September 2012

REPORT ON

Cumulative Impacts Assessment for Groundwater Takings in the Carden Plain Area

Submitted to:
Ontario Stone, Sand & Gravel Association
5720 Timberlea Blvd. Suite 103
Mississauga, Ontario
L4W 4W2

REPORT

Report Number: 09-1112-6065

Distribution:

1 e-copy - Ontario Stone, Sand & Gravel Association
1 e-copy - Golder Associates Ltd.

Golder Associates

Executive Summary

Due to the recent level of aggregate extraction activity in the Carden Plain Area, the Ontario Ministry of the Environment requested a multidisciplinary study and impact assessment to evaluate the potential cumulative impacts of quarry dewatering at multiple sites on groundwater, surface water and ecological receptors. Golder Associates Ltd. was retained by the Ontario Stone, Sand, and Gravel Association to complete the required study. The study area for the project focuses on the Carden Plain.

Along the northern edge of the study area, the Grenville Province of the Canadian Shield (Precambrian basement) is the upper bedrock unit. For the majority of the study area, the upper bedrock unit is a member of the Simcoe Group, which is composed of a depositional bedrock sequence representing a generally deepening oceanic shelf environment. The Simcoe Group starts with an erosional unconformity with the Precambrian basement, and consist of, from oldest to youngest, the Shadow Lake, Gull River (which includes the “green bed” layer), Bobcaygeon, Verulam and Lindsay Formations. The formations exhibit a gentle regional dip towards the southwest throughout the study area. This gentle dip results in rock layers often appearing as flat-lying in outcrops within the study area.

Within the study area, twelve quarries operated by ten companies were identified for inclusion in the cumulative impact assessment. These quarries were identified based on the understanding that the quarry locations currently have, or will require, a Permit to Take Water to allow for operation of the site, and extraction of bedrock below the groundwater table.

The objectives of the study were to screen out areas where cumulative impacts are unlikely, identify areas where cumulative impacts are likely, and to provide a preliminary assessment of the potential magnitude of predicted cumulative impacts. For the purpose of this study, a cumulative impact is defined as the additive effect of multiple quarry dewatering operations on groundwater, surface water and/or natural environment features. For groundwater, a cumulative impact could result from the intersection of various dewatering zones of influence associated with the operation of multiple quarries. The intersection of multiple dewatering zones of influence results in a cumulative impact because more groundwater level drawdown occurs within the intersection area than if each quarry was operated in isolation. For surface water, cumulative impacts to water quantity and water quality in a receiving watercourse(s) may result from the discharges from multiple quarries. Cumulative impacts may also occur as a result of drawdown of the shallow groundwater table beneath a surface water feature as a result of the dewatering of multiple quarries. For natural environment features, cumulative impacts relate to the potential effect of dewatering and discharge from multiple quarries on the surrounding flora and fauna.

The study involved the review of available groundwater, surface water and natural environment information, as well as the completion of discipline-specific field programs to gather additional information to assess potential cumulative impacts within the study area. The field programs included collection of baseline groundwater level data, borehole geophysical logging, instantaneous surface water flow measurements, surface water quality monitoring, continuous lake level monitoring, benthic invertebrate community monitoring, aquatic habitat assessments and a survey of the conditions in the Cranberry Lake Wetland. A numerical groundwater flow model was used to identify areas of potential cumulative impact associated with groundwater level drawdown based on an existing quarry conditions scenario, 20-Year Development scenario (the most reasonable scenario to be considered at this time) and a Full Licensed Depth quarry development scenario (which is not a reasonable scenario and is not likely to ever occur).

Based on the surface water budget analysis, monitoring stations with cumulative impacts (downstream of more than one quarry) were generally shown to have relatively small (between 0% and 6%) increases in annual surplus based on the 20-Year Development scenario water balance. Based on the surface water quality impact assessment, elevated measured concentrations of sulphate and chloride at downstream cumulative discharge locations and the predicted elevated concentrations of iron and boron at all stations are thought to be partially attributed to quarry discharges. The elevated concentrations of boron, iron, sulphate and chloride are related to naturally occurring concentrations of these parameters in the groundwater/bedrock within the study area. Based on the flooding and erosion impact assessment, adverse impacts are not anticipated under the 20-Year Development scenario.

The groundwater modelling identified two potential zones of cumulative impact within the upper weathered zone and two zones within the green bed layer. The zones of cumulative impact within the upper weathered zone were localized around the individual quarries, while the zones within the green bed layer showed the potential for greater lateral extension. The individual drawdown cones modelled in the upper weathered zone are generally similar in size and shape for the 20-Year Development scenario and the Full Licensed Depth scenario. This suggests that the drawdown predicted for the 20-Year Development scenario is at or near the maximum drawdown that will occur in the upper weathered zone. Because of the greater potential lateral extent of the drawdown in the green bed layer compared to the upper weathered zone, depressurization of the green bed layer has greater potential to result in cumulative impacts relating to groundwater within the study area. Based on the results for the 20-Year Development scenario, it is unlikely that within the next 20 years groundwater levels in the water supply wells identified within, or in close proximity to, the predicted zones of cumulative impacts will drawdown to the point where well interference will occur.

Based on the low flow impact assessment, the cumulative drawdown of groundwater levels between the Miller and Tomlinson quarries is not expected to have an additional effect on flows or the ecological condition in the drainage features.

A water balance for the adjoining Cranberry Lake (which included surface runoff, groundwater inputs, quarry dewatering and quarry discharges) suggests only minor net changes to flows in Cranberry Lake as a result of the predicted cumulative drawdown of groundwater levels between the Beamish and Holcim quarries. Due to the small magnitude of change to flows at the Cranberry Lake wetland edge, an area of the wetland which is relatively more resilient to annual water level fluctuation, the ecological form and function of the wetland is not expected to be significantly affected.

In summary, based on the analysis presented for the 20-Year Development scenario, cumulative effects of the quarries considered in this study, on groundwater drawdown, drinking water wells, wetland function, low flows in creeks and rivers, flooding and erosion in creeks and rivers and most water quality parameters are expected to be negligible. Increases in concentrations of boron, iron, sulphate and chloride are expected as a result of dewatering groundwater (which naturally contains these parameters) from quarries.

Table of Contents

TABLES

FIGURES

APPENDICES

1.0 INTRODUCTION

1.1 Background

Due to the recent level of aggregate extraction activity in the Carden Plain Area, the Ontario Ministry of the Environment (MOE) requested a multidisciplinary study and impact assessment to evaluate the potential cumulative impacts of quarry dewatering at multiple sites on groundwater, surface water and ecological receptors. Golder Associates Ltd. (Golder) was retained by the Ontario Stone, Sand and Gravel Association (OSSGA) to complete the required study. The study area for the project focuses on the Carden Plain, and the general location of the study area is shown on Figure 1.

The framework for the cumulative impact assessment (CIA) was laid out in the MOE‟s Terms of Reference dated February 2009 entitled "Cumulative Impact Assessment for Groundwater Takings in the Carden Plain Area, Geographic Township of Carden and Ramara" (MOE, 2009) and the July 2009 OSSGA Request for Proposal. The scope of work for the project was further refined in Golder‟s work plan (dated August 2009) submitted to the OSSGA, and reviewed by the MOE.

The following quarries were identified by the MOE for inclusion in the CIA:

- Bot Construction Group – Sebright Quarry (Bot);
- James Dick Concrete & Aggregates North Quarry (James Dick North);
- Ferma Aggregates Inc. – Carden Quarry (Ferma);
- Lafarge Canada Inc. – Kirkfield Quarry (Lafarge Kirkfield);
- Halton Crushed Stone Limited – Webster Quarry (Webster);
- Miller Paving Ltd. – Carden Quarry (Miller);
- R.W. Tomlinson Limited – Brechin Quarry (Tomlinson);
- Dufferin Aggregates, a division of Holcim (Canada) Inc. – Carden Quarry (Holcim);
- K.J. Beamish Construction Co. Ltd. – Carden Quarry (Beamish);
- MAQ Aggregates Inc. – McCarthy Quarry (McCarthy);
- Lafarge Canada Inc. – Brechin Quarry (Lafarge Brechin); and,
- James Dick Concrete & Aggregates Gamebridge Quarry (James Dick South).

The locations of the quarries included in the CIA are shown on Figure 2. The short-form names used to identify the quarries on Figure 2 and throughout this report are provided in brackets above. These quarries were identified for inclusion in the study based on the understanding that the quarry locations currently have, or will require, a Permit to Take Water (PTTW) to allow for operation of the site, and extraction of bedrock below the groundwater table. For the purpose of this study, the ten producers listed above are collectively referred to as the CIA Task Force.

The project schedule was developed with input from the MOE and OSSGA/CIA Task Force. The project was initiated in October 2009, and is scheduled to be completed in September 2011. During the course of the project, there were four progress meetings held with the MOE on December 15, 2009, February 24, 2010, October 4, 2010 and

March 3, 2011, and there were two public meetings held on May 13, 2010 and April 28, 2011. A third and final public meeting to present the study results will be scheduled following the completion of the reporting portion of the study.

1.2 Scope of Assessment

The CIA project is a multidisciplinary study assessing potential cumulative impacts associated with quarry development within the Carden Plain on groundwater, surface water and natural environment receptors. The study area is large, as shown on Figures 1 and 2, with a wide variety of natural features. The objectives of the study were to screen out areas where cumulative impacts are unlikely, identify areas where cumulative impacts are likely, and to provide a preliminary assessment of the potential magnitude of predicted cumulative impacts. For the purpose of this study, a cumulative impact is defined as the additive effect of multiple quarry dewatering operations on groundwater, surface water and/or natural environment features. For groundwater, a cumulative impact could result from the intersection of various dewatering zones of influence associated with operation of multiple quarries. The intersection of multiple dewatering zones of influence results in a cumulative impact because more groundwater level drawdown occurs within the intersection area than if each quarry was operated in isolation. For surface water, cumulative impacts to water quantity and water quality in a receiving watercourse(s) may result from the discharges from multiple quarries. Cumulative impacts may also occur as a result of drawdown of the shallow groundwater table beneath a surface water feature as a result of the dewatering of multiple quarries. For natural environment features, cumulative impacts relate to the potential effect of dewatering and discharge from multiple quarries on the surrounding flora and fauna.

As the quarries within the Carden Plain develop, the cumulative impacts will change over time and space. The available information was used to select an appropriate timeframe for completing an impact assessment to determine if the operation of multiple quarries within the Carden Plain will result in unacceptable cumulative impacts to identified groundwater, surface water or natural environment features. This study focuses on assessing potential adverse effects within an area of predicted cumulative impact. Potential impacts to groundwater, surface water and ecological resources as a result of the operation of a single quarry have previously been assessed as part of existing approval mechanisms including the *Aggregate Resources Act* (ARA) Site Licenses, PTTW and Certificates of Approval (C of A) under Section 34 and 53, respectively, of the *Ontario Water Resources Act* (OWRA), and were not re-assessed as part of this study.

1.3 Report Structure

This report consists of the main text and supporting tables, figures and appendices. The text provides a discussion of the following:

- Study methodology (Section 2.0);
- Description of the regional setting for geology, groundwater, surface water and natural environment (Section 3.0);
- General description of quarry operations for sites included in the CIA (Section 4.0);
- Results and discussion (Sections 5.0);
- Impact assessment focusing on identified areas of potential cumulative impact within the study area (Section 6.0); and,
- Conclusions (Section 7.0).

2.0 STUDY METHODOLOGY

The CIA study involved the review of available groundwater, surface water and natural environment information, as well as the completion of discipline-specific field programs to gather additional information to assess potential cumulative impacts within the study area. A description of the information reviewed and the methodologies used to complete the project are provided below.

2.1 Review of Available Information and Receptor Identification

2.1.1 Site-Specific Data Review

The following information was requested from the quarry operators for each quarry included in the study:

- Site Plans;
- Technical studies completed in support of ARA applications (i.e., groundwater, surface water and natural environment studies);
- Technical studies prepared in support of OWRA, PTTW applications;
- Technical studies prepared in support of OWRA Section 53 – Industrial Sewage Works Certificate of Approval (Section 53 C of A) applications;
- All monitoring data (groundwater, surface water and natural environment) and annual monitoring reports (i.e., prepared to satisfy conditions of a PTTW, Section 53 C of A or ARA license);
- All borehole logs and water level information;
- Pumping records;
- Geophysical logs of boreholes;
- Hydraulic testing data (i.e., pumping tests, rising head test, packer tests, etc.);
- Groundwater quality data; and,
- Surface water quality data and flow data.

Not all of the above information was available for all quarry sites. The information provided by the quarry operators was made available to the study team and reviewed to gather information on how the quarries operate, to locate previously identified receptors in the vicinity of the sites, as well as gather information on site-specific geology, groundwater, surface water and natural environment that could be utilized to assist in the development of the conceptual model for the study area.

A list of the documents reviewed for each site is provided in Appendix A.

2.2 Regional Data Review

In addition to the site-specific data, available regional data relating to geology, groundwater, surface water and natural environment was also reviewed to identify receptors and to develop the conceptual model of the study area. The regional data reviewed by the study teams are listed below.

2.2.1 Groundwater

The following regional data pertaining to geology and groundwater within the study area were reviewed:

- Mapping of the Quaternary geology within the study area, completed by the Ontario Geological Survey (OGS) provides detailed information regarding surficial geology of the study area;
- OGS bedrock mapping undertaken in the north Lake Simcoe area provides detailed geological information (Armstrong, 1999);
- Geological Survey of Canada reporting on the Paleozoic geology of the Lake Simcoe Area (Liberty, 1969);
- MOE Well Information System (WWIS) data, which compiles information from water well records including water well locations, static water levels, pumping test information, and basic lithology that can be used in support of detailed borehole records;
- The South Georgian Bay-Lake Simcoe source water protection draft assessment report (South Georgian Bay Lake Simcoe Source Protection Region, 2010);
- Non-quarry PTTW information, which outlines the authorized maximum daily water takings from other groundwater and surface water sources within the study area; and,
- Information regarding the City of Kawartha Lakes groundwater supply systems located within the study area, referred to as the Western Trent / Palmina systems as summarized by Genivar (2010).

2.2.2 Surface Water

The following regional data pertaining to surface water within the study area were reviewed:

- Ontario Base Mapping (OBM) was used to assess regional drainage and catchment areas;
- Water Survey of Canada (WSC) stream gauges information was reviewed for catchments in the vicinity of the study area having similar characteristics;
- Long-term Environment Canada meteorological data was reviewed for the study area to assist in preparing a water budget;
- Thornthwaite Water Budgets from the Engineering Climatology office of Environment Canada; and,
- Available water surface levels were reviewed for the Trent-Severn Waterway, Cranberry Lake and Lake Dalrymple.

2.2.3 Natural Environment

Various sources were consulted and/or reviewed in order to compile available background natural environment data and to determine the species of conservation concern whose range overlaps the study area including:

- Lake Simcoe Region Conservation Authority (LSRCA) (jurisdiction covers Talbot River watershed in the vicinity of McCarthy Quarry, Lafarge Brechin Quarry and James Dick South Quarry sites);
- LSRCA Lake Simcoe Ecological Land Classification Maps (http://www.lsrca.on.ca/maps/);

- Ministry of Natural Resources (MNR) Midhurst District Office (Email correspondence from Stacy McKee, Management Biologist); and,
- Ministry of Natural Resources, Natural Heritage Information Center (NHIC), Biodiversity Explorer https://www.biodiversityexplorer.mnr.gov.on.ca/nhicWEB/mainSubmit.do

2.2.3.1 Species of Conservation Concern Screening

Species of conservation concern are those federally or provincially listed *endangered*, *threatened* or *special concern* species, or provincially rare (S-rank 1 to 3) species. A list was initially compiled of these species whose broad „range of occurrence" mapping (range maps) overlapped with the study area. The range maps are provided by the Royal Ontario Museum (ROM) and the MNR as part of the Species at Risk project. Additionally, the NHIC database and Fisheries and Oceans (DFO) Aquatic Species at Risk mapping were used to further refine the list. Lastly, the species of conservation concern screening involved a review of the Ontario Breeding Bird Atlas (OBBA) and existing studies (e.g., Level1/2 Natural Environment Reports) in the study area. Given that the focus of this study was on water-related cumulative impacts, only those short-listed species of concern which rely on surface water features in the study area for all or part of their lifecycle were considered.

A habitat suitability ranking of low, moderate or high was given to each species based on the existing data obtained through the sources outlined above and through interpretation of the known habitat available in the study area. A habitat suitability rank of low indicates no habitat availability for that species and no known occurrence records or outdated occurrence records; moderate indicates there is potential for the species to occur as habitat is present in the study area but the occurrence of the species is questionable; and high potential indicates a known species record in the study area or high likelihood of occurrence in the study area and the appropriate habitat occurs in the study area.

2.3 Field Program

2.3.1 Study Area Reconnaissance

Site visits to each of the quarry locations included within the study were completed to observe the current operations (i.e., extraction areas and quarry faces), the groundwater monitoring well network, the on-site sewage works and discharge location(s), and the receiving watercourse. The site visits were completed for most of the quarries on November 25 and 26, 2009, with all site visits being completed by January 13, 2010.

2.3.2 Groundwater Field Program

The groundwater field component of the CIA included the collection of baseline groundwater level data and borehole geophysical logging.

2.3.2.1 Baseline Groundwater Water Level Data

Based on a review of the site-specific background information and information gathered during the site visits, key groundwater monitoring wells located within or near the quarry licensed areas were identified for inclusion in the groundwater level monitoring program. The groundwater level monitoring was completed at the selected locations in May 2010, August 2010 and October 2010. The objective of the groundwater level monitoring program was to obtain a snapshot of groundwater elevations across the study area at various points in time. In selecting wells for the monitoring program, effort was made to include those wells having screen intervals limited to one geological bedrock formation. Also, wells having multiple depth-specific monitoring intervals were selected to assess vertical groundwater gradients across the geological formations. A total of 83 monitoring intervals were selected for the groundwater level monitoring program. The monitoring intervals were selected to provide coverage of the quarry sites, as well as to gather groundwater level information from specific hydrostratigraphic units.

The depth to groundwater for each interval included in the monitoring program was measured from a known elevation. The measured water levels were then converted to elevations in metres above sea level (masl) to allow for the assessment of groundwater flow paths within the study area.

2.3.2.2 Borehole Geophysical Logging Program

During the review of the available site-specific geological data, some discrepancies in the identification of geologic contacts from site to site were identified. To assist in addressing these discrepancies additional stratigraphic data were gathered through geophysical logging for both natural gamma and apparent conductivity at two off-site wells recently installed by R.W. Tomlinson Limited (OW-32 and OW-33), as well as one borehole at the McCarthy Quarry (TW-3) and one borehole at the Beamish Quarry (MW-1).

Logging for both natural gamma and apparent conductivity response allows for a quantitative assessment of stratigraphy. The natural gamma log usually provides information about clay (shale) content in the sedimentary rocks, which can provide for lithological correlation in materials that are visually undifferentiated.

2.3.3 Surface Water Field Program

The surface water field component for the CIA included instantaneous flow measurements, water quality monitoring, and continuous lake level monitoring. The continuous lake level monitoring continued throughout the monitoring period (April 2010 to February 2011), while water quality sampling and flow monitoring were conducted on a quarterly basis.

The field work program was undertaken to quantify the existing condition of the surface water quantity and quality and support the assessment of the potential effects of the quarry discharges and withdrawals with a focus on the significant surface water features and receptors that may be subject to cumulative impacts.

The monitoring program for the CIA was developed in consultation with surface water personnel from the MOE. A network of twelve stations was selected based on a review of available information. The location of each of the quarries, along with its eventual discharge, was overlaid on the drainage map to show the ultimate flow paths for discharge from the quarries. A surface water flow schematic for the study area is provided on Figure 3. Eleven stations were selected, with a twelfth station, SW12, being added in fall 2010. One additional analysis location identified as SWA was added during the CIA to evaluate potential cumulative effects at the confluence of the SW2 and SW3 tributaries, although no flow or water quality information were collected at this location as part of this study. The monitoring locations are shown on Figure 4, and are identified as SW1 through SW12. Brief descriptions of the monitoring and assessment stations are provided below:

- SW1 – at Kirkfield Road south of Lake Dalrymple; chosen to reflect background conditions for the Lake Dalrymple system;
- SW2 – at Mara Carden Boundary Road west of Cranberry Lake; chosen to reflect the cumulative impact of the Miller and Tomlinson quarries;
- SW3 – at Concession Road 5 west of Cranberry Lake; chosen to reflect the cumulative impact of the Holcim and Beamish quarries;

- SW4 – at Cranberry Lake Road, immediately west of Cranberry Lake; chosen to reflect existing conditions in the Cranberry Lake Wetland;
- SW5 – adjacent to Kirkfield Road north of the Kirkfield Lift Lock; chosen to reflect conditions downstream of the Ferma and Lafarge Kirkfield quarries;
- SW6 – at the Concession Road 2 north ditch downstream of the discharge from the Lafarge Brechin Quarry; chosen to reflect discharge conditions for that quarry to support cumulative effects analysis further downstream;
- SW7 – at the Talbot River at the Highway 12 Bridge, chosen to reflect the cumulative effect of all quarries draining to the Talbot River;
- SW8 – at Fenel Road north of Mitchell Lake; chosen to reflect background conditions for the Talbot River system;
- SW9 – at the Simcoe Street swing bridge at Canal Lake; chosen to reflect the conditions at the downstream end of Canal Lake;
- SW10 – a pressure data logger installed by Holcim at Cranberry Lake adjacent to SW4. This logger is downloaded by Holcim and the data was made available to Golder;
- SW11 – in Lake Dalrymple near Kirkfield Road; chosen to measure water surface elevations in Lake Dalrymple;
- SW12 – at Miller Road north of Cranberry Lake; chosen to measure flows leaving Cranberry Lake PSW; and,
- SWA – this location was selected after the completion of the monitoring program to provide an additional point, for desktop hydrological assessment, downstream of both SW2 and SW3. No samples were collected at this location.

Photographs of the surface water stations are included in Appendix B. GPS coordinates for the surface water stations can be found in Table B1 in Appendix B.

Monitoring at these stations (and downloading of the level logger at SW11) occurred during four field visits: April 27, 2010, July 27, 2010, October 21, 2010 and February 16-18, 2011. Flow monitoring at SW4 and SW12 was added for the last two field visits to estimate the relative proportions of the flows leaving the Cranberry Lake Wetland through the northern drainage path.

2.3.3.1 Surface Water Flow Monitoring

Instantaneous flows were measured during all four field visits at five stations (SW1, SW2, SW3, SW5 and SW7), with flows being taken at two additional stations (SW4 and SW12) during the October 21, 2010, and February 18, 2011, site visits. For SW7, flows were not measured downstream of James Dick South Quarry discharge point at Highway 12 Bridge due to safety concerns and unstable cross section at the time of measurement. Flows were measured approximately 700 metres (m) upstream at Talbot Road Bridge. The drainage area at SW7 is approximately 320 km^2 and flows were measured during dry events and the addition of water discharged from James Dick South Quarry was considered to be minimal when compared to the large contributing drainage area.

Flow measurements were taken across a clear section of the stream using the velocity area method. Flow velocities were measured using a Valeport Model 801 Electromagnetic Open Channel Electromagnetic Flow Meter during the first three field visits (April 2010, July 2010 and October 2010), and using a Sontek Flowtracker during the final field visit in February 2011. Flow depths from the bottom of the channel were measured concurrently using a wading rod. Average stream flow velocities were taken at regular intervals across the section and the average two adjacent readings was applied to the cross-sectional area between the intervals. The sum of all the flows across the section was taken as the total instantaneous stream flow at the time of the measurement.

A flow measurement was taken at SW1 during a preliminary site visit on April 23, 2010, and is included in the results.

2.3.3.2 Surface Water Quality Monitoring

Water quality samples were collected at eight stations (SW1, SW2, SW3, SW4, SW5, SW6, SW8 and SW9) during all four site visits (April 27, 2010, July 27, 2010, October 21, 2010, and February 16-18, 2011). The temperature, pH and conductivity of the samples were measured in the field at the time of sample collection. Laboratory testing of the samples was completed for the following parameters:

> Inorganics: total ammonia-N, conductivity, Total Biochemical Oxygen Demand (BOD), Total Organic Carbon (TOC), fluoride, Total Kjeldahl Nitrogen (TKN), dissolved organic carbon, orthophosphate, pH, phenols-4AAP, total phosphorus, dissolved sulphate, dissolved chloride, nitrate, nitrite and dissolved bromide;
>
> General: total oil and grease, Total Suspended Solids (TSS), turbidity, alkalinity (total as $CaCO_3$); and,
>
> Metals: aluminum, calcium, magnesium, potassium, sodium, antimony, arsenic, barium, beryllium, boron, cadmium, calcium, chromium, cobalt, copper, iron, lead, magnesium, manganese, molybdenum, nickel, potassium, selenium, silicon, silver, sodium, strontium, thallium, titanium, uranium, vanadium and zinc.

Samples were taken midstream at each station, and were packed into ice-filled coolers to reduce reactivity during transport. Sample analysis was performed by Maxxam Analytics at Mississauga, Ontario.

Water quality samples were not collected at SW7 and data collected by James Dick South Quarry at the Talbot River downstream of their discharge point were used for the analysis.

2.3.3.3 Lake Level Monitoring

A water level monitor was installed in Lake Dalrymple at SW11 on April 27, 2010. This logger was downloaded quarterly during the field visits. Data from two other loggers in Cranberry Lake were also obtained from the Holcim and Beamish quarries. The data record from the Holcim logger begins in October 2009, while the data record for the Beamish logger begins in May 2010. For this report, the data record for these two loggers run to November 2010.

2.3.4 Natural Environment Field Program

The natural environment field component for the CIA included benthic invertebrate community monitoring, aquatic habitat assessments and a survey of the conditions in the Cranberry Lake Wetland. The field work program was undertaken to determine the existing condition of the natural features such as wetlands and watercourses that rely on surface water and/or groundwater for their form and function. The current conditions of these features will assist with the assessment of the potential effects of the quarry discharges and groundwater drawdown.

2.3.4.1 Benthic Invertebrate Community Monitoring

A study of the benthic invertebrate communities (BIC) was undertaken in select watercourses within the study area. Benthic invertebrates are used as indicators of water and habitat quality as they have limited mobility and spend all or most of their lives in water. Biological communities reflect the ecological integrity (i.e., chemical, physical and biological condition) of a waterbody and thus help to assess the impacts from multiple stressors. While the occurrence of chemical constituents in the water column provides a point-in-time assessment of water quality, the presence or absence of certain species in a community provides information on water conditions over time.

The objective of the benthic community sampling program was to identify the potential effects of cumulative quarry discharge on the composition of the benthic invertebrate community versus the influence of other land uses (e.g., agricultural impacts to water quality). Therefore, a control/impact experimental design was used wherein a series of references stations were located upstream of cumulative discharge points (i.e., upstream of quarry operations) and a series of exposure stations were located downstream of the confluence of the surface water discharges from two or more quarry operations. The community composition at the reference locations provides a comparison with the community composition at the exposure locations. The focus of this study is cumulative impacts, and as such, placement of stations in areas exposed to discharge from a single quarry was intentionally avoided. However, station B-Exp-1 is located downstream of Lafarge Brechin and McCarthy Quarry discharge on the Talbot River but not downstream of the James Dick South Quarry discharge. Additionally, at the time of sampling the McCarthy Quarry was not discharging. In a few instances, the reference stations are not located on the same watercourse where the exposure stations are located for a number of reasons (e.g., watercourse is too small or does not exist upstream, no access to upstream portions, etc.). Therefore, in these instances a reference sampling station was selected on watercourses with similar physiography (slope), channel size, and bottom substrates as the exposure station (e.g., C-Ref-1/C-Exp-1).

The BIC sampling was conducted on November 15-16, 2010. The BIC sample collection method was the traveling kick and sweep method for wadeable streams. This involves wading along transects across the stream, kicking substrates to dislodge benthos and collecting the benthos by sweeping with a hand-held „D"-net. Three samples were collected at each station (i.e., three different transects were sampled). Habitat characterization at all BIC stations involved habitat mapping, substrate composition, riparian vegetation, channel measurements, dissolved oxygen, pH, conductivity, etc. This habitat data can help to differentiate between a water quality response and a physical habitat quality response.

Once the samples were collected, they were preserved in 10% buffered formalin, labelled and transported to a taxonomist (William B. Morton, Guelph, Ontario) for sample sorting, invertebrate identification and enumeration. The processing of the samples involved placing each sample into a stacked series of geological sieves with a 4 millimetre (mm) mesh placed over a 1 mm mesh and a 0.5 mm mesh. Sediments from each sieve were then washed into smaller 500-1,000 millilitre (mL) containers for further processing. The sorting process involved searching through the sediments for any invertebrates with a dissecting microscope at 6-times power. The sorted sediments were discarded and any unsorted material returned to the original containers and preserved with the field preservative. All containers, dishes and sieves were completely scrubbed after each sample was processed to help prevent specimen contamination between samples.

Due to the high density of specimens and volume of sediment, some sub-sampling was required. An area-based sub-sample routine was used which involves placing the sediments into a large gridded tray and dividing the sediments into tenths (10%). For the samples with the highest densities only 1-2 tablespoons of material was analysed and recorded the sub-sample as 1%.

After removal from the sediments, the specimens were sorted into similar groups prior to identification to the lowest practical taxonomic level, species if possible. Chironomidae and Oligochaeta were sorted into similar groups and representatives slide mounted to confirm their identity. Slide preparations were made with CMC-10 (Masters Company Inc.). Once identified, all non-slide mounted material was placed into labelled shell vials with neoprene stoppers and re-preserved with 75% ethanol. A voucher collection containing examples of each taxa identified was also prepared. The resulting data was compiled into Excel spreadsheets, and a series of biological indices or metrics is calculated to summarize biological condition.

2.3.4.2 Aquatic Habitat Surveys

Aquatic habitats were surveyed to characterize the current condition of parameters such as bank vegetation, channel sediments, water pH, aquatic plants and fish habitats. As benthic invertebrate community composition is linked directly to site-specific habitat characteristics, the surveys were conducted at all BIC stations. The habitat data can help to differentiate between a water quality response and a physical habitat quality response in the benthic invertebrate communities.

The aquatic habitat surveys were conducted on November 15-16, 2010. Survey stations were coordinated with surface water monitoring stations to relate physical and flow information to habitat parameters as well as the benthic invertebrate community composition. Habitat survey stations matched those of the BIC sampling and thus were located in stream reaches that have the potential to be affected by cumulative quarry discharge (surface water discharge from more than one quarry).

2.3.4.3 Wetland Characterization

Wetlands were identified through a compilation of background data and a field investigation. The field investigation of wetlands also entailed a review of the hydrologic condition of the Cranberry Lake Wetland Complex as it relates to the wetland vegetation communities.

2.4 Groundwater Flow Modelling

As a part of the CIA, a numerical groundwater flow model was used to identify the areas of potential cumulative impact associated with groundwater level drawdown.

2.4.1 Modelling Approach

The groundwater modelling assessment was completed to identify potential areas impacted by cumulative groundwater drawdown resulting from quarry operations within the study area. The approach taken to meet this objective involved the construction of a three-dimensional (3D) numerical groundwater flow model, based on the conceptual model for the study area developed from the available geological and hydrogeological data (described in Section 3.0 Regional Setting). The 3D groundwater model is calibrated to existing conditions, and then subsequently modified to predict the effects of future quarry development.

The numerical simulations were completed under steady-state conditions, assuming that groundwater flow in the overburden and bedrock units can be approximated using an equivalent porous media (EPM) approach. This is considered reasonable provided the scale of the observation (in this case the extent of dewatering required for an individual quarry) is much greater than the scale of individual fractures, and consideration is given to the selection of a reasonable bulk hydraulic conductivities for the hydrostratigraphic units.

It should be recognized that the steady-state model does not account for seasonal variation in the overall water budget, but rather assumes that recharge rates and groundwater seepage rates are representative of long-term annual average conditions. Therefore, the results of the predictive simulations completed herein provide an estimation of the mean long-term potential impacts on the groundwater flow system.

The general assumptions and limitations of the groundwater flow models are summarized in Table C1 in Appendix C.

2.4.2 Code Selection and Description

MODFLOW-2000 (USGS, 2000) was used to simulate the groundwater flow field for the study area. MODFLOW is a multi-purpose 3D 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 graphical user interface for the simulations completed herein.

2.4.3 Extent of Model and Discretization

The extents of the groundwater models are illustrated on Figure 5. As shown on the figure, a compartmentalized approach was taken where three separate model domains were used to represent areas where cumulative impacts are most likely to occur (i.e., where quarries are grouped near to one another). The zones are defined as follows:

- **Zone 1** extends from Lake Saint John at the westernmost portion of the domain and follows Saint John Creek to the Black River. The northern boundary follows the Black River and Head River (north of Young Lake). The eastern portion of the boundary is formed by Lake Dalrymple and the wetland and drainage feature located on the northwestern side of the lake. Based on topographic mapping and regional groundwater elevation information, these surface drainage systems are anticipated groundwater discharge areas, and therefore represent groundwater flow divides. The southern portion of the model boundary is comprised of a topographic and groundwater divide, as determined by the digital elevation model (DEM) and regional groundwater elevation information.

  The Zone 1 groundwater model is comprised of a 100 m by 100 m grid cell network, resulting in 96 rows, 162 columns and 10 layers for a total of 155,520 grid cells. It contains the Bot and James Dick North quarries, neither of which are currently dewatering. The preliminary hydrogeological assessment and operational plan for the James Dick North Quarry indicate that the quarry will extract limestone above the water table only. This was confirmed through correspondence with James Dick. As such, this site will not contribute to a decrease in the groundwater elevations within the model domain, and the drawdown of groundwater elevations in Zone 1 will be limited to the Bot Quarry. Based on the scope of the CIA, which involves assessing only the impacts of multiple quarries, this model zone is described below in terms of model construction and calibration, although there are no cumulative impact results to present;

- **Zone 2** extends from Lake Simcoe (at Lagoon City) at the westernmost portion of the domain, following a low in the topographic and groundwater elevation surface (assumed groundwater flow divide) northeast towards Lake Dalrymple at Lakeview Beach. The north-eastern model boundary extends from the Community of Lake Dalrymple following a topographic low to an upland region. The boundary then trends south along a valley through Canal Lake, and follows the Talbot River at the exit of Canal Lake towards Lake Simcoe. The Zone 2 groundwater model boundary is generally consistent with previous models constructed within the study area, though it extends further towards the north (Golder, 2007a; Azimuth 2008a).

  The Zone 2 model contains the Miller Quarry, Tomlinson Quarry, Holcim Quarry, Beamish Quarry, McCarthy Quarry, Lafarge Brechin Quarry and James Dick South Quarry. It is comprised of 356 rows, 219 columns and 10 layers for a total of 779,640 grid cells; and,

- **Zone 3** extends from Balsam Lake on the eastern boundary and follows the Trent Canal through Mitchell Lake to Canal Lake. The western boundary follows a topographic low (and consistent groundwater elevation) north from Canal Lake, bends south-east through the valley containing Duck Lake, and continues to Balsam Lake.

The Zone 3 groundwater model contains the Ferma Quarry, Lafarge Kirkfield Quarry and Webster Quarry. It is comprised of 218 rows, 181 columns and 9 layers for a total of 355,122 grid cells.

For model zones 2 and 3, the grid spacing was specified as 100 m by 100 m cells away from the quarries, and transitioned to 50 m by 50 m cells in the areas close to the quarries.

2.4.4 Numerical Representation of Conceptual Model

2.4.4.1 Hydrostratigraphic Units

The numerical model layers are based on the regional hydrostratigraphic units identified during the review of the site-specific and regional geology and hydrogeology data. The models were divided into 10 vertical layers for Model Zone 1 and 2, and 9 vertical layers for Model Zone 3. Because the Verulam Formation is thin within Model Zone 3, there is no separate model layer for this formation. The model layers are briefly described below.

- **Layer 1 – Overburden**. A thin veneer of overburden is present over the majority of the study area, with thicker deposits found in isolated pockets. The overburden is composed of a mix of organic deposits, alluvium, fine-grained glaciolacustrine deposits, glacial tills, stratified drift and occasional sand deposits. Regionally, the overburden deposits were represented as a bulk unit with a hydraulic conductivity value that was ultimately determined through the calibration process (discussed in Section 2.4.6). In some places within the model domain, no overburden is present at surface. In these areas, the underlying weathered bedrock is defined at surface. The top surface of Layer 1 is defined by topography, based on DEM data (MNR, 2002). The bottom surface of this layer is defined as the top of bedrock, which was calculated based on all available borehole information;

- **Layers 2 and 3 – Upper Weathered Bedrock**. These layers represent a zone of enhanced fracturing as a result of weathering that is typically found within the upper 3 to 6 m of bedrock throughout the study area. The top surface of these layers was defined as the top of rock. As it is not possible to map the thickness of this unit with the amount of data currently available, this layer was specified with a minimum total thickness of approximately 4 m. However, the material properties of the upper weathered bedrock were extended into lower model layers where geological surfaces “pinch-out” and minimum numerical layer thicknesses were specified, effectively extending the thickness of the weathered zone in these areas;

- **Layer 4 – Verulam Formation**. This layer represents the Verulam Formation bedrock. The thickness of this unit is variable and increases towards the south. In areas where the Verulam Formation is not present, a minimum layer thickness of 1 m was used, and the material properties of the overlying (weathered bedrock) unit were applied. It should be noted that this unit is incorporated within model layer 3 within Model Zone 3;

- **Layer 5 – Bobcaygeon Formation**. Generally found throughout the study area, this layer is considered to be a thick, continuous unit of relatively low permeability (based on available hydraulic conductivity data);

- **Layer 6 – Upper Gull River Formation**. This layer represents the upper Gull River Formation and is approximately 5 m thick across the study area. This unit is considered to be an aquitard with hydraulic properties similar to those of the overlying Bobcaygeon Formation;

- **Layer 7 – Gull River Formation Green Beds**. Layer 7 represents the “green bed” unit, found approximately 5 m below the Gull River-Bobcaygeon formational contact. This unit is approximately 1 m to 3 m thick across the study area. Despite its limited thickness, this unit generally represents a regionally extensive aquifer capable of supplying significant volumes of water;

- **Layer 8 – Lower Gull River Formation**. This layer represents the lower Gull River Formation, consisting of limestone of varying thickness across the study area. This unit is interpreted to be an aquitard;
- **Layer 9 – Shadow Lake Formation**. This layer represents the Shadow Lake Formation of relatively consistent (8 m – 12 m) thickness across the study area. This unit is interpreted to be an aquitard; and,
- **Layer 10 – Shadow Lake / Precambrian Contact**. A zone of enhanced fracturing is sometimes found at the contact between the Shadow Lake Formation and the underlying Precambrian basement rock, and is considered as a continuous aquifer across the study area. Layer 10 was specified as a constant 5 m thick layer draped below the top of the Precambrian rock surface to represent this zone. The top of the Precambrian surface is irregular across the study area, and cuts through the overlying formations in places. The base of this layer forms the base of the numerical model, as it is assumed that the competent Precambrian rock found below the weathered zone at the Shadow Lake contact is impermeable relative to the overlying formations.

Table C2 in Appendix C summarizes the overall parameterization of the MODFLOW models, including boundary conditions (discussed further in Section 2.4.5).

2.4.4.2 Hydraulic Conductivity

Estimates of hydraulic conductivity of the hydrostratigraphic units found within the study area were identified through the data review process, and are summarized in Table C3 in Appendix C, and illustrated on Figure C1 in Appendix C. Estimates of hydraulic conductivity typically range within several orders of magnitude for a given hydrostratigraphic unit. One possible explanation for the wide range in hydraulic conductivity estimates is the local variability in the degree of fracturing within a given unit. As previously mentioned, the upper 3 to 6 m of bedrock experiences enhanced permeability due to weathering, regardless of which geological unit occurs at surface. As such, the maximum hydraulic conductivity estimate for each unit may be reflective of the increased conductivity due to weathering-enhanced fracturing. Another possible explanation for the wide range in estimates is discrepancy in the logged formation name associated with a particular unit. For example, the Verulam-Bobcaygeon formational contact is often indistinguishable without the assistance of geophysical logging. It is possible that hydraulic test results for an interval within the Bobcaygeon Formation could be recorded as being in the Verulam Formation.

The estimates provided are representative of the horizontal hydraulic conductivity of the principal hydrostratigraphic units. There are no supporting field data to describe the vertical hydraulic conductivity of these units. Due to the nature of their deposition, sedimentary rocks (such as those found within the study area) often exhibit stratification that results in the horizontal hydraulic conductivity being an order of magnitude greater than the vertical hydraulic conductivity. Based on this generalization, an anisotropy ratio of 10:1 (horizontal to vertical) was assumed for each of the hydrostratigraphic units, with the exception of the green bed units within the Gull River Formation, which were assigned an anisotropy ratio of 2:1 to account for assumed enhanced vertical connectivity within the unit.

2.4.5 Boundary Conditions

Figure C2 in Appendix C illustrates the boundary conditions applied for the CIA models. As noted earlier, the perimeter of the model generally follows regional topographic and surface water divides, and assumes that these are consistent with groundwater flow divides. Unless otherwise specified, the outer edges of the groundwater models were defined as “no-flow” boundaries; groundwater flow does not occur across these boundaries.

Seepage boundaries were specified in the upper layers of the models to represent the various streams, creeks, tributaries and marshy areas found within the study area. At these boundaries, groundwater discharge can occur during the simulation depending on the local gradients simulated in the model. Once groundwater discharge occurs at a seepage boundary the water is removed from the model and is not reapplied at subsequent downstream boundaries. Therefore, it is assumed that these surface water features are locations of groundwater discharge, and do not recharge the deeper groundwater flow system on an average annual basis. The elevation assigned to each seepage boundary was based on topography (MNR, 2002).

Operating quarries within the study area were simulated using seepage boundaries specified over the extraction footprint and floor elevation. Details regarding the current quarry configurations used in the groundwater model for calibration purposes are outlined in Table C4 in Appendix C. The Lafarge Kirkfield Quarry, which is presently flooded, was represented as a constant head boundary at the current water level in the quarry (253.5 masl) to ensure that a hydraulic connection exists between the hydrostratigraphic layers intersected by this excavation.

Constant head boundaries were specified in the groundwater flow model for the various lakes, major rivers, and to provide a regional groundwater outflow from Model Zone 3. Constant head boundary elevations used to represent the lakes and rivers were based on 2002 ground surface elevation data. At the regional outflow in Model Zone 3, the constant head boundary was specified to match the hydraulic head calculated by the Model Zone 2, which corresponds to the regional groundwater elevation map shown on Figure 11.

The City of Kawartha Lakes operates pumping wells within the modelled area, referred to as the Western Trent/Palmina water supply system (Genivar, 2010). These are located near the southern shore of Canal Lake, and extract water from the upper Precambrian weathered contact zone (see approximate well locations on Figure 12). Actual usage data were not available at the time of model development; the combined pumping rate from these wells was simulated as 50 cubic metres per day (m^3/day) in the model.

Recharge was applied to the top surface of the model to simulate annual average infiltration to the groundwater flow system from precipitation. The recharge distribution for the models is shown on Figure C3 in Appendix C. This considers two main areas of recharge: where overburden is present at ground surface, 65 mm per year (mm/y) is used, and where weathered bedrock is present at ground surface 75 mm/y is used. The recharge distribution was determined through the calibration process (discussed below).

2.4.6 Model Calibration

Calibration of the groundwater models involved the refinement of the recharge rates and the material properties of the main hydrostratigraphic units until the simulated hydraulic head distribution and groundwater seepage rates into the quarries compared reasonably well with the measured conditions in the study area. Visual spatial comparison of the hydraulic head distribution and the distribution of error were also considered throughout the calibration process. Water level data obtained during the baseline groundwater monitoring program were used as the primary dataset in the calibration process. In order to account for the areas between quarry license boundaries (not covered by the water level monitoring program) the static water levels recorded in the MOE WWIS database were utilized as discrete points of comparison. A total of 706 WWIS points were used following a QA/QC process that removed spurious and/or suspect data from the database (e.g., as defined by wells with a location accuracy code of 6 (less than 1 km of error) or better). The "best-fit" set of material properties established from the calibration process is illustrated on Figures C4 and C5 in Appendix C for groundwater Model Zones 2 and 3, respectively.

A comparison of the simulated and measured groundwater elevations for all calibration data is illustrated on Figure C6 in Appendix C. The simulated inflow rates to the currently operating quarries are provided on Table C5, and the simulated groundwater elevations in the upper weathered bedrock zone for current conditions are illustrated on Figure C7 in Appendix C. As noted earlier, the focus of the calibration was on the most recently available groundwater elevations from the key monitoring wells included in the baseline groundwater monitoring program. The differences in the simulated and observed groundwater elevations for the key monitoring locations are outlined on Table C6 in Appendix C. A review of the results on Figures C6 and C7, and in Tables C5 and C6 in Appendix C, allows the following observations:

- Simulated groundwater elevations are typically within five m of measured values; over 82% of calibration points have a calculated value within 5 m of the observed value and 99% of calibration points have a calculated value within 10 m of the observed value. The absolute mean difference ranges from 2.6 m to 3.3 m, and the mean difference is approximately 2 m for all model zones;
- The normalized Root Mean Square error for the models ranged from 5.8% to 9.8%.
- The groundwater flow patterns simulated by the calibrated model (Figure C7) are reasonably representative of those inferred from the conceptual model (Figure 11); and,
- The hydraulic conductivity values used in the calibrated model (as illustrated on Figures C4 and C5 and summarized in Table C2) are all within the estimates discussed in Section 2.4.4.2 and are considered reasonable. Further, these values are similar to hydraulic conductivities used in previous modelling (Golder 2007a, Azimuth, 2008a).

While there are no direct measurements or detailed estimates available of groundwater seepage into the currently operating quarries within the study area, approximations of the groundwater component of quarry discharge have previously been made for the Holcim, Lafarge Brechin, Webster and James Dick South quarries. The estimated values are compared to the simulated groundwater seepage rates from the groundwater modelling in Table C5 in Appendix C. As shown in Table C5, the simulated groundwater seepage rates for the quarries are of the same order of magnitude as those approximated from the available data.

2.4.7 Modelling Scenarios

The groundwater modelling scenarios considered in the CIA are described below.

2.4.7.1 Pre-Quarry Conditions Scenario

The groundwater models were used to simulate the pre-development groundwater conditions assuming no quarries exist within the study area. This scenario was used to evaluate the reasonableness of the selected hydrogeological properties without the influence of quarry dewatering. Also, the Pre-Quarry scenario was used for comparative purposes to calculate the simulated drawdown resulting from quarry operations (i.e., the Pre-Quarry scenario is the baseline condition that all subsequent scenarios are compared against). The groundwater flow models used to calculate the pre-development groundwater elevations were the same as previously described in Section 2.4.5, with one exception: boundary conditions used to define the quarries were inactivated.

2.4.7.2 *Existing Conditions Scenario*

The current depths and limits of extraction at each quarry were simulated and used for model calibration (described above, and summarized in Table C4 in Appendix C).

2.4.7.3 *20-Year Development Scenario*

The quarry depths for this scenario were calculated assuming that all quarries extract at the maximum permitted tonnage rate over the full licensed extraction area. For those quarries where extraction has already commenced, it was assumed that future extraction would commence in the undisturbed areas from ground surface and work towards the current floor elevation. The calculated 20-Year Development quarry floor elevations are provided on Table C7 in Appendix C. These elevations were applied to drain boundary conditions within the model to simulate the 20-Year Development scenario. It should be noted that only those quarries included as a part of the current study were considered in this scenario (i.e., any possible future quarry developments were not considered).

2.4.7.4 *Full Licensed Depth Scenario*

The maximum depths and limits of extraction at each quarry, as indicated by operational site plans, were applied at each quarry to approximate the “worst-case” cumulative drawdown impacts between quarries and at potential receptors. The full licensed extraction areas and floor elevations are provided on Table C8 in Appendix C. Again, drain boundaries were used to simulate these extraction areas and floor elevations within the groundwater model. It should be noted that only those quarries included as a part of the current study were considered in this scenario (i.e., any possible future quarry developments were not considered).

2.4.7.5 *Sensitivity Analysis*

Subsequent to establishing the “best-fit” set of hydrogeological parameters (i.e., the calibrated model discussed in Section 2.4.6), additional groundwater flow model simulations were completed to evaluate the reasonableness of these parameters. This was achieved by adjusting the hydrogeological parameters, rerunning the simulation and comparing the results (in this case the extent of the simulated drawdown) to those of the calibrated model. Specifically, the parameters evaluated as a part of this analysis were the hydraulic conductivity of the green bed layer and of the Bobcaygeon Formation layer. This approach, referred to as a sensitivity analysis, was taken to address the inherent uncertainty associated with these parameters, as evidenced by the variability in hydraulic testing data.

Four alternate model configurations were simulated using the 20-Year Development scenario as the reference simulation. These were developed based on the variability observed in previously completed hydraulic testing of the Bobcaygeon Formation and green bed layer, and included the following:

- **Sensitivity Run 1 (SR1)**: increased the horizontal and vertical hydraulic conductivity of the green bed layer to one order of magnitude above the calibrated value (i.e., the horizontal conductivity increases to $1x10^{-4}$ m/s from $1x10^{-5}$ m/s);
- **Sensitivity Run 2 (SR2)**: decreased the horizontal and vertical hydraulic conductivity of the green bed layer to one order of magnitude below the calibrated value (i.e., the horizontal conductivity decreases to $1x10^{-6}$ m/s from $1x10^{-5}$ m/s);
- **Sensitivity Run 3 (SR3):** increased the horizontal and vertical hydraulic conductivity of the Bobcaygeon Formation by a factor of five (i.e., the horizontal hydraulic conductivity increases to $5x10^{-9}$ m/s from $1x10^{-9}$ m/s); and,

- **Sensitivity Run 4 (SR4):** reduced the horizontal and vertical hydraulic conductivity of the Bobcaygeon Formation by a factor of two (i.e., the horizontal hydraulic conductivity decreases to 5×10^{-10} m/s from 1×10^{-9} m/s).

The results of the sensitivity analyses were compared to the calibrated conditions to ensure that reasonable model calibration was preserved following reconfiguration of the material properties.

2.4.8 Identification of Areas of Cumulative Impact

In order to estimate the areas of overlapping groundwater drawdown between quarries (i.e., the areas or cumulative impacts) for the forecast groundwater simulations, the following approach was adopted:

- A groundwater flow simulation was completed using only one active quarry drain boundary, representing one operational quarry within the model domain;
- The 1 m drawdown contour resulting from the simulation described above was calculated for the upper weathered zone and green bed layer, where the initial condition is based on the Pre-Quarry scenario;
- The drain boundaries that were active in the first simulation are deactivated, and the simulation is repeated using active drain boundaries for a second quarry within the domain. Again, in this simulation only one quarry is considered “operating”;
- The 1 m drawdown contour is again calculated for the upper weathered zone and green bed layer;
- The process above is repeated until all quarries in the model domain are accounted for; and,
- The drawdown contours are superimposed and areas where overlap occurs are identified. These are considered areas of potential cumulative impact on groundwater levels.

Although this approach does not consider the full extent of drawdown that will occur from all quarries operating in unison as a part of a given forecast simulation, this approach is considered reasonable with respect to individual quarry drawdowns, because the impacts of individual quarries are isolated from one another and not limited in lateral expansion by the drawdown of nearby quarries (i.e., the drawdowns are not cut-off by the presence of other quarries, or by greater magnitude drawdowns from nearby quarries).

2.5 Water Budget

As part of the cumulative impact assessment, the average annual flows at the monitoring stations in the study area needed to be estimated. Given that instantaneous flows were only measured at the monitoring stations on four occasions over a one year period, there are insufficient data to accurately describe average annual flows based on these measurements. A water budget analysis was therefore undertaken for each of the delineated catchments in the study area in order to provide more reliable estimates for average annual flow rates.

The following three scenarios were used in the water budget:

- Pre-Quarry Conditions Scenario – assuming no quarries and the remaining land use as existing;
- Existing Conditions Scenario – includes the quarries in place under existing conditions, this assumes no discharge from the McCarthy, Beamish and Tomlinson quarries at this stage; and,
- 20-Year Development Scenario – assumes all overburden has been removed over the entire licensed extraction area (including the McCarthy, Beamish and Tomlinson quarries) as per their site plans. Water discharge rates

were assumed as the existing maximum C of A for all quarries except for the McCarthy and James Dick South quarries where the C of A rates were unavailable. At these two locations, the maximum water taking rate for the PTTW was used instead.

2.5.1 Water Budget Methodology

The water budget was developed on the basis of Environment Canada water budget procedures. This method describes water flux in a unit area of soil on a monthly basis based on a balance of precipitation (rainfall and snowmelt), evapotranspiration (ET), soil storage, and surplus. The water budget can be summarized as follows:

Rainfall + Snowmelt – ET – Change in Soil Storage = Surplus

The various water budget components associated with catchment areas are typically presented in mm over their respective sub-catchments, and represent the amount of water per unit of watershed area. This amount is related to specific soil properties, including field capacity and wilting point.

The water budget model combines accumulated rainfall and snowmelt to estimate total precipitation. Rainfall represents precipitation when monthly mean temperatures are greater than 0^{o}C. Snowmelt is computed when snow is on the ground and monthly mean temperatures are greater than 0^{o}C. Hence, snowmelt is based on the depletion of snow storage (accumulated precipitation during periods of sub-zero temperatures).

The potential or maximum ET is estimated, in this case, by the empirical Thornthwaite equation (using average monthly temperature and hours of daylight) and represents the amount of water that would be evaporated or transpired under saturated soil-water conditions. The actual ET is the total evapotranspiration for the period of study based on evapotranspiration demand, available soil-water storage, and the rate at which that soil water is drawn from the ground (as defined by an established drying curve specific to the soil type).

The maximum soil storage is quantified using a Water Holding Capacity (WHC) that is based on guidelines provided in the MOE Stormwater Management Planning and Design Manual (MOE, 2003). The WHC represents the total amount of water that can be stored in the soil capillaries and is defined as the water content between the field capacity and wilting point (the practical maximum and minimum soil water content, respectively). WHCs are specific to the soil type and land use, whereby values typically range from 50 mm for a shallow rooted crop over sand to 350 mm for mature forest over hard clay. For temperate region watersheds, soil storage is relatively stable year round, remaining at or near field capacity with the exception of the typical mid- to late-summer dry period. As such, the change in soil storage is a minor component in the water budget, particularly at an annual scale.

Surplus water remains in the system after the actual ET has been removed (ET demand is met) and the maximum WHC is exceeded (soil-water storage demand is met).

The Meteorological Service Data Analysis and Archive division of Environment Canada provides monthly water budget summaries for meteorological stations with greater than 20 years of meteorological data. These monthly water budgets include monthly values for all parts of the water budget (rainfall, snowmelt, potential evaporation, etc.) for each of the years in the historical record, as well as average monthly values over the entire record.

For the study area, Environment Canada water budgets for a composite of meteorological (MET) stations at Orillia (25 km to the west of the site) were used in the water budget analysis. The combination of Orillia stations used in this analysis covered the years between 1978 and 2003. These water budgets contained monthly average precipitation, ET and surplus values (in mm/m^2) for a range of water holding capacities.

The catchment areas draining to the monitoring stations were divided into areas of different land use using MNR Land Information Ontario or LIO data. LIO results for the catchments are shown on Figure 6. Each of the identified land uses, (including coniferous forest, deciduous forest, forest, hedge row, bog, swamp, marsh, transportation, extraction, and undifferentiated) was assigned a WHC based on the guidelines in the MOE Stormwater Management Planning and Design manual. In the case of "undifferentiated", this was taken to be primarily treeless limestone plain.

The LIO information was taken as the Existing Conditions scenario, and further modified to show the Pre-Quarry and 20-Year Development scenarios. In the case of the Pre-Quarry scenario, all areas identified as extraction areas in the LIO were assumed as "undifferentiated" in order to estimate surpluses from the areas before quarry excavation began (resulting in the same total area for each catchment). In the case of the 20-Year Development scenario, quarry licenses were used to estimate the 20-Year Development extraction areas for each quarry, and the amount of extraction area in each catchment was increased to reflect the full quarry development area. The value of undifferentiated land use in the catchment was then decreased by the matching amount, thus maintaining the catchment area for the 20-Year Development scenario at the same value as the Pre-Quarry and Existing Conditions scenarios. In some cases, the expansion of the quarry extraction areas changed the catchment boundaries and increased the overall catchment area.

The annual precipitation, ET and surplus values from the MOE water budget for each WHC were then multiplied by the area of the matching land use in each watershed in each scenario to estimate a total monthly precipitation, ET and surplus for each land use in each catchment. The total annual precipitation, ET and surplus for the catchment were estimated by taking the sum of all of the surpluses from each land use for the catchment and each scenario, and dividing by the total catchment area.

Surplus values may be further divided into a surface runoff and groundwater infiltration components. Generally, some uncertainty exists in this division as to how much of the infiltrated surplus will ultimately report back to surface water. In the case of the study area water budget, a value for catchment infiltration was taken from the calibrated groundwater model for the Existing Conditions scenario. This value was compared to the estimated total annual surplus, and the groundwater infiltration as a percentage of total surplus was estimated.

With the exception of the James Dick North Quarry, which is staying above the water table, the future development conditions for all other quarries are assumed to involve some rate of groundwater seepage into the quarry and subsequent groundwater pumping. These represent both a taking from surplus for the catchments around the quarry (in the form of the seepage) and an equal contribution to the surplus of the catchment downstream of the quarry as the seepage is pumped into the receiving watercourse. Generally, both the quarry seepage and pumping occurs in the same surface water catchment, balancing out the results to the original surplus calculation. Thus, seepage into quarries and quarry pumping was not included in the water budget.

2.5.1.1 Cranberry Lake Wetland

As previously mentioned, the concentration of quarries close to Cranberry Lake Wetland is of interest in terms of the possible effect of groundwater seepage into the quarries. Seepage into the quarries diverts water that could otherwise have discharged into the wetland.

In order to assess the future reduction in seepage to the wetland, the total annual recharge to the wetland in the Pre-Quarry, Existing Conditions, and 20-Year Development scenarios were compared to the total surplus to the wetland (which is assumed as the sum of flows at SW4 and SW12).

2.5.2 Baseflow Separation

The baseflow in a watercourse has been used to estimate the amount of infiltration in a catchment. For large catchments, water which infiltrates in the upstream portions of the catchment is often assumed to eventually report back to surface water further downstream in the catchment as interflow (flow discharging into watercourses just below the ground surface but above the water table) and groundwater discharge, which together contribute baseflow in watercourses. In the short-term, changes in soil and groundwater storage may delay the transmission of this baseflow. This can occur in the spring when water discharged from frozen soil may have infiltrated during the previous year, or during the summer when infiltration into dry soils is used to make up for evaporation rather than being discharged. However, over long periods, changes in soil storage tend to be negligible, reducing their effect on the infiltration-baseflow relationship. Thus, if the volume of baseflow in a river or stream at the downstream end of a large catchment can be estimated for a sufficiently long period of time, dividing that volume by the catchment area provides an estimate of average infiltration.

In order to further understand the regional hydrology of the study area, a baseflow separation analysis was undertaken. This analysis uses the BFLOW program (Arnold, 1995) to estimate the baseflow yield from a daily stream flow record.

Generally, data for a baseflow analysis is taken from a nearby regional WSC stream gauge. While there are no WSC gauges within the study area, there are two WSC gauges within 30 km of the centre of the study area: the Black River near Washago (02EC002, 27 km to the northwest) and the Beaverton River near Beaverton (02EC011, 17 km to the south). The surficial soil types in both catchments were evaluated using Ontario soils mapping, and compared to the surficial soils found in the study area. Of the two, the Beaverton River watershed was found to be more representative of hydrologic conditions in the study area, as a significant portion of the Black River catchment area is Algonquin Highlands, while the Beaverton River catchment more closely matches the medium textured surficial soils of the study area. The WSC gauge on the Beaverton River at Beaverton was therefore used as a surrogate to estimate regional surplus and baseflow values for the study area. The results of the baseflow separation assessment are provided in Section 5.4.

3.0 REGIONAL SETTING

The regional setting for the study area presented below was developed based on the review of available information completed by the study team.

3.1 Topography

The topography in the study area is shown on Figure 7. The topography ranges from over 300 masl in the northeast and southeast portions of the study area to approximately 200 masl along the shores of Lake Simcoe in the western portion of the study area. The James Dick North and Bot quarries are located on a local topographic high in the north western portion of the study area. Portions of the study area have broad low hills and shallow valleys with a strong northeast to southwest orientation. Generally, the elevation difference between adjacent valleys and hills is less than 20 m.

3.2 Regional Meteorological Conditions

Long-term meteorological data for regional stations is provided by Environment Canada. The nearest MET gauge to the site is at Lagoon City (see location on Figure 2); however, the records for this station are incomplete. The next closest MET station is at Orillia (25 km to the west of the centre of the study area), where a series of stations (Orillia Brain, Orillia TS, Orillia STP and Orillia) provide a climate record from 1978 to 2003. As with the majority of the study area, the MET stations within the Orillia are located within the Ontario Snowbelt. Climate differences between the study area and Orillia are assumed to be negligible. The average total precipitation at the Orillia stations (to 2003) was 1,055 mm.

Unfortunately, 2010 records at the Orillia BRAIN station are incomplete, with a large number of missing days. Recent climate data (for 2010) is therefore taken from the Udora MET station, 35 km to the south of the centre of the study area. Data are available at this station from 1990 onwards. This station is south of Lake Simcoe, and slightly to the south of the Ontario Snowbelt, and has a tendency to have slightly less precipitation than the Orillia station (and consequently less precipitation than at the site). A comparison of overlapping complete years of data (1993-1998, 2001-2003, and 2005-2006) shows an average annual precipitation of 1,053 mm at Orillia BRAIN compared to 896 mm at Udora.

Table 1: MET Station Comparison

Station	Orillia (Composite)	Udora
Record	1871-2011	1989-2011
Average Annual Precipitation (mm)	1,043[1]	892[2]
Average Annual Precipitation – Overlapping Years of Data (mm)[3]	1,053	896

[1] *Average Annual Precipitation from Environment Canada Climate Normals 1971-2000*
[2] *Average Annual Precipitation 1992-2010*
[3] *Average Annual Precipitation for 1993-1998, 2001-2003 and 2005-2006*

The 2010 precipitation recorded at the Udora station was 829 mm. This is approximately 7% less precipitation than the long-term average annual precipitation at the station of 892 mm. Assuming that the broad scale regional climate patterns are consistent between the sites, this suggests that 2010 may have been an average to slightly drier than average year within the study area. However, this station comparison applies only to the 2010 precipitation.

3.3 Bedrock and Surficial Geology

3.3.1 Surficial Geology

The surficial geology within the study area is shown on Figure 8. Regionally, the Carden Plain area is defined as having little overburden. Units 1, 2, 3 and 4 on Figure 8 are associated with exposed bedrock at surface, or areas having a thin veneer of overburden (typically less than 1 m). Where overburden is found, it usually consists of a glacially-derived material including a sandy/stony till, Lake Algonquin sand deposits or thin deposits of silt and clay. Organic deposits are found in the areas of streams, creeks, rivers, lakes and swamps.

3.3.2 Bedrock Geology

The mapped upper bedrock unit within the study area is shown on Figure 9. Along the northern edge of the study area, the Grenville Province of the Canadian Shield (Precambrian basement) is the upper bedrock unit. For the majority of the study area, the upper bedrock unit is a member of the Simcoe Group, which is composed of a depositional bedrock sequence representing a generally deepening oceanic shelf environment (Armstrong, 1999). The Simcoe Group starts with an erosional unconformity with the Precambrian basement, and consist of, from oldest to youngest, the Shadow Lake, Gull River, Bobcaygeon, Verulam and Lindsay Formations. These formations are interpreted to date from the Ordovician Period within the Paleozoic Era. The formations exhibit a gentle regional dip towards the southwest throughout the study area. The dip varies from approximately 4 m to 5.5 m per kilometre (km) (Liberty, 1969). This gentle dip results in rock layers often appear flat lying in outcrops within the study area.

As shown on Figure 9, the upper bedrock unit varies as you move north/south through the study area. In the northern portion of the study area, post-Ordovician erosion has removed the younger formations completely leaving formations deeper in the sequence (i.e., older) as the upper bedrock unit. Therefore, as you move towards the south in the study area, the bedrock unit at surface transitions from the older formations to the younger formations. The Precambrian basement is exposed at surface in the northern most portion of the study area. A thin band of the Shadow Lake Formation is the upper bedrock unit to the south of the Precambrian. This is followed to the south by a band of Gull River Formation as the upper bedrock unit that thickens in the central portion of the study area around either side of Lake Dalrymple. As you continue south, the Bobcaygeon Formation is the upper bedrock unit, and most of the southern third of the study area has the Verulam Formation as the upper bedrock unit. The Lindsay Formation is found in the southern most portion of the study area.

Based on a review of the available site-specific information provided by the quarry operators as part of this study, it was noted that the transition from the Verulam Formation to the Bobcaygeon Formation as the upper bedrock unit may actually be slightly further to the north than is shown in the OGS mapping presented on Figure 9. The contact between the Verulam Formation and the Bobcaygeon Formation is transitional, and the observed variations are likely a result of differences in interpretation of the position of the formational contact.

The undulating nature of the Precambrian surface results in a large variability in the upper elevation of the unit. Of particular interest is the presence of two Precambrian inliers identified with the study area. The first is located to the east of the McCarthy property, and is referred to as the “Bolsover Inlier” (Armstrong, 2000). This Precambrian inlier protrudes approximately 40 m up through the surrounding Shadow Lake and Gull River Formations and terminates in the Bobcaygeon Formation (i.e., the Precambrian does not outcrop at this location). The second identified inlier is located near Rohallion. At this location, the Precambrian extends through the entire sequence of overlying formations, and outcrops in this area. The outcropping Precambrian bedrock can be seen on Figure 9 at the northern tip of the western half of Canal Lake.

A generalized geological cross-section through the study area is presented on Figure 10. The cross-section is based on available regional geological data and site-specific geological data provided by the quarry operators.

Based on the work of Liberty (1969) and Armstrong (1999 and 2000), the general characteristics of the Paleozoic bedrock formations underlying the study area are described below. Approximate thicknesses of the bedrock formations within the study area are provided based on a review of the site-specific geologic information provided by the quarry operators.

3.3.2.1 Shadow Lake Formation

The Shadow Lake Formation is the oldest Paleozoic unit in the study area and rests on the Precambrian basement. The formation consists predominantly of transgressive red, maroon and green siliciclastic mudstones/shales, and poorly sorted argillaceous siltstones, sandstones and conglomerates. The thickness of the formation ranges from zero over topographic “highs” in the Precambrian surface to approximately 12 m in depressions of the Precambrian surface (Liberty, 1969). Based on a review of available data, the stratigraphic thickness of the Shadow Lake Formation in the study area is typically between 4 m and 8 m. Due to its high clast and shale content, the Shadow Lake Formation is not a target for quarrying.

3.3.2.2 Gull River Formation

The Gull River Formation is subdivided into a lower and upper member. The lower member consists of a variety of green-grey to tan argillaceous dolostones and dolomitic limestones, and is capped by a green, argillaceous and silty, dolomitic limestone or dolostone bed that is informally call the “green marker bed” or “green beds” (Armstrong, 1999). The green beds have a higher content of silicate minerals, and are known to be associated with significant water bearing zones at some locations within the study area. The upper member consists mainly of very fine-grained, lime mudstones and may contain chert nodules. Based on a review of available information, the stratigraphic thickness of the Gull River Formation in the study area ranges from 15 m to 18 m, and is typically around 16 m.

3.3.2.3 Bobcaygeon Formation

Liberty (1969) subdivided the Bobcaygeon Formation into three members (upper, middle and lower) which generally reflected the depositional environment of the carbonate beds. The lower portion of the Bobcaygeon Formation is a lithographic, thick bedded limestone of creamy-white colour that is fossiliferous in some layers and has minimal shale content. The middle Bobcaygeon Formation has slightly higher shale content than the upper or lower parts with shaley partings and nodular form. The limestone beds are commonly fine to medium grained, grey-brown and sparsely fossiliferous. The upper portion of the Bobcaygeon Formation is a medium grained, thickly bedded limestone forming a gradational contact with the overlying Verulam Formation. Based on available information, the stratigraphic thickness of the Bobcaygeon Formation is typically between 12 m and 20 m within the study area.

3.3.2.4 Verulam Formation

The Verulam Formation has been subdivided into a lower and upper member. The lower member consisting of interbedded shale and limestone. The upper member is thinner and consists mainly of cross-bedded coarse-grained bioclastic limestone. The limestone in the lower member is generally similar to the underlying upper Bobcaygeon Formation. In general, the Verulam Formation is more susceptible to erosion due to the higher shale content. Several areas of the Verulam Formation exhibit solution enhanced weathering. The solution weathering is found in the upper 3 m to 6 m where the unit was exposed. The Verulam Formation is thickest in the southwest portion of the study area and generally decreases as you move north. The Verulam Formation has been completely eroded away over much of the northern half of the study area.

3.3.2.5 Lindsay Formation

The youngest Ordovician unit in the study area is the Lindsay Formation consisting of a thick lower member and a thin upper member. The lower member of the Lindsay Formation is similar to the lower member of the Verulam Formation (interbedded limestone and shale), except that it contains less shale. The upper member is similar to the lower member, but is a more nodular limestone. The Lindsay Formation is generally pale to medium grey, is sparsely fossiliferous and rarely exposed at surface. Based on Figure 9, and the site-specific information provided by the quarry operators, the Lindsay Formation is not present at any of the quarries included in the study.

3.4 Physiography

The study area is located in the Carden Plain Physiographic Region of Chapman and Putnam (1984). The study area can be further subdivided into three physiographic sub-regions herein referred to as bedrock dominated terrain, organic dominated terrain and lowland regions.

The most prominent physiographic sub-region in the study area is bedrock dominated terrain (units 3 and 4 on Figure 8). This region is characterized by a thin (less than 1 m thick), discontinuous veneer of sediment cover, which directly overlies bedrock. Areas of exposed bedrock belonging to the Ordovician-aged Simcoe Group are evident throughout the region. In some areas, solution enhanced tensional jointing form patterns that can be traced across the surface of the rock for approximately 100 m. Solution enhanced jointing have predominantly north-south and northeast to southwest orientations. Exotic clasts ranging in size from cobbles to boulders are scattered throughout this physiographic sub-region. The clasts are predominantly of granitic composition originating from the Precambrian basement exposed along the northern edge of the study area.

Organic terrain is evident around the periphery of the wetland and within topographically low-lying areas (unit 20 on Figure 8). The lowland area physiographic sub-region is characterized by thicker deposits (greater than 1 m) of sediment which blanket and subdue the morphological expression of underlying bedrock. This physiographic sub-region is most apparent in the western and southeastern portions of the study area; however, localized areas of thick sediment cover are scattered throughout the study area.

3.5 Hydrogeology

The groundwater flow system in the study area is characterized by the presence of three relatively permeable horizons (aquifers) separated by moderate to low permeability bedrock. The uppermost aquifer is defined by the combined overburden and weathered bedrock zone, which is typically found within the upper 3 to 6 m across the study area. The second aquifer is the green bed layer within the Gull River Formation, and is separated from the upper weathered zone by a relatively thick zone of low permeability bedrock (the lower Verulam, Bobcaygeon, and upper Gull River Formations) across the study area, except in areas where this geological unit subcrops (e.g., along the eastern shore of Lake Dalrymple). The lowermost aquifer is defined as the contact zone between the base of the Shadow Lake Formation and the Precambrian bedrock.

3.5.1 Groundwater Flow Patterns

Measured groundwater elevations across the study area are illustrated on Figure 11, which provides a contour map of bedrock groundwater elevations based on water levels from individual quarry monitoring wells and the WWIS database. A review of the information on this figure allows the following observations:

- Regional groundwater flow generally occurs from northeast to southwest, towards Lake Simcoe;
- Locally, groundwater flow converges towards the major surface water features within the study area (e.g., Lake Dalrymple and Canal Lake); and,
- Groundwater elevations generally follow topography across the study area, as shown on Figure 7.

3.6 Groundwater Use

Groundwater is the primary source of water for residents and businesses within the study area. The locations of water wells, based on the MOE WWIS are shown on Figure 12. The majority of wells are completed in bedrock and obtain their groundwater supplies from one of the limestone formations of the Simcoe Group described above, though some wells obtain water from the Paleozoic-Precambrian contact zone, and several dug wells obtain water from the relatively thin overburden horizon (primarily in the vicinity of the Talbot River). The greatest density of private wells is generally found around the larger lakes within the study area and along the Talbot River.

The City of Kawartha Lakes operates a communal well system consisting of two wells drawing water from the permeable zone at the interface between the Shadow Lake Formation and the Precambrian basement. The wells are located west of the southern tip of Canal Lake (see locations on Figure 12). The system is referred to as the Western Trent-Palmina Water Supply. Well 1 has been in service since 1972, and Well 2 has been in service since 1973. The wells are operated under PTTWs, and the maximum allowable pumping rates from Well 1 and Well 2 are 294 m^3/day and 273 m^3/day, respectively.

3.7 Regional Surface Water Setting

Regional drainage for the study area was determined from available OBM contour mapping, and shown on Figure 4. Generally, drainage is towards Lake Simcoe and Lake Couchiching, either through the Talbot River system (entering Lake Simcoe west of the Highway 48 and Highway 12 intersection) or Lake Dalrymple (which drains via the Head River and Black River to its outlet into Lake Couchiching at Washago). A portion of the study area also drains to the east into Balsam Lake and the Trent-Severn Waterway.

There are no active WSC stream gauges in the study area. Regional meteorological data were obtained for the site from nearby MET stations (discussed in Section 3.2). The study area can be broadly divided into three surface water systems: Talbot River Systems, Lake Dalrymple/Head River and Trent Severn Canal System as described below.

3.7.1 Talbot River System

The Talbot River System (a regulated river system on the east side of Lake Simcoe) drains a large portion of the study area. The headwaters of the Talbot River are located in the south-eastern quadrant of the study area. From its source in Mitchell Lake (the level in the lake being regulated as part of the Trent-Severn Waterway), the Talbot River flows northwest through Victoria Road, before doubling back to the west to Canal Lake. Canal Lake is a 7 km long lake with a southwest to northeast orientation. As with Mitchell Lake, the level of Canal Lake is regulated as part of the Trent-Severn Waterway. The lake drains southwest via the Talbot River, ultimately discharging to Lake

Simcoe through the Talbot River (discharges through the Trent Canal section between Canal Lake and Lake Simcoe are assumed to be negligible). The total drainage area at Highway 12 (just upstream of Lake Simcoe) is estimated to be 32,000 hectares (ha), with the majority of the drainage area (based on OBM mapping Land Use Information (LUI) data) being limestone plain overlain with shallow soils and vegetation, with forest, swamp and lakes.

3.7.2 Lake Dalrymple and Head River

Lake Dalrymple is located in the northern section of the study area. The lake is generally on a southwest to northeast orientation, with two prominent lobes that are linked by a narrow, navigable channel. A wetland at the south end of the lake has been identified as provincially significant by the MNR. The lake discharges via an 1.3 km long outlet channel to the northeast to the Head River, which in turn drains to the Black River system and ultimately into Lake Couchiching at Washago. Lake Dalrymple makes up only a small portion of the Black River system, which drains approximately 152,000 ha between Raven Lake (60 km north of the study area) and Washago. Generally, flows from the northern and western sections of the study area drain to Lake Dalrymple (which drains via Lake Dalrymple to the Head River, which in turn drains to the Black River and Severn River). Within the study area, this drainage area is similar to that of the Talbot River (limestone plain, forest, swamps and lakes), while the majority of the Black River system drains the bedrock, forests and lakes of the Algonquin Highlands to the north.

3.7.3 Trent-Severn Waterway

The Trent-Severn Waterway consists of a canal system and natural waterways connecting Lake Huron and Lake Ontario. Construction of the system officially started in 1833 and occurred in sections, with the first complete end-to-end ship passage occurring in 1920. Within the study area, the waterway connects Lake Simcoe to Canal Lake (via a series of locks south of the Talbot River), and Canal Lake to Mitchell Lake (via the Kirkfield Lift Locks). Both Mitchell Lake and Balsam Lake to the east are maintained at the same water level to allow ship passage from Mitchell Lake to Balsam Lake through a man-made channel, and ultimately through the rest of the Trent Waterway ending at Trenton, on Lake Ontario. These local connections between Lake Simcoe and Balsam Lake were completed in 1904.

During the boating season (May to October), dams at Canal Lake and Mitchell Lake maintain water levels at 241.2 masl and 256.2 masl, respectively, to allow ship passage through the lift lock at Kirkfield Road. Water elevations from 1973 to 2008 for Canal Lake and Mitchell Lake are shown on Figures 13A and 13B, respectively. Between November and April, the level in Canal Lake and Mitchell Lake is lowered to approximately 240.5 masl and 255.5 masl, respectively.

Mitchell Lake and Balsam Lake are located at the highpoint of the Trent-Severn system; the two lakes are maintained at the same level, and the water levels in the canal progressively fall away in both directions. Although Mitchell Lake is connected to Balsam Lake via a 3-km section of canal, both lakes have their own controlled outlets, and flows between the two lakes are assumed to be insignificant.

3.7.4 Main Lakes and Wetlands in Study Area

The main lakes and wetlands within the study area are briefly described below.

3.7.4.1 Cranberry Lake and PSW

Cranberry Lake is approximately 16 ha in size located midway between Lake Dalrymple and Canal Lake (see location on Figure 4). The lake makes up part of the larger Cranberry Lake Wetland complex, which has been identified as provincially significant by the MNR. The total area of lake, bogs, and swamps surrounding Cranberry

Lake is approximately 280 ha, and is bounded by Cranberry Lake road to the west, and limestone plains to the north, south, and east.

The lake and wetland complex drains an area of approximately 714 ha, with part of the wetland draining west across Miller Road to the north (SW12 on Figure 4), and the other section draining west across Cranberry Lake Road (SW4). Both flows eventually converge at SWA and ultimately drain into the provincially significant wetland (PSW) at the south end of Lake Dalrymple. Water levels in the lake and wetland are partially controlled by beaver activity at the Cranberry Lake Road culvert (SW4), where culverts which would otherwise outlet to the west are intermittently blocked by beaver dams.

3.7.4.2 Mitchell Lake

Mitchell Lake is a regulated lake approximately 300 ha in size. The water level in the lake is regulated by a dam at the northeast end of the lake. Drainage over this dam flows generally north then west into Canal Lake. Drainage into the lake occurs around the lake perimeter. A wetland extends to the south and west of the lake. Mitchell Lake is connected to Balsam Lake to the east via a 3-km long canal section. Both lakes are generally maintained at the same elevation during canal operation, and flow through the canal section is assumed to be insignificant.

3.7.4.3 Canal Lake

Canal Lake is a regulated lake approximately 700 ha in size. The water level in the lake is regulated by a dam at the west end of the lake. Drainage into the lake occurs around the lake perimeter, including the Talbot River entering the lake near the Kirkfield Lift Lock.

3.7.4.4 Lake Dalrymple

Lake Dalrymple is a regulated lake approximately 1,400 ha in size. The lake drains to the north into the Head River, which in turn drains into the Black River and ultimately to the Severn River. A PSW extends to the south of the lake.

3.8 Regional Ecological Setting

The Carden Plain contains a variety of habitats and thus diverse populations of flora and fauna, including Species at Risk. The key natural heritage features in the study area include numerous PSW, lakes and watercourses (Figure 14).

The Carden Plain is known primarily for its rare alvar habitats and the populations of species at risk that rely on these habitat areas. Alvars are limestone plains that are ecologically harsh environments that support an extraordinary diversity of hardy but rare plants, animals and invertebrates. However, in discussions of sensitive features and species, this study focuses on those that depend on hydrological or hydrogeological conditions that could be affected by multiple aggregate operations in the study area (i.e., cumulative impacts) and thus alvars and the sensitive species that inhabit alvars are not considered further.

3.8.1 Aquatic Habitat and Fisheries

The majority of the study area drains through three main systems, the Talbot River system, Lake Dalrymple system and smaller tributaries draining directly to Lake Simcoe. The Talbot River system includes Canal Lake, Mitchell Lake and Kirkfield Lake. Those named water bodies with a connection to the Lake Dalrymple system include Young Lake, Duck Lake, Kelly Lake, Cranberry Lake and Head River. The MNR classifies the majority of the watercourses in Ramara Township as warm water (MNR, 2010). The natural environment characteristics of the main surface water features within the study area are discussed below.

3.8.1.1 Talbot River System

The Talbot River and its tributaries within the study area contain a diverse warm water fishery including walleye, muskellunge, brown bullhead, white sucker, mottled sculpin, smallmouth bass, largemouth bass and yellow perch. Notable critical fish habitat in the Talbot River includes significant walleye (and possibly muskellunge) spawning areas (MNR, 2010). The Ontario Fishery Regulation (MNR, 2010b) indicates that the Talbot River has annual restrictions on recreational fishing from March 1 to the Friday before the second Saturday in May for the section of the Talbot River and its tributaries (excluding the Trent Canal system) in Thorah and Mara Townships from Lake Simcoe up to the dam at Lot 6, Concession XI. As these reaches are important spawning habitat for Lake Simcoe walleye populations, the restriction on recreational fishing ("sanctuary") is instituted during their spawning period. The majority of walleye spawning occurs in spawning riffles located in the Talbot River downstream of the water control dam at the end of Canal Lake. The walleye spawning "fish sanctuary" portion of the Talbot River is identified on Figure 14.

The following quarry operations are located within the Talbot River watershed: McCarthy Quarry, Lafarge Brechin Quarry, James Dick South Quarry, Ferma Quarry, Lafarge Kirkfield Quarry and Webster Quarry. While the MNR does not have fisheries data available for the tributaries of the Talbot River that are in close proximity to McCarthy Quarry, the McCarthy Natural Environment report (SAAR, 2000) describes cyprinids (minnow species) in the watercourse in the central part of this site. Additional data received from the LSRCA noted the McCarthy property is located in the headwaters of two warm water tributaries of the Talbot River known at the LSRCA as Gilchrist Creek (flowing to the west of the property) and "tributary 13" flowing to the south of the property.

The Lafarge Brechin Quarry is also located in the warm water headwaters of Gilchrist Creek to the east of the property and the McNabb Drain to the west of the property. Drainage classification mapping obtained from the LSRCA, indicates that Gilchrist Creek upstream of Concession Road 2 is *intermittent* and downstream is *permanent, warm water, top predators, not cleaned for 10 years*. The McNabb Drain is also considered warm water habitat that flows directly to Lake Simcoe and the drainage classification is *intermittent*. The James Dick South Quarry drains to the south of the property into an unnamed and unevaluated watercourse known at LSRCA as "Ramara Creek Un-named Watercourse #12" (LSRCA, 2009). No specific fisheries data was available from the LSRCA for the tributaries of Lake Simcoe in proximity to the Lafarge Brechin and James Dick South quarries (LSRCA, 2009). However, a general list of species that use habitat within tributaries of Lake Simcoe in this area are rock bass, pumpkinseed, yellow perch, bluegill, northern pike, golden shiner, black crappie, largemouth bass, common carp and smallmouth bass (MNR, 2010a).

The Ferma and Lafarge Kirkfield quarries drain in a southerly direction to the Talbot River system upstream of Canal Lake. A species of conservation concern in the Talbot River system upstream of Canal Lake is the greater redhorse, whose current status is S3, which means it is vulnerable in the province due to a restricted range, relatively few populations, recent and widespread declines, or other factors making it vulnerable to extirpation (NHIC, 2011).

3.8.1.2 Lake Dalrymple System

Lake Dalrymple is located in the central portion of the study area. The lake discharges to the northwest to the Head River, which in turn drains to the Black River system and ultimately into Lake Couchiching at Washago. Generally, flows from the northern and western sections of the Carden Plain drain to Lake Dalrymple and via the Head River to the Black River. No fisheries data are available for the tributaries of the Head River in Ramara Township. However in Wainman‟s Creek, a tributary to Lake Dalrymple located between Rama Road 46 and Mara County Forest

Wetland, the diversity of the fish community consists of brook stickleback, white sucker, northern redbelly dace, central mudminnow, creek chub, common shiner and fathead minnow (MNR, 2010).

3.8.1.3 Wetlands

There are numerous wetlands within the study area. Most of the wetlands have been evaluated using the Ontario Wetland Evaluation System (OWES) for Southern Ontario and are either designated as PSW, non-PSW or life science Areas of Natural and Scientific Interest (ANSI). The following descriptions provide a summary characterization of the form and function of the known wetlands within the study area. Figure 14 shows the location of these designated natural features in the study area.

3.8.1.3.1 Provincially Significant Wetlands

Cranberry Lake Wetland

The Cranberry Lake Wetland occupies approximately 280 ha with the Carden Plain physiographic region (Chapman and Putnam 1984), an area of flat-lying limestone bedrock with a shallow overburden. Cranberry Lake represents a relatively shallow bedrock depression that, over the life of lake, has developed a variety of shoreline and nearshore wetland communities. The lake is located approximately 2.5 km west of Canal Lake and its centroid has Universal Transverse Mercator grid coordinates of 651468E.4937625N in Zone 17 (NRCan, 2011). The lake has an open water area of approximately 16 ha and, based upon its appearance in aerial imagery, is little more than 3 to 4 m deep in its deepest portions. However, no study of the lake bathymetry has been found. In 1991, the Cranberry Lake wetlands were evaluated under the MNR wetland evaluation system (MNR, 1986) and scored as being a PSW feature (Haxton et al., 1992).

An investigation of the Cranberry Lake Wetland was made by MNR staff in 1991 and 1992. Inventories of plants and animals were compiled and background information was solicited from knowledgeable MNR staff and area naturalists. In 1992, the boundaries of the plant communities in the wetland were delineated and their dominant species and life form types were identified to meet the requirements of the OWES (MNR, 1986). Based upon a combination of air photo interpretation and ground-truthing, Haxton *et al*. (1992) identified three wetland types in the feature, the most prevalent of which was marsh occupying 74.8% of the wetland area. The other wetland types identified by Haxton *et al*. (1992) were swamp, calculated to occupy 16.5% of the wetland, and bog occupying 8.7% of the wetland area. Based upon Haxton *et al*. (1992), the communities of the different wetland types include:

- Marsh: Cattail; cattail-reed canary grass; robust sedges; narrow-leaved, tussock sedges;
- Swamp - Thicket: Speckled alder; mixed willows;
- Swamp - Forest: Conifer (eastern white cedar); mixed woods swamps (eastern white cedar, trembling aspen and balsam poplar); and
- Bog: Sphagnum with scattered tamarack, low shrubs and sedges.

In 1999, Highland Environmental Consulting used the information provided by Haxton *et al*. (1992) to evaluate the Cranberry Lake Wetland with the revised edition of the OWES (MNR, 1993) and confirmed the status of the wetland as „provincially significant" (Highland, 1999). No new field work was conducted for this re-evaluation but the community types were re-examined. Based upon the species composition reported by Haxton *et al*. (1992), Highland classified the most prevalent community type as swamp, including both forest and thicket, occupying 81.8% of the wetland. Marsh was identified as occupying 9.5% of the wetland and bog was identified as occupying

8.7% of the area (Highland, 1999). The discrepancies highlight the considerable heterogeneity of the wetland communities in the Cranberry Lake Wetland, much of which appears to be a mosaic of different community types, as described below.

Based upon relatively recent, high-resolution aerial imagery, there appears to be a considerable mosaic of different communities and wetland types across most of the northern sub-basin, whereas the southern sub-basin appears to be more extensively dominated by marsh communities, including a large area of floating-leaved aquatics associated with Cranberry Lake. It is unclear if there are any true bog communities in the Cranberry Lake Wetland. Due to the highly calcareous bedrock around the wetland, it is likely that groundwater moving through the system is high in calcium and other basic anions. It appears unlikely that there are any areas in the wetland where ombrotrophic conditions exist and the communities classified as „bog‟ may be more correctly considered „poor fen‟.

No plants with designated conservation status have been identified in the wetland but a small colony of nesting black terns (*Chlidonias niger*) was identified in 1991. This record is now 20 years old and the continued presence of black terns at Cranberry Lake Wetland has not been confirmed. This species is presently considered a species of „special concern‟ in Ontario (2007).

Commercial baitfish are abundant during at least part of the year, and bullfrog (*Rana catesbeiana)* and snapping turtle *(Chelydra serpentina)* have also been observed (NHIC, 2011).

Dalrymple Lake Wetland

Dalrymple Lake Wetland is a PSW composed of three wetland types (>1% bog, 76% swamp and 24% marsh) (NHIC, 2011). Colonial waterbirds such as great blue heron (*Ardea herodias*) and black tern currently use the area for nesting (NHIC, 2011). The wetland is designated locally significant for white-tailed deer, which use the area for winter cover (NHIC, 2011). In addition, the Dalrymple Lake Wetland has been designated regionally significant for both waterfowl staging and waterfowl production (NHIC, 2011). Bullfrogs and furbearers such as muskrat and raccoon (*Procyon lotor*) have also been observed (NHIC, 2011).

Grass Creek Wetland

Grass Creek is a PSW composed of two wetland types (95% swamp and 5% marsh) (NHIC, 2011). Colonial waterbirds such as great blue heron currently use the area for nesting (NHIC, 2011). The wetland is designated locally significant for white-tailed deer, which use the area for winter cover (NHIC, 2011). In addition, the area has been designated regionally significant for fish spawning and rearing of muskellunge (*Esox masquinongy*) and largemouth bass (NHIC, 2011). Bullfrog, snapping turtle, and furbearers such as muskrat, raccoon, beaver and coyote (*Canis latrans*) have also been observed (NHIC, 2011).

Raven Lake Wetland

Raven Lake is a PSW, composed of three wetland types (1% fen, 86% swamp and 13% marsh) (NHIC, 2011). The area is an active feeding area for nesting colonial waterbirds. The wetland is designated locally significant for white-tailed deer, which use the area for winter cover (NHIC, 2011). In addition, Raven Lake PSW is considered locally and regionally significant for waterfowl production, as well as regionally significant for fish spawning and rearing (muskellunge, largemouth bass). Bullfrog, snapping turtle and furbearers such as raccoon, beaver, black bear and fox have all been observed (NHIC, 2011).

Butternut Creek Wetland

Butternut Creek Wetland is a PSW, composed of two wetland types (90% swamp and 10% marsh) (NHIC, 2011). Colonial waterbirds such as great blue heron currently use the area for nesting (NHIC, 2011). The wetland is designated locally significant for white-tailed deer, which use the area for winter cover (NHIC, 2011). In addition, Butternut Creek Wetland is designated locally significant for waterfowl production. Bullfrog, snapping turtle and furbearers such as muskrat and raccoon have been observed (NHIC, 2011).

Mara County Forest Wetland

Mara County Forest Wetland is a PSW complex, made up of six individual wetlands, composed of three wetland types (5% bog, 91% swamp and 4% marsh) (NHIC, 2011). The wetland complex is an active feeding area for nesting colonial waterbirds, such as the great blue heron. The wetland is designated locally significant for white-tailed deer, which use the area for winter cover (NHIC, 2011). In addition, the Mara County Forest Wetland is designated locally significant for waterfowl production, as well as significant for fish spawning and rearing. Furbearers such as muskrat, raccoon and beaver have been observed (NHIC, 2011).

Sedge Wren Marsh

Sedge Wren Marsh is part of a PSW and is the only site supporting sedge wren south of Hudson Bay (Carden Plain IBA, 2011). Yellow rails are also observed at night.

Rush/Duck Wetland

Rush/Duck Wetland is a PSW complex, made up of 10 individual wetlands, composed of four wetland types (4% bog, 3% fen, 31.5% swamp and 61.4% marsh) (NHIC, 2011).

3.8.1.3.2 Other Wetlands

Victoria Road Bog life science ANSI is a small bog of about 35 ha located just south of the Talbot River and 1.5 km north of Victoria Road. The area is associated with an esker. Highway 505 dissects the bog. East of the highway is treed low shrub bog (black spruce-larch). West of the highway is a combination of treed bog and open low shrub bog. The west side is disturbed by a small amount of peat mining (NHIC, 2011).

Talbot River Wetland is a non-PSW, composed of two wetland types (7% bog and 93% swamp) (NHIC, 2011). The area is an active feeding area for nesting colonial waterbirds. The wetland is designated locally significant for White-tailed deer, which use the area for winter cover (NHIC, 2011). In addition, Talbot River Wetland is designated locally significant for waterfowl production and regionally significant for fish spawning and rearing (muskellunge) (NHIC, 2011). Bullfrog, snapping turtle and furbearers such as raccoon and beaver have also been observed (NHIC, 2011).

Argyle Northwest Wetland is a non-PSW, composed of one wetland type (100% swamp) (NHIC, 2011). The wetland is designated locally significant for white-tailed deer, which use the area for winter cover (NHIC, 2011). Bullfrog, snapping turtle and furbearers such as muskrat and raccoon have been observed (NHIC, 2011).

Eldon West Wetland is a non-PSW, composed of one wetland type (100% swamp) (NHIC, 2011). The area is an active feeding area for nesting colonial waterbirds such as the great blue heron. The wetland is designated locally significant for white-tailed deer, which use the area for winter cover, as well as good winter cover for black bear, red fox (*Vulpes vulpes*), coyote, muskrat, raccoon and skunk (*Mephitis mephitis*). Bullfrog and furbearers including mink (*Neovison vison*) have also been observed (NHIC, 2011).

Kirkfield South Wetland is a non-PSW, composed of one wetland type (100% swamp) (NHIC, 2011). The area is an active feeding area for nesting colonial waterbirds such as the great blue heron. The wetland has good winter cover for grouse. Bullfrog, snapping turtle and furbearers such as raccoon, beaver and mink have been observed (NHIC, 2011).

Perch Creek Wetland Complex is a non-PSW complex, made up of two individual wetlands, composed of one wetland type (100% swamp) (NHIC, 2011). The area is an active feeding area for nesting colonial waterbirds such as the great blue heron. The wetland is designated locally significant for white-tailed deer, which use the area for winter cover. Bullfrogs, snapping turtle and furbearers such as muskrat, raccoon and beaver have been observed (NHIC, 2011).

4.0 QUARRY OPERATIONS

Operators of each of the quarries included in the study were asked to provide site plans, along with information regarding PTTW, C of A and water quality/quantity monitoring programs in place at the quarries. The following table provides general operational information about each quarry including current extraction area, final extraction area, lowest final floor elevation and licensed annual tonnage.

Table 2: Quarry Operational Information (as of March 30, 2011)

Site	Current Extraction Area (ha)[1]	Final Extraction Area (ha)	Lowest Final Floor Elevation (masl)	Licensed Annual Tonnage
Tomlinson Quarry	<1	131	222	2,700,000
Holcim Quarry	40	197	187	1,814,000
Beamish Quarry	<1	75	206	1,500,000
Miller Quarry	47	226	215	2,721,000
Lafarge Brechin Quarry	43	251	181	2,800,000
James Dick South Quarry	11	82	210	870,000
McCarthy Quarry	0	29.5	234	500,000
Ferma Quarry	6	186	230	1,000,000
Lafarge Kirkfield Quarry	21	22.1	211	453,000
Webster Quarry	16	134	240	500,000
Bot Quarry	2.5	226	234	1,500,000
James Dick North Quarry	0	147	250	500,000

1. *Current extraction area based on information provided by the quarry operators, final extraction area and lowest final floor elevation is from quarry site plans.*

All data and documents provided by the operators were reviewed by the study team. In addition to the general operational information provided above, important information taken from the data, including the location of pump outlets, allowable pumping rates/discharge rates, measured pumping rates, results from water quality monitoring programs, and identified natural environment features (where available) are summarized below.

4.1 Tomlinson Quarry

The Tomlinson Quarry is located on the east side of Miller Road, north of Cranberry Lake (see location on Figure 2). The quarry includes separate north and south extraction areas on either side of a watercourse running from east to west across the site.

The quarry operates under an existing PTTW No. 4340-86NRP9 and Sewage Works C of A No. 7458-842L3X. Under the existing C of A, the maximum allowable discharge from the north pond is 0.211 m^3/s while from the south pond; the maximum discharge is 0.119 m^3/s. The quarry has an existing monitoring program (as per C of A), which includes samples taken in both north and south drainage both upstream and downstream of the quarry discharge.

The quarry will be operated such that water taken from the north and south extraction areas will be discharged to the north and south settling ponds. The north pond would drain to two separate watercourses; the first drainage feature being the Cranberry Lake Wetland outlet flowing from east to west across the middle of the property referred to as the south drainage feature. This feature crosses the west property line upstream of SW12. The second drainage feature is found along the north property line and is referred to as the north drainage feature. Both drainage features cross Miller Road and join a separate stream from the Miller quarry area upstream of SW2. This combined feature ultimately discharges to Dalrymple Lake. The southern settling pond would drain to the Cranberry Lake Wetland upstream of the south drainage feature, which drains to SW2 and ultimately to Dalrymple Lake.

The southern drainage feature originates from a northern outlet from Cranberry Lake, which only flows during periods of high water levels (Golder, 2007b). A number of fish species, which are widespread across southern Ontario, were observed in the south drainage feature; most associated with warmwater habitat. The exception is yellow perch (*Perca flavescens*), which is associated with coolwater habitats. The presence of yellow perch in the south drainage feature suggests that a surficial connection to Cranberry Lake may be present during periods of high flow conditions. The north drainage feature is made up of a number of constructed drainage ditches and originates northeast of the Miller Quarry. Common warm water fish species use the north drainage feature and pond, but fish habitat on this site is considered of marginal quality (Golder, 2007b).

The majority of the Tomlinson property (78.4%) is presently being converted from cultural vegetation (resulting from historical and ongoing agricultural use) to newly licensed extraction area. The native plant communities on the property are primarily associated with portions of the Cranberry Lake Wetland that occupies the east side of the property. In addition, narrow bands of mixed forest located on the edges of the wetland basin and following the arc of a shallow bedrock depression are located in the southwest corner of the larger (northern) land parcel. No provincially designated plant species were observed on the site (Golder, 2007b).

No bird species of national, provincial or regional significance were identified breeding on the property (Golder, 2007b). American bullfrog (*Rana catesbeiana*) and Western chorus frog (*Pseudacris triseriata*) were identified on-site and are both currently ranked S4 in Ontario. Blanding‟s turtle (*Emydoidea blandaingii*) is found in the northeast corner of the property and is currently designated as threatened in Ontario (MNR, 2011).

4.2 Holcim Quarry

The Holcim Quarry is located immediately west of Cranberry Lake (see location on Figure 2). At the site, surface discharges from Cranberry Lake (SW4) are collected in a diversion channel and routed along the northern edge of the current extraction area to a culvert under Mara Carden Boundary Road. From there, flows progress downstream towards SW3.

In the existing quarry dewatering operations, water is collected in a pair of settling ponds, and then flows to a sump on the quarry floor. From the sump, water is pumped up to a discharge pond on the east side of Mara Carden Boundary Road, which in turn discharges to the diversion channel immediately upstream of the Mara Carden Boundary Road culvert crossing.

The quarry operates under an existing PTTW No. 1573-7RYPR7 and Sewage Works C of A No. 3342-7YKGZ9. The maximum quarry discharge allowed under the C of A is 0.061 m^3/s. As part of the site C of A, monthly water quality samples are taken in the diversion channel just west of Cranberry Lake Road, the quarry sump, the discharge pond, and at the upstream end of the Mara Carden Boundary Road crossing culvert.

4.3 Beamish Quarry

The Beamish Quarry is located to the southeast of Cranberry Lake (see location on Figure 2). As the quarry develops, dewatering flows will be collected in a sump on the quarry floor, then pumped to a settling pond that is coupled in series with a second settling pond, and ultimately will discharge from the second settling pond into the Cranberry Lake Wetland.

The quarry operates under an existing PTTW No. 4017-7YSN8B and Sewage Works C of A No. 9491-7ZDKEU. The maximum quarry discharge allowed under the C of A is 0.058 m^3/s. The C of A for the site requires water quality monitoring at the following locations; outlet of settling pond, wetland, ditch on the northern portion of the access road draining the north-central portion of the site, southern tributary at Rohallion Road and the quarry sump.

The Cranberry Lake Wetland is located to the northwest of the poperty. Tamarack (*Larix laricina*) is the dominant tree species in the Cranberry Lake Wetland, as well as black ash (*Fraxinus nigra*), white elm (*Ulmus laevis*) and eastern white cedar (AECOM, 2009c). American toad (*Bufo americanis*), green frog (*Rana clamitans*), leopard frog and painted turtle (*Chrysemys picta*) were observed on the property (AECOM, 2009c). The habitat is also suitable for blandings turtle, which at one point, were common to the area. Blanding"s turtle is currently designated as threatened in Ontario. Sandhill crane and common loons have been observed in the Cranberry Lake Wetland (AECOM, 2009c).

4.4 Miller Quarry

The Miller Quarry is located on the east side of Miller Road, southeast of Lake Dalrymple (see location on Figure 2). Currently, dewatering flows are collected in sumps and discharged to an east-west drainage feature crossing Miller Road. This drainage feature eventually discharges to SW2, and ultimately to Lake Dalrymple.

The quarry operates under an existing PTTW No. 2431-8FXKP4 and Sewage Works C of A No. 9412-6GWJM6. The maximum quarry discharge allowed under the C of A is 0.067 m^3/s. As part of the site C of A, monthly water quality samples are taken at the quarry discharge and in the east-west drainage feature both upstream and downstream of the discharge point.

4.5 Lafarge Brechin Quarry

The Lafarge Brechin Quarry is located on the north side of Concession Road 2 east of Highway 12 and north of the Talbot River (see location on Figure 2). Currently, extraction is occurring only on the north side of Concession Road 2, with a planned expansion south of Concession Road 2.

The quarry operates under an existing PTTW No. 1177-7QRJUQ and Sewage Works C of A No. 4952-522RQ6. The C of A is currently being amended and a maximum quarry discharge rate of 0.053 m^3/s has been applied for. The latter rate was used for discharge and loading estimates. As part of the site C of A, monthly water quality samples are taken at the outlet to the receiving watercourse.

Dewatering flows from the Lafarge Brechin Quarry are currently pumped into the roadside ditch on the north side of Concession Road 2 (see location of SW6 on Figure 4). The site drainage is split between the McNabb Drain and the municipal drain (Gilchrist Creek) that eventually drains to the Talbot River south of the site (upstream of SW7). Drainage on the site includes a number of ditches and ponds associated with the existing extraction activities and ditches along the berms located along the property boundaries and the railway line. Surface water on the portion of the site located west of the rail line drains west to the McNabb Drain through roadside ditches, including the wet meadow area located along Highway 12. Potential fish habitat exists in the roadside drains, but whether that potential is realized is dependent upon the permanence of any connection to a natural watercourse or waterbody with a fish population.

Existing conditions on the site include a large block of wet woods at the east edge of the property located north of Concession Road 2. The forested area contains a number of deciduous tree species that are tolerant of seasonal flooding, including red maple (*Acer rubrum*) and bur oak (*Quercus macrocarpa*) along with trembling aspen

(*Populus tremuloides*) scattered throughout the community and along its perimeter. The intermittent roadside ditch that receives discharge has some seasonal fish habitat (Golder, 2009d) and the municipal drain (Gilchrist Creek) that eventually drains to the Talbot River south of the site which is classified by the conservation authority as *warm water having top predators*. The McNabb Drain is considered intermittent warm water habitat that flows directly to Lake Simcoe.

4.6 James Dick South Quarry

The James Dick South Quarry is located on the north side of Concession Road A, west of Highway 12 and north of the Talbot River (see location on Figure 2). Currently, dewatering flows from the quarry are captured in a sump located on the quarry floor at the southern end of the property, and pumped to the municipal ditch on the north side of Concession Road A. This ditch ultimately discharges to the Talbot River upstream of Highway 12 Bridge.

The quarry operates under an existing PTTW No. 6536-7QJH9L and Sewage Works C of A No. 6947-5WZKFF. The maximum water taking rate allowed under the existing PTTW is 0.033 m^3/s. The existing C of A does not specify a discharge rate, so to remain conservative, the maximum pumping rate allowable under the PTTW was assumed to be the maximum discharge rate. As part of the site C of A, weekly samples are taken both at the point of discharge in the municipal ditch and in the Talbot River at SW7.

4.7 McCarthy Quarry

The McCarthy Quarry is located on the north side of Concession Road 1 and north of the Talbot River (see location on Figure 2). At this time, the McCarthy Quarry has not started operations.

As the quarry develops, dewatering flows will be collected in a sump on the quarry floor. The incidental waters collected in the sump will be pumped from the sump and allowed to flow via gravity through a 0.2-m diameter discharge pipe. The discharge pipe will follow the eastern extraction boundary to a horseshoe-shaped settling pond which has an approximate volume of 14,000 m^3. Discharge from the settling pond is controlled by a Hickenbottom structure. Treated sump water will flow from the settling pond and into an existing drainage ditch, which flows through an existing culvert under Concession Road 1, and ultimately discharge to the Talbot River south of the site.

Although not currently operational, the quarry has obtained PTTW No. 5716-7L6KBF and Sewage Works C of A No. 68930-5NTJSV. The maximum water taking rate allowed under the PTTW is 0.076 m^3/s. The existing C of A does not specify a discharge rate, so to remain conservative, the maximum pumping rate allowable under the PTTW was assumed to be the maximum discharge rate. The C of A for the site requires water quality monitoring at the Concession Road 1 CSP culvert, the Box culvert on Eldon-Ramara Townline and the Outfall of settling pond.

Nearby offsite watercourses include Canal Lake and the Talbot River. An intermittent swale crosses the center of the licensed area. This area has eastern hemlock (*Tsuga canadensis*), white cedar (*Thuja occidentalis*), white birch (*Betula papyrifera*), ironwood (*Ostrya virginiana*) and white spruce (*Picea glauca*). A drainage ditch is located in the central/northwest portion of the parcel. The drainage ditch, considered to be an intermittent watercourse, flows south along the eastern property boundary. There is also a drainage ditch, which receives westerly off-site water and drains along the southwest property boundary. Drainage from the site discharges into the Talbot River located approximately 1.3 km to the south of the property.

No PSWs are documented on or near the McCarthy property. A number of small isolated wetland patches occur in the northeast corner of the site and within central forest cover (SAAR, 2000). The northern property has forest cover, which functions as fall migratory passerine stopover habitat, forage habitat for bears, herpetofauna production area in spring, breeding bird habitat and a wildlife corridor (SAAR, 2000).

There were no threatened or endangered species identified on the site (SAAR, 2000). Wildlife species identified on-site include red-backed salamander (*Plethodon cinereus*), leopard frog (*Rana pipiens*), smooth green snake (*Opheodrys vernalis*) and sharp-shinned hawk (*Accipiter striatus*). A number of furbearers also use the site (SAAR, 2000).

4.8 Ferma Quarry

The Ferma Quarry is located on Horncastle Road to the northeast of Canal Lake (see location on Figure 2). Quarry dewatering flows are collected in a sump in the south east corner of the quarry floor, and discharged to the ditch along the west side of Horncastle Road. This ditch eventually discharges to a tributary of Canal Lake (upstream of SW5).

The quarry operates under an existing PTTW No. 3745-648QTH and Sewage Works C of A No. 9123-5WAQUT. The maximum quarry discharge allowed under the C of A is 0.060 m^3/s. As part of the site C of A, monthly samples will be taken of both the quarry discharge and receiving stream (upstream of SW5).

4.9 Lafarge Kirkfield Quarry

The Lafarge Kirkfield Quarry is located on the west side of Kirkfield Road, north of the Talbot River and the Kirkfield Lift Locks (see location on Figure 2). Quarry dewatering flows are collected in a sump, and from there they are pumped into two settling ponds in series to the south of the quarry. Water from the second pond is discharged into an east-west groundwater recharge trench, which can overflow into a tributary to Canal Lake upstream of SW5 (Figure 4).

The quarry operates under an existing PTTW No. 1346-7ELPP2 and Sewage Works C of A No. 4-0035-92-006. The maximum quarry discharge allowed under the C of A is 0.030 m^3/s. As part of the site C of A, monthly samples are to be collected at the outfall into the groundwater recharge trench.

4.10 Webster Quarry

The Webster Quarry is located on the north side of County Road 48, east of Fenel Road and east of the Mitchell Lake outlet (see location on Figure 2). Quarry dewatering flows are collected in a sump on the quarry floor, and flow by gravity into a pond to the northwest of the extraction area where it infiltrates into the ground. The pond has a spillway which discharges into a tributary of the Talbot River System.

The quarry operates under an existing PTTW No. 3274-62UJCV and Sewage Works C of A No. 2173-653R27. The maximum quarry discharge allowed under the C of A is 0.145 m^3/s. The C of A requires the monitoring of the discharge at the Pond overflow weir, within the sedimentation pond and receiving watercourse.

4.11 Bot Quarry

The Bot Quarry is located to the northwest of Lake Dalrymple. It is immediately to the southeast of the James Dick North Quarry (see location on Figure 2). The southeast portion of the site includes a small area of existing extraction.

The quarry has just started its operation and has obtained a PTTW (No. 7614-8C6N8N) for quarry dewatering. The on-site sewage works are approved under C of A No. 4540-8MCJ32. At this stage, we are not aware of any cumulative impact on the surface water associated with the operation of the Bot Quarry; however, this should be confirmed with further studies after the issuance of the C of A.

4.12 James Dick North Quarry

The James Dick North Quarry is located immediately to the northwest of the Bot Quarry (see location on Figure 2). Relatively little information is available for the James Dick North Quarry. Charlesworth and Associates (1991) completed a preliminary hydrogeological assessment of the quarry with the objective of defining the depth to groundwater across the site. The operation plan, completed by W.D. Kirby and Associates (1994), is also available. Both documents indicate that the proposed plans for the James Dick North Quarry involve extraction of limestone above the water table only. This was confirmed through correspondence with James Dick. As such, it is anticipated that this site will not contribute to cumulative impacts associated with groundwater lowering within the study area.

This quarry has just started operations, and at this time we are not aware of any approvals for water taking and/or discharge associated with this site.

5.0 RESULTS AND DISCUSSION

5.1 Species of Conservation Concern Screening

In accordance with the objective of the cumulative impact study, the list of species of conservation concern was defined as those species that rely solely or in part on aquatic resources (surface water features) for their life cycles. Thus Table D1 in Appendix D is the scoped list of species of special concern for this study. The following sources were used to compile the species list:

- Royal Ontario Museum (ROM, 2011) range maps;
- Natural Heritage Information Center (NHIC, 2011) database;
- The Couchiching Conservancy (Reid, 2011);
- Ontario Breeding Bird Atlas (OBBA) data summaries (Birds Ontario, 2011);
- Ontario Herpetological Atlas species range maps (Herp. Atlas) (NHIC, 2011);
- Ontario Odonata Atlas species range maps(Odonata) (NHIC, 2011); and,
- DFO Aquatic Species at Risk maps (Aquatics) (DFO, 2011).

5.2 Baseline Groundwater Level Monitoring

Based on a review of the site-specific background information and information gathered during the site visits, key groundwater monitoring wells located within or near the quarry license areas were identified and groundwater level monitoring was completed at these locations in May 2010, August 2010 and October 2010. A total of 83 monitoring intervals were selected for the water level monitoring program. The selected monitoring locations are shown on Figure 15 and the measured baseline groundwater elevations are provided in Table E1 in Appendix E. Table E1 also provides information on the elevation of the monitoring interval and the formation screened.

The groundwater elevation data collected as part of the baseline monitoring were used as calibration points for the groundwater flow model.

5.3 Borehole Geophysical Logging

During the review of the available site-specific geological data, some discrepancies in the identification of geologic contacts from site to site were identified. To assist in addressing these discrepancies, additional data were gathered through the geophysical logging for both natural gamma and apparent conductivity at two off-site wells recently installed by R.W. Tomlinson Limited, as well as one borehole at the McCarthy Quarry and one borehole at the Beamish Quarry.

The additional stratigraphy information collected as part of the borehole geophysical logging was combined with the existing geophysical logging data from the Holcim, Tomlinson, Lafarge Brechin and Webster quarries, and was used during the development of the geological surfaces for the groundwater flow model.

5.4 Baseflow Separation

In order to further understand the regional hydrology of the study area, a baseflow separation analysis was undertaken. This analysis uses the BFLOW program (Arnold, 1995) to estimate the baseflow yield from a daily stream flow record.

The average annual flow for the Beaverton Gauge (located 17 km south of the study area) is 2.89 m^3/s, and the catchment area is 282 km^2. This results in an average annual yield of roughly 323 mm/yr. The BFLOW program was run with the available complete years of daily data for the Beaverton Station (1967 to 1992, and 2007 to 2008). The BFLOW program runs three passes over a daily flow hydrograph, and outputs three progressively smaller estimates of baseflow, providing a possible range for the baseflow estimate. The results suggest an average annual baseflow contribution to the river of between 223 mm/yr (based on the BFLOW1 run) and 142 mm/yr (based on the BFLOW3 run) spread over the entire catchment. These overall flow and baseflow values are assumed to be similar to the flows in the study area. A summary of the results of the baseflow analysis are provided Table 3 below:

Table 3: Baseflow Analysis Results

Station	Location	Area (km^2)	Record	Annual Avg. Flow (as m^3/s)	Yield (mm/yr)	BFLOW Results (as mm/yr)
02EC011	Beaverton River near Beaverton	282	1967 - 2008	2.887	323	142 - 223
02EC002	Black River near Washago	1520	1965 - 2009	23.032	478	262 - 374

Based on the calibrated groundwater model for existing conditions, infiltration to the groundwater in the study area is between 65 mm/yr and 75 mm/yr. These infiltration values are roughly 50% of the lowest estimated baseflow values above; however, the baseflow values shown in Table 3 above include interflow (shallow groundwater discharge from the unsaturated zone) and the groundwater model discharge values do not. A comparison to the Beaverton River baseflow suggests that interflow is roughly 50% of baseflow reporting to the river.

5.5 Surface Water Flow Monitoring

The results from the flow monitoring are shown in Table 4 below. There is no overall agreement for the timing of high flows between the stations. Flows at SW1, SW2, SW7 and SW12 were highest in October 2010, while flows at SW4 and SW5 were highest in February 2011. The lowest flows were measured in April 2010 (SW1 and SW2), July 2010 (SW5), October 2010 (SW4) and February 2011 (SW7 and SW12).

Flows at SW4 were largely controlled by beaver activity at the culvert under Cranberry Lake Road. The culvert has been mostly blocked with debris during site visits in 2010, resulting in flows overtopping the road at the low points in the area of the culvert. The flow measurements were taken downstream of the road where flows became concentrated in one location (on October 21, 2010) and at two locations (February 18, 2011). In the case of February 2011, the flow is shown as the sum of the two individual flow measurements.

During the February 18, 2011 visit, stations SW2 and SW3 were covered by ice thickness of greater than 20 cm. Flows at SW2 were measured by creating an open cross section across the channel, while at SW3, a hole was drilled through the ice layer to confirm that the flow under the ice was below the instrument detection limit. The other five flow measurement stations were generally flowing with cross sections sufficiently clear to allow flow measurements to be taken. During all four of the field visits, the measured flow at SW3 was found to be below the instrument detection limits.

A row has been included in Table 4 to show the combined SW4 and SW12 flows, which together represent the total surface outflow from the Cranberry Lake Wetland.

Table 4: 2010-2011 Flow Monitoring Results

Station	Catchment Area (ha)	Measured Flow (m^3/s)					Weighted Average Annual Flow		Estimated Yield (mm/yr)
		23-Apr-10	27-Apr-10	27-Jul-10	21-Oct-10	18-Feb-11	(m^3/s)	(m^3/s/km^2)	
SW1	685	0.058	0.054	0.080	0.135	0.080	0.090	0.0132	415
SW2	3,218	-	0.029	0.093	0.132	0.124	0.098	0.0031	96
SW3	1,335	-	Stagnant	Stagnant	Stagnant	Stagnant	-	-	-
SW4	237	-	-	-	0.005	0.037	0.021	0.0088	276
SW5	1,145	-	0.040	0.032	0.100	0.286	0.119	0.0104	326
SW7	32,068	-	3.014	3.694	4.286	1.932	3.259	0.0102	321
SW12	477	-	-	-	0.056	0.053	0.054	0.0114	361
SW4+ SW12	714	-	-	-	0.061	0.090	0.075	0.0105	332

The average flow rate at each station was estimated by dividing the year into sections based on the date that the measurement was taken (starting and ending halfway between each consecutive measurement date), and calculating an annual weighted average using the flow measured and the length of the section in which it was measured. The results are shown in Table 4. None of the flows were taken during rainfall events, although the February 2011 flows represent a partial melt event. The lack of representative measurements of peak flows, which may make up a significant portion of annual flows, is likely to result in an underestimation in Table 4 compared to actual average flows.

As mentioned in Section 2.3, flows at SW7 were measured upstream of James Dick South Quarry discharge point due to safety concerns and unstable cross section at the time of measurement at Highway 12 Bridge. If the James Dick South Quarry is discharging at their maximum pumping rate of 0.033 m^3/s, it will make approximately 1% of the measured average annual flow in Talbot River (0.033/3.259*100). Due to the large contributing drainage area at SW7 (approximately 320 km^2) and relatively small discharge rate from James Dick South Quarry, flows measured upstream of discharge point at Talbot River Bridge was considered representative flows at SW7. Moreover, in the water budget and water quality parameter loading estimates, areas draining to Talbot River at the Highway 12 Bridge were used; the latter location is downstream of the James Dick South Quarry discharge point.

Generally, the results at each station reflect the runoff/baseflow patterns in the study area. Stations with larger drainage areas generally had larger flows during monitoring events. The exception to this is SW2, which displayed an average unit flow value of 0.0029 m^3/s/km^2, which is between 65% and 76% less than at other stations, indicating a larger disparity between measured flows and catchment size. These flows are nonetheless generally comparable to the 2007 monthly flows taken 2 km upstream of SW2 at the Miller Quarry as part of the quarry C of A monitoring requirements (see Table 5 below). The annual average for the stations not including SW2 is 340 mm/yr.

Table 5: Miller Quarry 2007 Flows

Sampling Date	Discharge (L/s)
26-Jan-07	*
15-Feb-07	*
26-Mar-07	772
23-Apr-07	20
25-May-07	dry
26-Jun-07	14
26-Jul-07	70
31-Aug-07	*
24-Sep-07	22
31-Oct-07	dry
21-Nov-07	*
18-Dec-07	*

** Frozen / flow too low to measure*

The agreement between the two flows suggests that the results may not be due to measurement error, and may in fact be representative of average flow conditions. It is possible therefore that the difference is the result of greater evaporation from the limestone plain areas (which are the dominant land type for the SW2 catchment), combined with greater infiltration and subsequent interflow and groundwater flow bypassing the flow measurement station. A portion of this infiltration may also discharge, via shallow groundwater flow, to the SW1 catchment located directly to the west. This may be the reason for SW1 having a slightly higher unit flow ($m^3/s/km^2$) value than the other stations (a difference of 650,000 m^3/yr based on the drainage area and the average yield for the remaining monitoring stations, excluding SW2).

The average flows were also used to estimate an annual yield at each station by the catchment area, as shown in Table 4. As these flows are based on the average flow from the instantaneously measured flow data (four in a year), they are subject to the same errors in estimation as the estimated average annual flow. Despite this underestimation, the average yields estimated using this method are roughly comparable to the 323 mm/yr yield calculated for the Beaverton River in the baseflow section above (roughly 5% less than the 340 mm/yr average estimate for SW1, SW3, SW4, SW5, SW7, and SW12). This suggests that either the average flows are representative of flows for the sub-catchment (despite the lack of representative peak flows), or that yields for the Beaverton River (1967-2008) would generally be less than the actual yields for the study area sub-catchments if continuous monitoring had taken place, or that the 2010 climate at the monitoring stations was different compared to the historic climate at the Beaverton River.

5.6 Surface Water Quality Monitoring

Water quality samples were collected at eight stations (SW1, SW2, SW3, SW4, SW5, SW6, SW8 and SW9) during all four site visits (April 27, 2010, July 27, 2010, October 21, 2010 and February 16-18, 2011). Stations SW2, SW3, SW4, SW6, SW8 and SW9 were ice-covered during the February 16-18 site visit. Samples were taken at the section cut for flow measurements at SW2, while samples at SW3, SW4, SW6, SW8 and SW9 were sampled through holes cut using an ice auger.

Results from the laboratory analysis are presented in Table F1 in Appendix F. A brief description of the exceedances is summarized below. Individual samples recorded at or below the reportable detection limit (RDL) were reported as the RDL for comparison to applicable guidelines. Results are compared against Ontario Provincial Water Quality Objectives (PWQO) where available. Where there is no PWQO, results are compared to either Canadian Council of Ministers of the Environment (CCME) guidelines or, if those are also unavailable for a given parameter, other available provincial guidelines were used. Average concentrations shown are weighted averages using the seasonal water balance results (see Section 5.11 below).

5.6.1 Inorganics

Generally, the pH results (a measure of acidity) were within the 6.5 to 8.5 range specified in the PWQO. The average field-measured pH across all the sample points was 7.6, with the highest recorded pH at 8.8 (SW6 on July 27, 2010-measured in field) and the lowest pH of 6.7 (SW6 on February 16, 2011-measured in field). Generally, the difference in pH between stations was marginal.

Conductivity, which is an indication of the amount of dissolved ions in solution, ranged between 15 umho/cm (SW8 on October 21, 2010-measured in field) and 2650 umho/cm (SW6, February 16, 2011-measured in field), with an average of 620.5 umho/cm. SW6 generated higher conductivity readings than other stations, with an average of 2100 umho/cm.

Hardness values calculated in the lab ranged from 71 milligrams per Litre (mg/L) $CaCO_3$ equivalent (SW8 on October 21, 2010) to 580 mg/L $CaCO_3$ equivalent (SW6 on Feb 16, 2011), with an average of 216 mg/L $CaCO_3$ equivalent. Similar to the conductivity readings, the station with the highest average hardness was SW6, with 487 mg/L.

As there is no PWQO or CCME guideline for sulphate, results were compared with the British Columbia (BC) Ministry of the Environment guideline, which sets a guideline for sulphate for freshwater aquatic life at 50 mg/L (superficially, an alert level to monitor for health of aquatic moss populations on an occasional basis). While this guideline does not apply to the study area, it has been included to provide an order of magnitude comparison. Dissolved sulphate concentrations at the stations measured between <1 mg/L (the RDL for dissolved sulphate) and 270 mg/L, with an average concentration of 43.5 mg/L. Generally, stations with smaller upstream drainage areas (SW1, SW4 and SW8) had lower average sulphate concentrations (4.2 mg/L, 1.4 mg/L and 4.4 mg/L for SW1, SW4 and SW8, respectively) than stations with larger catchment areas. Average concentrations over the four monitoring events at the other stations ranged from 6.44 mg/L at SW9 to 44.6 mg/L at SW2, and as high as 251 mg/L at SW6.

As there is no PWQO or CCME guideline for chloride, results were compared with the BC Ministry of the Environment guideline, which sets a guideline 30-day average concentration of 150 mg/L for chloride. While this guideline does not apply to the study area, it has been included to provide an order of magnitude comparison. The results for dissolved chloride during the monitoring period ranged between 1 mg/L (measured at SW4 on July 27, 2010) to 530 mg/L (at SW6 on February 16, 2010). Generally, the two stations with the least amount of upstream development (SW1 and SW4) had the lowest average dissolved chloride concentrations (10 mg/L and 2 mg/L for SW1 and SW4, respectively), while average concentrations at SW2, SW5, SW8 and SW9 ranged from 9 mg/L to 14 mg/L. The average concentration at SW3 was 84 mg/L. This suggests that chloride loading was taking place between SW4 and SW3. Chloride values at SW3 ranged between 68 mg/L to 90 mg/L and were below the BC chloride guideline. The average chloride concentration at SW6 was 394 mg/L.

Total phosphorus concentrations taken at the monitoring stations ranged from <0.002 mg/L (the RDL for total phosphorus) to 0.310 mg/L (measured at SW3 on July 27, 2010 and February 16, 2011). Average phosphorus concentrations at SW1, SW4, SW6 and SW8 were below the Interim PWQO limit of 0.02 mg/L, with averages of 0.009 mg/L, 0.016 mg/L, 0.007 mg/L,0.016 mg/L, and 0.018 mg/L for SW1, SW4, SW6, SW8 and SW9, respectively. The average concentrations of total phosphorus at the remaining stations (SW2, SW3 and SW5) were higher than the PWQO limit, ranging from 0.029 mg/L at SW2 to 0.128 mg/L at SW3. With the exception of SW3, average concentrations were all within the 0.0071 mg/L to 0.047 mg/L range, suggesting this may be the result of background concentrations. The relatively higher average concentration value of 0.128 mg/L for SW3, which is roughly three times higher than the next highest concentration, suggests that there may be additional loading above the background concentration upstream of SW3.

Nitrate concentrations at the stations measured between <0.1 mg/L (the RDL for nitrate) and 2.2 mg/L, with an average concentration of 0.3 mg/L. Generally, the stations further upstream in the systems (SW1, SW2 and SW8) had lower concentrations of nitrate than other stations. Samples at these three stations were generally below the RDL of 0.1 mg/L. Concentrations of nitrate were highest at SW6, with an average concentration of 2.093 mg/L for the four monitoring sessions. There is currently no PWQO for nitrate; however, all readings are below the Interim CCME guideline for freshwater of 13 mg/L (as NO_3) or 2.9 mg/L (as N).

5.6.2 Organics

Concentrations of oil and grease were found in samples between <0.5 mg/L (the RDL for oil and grease) and 1.9 mg/L (SW8 on April 27, 2010), with an average concentration of 0.90 mg/L. The concentration of oil and grease was above the RDL in samples collected on April 27, 2010 and below the RDL in the remaining three sampling rounds. The PWQO limit is that oil and grease should not be detected either visually or by odour; there were no such detections of oil and grease during the field sampling.

5.6.3 Metals

Water quality monitoring results for boron vary between 10 micrograms per Litre (µg/L), the RDL for boron, and 720 µg/L (SW6 on October 21, 2010), with an average concentration of 112 µg/L across all stations. The PWQO limit for boron is 200 µg/L, which was exceeded once at SW2 (February 16, 2011) and in all samples taken at SW6. Generally, these two stations (SW2 and SW6) have higher average concentrations (120 µg/L and 654 ug/L) than the other stations, which have a combined average of 14 µg/L. These higher concentrations of boron are likely linked to the concentrations of boron in the groundwater present in the Bobcaygeon and Verulam Formations.

All but one water quality sample tested below the 5 µg/L RDL for Chromium. The only sample that tested above this value was reported as 14 µg/L and was taken at SW9 on July 27, 2010. This result is above the 1 µg/L to 8.9 µg/L limit; however, the cause of this exceedance is not known. Because a similar concentration was not reported at SW5 on that day, it is likely the result of either a sampling/testing anomaly or a source at Canal Lake. The PWQO sets limits for Chromium based on the type, with a 1 µg/L limit for Chromium IV, and an 8.9 µg/L limit for

Chromium III. Because it is not known what type of chromium was detected in the sample, there is a possibility that the 14 µg/L reading exceeded one or both of these limits.

Cobalt readings were, below the RDL of 0.5 µg/L in all samples taken. As such, the PWQO limit of 0.9 µg/L was not exceeded.

Iron concentrations vary between <100 µg/L (the RDL for iron) and 1,000 µg/L (at SW4 on February 18, 2011). The average iron concentration for all stations of 153 ug/L is below the PWQO limit of 300 µg/L. Five stations reported concentrations of iron above the PWQO limit: SW1 (320 µg/L on February 18, 2011), SW2 (760 µg/L on October 21, 2010), SW3 (370 µg/L on February 16, 2011), SW4 (670 µg/L on July 27, 2010 and 1,000 µg/L on February 18, 2011) and SW5 (760 µg/L on February 18, 2011). As two of these stations are background stations (SW1 and SW4) with no quarries upstream of them, these levels are assumed to occur naturally. It is also assumed that in-stream processes downstream serve to remove iron from suspension as the water moves down the flow paths.

Reported concentrations of zinc ranged from <5 µg/L (the RDL for zinc) to 8.0 µg/L (at SW3 on February 16, 2010), with an overall average concentration of 3.4 ug/L. These levels are all below the interim PWQO of 20 µg/L.

5.7 Lake Level Monitoring

Relative lake levels at Dalrymple Lake are shown on Figure 16. In general, the lake level remained within a 0.5 m fluctuation range throughout the monitoring period. Levels in the lake were at their highest during two peaks; the first in July 2010, and the second in December 2010. These peaks appear to be in response to rainfall events.

Water level data from two existing loggers in Cranberry Lake were obtained from the Holcim and Beamish quarries. Cranberry Lake levels (relative to the Beamish staff gauge) are shown on Figure 17, with the Holcim record referenced to the Beamish record assuming equal water surface elevations at 12:00 PM on May 3, 2010. Generally, the two records are similar for the overlapping period of record. There appears to be little change in the water level during the overlapping period.

Of note, a 0.35 m drop in water surface elevation was recorded at the Holcim logger between December 2009 and February 2010 (prior to the 2010 field investigations); this is thought to have been the result of clearing the Cranberry Lake Road culvert, although no record of this exists either with Holcim or the City of Kawartha Lakes. The water level recovered rapidly between May 7, 2010, and May 14, 2010; assuming that the lake area is 15 ha, the estimated change in storage was approximately 48,750 m^3. This increase appears to correspond to a snowmelt event observed at the Udora MET station, indicating that the culvert had been blocked by the beavers as observed during the 2010 monitoring.

Throughout the rest of the record, the Cranberry Lake water level has been within a 0.15 m fluctuation range with some peaks which correspond to rainfall events. The rate at which the water surface elevations decrease between precipitation events was generally consistent in 2010 (between 2 mm/day and 4 mm/day). Due to the limited dataset, it is not clear at this time if there is any upward trend in water levels. Also, the level of the lake may also be subject to further significant change due to beaver activity at the outlet culvert on Cranberry Lake Road.

5.8 Benthic Invertebrate Community Monitoring and Aquatic Habitat Assessment

The distribution and composition of BICs are influenced by the chemical, physical and biological characteristics of the aquatic ecosystem in which they live. As they are relatively sessile organisms, they are exposed directly to the stress of pollutants. Thus BICs can be considered useful indicators for assessing the state of the watercourses which receive cumulative surface water discharge from quarry operations.

The BIC/aquatic habitat survey locations are shown on Figures 18, 19 and 20 and the coordinates are provided in Table G1 in Appendix G. For the most part, the BIC/aquatic habitat survey stations are the same as the surface water quality stations so that a comparison of water quality, physical habitat quality and BIC can occur. The exposure stations (e.g., A-Exp-1) are located on watercourses that will ultimately receive discharge from more than one quarry operation, thus allowing for a test of potential cumulative effects from quarry discharge. The reference stations (e.g., A-Ref-1) are located immediately upstream of quarry operations. As such the BICs sampled in the reference stations are compared to the BICs from the exposure stations so that influences from land use activities upstream of quarry operations can be deciphered from the potential effects of cumulative quarry discharge. The Carden Plain is also heavily modified by agricultural practices which make up a large portion of the surface water catchments areas for these same streams. Therefore, as well as the influence of quarry discharge on these watercourses, consideration is given to the water and habitat quality changes that agricultural practices present on the Carden Plain.

The taxonomic BIC data for each station is provided in Table G2 in Appendix G. The data were used to calculate a number of biotic indices which characterize the biological condition and synthesize with the chemical and physical condition of the streams. As there are a multiple stressors on the biota in the watercourses within the study area due to the variety of land uses, it was considered necessary to calculate a variety of indices. When selecting biotic indices to assess the potential effects of quarry discharge it was necessary to select those that will display a difference under the particular stressors that are within the study area. For example, Hilsenhoff‟s FBI was selected as it measures the tolerance of BICs to organic pollution such as nitrogen and phosphorus which is attributed primarily to agricultural activities upstream of the quarry discharges in the study area.

The biotic indices calculated to summarize the results of the BIC monitoring are:

- Abundance Measures

  Abundance: indicates the number of individuals inhabiting the benthic samples.

- Richness Measures

  Taxa richness: indicates the health of the community through its diversity, and increases with increasing habitat diversity suitability, and water quality (Plafkin et al., 1989). Taxa richness equates the total number of different taxa found within the sample. The healthier the community is, the greater the number of taxa found within the community.

  Ephemeroptera, Plecoptera, Trichoptera (EPT) Richness: Ephemeroptera (Mayflies), Plecoptera (Stoneflies), and Trichoptera (Caddisflies) are all species that are considered to be very sensitive to poor water quality conditions, therefore the presence of these organisms are indicators of good water quality sites. Higher populations of these organisms in a sample typically indicate increased stability for the site.

- Compositional Measures

  % EPT: percent of the total sample counts that are mayfly, stonefly and caddisfly larvae or nymphs.

  % Oligochaeta: percent of the total sample counts that are aquatic worms.

  % Diptera: percent composition of the station made up of true fly taxa, including midges.

- Tolerance Measures

  Hilsenhoff Family Biotic Index (FBI): the FBI is the average tolerance value of individual families of benthic invertebrates. It is calculated by multiplying the number of individuals of each family by their tolerance value, summing the products and dividing by the total number of individuals with tolerance values. The Hilsenhoff FBI is described further in Table 6 below.

Table 6: Hilsenhoff Family Biotic Index

Family Biotic Index	Water Quality	Degree of Organic Pollution
0.00 - 3.75	Excellent	Organic pollution unlikely
3.76 - 4.25	Very Good	Possible slight organic pollution
4.26 - 5.00	Good	Some organic pollution probable
5.01 - 5.75	Fair	Fairly substantial pollution likely
5.76 - 6.50	Fairly Poor	Substantial pollution likely
6.51 - 7.25	Poor	Very substantial pollution likely
7.26 - 10.00	Very Poor	Severe organic pollution likely

The following tables provide a summary of the aquatic habitat parameters (Table 7) and benthic invertebrate community indices (Table 8) for the reference and exposure stations.

Table 7: Aquatic Habitat Parameters

Site	Water Temp(°C)/ Air Temp (°C)/Time	pH	Conductivity (uS/cm)	Dissolved oxygen (mg/l)	Substrate Composition (dominant/ co-dominant/ co-dominant)	Average depth (m)	Average wetted width (m)	Average Bankfull Width(m)
A-Ref-1	4.6/-2/8:00	7.4	0.34	9.5	cobble/sand/silt	0.78	3.49	4.30
A-Exp-1	2.9/0/9:30	7.1	0.47	7	silt	0.67	8.77	8.77
A-Ref-2	4.9/5/13:00	6.8	0.63	7	sand/silt	0.25	1.10	1.75
A-Exp-2	4.8/6/10:50	7.2	0.56	9	bedrock/silt	0.33	6.70	1.75
B-Ref-1	4.8/8/15:00	7.1	0.29	12	gravel/cobble/ silt/sand	1.63	17.30	18.50
B-Exp-1	5.2/7.6/13:30	6.9	0.21	13	sand/gravel/ bedrock	0.81	11.34	15.80
C-Ref-1	6.8/9.2/14:50	7.6	0.42	n/a	bedrock/gravel	0.32	2.69	2.85
C-Exp-1	6.8/10/14:20	7.3	0.41	n/a	cobble/boulder/ sand/ bedrock	0.43	2.85	4.50

Table 8: Benthic Invertebrate Community Indices

Sample Location	A-Ref-1	A-Exp-1	A-Ref-2	A-Exp-2	B-Ref-1	B-Exp-1	C-Ref-1	C-Exp-1
Taxa Richness	45	38	26	22	44	45	42	39
Abundance	452	1050	2443	1717	1387	2067	10267	10300
EPT taxa richness	15	10	4	2	11	17	18	16
% EPT for station	22.1	32.3	2.2	0.6	38.8	45.1	48.3	23.0
%Insects	91.4	85.4	55.2	38.0	85.2	82.3	71.0	48.9
%Oligochaeta	1.6	0.0	1.6	13.7	3.2	0.0	0.0	2.6
%Diptera	62.6	29.9	48.5	35.8	7.4	3.9	18.1	21.7
Hilsenhoff FBI	5.7	4.9	6.4	7.2	4.7	4.1	5.2	5.9

Additional details regarding the aquatic habitat and benthic communities at each monitoring station are provided below.

5.8.1 Reference Station A-Ref-1

Aquatic Habitat

This station is located on a tributary of Lake Dalrymple that is north of the Miller Paving Limited site (see location on Figure 18). This station is a reference for the cumulative discharge of the Miller Quarry and Tomlinson Quarry. The tributary flows from east of Centennial Park Road to the portion of the lake west of this road. Station A-Ref-1 is located downstream of the road.

The station reach has a bank height ranging from 0.5 m-1.0 m and land use is pasture on the south side of the channel and meadow on the north. The meadow area consisted mainly of willows, dogwood, goldenrod and some red maple. The station reach had abundant watercress and in-stream organic debris. The general morphology of the channel is „flat", with fairly unstable banks due to erosion and undercutting. The substrates are composed predominantly of cobble with some silt and sand.

Benthic Community

The FBI calculated for this reference station is 5.7 which indicates *fairly substantial organic pollution likely* or the representation of a moderate amount of tolerant species in this community. While the sampling technique used was qualitative and not quantitative, this station had the lowest abundance of organisms in relation to the other stations sampled throughout the study area. However, it also had relatively high taxa richness (45 taxa). The number of EPT taxa is also relatively high with 15 taxa represented or a third of all taxa in the sample. The percent of oligochaetes was very low at 1.6%. This indicates that there are few species tolerant to pollution and many that are sensitive to pollution.

While diversity of benthic invertebrates is high at this station, abundances are low. This could be attributed to the size of the stream and the low flow during the sampling event. While it had diverse representation by pollution intolerant species, these taxa represented only 22% of the community.

The BIC at reference station A-Ref-1 displays high diversity and good representation by sensitive EPT taxon which indicates that water and habitat quality at this station is likely good.

5.8.2 Exposure Station A-Exp-1

Aquatic Habitat

This station is located on a tributary to the Lake Dalrymple and will receive discharge from both the Miller Quarry and Tomlinson Quarry (see location on Figure 18). This watercourse is described as the north drainage feature in the Tomlinson Quarry Level I and 2 Report (Golder, 2007b). The station reach is located immediately upstream (east side) of Mara Carden Boundary Road. The station reach is surrounded by a 15 m-30 m wide riparian area composed of red-osier dogwood, speckled alder, sedges, cattails, goldenrod, eastern white cedar and red maple saplings. Beyond the 30 m wide riparian buffer is a forested area composed mainly of coniferous trees. Upstream of the station reach the tributary flows through agricultural fields.

At the time of the survey, flow was very slow moving and the channel exhibited a flat morphology. The channel banks are stable with abundant growth of dogwood and alder. The water level at the time of the benthic survey was at bankfull height in areas. Substrates are composed entirely of silt which may be washing in from the agricultural area upstream. The reach contained an abundance of floating algae and aquatic macrophyte growth consisted of pondweed species and patches of watercress. Several frogs were observed within this station reach during the survey (green frog and leopard frog).

Benthic Community

This station reach had relatively good taxa richness of 38 families represented. Of those 38 macroinvertebrate families, 10 taxa are pollution sensitive EPT taxa. The community has a high composition of insect families (85%) with dominance by chironomidae taxa. This is typical in a depositional reach with soft substrates such as this station. There were no pollution tolerant oligochaetes present in the community. The FBI was calculated to be 4.9, which indicates *good water quality*.

Overall this station‟s BIC reflects good water quality but moderately impacted habitat quality due to the adjacent agricultural activities.

5.8.3 Reference Station A-Ref-2

Aquatic Habitat

The second reference station for the Area A quarries shown on Figure 18 is located on a tributary of Lake Dalrymple (south of the Dalrymple Lake Wetland). The sampling station is located downstream of County Road 47 and is a reference for the cumulative discharge of the Beamish and Holcim quarries.

The station reach is surrounded by mixed forest which consists mainly of balsam poplar and eastern white cedar. The watercourse has patchy growth of watercress and also patches of terrestrial grasses growing within the main channel. The growth of terrestrial grasses may indicate that this watercourse is intermittent or that portions of the station reach are dry for most of the year.

This station is located in a portion of the watercourse characterized by runs. The substrates are dominated by sand and silt. While the flow was low at the time of the benthic survey, the wetted portion was near bankfull conditions. The banks are stable with heavy growth of red-osier dogwood, balsam poplar saplings and eastern white cedar. The growth of abundant filamentous algae was apparent throughout the station reach at the time of the survey.

Benthic Community

The benthic community at this station has relatively low taxa richness compared to the other stations sampled within the study area. The FBI calculated for this BIC is 6.4 which indicates *substantial organic pollution likely* or dominance by tolerant macroinvertebrate species. The composition of the community at this station is made up mostly of insects (55%), particularly dipteran taxa dominated by chironomids (midges). The EPT taxa richness is relatively low at 4 taxa which further emphasize the tolerance of this community to pollution. The community composition likely reflects the slow flow and depositional sediments (sand/silt) present in this station reach in addition to organic enrichment from agricultural practices.

The BIC at this station is composed mainly of insect families dominated by pollution tolerant chironomids. This is likely attributed to the soft depositional sediments at this station and the nutrient enrichment from the adjacent agricultural operations.

5.8.4 Exposure Station A-Exp-2

Aquatic Habitat

This station is located immediately downstream of the Holcim Quarry in the watercourse that will receive discharge from both Holcim (directly) and Beamish (discharge first through Cranberry Lake). The location of exposure station A-Exp-2 is shown on Figure 18. This station is located approximately 60 m downstream of Mara Carden Boundary Rd (watercourse flows through 1.8 m wide round steel culvert).

Within the station reach, the watercourse has low bank heights and was near bankfull width at the time of the survey. The substrates are predominantly bedrock with silt. This station reach is impacted by agricultural activities as it is surrounded by pasture with evidence of cattle access to the stream. The impacts from cattle trampling of the banks has widened the channel and caused bank erosion. The general morphology in the station reach is predominantly run habitat. At the time of the survey, the watercourse had moderate to high flows with very turbid water.

Benthic Community

The benthic community at this exposure station has relatively low taxa richness compared to the other stations sampled within the study area (22 taxa). Of the 22 taxa, only two EPT taxa were represented in the community. This could be attributable to the channel and bank disturbance caused by cattle access, the lack of substrate attachment sites for invertebrates within bedrock and silt substrates, as well as periodic high flows. The FBI calculated for this community is 7.3 which indicates *very substantial organic pollution likely* which can be partially attributed to the cattle access to the stream. Similar to the reference station above (A-Ref-2), the composition of the community at this station is made up mostly of dipterans dominated by chironomids (midges). The findings of decreased diversity, low representation of sensitive organisms and increased dominance by chironomids is consistent with observations from other impaired systems (Mackie, 2001).

The BIC sampled at A-Exp-2 reflects a stream habitat and water quality that is currently being impaired by adjacent agricultural activities and perhaps periodic high, turbid flows.

5.8.5 Reference Station B-Ref-1

Aquatic Habitat

This reference station is located on the Talbot River south of Concession Road 1, upstream of the confluence of the municipal drain (Gilchrist Creek) that flows south of the Lafarge Brechin Quarry (see location on Figure 19). This station reach represents a reference for the cumulative discharge from Lafarge Brechin and James Dick South quarries. It is also downstream of Canal Lake and thus is/will be receiving cumulative discharge water that flows into Canal Lake from the Ferma Quarry and Lafarge Kirkfield Quarry.

In this station reach, the riparian zone on the west bank was dominated by eastern white cedar, and on the east bank it was predominantly meadow with some red-osier dogwood, *Salix* spp. and *Solidago* spp. The river was slow moving at the time of the surveys and the channel morphology is mainly flat. The river channel averages 18.5 m bankfull width in this section.

Substrates in this reach were dominated by gravel and cobble with some silt and sand. Bank heights averaged 2.5 m high and were heavily eroded. Fish cover is provided by abundant large organic debris and overhanging eastern white cedars in this reach. Beaver activity was noted along the banks of the river in this reach.

Benthic Community

The benthic community at this station is dominated by insects (85%); however, only 7.4% of the insect population belongs to the dipteran families. Some of the dominant insect families are Elmidae (beetles), Taeniopterygidae (stoneflies) and Heptageniidae (mayflies) which are indicators of good water quality. The variety of substrates at this station reach likely enhances the diversity of the benthic invertebrate community. The FBI calculated for the community in this reach is 4.7 which also indicates *good water quality with some organic pollution likely*. Of the 44 taxa present in this benthic invertebrate community, 11 are EPT taxa which indicate relatively good water and habitat quality at this station.

The relatively good quality of the stream environment at station B-Ref-1 is reflected in a diverse BIC with representation by a variety of pollution sensitive species.

5.8.6 Exposure Station B-Exp-1

Aquatic Habitat

This exposure station is located on the Talbot River near the Town of Gamebridge, just downstream of the bridge crossing at Regional Road 50/Talbot Road (see location on Figure 19). This station is downstream of the discharge locations of the Lafarge Brechin Quarry and McCarthy Quarry. However, it is suggested that this station be relocated downstream of the James Dick South Quarry discharge in order to capture all quarry discharges to Talbot River in the future.

The banks at this station are highly developed with both parking lots and buildings within 30 m of the river. The riparian vegetation (approximately 30 m wide in some areas) consists of goldenrod, willow, grasses, ash, Manitoba maple and dogwood. The banks in this station reach are composed of sand and are heavily eroded. The left upstream bank immediately downstream of the bridge has rip-rap implemented for bank stability.

At the time of the survey, the river had moderate flow. Substrates are predominated by sand with gravel and bedrock. There were no observations of in-stream algae or aquatic macrophytes in this station reach.

Benthic Community

The community at this station has relatively high taxa richness with 45 different taxa represented. Of the different taxa, 17 are pollution sensitive EPT taxa which indicated very good water and habitat quality. The composition of the community is predominated by EPT which comprise 45% of the abundance. There is very low to no representation by pollution tolerant species such as oligochaetes and chironomids. The station has the lowest calculated FBI of 4.1 of the stations sampled and indicates *good water quality* at this location.

The BIC at B-Exp-1 reflects very healthy stream conditions at this station in the Talbot River. The absence of pollution tolerant species and abundance and diversity of sensitive species indicates excellent habitat and water quality.

5.8.7 Reference Station C-Ref-1

Aquatic Habitat

This reference station is located on a tributary of Canal Lake that flows in a south-westerly direction from the area north of Ferma Quarry (see location on Figure 20). The watercourse flows under a 6.1 m wide concrete bridge at Shrike Road. The station reach is located downstream of Shrike Road and has a narrow riparian buffer of approximately 5 m wide and is herbaceous consisting of goldenrod and terrestrial grasses. Beyond the narrow buffer area is predominantly agricultural fields (hayfields). Cattle have access to the watercourse upstream of Shrike Rd which was made evident by the tracks and eroded banks. There was no evidence of cattle access in the reach downstream of Shrike Road.

The general morphology of the watercourse in the station reach is run-type habitat. Substrates are composed of bedrock and gravel. Watercress is abundant throughout the reach in addition to algae growth (floating, filamentous, and attached) as is likely a result of nutrient input from the cattle upstream. The bank heights are low in this reach with water levels being near bankfull at the time of the survey. There was some evidence of undercut banks in this station reach.

Benthic Community

The benthic community at this reference station has relatively high taxa richness (42 taxa) with 18 EPT taxa represented. This is the highest representation of EPT taxa (both richness and 48% community composition) of all the stations sampled for this study. The FBI calculated at 5.2 indicates *fairly substantial organic pollution* which can be partially attributed to the cattle access to the stream. The presence of watercress may indicate a groundwater discharge into the stream in this station reach which could balance the nutrient enrichment from upstream reaches and create the conditions suitable for pollution sensitive EPT taxa.

The high representation by a number of different EPT taxa suggests a very healthy stream in terms of water and habitat quality at station C-Ref-1.

5.8.8 Exposure Station C-Exp-1

Aquatic Habitat

This exposure station represents the cumulative discharge from the Lafarge Kirkfield Quarry and Ferma Quarry (see location on Figure 20). The station is located on a tributary to Canal Lake located east of Kirkfield Road. Cattle have access to this station reach and thus it is impacted through trampling of the banks which has widened the channel and caused severe bank erosion. There is no riparian buffer and the cattle pasture of both banks is heavily grazed.

The general morphology of the channel in this station reach contained a mix of both riffle, run and pool habitat and had moderate flow at the time of the benthic survey. The substrates are composed mainly of cobble and boulder with some sand and bedrock. The bank heights range from 0.3 m-0.5 m in this station reach. The growth of filamentous algae was abundant throughout.

Benthic Community

The benthic community at this exposure station has a relatively good representation by 16 taxa of pollution sensitive EPT and a relatively good overall taxa richness of 39. Insects dominate the composition of the community at this station (48.9%) with almost half of this composition by EPT (23%). This suggests that the mix of the habitats within this station reach likely supports the variety of EPT in this community. The FBI was calculated as 5.9 which indicate *fairly poor water quality* which is at least partially due to the cattle access to the stream.

Even though the channel is heavily impacted by cattle access, the good representation of pollution sensitive species in the benthic community suggests a relatively healthy and diverse aquatic environment at this station.

Summary of Benthic Invertebrate Community Monitoring and Aquatic Habitat Assessment

In summary, while agricultural practices in the study area appear to be impacting the stream habitat through erosion and sedimentation, the BICs sampled display relatively good diversity and representation by sensitive species such as EPT taxa. There was not a clear difference between the reference versus exposure stations BIC taxa richness and representation of intolerant species.

5.9 Cranberry Lake Wetland Assessment

Field work in 2010 in a portion of the wetland that occurs on the Tomlinson Quarry property adjacent to Miller Road identified a characteristic pattern of hummocks and shallow channels along the western edge of the Cranberry Lake Wetland in the vicinity of the central „neck‟ of the feature. The cattail-reed canary grass community was dominant along most of this edge, but many of the hummocks supported clumps of willows or individual alders. A narrow fringe of alders was also present on the landward edge of the marsh community and small patches of narrow-leaved tussock sedge were scattered through the marsh community. The hummocky characteristics of this community in this area, and the plants species present, indicate a tolerance of seasonal and annual variation in water levels.

5.10 Groundwater Flow Modelling

The objective of the groundwater modelling assessment is to provide an estimate of the potential areas impacted by cumulative groundwater drawdown resulting from quarry operations within the study area. As a part of the scope of work for this study, numerical groundwater flow models were used to assess the areas of potential cumulative impact. A thorough review of geological, hydrogeological and hydrological data within the study area provided the framework for the development of a conceptual model, which was then used to construct the numerical models. The numerical representation of the conceptual model that was used to complete the modelling scenarios is illustrated in cross-sections through the model domains on Figure C8, and in plan view on Figure C4 and Figure C5 in Appendix C.

The results of this numerical modelling are provided in a series of figures and tables (described briefly below) that summarize the influence of quarries on the upper weathered zone and the green bed layer, as these are the units that can potentially result in cumulative impacts for receptors identified within the study area.

Model Zone 1 contains the Bot and James Dick North quarries. The preliminary hydrogeological assessment and operational plan for the James Dick North Quarry indicate that the quarry will extract limestone above the water table only. This was confirmed through correspondence with James Dick. As such, this site will not contribute to a decrease in the groundwater elevations within the model domain, and the drawdown in groundwater elevations will be limited to the Bot Quarry. Based on the scope of the CIA, which involves assessing only the impacts of multiple quarries, there are no cumulative impact results to present for Model Zone 1.

5.10.1 Pre-Quarry Conditions Scenario

Groundwater flow model simulations were completed following removal of the boundary conditions representing the quarries in order to approximate the groundwater conditions that would have existed in the study area before quarry development commenced. The groundwater elevation maps resulting from this simulation were used as a basis for comparison to all subsequent simulations (i.e., simulated drawdown resulting from quarry operation was calculated as the difference between the pre-quarry groundwater elevations and the groundwater elevations under operating conditions). The simulated groundwater elevations for the Pre-Quarry scenario are illustrated on Figure C9 in Appendix C.

5.10.2 Existing Conditions Scenario

The “existing conditions” groundwater modelling scenario is synonymous with the calibrated groundwater flow model, which was discussed in terms of the simulated groundwater flow patterns and inflows to the quarries in Section 2.4. The current condition for each quarry included in the study is accounted for in the Existing Conditions scenario including the size and depth of existing extraction area and whether the extraction area is dewatered or flooded. Groundwater flow simulations were completed to evaluate the extent of drawdown in the upper weathered zone and green bed layer under existing conditions (defined as 1 m of drawdown resulting from each individual quarry operations). The drawdown resulting from quarries operating under existing conditions is illustrated on Figure 21 for the upper weathered zone and Figure 22 for the green bed layer.

5.10.2.1 Upper Weathered Zone

As shown on Figure 21, there are no areas where overlapping drawdown is simulated in the upper weathered zone for existing conditions.

5.10.2.2 Green Bed Layer

As shown on Figure 22, under existing conditions one area of overlapping drawdown was simulated within the green bed layer between the Holcim and Lafarge Brechin quarries. This area of overlap results from the simulated drawdown cones at the Holcim and Lafarge Brechin quarries. Drawdown of the green bed layer at the Tomlinson, Beamish, McCarthy, James Dick South, Ferma, Webster and Lafarge Kirkfield quarries was limited to less than 1 m, and therefore no cumulative drawdown within the green bed layer is associated with these quarries under existing conditions. The drawdown at Lafarge Kirkfield in the green bed layer under existing conditions is less than 1 m because the quarry is currently flooded and active dewatering is not occurring.

5.10.3 20-Year Development Scenario

Groundwater flow simulations were completed to evaluate the extent of drawdown in the upper weathered zone and green bed layer (defined as 1 m of drawdown resulting from each individual quarry operations) following 20 years of (potential future) quarry development. The extent of quarry drawdown and areas of overlapping drawdown are shown on Figure 23 for the upper weathered zone and Figure 24 for the green bed layer.

5.10.3.1 Upper Weathered Zone

As shown on Figure 23, there are two areas where overlapping drawdown is simulated in the upper weathered zone for the 20-Year Development scenario. The areas of overlapping drawdown are between the Miller and Tomlinson quarries, and between the Holcim and Beamish quarries. The majority of the area of overlap between Miller and Tomlinson occurs within the licensed boundaries of the quarries, although a portion beyond the licensed areas extends to the west. Overlapping drawdown between the Holcim and Beamish quarries occurs within the area immediately between the license boundaries, extending south from the southern portion of the Cranberry Lake Wetland.

5.10.3.2 Green Bed Layer

As shown on Figure 24, two areas of overlapping drawdown were simulated within the green bed layer for the 20-year Development scenario: one resulting from the drawdown that occurs over the southern portion of the Tomlinson Quarry, and one that occurs between the Holcim and Lafarge Brechin quarries. The former area of overlap results from the simulated drawdown cones at the Miller and Holcim quarries, where the latter results from the simulated drawdown cones at the Holcim and Lafarge Brechin quarries. The overlapping drawdown area between the Holcim and Lafarge Brechin quarries for the 20-Year Development scenario is in a similar position to the overlapping area predicted between the Holcim and Lafarge Brechin quarries under existing conditions, but the 20-Year Development overlapping area is slightly larger.

Drawdown of the green bed layer resulting from the 20-year forecast extraction at the Tomlinson, Beamish, McCarthy, James Dick South, Ferma and Webster quarries was limited to less than 1 m, and therefore no cumulative drawdown within the green bed layer is associated with these quarries for the 20-Year Development scenario.

It should be noted that the simulated influence of the Lafarge Kirkfield Quarry within the green bed layer reached the western boundary of Model Zone 3 under the 20-Year Development scenario. The following approach was taken in order to account for this influence within Model Zone 2:

- The maximum drawdown resulting from the Kirkfield Quarry was calculated at the western edge of the Model Zone 3 boundary to be 5 m;
- A constant head boundary was applied at the respective location along the eastern edge of Model Zone 2 within the green bed model layer to reflect the depressurization resulting from the Lafarge Kirkfield Quarry. The elevation of this boundary was set at 241 masl, reflecting the calibrated groundwater elevation, minus the 5 m depressurization;
- Model 2 was re-run with inactive boundary conditions for the remaining quarries, and the resulting depressurization from the additional constant head boundary within the green bed model layer was allowed to propagate into Model Zone 2; and,
- The resulting drawdown was calculated based on the Pre-Quarry scenario groundwater elevations, as previously discussed.

5.10.4 Full Licensed Depth Scenario

Results of groundwater flow simulations that estimated the extent of drawdown in the upper weathered zone and green bed layer under fully-licensed conditions are illustrated on Figure 25 and Figure 26, respectively. A review of the results on these figures allows the following observations.

5.10.4.1 Upper Weathered Zone

The extent of simulated overlapping drawdown in the upper weathered zone is similar to that attained in the 20-Year Development scenario. Further, the individual drawdown cones in the upper weathered zone are generally similar in size and shape to those of the 20-Year Development scenario (although slightly larger drawdown cones are predicted at the Webster, Ferma and McCarthy quarries). This suggests that the drawdown predicted for the 20-Year Development scenario is at or near the maximum drawdown that will occur in the upper weathered zone.

5.10.4.2 Green Bed Layer

The simulated areas of overlapping drawdown for the green bed layer under the full development scenario encompass over half of the model domain areas, and reach the extents of the model boundaries in a number of places. The zones of overlap would extend past those boundaries, though to an unknown extent.

The Full Licensed Depth scenario assumes that all quarries will be fully dewatered at their maximum allowable extraction limits at the same time. This is not considered a reasonable scenario, and is not likely to ever occur. It is more likely that some quarries will complete their life span faster than others, and some will be closed and rehabilitated while other locations are continuing to extract. The Fully Licensed Depth scenario was included in this analysis only to represent the “worst-case” scenario. The scenario results are based on our current understanding of the behaviour of the green bed layer, and the current maximum extraction limits of the quarries included in the study. It is anticipated that additional information on the behaviour of the green bed layer will be gathered as quarry development progresses within the study area, and the results of the Full Licensed Depth scenario will be refined over time.

5.10.5 Sensitivity Analysis

Four sensitivity runs were completed to assess the sensitivity of the modelling results to variability in the hydraulic conductivity of the green bed layer, as well as the overlying Bobcaygeon Formation aquitard. The results of the sensitivity analysis are illustrated on Figures C10 through Figure C13 in Appendix C. The figures illustrate the effects of changes in hydraulic conductivity on the simulated 1 m groundwater drawdown contour in the green bed layer. The results of the sensitivity analysis can be compared to those of the 20-Year Development scenario (shown on Figure 24), as the model configuration used in 20-Year Development scenario was the starting point for subsequent sensitivity simulations. A review of these figures allows the following observations:

- As the simulated hydraulic conductivity of the green bed layer was increased from 1×10^{-5} m/s to 1×10^{-4} m/s (SR1; Figure C10), the drawdown areas decrease relative to the 20-Year Development scenario for the Miller and Holcim quarries and increase for the Lafarge Kirkfield and Lafarge Brechin quarries. All other quarry operations do not depressurize the green bed layer to the 1 m threshold under this scenario;

- As the simulated hydraulic conductivity of the green bed layer was decreased from 1×10^{-5} m/s to 1×10^{-6} m/s (SR2; Figure C11), the drawdown areas show no significant change around the Miller and Holcim quarries, and decreased slightly around the Lafarge Kirkfield and Lafarge Brechin quarries. Additionally, the 1 m drawdown threshold is reached within the boundaries of the Tomlinson and Ferma quarries;

- As the hydraulic conductivity of the Bobcaygeon Formation was increased from 1x10^{-9} m/s to 5x10^{-9} m/s (SR3; Figure C12), the simulated drawdown area decreased around those quarries which already had drawdown areas under the 20-Year Development scenario (i.e., Miller, Holcim, Lafarge Brechin and Lafarge Kirkfield). However, the 1 m drawdown threshold was reached locally around additional quarries where it was not reached under the 20-Year Development scenario, with the exception of the Webster Quarry (i.e., Tomlinson, Beamish, McCarthy, James Dick South and Ferma). This results in additional areas of cumulative impact (defined as overlapping zones of 1 m drawdown or greater) occurring locally around the Tomlinson, Ferma and Beamish quarries; and,
- Conversely to the relationship identified above, as the simulated hydraulic conductivity of the Bobcaygeon Formation was decreased from 1x10^{-9} m/s to 5x10^{-10} m/s (SR4; Figure C13), the simulated drawdown area increased for the Miller, Holcim, Lafarge Brechin and Lafarge Kirkfield properties. The 1 m drawdown threshold was not reached for other quarries under this scenario.

The relationship between the Bobcaygeon Formation hydraulic conductivity and the predicted drawdown in the green bed layer is related to the amount of groundwater that can infiltrate vertically through the Bobcaygeon Formation. As the hydraulic conductivity of this formation increases, more groundwater infiltrates vertically and supplies the drawdown cone around each quarry, thereby reducing the overall lateral extent of the drawdown cone. Reducing the hydraulic conductivity of the Bobcaygeon formation reduces vertical infiltration through this unit, and therefore results in an increased lateral extent of the localized drawdown cone.

Overall, the sensitivity runs indicate that the size and location of the areas of predicted cumulative impact are influenced by the hydraulic conductivity of the Bobcaygeon Formation and the green bed layer. As additional information is gathered through future hydrogeological investigations, confidence in the range of hydraulic conductivity for these units will increase, and confidence in the locations of the predicted zones of cumulative impact will also increase.

5.11 Water Budget

The following three scenarios were used in the water budget analysis:

- Pre-Quarry Conditions Scenario – assuming no quarries and the remaining land use as existing;
- Existing Conditions Scenario – includes the quarries in place under existing conditions, this assumes no discharge from the McCarthy, Beamish and Tomlinson quarries at this stage; and,
- 20-Year Development Scenario – assumes all overburden has been removed over the entire licensed extraction area (including the McCarthy, Beamish and Tomlinson quarries) as per their site plans. Water discharge rates were assumed as the existing maximum C of A for all quarries except for the McCarthy and James Dick South quarries where the C of A rate was unavailable. At these two locations, the maximum water taking rate for the PTTW was used instead. For the subsequent water quality assessment, the quality of the water discharged from the future condition quarries is assumed to have the same characteristics as observed under existing conditions.

The following assumptions were used in the water budget calculations:

- Monthly water budgets at Orillia (1978 to 2003) obtained from Environment Canada were assumed to be representative of the conditions within the study area. This water budget record was created by Environment Canada using a composite of Orillia stations. The average annual water budget results for each WHC were used in the water budget analysis; and,
- The catchment areas for the wetland were delineated based on DEM information and NRVIS/LEO mapping (Figure 4) and summarized in Table 9 below. The catchments areas in some locations differ between scenarios as a result of expanding quarry operations.

Table 9: Catchment Areas

Location	Catchment Area (ha)[1]		
	Pre-Quarry	Existing Conditions	20-Year Development
SW1	685	685	685
SW2	3220	3220	3220
SW3	1340	1340	1340
SWA	5920	5920	5920
SW4	237	237	261
SW5	1150	1150	1150
SW6	116	116	161
SW7	32100	32100	32100
SW8	4570	4570	4570
SW9	28800	28800	28800
SW12	477	477	477

[1] Based on DEM information and NRVIS/LEO mapping.

- Water holding capacities (WHCs) were assumed as follows: 3 mm for transportation land use, 10 mm for extraction areas, 250 mm for hedge rows and undifferentiated land use, and 400 mm for forest, coniferous forest, and deciduous forest, after MOE (2003). For the first two WHCs (3 mm and 10 mm), the WHC represents initial abstraction and depression storage only, while for the latter two WHCs (250 mm and 400 mm) the estimate includes initial abstraction, depression storage, and soil storage. A summary is presented in Table 10 below.

Table 10: Water Holding Capacities

	WHC (mm)	Average Annual Surplus (mm)
Transportation	3	567
Built-Up Impervious	10	558
Extraction	10	558
Built-Up Pervious	250	427
Hedge Rows	250	427
Undifferentiated	250	427
Plantations - Trees Cultivated	400	419
Forest	400	419
Mixed Forest	400	419
Coniferous Forest	400	419
Deciduous Forest	400	419
Bog	400	419
Swamp	400	419
Fen	400	419
Marsh	400	419
Open Water	400	419

Average annual surplus based on Environment Canada Thornthwaite water budget for Orillia (1993-2006).

Bog, swamp, fen, marsh, and open water land uses were also assumed at the highest available WHC (400 mm) in order to maximize evaporative losses (such that actual ET matched potential ET) and properly simulate locations with water at the ground surface.

A summary of the average annual results from the water budget model for all three scenarios is shown in Table 11 and 12 below. Using the Orillia water budget results, the overall average surplus values ranged from 426 mm/yr in the Pre-Quarry scenario, 435 mm/yr in the Existing Conditions scenario, and 451 mm/yr for the 20-Year Development scenario. This increasing trend in annual surplus reflects the increased surplus from the extraction areas, which have a lower WHC (and consequently a higher annual surplus) than the undifferentiated land use they replace. The annual yield numbers are also higher in smaller catchments (such as SW6), which have a larger ratio of extraction areas to total areas, as compared to the catchments further downstream (such as SW9 or SW7), where the ratio of extraction areas compared to the overall catchment area is much smaller.

Table 11: Water Budget Estimated Average Annual Yields

Location	Precipitation (mm/yr)	Pre-Quarry	Existing Conditions		20-Year Development	
		Surplus (mm/yr)	Surplus (mm/yr)	Diff. (%)	Surplus (mm/yr)	Diff. (%)
SW1	1046	422	422	0%	422	0%
SW2	1046	425	428	1%	439	3%
SW3	1046	428	438	2%	454	6%
SWA	1046	425	430	1%	439	3%
SW4	1046	425	426	0%	463	9%
SW5	1046	428	430	0%	452	6%
SW6	1046	427	507	19%	558	31%
SW7	1046	427	428	0%	430	1%
SW8	1046	429	429	0%	429	0%
SW9	1046	427	427	0%	428	0%
SW12	1046	423	423	0%	444	5%
Avg.	1046	426	435	2.2%	451	5.8%

Average annual surplus based on Environment Canada Thornthwaite water budget for Orillia (1993-2006).

Table 12: Water Budget Estimated Annual Surplus

Location	Pre-Quarry	Existing Conditions		20-Year Development	
	Surplus (m^3/yr)	Surplus (m^3/yr)	Difference (%)	Surplus (m^3/yr)	Difference (%)
SW1	2,893,000	2,893,000	0%	2,893,000	0%
SW2	13,669,000	13,788,000	1%	14,137,000	3%
SW3	5,709,000	5,844,000	2%	6,066,000	6%
SWA	25,168,000	25,425,000	1%	25,992,000	3%
SW4	1,009,000	1,010,000	0%	1,210,000	20%
SW5	4,906,000	4,922,000	0%	5,179,000	6%
SW6	496,000	589,000	19%	898,000	81%
SW7	136,885,000	137,154,000	0%	137,804,000	1%
SW8	19,606,000	19,619,000	0%	19,606,000	0%
SW9	122,798,000	122,909,000	0%	123,247,000	0%
SW12	2,016,000	2,016,000	0%	2,115,000	5%

Average annual surplus based on Environment Canada Thornthwaite water budget for Orillia (1993-2006).

With the exception of SW4 and SW6, the estimated changes in annual surplus flows (in m^3/yr) are between 0% and 6% of the Pre-Quarry flow, reflecting the small size of the quarry footprints compared to the larger drainage catchment. When the quarry area is small, the change from the undifferentiated land use to the extraction land use generates only a small increase in runoff compared to the overall catchment.

In the case of SW6, both the translation from the Pre-Quarry scenario to the Existing Conditions scenario, as well as the Pre-Quarry to the 20-Year Development scenario, generates an increase in annual runoff (19% and 81% in the Existing Conditions and 20-Year Development scenarios, respectively). This increase in flows is the result of both quarry expansion, and the fact that the drainage area for the SW6 catchment is entirely made up of the extraction area with only minor contributions from outside drainage. Thus, the water budget estimated flows are directly proportional to the size of the upstream quarry. This results in increased annual flow volumes in the receiving watercourse as the quarry expands. This effect is expected to be mitigated by the fact that most of the land areas being added to the future extraction areas currently drain in the same direction (to the Talbot River), and that the catchment changes are expected to be largely balanced moving downstream.

The same cause of increase at SW6 is true (to a lesser degree) for SW4 and SW12 which show respective 20% and 5% increases in annual flow between Pre-Quarry and 20-Year Development scenarios. This increase is largely the result of additional area draining to the Cranberry Lake Wetland via the quarry discharges (in the case of SW4, from the Beamish Quarry, and in the case of SW12, from the Tomlinson Quarry). In the case of SW4, the new extraction areas for the Beamish Quarry previously drained to SW3, and redirecting drainage to SW4 (which is also upstream of SW3) leaves the total area draining to SW3 unchanged. In the case of SW12, the new extraction areas for the Tomlinson Quarry previously drained to the north drainage feature (at the boundary of Miller and Tomlinson Quarry), and redirecting them to SW12 (which is also upstream of SW2) leaves the total drainage area to SW2 unchanged. Thus, while the annual flow increases at SW4 and SW12, the overall flow change at SW2 and SW3 is minimal (3% and 6% for SW2 and SW3, respectively, in the 20-Year Development scenario).

Surplus values can be further broken into a surface runoff and an infiltration component. Results from the calibrated groundwater model indicate an infiltration rate for the study area of between 65 mm/yr and 75 mm/yr, depending on the amount of overburden present. These infiltration values correspond to roughly 16% of the average annual study area surplus value for the Existing Conditions scenario. Groundwater modelling results show that most of this infiltration is expected to be discharged to surface waters (via groundwater discharge and quarry dewatering) within the study area.

In Table 13, the results from the water budget are compared to the surplus results for the Beaverton River WSC station (located 17 km south of the study area, as previously discussed in Section 5.4). Generally, the average surplus results from the water budget analysis are somewhat higher than the average yield value of the Beaverton River of 323 mm/yr, with an average difference of between 106 mm (for the Pre-Quarry condition) and 128 mm (for the 20-Year Development scenario). This difference suggests that some part of the surplus infiltrating upstream of the WSC flow gauge may have joined the regional groundwater system and may not be reporting back to surface within the catchment.

Table 13: Comparison Between Water Budget Results and Average Measured Flows

Station	Water budget Estimated Surplus	Beaverton River Surplus		Flow Measurement Estimated Surplus	
	(mm/yr)	(mm/yr)	Percent Difference (%)	(mm/yr)	Percent Difference (%)
SW1	422	323	-24%	415	-2%
SW2	428	323	-25%	96	-77%
SW4	426	323	-24%	276	-35%
SW5	430	323	-25%	326	-24%
SW7	428	323	-24%	321	-25%
SW12	423	323	-24%	361	-15%

Average annual surplus based on Environment Canada Thornthwaite water budget for Orillia (1993-2006).

A comparison between the average annual surplus values for the Existing Conditions scenario, and the estimated annual yield values for the available catchments (i.e., where streamflows were measured) is shown in Table 13. Generally, estimated annual yield from the flow monitoring represents a moderate decrease (2% to 35%) compared to the estimated average annual yield from the water budget method. This difference is expected due to the underestimation of the yield using the monitoring data, which was discussed in Section 5.5. However, at station SW2, the yield estimated using the monitoring data is nearly 77% less than the water budget estimated annual yield; this is assumed to be related to drainage and infiltration in that watershed.

5.11.1 Cranberry Lake Water Budget

Based on the values presented in Table 12, the water budget estimated surplus contributing to the Cranberry Lake Wetland (assumed as the sum of the average annual surpluses at SW4 and SW12) was estimated at roughly 3,024,000 m^3/yr in the Pre-Quarry scenario, 3,026,000 m^3/yr in the Existing Conditions scenario, and 3,325,000 m^3/yr in the 20-Year Development scenario. This increase is primarily the result of the changing land use (from undifferentiated to extraction area) in the water budget analysis. As previously discussed, this estimated surplus includes both runoff and groundwater discharge/interflow into the Cranberry Lake Wetland.

Table 14: Cranberry Lake Wetland Water Budget

	Average Annual Flow (m^3)		
	Pre-Quarry	**Existing Conditions**	**20-Year Development**
Water budget Surplus to Cranberry Lake (SW4 + SW12)	3,024,000	3,025,000	3,325,000
Change in Surplus to Wetland	0	+ 1,000	+ 301,000
Groundwater Discharge to Wetland	362,000	364,000	279,000
Change in Groundwater Discharge to Wetland	0	+ 2,000	-83,000
Total Change in Wetland Surplus	0	+ 3,000	+ 218,000

From the calibrated groundwater model, the amount of groundwater contributing to the Cranberry Lake Wetland was estimated at roughly 360,000 m^3/yr in the Pre-Quarry scenario and the Existing Conditions scenario, and 280,000 m^3/yr in the 20-Year Development scenario (Table 14). This represents a decrease in groundwater discharge to the wetland of 83,000 m^3/yr between the Existing Conditions and 20-Year Development scenarios. This suggests that a portion of the water budget estimated surplus in the wetland catchment is not reaching the wetland; however, because of the changing land use, the Cranberry Lake Wetland is still expected to see a net increase in average annual flows.

6.0 CUMULATIVE IMPACT ASSESSMENT

For the purpose of this study, a cumulative impact is defined as the additive effect of multiple quarry dewatering operations on groundwater, surface water and/or natural environment features. For groundwater, a cumulative impact could result from the intersection of various dewatering zones of influence associated with operation of multiple quarries. The intersection of multiple dewatering zones of influence results in a cumulative impact because more groundwater level drawdown occurs within the area of intersection than if each quarry was operated in isolation. For surface water, cumulative impacts to water quantity and water quality in a receiving watercourse(s) may result from the discharges from multiple quarries. Cumulative impacts may also occur as a result of drawdown of the shallow groundwater table beneath a surface water feature as a result of the dewatering of multiple quarries. For natural environment features, cumulative impacts relate to the potential effect of dewatering and discharge from multiple quarries on the surrounding flora and fauna.

Dewatering of quarries below the groundwater table has the potential to cause a decline in groundwater levels beyond the quarry boundaries. These drawdown effects have the potential to lower the groundwater levels in water supply wells, and/or to reduce the groundwater contribution to local surface water features that may result in subsequent impacts to ecological receptors.

As the quarries within the Carden Plain develop, the cumulative impacts may change over time and space. The available information was used to select an appropriate timeframe for completing an impact assessment to determine if the operation of multiple quarries within the Carden Plain will result in unacceptable cumulative impacts to identified groundwater, surface water or natural environment features. This assessment focuses on potential adverse effects within an area of predicted cumulative impact. Potential impacts to groundwater, surface water and ecological resources as a result of the operation of a single quarry are not assessed.

The 20-Year Development scenario was selected for use during the impact assessment because it represents a reasonable timeframe for considering impacts and for developing monitoring programs. As the timeframe is increased, the uncertainty associated with quarry development within the study area increases, which can result in potentially unrealistic scenarios. For example, the Full Licensed Depth scenario assumes that all quarries will be fully dewatered at their maximum allowable extraction limits at the same time. This is not a reasonable scenario, and is not likely to ever occur. It is more likely that some quarries will complete their life span faster than others, and some will be closed and rehabilitated while other locations are continuing to extract.

Given that the CIA study is to be revisited every five years, and the life of the PTTWs for the various quarries is a maximum of ten years, the 20-Year Development scenario is considered appropriate for assessing impacts to identified receptors, and for proposing associated monitoring programs (if required).

As part of the assessment, the following surface water cumulative impacts for the quarries present in the study area were considered; the impacts on water quality of receiving streams; the potential for flooding and erosion impacts in receiving streams; and, the impacts on low flows around the study area resulting from cumulative groundwater drawdown adjacent to the quarries. Based on a review of the identified receptors within the study area, which include water supply wells (see Figure 12) and surface water and natural environment features (see Figure 14), the cumulative impacts associated with groundwater drawdown focus on potential impacts to the upper weathered zone and potential impacts to the green bed layer, as these are the units that can potentially result in cumulative impacts associated with groundwater for the identified receptors.

The cumulative impact assessment presented below is divided into the following sections:

- Surface water and natural environment features; and,
- Water supply wells.

6.1 Surface Water and Natural Environment Features

The cumulative impact assessment for surface water and natural environment features is further divided into a surface water quality impact assessment, a flooding and erosion impact assessment and a low flow impact assessment.

6.1.1 Surface Water Quality Impact Assessment

The potential water quality impacts of individual quarry discharges to natural streams are generally evaluated in PTTW and C of A applications. However, in the case of the study area, there exists the potential for multiple quarries, discharging to the same watercourse, to have a cumulative impact. In order to assess these impacts, a water quality impact assessment was undertaken for the existing measured conditions at the site using the water budget estimated average annual flow rates and the measured water quality data.

Based on the exceedances noted during the water quality monitoring program and subsequent discussions with MOE representatives, the target parameters chosen for the cumulative impact assessment include total phosphorus, dissolved sulphate, dissolved chloride, total boron, total copper, total iron and total zinc.

With respect to scenarios, this analysis was completed for both the Existing Conditions scenario and the 20-Year Development scenario. In order to carry through this analysis, water quality in the receiving waters below the existing and proposed quarries is assumed to be the same as measured during the 2010-2011 field program.

6.1.2 Surface Water Quality Assessment Methodology

The water quality conditions at the SW2, SW3, SWA, SW5, SW9 and SW7 stations in the Pre-Quarry, Existing Conditions, and 20-Year Development scenarios were evaluated by estimating the loading at each station. The Existing Conditions and 20-Year Development cumulative discharge zones are shown on Figure 27 and 28, respectively.

The loading at each station for each scenario was estimated on a seasonal basis for SW2, SW3, SWA, SW5 and SW9; the seasons (taken as March to May, June to August, September to November, and December to February) were chosen to match quarterly monitoring events. In the case of SW7, the loadings were estimated as annual averages, because seasonal water quality information was not available at SW7 (James Dick South Quarry monitoring data).

For each of the downstream stations, average seasonal and average annual flows were estimated using the results from the water budget method described in Section 5.11. Flows were broken up into quarry flows (flows from the extraction areas in the water budget analysis) and non-quarry flows (based on the remaining non-extraction areas). The load to each station was estimated by multiplying the concentration (assumed as the background concentration in the Pre-Quarry scenario and the sample results for the Existing Conditions and 20-Year Development scenarios) by the estimated seasonal and annual flows. Total loading to the downstream station was then estimated by adding the load from quarry and non-quarry sources. Total concentrations (the average concentration for the combined quarry and non-quarry flows at the station) were estimated by dividing the total load from all sources by the estimated total annual flow volume at each point of analysis.

It is important to note that this method assumes that any change in water quality between the background station and the downstream stations is the result of quarry seepage and discharging groundwater to the surface. It is assumed that any other activities or land use changes upstream of the cumulative assessment stations have no effect on water quality. This may result in overestimation of the loadings contributed by quarry operations at the downstream assessment locations. This method also assumes that there will be no change in land use outside of the quarry development for the 20-Year Development scenario: Future changes in land use cannot be estimated with the available information, which represents a limitation of the modelling.

Parameter concentrations for the scenarios were based on concentrations measured during the 2010-2011 monitoring period, and reported in this report (presented in Table F1 in Appendix F). For the Pre-Quarry scenario, concentrations at the six stations were assumed as „background" concentrations. For stations SW2, SW3 and SWA, the background concentrations were assumed as the measured concentrations at SW1. For stations SW5 and SW9, the background concentrations were assumed as the measured concentrations at SW8. For station SW7, the background was assumed as SW9. For the Existing Conditions scenario, measured concentrations at the stations were used in conjunction with the water budget estimated annual flows to estimate a total loading under the existing condition. The non-quarry contribution to the load was then estimated using the water budget flow results for the non-quarry areas, assuming background concentrations of the various parameters. The difference between the total loading and the non-quarry contribution was assumed to be the loading from the upstream quarries. The concentration of quarry loading was estimated by dividing the loading by the water budget estimated flow rate.

For the 20-Year Development Scenario, the load from the non-quarry areas (estimated by multiplying the background concentration by the 20-Year Development non-quarry flow contribution) and the load from the quarry areas (estimated by multiplying the 20-Year Development quarry flow by the quarry concentrations estimated under the Existing Conditions scenario) were added together to produce an estimated value for the total loading under the 20-Year Development scenario. This final 20-year loading was also used to estimate a concentration by dividing the total loading by the total water budget estimated flow for the 20-Year Development condition for each point of assessment.

In the case of SWA, which was not monitored during the 2010-2011 monitoring program, the Existing Conditions and 20-Year Development concentrations were estimated as the loading from the SW2 and SW3 stations, plus an assumed background loading (based on the background concentrations monitored at SW1), divided by the estimated total flow. The background loading was assumed to be the difference between the sum of the SW2 and SW3 flows and the water budget flow for SWA, multiplied by the concentrations at the SW1 background station.

The separation of quarry and non-quarry flows in the catchments for this analysis required an accounting of both the surface flows (derived from the quarry extraction area and the water budget surplus) and the groundwater contribution to the quarries. The groundwater contribution on both an annual and seasonal basis was estimated using the projected annual values for quarry seepage/pumping rates from the groundwater model for the Existing Conditions and 20-Year Development scenarios. These quarry/seepage rates were added to the quarry surface water budget surpluses for their respective catchments, and subtracted from the natural area surpluses for those catchments.

In some summer season cases (SW3 in the Existing Conditions scenario, and SW2, SW3, SWA and SW5 in the 20-Year Development scenario), the seasonal quarry seepage/pumping estimated from the groundwater model was found to exceed the seasonal natural catchment surplus. In these cases, the natural area surplus contribution is assumed to be zero, and the excess quarry seepage/pumping is assumed to be stored groundwater.

In some situations, the measured station value for a parameter was found to be lower than the assumed „background" parameter. The results using these values and the above method would indicate a negative load coming from the quarry areas, existing concentrations at these locations and for these parameters were assumed as the background concentration for comparison to the Pre-Quarry and 20-Year Development Scenarios. This occurs in the Existing Conditions scenario for Unionized Ammonia (SW5, SW9, and SW7), Total Phosphorus (SW5 and SW7), Dissolved Sulphate (SW9), Dissolved Chloride (SW2, SW5, and SW9), Total Boron (SW9), Total Copper (SW2, SW3, SW5, and SW9), and Total Iron (SW2). This results in the quarry loading concentrations being equal to the background concentrations.

Of the six stations being assessed for water quality impacts, only three (SWA, SW9 and SW7) have more than one quarry discharging upstream of them under the Existing Condition scenario. As the remaining stations (SW2, SW3 and SW5) do not have more than one quarry discharging upstream of them, there is not a cumulative impact on these surface water locations. While the results shown below include all stations in the assessment, only those stations with cumulative impacts will be discussed.

The resulting load estimates were converted to a mass per unit area per year value by dividing the load estimates by the total catchment area upstream of the station. The changes in load per unit area at each station from the Pre-Quarry scenario to the Existing Conditions scenario and from the Pre-Quarry scenario to the 20-Year Development scenario were then estimated, and the impact of the change in concentrations was assessed.

6.1.3 Surface Water Quality Assessment Results

The water quality cumulative impact results are shown in Tables F2 through F8 in Appendix F. The tables show the loadings to each of the assessment stations (SW2, SW3, SWA, SW5, SW9 and SW7) under the Pre-Quarry, Existing Conditions and 20-Year Development scenarios. As discussed in the methodology, the Pre-Quarry scenario loadings are based on the background concentrations, while Existing Conditions loadings are based on measured concentrations at the stations during the 2010-2011 monitoring period, and 20-Year Development loadings are based on the estimates for quarry surplus contribution concentrations estimated for the Existing Conditions scenarios. As with the sampled water quality monitoring, the results were compared with the PWQO, CCME, and BC MOE guidelines; although the latter not applied as a regulatory limit in Ontario, it is used in this case for order of magnitude comparisons. As noted above in the methodology, this method assumes that there is no change in land use beyond the development of the quarries for the 20-Year Development scenario.

The water quality impact assessment shows that dissolved sulphate loadings are expected to increase from the Pre-Quarry scenario to 20-Year Development scenarios at stations SW2, SW3, SWA, SW5, and SW7 (Appendix F). This difference is partially the result of low concentrations of sulphate at the background stations (with averages of 4.2 mg/L and 4.4 mg/L at SW1 and SW8, respectively) compared to the sulphate concentrations measured at the downstream stations (45.23 mg/L, 39.38 mg/L, 18.96 mg/L, 6.46 mg/L and 21.0 mg/L at SW2, SW3, SW5, SW9 and SW7, respectively). Quarry water quality monitoring records generally suggest high concentrations of sulphate in water immediately downstream of quarries compared to lower concentrations taken immediately upstream of quarry discharges. These sulphate levels in the discharges (as well as those measured by the operators immediately downstream of the quarries) occasionally represent levels above the BC guidelines (although not applicable, they are being used for order of magnitude comparisons in this assessment), and suggests that quarry sulphate loading is likely one source of the elevated sulphate readings downstream. This will likely continue to be the case in future scenarios.

The results for total phosphorus generally show an increase in the Existing Conditions scenarios at all stations in the Existing scenario, and at all stations in the 20-Year Development scenario (Appendix F). As with sulphate, the difference is largely the result of lower phosphorus concentrations at the background stations (0.009 mg/L at SW1 and 0.016 mg/L at SW8) compared to the existing condition analysis concentrations at the cumulative effects assessment stations (0.029 mg/L, 0.128 mg/L, 0.054 mg/L, 0.020 mg/L and 0.021 mg/L at SW2, SW3, SW5, SW9 and SW7, respectively). Unlike sulphate however, quarry monitoring generally has not shown significantly higher levels of phosphorus in quarry discharges (over background concentrations). The phosphorus is therefore thought to be the result of an external loading and not the result of the quarry cumulative impacts.

The water quality impact assessment shows that dissolved chloride loadings are expected to increase from the Pre-Quarry scenario to the 20-Year Development scenario at SW3 (Appendix F). This difference is largely the result of high concentrations of dissolved chloride at SW3 (84.4 mg/L) compared to the dissolved chloride concentrations measured at the background SW1 station (10.3 mg/L). Furthermore, when SW3 is compared to SW4 (immediately upstream of the station, at Cranberry Lake), the downstream SW3 average appears to be higher than (approximately 40 times) the concentration at the SW4 station (where the average recorded chloride concentration was 2.0 mg/L, see Table F1). Quarry water quality monitoring records generally suggest high concentrations of chloride in water discharged from the quarries). These elevated chloride levels in the discharges (as well as those measured by the operators immediately downstream of the quarries) suggests that quarry chloride loading is likely one source of the elevated chloride readings downstream. This will likely continue to be the case in future scenarios.

The results for boron show increasing loading between Pre-Quarry and 20-Year Development scenarios at stations SW2, SW3, SWA, and SW5 (Appendix F). Available water quality monitoring of quarry discharges generally show boron concentrations comparable to those measured increasing boron concentrations moving from upstream to downstream of the quarry discharge location, suggesting that the boron loading is the result of quarry operations. This will likely continue to be the case in future scenarios.

The total copper concentrations at SW5 are shown to exceed the PWQO limit of 5 µg/L in the 20-year Development scenario. The concentrations of copper at SW5 were at or below the laboratory RDL for the July 27, 2010 reading and the October 21, 2010 reading, and were only slightly above the RDL for the remaining two readings (1 µg/L reading on April 2010 and a 2 µg/L reading on February 18, 2011). Because quarry monitoring results generally do not show any increases in copper downstream of the quarry discharges, this predicted increase is therefore assumed to not be the result of quarry activity.

Analysis results for total iron are variable, suggesting an increase at SW2, SWA, SW5 and SW7 in the 20-Year Development scenario (Appendix F). Given that iron concentrations were generally higher upstream of quarry discharges at SW4, (where the average iron concentration was 374 µg/L) compared to downstream of the quarry discharges at SW3 and SW4 (where the average iron concentration were 204 µg/L and 147 µg/L for the existing condition analysis, respectively), the iron loadings at SW2 and SW3 are likely not the result of quarry activities, and iron concentrations are likely linked to other in-stream processes or land uses. However, iron concentrations between the upstream SW8 station (where the average measured iron concentration was 50 µg/L) and locations downstream of quarries in that area (at SW5, SW7, and SW9) show a slight increase in iron concentration (with average annual concentrations of 262 µg/L, 57 µg/L, and 139 µg/L at SW5, SW9, and SW7, respectively in the existing condition analysis, which remain below the PWQO for this parameter.). As such, at these locations the increase in iron concentration may be the result of a combination of quarry activities and other land uses.

The total zinc concentrations at SW5 are shown to exceed the PWQO limit of 20 µg/L in the 20-Year Development scenario. As with copper, concentrations of copper were at or below the laboratory RDL, with only three results (SW3, SW5, and SW9 in February, 2011) testing over the laboratory RDL. The increase in concentrations in this analysis for the 20-Year Development scenario is therefore assumed to be the results of these high samples (when compared to background samples below RDL concentrations), and likely not the result of quarry dewatering activities. A summary of all exceedances for the Existing Conditions scenario shown in the analysis is provided in Table 15 below.

Table 15: Summary of Predicted Exceedances of Available Guidelines for the Existing Scenario

Location	Location of Exceedances in the Existing Scenario						
	Total Phosphorus[1]	Dissolved Sulphate (SO4)[2]	Dissolved Chloride (Cl)[2]	Total Boron (B)[1]	Total Copper (Cu)[1]	Total Iron (Fe)[1]	Total Zinc (Zn)[1]
SW2	Yes[4]						
SW3	Yes[4]						
SWA	Yes[4]						
SW5	Yes[4]						
SW9	Yes[4]						
SW7	Yes[4]						

[1] *Exceedance of PWQO or CCME guideline*

[2] *Exceedance of BC MOE guideline (not applicable in Ontario)*

[3] *Exceedance likely the result of discharging groundwater from quarries*

[4] *Exceedance likely not the result of discharging groundwater from quarries*

[5] *Exceedance likely the result of a combination of discharging groundwater from quarries and other land uses*

A summary of all exceedances for the 20-Year Development scenario shown in the analysis is provided in Table 16 below:

Table 16: Summary of Predicted Exceedances of Available Guidelines for the 20-Year Development Scenario

Location	Location of Exceedances in the 20-Year Development Scenario						
	Total Phosphorus[1]	Dissolved Sulphate (SO4)[2]	Dissolved Chloride (Cl)[2]	Total Boron (B)[1]	Total Copper (Cu)[1]	Total Iron (Fe)[1]	Total Zinc (Zn)[1]
SW2	Yes[4]	Yes[3]		Yes[3]		Yes[4]	
SW3	Yes[4]	Yes[3]	Yes[3]	Yes[3]			
SWA	Yes[4]	Yes[3]		Yes[3]		Yes[4]	
SW5	Yes[4]	Yes[3]		Yes[3]	Yes[4]	Yes[5]	Yes[4]
SW9	Yes[4]						
SW7	Yes[4]	Yes[3]				Yes[5]	

[1] *Exceedance of PWQO or CCME guideline*

[2] *Exceedance of BC MOE guideline (not applicable in Ontario)*

[3] *Exceedance likely the result of discharging groundwater from quarries*

[4] *Exceedance likely not the result of discharging groundwater from quarries*

[5] *Exceedance likely the result of a combination of discharging groundwater from quarries and other land uses*

6.1.4 Natural Environment Impact Assessment – Surface Water Quality

The stations at which surface water quality was monitored in 2010-2011 generally coincide with the benthic invertebrate and aquatic habitat monitoring stations used for the natural environment assessment. The table below indicates the corresponding sampling stations for both surface water quality and aquatic assessment.

Table 17: Corresponding Sampling Stations for Surface Water Quality and Aquatic Assessment

Aquatic Assessment Station	Surface Water monitoring Station	Watercourse/Drainage Feature Name
A-Ref-1	SW1 (background station)	unknown
A-Exp-1	SW2	unknown
A-Ref-2	N/A	unknown
A-Exp-2	SW3*	North Drainage Feature
B-Ref-1	SW9**	Talbot River
B-Exp-1	SW7	Talbot River
C-Exp-1	SW5	unknown
C-Ref-1	SW8***	unknown

* Although these two stations are located on a different reach of the watercourse, they receive the same cumulative discharge.

** While B-Ref-1 is considered a reference station for B-Exp-1 in the benthic community analysis, SW9 is considered a station which receives cumulative quarry discharge and thus effects at this station will also be discussed.

*** Although these two stations are located on different watercourses, they represent a background station with which to compare conditions of cumulative discharge at C-EXP-1/SW5.

For the surface water quality assessment, there are predicted concentrations for all parameters at SWA which were calculated from the loadings and concentrations at SW2 and SW3. SWA is located at the south end of Lake Dalrymple in a wetland. A BIC station was not located near SWA as this location would be difficult to sample and compare to reference stream stations. Also, as it is far downstream from the quarries on the edge of a lake, it would be difficult to discern the effects of cumulative quarry discharge from the influence of other land uses in the catchment. It is suggested that this station should not represent a future BIC monitoring station.

As benthic invertebrates are an indicator of aquatic health, a comparison of the BIC survey results with those of the surface water quality analysis provides a context for assessment of potential cumulative aquatic habitat and biological effects for the Existing Conditions and 20-Year Development scenarios.

6.1.4.1 Existing Conditions Scenario

Under existing conditions scenario, the only benthic invertebrate stations that were receiving surface water discharge from more than one quarry in the study area are C-Exp-1/SW5 and B-Ref-1/SW9 which both receive quarry discharges from Lafarge Kirkfield Quarry and Ferma Quarry. The other benthic invertebrate stations represent future cumulative discharge locations.

Based on the results of the surface water quality assessment for the Existing Conditions scenario, there are no parameters that exceeded the applicable guidelines that are considered to be the sole result of the quarry cumulative impacts. The exceedance of the nutrient parameter phosphorus at all stations is thought to be mostly from agricultural land uses in the watershed, and as the Hilsenhoff FBI displays, the reference and exposure stations did not differ significantly in the tolerance of the benthic invertebrate communities to organic pollution. As such, for existing conditions water quality, there are no identified cumulative impacts to natural environment features.

6.1.4.2 20-Year Development Scenario

Based on the results of the surface water quality assessment, there are four parameters that are anticipated to exceed guidelines in the 20-Year Development scenario that can be attributed to quarry discharge; sulphate, chloride, boron and iron. Dissolved sulphate loadings are expected to increase from the Pre-Quarry scenario to 20-Year Development scenario at stations A-Exp-1/SW2, A-Exp-2/SW3, SWA, C-Exp-1/SW5, B-Exp-1/SW7 and B-Ref-1/SW9. It is suggested that elevated sulphate levels in the quarry discharges (and measured by the operators immediately downstream of the quarries) are likely one source of the elevated sulphate readings at these stations downstream. The BC MOE criterion of 50 mg/L is predicted to be exceeded slightly at B-Exp-1/SW7 and A-Exp-2/SW3 (59 to 89 mg/L) while at the remaining stations it is predicted to exceed the guideline (89 to 389 mg/L). While different invertebrate species are tolerant of elevated sulphate concentrations (LC50 at concentrations from >500 mg/L to >14, 000 mg/L) (Soucek and Kennedy, 2005), elevated concentrations may have some effect on the abundance and diversity of aquatic invertebrate communities. However, as discussed below increased chloride concentrations, which may also be attributable to cumulative quarry effects, reduce sulphate toxicity, further lowering this minor effect (Soucek and Kennedy, 2005). It has been suggested that sulphate toxicity can be ameliorated by increased water hardness and/or major ions such as chloride (Soucek and Kennedy, 2005; Davies et. al. 2009; Elphick et. al. 2011).

Dissolved chloride loadings are expected to increase from the Pre-Quarry scenario to the 20-Year Development scenario. Quarry water quality monitoring records generally suggest high concentrations of chloride in water discharged from the quarries (approximately 10 mg/L to over 1,000 mg/L). These elevated chloride levels in the discharges (as well as those measured by the operators immediately downstream of the quarries) suggests that quarry chloride loading is likely one source of the elevated chloride readings downstream. Of the predicted 20-Year Development chloride loadings, only the concentration at A-Exp-2/SW3 exceeds the 50 mg/L BC MOE guideline. It is suggested that elevated water hardness and/or major ions such as chloride (Soucek and Kennedy, 2005; Davies et. al. 2009; Elphick et. al. 2011) may alleviate the effects of high concentrations of sulphate.

Results for boron indicate increasing loading between Pre-Quarry and 20-Year Development scenarios at all stations. Water quality monitoring of quarry discharges at all quarries suggests that the boron loading in the analysis is the result of quarry operations; however this is likely to be the result of naturally elevated levels in groundwater. While the effects are species specific, levels of boron at A-Exp-1/SW2, A-Exp-2/SW3, SWA and C-Exp-1/SW5 are predicted to exceed 0.2 mg/L in the 20-Year Development scenario. Studies have indicated that fish are more sensitive to elevated levels of boron than are aquatic invertebrates (Eisler, 1990). Concentrations of boron that produced effects during invertebrate acute toxicity studies ranged from a threshold concentration of 1 mg/L for protozoans up to an effect concentration of 2,797 mg/L for pupae of mosquito larvae (Knezevich, et. al. 2008).

The U.S. EPA (1986) notes that boron is primarily phytotoxic and provides a lowest chronic effect level for fish (minnows) of 18,000 mg/L. It is suggested that boron concentrations over 0.1 mg/L can adversely affect the early life stages of largemouth bass (a common warm water species found in the study area) (Knezevich, et. al. 2008). However, these results are from undiluted water samples and fish are more mobile than invertebrates and can avoid direct affects, although a habitat suitability and/or species distribution effect could result.

Total iron at all stations except SW3 and B-Ref-1/SW9 is expected to exceed the PWQO in the 20-Year Development scenario. Iron is considered a relatively non-toxic element and is an essential micronutrient for most organisms. A review of available literature indicates that concerns with iron in aquatic systems relate mainly to the precipitation of iron hydroxides under acidic conditions. It should be noted that the PWQO for iron is not based on toxicity, but rather, on a concentration that is intended to prevent precipitation of iron complexes and precipitates. Because iron precipitation commonly occurs when groundwater is exposed to the atmosphere, iron precipitation is expected to occur in the sump or ponds, and not in the receiving water.

While concentrations of total phosphorus at all stations are predicted to exceed the PWQO in the 20-Year Development scenario, it is thought to be primarily the result of an external loading and not the result of the quarry cumulative impacts.

6.2 Flooding and Erosion Impact Assessment

Generally, quarry discharge rates are set with the aim of clearing water from the active quarry area in a timely manner without discharging effluent with elevated TSS concentrations or increasing the risk of downstream flooding. However, in areas with a higher concentration of quarries such as the Carden Plain, the result of several quarries discharging simultaneously into the same watercourse may have unforeseen effects on peak flow rates in the receiving watercourse. To assess the cumulative impact of quarry discharges on streams, the potential for flooding and erosion impacts was screened for each monitoring station under the Pre-Quarry, Existing Conditions and 20-Year Development scenarios.

6.2.1 Flooding and Erosion Assessment Methodology

To identify the impact of quarry discharges on flooding and erosion on watercourses downstream of the quarries, a flow rate against which to compare the discharge rates must first be estimated. While erosion and sedimentation are natural and ongoing processes, the threshold flow for significant flooding and erosion can be considered to approximate the bankfull flow, or the flow at which a watercourse will rise above the limits of the defined channel. In unregulated natural channels, the bankfull flow rate typically has a return period of between 1.5 years and 3 years. As hydrometric data for the study area catchments are limited, the Modified Flood Index (MFI) method was used to estimate the 2.33 year return period, which was used as a proxy for the bankfull conditions under the Pre-Quarry scenario. This method, which is described in the Ministry of Transportation (MTO) Drainage Manual (MTO, 1995) can be used to estimate various return period flow events for a variety of watersheds in Ontario.

The general equation for the MFI method is:

$$Q_{25} = C_{25} \times A^{0.75}$$

Where Q_{25} is the 25 year return period flow in m^3/s, C is the watershed class coefficient (a unitless coefficient), and A is the watershed basin area in km^2. The C_{25} coefficient is unique to each watershed, and is determined from a series of design charts in the manual based on the watershed soils, slope, storage within the watershed, and whether the watershed is a northern (primarily Canadian Shield) watershed, southern (primarily clay or till subsurface), or a mixture of both northern and southern watersheds. The 25-year flow estimate can then be used to estimate the 2.33 year return period flow using conversion factors from the 1986 MTO drainage manual (MTO, 1986).

Based on the cumulative effects assessment, the 2.33 return period flows were estimated at locations downstream of more than one existing or proposed quarry in the 20-Year Development scenario (the analysis did not include flooding and erosion under existing conditions). Monitoring locations downstream of more than one quarry in the existing scenario include SWA, SW5, SW9, and SW7, while locations downstream of more than one quarry in the 20-Year Development scenario include SW2, SW3, SWA, SW5, SW9 and SW7. The 2.33 year flows were estimated for the natural (non-quarry) areas only, as outflow from the quarry extraction areas was assumed to be controlled as per their PTTWs and C of As. The expansion of the quarry extraction areas between the Pre-Quarry and Existing Conditions scenarios, and between the Existing Conditions and 20-Year Development scenario, generally leads to a decrease in natural drainage areas and subsequent decrease in natural area peak runoff. However, these flows from the natural areas do not account for quarry discharges. In order to gauge the potential effect of quarry discharges on the 2.33 year return period flow estimates, the peak quarry discharge rates in each watershed upstream of the flow stations, with multiple quarries upstream of them, were estimated. These were added to the appropriate 2.33 year flows at the selected stations in the Existing Conditions and 20-Year Development scenarios. In order to provide a conservative estimate of the increase in flow resulting from quarry pumping, the maximum pumping rates from the C of As and PTTWs were used.

6.2.2 Flooding and Erosion Assessment Results

The results for the Modified Flood Index (MFI) Method are shown below in Table 18 below.

Table 18: Modified Flood Index Method Results

Scenario	Pre-Quarry	Existing Conditions		20-Year Development	
Location	**Flow (m^3/s)**	**Flow (m^3/s)**	**Difference (%)**	**Location**	**Flow (m^3/s)**
SW2	7.63	N/A[1]		6.67	-13%
SW3	4.04	N/A[1]		3.43	-15%
SWA	12.61	12.19	-3%	11.49	-9%
SW5	4.96	4.94	0%	4.17	-16%
SW7	36.89	36.89	0%	36.26	-2%
SW9	32.27	32.25	0%	31.93	-2%

[1] *There are no cumulative effects at this location (less than two quarries upstream)*

As a calibration check, the 2.33 year return period flow value for the Talbot River at SW7 was compared to pro-rated 2.33 year return period flow estimate for the Beaverton River (using the daily flow data at the Beaverton River gauge located approximately 17 km south of the study area). The pro-rating was done based on drainage areas (288 km^2 for SW7 and 282 km^2 for the Beaverton gauge). The resulting pro-rated flow of 39.7 m^3/s is within 7% of the SW7 MFI flow estimate of 36.90 m^3/s, indicating general agreement between the MFI method and at least one nearby gauged river (Beaverton River).

In general, the results suggest that peak flows would be expected to decrease from the Pre-Quarry conditions in both the Existing Conditions and 20-Year Development scenarios. This decrease is the result of natural area flows, which previously contributed in an uncontrolled fashion, instead will be draining to the quarry areas and subsequently being pumped out of the quarry at a controlled rate (which is less than the previous uncontrolled rate during high flow events). The resulting flow reduction is more pronounced in smaller catchments (where the quarry makes up a larger portion of the total catchment area) than in larger catchments. These results indicate that the frequency of flooding and erosion is not likely to be worsened by the cumulative effects of quarry discharge in the study area.

6.2.3 Natural Environment Impact Assessment – Flooding and Erosion

The flooding and erosion assessment results suggest that generally peak flows would be expected to decrease from the pre-quarry conditions for both the Existing Conditions and 20-Year Development scenarios. This will likely be beneficial to the quality of aquatic habitat available at the cumulative discharge stations as it will act to decrease the potential to exacerbate the moderate to severe bank erosion noted at several locations (e.g., C-Exp-1 and A-Exp-2), as well as the deposition of fine sediments.

6.3 Low Flow Impact Assessment

In general, the quarries in the study area are expected to have a minor reducing effect on low flows in watercourses immediately upstream of the quarries. Because none of the selected quarries takes water from any existing surface features (relying instead on seepage water/direct precipitation collected in sumps for quarry processes), this reduction is directly proportional to the reduction in stream discharge caused by the decrease in groundwater discharge to the stream as a result of the lowering of near-surface groundwater levels. Subsequent pumping of the water from the quarry is in turn expected to result in minor increases in low flows downstream of the quarry discharge points. Additionally, quarries discharging sump water generally do so at a much lower rate than during peak storm events, which will likely augment low flows in the receiving watercourses for an extended period following precipitation events. This is particularly true during summer, when the existing flows are depleted.

The low flow impact assessment for surface water and natural environment features addresses potential impacts associated with the identified areas of cumulative groundwater lowering in the upper weathered zone for the 20-Year Development scenario (Figure 23). Due to the depth of the green beds in the predicted areas of cumulative impact (typically greater than 15 metres below ground surface (mbgs)) and the hydraulic separation provided by the low hydraulic conductivity Bobcaygeon Formation, adverse impacts to surface water features and natural environment receptors within the areas of predicted cumulative impact for the green beds (Figure 24) are not predicted.

Groundwater modelling for the 20-Year Development scenario has identified two locations where groundwater drawdown in the upper weathered zone, as a result of two or more quarries, combines to produce a cumulative groundwater effect (see Figure 23) in the 20-Year Development scenario. The two locations are found between the Tomlinson and Miller quarries, and between the Beamish and Holcim quarries (including a section of Cranberry Lake).

For the area north of the Tomlinson Quarry, groundwater modelling suggests that the water level at this location is already drawn down under existing conditions. As flow in this area still continues intermittently despite the low groundwater levels, it is assumed to be seasonally perched (at least partially) on overburden and maintained by surface runoff. If the feature is seasonally perched, additional drawdown of groundwater levels is not expected to have an additional effect on flows in the drainage feature.

For the area between Holcim and Beamish quarries, there is insufficient information (with regards to conductivity of soils under Cranberry Lake) to confirm that the surface water system in that area is perched. If the system is perched in that area, a decrease in groundwater caused by the cumulative effect of the quarry dewatering operations is less likely to have an effect than if the system is not perched. The results from water budget assessment for Cranberry Lake (which included both surface water results and results from the groundwater model) suggest that, given the available information, the total net changes in flow contributions to the Cranberry Lake system were minor. This was largely due to the mitigative effects of direct quarry discharge into the wetland, which returns water to Cranberry Lake.

In addition to the overlapping cumulative impacts mentioned above, groundwater modelling has identified several locations where groundwater drawdowns in the upper weathered zone (as a result of quarry dewatering) from two or more quarries intercept the same catchment in the 20-Year Development scenario. Figure 29 shows the catchments areas and 1 m drawdown in the upper weathered zone for each quarry. This drawdown has the potential to reduce baseflow contribution (and consequently low flows) to the catchment; however, it may be mitigated if the quarry causing the drawdown likewise discharges to the same catchment, because the quarry discharge is assumed to discharge a quantity of groundwater similar to that being removed by the quarry drawdown. The areas of potential cumulative impact associated with multiple drawdown cones intersecting a single catchment area (in this case individual drawdown cones do not have to intersect each other) are referred to as "non-overlapping cumulative drawdowns".

The locations of non-overlapping cumulative drawdowns, along with the quarries affecting them, are provided in Table 19 below. Potential impacts of cumulative effects from more than one quarry are discussed below.

Table 19: Drawdown Zones Intercepting Surface Water Catchments

Location	Quarries With Intercepting Drawdown
SW2	Miller Quarry, Tomlinson Quarry and Holcim Quarry
SW3	Beamish Quarry and Holcim Quarry
SW4	Beamish Quarry and Holcim Quarry
SW5	Ferma Quarry and Lafarge Kirkfield Quarry
SW9	Webster Quarry, Ferma Quarry, Lafarge Kirkfield Quarry, Beamish Quarry and McCarthy Quarry
SW7	Webster Quarry, Ferma Quarry, Lafarge Kirkfield Quarry, Beamish Quarry, McCarthy Quarry, Lafarge Brechin Quarry and James Dick South Quarry

In the case of SW2, both Miller and Tomlinson quarries discharge to the SW2 catchment, which is assumed to mitigate the groundwater drawdown from those quarries (because quarry discharge would include dewatering flows). Because only one quarry (Holcim) has an unmitigated (by direct discharge) drawdown cone affecting this catchment, it is not considered a cumulative impact.

In the case of SW3, both the Beamish Quarry and Holcim Quarry discharge to the SW3 catchment, which is assumed to mitigate the groundwater drawdown from those quarries. Because no quarry has an unmitigated (by direct discharge) drawdown cone affecting this catchment, it is not considered a cumulative impact.

In the case of SW4, the Beamish Quarry discharges to the SW4 catchment; this is assumed to mitigate the groundwater drawdown from that quarry. Because only one quarry (Holcim) has an unmitigated drawdown cone affecting this catchment, it is not considered a cumulative impact.

In the case of SW5, both Ferma and Lafarge Kirkfield quarries discharge to the SW5 catchment, which is assumed to mitigate the groundwater drawdown from those quarries. Because no quarry has an unmitigated (by direct discharge) drawdown cone affecting this catchment, it is not considered a cumulative impact.

In the case of SW9, the Webster, Ferma and Lafarge Kirkfield quarries discharge to the SW9 catchment, which is assumed to mitigate the groundwater drawdown from those quarries.

In the case of SW7, the Webster, Ferma, Lafarge Kirkfield, McCarthy, Lafarge Brechin, and James Dick South quarries discharge to the SW7 catchment, which is assumed to mitigate groundwater drawdown from those quarries. Because only one quarry (Beamish) has an unmitigated drawdown cone affecting this catchment, it is not considered a cumulative impact.

A summary of the cumulative low flow impact assessment is provided in Table 20 below.

Table 20: 20-Year Development Low Flow Impact Assessment Summary

Location	Cumulative Effect	Direct Quarry Discharge	Cumulative Residual Effect
SW2	Overlapping[2]	Yes	No
SW3	Overlapping[2]	Yes	Insufficient Information at Cranberry Lake to determine whether the wetland is perched
SW4	Overlapping[2]	Yes	Insufficient Information at Cranberry Lake to determine whether the wetland is perched
SW5	Non-Overlapping[3]	Yes	No
SW9[1]	Non-Overlapping[3]	Yes	No
SW7	Non-Overlapping[3]	Yes	No

[1] *Given* the size of the total catchment upstream of SW9 (approximately 288 km^2) compared to the portion of the catchment area within the predicted 1 m drawdown zones for McCarthy and Beamish quarries (approximately 0.4 km^2), the impact on low flow is assumed to be negligible

[2] *Overlapping* Cumulative effects indicate that modelled 1-m drawdown areas for two or more quarries overlap each other in this catchment

[3] *Non*-Overlapping Cumulative effects indicate that while modelled 1-m drawdown areas for two or more quarries may affect the catchment, no two 1-m drawdown areas overlap each other

6.3.1 Natural Environment Impact Assessment – Low Flows

Groundwater modelling has identified two locations (shown in Figure 23) where groundwater drawdown in the upper weathered zone from two or more quarries combine to produce a cumulative groundwater effect in the 20-Year Development scenario. The potential for habitat impacts from cumulative groundwater effects include loss of flow in local streams or reduced water levels in surface water bodies such as wetlands. The two locations with predicted cumulative groundwater effects are between the Beamish and Holcim quarries, and between the Tomlinson and Miller quarries, respectively. In both of these locations, groundwater levels were below the ground elevation in the Existing Conditions scenario, suggesting that surface water features in these areas are at least partially perched on overburden, and not connected to the aquifers directly affected by the individual quarries. Therefore, the decrease in groundwater elevation as a result of quarry groundwater pumping is not expected to have a significant impact on surface water flows in the future 20-Year Development scenario.

The overlapping drawdown area between Miller and Tomlinson is located beneath the north drainage feature on the Tomlinson property. The north drainage feature is an intermittent drainage ditch which provides habitat, at least seasonally, for common warm water fish species. The fish habitat within this drainage feature is considered of marginal quality (Golder, 2007b). As stated in the surface water analysis, it is not expected that groundwater maintains the flow in this watercourse (i.e., flow in the feature continues intermittently despite indications of low groundwater levels through groundwater modelling), It is suggested that this feature is maintained by surface runoff and thus the cumulative drawdown of groundwater levels is not expected to have an additional effect on flows in the drainage feature. Therefore, the impact to ecological conditions in this watercourse from the cumulative groundwater effect in the 20-Year Development scenario is expected to be negligible.

The cumulative groundwater drawdown in the upper weathered zone between the Holcim and Beamish quarries is located beneath a small portion of the edge of the Cranberry Lake Wetland. Typically, the edges of wetlands experience a greater natural variability in water levels and thus the vegetation communities in these edge areas become more resilient to annual water level fluctuation regimes (composed of a mix of facultative and obligate wetland species). Therefore, the decrease in groundwater elevation as a result of quarry pumping is not expected to cause a significant impact on the ecological conditions of this portion of the wetland. As stated above, the effect of cumulative groundwater drawdown on surface water levels in the wetland in the 20-Year Development scenario is not expected to be significant, as one quarry directly discharges into the wetland and returns water to Cranberry Lake. The water budget exercise for Cranberry Lake (which included both surface water results and the results from the groundwater model) suggest that the total net changes in flow contributions to the Cranberry Lake system were minor. This was largely due to the mitigative effects of direct quarry discharge into the wetland, which returns water to Cranberry Lake Given the scale and scope of this study, this finding should be confirmed with ongoing monitoring of wetland water levels. Due to the small magnitude of cumulative effects, the Cranberry Lake Wetland edge is not expected to be measurably affected by the cumulative drawdown in the 20-Year Development scenario. In turn, habitat for the species of conservation concern (Table D1 in Appendix D) that occurs within the Cranberry Lake Wetland is not expected to be affected.

6.4 Water Supply Well Impact Assessment

The location of the water supply wells within the study area (as per the MOE WWIS database) is shown on Figure 12. The groundwater supply cumulative impact assessment for the 20-Year Development scenario is divided into potential impacts to the upper weathered zone and potential impacts to the green bed layer, as these are the units that can potentially result in cumulative impacts to water supply wells.

6.4.1 Upper Weathered Zone

There are no water supply wells located within upper weathered zone cumulative impact areas shown on Figure 23. As a result, the identified areas of cumulative impact in the upper weathered zone will have no impact on local water supply wells.

6.4.2 Green Beds of the Gull River Formation

The predicted areas of cumulative impact in the green beds for the 20-Year Development scenario are shown on Figure 30. The northern zone of predicted cumulative impacts is centred over the southern extraction area of the Tomlinson Quarry. As part of the technical studies prepared in support of the Aggregate Resource Act license application for the Tomlinson Quarry, a private well survey was completed within 1.5 km of the property to obtain details of well construction and water use. The northern cumulative impact area is located within the 1.5-km radius around the Tomlinson Quarry. The private wells identified within 1.5 km of the Tomlinson Quarry are shown on Figure 30. Based on the results of the previous private well survey, there are no private wells located within the northern cumulative impact area; however, there are two wells located in close proximity (SCOT-71 and MARA-3405). To remain conservative, these two nearby private wells are included in the impact assessment provided below.

The southern zone of predicted cumulative impacts is roughly centred between the Lafarge Brechin Quarry and Holcim Quarry. Based on a review of the MOE WWIS, there is one private well located within the southern zone of cumulative impact. The private well is identified in the WWIS database as 4605249, and the well location is shown on Figure 30. Due to the unreliability of the well locations in the WWIS database, all wells within 1.5 km of southern cumulative impact zone were included in the impact assessment provided below. Using this criteria, the additional wells from the WWIS database included are 5733713, 5722479 and 5727662. The locations for the additional wells (as provided in the WWIS database) are shown on Figure 30. Based on the groundwater modelling results, the maximum predicted cumulative drawdown within the southern area is approximately 3 m. To remain conservative during the impact assessment, it was assumed that the additional wells were located in the portion of southern area having the maximum predicted drawdown (i.e., each additional well was assumed to have a drawdown of the maximum 3 m). The monitoring wells drilled on the McCarthy Quarry property that are within 1.5 km of the southern cumulative impact zone were not included in the impact assessment provided below.

Because the southern zone of predicted cumulative impact for the 20-Year Development scenario is almost identical to the zone of cumulative impact identified under the Existing Conditions scenario (see Figure 22 and Figure 24), the assessment provided below relating to private wells 4605249, 5733713, 5722479 and 5727662 would also apply under existing conditions.

The table below provides a summary of the well construction details, estimates the available drawdowns in the wells, and provides the predicted reductions in available drawdown for the 20-Year Development scenario for the private wells included in the impact assessment.

Table 21: Predicted Reduction in Available Drawdown – 20-Year Development Scenario

Location	Total Depth (m)	Static Water Level[1] (mbgs)	Estimated Available Drawdown[2] (m)	Predicted Cumulative Drawdown (m)	Remaining Available Drawdown[2] (m)
SCOT-71	16.15	5.79	9.36	<2[3]	>7.36
MARA-3405	25.91	1.22	23.69	<2[3]	>21.69
4605249	13.72	3.05	9.67	2.6	7.07
5733713	47.24	4.27	41.97	3	38.97
5722479	50.29	3.05	46.24	3	43.24
5727662	17.37	3.05	13.32	3	10.32

[1] Static water level at the time of drilling;
[2] Estimate of available drawdown assumes that the pump is set 1 m above the bottom of the well;
[3] Predicted drawdown is less than 2 m because the well is outside the cumulative impact zone; and mbgs

Based on the results for the 20-Year Development scenario, it is unlikely that water levels in the identified wells will drawdown to the point where well interference occurs within the next 20 years of quarry development. The actual drawdown in water levels within the predicted zones of cumulative impact could be monitored as part of the long-term monitoring program (discussed further in Section 7.0).

7.0 CONCLUSIONS

Based on the analysis presented above for the 20-Year Development scenario, cumulative effects of the quarries considered in this study, on groundwater drawdown, drinking water wells, wetland function, low flows in creeks and rivers, flooding and erosion in creeks and rivers and most water quality parameters are expected to be negligible. Increases in concentrations of boron, iron, sulphate and chloride are expected as a result of dewatering groundwater, which naturally contains these parameters, from quarries. The expected effects of these increases are discussed in the sections above and summarised below.

The following conclusions are provided based on the results of the CIA conducted for the Carden Plain.

7.1 Surface Water and Natural Environment

Generally, there are only minor changes in annual water budget surplus values as a result of quarry development. Some cumulative water quality impacts are expected as a result of discharging groundwater from quarries. The cumulative effects of quarry development are expected to reduce peak flows at cumulative assessment stations due to flow attenuation by the quarries, and the cumulative drawdown from the quarries is thought to have relatively insignificant effects on low flow conditions.

7.1.1 Water Budget Analysis

Conclusions drawn from the water budget analysis include:

- Under existing conditions, stations with cumulative impacts (downstream of more than one quarry-SW2, SW3, SWA, SW5, SW7 & SW9) show a small increase between 0% to 2% in annual surplus;
- Stations with cumulative impacts (downstream of more than one quarry) were generally shown to have relatively small (between 0% and 6%) increases in annual surplus based on the 20-Year Development water balance; and,
- Generally, the average surplus results from the water budget analysis are roughly 5% higher than the average yield value of the Beaverton River of 323 mm/yr, and are also higher than the average annual yield estimated using the 2010-2011 quarterly flow measurements. The differences between the two methods agree with the assumption that the annual yield estimated using the quarterly flows was an underestimation because of the lack of representative peak flows.

7.1.2 Surface Water Quality Impact Assessment

It is evident that the aquatic environments in the study area are being influenced through current agricultural practices. However, based upon the results of the BIC sampling program, scoped by this study to distinguish if there are additional aquatic biota impacts from cumulative quarry discharge, there does not appear to be a significant difference in taxa richness or representation of pollution sensitive species between the upstream reference station BICs and the communities at the downstream cumulative discharge stations.

Conclusions drawn from the water quality assessment include:

- In the existing conditions scenario, the only water quality parameter to exceed guidelines is phosphorus (exceeds the PWQO). This is thought to be mostly from agricultural land uses in the watershed as is substantiated by the similarity of the calculated Hilsenhoff FBI (tolerance of BIC to organic pollution) between the reference and exposure stations. Thus, there are no identified cumulative water quality impacts to benthic invertebrate communities from the existing conditions scenario;
- While concentrations of total phosphorus at all stations are predicted to exceed the PWQO in the 20-Year Development scenario, it is thought to be primarily the result of an external loading and not the result of the quarry cumulative impacts;
- Projected future loading of boron (naturally present in groundwater and added to surface water through quarry dewatering) and iron may be in part the result of upstream quarry discharges at SW2, SW3, SWA and SW5 resulting in values above PWQO and CCME guidelines;
- Projected concentrations for sulphate and chloride are above the recommended values from BC MOE guidelines, which are being used solely for comparison in this case;
- Elevated sulphate and chloride concentrations (both sulphate and chloride are present in groundwater and added to the surface water through quarry dewatering activities) at downstream cumulative discharge locations are thought to be partially attributed to quarry discharges. However, research suggests an increase in the concentration of sulphate in the aquatic environment will be ameliorated by the increase in chloride concentration, thus decreasing the potential effect of sulphate toxicity; and,
- The predicted elevated concentrations of boron at all stations are thought to be partially the result of cumulative quarry discharge. While fish are relatively more sensitive to elevated levels of boron than other aquatic organisms, they are more mobile and can avoid direct effects, although a habitat suitability and/or species distribution effect could result.

7.1.3 Flooding and Erosion Impact Assessment

Conclusions drawn from the flooding and erosion assessment include:

- At locations downstream of more than one quarry in future conditions (SW2, SW3, SWA, SW5, SW9 and SW7), a decrease in peak flow during the 2.33 year return period storm is expected as the quarries are developed. This decrease in flows is the result of detention of surplus volumes in quarry sumps and gradual discharge from those sumps under the Existing Conditions and 20-Year Development scenarios as compared to uncontrolled runoff rates in the Pre-Quarry scenario. Therefore, adverse impacts associated with flooding and erosion are not anticipated; and,
- The predicted decrease in peak flows between the Existing Conditions and the 20-Year Development scenarios will likely be beneficial to the quality of aquatic habitat available at the cumulative discharge stations, as it will act to decrease the potential to exacerbate the moderate to severe bank erosion noted at several locations, as well as the deposition of fine sediments.

7.1.4 Low Flow Impact Assessment

Conclusions drawn from the low flow assessment include:

- Groundwater modelling suggests a cumulative drawdown of groundwater between the Miller and Tomlinson quarries in future scenarios; however observation of flows in this area suggests that the surface features are seasonally perched and maintained by surface runoff. Therefore, additional drawdown of groundwater levels is not expected to have an additional effect on flows or the ecological condition in the drainage features;
- Groundwater modelling also suggests a cumulative drawdown of groundwater between the Beamish and Holcim quarries in future scenarios. This section includes a portion of the Cranberry Lake Wetland edge. At present, there is insufficient information (with regards to conductivity of soils under Cranberry Lake) to confirm that the surface water system in that area is perched. A water balance for the adjoining Cranberry Lake (which included surface runoff, groundwater inputs, quarry dewatering and quarry discharges) suggests only minor net changes to flows in Cranberry Lake. Due to the small magnitude of change to flows at the Cranberry Lake wetland edge, an area of the wetland which is relatively more resilient to annual water level fluctuation, the ecological form and function of the wetland is not expected to be significantly affected; and,
- One additional catchment (SW9) showed a potential non-overlapping cumulative groundwater impact from two or more quarries on surface water; however, due to the size of the catchment the impact on low flows is assumed to be negligible.

7.2 Groundwater

The following conclusions were drawn based on the groundwater and water well impact assessment portions of the CIA:

- Based on a review of the available information, it was Golder‟s opinion that there was enough existing information to move forward with the development of the numerical model to provide an initial assessment of the potential for cumulative impacts associated with groundwater level lowering within the study area;
- Four development scenarios were investigated using the groundwater flow model, and the 20-Year Development scenario was identified as the most reasonable scenario to use for the cumulative impact assessment;
- The groundwater modelling identified two potential zones of cumulative impact within the upper weathered zone and two zones within the green bed layer. The zones of cumulative impact within the upper weathered zone were localized around the individual quarries, while the zones within the green bed layer showed the potential for greater lateral extension;
- The individual drawdown cones modelled in the upper weathered zone are generally similar in size and shape for the 20-Year Development scenario and the Full Licensed Depth Scenario. This suggests that the drawdown predicted for the 20-Year Development scenario is at or near the maximum drawdown that will occur in the upper weathered zone;
- Because of the greater potential lateral extent of the drawdown in the green bed layer compared to the upper weathered zone, depressurization of the green bed layer has greater potential to result in cumulative impacts relating to groundwater within the study area;

- The sensitivity runs completed using the groundwater model indicate that the size and location of the areas of predicted cumulative impact in the green bed layer are influenced by the hydraulic conductivity of the Bobcaygeon Formation and the green bed layer specified within the model;
- Due to the depth of the green beds in the predicted areas of cumulative impact (typically greater than 15 mbgs) and the hydraulic separation provided by the low hydraulic conductivity Bobcaygeon Formation, adverse impacts to surface water features and natural environment receptors within the areas of predicted cumulative impact for the green beds are not predicted;
- Based on the results for the 20-Year Development scenario, it is unlikely that within the next 20 years groundwater levels in the water supply wells identified within, or in close proximity to, the predicted zones of cumulative impacts will drawdown to the point where well interference will occur; and,
- The Fully Licensed Depth scenario was modelled to present the “worst-case” scenario based on our current understanding of the behaviour of the green bed layer, and the current maximum extraction limits of the quarries included in the study. The depressurization of the green bed layer observed in this scenario illustrates the importance of understanding the behaviour of the green beds within the study area.

8.0 LIMITATIONS AND USE OF REPORT

This report was prepared for the exclusive use of Bot Construction Group, Dufferin Aggregates (a division of Holcim Canada Inc.), Ferma Aggregates Inc., James Dick Concrete & Aggregates, K.J. Beamish Construction Co. Ltd., Halton Crushed Stone Limited, Lafarge Canada Inc., MAQ Aggregates Inc., Miller Paving Ltd., R.W. Tomlinson Limited and the Ontario Stone, Sand & Gravel Association. The report, which specifically includes all tables, figures and appendices, is based on data and information collected by Golder Associates Ltd. and is based solely on the conditions of the property at the time of the work. Any use which a third party makes of this report, or any reliance on, or decisions to be made based of 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.

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.

The groundwater level lowering and groundwater inflow/seepage estimates developed from the groundwater model described in this report are considered to represent reasonable "theoretical" estimates based on the available data. There is uncertainty inherently associated with the (subsequent) forecasts by the groundwater model, stemming from limitations in the available subsurface information and can be related to variability in the bedrock properties (e.g., hydraulic conductivity, porosity, etc.) 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, etc.). It is the intention of Golder Associates Ltd. that the model results be used as a screening tool to predict groundwater inflow/seepage rates and groundwater level lowering for the purposes of this cumulative impact assessment, and not for any other purposes.

The surface water quality impact assessment assumes, among other things, that any change in water quality between the background station and the downstream stations is the result of quarry seepage and discharging groundwater to the surface. It is assumed that any other activities or land use changes upstream of the cumulative assessment stations have no effect on water quality. The method used assumes that there will be no change in land use outside of the quarry development for the 20-Year Development scenario: Future changes in land use cannot be estimated with the available information, which represents a limitation of the modelling.

The 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 practicing under similar conditions, subject to the time limits and financial and physical constraints applicable to the services.

9.0 CLOSURE

We trust this report meets your requirements. If you have any questions regarding this report, please contact the undersigned.

GOLDER ASSOCIATES LTD.

Kevin Trimble, M.Sc.
Senior Ecologist, Principal

Kevin MacKenzie, M.Sc., P.Eng.
Water Resources Engineer, Associate

Jamie Oxtobee, M.Sc., P.Geo.
Senior Hydrogeologist, Associate

N. Bishop

Nick Bishop, M.Sc., P.Eng.
Geological Engineer, Groundwater Modeller

[illegible]
[illegible]

Reviewed by [illegible], M.Sc., P.Geo., Senior Hydrogeologist, Principal

Reviewed by Craig Kelly, B.Sc., P.Geo., Senior Hydrogeologist, Associate

REFERENCES AND DOCUMENTS REVIEWED

AECOM (2010a). Amendment Application for PTTW #97-P-4005, Part Lots 10, 11, Concession III, Lots 7, 8, 10, Concession II, Part Lots 11, 12, Concession II, Carden Township, City of Kawartha Lakes, Miller Paving Limited. March, 2010.

AECOM (2010b). Annual Permit-To-Take-Water and Certificate of Approval – 2009 Monitoring Report for the Miller Aggregate Resource Quarry in Carden, Ontario. March, 2010.

AECOM (2010c). 2009 Dufferin Aggregates Carden Quarry Annual Monitoring Report for C of As #2022-65KHZT and #3342-7YKGZ9. March, 2010.

AECOM (2010d). 2009 Dufferin Aggregates Carden Quarry Annual Monitoring Report for PTTWs #7817-75NKR4 and #1573-7RYPR7. March, 2010.

AECOM (2009a). Miller Paving Carden Quarry, Hydrogeological Updates. November 2009.

AECOM (2009b). 2008 Dufferin Aggregates Carden Quarry Annual Monitoring Report for C of A. March, 2009.

AECOM (2009c). K.J. Beamish Construction Co., Ltd. Campbell Quarry – Environmental Study Report. September 2009.

Armstrong, D.K. (2000). Paleozoic Geology of the Northern Lake Simcoe Area, South-Central Ontario. Ontario Geological Survey Open File Report 6011.

Armstrong, D.K. (1999). Results of Paleozoic Bedrock Drilling Project, Northern Lake Simcoe Area, South-Central Ontario. Ontario Geological Survey Open File Report 5999.

Arnold, J.G., Allen, P.M., Muttiah, R., Bernhardt, G. (1995). Automated Base Flow Separation and Recession; Analysis Techniques, Ground Water Vol. 33, No. 6, November-December 1995.

Azimuth Environmental (2008a). McCarthy Quarry Hydrogeological Assessment. April 2008.

Azimuth Environmental (2008b). McCarthy PTTW Application: MOE Reference No.:4715-772J38. Letter from Tecia White to Chris Murno, dated November 4, 2008.

Birds Ontario (2011). Ontario Breeding Bird Atlas.
Accessed February 2011 from http://www.birdsontario.org/atlas/maps.jsp?lang=en.

Chapman, L.J. and D.F. Putnam (1984). The Physiography of Southern Ontario. 3rd ed. Ontario Ministry of Natural Resources. Toronto, ON. 270 pp. + map.

Charlesworth and Associates (1991). Proposed Rama Quarry, Rama Township, Interim Hydrogeological Report. September 1991.

Coe, Fisher, Cameron Ontario Land Surveyors (2007). Webster Quarry Operational Plan. March 22, 2007.

Dixon Hydrogeology (2001). McCarthy Property Certificate of Approval Application. July 27, 2001.

Eisler, Ronald (1990). Boron Hazards to Fish, Wildlife and Invertebrates: A Synoptic Review. U.S. Fish and Wildlife Service. Patuxent Wildlife Research Center. Biological Report 85(1.20).

Fisheries and Oceans Canada (DFO) 2011. Aquatic Species at Risk mapping downloaded from Conservation Ontario website at http://www.conservation-ontario.on.ca/projects/DFO.html. Accessed February 2011.

Gartner Lee Ltd. (2006-2008). Dufferin Aggregates Carden Quarry Annual Monitoring Reports for C of A #2022-65KHZT.

Gartner Lee Ltd. (1993 – 2003). Groundwater and Surface Water Monitoring Reports. Various, 1993 through 2003.

Gartner Lee Ltd. (1989). Carden Township Quarry Hydrogeologic Study (Phase II). December 12, 1989.

Genivar (2010). Groundwater Vulnerability Assessment Methods – The City of Kawartha Lakes – Technical Memorandum to the City of Kawartha Lakes. March 22, 2010.

Geological Investigations (2009). Sebright Quarry Operational Plan. April 2009.

Golder Associates Ltd. (2010). Brechin Quarry PTTW 2009 Annual Monitoring Report. April 2010.

Golder Associates Ltd. (2009a). Draft Technical Memorandum on Victoria Road Quarry On-Going Groundwater Level Monitoring and Groundwater Quality. August 7, 2009.

Golder Associates Ltd. (2009b). Application for a Category 3 Permit to Take Water, R.W. Tomlinson Limited Brechin Quarry, City of Kawartha Lakes, Ontario. October, 2009.

Golder Associates Ltd. (2009c). Technical Support Document, Application to Renew Permit to Take Water, Lafarge Brechin Quarry. February 2009.

Golder Associates Ltd. (2009d). Technical Memorandum-Aquatic Assessment of Lafarge Brechin Quarry Surface Water Features. April 2009.

Golder Associates Ltd. (2007a). Hydrogeological and Hydrological Assessments in Support of a Category 2 Class “A” Quarry Below Water – R.W. Tomlinson Ltd Proposed Brechin Quarry. April 2007.

Golder Associates Ltd. (2007b). Level I and 2 Natural Environment Report for R.W. Tomlinson Limited Brechin Quarry, June 2007.

Golder Associates Ltd. (2005). Monitoring Well Records. Letter from Rob Blair to James Webster. October 24, 2005.

Golder Associates Ltd. (2003). Hydrogeological Monitoring Review and Supporting Document for Section 34 Permit to Take Water and Section 53 permit to Discharge Water, Victoria Road Quarry. December 2003.

Golder Associates Ltd. (1998). Aggregate Resource Evaluation – Carden Quarry, Brechin, Ontario. July 1998.

Golder Associates Ltd. (1994). Report on Geological and Hydrogeological Conditions, Proposed Quarry Development, Victoria Road, Ontario. March 1994.

Harden Environmental (2010). Gamebridge Quarry 2010 Hydrogeological Activities Letter Report. October 8, 2010.

Harden Environmental (2009). Ramara Quarry PTTW. March 2009.

Harden Environmental (2004-2010). Annual Monitoring Report Letters.

Harden Environmental (2004). Certificate of Approval for Sewage Works, James Dick Ltd. Letter report to Shiraz Khimji, dated March 15, 2004.

Haxton, T., M. Strachan and K. Hussey, (1992). Wetland Data Record – Cranberry Lake Wetland, Carden Township. Second Edition (Draft). August 5-14, 1992. Manuscript. Ontario Ministry of Natural Resources. 14pp.

Highland Environmental Consulting (1999). Cranberry Lake Wetland – Carden Township. Desktop Update Wetland Evaluation, 3rd Edition. MS. Ontario Ministry of Natural Resources. Irreg. Pagin.

Hulme D.T. Enterprises Inc. (2006). McCarthy Quarry Operations Plan. January 2006.

Kirby W.D. and Associates (1994). Rama Limestone Quarry Operational Plan. February 4, 1994.

Lake Simcoe Region Conservation Authority (2009). Letter from Jeff Anderson (LSRCA Senior Fisheries Biologist) to Jamie Weir (Golder Fisheries Technician) dated November 23, 2009.

Liberty, B.A. (1969). Paleozoic Geology of the Lake Simcoe Area, Ontario. Geological Survey of Canada Memoir 355.

Long and Associates (1993). Gormley Aggregates Division, Essroc Canada Inc. Permit to Take Water Application. 21 May, 1993.

Mackie, Gerald, L. (2001). Applied Aquatic Ecosystem Concepts, Kendall/Hunt Publishing Company, Dubuque, Iowa.

MHBC (2009). Brechin Quarry Operational Plan. January 19, 2009.

MHBC Planning Limited (1994a). Brechin Quarry Operational Plan. May 3, 1994.

MHBC Planning Limited (1994b). Gamebridge Quarry Operational Plan. December 12, 1994.

Ministry of Environment (2009). Terms of Reference - Cumulative Impact Assessment for Groundwater Takings in the Carden Plain Area, Geographic Townships of Carden and Ramara, February 2009.

Ministry of the Environment (2003). Stormwater Management Planning and Design Manual, March 2003.

Ministry of Municipal Affairs and Housing (MMAH) (2005). Provincial Policy Statement. Queens Printer for Ontario.

Ministry of Natural Resources (2011). MNR website Species at Risk in Ontario (SARO) list http://www.mnr.gov.on.ca/en/Business/Species/2ColumnSubPage/276722.html

Ministry of Natural Resources (2010a). Email correspondence from Stacy McKee, Management Biologist, MNR. Dec 21, 2010

Ministry of Natural Resources (2010b). Fish and Wildlife Services Branch, 2011 Fishing Ontario. Recreational Fishing Regulations Summary. Government of Ontario Canada. 104pp.

Ministry of Natural Resources (2002). NRVIS Provincial Digital Elevation Model Data. Toronto, Ontario: The Ontario Ministry of Natural Resources.

Ministry of Natural Resources (1993). Ontario Wetland Evaluation System: Southern Manual. 3rd Edition.

Ministry of Natural Resources (1986). Ontario Wetland Evaluation System for Southern Ontario. 2nd Edition.

Ministry of Natural Resources (1984). Ontario Geological Survey Map P.2697 – Quaternary Geology of the Orillia Area. Scale 1:50 000.

Ministry of Transportation (1995). Drainage and Hydrology Section, Transportation and Engineering Branch, Quality and Standards Division, “Drainage Management Manual” 1995-1997.

Ministry of Transportation (1986). Drainage and Hydrology Section, Highway Design Office, MTO Drainage Manual.

Moneco Consultants Limited (1989). Report of Findings – Phase I Investigation to Confirm and Determine Site Specific Hydrogeology of Carden Quarry (Gormley Aggregates). November 1989.

MTE Consultants (2009). Interim Groundwater Monitoring Report. July 2009.

Natural Heritage Information Center, (2011). Species occurrences, atlases and natural areas information. Accessed February 2011 from https://www.biodiversityexplorer.mnr.gov.on.ca/nhicWEB/mainSubmit.do.

Natural Resource Canada (2011). Interactive topographical maps accessed on the website http://atlas.nrcan.gc.ca/site/english/maps/topo/map.

Oliver, Mangione, McCalla and Associates (1995). Hydrotechnical Report – Ferma Carden Quarry. April 1995.

Oliver, Mangione, McCalla and Associates (1994). Hydrotechnical Report – Ferma Carden Quarry. December 1994.

Ontario Geological Survey Map P.2697 – Quaternary Geology of the Orillia Area. Scale 1:50 000.

Ontario, Government (2007). Endangered Species Act, 2007. Statutes of Ontario. Chapter 6.

Plafkin, J.L, et al. (1989). Rapid Bioassessment Protocols for Use in Streams and Rivers; Benthic Macroinvertebrates and Fish. U.S. E.P.A., Cincinnati, OH (Publ No. EPA/440/4-89/001).

Reid, Ron. 2011. Personal communication between K Trimble (Golder) and R. Reid (Couchiching Conservancy) on May 4, 2011.

Royal Ontario Museum (2011). Species at Risk in Ontario. Maps of their Ontario and North American distribution. Accessed February 2011 from http://www.rom.on.ca/ontario/risk.php.

SAAR Environmental Limited (2000). Natural Environment Level II Study. Proposed Limestone Extraction. Prepared for Mr. T.S. McCarthy and B. McCarthy. 43pp.

Skelton Brumwell (2000). Dufferin Carden Quarry Operational Site Plan. November 2000.

Soucek, D. J., and A. J. Kennedy (2005). Effects of hardness, Chloride, and Acclimation on the Acute Toxicity of Sulfate to Freshwater Invertebrates. Environmental Toxicology and Chemistry 24:1204–1210.

South Georgian Bay Lake Simcoe Source Protection Region (2011). Updated Draft Assessment Report: Lake Simcoe and Couchiching-Black River Source Protection Area. June 2011.

Thomas Engineering Ltd. (2010). Carden Quarry – Carden Ponds – Profiles, drawing. November 2010.

Thomas Engineering Ltd. (2011). Brechin Quarry Site Plan, drawing. January 2011.

Trow Consulting Engineers (2002). Hydrotechnical Report Update – Ferma Aggregates Inc. Carden Quarry. May 22, 2002.

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.

Warren Paving and Materials Group (1999). Kirkfield Quarry Operational Plan. October, 1999.

Waterloo Geoscience Consultants (2009). 2008 Groundwater Monitoring Report, Burton Quarry. March 2009.

Waterloo Geoscience Consultants (1999). Hydrogeological Investigation, Proposed Quarry, Part Lots 11, 12, 13, 14, and 15, Concession A, Lots, 11, 12, 13, 14, 15, 16, and 17, Concession B, Part Lot 15, Concession C, Township of Ramara. September, 1999.

Winter R.E. and Associates (1998). Miller Paving Operational Sit Plan. February 3, 1998.

NOTE

This figure is to be read in conjunction with the accompanying Golder Associates Ltd. report No. 09-1112-6065

REFERENCE

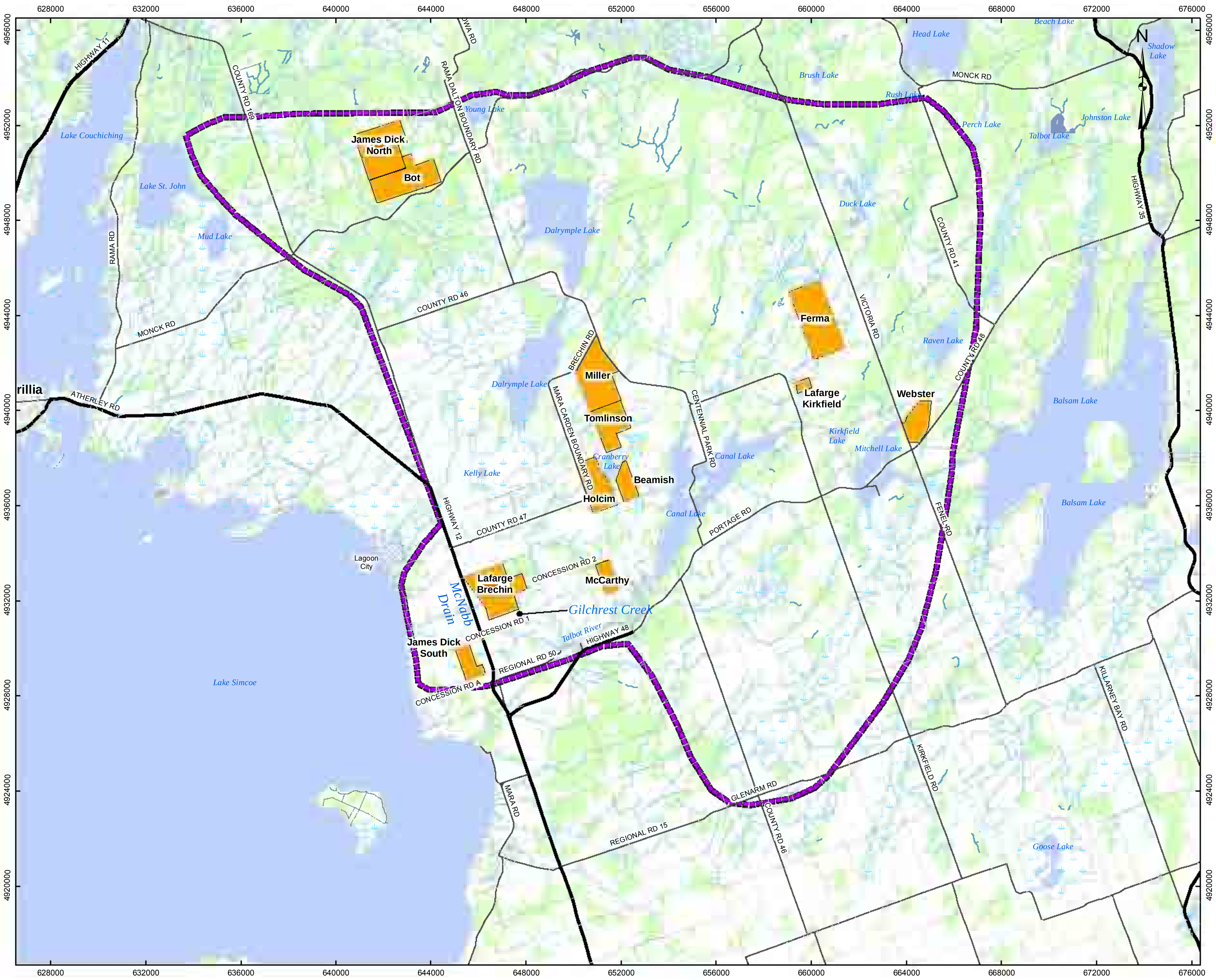
Digital base map data supplied by DMTI Spatial Inc. CANMAP, 2008
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 18

20 0 20
SCALE 1:750,000 KILOMETRES

Golder Associates
Ottawa, Ontario

DATE	Sept. 2012	TITLE	KEY PLAN
DESIGN	BT		
GIS	BT		
PROJECT No. 09-1112-6065	CHECK JPAO	PROJECT	CARDEN PLAIN CUMULATIVE IMPACT ASSESSMENT
SCALE AS SHOWN	REV. 0	REVIEW KAM	FIGURE 1

Path: N:\Active\2009\1112 - Mississauga\09-1112-6065 Carden CIA\GIS\GIS\MXDs\09-1112-6065\Reporting\0911126065-01.mxd



LEGEND

- ▬ Highway
- — Major Road
- Local road
- — Watercourse, Permanent
- - - Watercourse, Intermittent
- ▨ Approximate Outline of The Carden Plain
- 🟧 Quarry Property Included in Study
- Waterbody
- Provincially Significant Wetland
- Wooded Area

Bot Construction Group - Sebright Quarry (Bot);

James Dick Concrete & Aggregates North Quarry (James Dick North);

Ferma Aggregates Inc. – Carden Quarry (Ferma);

Lafarge Canada Inc. – Kirkfield Quarry (Lafarge Kirkfield);

Halton Crushed Stone Limited - Webster Quarry (Webster);

Miller Paving Ltd. – Carden Quarry (Miller);

R.W. Tomlinson Limited – Brechin Quarry (Tomlinson);

Dufferin Aggregates, a division of Holcim (Canada) Inc. – Carden Quarry (Holcim);

K.J. Beamish Construction Co. Ltd – Carden Quarry (Beamish);

McCarthy Quarry (McCarthy);

Lafarge Canada Inc. – Brechin Quarry (Lafarge Brechin); and,

James Dick Concrete & Aggregates Gamebridge Quarry (James Dick South).

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 17

3.5 1.75 0 3.5
SCALE 1:160,000 KILOMETRES

PROJECT

CARDEN PLAIN
CUMULATIVE IMPACT ASSESSMENT

TITLE

STUDY AREA

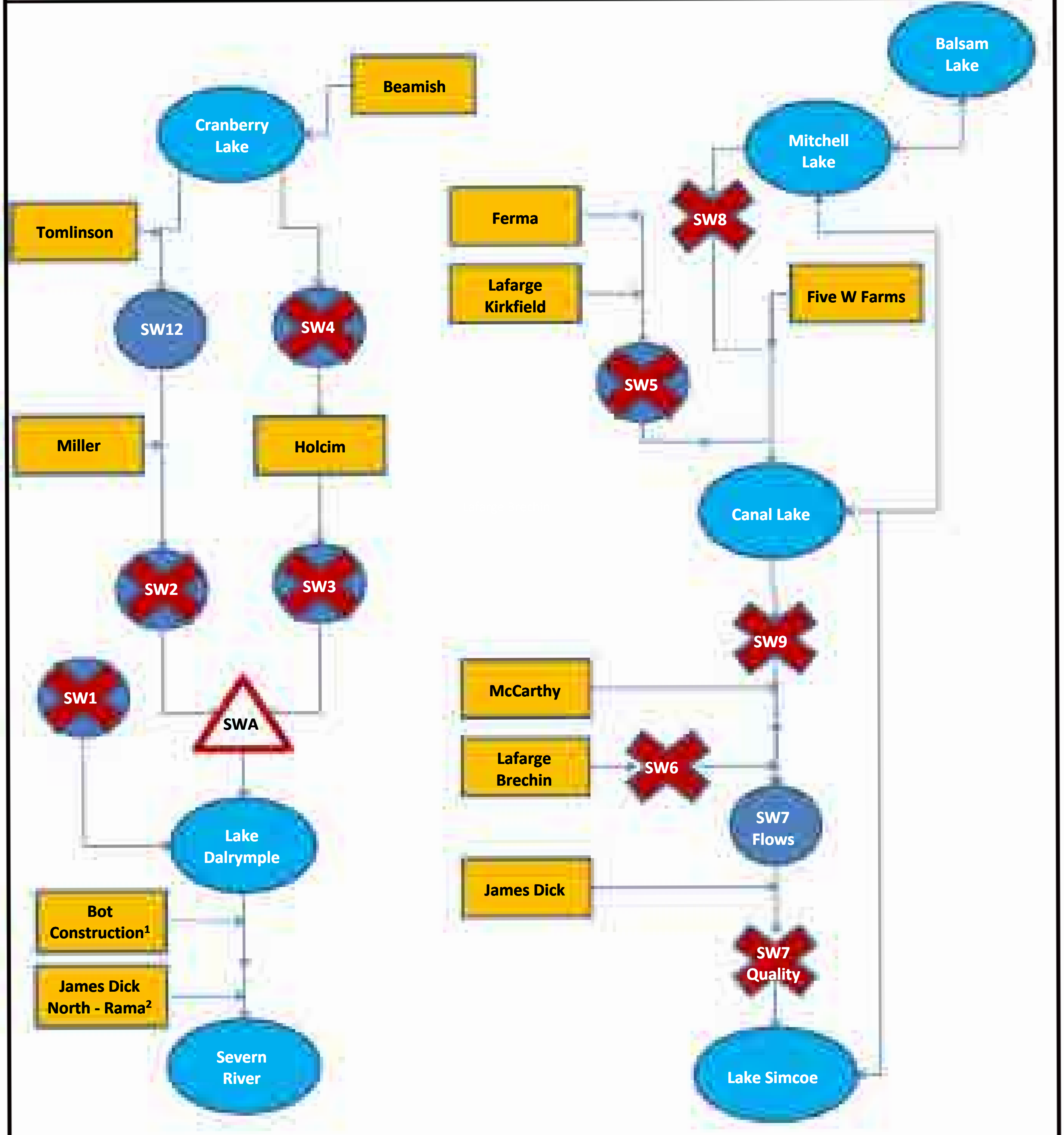
Golder Associates
Mississauga, Ontario

PROJECT No. 09-1112-6065			SCALE AS SHOWN	REV. 0.0
DESIGN	JPAO	10 MAY 2011	FIGURE: 2	
GIS	BT	10 MAY 2011		
CHECK	JPAO	Sept. 2012		
REVIEW	KAM	Sept. 2012		

Path: N:\Active\2009\1112 - Mississauga\09-1112-6065 Carden CIA\GIS\GIS\MXDs\09-1112-6065\Reporting\0911126065-02.mxd

Surface Water Flow Schematic

FIGURE 3



[1] - BOT Construction – Discharge plan not known at this time – Discharge to Lake Couchiching assumed - C of A Application for discharge into MOE

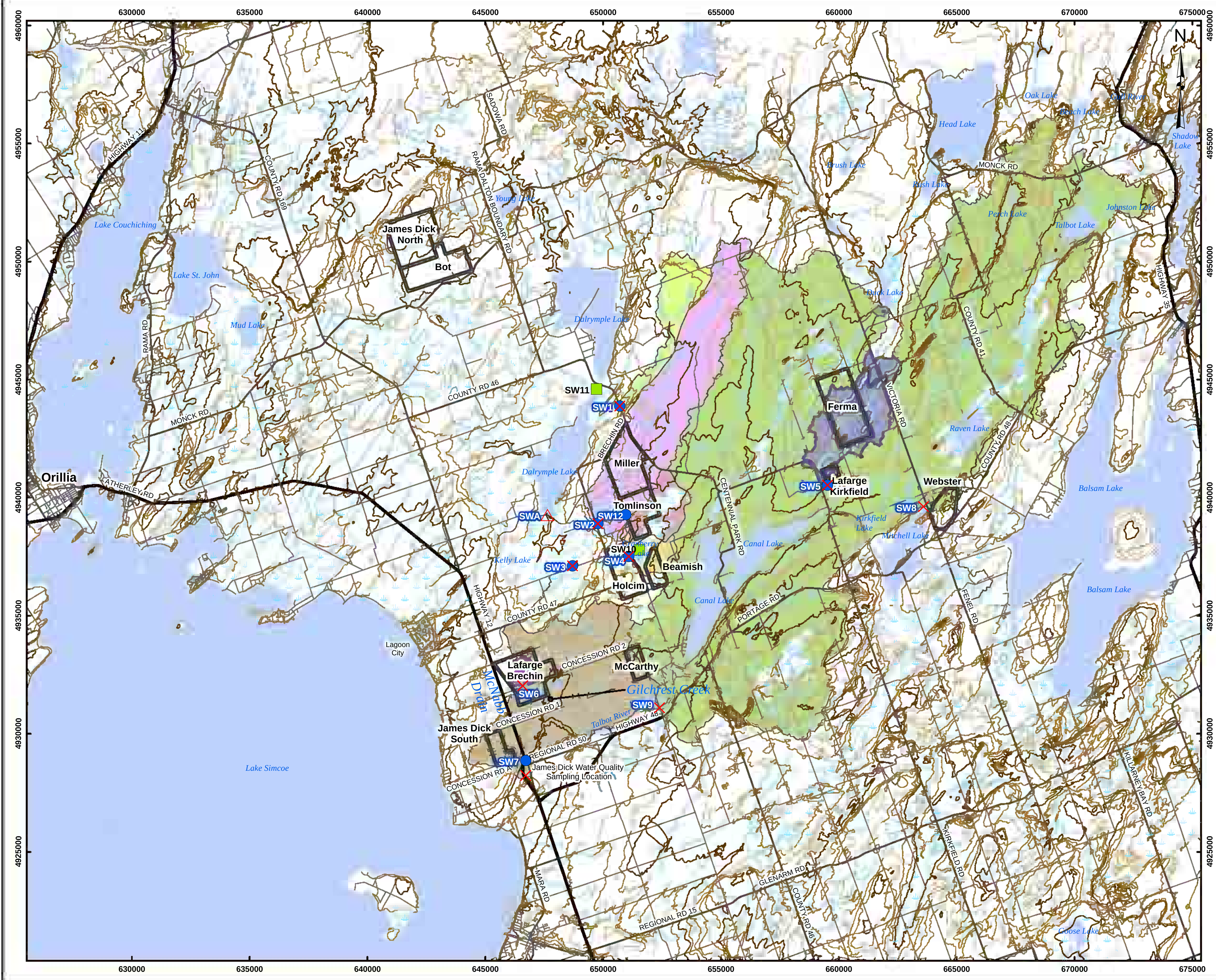
[2] - James Dick North – Above water table license – not considered in CIA

Note - Natural drainage catchments, which otherwise make up the majority of each drainage catchment, are not shown on this schematic.
This figure is meant to show only the arrangement of quarry surface water discharges and monitoring stations.

Legend

PROJECT: 09-1112-6065
DATE: March 2011

DRAWN: CD
CHECK: JK

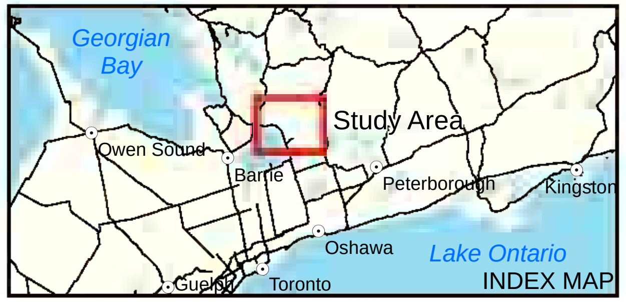


LEGEND

- ● Flow Monitoring Location
- 🟩 Water Level Logger Location
- △ Desktop Assessment Location
- ✕ Water Quality Monitoring Location
- — Minor Contour (5 m)
- — Major Contour (25 m)
- — Watercourse, Permanent
- - - Watercourse, Intermittent
- ▨ Waterbody
- ▭ Quarry Property Included in Study

Catchment Area (ha)

		Existing Conditions	
		Incremental	Total
🟩	**SW1**	-	685
🟪	**SW2**	2700	3220
🟨	**SW3**	1100	1340
▨	**SWA**	1360	5920
🟧	**SW4**	-	237
🟦	**SW5**	-	1150
🟪	**SW6**	-	116
🟩	**SW7**	3300	32100
▨	**SW8**	-	4570
🟩	**SW9**	23100	28800
🟪	**SW12**	-	477



REFERENCE

Base Data - MNR NRVIS, obtained 2004, 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 17
Pits & Quarries, wetlands, ANSI's, and water well records supplied by MOE.

3.5 1.75 0 3.5
SCALE 1:160,000 KILOMETRES

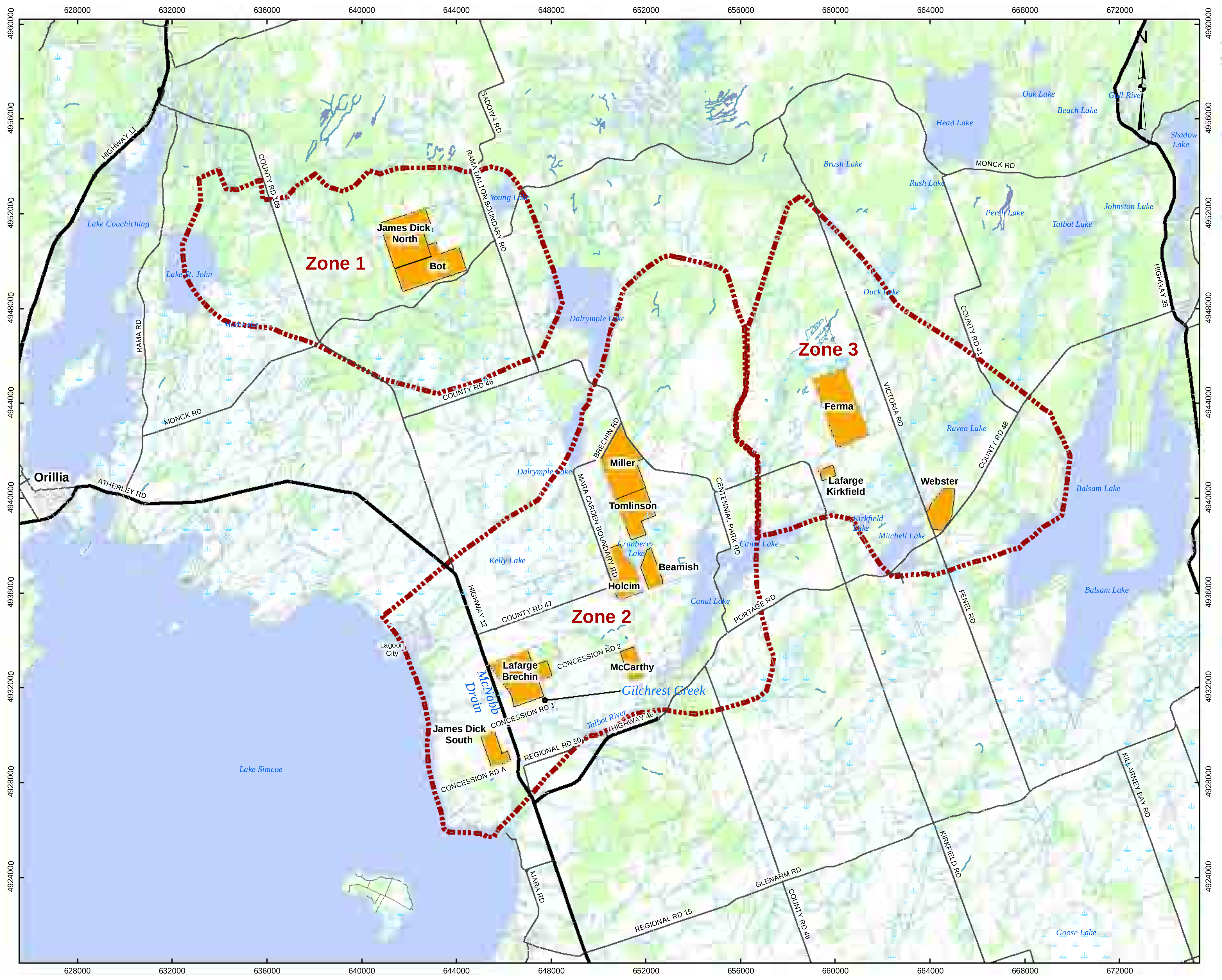
PROJECT
CARDEN PLAIN
CUMULATIVE IMPACT ASSESSMENT

TITLE
CATCHMENT AREAS

Golder Associates
Mississauga, Ontario

PROJECT NO. 09-1112-6065			SCALE AS SHOWN	REV. 0.0
DESIGN	JPAO	04 JULY 2011	FIGURE: 4	
GIS	PRM	04 JULY 2011		
CHECK	JPAO	Sept. 2012		
REVIEW	KAM	Sept. 2012		

G:\Projects\2009\09-1112-6065_CIA\GIS\MXDs\Draft\Surface_Water\Catchment_Area.mxd



LEGEND

- Highway
- Major Road
- Local road
- Watercourse, Permanent
- Watercourse, Intermittent
- 🟧 Quarry Property Included in Study
- Waterbody
- Provincially Significant Wetland
- Wooded Area
- Model Domain

INDEX MAP

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 17

3.5 1.75 0 3.5
SCALE 1:160,000 KILOMETRES

PROJECT

CARDEN PLAIN
CUMULATIVE IMPACT ASSESSMENT

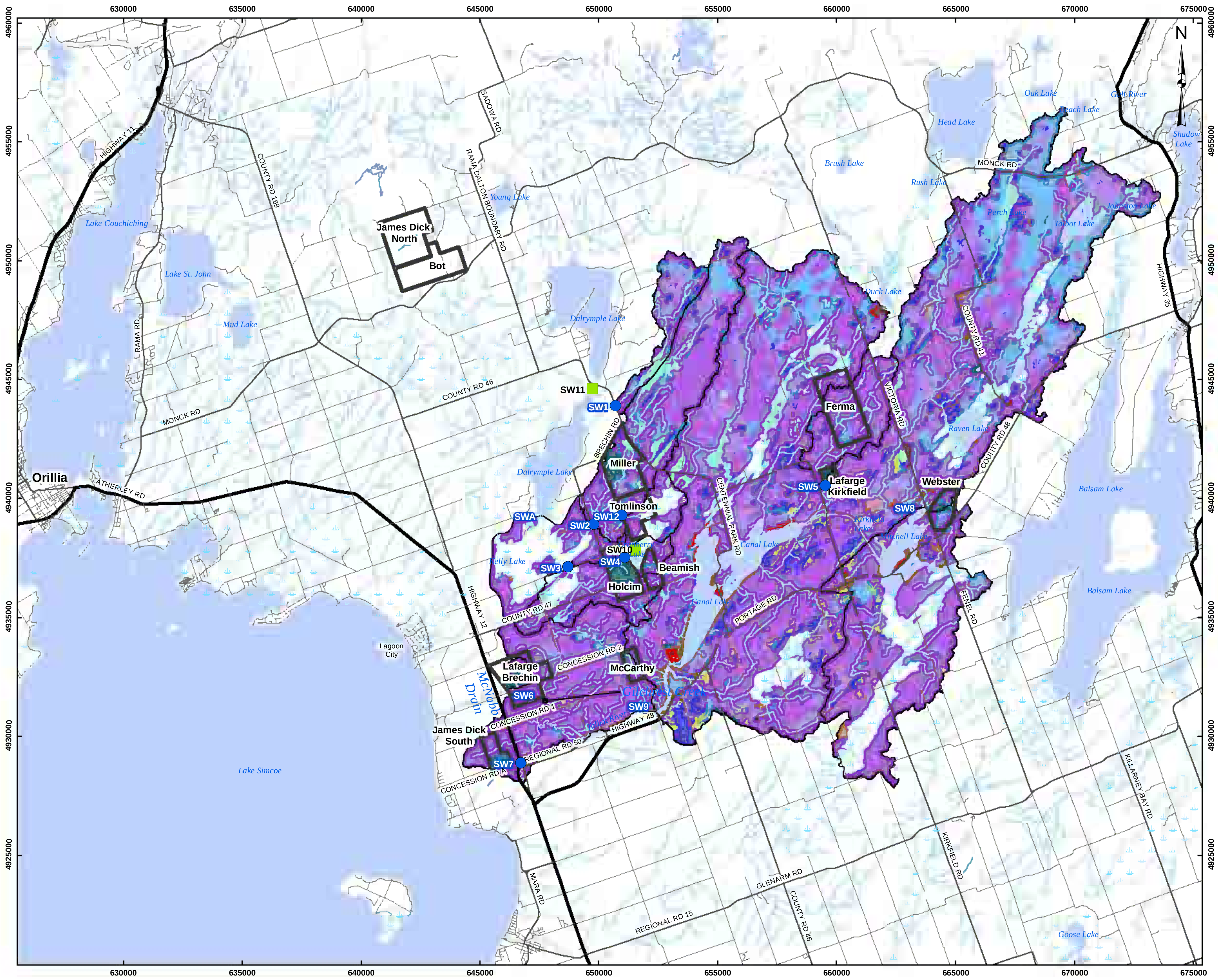
TITLE

GROUNDWATER MODEL DOMAINS

Mississauga, Ontario

PROJECT No. 09-1112-6065			SCALE AS SHOWN	REV. 0.0
DESIGN	JPAO	10 MAY 2011	FIGURE: 5	
GIS	BT	10 MAY 2011		
CHECK				
REVIEW				

Path: N:\Active\2009\1112 - Mississauga\09-1112-6065 Carden CIA\GIS\GIS\MXDs\09-1112-6065\Reporting\0911126065-05.mxd

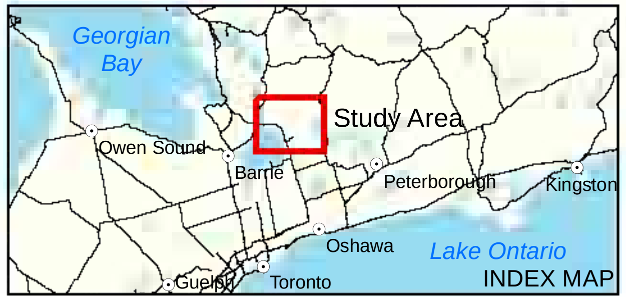


LEGEND

- ● Flow Monitoring Location
- 🟩 Water Level Logger Location
- Minor Contour (5 m)
- Major Contour (25 m)
- — Watercourse, Permanent
- - - Watercourse, Intermittent
- ▨ Waterbody
- ☐ Quarry Property Included in Study
- ☐ Catchment

Land Use

- ▨ Plantations - Tree Cultivated
- ▨ Coniferous Forest
- ▨ Fen
- ▨ Deciduous Forest
- ▨ Forest
- ▨ Hedge Rows
- ▨ Mixed Forest
- ▨ Bog
- ▨ Marsh
- ▨ Swamp
- ▨ Open Water
- ▨ Transportation
- ▨ Extraction
- 🟥 Built-up Area Pervious
- ▨ Built-up Area Impervious
- ▨ Undifferentiated



REFERENCE

Base Data - MNR NRVIS, obtained 2004, 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 17
Pits & Quarries, wetlands, ANSI's, and water well records supplied by MOE.

3.5 1.75 0 3.5
SCALE 1:160,000 KILOMETRES

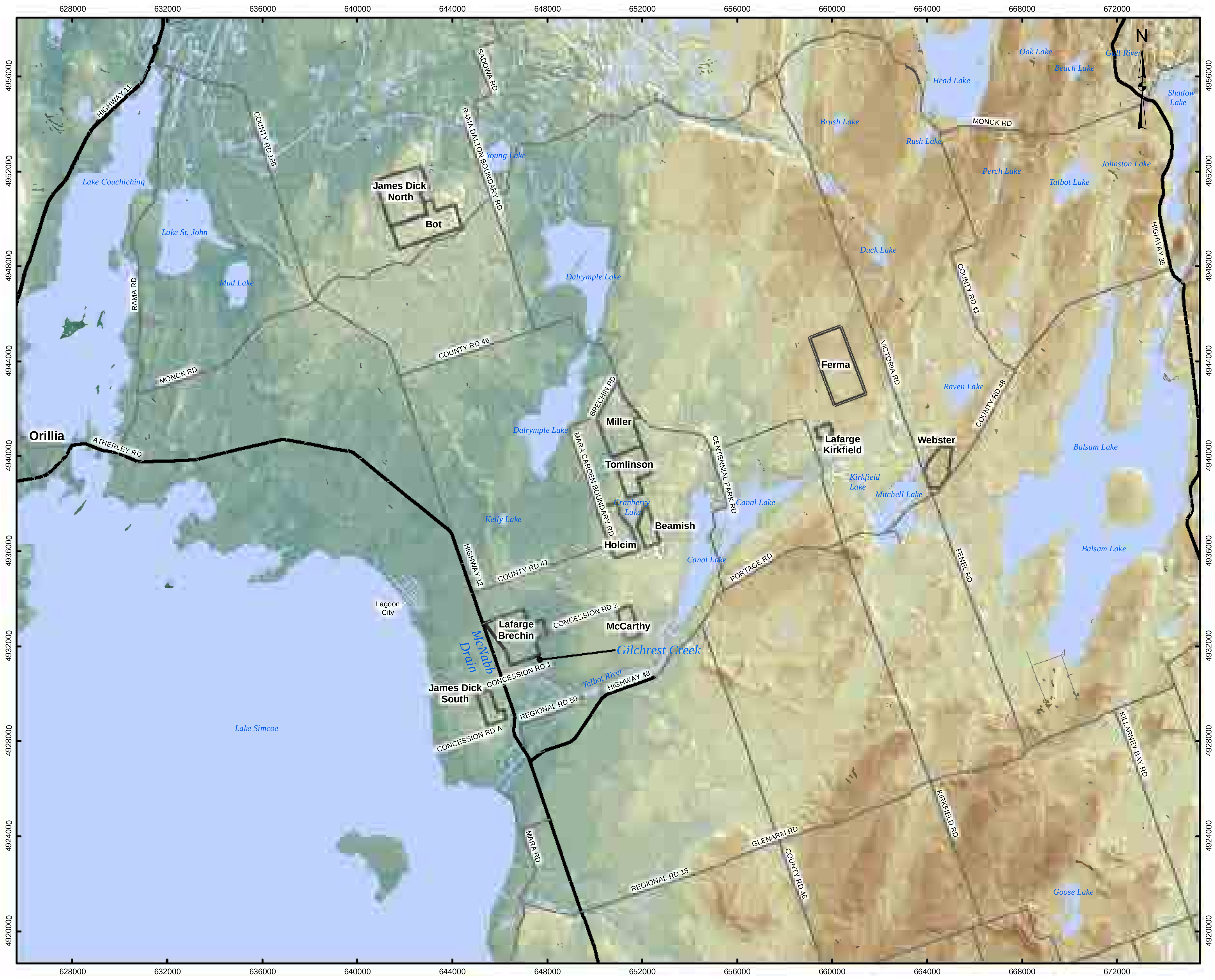
PROJECT
CARDEN PLAIN
CUMULATIVE IMPACT ASSESSMENT

TITLE
CATCHMENT LAND USE

Golder Associates
Mississauga, Ontario

PROJECT NO. 09-1112-6065			SCALE AS SHOWN	REV. 0.0
DESIGN	JPAO	04 JULY 2011	FIGURE: 6	
GIS	PRM	04 JULY 2011		
CHECK	JPAO	Sept. 2012		
REVIEW	KAM	Sept. 2012		

G:\Projects\2009\09-1112-6065_CIA\GIS\MXDs\Draft\Surface_Water\Catchment_Area.mxd



LEGEND

- Highway
- Major Road
- Local road
- ▭ Quarry Property Included in Study
- Waterbody

Ground Surface Elevation (masl)

- > 320
- 310 - 320
- 300 - 310
- 290 - 300
- 280 - 290
- 270 - 280
- 260 - 270
- 250 -260
- 240 - 250
- 230 - 240
- 220 - 230
- 210 - 220
- 200 - 210
- < 200

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
NRVIS Provincial Digital Elevation Model Data.
Toronto, Ontario: The Ontario Ministry of Natural Resources, [2002]
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 17

4 2 0 4
SCALE 1:160,000 KILOMETERS

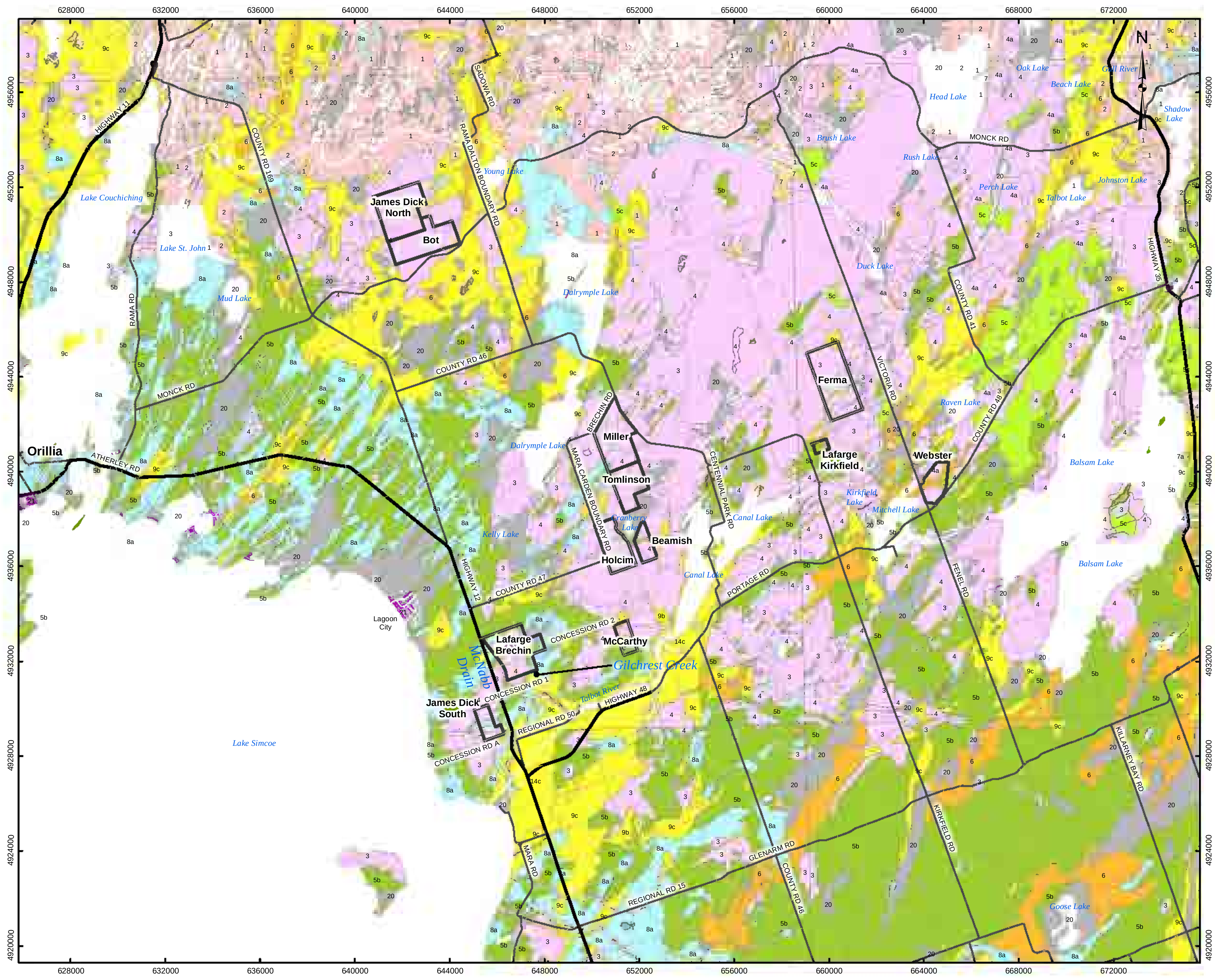
PROJECT
CARDEN PLAIN
CUMULATIVE IMPACT ASSESSMENT

TITLE
TOPOGRAPHY

Mississauga, Ontario

PROJECT No. 09-1112-6065			SCALE AS SHOWN	REV. 0.0
DESIGN	JPAO	10 MAY 2011	FIGURE: 7	
GIS	BT	10 MAY 2011		
CHECK	JPAO	Sept. 2012		
REVIEW	KAM	Sept. 2012		

Path: N:\Active\2009\1112 - Mississauga\09-1112-6065 Carden CIA\GIS\MXDs\Reporting\09111126065-07.mxd



LEGEND

- Highway
- Major Road
- Local road
- Quarry Property Included in Study
- Waterbody
- 1: Precambrian bedrock
- 2: Precambrian bedrock-drift complex
- 2a: Mainly till veneer
- 2b: Mainly stratified veneer
- 3: Paleozoic bedrock
- 4: Paleozoic bedrock-drift complex
- 4a: Mainly till veneer
- 4b: Mainly stratified veneer
- 5a: Shield-derived silty to sandy till
- 5b: Stone-poor, carbonate-derived silty to sandy till
- 5c: Stony, carbonate-derived silty to sandy till
- 5d: Glaciolacustrine-derived silty to clayey till
- 5e: Undifferentiated older till and stratified sediment
- 6: Ice-contact stratified deposits
- 6a: In moraines, kames, eskers and crevasse fills
- 6b: In subaquatic fans
- 7: Glaciofluvial deposits
- 7a: Sandy deposits
- 7b: Gravelly deposits
- 8: Fine-textured glaciolacustrine deposits
- 8a: Massive-well laminated
- 8b: Interbedded flow till, rainout deposits and silt and clay
- 9: Coarse-textured glaciolacustrine deposits
- 9a: Deltaic deposits
- 9b: Littoral-foreshore deposits
- 9c: Foreshore-basinal deposits
- 12: Older alluvial deposits
- 14: Coarse-textured lacustrine deposits
- 14a: Deltaic deposits
- 14b: Littoral-foreshore deposits
- 14c: Foreshore-basinal deposits
- 17: Eolian deposits
- 19: Modern alluvial deposits
- 20: Organic deposits
- 21: Man-made deposits

REFERENCE

MRD128-Surficial Geology of Ontario, 2006
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 17

3.5 1.75 0 3.5
SCALE 1:160,000 KILOMETRES

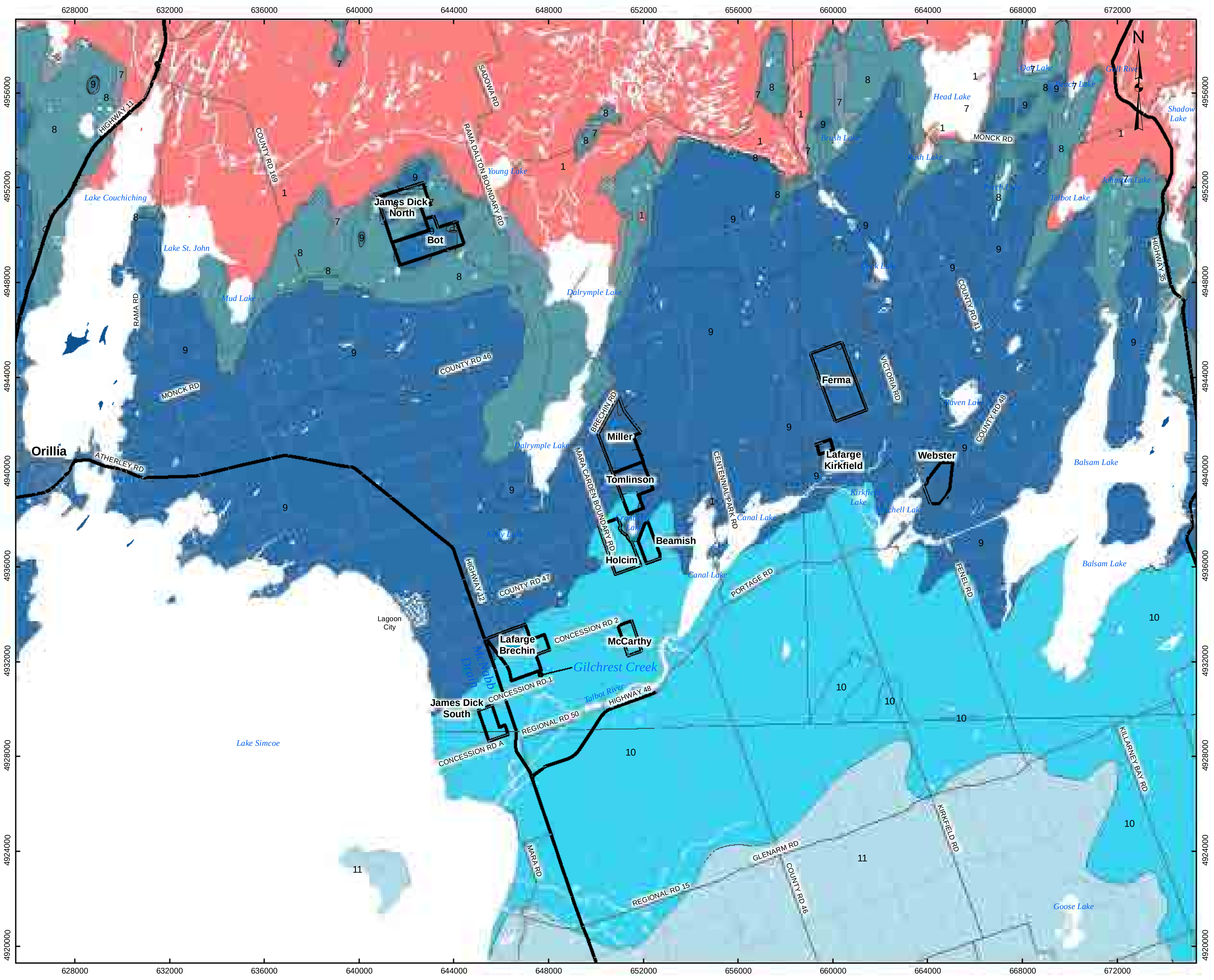
PROJECT
CARDEN PLAIN
CUMULATIVE IMPACT ASSESSMENT

TITLE
SURFICIAL GEOLOGY

Mississauga, Ontario

PROJECT No. 09-1112-6065			SCALE AS SHOWN	REV. 0.0
DESIGN	JPAO	10 MAY 2011	FIGURE: 8	
GIS	BT	10 MAY 2011		
CHECK	JPAO	Sept. 2012		
REVIEW	KAM	Sept. 2012		

Path: N:\Active\2009\1112 - Mississauga\09-1112-6065 Carden CIA\GIS\GIS\MXDs\09-1112-6065\Reporting\0911126065-08.mxd



LEGEND

- Highway
- Major Road
- Local road
- Quarry Property Included in Study
- Waterbody
- 11: Lindsay - limestone; nodular to black laminated (Collingwood)
- 10: Verulam - limestone and shale
- 9: Bobcaygeon - limestone, with minor shales in upper part
- 8: Gull River - limestone, dolostone (towards base)
- 7: Shadow Lake - shale, argillaceous sandstone, silty dolostone
- 1: Precambrian - crystalline basement

INDEX MAP

REFERENCE

MRD219-Paleozoic Geology of Southern Ontario, 2007
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 17

4 2 0 4
SCALE 1:160,000 KILOMETERS

PROJECT

CARDEN PLAIN
CUMULATIVE IMPACT ASSESSMENT

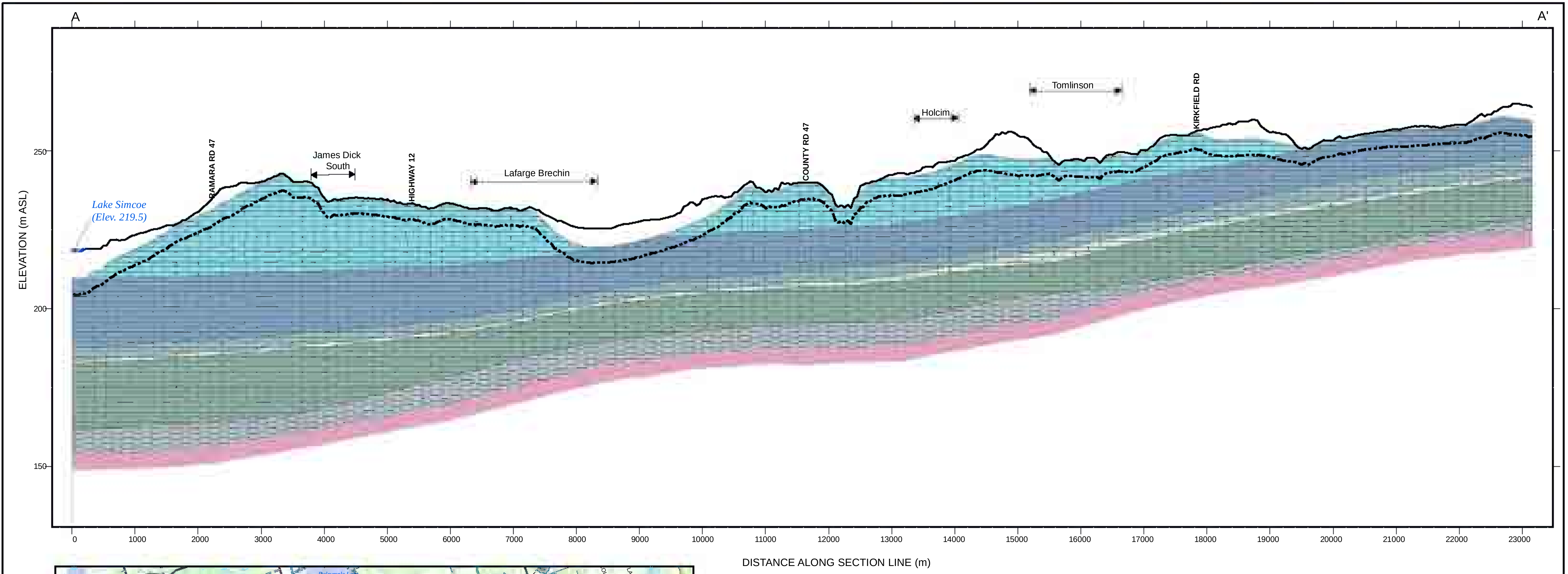
TITLE

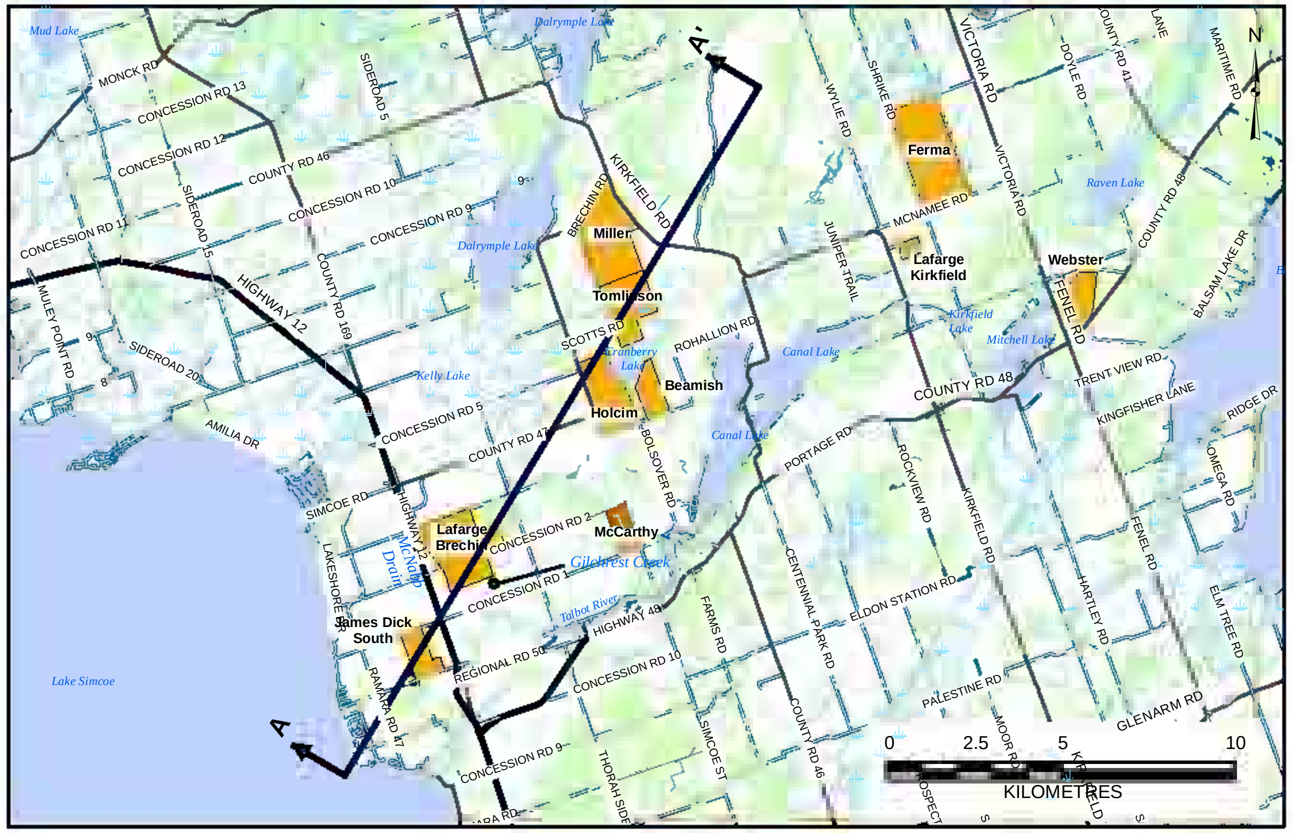
BEDROCK GEOLOGY

Golder Associates
Mississauga, Ontario

PROJECT No. 09-1112-6065			SCALE AS SHOWN	REV. 0.0
DESIGN	JPAO	10 MAY 2011	FIGURE: 9	
GIS	BT	10 MAY 2011		
CHECK	JPAO	Sept. 2012		
REVIEW	KAM	Sept. 2012		

Path: N:\Active\2009\1112 - Mississauga\09-1112-6065 Carden CIA\GIS\GIS\MXDs\09-1112-6065\Reporting\0911126065-09.mxd





LEGEND

- ‒ · ‒ · Limit of Weathered Rock
- ― Ground Surface (m ASL)
- Overburden
- ▨ Verulam Formation
- ▨ Bobcaygeon Formation
- ▨ Gull River Formation Above Green Bed
- ▨ Green Bed
- ▨ Gull River Formation Below Green Bed
- ▨ Shadow Lake Formation
- ▨ Weathered Precambrian
- Precambrian

PROJECT

CARDEN PLAIN
CUMULATIVE IMPACT ASSESSMENT

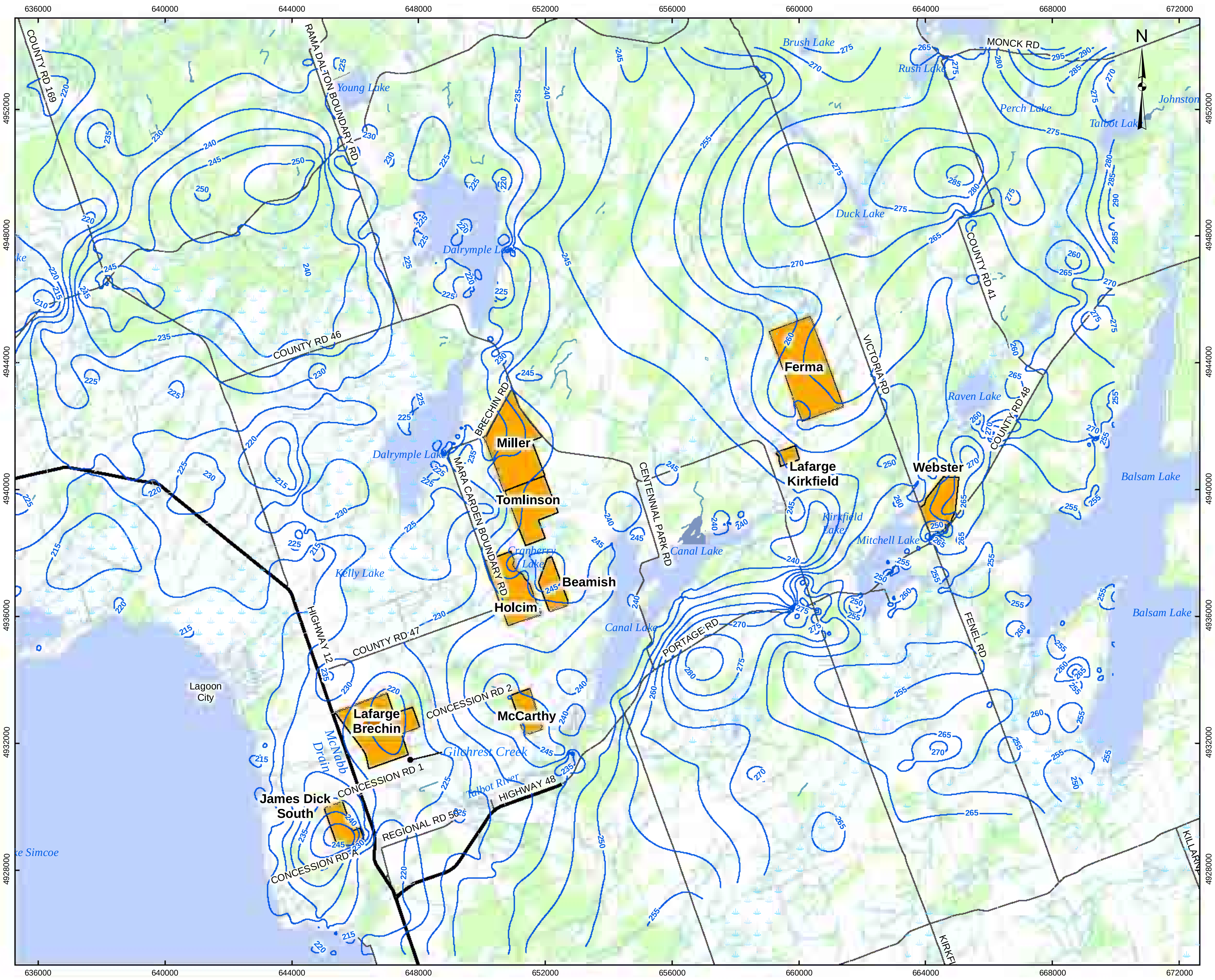
TITLE

HYDROGEOLOGICAL CROSS-SECTION A-A'

Golder Associates
Mississauga, Ontario

PROJECT No. 09-1112-6065			SCALE AS SHOWN	REV. 0.0
DESIGN	JPAO	10 MAY 2011	FIGURE: 10	
GIS	BT	10 MAY 2011		
CHECK	JPAO	Sept. 2012		
REVIEW	KAM	Sept. 2012		

Path: N:\Active\2009\1112 - Mississauga\09-1112-6065 Carden CIA\GIS\GIS\MXDs\09-1112-6065\Reporting\0911126065-10.mxd



LEGEND

- Measured Groundwater Elevation (m ASL)
- Highway
- Major Road
- Local road
- Watercourse, Permanent
- Watercourse, Intermittent
- Waterbody
- Provincially Significant Wetland
- Wooded Area
- 🟧 Quarry Property Included in Study

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 17

2.5 1.25 0 2.5
SCALE 1:120,000 KILOMETRES

PROJECT

CARDEN PLAIN
CUMULATIVE IMPACT ASSESSMENT

TITLE

CONTOUR PLOT OF MEASURED GROUNDWATER ELEVATIONS

Mississauga, Ontario

PROJECT No. 09-1112-6065			SCALE AS SHOWN	REV. 0.0
DESIGN	JPAO	10 MAY 2011	FIGURE: 11	
GIS	BT	10 MAY 2011		
CHECK	JPAO	Sept. 2012		
REVIEW	KAM	Sept. 2012		

Path: N:\Active\2009\1112 - Mississauga\09-1112-6065 Carden CIA\GIS\GIS\MXDs\09-1112-6065\Reporting\0911126065-11.mxd