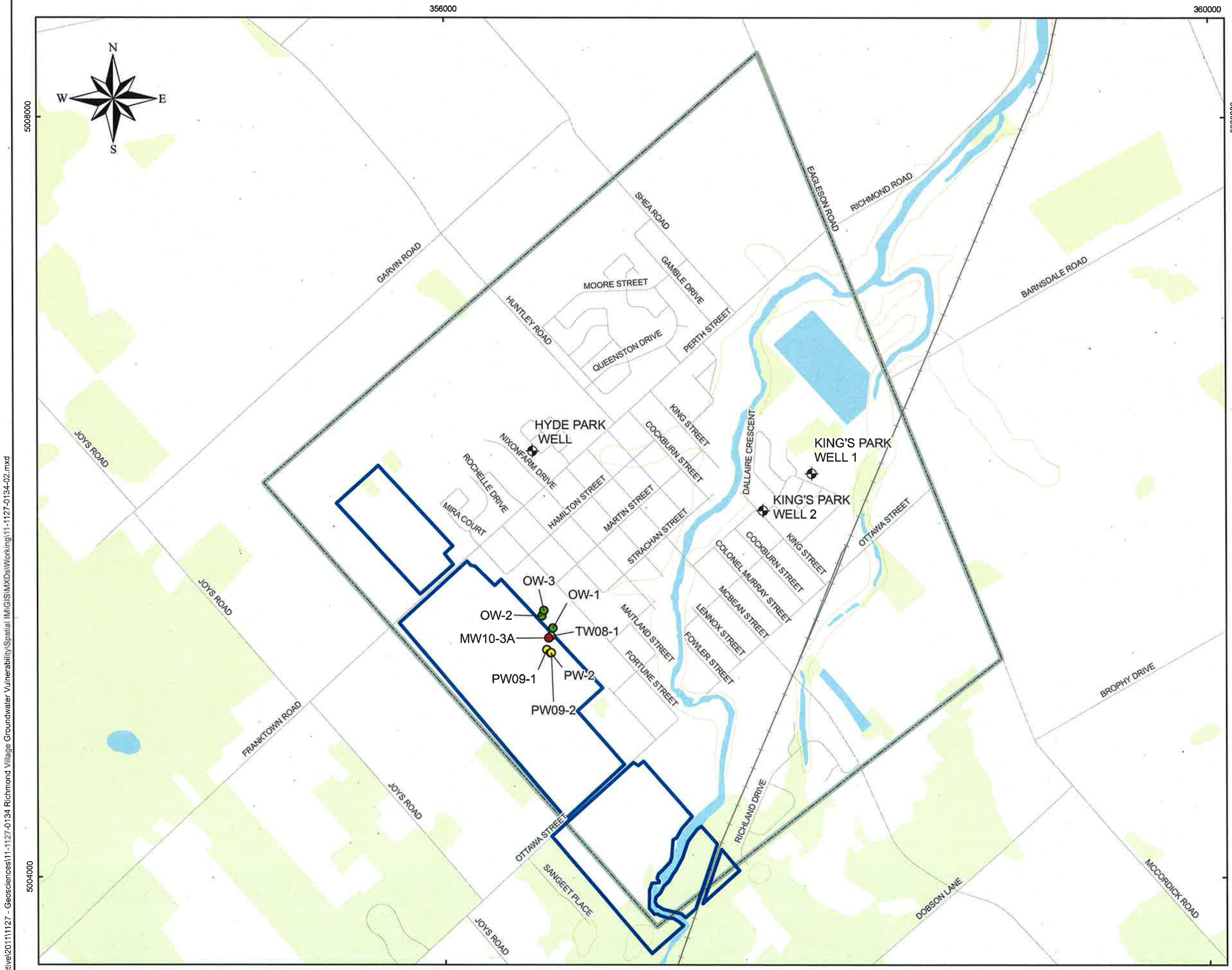
TITLE

KEY PLAN

Golder Associates
Ottawa, Ontario

PROJECT No. 11-1127-0134			SCALE AS SHOWN	REV. 0.0
DESIGN	NB	15 Feb. 2012	**FIGURE 1**	
GIS	BJ	15 Feb. 2012		
CHECK		12/03/12		
REVIEW		12/3/12		

N:\Active\2011\1127 - Geosciences\11-1127-0134 Richmond Village Groundwater Vulnerability\Spatial IM\GIS\MXDs\Working\11-1127-0134-01.mxd



LEGEND

- OBSERVATION WELL (INSTALLED BY OTHERS)
- OBSERVATION WELL (INSTALLED BY GOLDER)
- TEST WELL (INSTALLED BY GOLDER)
- WELL
- MATTAMY RICHMOND LANDS
- RAILWAY
- ROAD
- TOPOGRAPHIC CONTOUR (m)
- RICHMOND VILLAGE BOUNDARY
- WATERBODY
- VEGETATION

NOTE

THIS FIGURE IS TO BE READ IN CONJUNCTION WITH THE ACCOMPANYING GOLDER ASSOCIATES LIMITED REPORT NO. 11-1127-0134

REFERENCE

BASE DATA - CANVEC PROVIDED BY HER MAJESTY THE QUEEN IN RIGHT OF CANADA, DEPARTMENT OF NATURAL RESOURCES
PROJECTION: TRANSVERSE MERCATOR DATUM: NAD 83
COORDINATE SYSTEM: UTM ZONE 18

500 0 500
SCALE 1:20,000 METRES

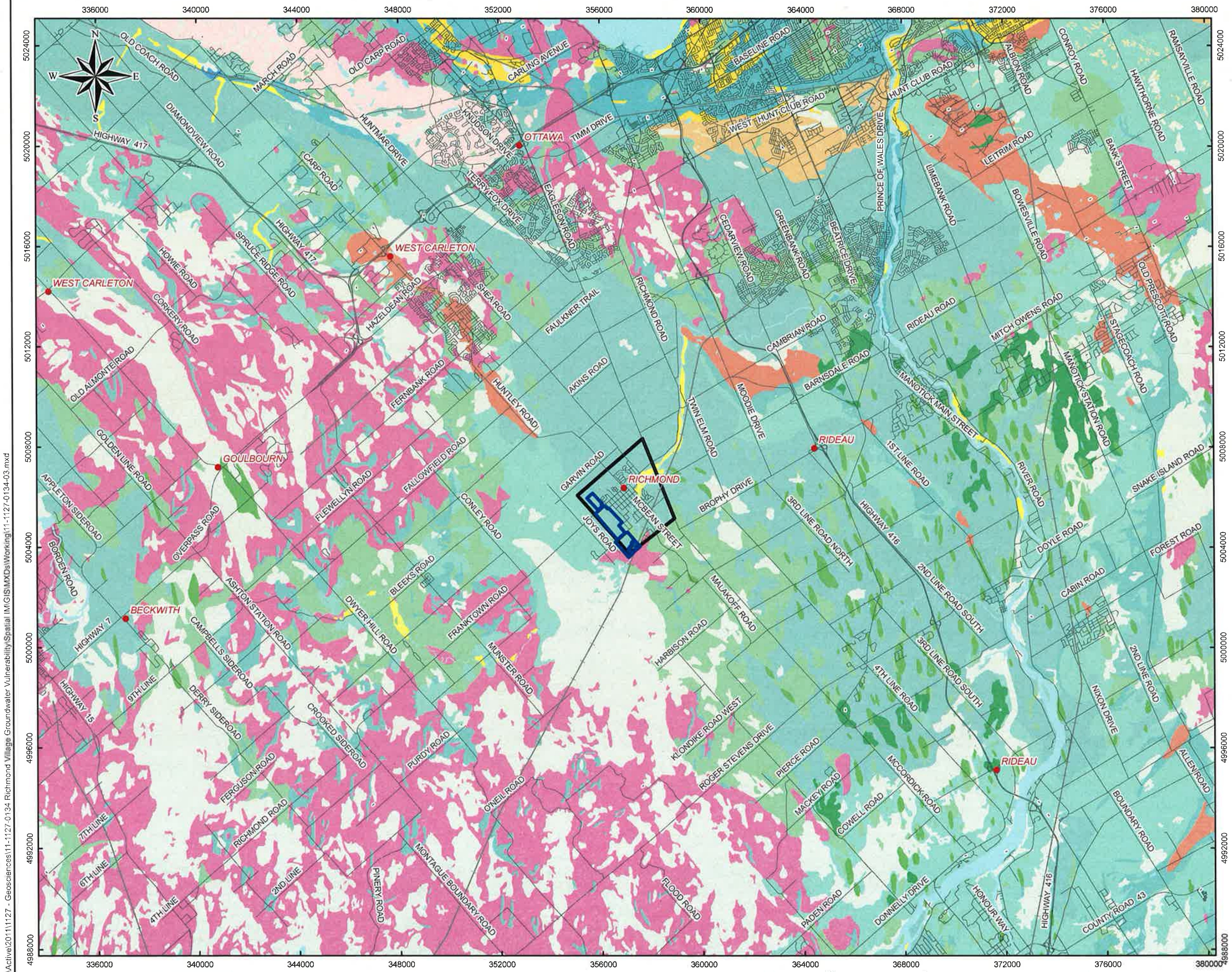
PROJECT
RICHMOND VILLAGE
GROUNDWATER VULNERABILITY

TITLE
SITE PLAN

Golder Associates
Ottawa, Ontario

PROJECT No. 11-1127-0134			SCALE AS SHOWN	REV. 0.0
DESIGN	NB	15 Feb. 2012	**FIGURE 2**	
GIS	BT	15 Feb. 2012		
CHECK		03/12/2012		
REVIEW		3/11/12		

N:\Active\2011\1127 - Geosciences\11-1127-0134 Richmond Village Groundwater Vulnerability\Spatial IM\GIS\MXDs\Working\11-1127-0134-02.mxd



LEGEND

- POPULATED PLACE
- MATTAMY RICHMOND LANDS
- RAILWAY
- ROAD
- RICHMOND VILLAGE BOUNDARY

SURFICIAL GEOLOGY

- ORGANIC DEPOSITS
- SAND DUNES
- FLOODPLAINS, SAND, SILT, CLAY
- FLUVIAL TERRACES, SAND, SILT
- REWORKED MARINE SEDIMENTS
- BEACH FORMATIONS
- SAND, REWORKED GLACIOFLUVIAL
- DELTAIC AND ESTUARIAN DEPOSITS
- MARINE DEPOSITS, CLAY, SILT
- EROSIONAL TERRACES
- GLACIOFLUVIAL DEPOSITS
- TILL, PLAIN
- TILL, DRUMLINIZED
- TILL, HUMMOCKY TO ROLLING
- PALEOZOIC BEDROCK
- PRECAMBRIAN BEDROCK
- WATER

NOTE

THIS FIGURE IS TO BE READ IN CONJUNCTION WITH THE ACCOMPANYING GOLDER ASSOCIATES LIMITED REPORT NO. 11-1127-0134

REFERENCE

1. CANVEC PROVIDED BY HER MAJESTY THE QUEEN IN RIGHT OF CANADA, DEPARTMENT OF NATURAL RESOURCES
2. BÉLANGER, J. R., URBAN GEOLOGY OF THE NATIONAL CAPITAL AREA, GEOLOGICAL SURVEY OF CANADA, OPEN FILE D3256, 2001

PROJECTION: TRANSVERSE MERCATOR DATUM: NAD 83
COORDINATE SYSTEM: UTM ZONE 18

5 0 5
SCALE 1:150,000 KILOMETRES

PROJECT

RICHMOND VILLAGE
GROUNDWATER VULNERABILITY

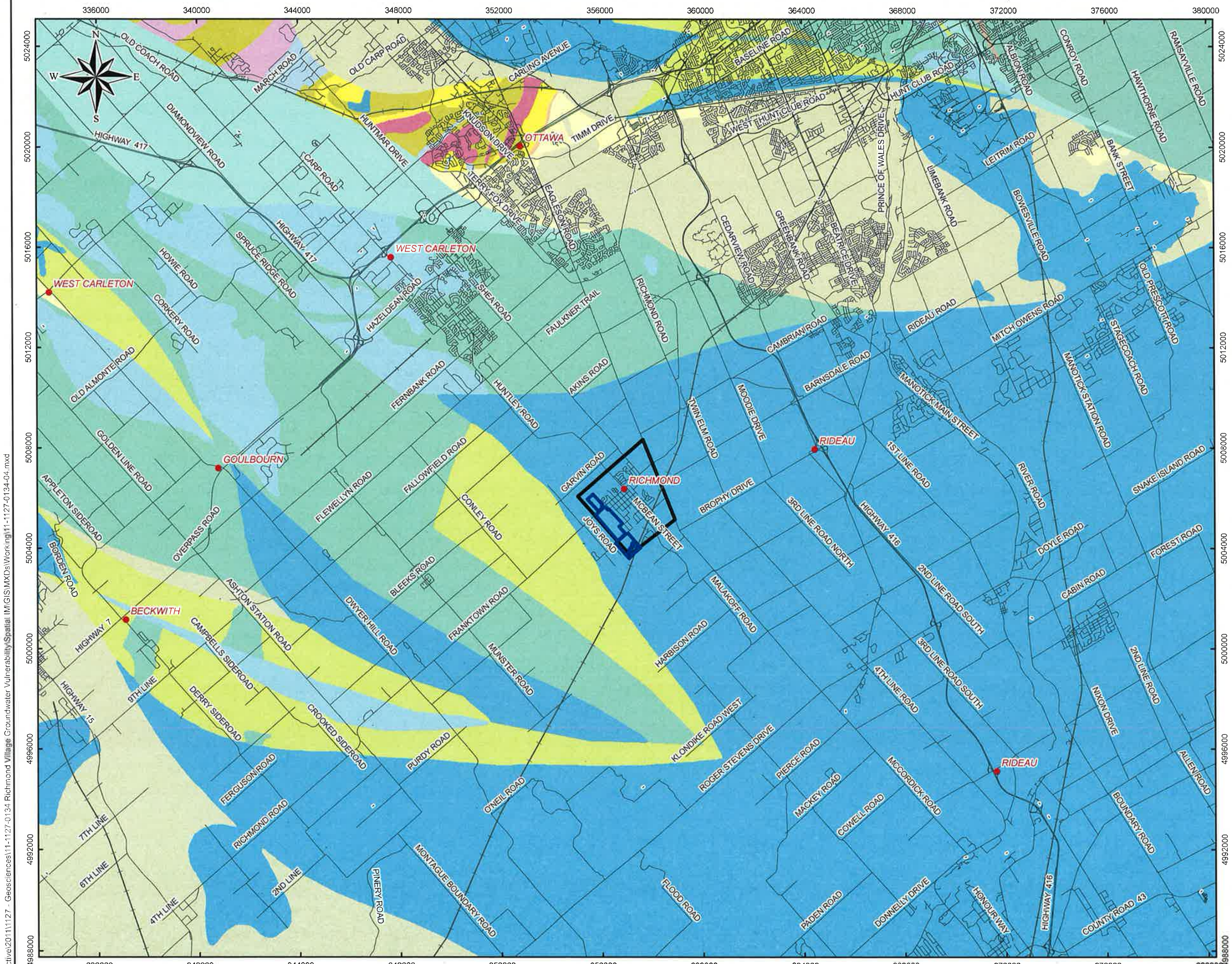
TITLE

SURFICIAL GEOLOGY

Golder Associates
Ottawa, Ontario

PROJECT No. 11-1127-0134			SCALE AS SHOWN	REV. 0.0
DESIGN	NB	15 Feb. 2012	**FIGURE 3**	
GIS	BJ	15 Feb. 2012		
CHECK				
REVIEW				

N:\Active\2011\1127 - Geosciences\11-1127-0134 Richmond Village Groundwater Vulnerability\Spatial IM\GIS\MXDs\Working\11-1127-0134-03.mxd



LEGEND

- POPULATED PLACE
- MATTAMY RICHMOND LANDS
- RAILWAY
- ROAD
- RICHMOND VILLAGE BOUNDARY

BEDROCK GEOLOGY

- QUEENSTON FORMATION
- CARLSBAD FORMATION
- BILLINGS FORMATION
- EASTVIEW FORMATION
- LINDSAY FORMATION
- VERULAM FORMATION
- BOBCAYGEON FORMATION
- GULL RIVER FORMATION
- ROCKLIFFE FORMATION
- OXFORD FORMATION
- MARCH FORMATION
- NEPEAN FORMATION
- COVEY HILL FORMATION
- GRANITIC (QUARTZ-RICH)
- SYENITIC (QUARTZ-POOR)
- BASALTIC ORIGIN, AMPHIBOLITE
- DIORITE, GABBRO
- GRANITIC ORIGIN, PARAGNEISS
- NON CARBONATE, QUARTZITE
- CARBONATE, MARBLE
- DYKES, PEGMATITE

NOTE

THIS FIGURE IS TO BE READ IN CONJUNCTION WITH THE ACCOMPANYING GOLDER ASSOCIATES LIMITED REPORT NO. 11-1127-0134

REFERENCE

1. CANVEC PROVIDED BY HER MAJESTY THE QUEEN IN RIGHT OF CANADA, DEPARTMENT OF NATURAL RESOURCES
2. BÉLANGER, J. R., URBAN GEOLOGY OF THE NATIONAL CAPITAL AREA, GEOLOGICAL SURVEY OF CANADA, OPEN FILE D3256, 2001

PROJECTION: TRANSVERSE MERCATOR DATUM: NAD 83
COORDINATE SYSTEM: UTM ZONE 18

5 0 5
SCALE 1:150,000 KILOMETRES

PROJECT

RICHMOND VILLAGE
GROUNDWATER VULNERABILITY

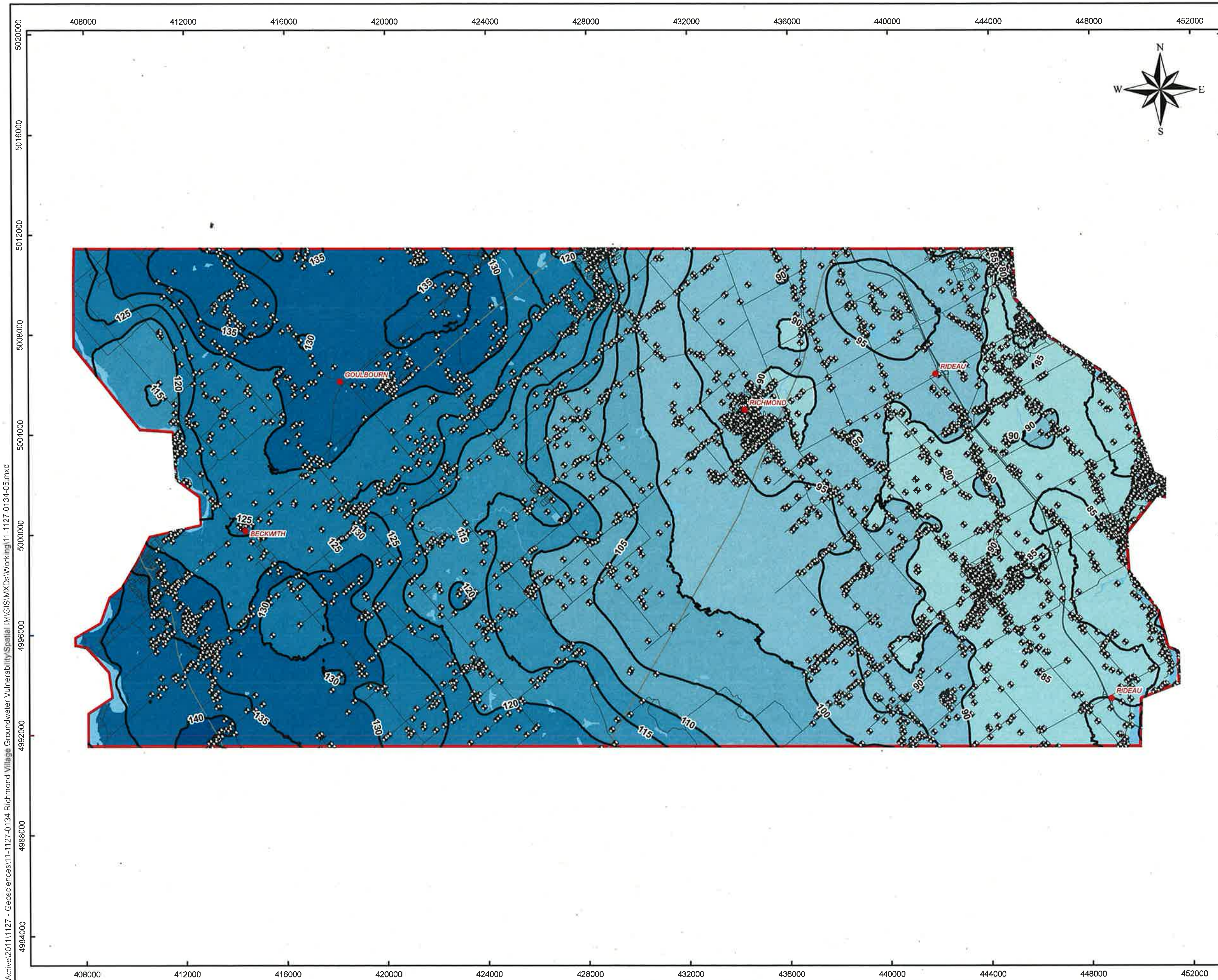
TITLE

BEDROCK GEOLOGY

Golder Associates
Ottawa, Ontario

PROJECT No. 11-1127-0134			SCALE AS SHOWN	REV. 0.0
DESIGN	NB	15 Feb. 2012	FIGURE 4	
GIS	BJ	15 Feb. 2012		
CHECK				
REVIEW				

N:\Active\2011\1127 - Geosciences\11-1127-0134 Richmond Village Groundwater Vulnerability\Spatial IM\GIS\MXDs\Working\11-1127-0134-04.mxd



LEGEND

- POPULATED PLACE
- WATER WELLS (UTM RELIABILITY CODE <=6)
- GROUNDWATER CONTOUR (5m)
- RAILWAY
- ROAD
- MODEL BOUNDARY
- WATERBODY

GROUNDWATER ELEVATION (mASL)

- < 80
- 80 - 90
- 90 - 100
- 100 - 110
- 110 - 120
- 120 - 130
- 130 - 140
- 140 - 150

NOTE

THIS FIGURE IS TO BE READ IN CONJUNCTION WITH THE ACCOMPANYING GOLDER ASSOCIATES LIMITED REPORT NO. 11-1127-0134

REFERENCE

CANVEC DATA PROVIDED BY HER MAJESTY THE QUEEN IN RIGHT OF CANADA, DEPARTMENT OF NATURAL RESOURCES
PROJECTION: TRANSVERSE MERCATOR DATUM: NAD 83
COORDINATE SYSTEM: UTM ZONE 18

5 0 5

SCALE 1:150,000 KILOMETRES

PROJECT

RICHMOND VILLAGE
GROUNDWATER VULNERABILITY

TITLE

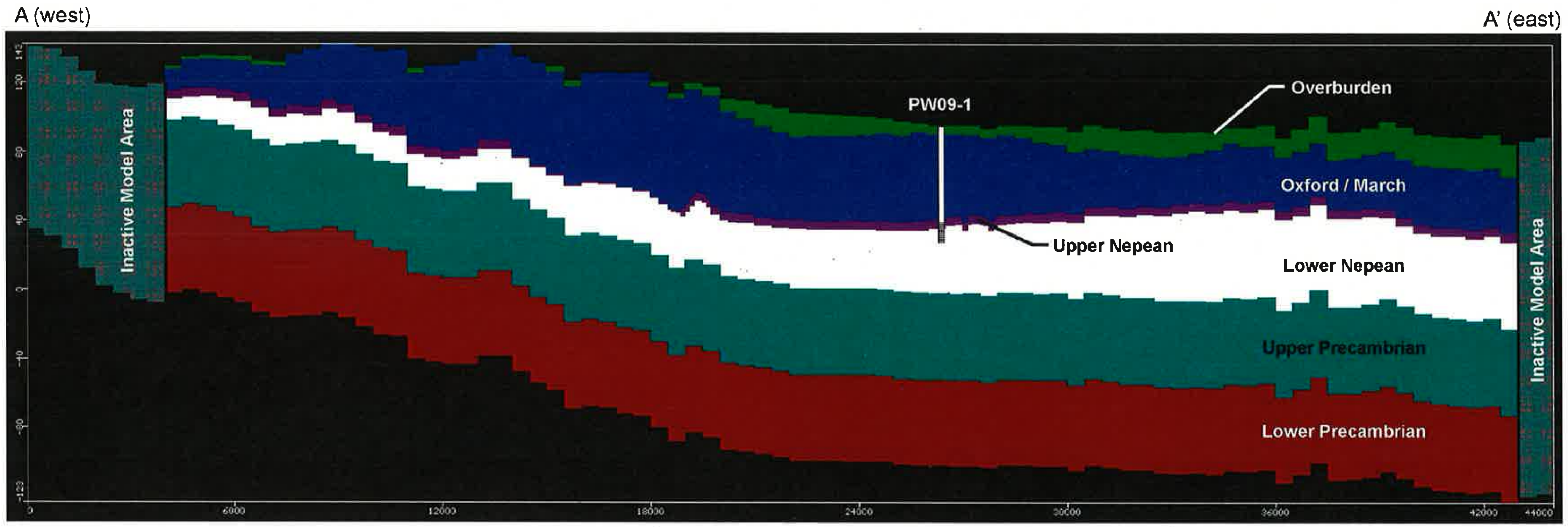
GROUNDWATER ELEVATION IN NEPEAN FORMATION AQUIFER

Golder Associates
Ottawa, Ontario

PROJECT No. 11-1127-0134			SCALE AS SHOWN	REV. 0.0
DESIGN	NB	15 Feb. 2012		
GIS	BJ	15 Feb. 2012		
CHECK		03/2/2012		
REVIEW		3/2/12		

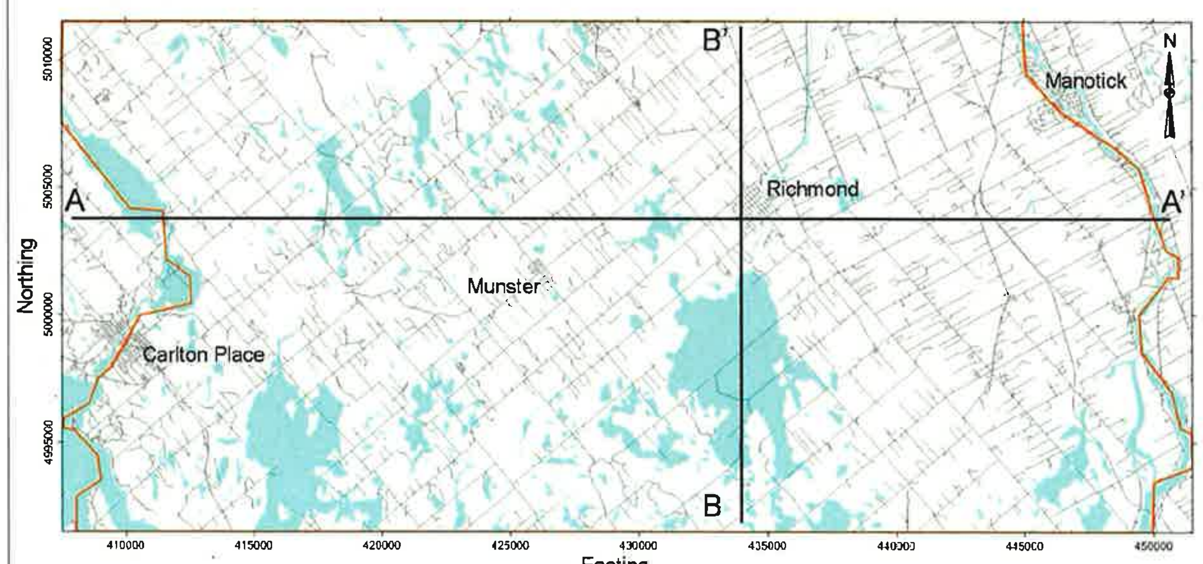
FIGURE 5

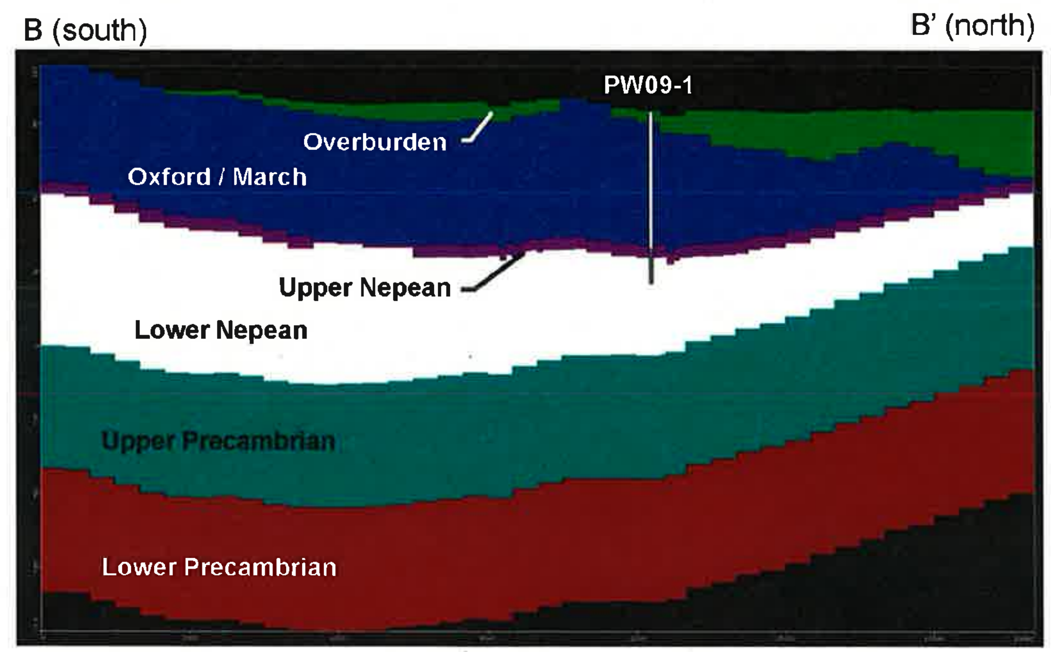
N:\Active\2011\1127 - Geosciences\11-1127-0134 Richmond Village Groundwater Vulnerability\Spatial IM\GIS\MXDs\Working\11-1127-0134-05.mxd



LEGEND

- Overburden ($5x10^{-7}$ m/s)
- Oxford / March Formation ($5x10^{-7}$ m/s)
- Upper Nepean ($4x10^{-4}$ m/s)
- Lower Nepean ($1x10^{-5}$ m/s)
- Upper Precambrian ($1x10^{-7}$ m/s)
- Lower Precambrian ($1x10^{-8}$ m/s)





NOTE

1. THIS FIGURE IS TO BE READ IN CONJUNCTION WITH THE ACCOMPANYING GOLDER ASSOCIATES LTD. REPORT No. 11-1127-0134
2. THIS FIGURE IS NOT TO SCALE.

PROJECT

RICHMOND VILLAGE WELL SYSTEM - GROUNDWATER VULNERABILITY STUDY

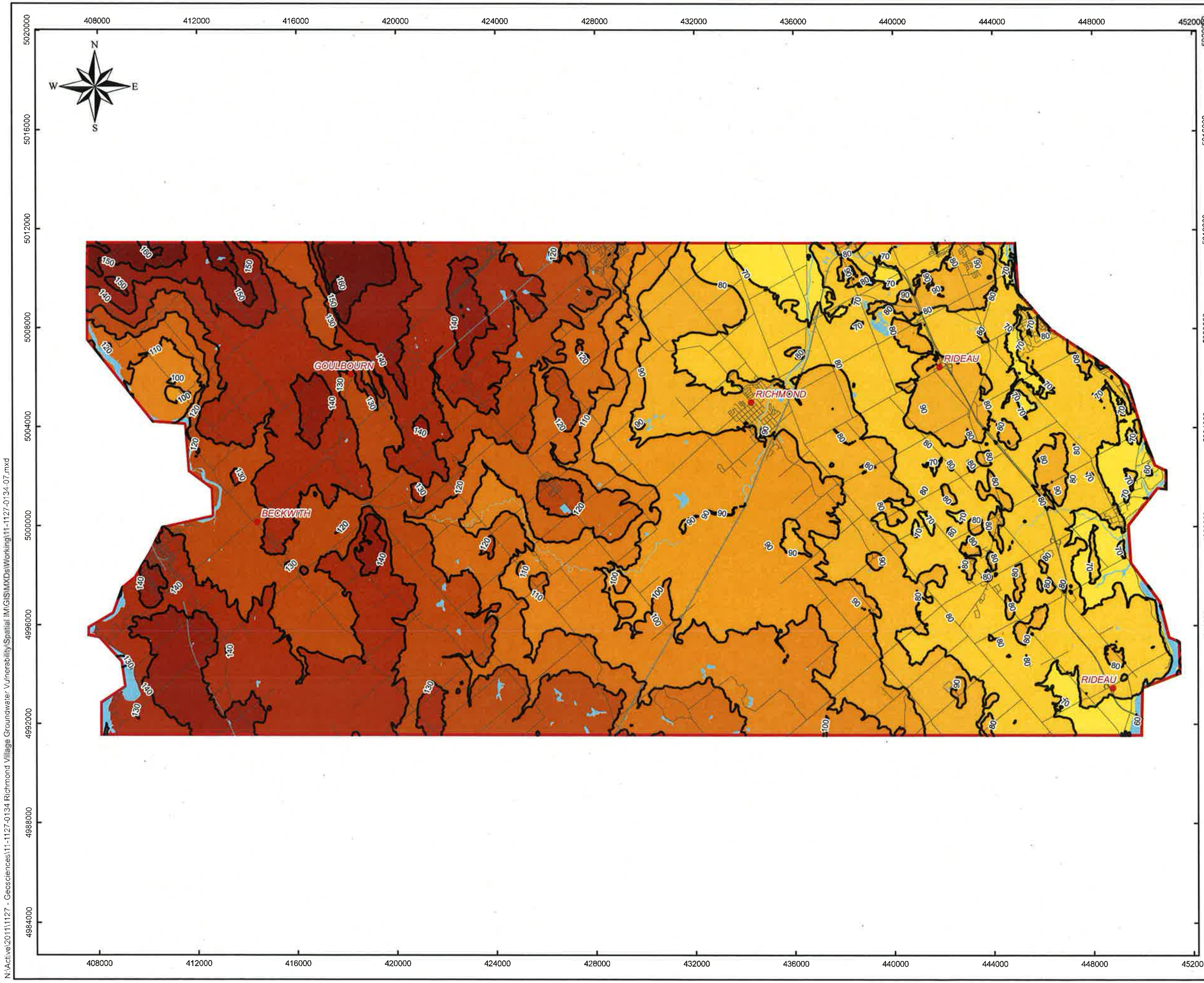
TITLE

MODEL LAYERING AND HYDROSTRATIGRAPHIC CONCEPTUALIZATION

Golder Associates
Ottawa, Ontario

PROJECT No.	1111270134		FILE No. 1111270134-06.dwg	
DESIGN	N.B.	Feb 2012	SCALE N.T.S.	REV.
CADD	B.J.	Feb 2012		
CHECK		07/11/2012	**FIGURE 6**	
REVIEW				

FILENAME: C:\Users\brijohnson\appdata\local\temp\AcPublish_5300\1111270134-06.dwg



LEGEND

- POPULATED PLACE
- BEDROCK SURFACE CONTOUR (mASL)
- RAILWAY
- ROAD
- MODEL BOUNDARY
- WATERBODY

BEDROCK SURFACE ELEVATION (mASL)

- < 60
- 60 - 70
- 70 - 80
- 80 - 90
- 90 - 100
- 100 - 110
- 110 - 120
- 120 - 130
- 130 - 140
- 140 - 150
- 150- 160
- 160 - 170

NOTE

THIS FIGURE IS TO BE READ IN CONJUNCTION WITH THE ACCOMPANYING GOLDER ASSOCIATES LIMITED REPORT NO. 11-1127-0134

REFERENCE

CANVEC DATA PROVIDED BY HER MAJESTY THE QUEEN IN RIGHT OF CANADA, DEPARTMENT OF NATURAL RESOURCES
PROJECTION: TRANSVERSE MERCATOR DATUM: NAD 83
COORDINATE SYSTEM: UTM ZONE 18

5 0 5

SCALE 1:150,000 KILOMETRES

PROJECT

RICHMOND VILLAGE
GROUNDWATER VULNERABILITY

TITLE

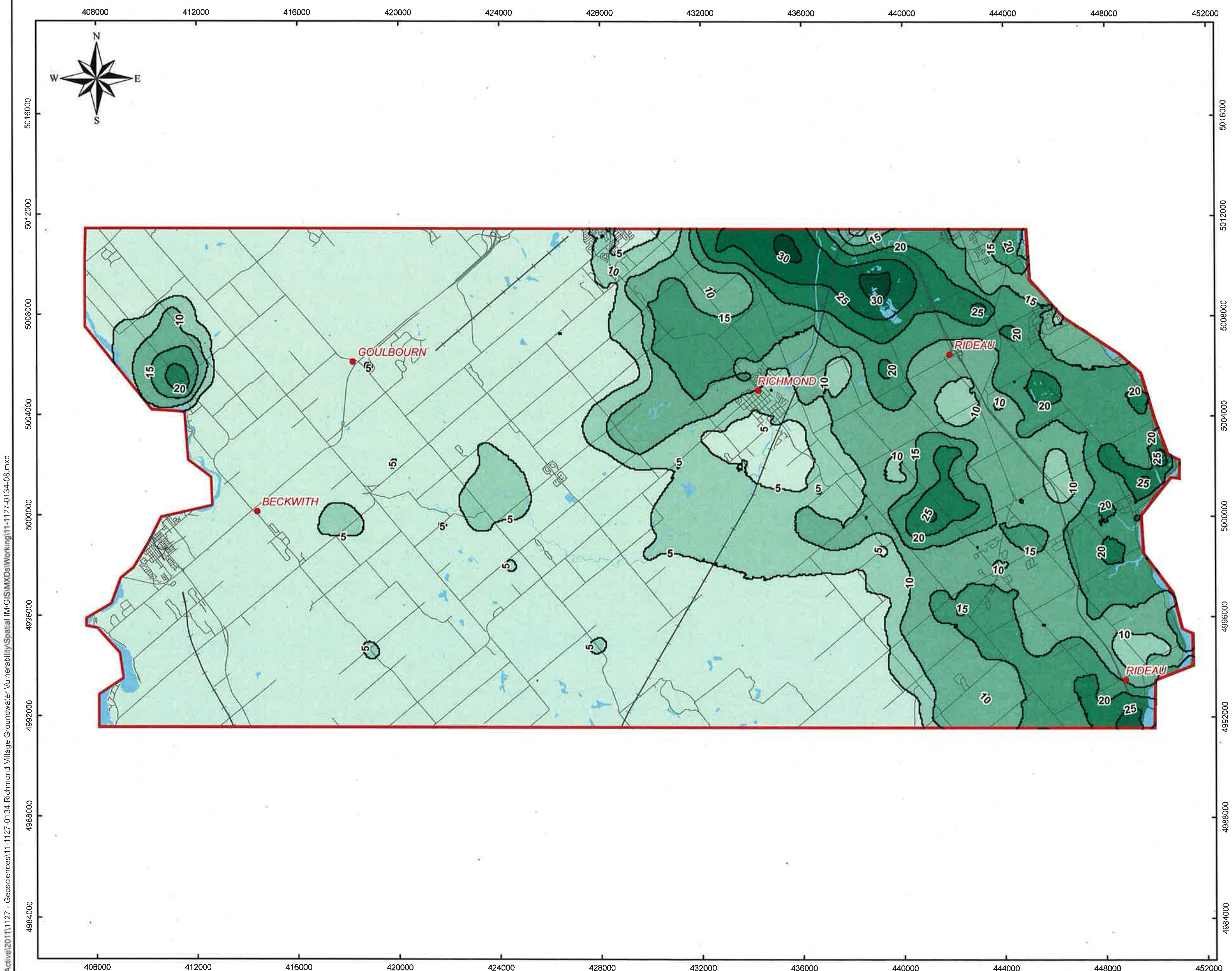
BEDROCK SURFACE - PALEOZOIC

Golder Associates
Ottawa, Ontario

PROJECT No. 11-1127-0134			SCALE AS SHOWN	REV. 0.0
DESIGN	NB	15 Feb. 2012		
GIS	BJ	15 Feb. 2012		
CHECK				
REVIEW				

FIGURE 7

N:\Active\2011\1127 - Geosciences\11-1127-0134 Richmond Village Groundwater Vulnerability\Spatial IM\GIS\MXDs\Working\11-1127-0134-07.mxd



LEGEND

- POPULATED PLACE
- OVERBURDEN THICKNESS (m)
- RAILWAY
- ROAD
- MODEL BOUNDARY
- WATERBODY

OVERBURDEN THICKNESS (m)

- < 5
- 5 - 10
- 10 - 15
- 15 - 20
- 20 - 25
- 25 - 30
- 30 - 35

NOTE

THIS FIGURE IS TO BE READ IN CONJUNCTION WITH THE ACCOMPANYING GOLDER ASSOCIATES LIMITED REPORT NO. 11-1127-0134

REFERENCE

CANVEC DATA PROVIDED BY HER MAJESTY THE QUEEN IN RIGHT OF CANADA, DEPARTMENT OF NATURAL RESOURCES
PROJECTION: TRANSVERSE MERCATOR DATUM: NAD 83
COORDINATE SYSTEM: UTM ZONE 18

5 0 5
SCALE 1:150,000 KILOMETRES

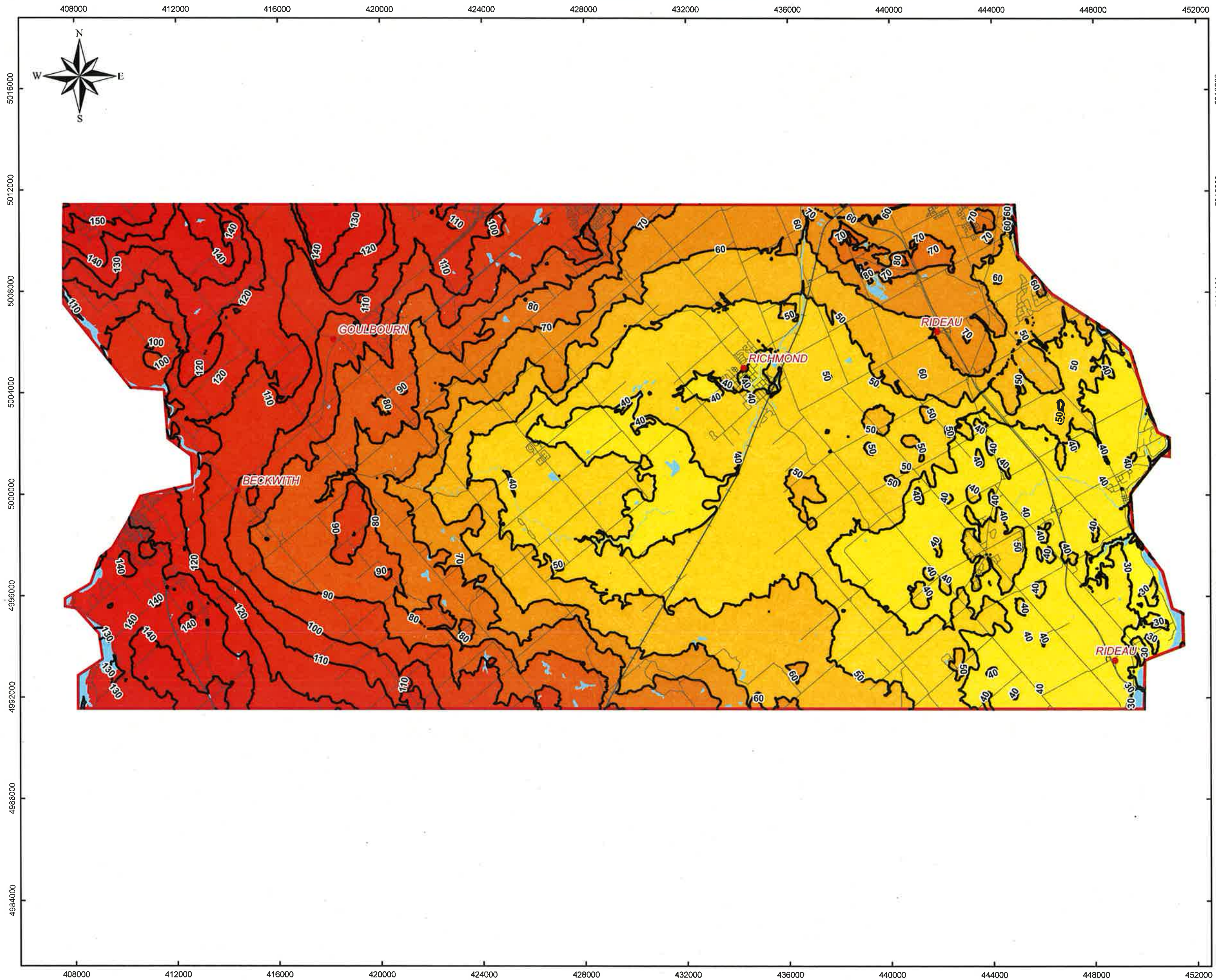
PROJECT
RICHMOND VILLAGE
GROUNDWATER VULNERABILITY

TITLE
DISTRIBUTION AND THICKNESS OF OVERBURDEN

Golder Associates
Ottawa, Ontario

PROJECT No. 11-1127-0134			SCALE AS SHOWN	REV. 0.0
DESIGN	NB	15 Feb. 2012	**FIGURE 8**	
GIS	BJ	15 Feb. 2012		
CHECK				
REVIEW				

N:\Active\2011\1127 - Geosciences\11-1127-0134 Richmond Village Groundwater Vulnerability\Spatial IM\GIS\MXDs\Working\11-1127-0134-08.mxd



LEGEND

- POPULATED PLACE
- NEPEAN FORMATION SURFACE CONTOUR (m)
- RAILWAY
- ROAD
- MODEL BOUNDARY
- WATERBODY

NEPEAN FORMATION ELEVATION (m)

- < 30
- 30 - 40
- 40 - 50
- 50 - 60
- 60 - 70
- 70 - 80
- 80 - 90
- 90 - 100
- 100 - 110
- 110 - 120
- 120 - 130
- 130 - 140
- 140 - 150
- 150 - 160
- 160 - 170

NOTE

THIS FIGURE IS TO BE READ IN CONJUNCTION WITH THE ACCOMPANYING GOLDER ASSOCIATES LIMITED REPORT NO. 11-1127-0134

REFERENCE

CANVEC DATA PROVIDED BY HER MAJESTY THE QUEEN IN RIGHT OF CANADA, DEPARTMENT OF NATURAL RESOURCES
PROJECTION: TRANSVERSE MERCATOR DATUM: NAD 83
COORDINATE SYSTEM: UTM ZONE 18

5 0 5
SCALE 1:150,000 KILOMETRES

PROJECT

RICHMOND VILLAGE
GROUNDWATER VULNERABILITY

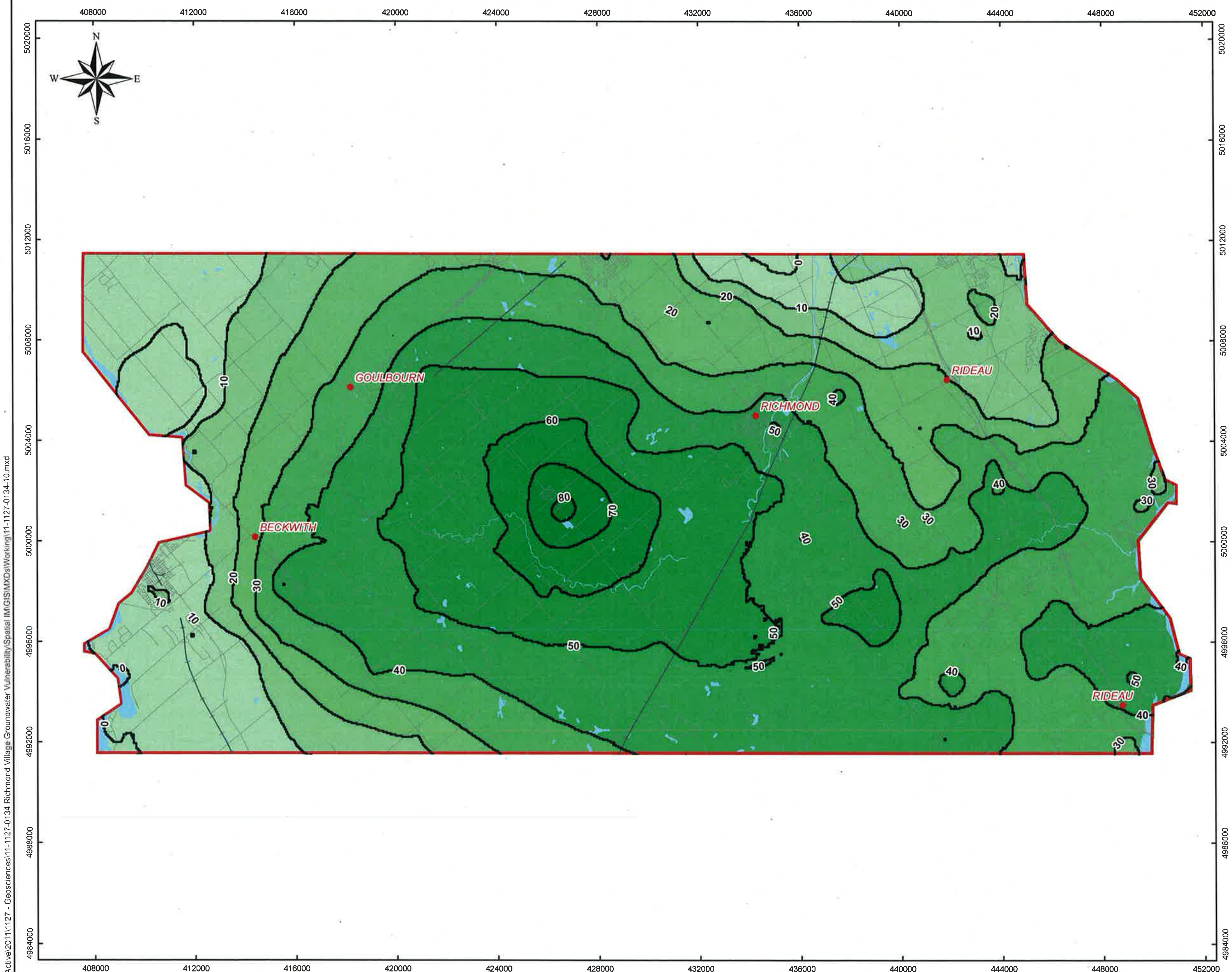
TITLE

NEPEAN FORMATION SURFACE

Golder Associates
Ottawa, Ontario

PROJECT No. 11-1127-0134			SCALE AS SHOWN	REV. 0.0
DESIGN	NB	15 Feb. 2012		
GIS	BJ	15 Feb. 2012	**FIGURE 9**	
CHECK				
REVIEW				

N:\Active\2011\1127 - Geosciences\11-1127-0134 Richmond Village Groundwater Vulnerability\Spatial_IM\GIS\MXDs\Working\11-1127-0134-09.mxd



LEGEND

- POPULATED PLACE
- UPPER PALEOZOIC THICKNESS CONTOUR (m)
- RAILWAY
- ROAD
- MODEL BOUNDARY
- WATERBODY

UPPER PALEOZOIC THICKNESS (m)

- 0 - 10
- 10 - 20
- 20 - 30
- 30 - 40
- 40 - 50
- 50 - 60
- 60 - 70
- 70 - 80
- 80 - 90

NOTE

THIS FIGURE IS TO BE READ IN CONJUNCTION WITH THE ACCOMPANYING GOLDER ASSOCIATES LIMITED REPORT NO. 11-1127-0134

REFERENCE

CANVEC PROVIDED BY HER MAJESTY THE QUEEN IN RIGHT OF CANADA, DEPARTMENT OF NATURAL RESOURCES
PROJECTION: TRANSVERSE MERCATOR DATUM: NAD 83
COORDINATE SYSTEM: UTM ZONE 18

5 0 5
SCALE 1:150,000 KILOMETRES

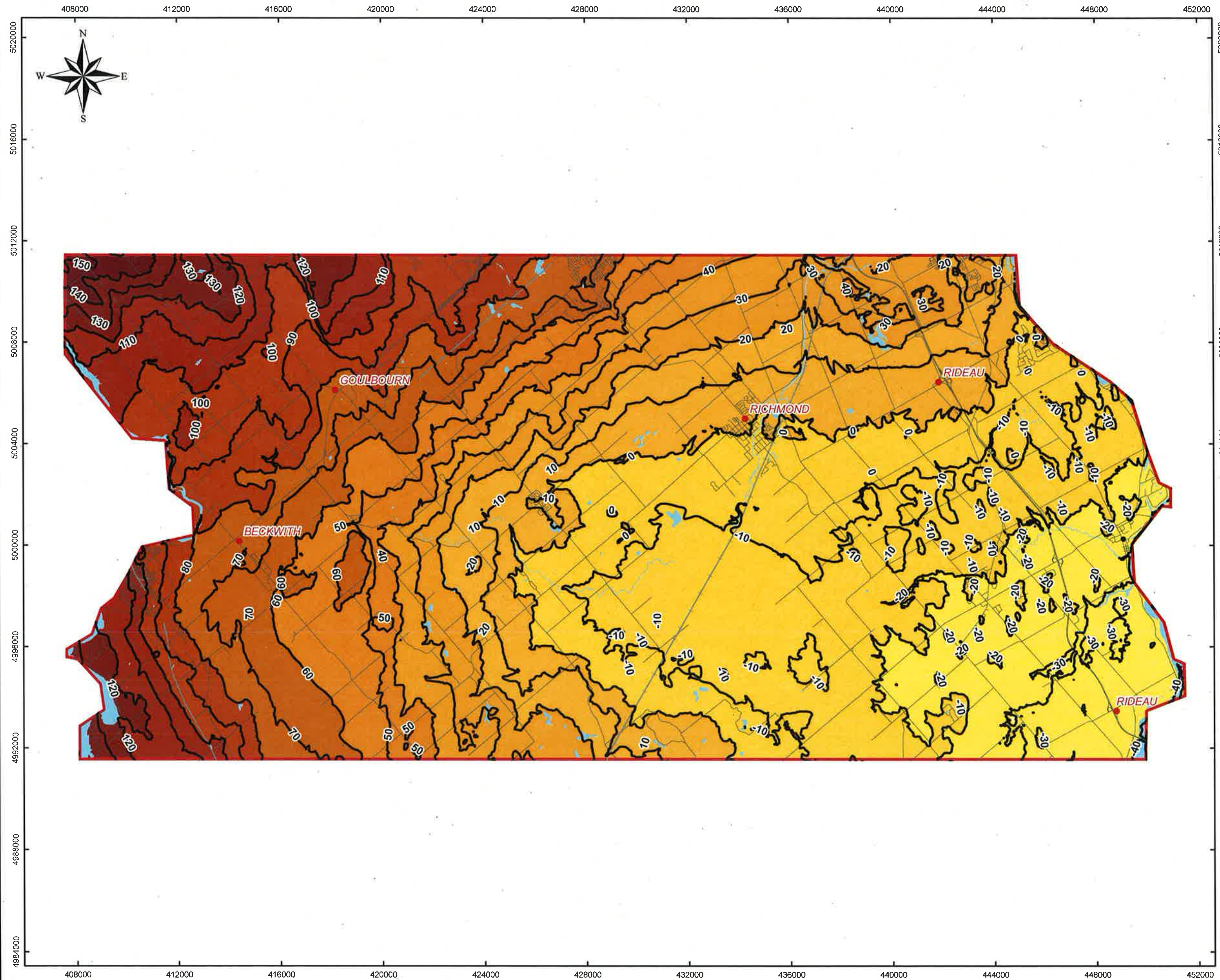
PROJECT
RICHMOND VILLAGE
GROUNDWATER VULNERABILITY

TITLE
DISTRIBUTION OF THICKNESS OF UPPER PALEOZOIC FORMATIONS

Golder Associates
Ottawa, Ontario

PROJECT No. 11-1127-0134			SCALE AS SHOWN	REV. 0.0
DESIGN	NB	15 Feb 2012		
GIS	BJ	15 Feb 2012		
CHECK			**FIGURE 10**	
REVIEW				

N:\Active\2011\1127 - Geosciences\11-1127-0134 Richmond Village Groundwater Vulnerability\Spatial IM\GIS\MXDs\Working\11-1127-0134-10.mxd



LEGEND

- POPULATED PLACE
- PRECAMBRIAN BEDROCK SURFACE CONTOUR (mASL)
- RAILWAY
- ROAD
- MODEL BOUNDARY
- WATERBODY

PRECAMBRIAN BEDROCK ELEVATION (mASL)

- < -40
- -40 - -20
- -20 - 0
- 0 - 20
- 20 - 40
- 40 - 60
- 60 - 80
- 80 - 100
- 100 - 120
- 120 - 140
- 140 - 160

NOTE

THIS FIGURE IS TO BE READ IN CONJUNCTION WITH THE ACCOMPANYING GOLDER ASSOCIATES LIMITED REPORT NO. 11-1127-0134

REFERENCE

CANVEC DATA PROVIDED BY HER MAJESTY THE QUEEN IN RIGHT OF CANADA, DEPARTMENT OF NATURAL RESOURCES
PROJECTION: TRANSVERSE MERCATOR DATUM: NAD 83
COORDINATE SYSTEM: UTM ZONE 18

5 0 5
SCALE 1:150,000 KILOMETRES

PROJECT
RICHMOND VILLAGE
GROUNDWATER VULNERABILITY

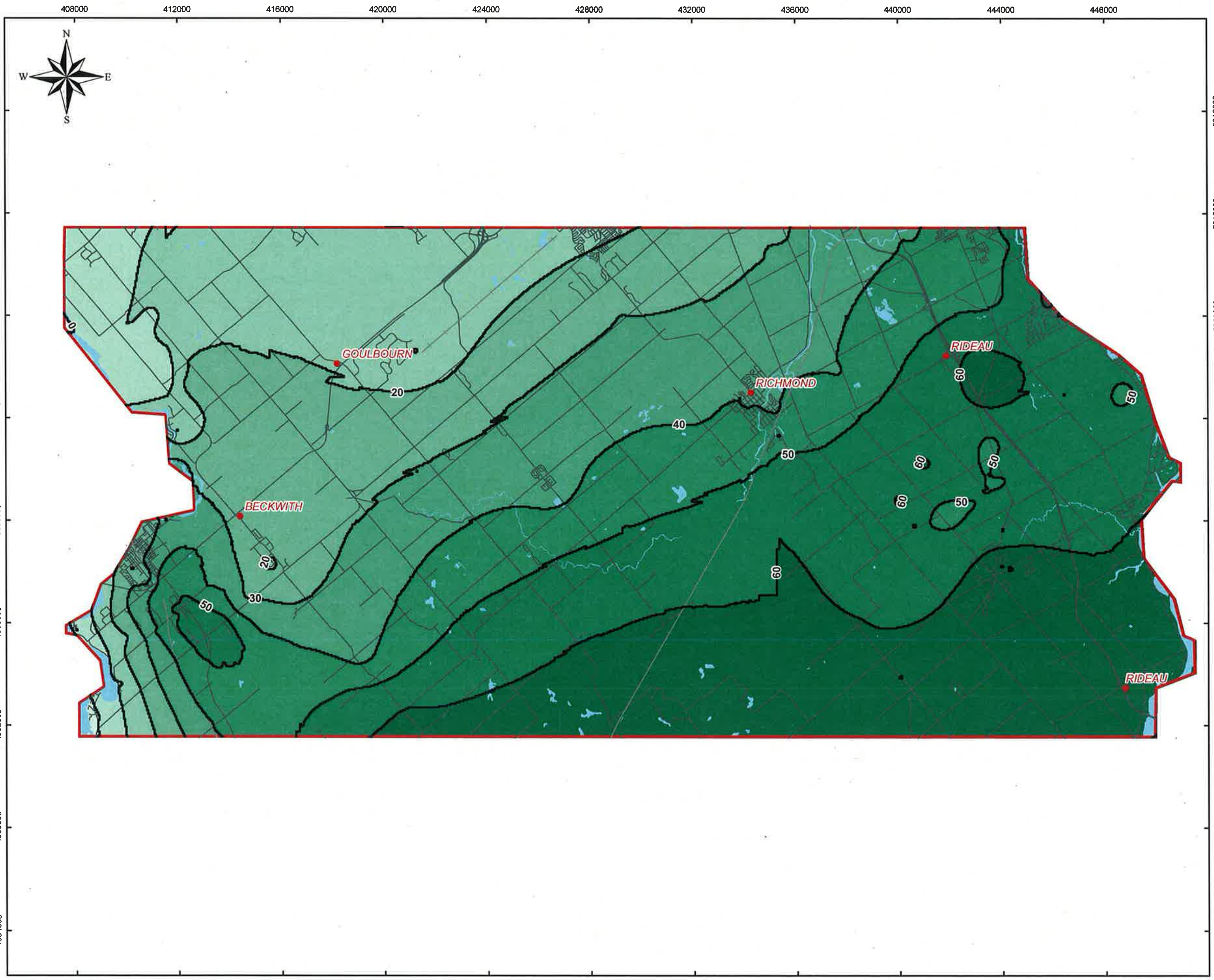
TITLE
PRECAMBRIAN BEDROCK SURFACE

Golder Associates
Ottawa, Ontario

PROJECT No. 11-1127-0134			SCALE AS SHOWN	REV. 0.0
DESIGN	NB	15 Feb. 2012		
GIS	BJ	15 Feb. 2012		
CHECK				
REVIEW				

FIGURE 11

N:\Active\2011\1127 - Geosciences\11-1127-0134 Richmond Village Groundwater Vulnerability\Spatial IM\GIS\MXDs\Working\11-1127-0134-11.mxd



LEGEND

- POPULATED PLACE
- NEPEAN FORMATION THICKNESS CONTOUR (10m)
- RAILWAY
- ROAD
- MODEL BOUNDARY
- WATERBODY

THICKNESS OF NEPEAN FORMATION (m)

- < - 0
- 0 - 10
- 10 - 20
- 20 - 30
- 30 - 40
- 40 - 50
- 50 - 60
- 60 - 70
- 70 - 80

NOTE

THIS FIGURE IS TO BE READ IN CONJUNCTION WITH THE ACCOMPANYING GOLDER ASSOCIATES LIMITED REPORT NO. 11-1127-0134

REFERENCE

CANVEC DATA PROVIDED BY HER MAJESTY THE QUEEN IN RIGHT OF CANADA, DEPARTMENT OF NATURAL RESOURCES
PROJECTION: TRANSVERSE MERCATOR DATUM: NAD 83
COORDINATE SYSTEM: UTM ZONE 18

5 0 5
SCALE 1:150,000 KILOMETRES

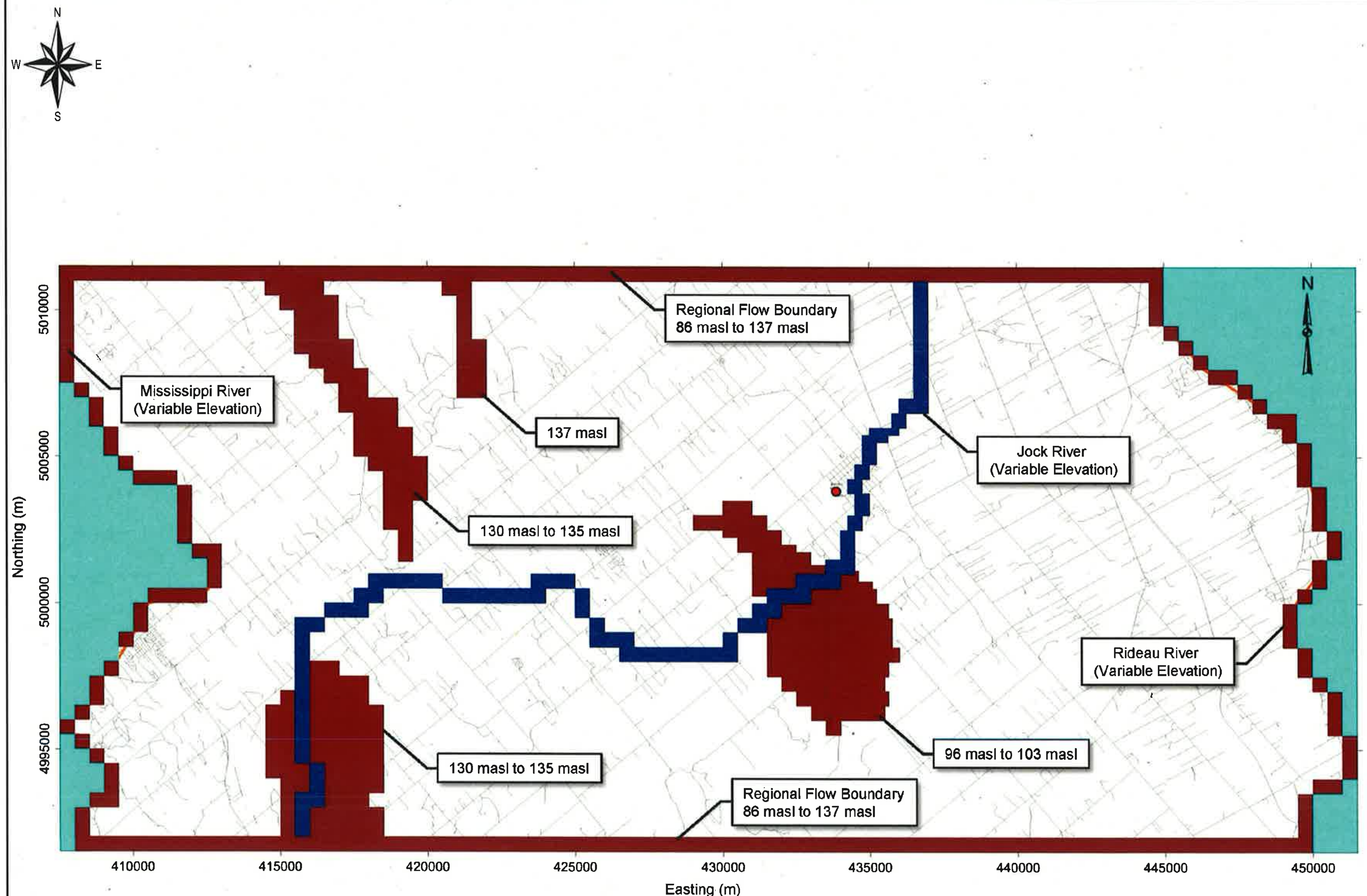
PROJECT
RICHMOND VILLAGE
GROUNDWATER VULNERABILITY

TITLE
DISTRIBUTION OF THICKNESS OF NEPEAN FORMATION

Golder Associates
Ottawa, Ontario

PROJECT No. 11-1127-0134			SCALE AS SHOWN	REV. 0.0
DESIGN	NB	15 Feb. 2012		
GIS	BJ	15 Feb. 2012	**FIGURE 12**	
CHECK				
REVIEW				

N:\Active\2011\1127 - Geosciences\11-1127-0134 Richmond Village Groundwater Vulnerability\Spatial IM\GIS\MXDs\Working\11-1127-0134-12.mxd



LEGEND

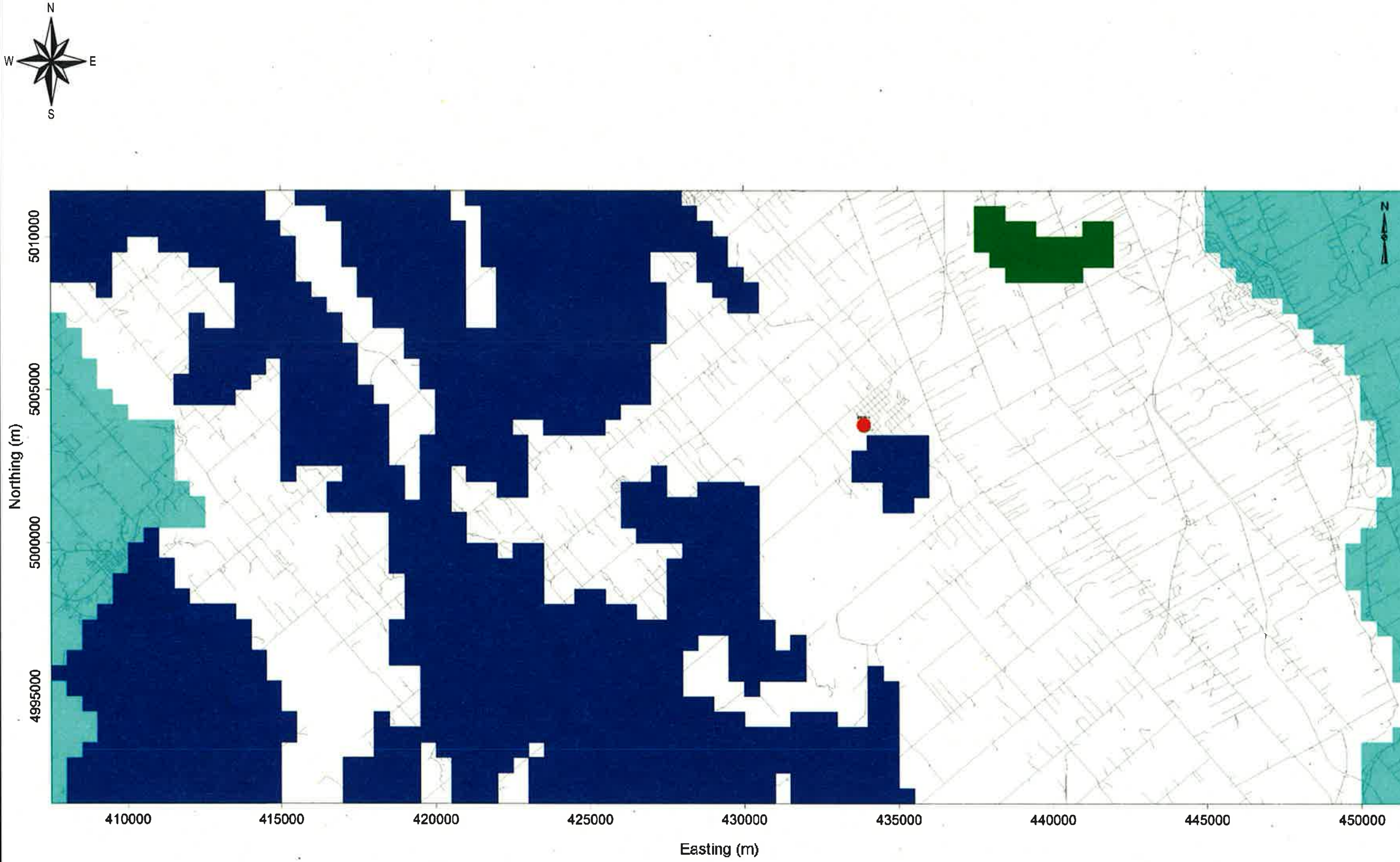
- River Boundary
- Constant Head Boundary
- Inactive Model Area
- Richmond Pumping Wells

NOTE

1. THIS FIGURE IS TO BE READ IN CONJUNCTION WITH THE ACCOMPANYING GOLDER ASSOCIATES LTD. REPORT No. 11-1127-0134
2. THIS FIGURE IS NOT TO SCALE.

PROJECT	RICHMOND VILLAGE WELL SYSTEM - GROUNDWATER VULNERABILITY STUDY			
TITLE	**GROUNDWATER FLOW MODEL BOUNDARIES**			
Golder Associates Ottawa, Ontario	PROJECT No.	11-1127-0134	FILE No. 1111270134-13.dwg	
	DESIGN	N.B. Feb. 2012	SCALE N.T.S.	REV.
	CADD	B.J. Feb. 2012		
	CHECK	12/03/20	**FIGURE 13**	
	REVIEW	3/12/12		

FILENAME: C:\Users\brijohnson\appdata\local\temp\AcPublish_7764\1111270134-13.dwg



LEGEND

- 200 mm/yr Recharge
- 15 mm/yr Recharge
- 5 mm/yr Recharge
- Inactive Model Area
- Location of Richmond Pumping Wells

NOTE

1. THIS FIGURE IS TO BE READ IN CONJUNCTION WITH THE ACCOMPANYING GOLDER ASSOCIATES LTD. REPORT No. 11-1127-0134
2. THIS FIGURE IS NOT TO SCALE.

PROJECT

RICHMOND VILLAGE WELL SYSTEM - GROUNDWATER VULNERABILITY STUDY

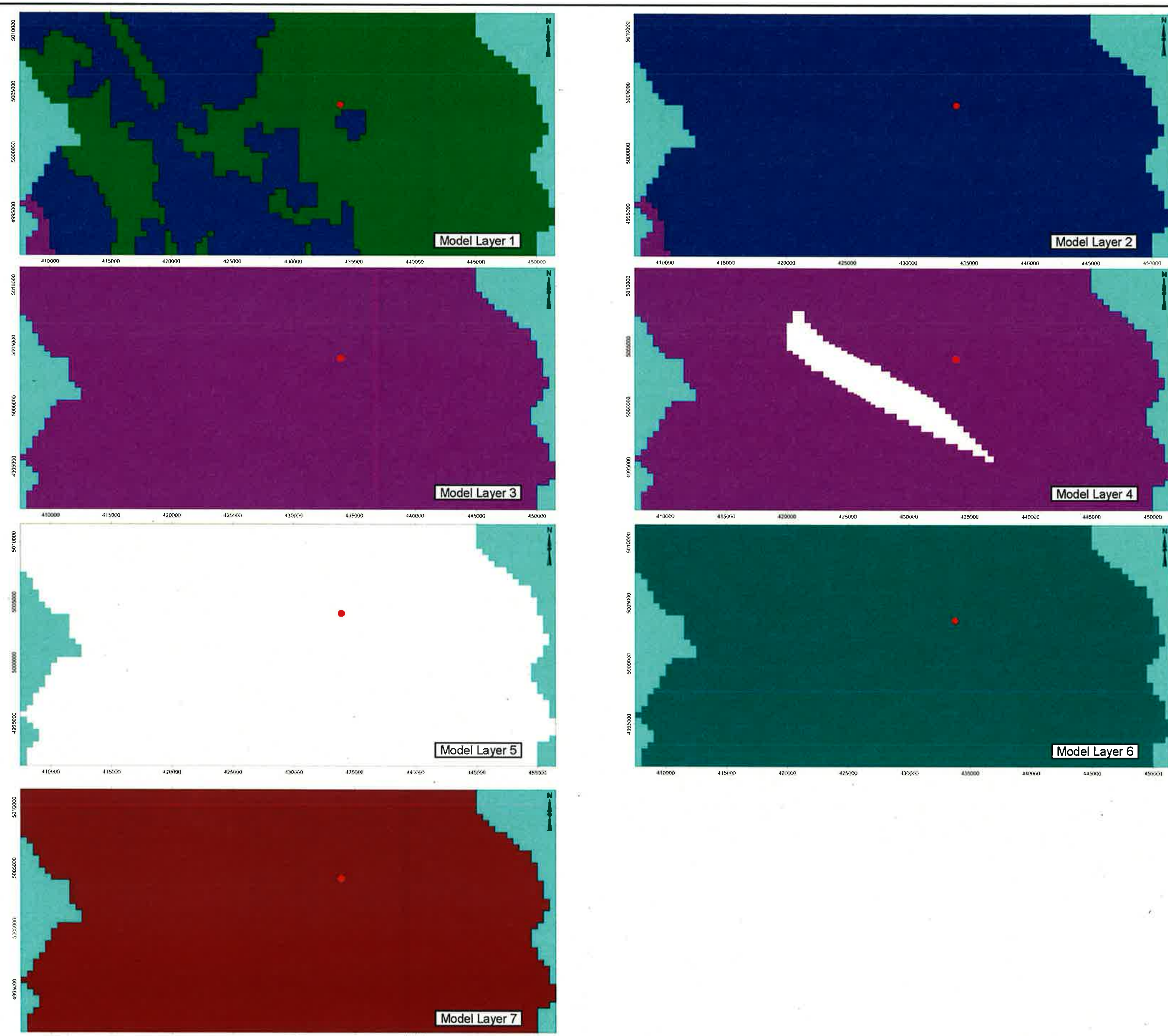
TITLE

MODEL RECHARGE DISTRIBUTION

Golder Associates
Ottawa, Ontario

PROJECT No.	11-1127-0134	FILE No. 1111270134-14.dwg		
DESIGN	N.B.	Feb. 2012	SCALE N.T.S.	REV.
CADD	B.J.	Feb 2012	**FIGURE 14**	
CHECK		12/03/2012		
REVIEW		3/12/12		

FILENAME: N:\Active\2011\1127 - Geosciences\11-1127-0134 Richmond Village Groundwater Vulnerability\Spatial IM\CAD\DWG\1111270134-14.dwg



LEGEND

- Overburden ($5x10^{-7}$ m/s)
- Oxford / March Formation ($5x10^{-7}$ m/s)
- Upper Nepean ($4x10^{-4}$ m/s)
- Lower Nepean ($1x10^{-5}$ m/s)
- Upper Precambrian ($1x10^{-7}$ m/s)
- Lower Precambrian ($1x10^{-8}$ m/s)
- Inactive Model Area
- Location of Richmond Pumping Wells

NOTE
1. THIS FIGURE IS TO BE READ IN CONJUNCTION WITH THE ACCOMPANYING GOLDER ASSOCIATES LTD. REPORT No. 11-1127-0134
2. THIS FIGURE IS NOT TO SCALE.

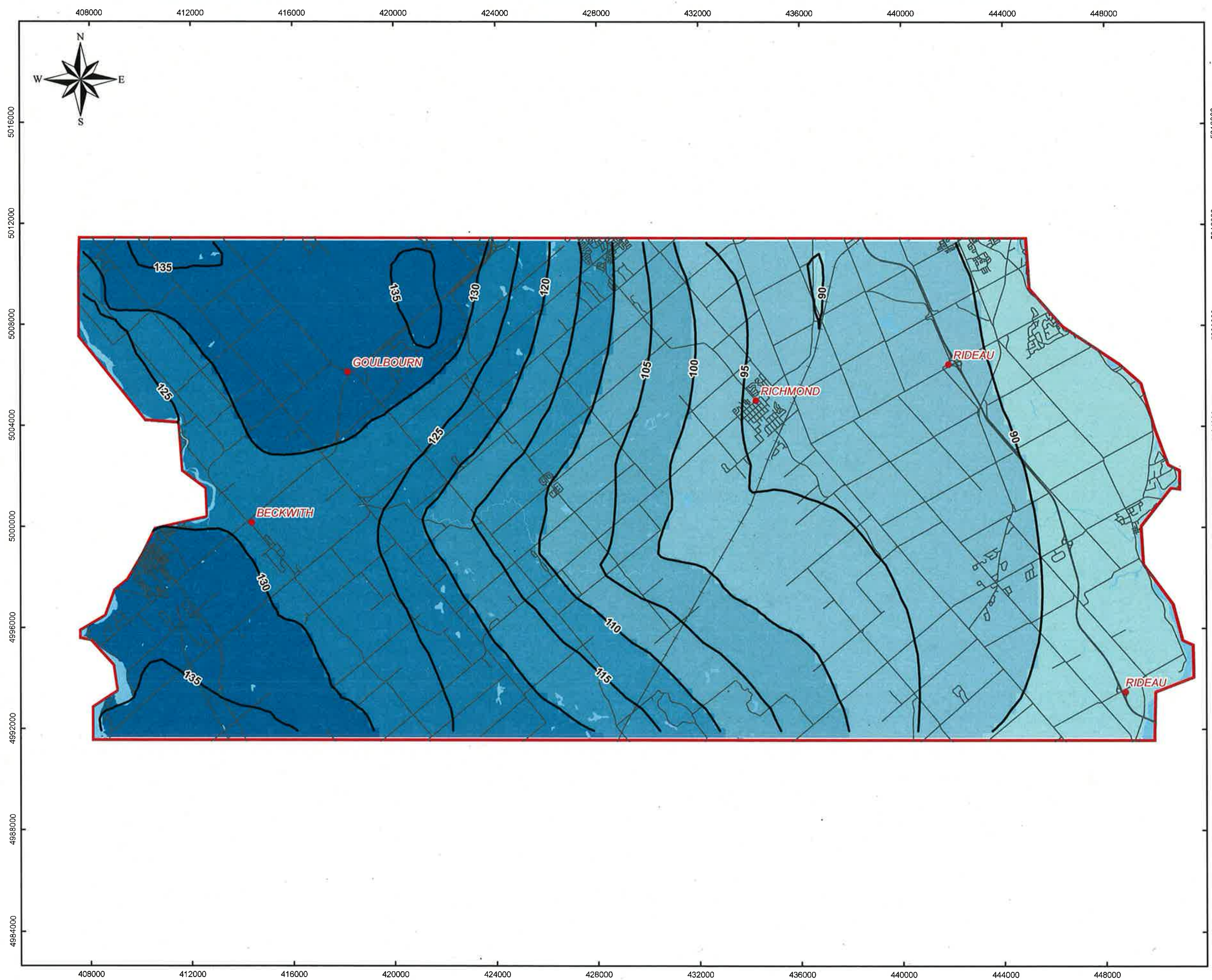
PROJECT
RICHMOND VILLAGE WELL SYSTEM - GROUNDWATER VULNERABILITY STUDY

TITLE
MODEL HYDRAULIC CONDUCTIVITY DISTRIBUTION

Golder Associates
Ottawa, Ontario

PROJECT No.	11-1127-0134		FILE No. 1111270134-15.dwg
DESIGN	N.B.	Feb. 2012	SCALE N.T.S. REV.
CADD	B.J.	Feb. 2012	
CHECK			**FIGURE 15**
REVIEW			

FILENAME: C:\Users\brjohnson\appdata\local\temp\AcPublish_7764\1111270134-15.dwg



LEGEND

- POPULATED PLACE
- SIMULATED GROUNDWATER CONTOUR IN BEDROCK (mASL)
- RAILWAY
- ROAD
- MODEL BOUNDARY
- WATERBODY

GROUNDWATER ELEVATION (mASL)

- < 80
- 80 - 90
- 90 - 100
- 100 - 110
- 110 - 120
- 120 - 130
- 130 - 140
- 140 - 150

NOTE

THIS FIGURE IS TO BE READ IN CONJUNCTION WITH THE ACCOMPANYING GOLDER ASSOCIATES LIMITED REPORT NO. 11-1127-0134

REFERENCE

CANVEC DATA PROVIDED BY HER MAJESTY THE QUEEN IN RIGHT OF CANADA, DEPARTMENT OF NATURAL RESOURCES
PROJECTION: TRANSVERSE MERCATOR DATUM: NAD 83
COORDINATE SYSTEM: UTM ZONE 18

5 0 5
SCALE 1:150,000 KILOMETRES

PROJECT
RICHMOND VILLAGE
GROUNDWATER VULNERABILITY

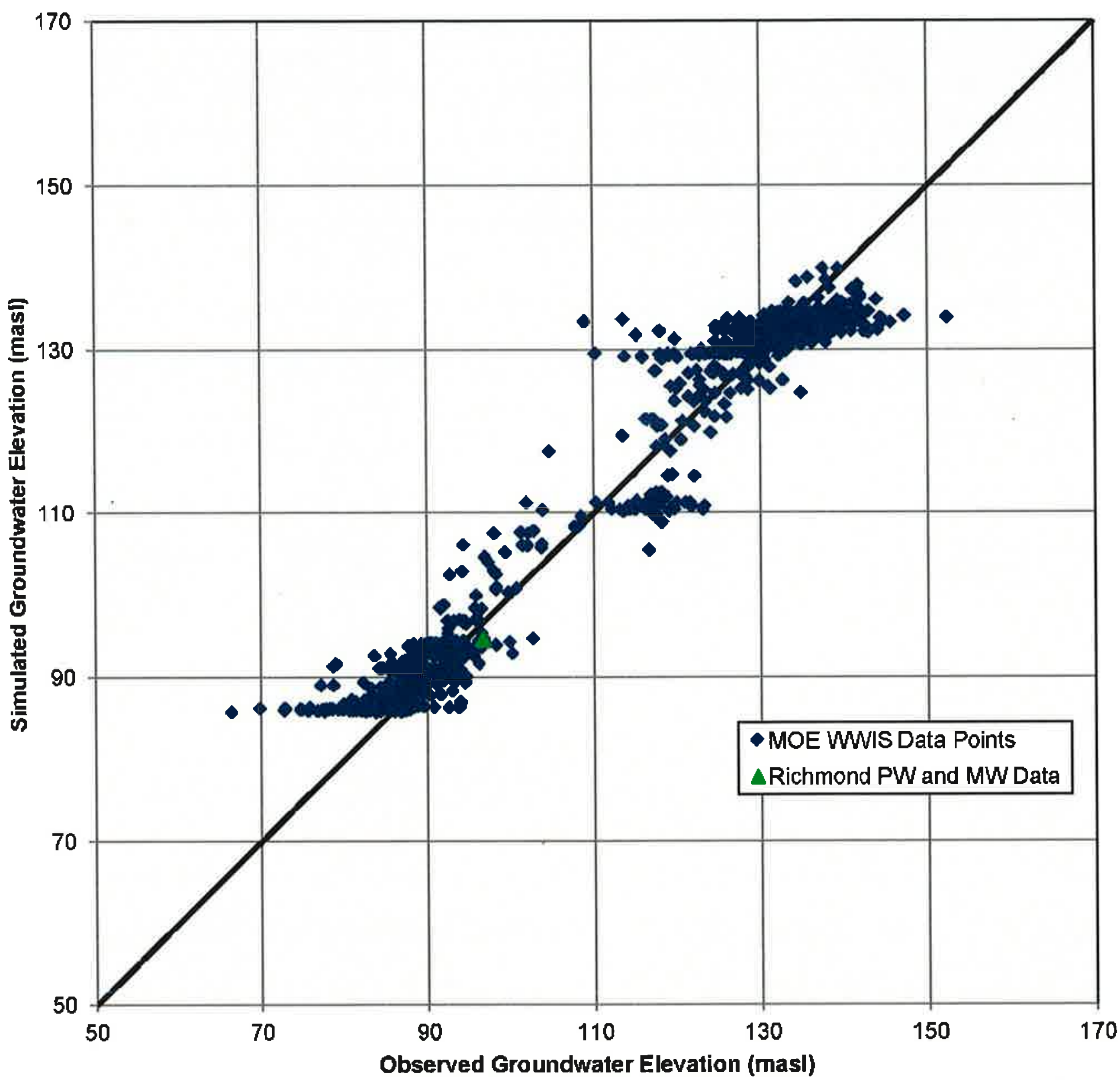
TITLE
SIMULATED GROUNDWATER ELEVATION CONTOURS IN BEDROCK

Golder Associates
Ottawa, Ontario

PROJECT No. 11-1127-0134			SCALE AS SHOWN	REV. 0.0
DESIGN	NB	15 Feb. 2012		
GIS	BJ	22 Feb. 2012		
CHECK				
REVIEW				

FIGURE 16

N:\Active\2011\1127 - Geosciences\11-1127-0134 Richmond Village Groundwater Vulnerability\Spatial IM\GIS\MXDs\Working\11-1127-0134-16.mxd



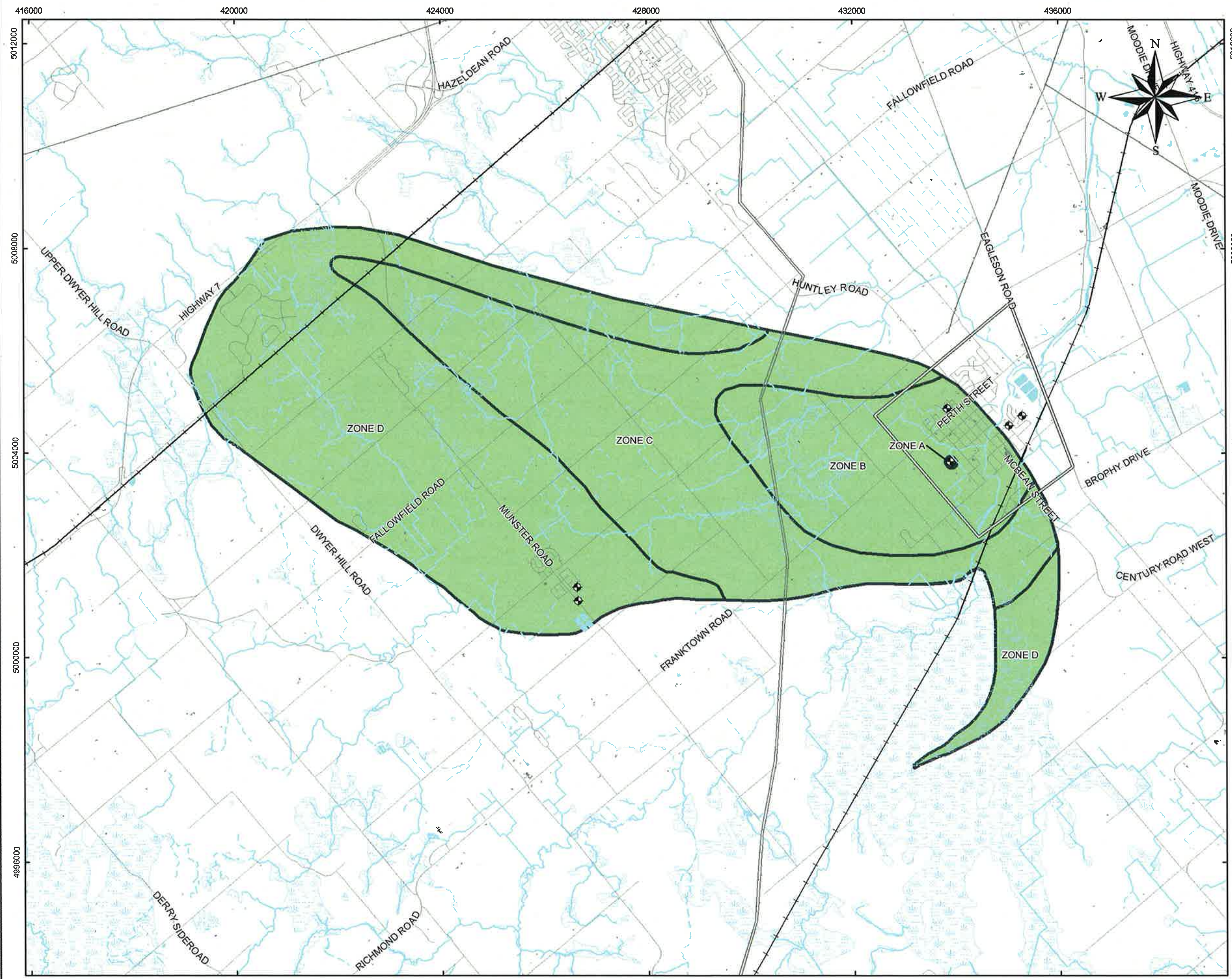
Calibration Statistics:

Number of Observation Points: 982
Residual Mean: 0.53 m
Abs. Residual Mean: 3.5 m
Normalized RMS: 5.5%

NOTE

THIS FIGURE IS TO BE READ IN CONJUNCTION WITH THE ACCOMPANYING GOLDER ASSOCIATES LTD. REPORT No. 11-1127-0134.

Golder Associates, Ottawa, Ontario	SCALE N.T.S.	TITLE
	DATE 9 MAR. 2012	**CALIBRATION STATISTICS**
	DESIGN N.B.	
	CADD B.J.	
FILE No. 1111270134-17.dwg	CHECK 12/03/2012	RICHMOND VILLAGE WELL SYSTEM - GROUNDWATER VULNERABILITY STUDY
PROJECT No. 11-1127-0134 REV. 0	REVIEW 3/12/11	FIGURE 17



LEGEND

- WELL
- ROAD
- RAILWAY
- UTILITY LINE
- WATERCOURSE, PERMANENT
- WATERCOURSE, INTERMITTENT
- WELLHEAD PROTECTION AREA ZONE
- VILLAGE BOUNDARY
- BUILDING
- WATER AREA, PERMANENT
- WETLAND, PERMANENT

INTRINSIC VULNERABILITY LEVEL

- LOW

NOTE

THIS FIGURE IS TO BE READ IN CONJUNCTION WITH THE ACCOMPANYING GOLDER ASSOCIATES LIMITED REPORT NO. 11-1127-0134

REFERENCE

BASE DATA - MNR NRVIS, OBTAINED 2008, CANMAP V2008.4
PRODUCED BY GOLDER ASSOCIATES LTD UNDER LICENCE FROM ONTARIO MINISTRY OF NATURAL RESOURCES, © QUEENS PRINTER 2008
PROJECTION: TRANSVERSE MERCATOR DATUM: NAD 83
COORDINATE SYSTEM: UTM ZONE 18

2,000 0 2,000
SCALE 1:75,000 METRES

PROJECT

RICHMOND VILLAGE
GROUNDWATER VULNERABILITY

TITLE

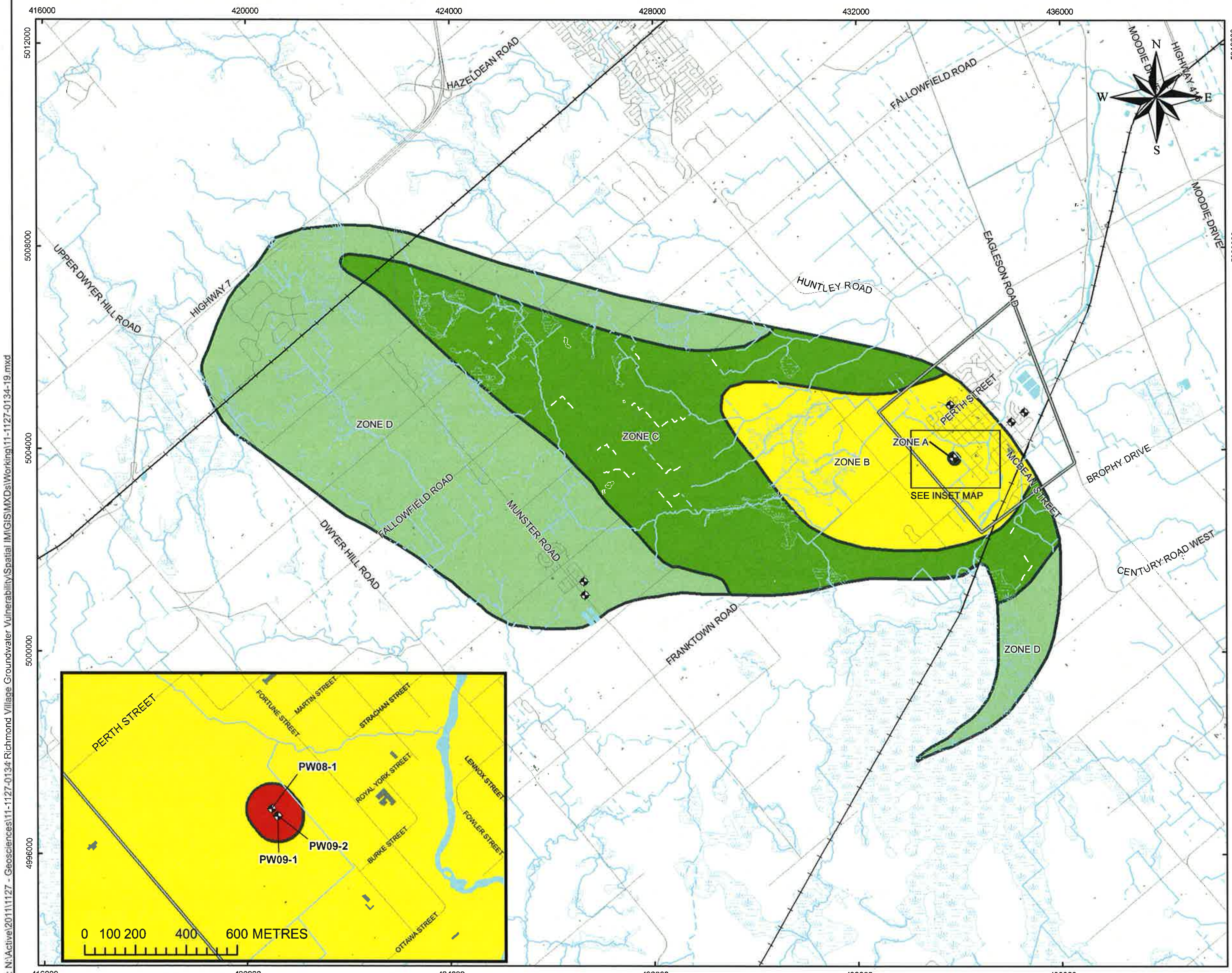
WELLHEAD PROTECTION AREAS AND VULNERABILITY (ISI METHOD)

Golder Associates
Ottawa, Ontario

PROJECT No. 11-1127-0134			SCALE AS SHOWN REV. 0.0
DESIGN	NB	10 Feb. 2012	
GIS	BJ	13 Feb. 2012	
CHECK			
REVIEW			

FIGURE 18

Path: N:\Active\2011\1127 - Geosciences\11-1127-0134 Richmond Village Groundwater Vulnerability\Spatial IM\GIS\MXDs\Working\11-1127-0134-18.mxd



LEGEND

- WELL
- ROAD
- RAILWAY
- WATERCOURSE, PERMANENT
- WATERCOURSE, INTERMITTENT
- WELLHEAD PROTECTION AREA ZONE
- VILLAGE BOUNDARY
- BUILDING
- WATER AREA, PERMANENT
- WETLAND, PERMANENT

INTRINSIC VULNERABILITY SCORE

- 2
- 4
- 6
- 10

NOTE

THIS FIGURE IS TO BE READ IN CONJUNCTION WITH THE ACCOMPANYING GOLDER ASSOCIATES LIMITED REPORT NO. 11-1127-0134

REFERENCE

BASE DATA - MNR NRVIS, OBTAINED 2008, CANMAP V2008.4
PRODUCED BY GOLDER ASSOCIATES LTD UNDER LICENCE FROM ONTARIO MINISTRY OF NATURAL RESOURCES, © QUEENS PRINTER 2008
PROJECTION: TRANSVERSE MERCATOR DATUM: NAD 83
COORDINATE SYSTEM: UTM ZONE 18

2,000 0 2,000
SCALE 1:75,000 METRES

PROJECT

RICHMOND VILLAGE
GROUNDWATER VULNERABILITY

TITLE

INTRINSIC VULNERABILITY SCORING (ISI METHOD)

Golder Associates
Ottawa, Ontario

PROJECT No. 11-1127-0134			SCALE AS SHOWN	REV. 0.0
DESIGN	NB	10 Feb. 2012		
GIS	BJ	13 Feb. 2012		
CHECK				
REVIEW				

FIGURE 19

Path: N:\Active\2011\1127 - Geosciences\11-1127-0134 Richmond Village Groundwater Vulnerability\Spatial IM\GIS\MXDs\Working\11-1127-0134-19.mxd

LEGEND

- WELL
- RAILWAY
- WATERCOURSE, PERMANENT
- WATERCOURSE, INTERMITTENT
- BUILDING
- WATER AREA, PERMANENT
- WETLAND, PERMANENT
- VILLAGE BOUNDARY
- WELLHEAD PROTECTION AREAS
- VULNERABULITY SCORE = 10

NOTE

THIS FIGURE IS TO BE READ IN CONJUNCTION WITH THE ACCOMPANYING GOLDER ASSOCIATES LIMITED REPORT NO. 11-1127-0134

REFERENCE

BASE DATA - MNR NRVIS, OBTAINED 2008, CANMAP V2008.4
PRODUCED BY GOLDER ASSOCIATES LTD UNDER LICENCE FROM ONTARIO MINISTRY OF NATURAL RESOURCES, © QUEENS PRINTER 2008
PROJECTION: TRANSVERSE MERCATOR DATUM: NAD 83
COORDINATE SYSTEM: UTM ZONE 18

1,500 0 1,500
SCALE 1:75,000 METRES

PROJECT
RICHMOND VILLAGE
GROUNDWATER VULNERABILITY

TITLE
DNAPL SCORING

Golder Associates
Ottawa, Ontario

PROJECT No. 11-1127-0134			SCALE AS SHOWN	REV. 0.0
DESIGN	NB	10 Feb. 2012		
GIS	BJ	21 Feb. 2012		
CHECK				
REVIEW				

FIGURE 20

Path: N:\Active\2011\1127 - Geosciences\11-1127-0134 Richmond Village Groundwater Vulnerability\Spatial IM\GIS\MXDs\Working\11-1127-0134-20.mxd

LEGEND

- WELL
- RAILWAY
- WATERCOURSE, PERMANENT
- WATERCOURSE, INTERMITTENT
- BUILDING
- WATER AREA, PERMANENT
- WETLAND, PERMANENT
- VILLAGE BOUNDARY
- WELLHEAD PROTECTION AREAS
- LOW UNCERTAINTY
- HIGH UNCERTAINTY

NOTE

THIS FIGURE IS TO BE READ IN CONJUNCTION WITH THE ACCOMPANYING GOLDER ASSOCIATES LIMITED REPORT NO. 11-1127-0134

REFERENCE

BASE DATA - MNR NRVIS, OBTAINED 2008, CANMAP V2008.4
PRODUCED BY GOLDER ASSOCIATES LTD UNDER LICENCE FROM ONTARIO MINISTRY OF NATURAL RESOURCES, © QUEENS PRINTER 2008
PROJECTION: TRANSVERSE MERCATOR DATUM: NAD 83
COORDINATE SYSTEM: UTM ZONE 18

1,500 0 1,500

SCALE 1:75,000 METRES

PROJECT

RICHMOND VILLAGE
GROUNDWATER VULNERABILITY

TITLE

GROUNDWATER VULNERABILITY UNCERTAINTY

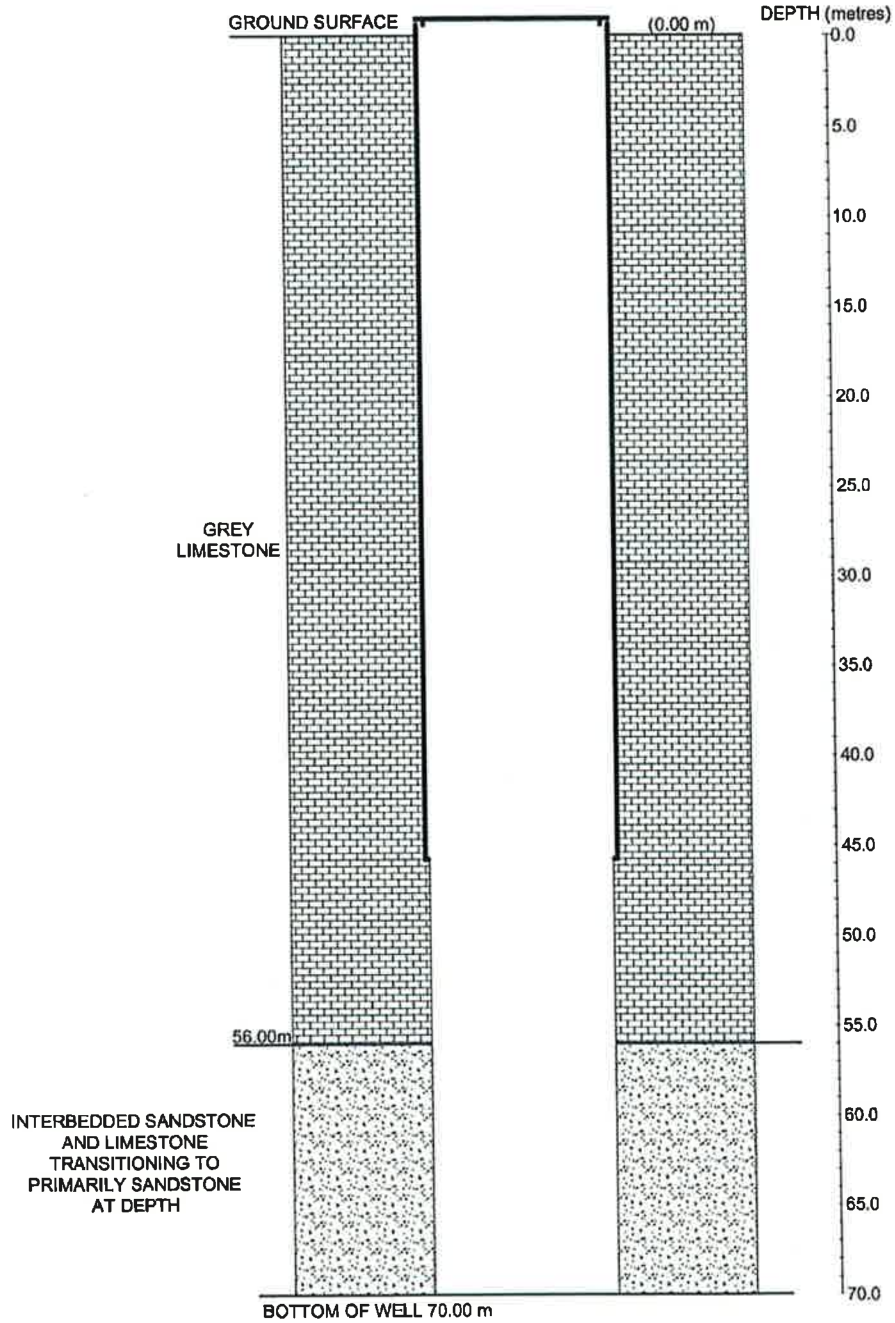
PROJECT No. 11-1127-0134			SCALE AS SHOWN	REV. 0.0
DESIGN	NB	10 Feb. 2012		
GIS	BJ	21 Feb 2012		
CHECK		17/03/2012	**FIGURE 21**	
REVIEW				

Golder Associates
Ottawa, Ontario

Path: N:\Active\2011\1127 - Geosciences\11-1127-0134 Richmond Village Groundwater Vulnerability\Spatial IM\GIS\MXDs\Working\11-1127-0134-21.mxd

APPENDIX A

Borehole and Water Well Records



NOTE

1. THIS FIGURE IS TO BE READ IN CONJUNCTION WITH THE ACCOMPANYING GOLDER ASSOCIATES LTD. REPORT No. 08-1122-0078
2. WELL DIAMETER 0.254 m
3. OPEN HOLE FROM 45.72 m TO 70.00 m

Golder Associates Ottawa, Ontario	SCALE NTS	TITLE PRODUCTION WELL CONSTRUCTION DETAILS FOR PW09-1
	DATE 4 Nov. 2011	
	DESIGN	
	CADD PG	
FILE No. 0811220078-8000-03.dwg	CHECK	MATTAMY RICHMOND LANDS HYDROLOGICAL INVESTIGATION
PROJECT No. 08-1122-0078 REV. 0	REVIEW	FIGURE 1

FILENAME: N:\Active\2008\1122 - Environmental\08-1122-0078 Mattamy Richmond\ACAD\Phase 8000\0811220078-8000-03.dwg

Ontario Ministry of the Environment

Measurements recorded in: ☐ Metric ☑ Imperial

Well Tag No. (Print Below): **A 089810**

PW09-2

Well Record

Regulation 903 Ontario Water Resources Act

Page ___ of ___

Well Owner's Information

First Name	Last Name / Organization	E-mail Address	☐ Well Constructed by Well Owner
	Mattamy (Jock River) Limited.		

Mailing Address (Street Number/Name)	Municipality	Province	Postal Code	Telephone No. (inc. area code)
123 Huntmar Drive	Ottawa.	On.	K2S1B9	613 825 3479

Well Location

Address of Well Location (Street Number/Name)	Township	Lot	Concession
	Goulbourn	22	3.

County/District/Municipality	City/Town/Village	Province	Postal Code
Goulbourn	Richmond	Ontario	

UTM Coordinates: Zone ___ Easting ___ Northing ___ NAD 8 3

Municipal Plan and Sublot Number: ___ Other: ___

Overburden and Bedrock Materials/Abandonment Sealing Record

General Colour	Most Common Material	Other Materials	General Description	Depth From (m/ft)	Depth To (m/ft)
Brown.	Clay.		Packed	0	14
black	Shale.			14'	180
white	Sandstone			180	195
black	Shale			195	255

Annular Space

Depth Set at From (m/ft)	To	Type of Sealant Used (Material and Type)	Volume Placed (m³/ft³)
0	150'	High Yearly Cement	103

Method of Construction

☐ Cable Tool ☑ Rotary (Conventional) ☐ Rotary (Reverse) ☐ Boring ☐ Air percussion ☐ Other, specify ☐ Diamond ☐ Jetting ☐ Driving ☐ Digging

Well Use

☐ Public ☐ Domestic ☐ Livestock ☐ Irrigation ☐ Industrial ☐ Other, specify ☐ Commercial ☐ Municipal ☑ Test Hole ☐ Cooling & Air Conditioning ☐ Not used ☐ Dewatering ☐ Monitoring

Construction Record - Casing

Inside Diameter (cm/in)	Open Hole OR Material (Galvanized, Fibreglass, Concrete, Plastic, Steel)	Wall Thickness (cm/in)	Depth From (m/ft)	Depth To (m/ft)
10 5/8	Steel	1.88	0	150

Status of Well

☐ Water Supply ☐ Replacement Well ☑ Test Hole ☐ Recharge Well ☐ Dewatering Well ☐ Observation and/or Monitoring Hole ☐ Alteration (Construction) ☐ Abandoned, Insufficient Supply ☐ Abandoned, Poor Water Quality ☐ Abandoned, other, specify ☐ Other, specify

Construction Record - Screen

Outside Diameter (cm/in)	Material (Plastic, Galvanized, Steel)	Slot No.	Depth From (m/ft)	Depth To (m/ft)

Water Details

Water found at Depth	Kind of Water
73 (m/ft) ☐ Gas	☐ Fresh ☑ Untested ☐ Other, specify
180 (m/ft) ☐ Gas	☐ Fresh ☑ Untested ☐ Other, specify
210 (m/ft) ☐ Gas	☐ Fresh ☑ Untested ☐ Other, specify

Hole Diameter

Depth From (m/ft)	Depth To	Diameter (cm/in)
0	255	10 5/8

Results of Well Yield Testing

After test of well yield, water was: ☐ Clear and sand free ☐ Other, specify

If pumping discontinued, give reason:

Pump intake set at (m/ft):

Pumping rate (l/min / GPM):

Duration of pumping: ___ hrs + ___ min

Final water level end of pumping (m/ft):

If flowing give rate (l/min / GPM): 200

Recommended pump depth (m/ft):

Recommended pump rate (l/min / GPM):

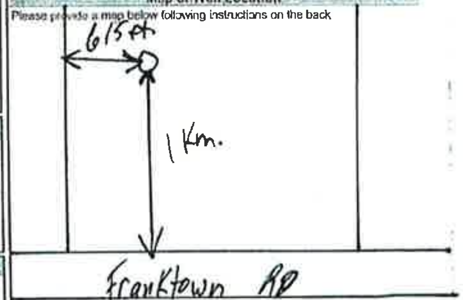
Well production (l/min / GPM):

Disinfected? ☑ Yes ☐ No

Draw Down Time (min)	Water Level (m/ft)	Recovery Time (min)	Water Level (m/ft)
Static Level			
1		1	
2		2	
3		3	
4		4	
5		5	
10		10	
15		15	
20		20	
25		25	
30		30	
40		40	
50		50	
60		60	

Map of Well Location

Please provide a map below following instructions on the back



Comments:

Well Contractor and Well Technician Information

Business Name of Well Contractor	Well Contractor's Licence No.
J.R. Drilling Co. LtD.	3749

Business Address (Street Number/Name)	Municipality
23 Mitchem rd.	Clarendon.

Province	Postal Code	Business E-mail Address
Qc.	J0X2Y0	jrdrilling2@hotmail.com.

Bus. Telephone No. (inc. area code)	Name of Well Technician (Last Name, First Name)
613 860 9986	Molowney Bill

Well Technician's Licence No.	Signature of Technician and/or Contractor	Date Submitted
T 0 5 0	[signature]	2010

Well owner's information package delivered: ☐ Yes ☑ No

Date Package Delivered: Y Y Y Y M M D D

Date Work Completed: 20100103

Ministry Use Only — Audit No. Z 103267

0506E (12/2007) Ministry's Copy © Queen's Printer for Ontario, 2007

Ontario — Ministry of the Environment

Measurements recorded in: ☐ Metric ☑ Imperial

A 089809

Well Record
Regulation 903 Ontario Water Resources Act

PW08 – 1 Page 1 of 1.

Well Owner's Information

First Name	Last Name / Organization	E-mail Address	☐ Well Constructed by Well Owner
	Mattamy (Jock River) Limited.		

Mailing Address (Street Number/Name)	Municipality	Province	Postal Code	Telephone No. (inc. area code)
123 Huntmar Drive.	Ottawa.	On.	K2S 1B9	6138253479

Well Location

Address of Well Location (Street Number/Name)	Township	Lot	Concession
	Goulbourn.	22.	3.

County/District/Municipality	City/Town/Village	Province	Postal Code
Goulbourn	Richmond.	Ontario	

UTM Coordinates Zone Easting Northing: NAD 8 3 | 7 | 5 | 50 | 496 | 75 | 11105

Municipal Plan and Sublot Number: Other:

Overburden and Bedrock Materials/Abandonment Sealing Record (see instructions on the back of this form)

General Colour	Most Common Material	Other Materials	General Description	Depth (m/ft) From	To
Brown	Clay		Packed.	0	11'
black.	Shale.		soft	11	150'
black	Shale			150	180
white	Sandstone			180	195
black	Shale			195	255
black.	granite			255	375
				395	450

Annular Space

Depth Set at (m/ft) From	To	Type of Sealant Used (Material and Type)	Volume Placed (m³/ft³)
0	150'	High early Rement	103

Results of Well Yield Testing

After test of well yield, water was: ☐ Clear and sand free ☐ Other, specify

If pumping discontinued, give reason:

Pump intake set at (m/ft)

Pumping rate (l/min / GPM)

Duration of pumping: hrs + min

Final water level end of pumping (m/ft): /

If flowing give rate (l/min / GPM): 100

Recommended pump depth (m/ft)

Recommended pump rate (l/min / GPM)

Well production (l/min / GPM)

Disinfected? ☑ Yes ☐ No

Draw Down Time (min)	Water Level (m/ft)	Recovery Time (min)	Water Level (m/ft)
Static Level			
1		1	
2		2	
3		3	
4		4	
5		5	
10		10	
15		15	
20		20	
25		25	
30		30	
40		40	
50		50	
60		60	

Method of Construction

☐ Cable Tool ☐ Rotary (Conventional) ☐ Rotary (Reverse) ☐ Boring ☐ Air percussion ☐ Other, specify ☐ Diamond ☐ Jetting ☐ Driving ☐ Digging

Well Use

☐ Public ☐ Domestic ☐ Livestock ☐ Irrigation ☐ Industrial ☐ Other, specify ☐ Commercial ☐ Municipal ☑ Test Hole ☐ Cooling & Air Conditioning ☐ Not used ☐ Dewatering ☐ Monitoring

Construction Record - Casing

Inside Diameter (cm/in)	Open Hole OR Material (Galvanized, Fibreglass, Concrete, Plastic, Steel)	Wall Thickness (cm/in)	Depth (m/ft) From	To
7 1/8"	Steel	1.88"	0	150'

Status of Well

☐ Water Supply ☐ Replacement Well ☑ Test Hole ☐ Recharge Well ☐ Dewatering Well ☐ Observation and/or Monitoring Hole ☐ Alteration (Construction) ☐ Abandoned, Insufficient Supply ☐ Abandoned, Poor Water Quality ☐ Abandoned, other, specify ☐ Other, specify

Construction Record - Screen

Outside Diameter (cm/in)	Material (Plastic, Galvanized, Steel)	Slot No.	Depth (m/ft) From	To

Water Details

Water found at Depth Kind of Water: ☐ Fresh ☑ Untested
3 (m/ft) ☐ Gas ☐ Other, specify

Water found at Depth Kind of Water: ☐ Fresh ☑ Untested
? (m/ft) ☐ Gas ☐ Other, specify

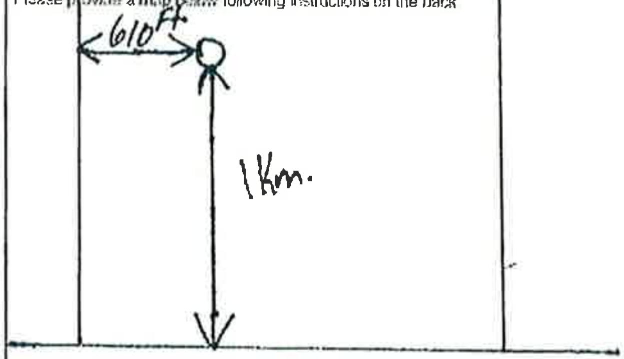
Water found at Depth Kind of Water: ☐ Fresh ☐ Untested
(m/ft) ☐ Gas ☐ Other, specify

Hole Diameter

Depth (m/ft) From	To	Diameter (cm/in)
150	255	10 1/8.
255	450	6 1/8

Map of Well Location

Please provide a map below following instructions on the back



Well Contractor and Well Technician Information

At Golder Associates we strive to be the most respected global company providing consulting, design, and construction services in earth, environment, and related areas of energy. Employee owned since our formation in 1960, our focus, unique culture and operating environment offer opportunities and the freedom to excel, which attracts the leading specialists in our fields. Golder professionals take the time to build an understanding of client needs and of the specific environments in which they operate. We continue to expand our technical capabilities and have experienced steady growth with employees who operate from offices located throughout Africa, Asia, Australasia, Europe, North America, and South America.

Africa	+ 27 11 254 4800
Asia	+ 86 21 6258 5522
Australasia	+ 61 3 8862 3500
Europe	+ 356 21 42 30 20
North America	+ 1 800 275 3281
South America	+ 55 21 3095 9500

solutions@golder.com
www.golder.com

Golder Associates Ltd.
32 Steacie Drive
Kanata, Ontario, K2K 2A9
Canada
T: +1 (613) 592 9600