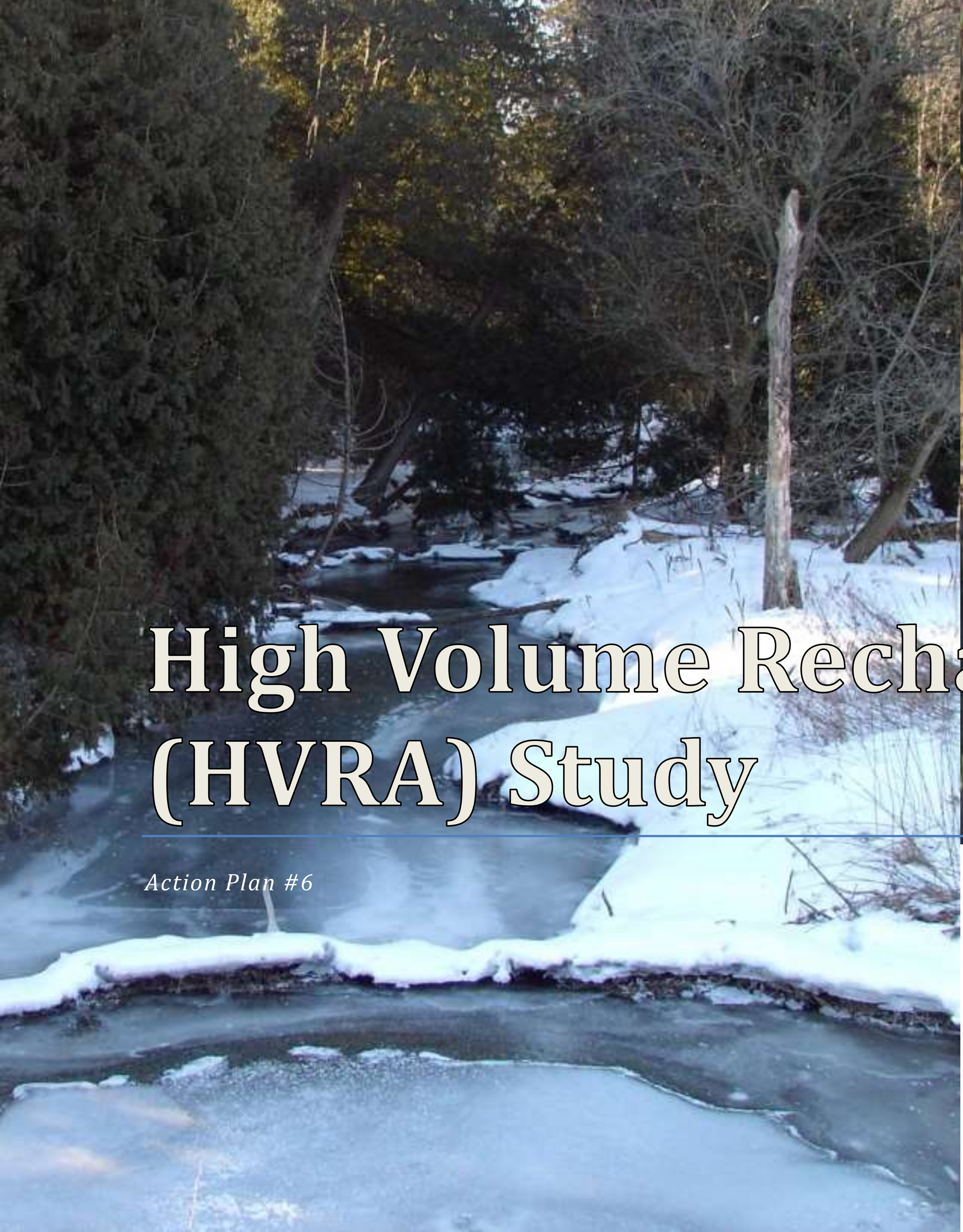

High Volume Recharge Area (HVRA) Study

Action Plan #6

Central Lake Ontario Conservation

June 2014

Contents

1. INTRODUCTION

The Central Lake Ontario Conservation Authority (CLOCA) mission is "To increase the awareness, understanding, wise use and enhancement of our watershed resources for the benefit of the natural environment in partnership with the Region of Durham including: Cities of Oshawa and Pickering, Towns of Ajax and Whitby, Municipality of Clarington, Townships of Scugog and Uxbridge and our watershed communities." In working towards fulfilling this mission, CLOCA has prepared watershed plans examining the environment and human activities within a watershed area and assessing the relationships between these activities to determine how the ecosystems of the watershed should be managed to ensure they retain their ecological integrity and health in a sustainable manner. Watershed management recommendations are made in these Plans, which when implemented, will work to achieve specific watershed goals and targets. To direct and support implementation of these recommendations, a suite of tools are provided in the Watershed Plans. These tools include Action Plans which CLOCA will undertake in an effort to achieve and attain specific watershed health objectives, contributing to the fundamental watershed goal of a healthy and resilient watershed. All Action Plans address watershed concerns, issues and actions identified during development of the Watershed Plans. Some of the Action Plans are designed to be implemented at a larger scale i.e., the CLOCA jurisdiction, while other Action Plans will be directed to specific watersheds, subwatersheds or even a site specific area. While CLOCA is taking the lead on preparing these Action Plans, some specific Plans will compliment, support and/or inform Regional and/or Municipal programs. These Plans will provide greater detail for achieving specific watershed goals and targets and will provide the framework and implementation planning necessary to complete future on-the-ground monitoring, research, restoration and rehabilitation work. One of these Action Plans as identified in all the Watershed Plans is Action Plan # 6: High Volume Recharge Area (HVRA) Study.

1.1 PURPOSE

The Watershed Plans identified High Volume Recharge Areas (HVRAs) as an important component in sustaining the overall health of the watershed and the natural systems, features and functions that rely on groundwater resources. HVRAs are those areas which, due to their soils, are conducive to absorbing precipitation. Water infiltrates these soils, penetrating down to underground aquifers. These aquifers sustain wetlands and provide baseflow to streams. Of course, aquifers are also what supplies drinking water to area residents. HVRAs have been mapped and recommendations to protect recharge function are provided in each Watershed Plan.

1.2 CONTEXT

The goal of watershed planning is to provide a framework to protect, restore and enhance a healthy and resilient watershed. A Watershed Plan examines the environment and human activities within a watershed area and assesses the relationships between these activities to determine how the ecosystems of the watershed should be managed to ensure that they retain their ecological integrity and health in a sustainable manner. In 2012 and 2013, Watershed Plans for CLOCA's 4 large watersheds were completed; the watershed management recommendations that were made in these Plans will, when implemented, work to achieve specific watershed goals and targets. In order to reach these goals, CLOCA has provided a suite of tools, including 24 Action Plans, to direct and support implementation of the Watershed Plan recommendations.

CLOCA Action Plans

The Action Plans described in the Watershed Plans work to achieve and attain specific health objectives, contributing to the fundamental goal of a healthy and resilient watershed. All of the Action Plans address watershed concerns, issues and actions identified during development of the Watershed Plans. Some of the Action Plans are designed to be implemented at a larger scale, i.e., the CLOCA jurisdiction, while other Action Plans will be directed to specific watersheds, subwatersheds or even a site specific area. While CLOCA is taking the lead on preparing these Action Plans, some specific Plans will compliment, support and/or inform Regional and/or Municipal programs. These Plans will provide greater detail for achieving specific watershed goals and targets, and will provide the framework and implementation planning necessary to complete future on-the-ground monitoring, research, restoration and rehabilitation work.

Action Plan #6: High Volume Recharge Area Study states "*As growth proceeds within CLOCA's jurisdiction, CLOCA can be proactive by investigating methods, technologies, techniques and tools for protecting High Volume Recharge Areas (HVRAs) within the watershed. CLOCA will research various approaches and prepare a discussion paper with recommendations regarding BMPs for the protection of HVRAs… and look for local research opportunities for testing of various methods. This project will provide recommendations for a future case study to assess the effectiveness of applied BMPs.*"

The intent of this Action Plan is to investigate, assess and provide technique/tools, including BMPs, for protecting HVRAs and to provide recommendations for a future case study to assess effectiveness of applied BMPs and other technique/tools in protecting HVRAs. There is a strong relationship between the objectives of this Action Plan and the objectives of Action Plan #9 – CLOCA Urban Land Use Low Impact Development (LID) Retrofits Plan. Both Action Plans essentially address how best to protect HVRAs, but from a different focus; with Action Plan #9 focused on restoration within urbanized areas and this Action Plan focused on identifying measures to protect HVRAs from development impacts. In reality, many of the techniques, BMPs, tools etc would apply in both circumstances, as would development of performance measures and the preparation of educational material providing recommendations regarding the effectiveness of these tools. As such, the scope of Action Plan #9 will now be expanded to provide the techniques, tools and performance measures to protect HVRAs throughout the watershed, not just focused on urban lands and retrofit opportunities. In light of this, Action Plan #6 has been revised to identify broad jurisdiction-wide tools and resources that support protection of HVRAs: specifically, the "Ecologically Significant Groundwater Recharge Area Delineation in the Central

Lake Ontario Conservation Authority Area" and "Hydrogeological Assessment Submissions, Conservation Authority Guidelines to Support Development Applications".

2. DISCUSSION

Ecologically Significant Groundwater Recharge Area Delineation in the Central Lake Ontario Conservation Authority Area

Both HVRAs and ESGRAs describe recharge patterns; but they do so at differing scales. The HVRAs identified in the Watershed Plans were delineated using the best information at the time which was developed in support of the Source Water Protection Program. These HVRAs identify areas where the rate of recharge is 15% greater than the overall average recharge rate across CLOCA. HVRAs possess above average infiltration capacity and as such these areas contribute groundwater flow to a large number of widely distributed ecological features. However, what this information does not convey is the connection between an HVRA and an area of ecological significance. Delineation of ecologically significant groundwater recharge areas (ESGRAs) identifies those natural features that are reliant upon groundwater resources. ESGRAs are particularly important in identifying areas which directly support nearby ecological features. To identify ESGRAs an excellent understanding of the local hydrogeology and the factors that affect groundwater/surface water interaction is needed as well as identification of local ecological features. Features deemed to be ecologically significant included stream reaches and all wetlands as mapped by CLOCA. To carry out the modelling, analytical reporting and mapping, CLOCA engaged EarthFX. The study produced identifies the important recharge areas (ESGRAs) which supply CLOCA's wetlands and streams with groundwater. A copy of the complete study, including methodology and findings is contained in Appendix A. As expected, there was some overlap (38%) when the HVRAs and ESGRAs were compared. A key recommendation of this study is that both the HVRA and ESGRA mapping and analysis be considered together when assessing groundwater flow.

Hydrogeological Assessment Submissions, Conservation Authority Guidelines to Support Development Applications

The "Hydrogeological Assessment Submissions, Conservation Authority Guidelines to Support Development Applications" provides standardized hydrogeological study requirements with the intent that this document be used by Conservation Authorities, environmental consultants and the development community alike. These guidelines establish the minimum information requirements for inclusion within a hydrogeological study, clearly identifying for the developer and consultant what needs to be reported upon and for review agencies (Conservation Authorities) what comprises a complete study. Essentially, it is recommended that the existing hydrogeological and surface water conditions be documented, that an impact assessment be undertaken, and mitigation recommendations provided. Recognizing that not all development proposals are alike, and that the level of risk will vary, a range of study requirements are provided. The guidelines also identify those qualified people having the necessary expertise to prepare such a report. Having gone through an extensive peer review and consultation process, this document received Conservation Ontario approval in June 2013 and has been approved for use in CLOCA. It is attached in Appendix B and it is recommended that the reader review the document in its entirety.

Future Pilot Project – Sustainable Groundwater Recharge Pilot Project

CLOCA will continue to investigate and pursue local opportunities to test various methods which protect recharge function. Key in the identification and selection of a future opportunity will be site conditions. In order to test the effectiveness and performance of any tools, techniques or BMPs, the optimal soil/subsurface conditions must be present. Also important will be securing partners and resources to undertake this type of project. At this time, appropriate sites are not available and partnerships have not been formalized, however, CLOCA will continue to look for opportunities to carry out a sustainable groundwater recharge pilot project.

APPENDIX A – Ecologically Significant Groundwater Recharge Area Delineation in the Central Lake Ontario Conservation Authority Area

Prepared for:

The Central Lake Ontario Conservation Authority
100 Whiting Avenue
Oshawa, Ontario L1H 3T3

Prepared by:

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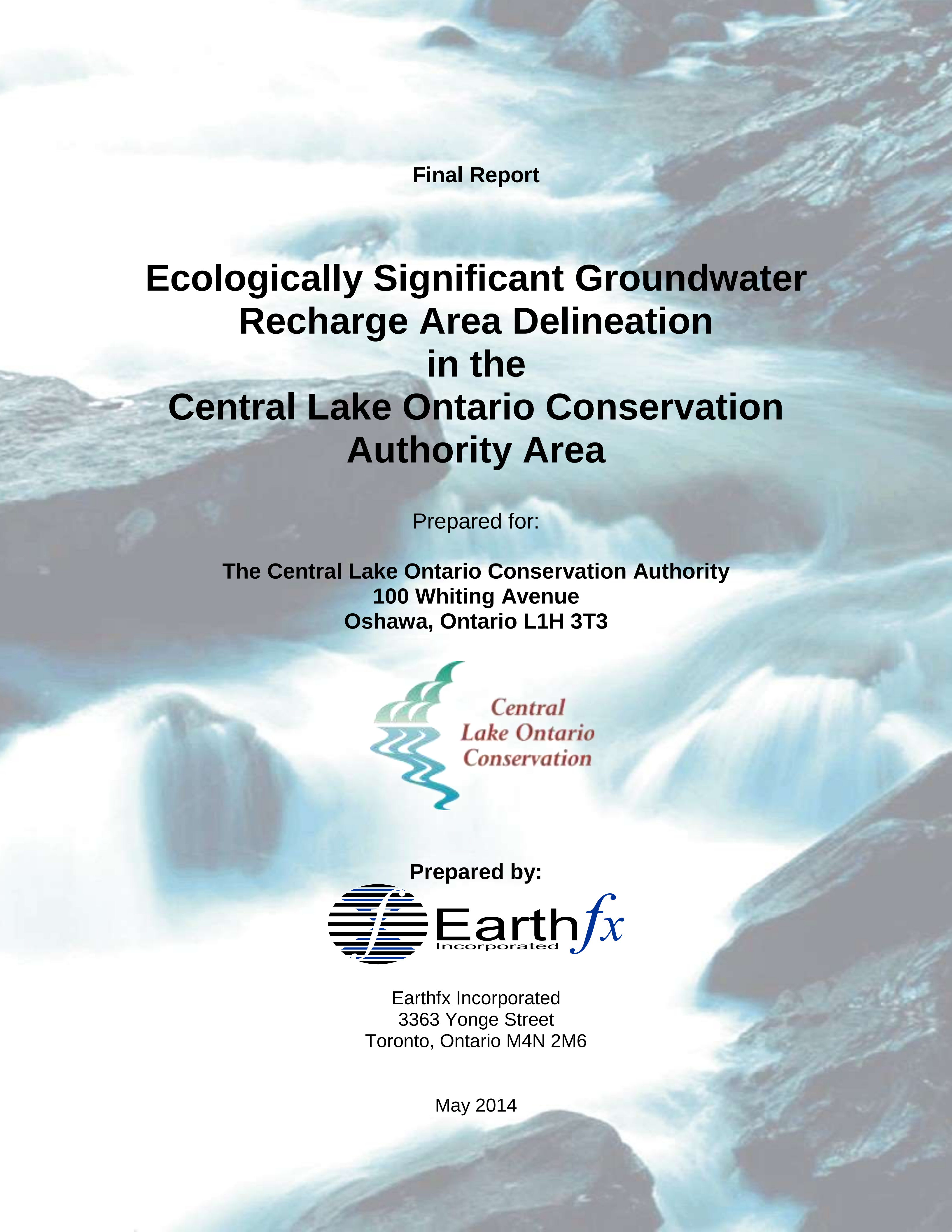
May 2014



Final Report

Ecologically Significant Groundwater Recharge Area Delineation in the Central Lake Ontario Conservation Authority Area

Prepared for:

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May 2014

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Earth Science Information Systems

May 12, 2014

Gayle Soo Chan, P.Geo.
Director – Groundwater Resources
Central Lake Ontario Conservation Authority
100 Whiting Avenue
Oshawa, Ontario L1H 3T3

RE: Ecologically Significant Groundwater Recharge Area Delineation in the Central Lake Ontario Conservation Authority Area

Dear Gayle:

We are pleased to provide a copy of this final report describing our assessment of Ecologically Significant Groundwater Recharge Areas (ESGRAs) within the CLOCA watersheds. The primary goal of the study was to use existing groundwater models and particle tracking techniques to delineate the groundwater recharge areas supplying flow to ecologically sensitive areas such as wetlands and stream reaches. A number of additional particle tracking exercises were undertaken to analyse the regional movement of water with respect to recharge sources. This work builds on our previous Tier 1 modelling work in the CLOCA area and on techniques developed for ESGRA analyses in recent studies conducted for Lake Simcoe Region Conservation Authority.

We trust this work meets with your satisfaction. We would like to thank you for the opportunity to work on this project. If you have any questions, please call.

Yours truly,
EarthFX Incorporated

Dirk Kassenaar, M.Sc., P.Eng.
President

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Ecologically Significant Groundwater Recharge Area Delineation in the Central Lake Ontario Conservation Authority Area

1 Introduction

As part of the Drinking Water Source Water Protection Program (SWP) established by the Clean Water Act, 2006, Source Protection Regions completed water budget assessments and delineated "significant groundwater recharge areas" (SGRA). SGRAs (also referred to as "high volume recharge areas") are defined under SWP simply as areas where groundwater recharge is greater than 1.15 times the average rate of recharge.

While identifying high-volume recharge areas is important, recharge volume alone does not imply ecological significance. To identify ecologically significant groundwater recharge areas (ESGRAs), a linkage must be established between the recharge area and ecological features such as streams, wetlands, or areas of natural or scientific interest (ANSI). Establishing this linkage requires an understanding of the local hydrogeology and the factors affecting groundwater/surface water interaction. More importantly, it requires a methodology, typically based on the use of a numerical model, to trace the movement of water from the ecological features back to the point of recharge.

This report describes the delineation of ESGRAs in the Central Lake Ontario Conservation Area (CLOCA) watersheds (Figure 1). The work builds directly on an earlier SWP study to estimate groundwater recharge in the CLOCA watersheds (Earthfx, 2008) and on a study of the rates and directions of groundwater flow across the entire Regional Municipality of Durham and the CLOCA watersheds in particular (Earthfx, 2010). Background information and significant findings of these two studies are described briefly in this report.

1.1 ESGRA Delineation Methodology

A methodology for quantitative ESGRA analysis was recently developed by Earthfx for the Lake Simcoe Region Conservation Authority (LSRCA) in a project funded by the Ontario Ministry of Natural Resources (MNR). The methodology was tested in the Barrie, Lovers and Hewitts watersheds (Earthfx, 2011) and has been applied in a number of other watersheds in the LSRCA (AquaResource, 2013; Earthfx, 2013a; GENIVAR, 2013). Steps in the ESGRA methodology include:

1) identifying the ecological features;
2) developing a conceptual understanding of the local hydrogeology and factors affecting groundwater/surface water interaction;
3) representing this conceptual understanding with a numerical model (or, if one already exists, assessing the groundwater model, including stream and wetland boundary conditions, upper layer geometry, aquifer properties, recharge rates, and calibration);
4) applying particle tracking techniques to trace the movement of groundwater from the feature back to the point where the recharge entered the subsurface (hereinafter referred to as *particle endpoints*);
5) evaluating or scoring groups of particle endpoints produced by the model to establish whether they indicate that significant recharge is occurring;
6) mapping the ESGRAs; and
7) analyzing the sensitivity of model results.

Identification of ecological features (Step 1) was conducted by CLOCA staff at the outset of this study based on their knowledge of the local features and previous investigations conducted in the study area. CLOCA staff indicated that all stream reaches were considered ecologically significant and should be analyzed. CLOCA staff also provided mapping of wetland features (including provincially significant wetlands (PSWs) as well as wetlands mapped in environmental land classification (ELC) mapping and confirmed through field verification. Locations of these features are shown in Figure 2.

The second step in the methodology includes developing a conceptual understanding of the local hydrogeology and factors affecting groundwater/surface water interaction. A characterization of the CLOCA watersheds was conducted early in the SWP study program CLOCA (2006). The study provided important background information on the physical setting, watershed descriptions, water quality and quantity, vulnerable areas, ongoing monitoring programs, drinking water threats and issues, and knowledge gaps. A detailed Tier 1 level study of the water budget in the CLOCA watersheds (Earthfx, 2008) built on the information in the CLOCA (2006) report and included development of a hydrologic model to estimate all components of the water balance including groundwater recharge as affected by topography, vegetative cover, land use and soil properties. The study also utilized an existing groundwater model to represent the local hydrogeology and simulate groundwater flow in the CLOCA watersheds and to quantify groundwater/surface water interaction. Appendix A of Earthfx (2008) provided additional information on the physical setting and hydrostratigraphy of the study area.

2 Assessment of the Groundwater Flow Model

The third step in the methodology for ESGRA analysis developed by Earthfx for LSRCA includes an assessment of the existing groundwater model, including stream and wetland boundary conditions, upper layer geometry, aquifer properties, recharge rates, and calibration. As noted above, this ESGRA analysis builds directly on the hydrologic modelling and groundwater modelling assessment completed in support of the CLOCA Tier 1 Water Budget and Stress Assessment (Earthfx, 2008). Brief descriptions of the groundwater flow model and the hydrologic model developed for the study area are provided here.

2.1 Previous Modelling Work

A three-dimensional groundwater flow model was developed by Earthfx for the Regional Municipality of Durham over a several-year period as an extension of earlier work in the Oak Ridges Moraine area. The Durham Region study (Earthfx, 2010) and the original Oak Ridges Moraine study (Kassenaar and Wexler, 2006) were conducted under a partnership between four municipalities (York, Peel, Durham and the City of Toronto) and the Conservation Authority Moraine Coalition (CAMC). The "Durham Model", as it is referred to in Earthfx (2010), encompassed an area of approximately 3380 square kilometres (km^2) and extended from Lake Ontario in the south to Lake Simcoe in the north (Figure 3). The Oak Ridges Moraine, a significant physiographic feature and an area of high groundwater recharge that runs parallel to the Lake Ontario shoreline across the centre of the Durham Model area, was a major focus of these modelling studies.

The model extents varied considerably over the course of the Durham Model study and, at one time, included the Region of York and the City of Toronto. This model was referred to at the time as the "East Model". The model used in the CLOCA Tier 1 study was based on a truncated version of the East Model. As noted in Earthfx (2010), results of the CLOCA Tier 1 study, which included significant modifications to the East Model, were incorporated into the final Durham Model.

The "CLOCA Groundwater Model" was used to simulate groundwater levels, quantify cross-watershed groundwater flow, and calculate groundwater discharge to streams and wetlands within the CLOCA watersheds. The CLOCA Groundwater Model excluded the western half of the East Model area (west of the Duffins Creek watershed) to focus attention on the CLOCA watersheds.

The numerical model was based on a hydrostratigraphic model and a conceptual flow model that integrated data on the physical, geologic, and hydrogeologic features that govern groundwater flow. The conceptual flow model was originally developed as part of the YPDT-CAMC study of the Oak Ridges Moraine area described in Kassenaar and Wexler (2006). Expansion of this conceptual model to incorporate Durham Region and the CLOCA watersheds was discussed in Appendix A in Earthfx (2008).

2.2 Model Code

The CLOCA Groundwater Model used the U.S. Geological Survey MODFLOW code. This code is recognized worldwide and has been extensively tested and verified. The MODFLOW code is well-suited for modelling regional and local-scale flow in multi-layered aquifer systems and can account for irregular boundaries, complex stratigraphy, and spatial variations in hydrogeologic properties. The version of MODFLOW used is documented in McDonald and Harbaugh (1988) and Harbaugh and McDonald (1996). Best practices for groundwater modelling and professional judgement were followed in applying and calibrating the numerical models as outlined in the ASTM (2000) standards for groundwater flow modelling.

2.2.1 Model Code Update

As part of the ESGRA assessment, the CLOCA Groundwater Model was updated to a newer version of the MODFLOW code, MODFLOW-NWT (Niswonger *et al.*, 2011). This code is especially well-suited for representing thin, discontinuous aquifers and sharp changes in model layer stratigraphy, especially at shallow depth. The data sets from the earlier model were converted to MODFLOW-NWT compatible input and the new model was tested to ensure it could replicate previous results. The updated model proved to be much more stable, converged quicker, and had less residual mass balance error.

2.3 Model Layers

There are a number of approaches that can be used to represent the hydrostratigraphy in a MODFLOW model. In the CLOCA Groundwater Model, the study area was subdivided into layers, where each layer represented a separate hydrostratigraphic unit, which were categorized as either an aquifer or aquitard.

Eight model layers, coinciding with the eight hydrostratigraphic layers, were used to represent the overburden and shallow bedrock (Table 1). Unlike the later Durham Model, the Newmarket Aquitard was not subdivided into separate units to represent the Upper and Lower Newmarket Tills and the Inter-Newmarket sediments. The subdivision of the Newmarket Till is more critical to understanding groundwater flow in the area north of the Oak Ridges Moraine and representing an unsubdivided Newmarket Aquitard in the CLOCA Groundwater Model was felt to be appropriate.

Table 1: Model layers.

	Description
Layer 1	Recent Deposits/Weathered Halton/Newmarket Tills
Layer 2	Halton Aquitard (south of ORM); Recent Deposits (north of ORM)
Layer 3	Oak Ridges Aquifer Complex (ORAC)
Layer 4	Lower Newmarket Aquitard or Tunnel Channel Silts
Layer 5	Thorncliffe Aquifer Complex (TAC) or Tunnel Channel Sands
Layer 6	Sunnybrook Aquitard
Layer 7	Scarborough Aquifer Complex
Layer 8	Weathered Bedrock

Land surface forms the uppermost model layer surface (i.e., top of model Layer 1). Land surface topography is shown in Figure 4. The 5-m digital elevation model (DEM), provided by MNR, was re-sampled to the 100-m model grid. Also shown on the figure is the regional groundwater divide which, as can be seen, does not coincide with the topographic divide.

Layer 1 represents Recent Deposits (e.g., alluvium or organic) or late-stage lacustrine (e.g., glacial Lake Iroquois or Lake Algonquin) deposits, where present. In much of the southern part of the CLOCA Groundwater Model area (which extends outside of CLOCA), the Halton and Newmarket Tills or Oak Ridges Moraine deposits are found at surface.

The numerical model code (MODFLOW) used in the Tier 1 study required continuity of aquifer layers whereas the hydrostratigraphic model allows units to have zero thickness. A pre-processor code was written with a set of rules to adjust layer thickness and properties to maintain layer continuity. Where upper layers pinched out, layer thickness was set to zero and the cells were designated as “inactive” (i.e., they were no longer considered part of the groundwater flow system). Recharge was allowed to pass through to lower active layers. This rule was not required in the MODFLOW-NWT version of the CLOCA Groundwater Model used in this study and all discontinuous layers were treated as described below. These changes were felt to have only a modest effect on the model results and would not likely change the outcome of the Tier 1 analyses.

In the CLOCA Groundwater Model, all of the model layers were checked for pinch-outs and discontinuities, including layer 1 as discussed above. Where this occurred in an aquifer layer, the aquifer layer was assigned a minimum thickness (1.0 m). A minimum thickness of 0.5 m was set where aquitard thickness was zero and the hydraulic conductivity was increased to allow vertical flow between the overlying and underlying aquifers. Figure 5 shows a north-south cross section along Townline Road (through the Oshawa, Harmony, and Farewell Creek watersheds) showing model layers and how layer continuity was enforced in the numerical model.

Special treatment was afforded Layers 4 and 5 in the tunnel channel areas (see Figure 3). A tunnel channel occurs only in the northwest corner of the CLOCA Groundwater Model area. The Newmarket Till and Thorncliffe aquifer complex (TAC) were assumed to be mostly removed by subglacial erosion processes and replaced by tunnel channel sands and overlying silts. The layer geometry was adjusted in these areas to assure that the Channel Sands were in hydraulic contact with the TAC and that the Channel Silts were continuous with the Lower Newmarket Till at the edges of the tunnel channels. Hydraulic properties of the two layers were also adjusted in the tunnel channel areas to represent properties of the Channel Sands and Channel Silts, as described further on. It should be noted that the outlines of the tunnel channel areas were updated for the Durham Model but these changes were not incorporated in the CLOCA Groundwater Model. These changes were felt to mostly affect flow patterns north of the Oak Ridges Moraine and would have only a modest effect on model results.

2.4 Model Grid

The MODFLOW code uses the finite-difference method for approximating the differential equation of groundwater flow. The method requires that the study area be subdivided into a grid of small rectangular cells. Aquifer properties, such as top and bottom elevations for each layer, hydraulic conductivity, and recharge and discharge rates, are assigned to each cell in the grid. Boundary conditions are specified for cells that lie along lines corresponding to the physical boundaries of the flow system (e.g., model edges and streams/wetlands). The model grid for the CLOCA area has 1056 rows and 1300 columns with square cells, each 100 m on a side. The grid size is the same as for the original East Model but much of the model area to the west of the CLOCA watersheds is inactive.

MODFLOW works in a local, grid coordinate system based on row and column numbers. The VIEWLOG pre-processor was used to help translate geo-referenced map data into MODFLOW coordinates. The local origin for the model grid is at UTM coordinates 580000 E and 4825000 N. All digital maps and well data for the study area were referenced using NAD83 (UTM Zone 17) grid coordinates.

2.5 Model Boundaries

Constant head, no-flow, and head-dependent discharge boundaries were used to represent natural hydrologic boundaries in the CLOCA Groundwater Model. Lake Ontario and Lake Scugog were all represented as constant head boundaries with the water level set to average lake stage - 75.2 metres above sea level (masl) for Lake Ontario and 250.0 masl for Lake Scugog. No-flow boundary conditions were applied at the eastern and western watershed boundaries (located beyond the CLOCA area and shown in Figure 3) and along the base of the lowest model layer to represent the unweathered bedrock.

2.5.1 Streams and Wetland Boundaries

Groundwater discharge to streams was simulated using two different types of head-dependent discharge boundaries, referred to in MODFLOW terminology as “rivers” and “drains” (McDonald and Harbaugh, 1988). Locations of the drain and river cells are shown in Figure 6. MODFLOW drains were used to simulate discharge to the headwater tributaries of the streams (Strahler Class 1 through 4). The key assumption regarding drains is that leakage occurs in only one direction, from the aquifer to the drain. When simulated aquifer heads drop below the controlling elevation of the drain, the drain is presumed to go dry and no flow occurs from the drain back to the groundwater system. A MODFLOW parameter, called the “drain conductance”, is calculated as the stream length within the cell multiplied by the stream width and by the streambed hydraulic conductivity and divided by the streambed thickness. Drain conductance values and drain control elevations were specified for each drain segment that passed through a model cell.

Wetlands were also simulated as groundwater drains. The “drain conductance” was calculated as the area of the cell multiplied by the hydraulic conductivity of the low permeability wetland soils and divided by the assumed thickness of the low permeability material. The hydraulic conductivity (K) value was set to 5.0×10^{-6} m/s. As with the headwater streams, it was assumed that wetlands act as points of groundwater discharge when aquifer heads rise above land surface.

MODFLOW rivers were used to simulate groundwater discharge to the lower reaches of major streams (Strahler Class 5 and 6). The key assumption regarding MODFLOW rivers is that leakage can occur in either direction when the aquifer head is above the bottom elevation of the streambed. When aquifer heads drop below the base of the streambed, the river is assumed to be perched and water leaks out of the river at a constant rate based on the difference between the river stage and the elevation of the streambed bottom. A MODFLOW parameter, called the "river conductance", is calculated as the stream length within the cell multiplied by the stream width and by the streambed hydraulic conductivity and divided by the streambed thickness. River conductance, river stage, and streambed bottom elevation values were assigned to each river segment that passed through a model cell.

Better methods to represent stream/aquifer interaction which include routing of overland runoff and streamflow and the dynamic calculation of stream stage are available but were beyond the scope of the present study to implement.

2.6 Hydraulic Conductivity Values

Estimates of the distribution of aquifer properties in the original part of the model (i.e., the Core Model area) were determined primarily through an analysis of aquifer test data and through interpolation of hydraulic conductivities estimated from the lithologic log descriptions. These estimates were refined in the process of Core Model calibration as described in Kassenaar and Wexler (2006). A more simplified distribution of hydraulic properties was used in the East Model with more uniform properties assumed for the aquifer units. Groundwater flow patterns were thereby influenced to a greater degree by spatial variation in aquifer and aquitard thickness. Calibrated values for aquifer properties are provided in Table 2. The vertical hydraulic conductivity (K_V) was assumed to be a constant ratio of the assigned horizontal hydraulic conductivity (K_H).

Table 2: Hydraulic properties assumed for the aquifers in the CLOCA Groundwater Model.

Aquifer Name	Horizontal Hydraulic Conductivity (m/s)	Anisotropy Ratio (K_V/K_H)
Recent Deposits	2×10^{-5}	1.0
Oak Ridges Aquifer Complex (ORAC)	2×10^{-5}	0.5
Thorncliffe Aquifer Complex (TAC)	2×10^{-5}	0.5
Channel Aquifer	1×10^{-4}	1.0
Scarborough Aquifer Complex (SAC)	2×10^{-5}	1.0
Weathered Bedrock (Georgian Bay)	8×10^{-6}	1.0
Weathered Bedrock (Simcoe Limestone)	1.6×10^{-5}	1.0

Limited data were available on the spatial distribution of aquitard hydraulic conductivities. Again, uniform properties were assigned to each of the units and modified locally where the units thinned or were missing (as described earlier). Calibrated aquitard properties are provided in Table 3.

Table 3: Hydraulic properties assumed for the aquitards in the CLOCA Groundwater Model.

Aquitard Name	Horizontal Hydraulic Conductivity (m/s)	Anisotropy Ratio (K_V/K_H)
Halton Till	5×10^{-7}	0.3
Weathered (thin) Halton Till	5×10^{-6}	1.0
Newmarket Till	5×10^{-8}	0.5
Weathered (thin) Newmarket Till	5×10^{-7}	1.0
Channel Silt	5×10^{-7}	0.5
Sunnybrook	5×10^{-8}	0.5

As noted earlier, the hydraulic conductivity of Layer 4 was adjusted in the tunnel channel areas where it corresponds to the Channel Silt rather than the Lower Newmarket Till. The aquitard was interpreted to be missing in these areas but a degree of confinement of the lower units was still afforded by silt layers deposited in the tunnel channels. The higher vertical permeability of the channel silts allowed for a greater exchange of water between the upper and intermediate aquifers. The hydraulic conductivity of Layer 5, representing the TAC, was also adjusted in the tunnel channel areas and assigned a uniform value of 1×10^{-4} m/s to represent properties of the Channel Sands aquifer. The effect of tunnel channels (only one observed in the area, northwest of the CLOCA boundary) is expected to be small in CLOCA's jurisdiction.

After reviewing the original Tier 1 model properties, a number of modest changes to aquifer and confining unit properties were made (reflected in the tables above). These were felt to have a minor effect on the model results and would not likely change the outcome of the Tier 1 analyses. Checks on the model calibration showed an overall model improvement.

2.7 Groundwater Recharge

The rate of groundwater recharge varies over the study area. Recharge rates for areas outside the CLOCA watersheds were obtained from previous modelling studies and were assigned based primarily on surficial geology mapping. Recharge rates were decreased over urban areas by a constant factor of 0.60. Values ranged from 30 to 420 mm/year with highest values occurring over the Oak Ridges Moraine deposits and over Lake Iroquois/ Lake Algonquin beach deposits. Lower values occurred in areas of deep glacial lake deposits and over the weathered tills.

Estimates for recharge in the CLOCA watersheds were initially obtained from the East Model values and then updated in an iterative manner using the Tier 1 hydrologic model results.

The Tier 1 hydrologic model was based on the original U.S. Geological Survey (USGS) Precipitation-Runoff Modelling System (PRMS) code (Leavesly *et al.*, 1983). The model incorporates data on land use, climate, and soil properties to estimate the components of the water budget including precipitation, snowmelt, interception losses, depression storage losses, potential and actual ET, and groundwater recharge. Detailed discussions of the PRMS model development and application can be found in Earthfx (2008). A brief summary is provided below.

The PRMS code calculates a water budget for each Hydrologic Response Unit (HRU), defined as a watershed or catchment with similar hydrologic properties. The code was modified by Earthfx to allow each HRU to represent one grid cell and, thereby, easily link PRMS to the MODFLOW model. The CLOCA area watersheds were discretized with a 25-m cell size to better represent land use and surficial geology variation (land use data and surficial geology are shown in Figure 7 and Figure 8, respectively). The estimated recharge values determined for the 25-m cells were summed and remapped to the 100-m CLOCA Groundwater Model cells.

The PRMS model was run in "daily" mode and used daily rainfall and temperature data from eight Environment Canada climate stations. The model tracks water in each HRU (25-m cell) as it moves through a number of "storage reservoirs", such as interception storage, depression storage, snowpack, shallow soil moisture, "subsurface water" (a perched water zone), and the groundwater reservoir. Water in the snowpack is subject to sublimation and melting/refreezing. The interception, depression, and soil moisture storage reservoirs are subject to evaporation and/or evapotranspiration (ET) on a daily basis.

Each HRU (25-m cell) can contain pervious and impervious surfaces and the water balance for each type is computed separately. The model computes interception by vegetation in both pervious and impervious areas. Water can also be captured in depression storage over the impervious portion of the HRU. Net precipitation after interception is added to the snowpack, if present, and the snowpack depth, density, and temperature are adjusted based on maximum and minimum air temperature and solar radiation. Net precipitation plus snowmelt on impervious areas is assumed to run off and contribute to daily streamflow. Net precipitation plus snowmelt on pervious areas is partitioned between infiltration and overland runoff. Partitioning to overland runoff was computed using the U.S. Soil Conservation Service (SCS) curve number technique. Deposits in areas of hummocky topography were assumed to have lower runoff and higher infiltration rates than similar deposits in non-hummocky areas. A more detailed description of the treatment of hummocky areas is provided in Earthfx (2008).

Water entering the soil in pervious areas is subject to ET. Excess water (above field capacity of the soil) percolates beyond the active soil zone and enters the subsurface reservoir. The depth of the active soil zone was estimated by the water table depth and soil type, and adjusted as part of model calibration. Percolation to groundwater from the subsurface reservoir is assumed to have a maximum daily limit dependent on hydraulic conductivity. Excess water is held back in the subsurface. The retained water can discharge to streams (as interflow) or percolate to the groundwater reservoir over several days. The groundwater reservoir discharges to baseflow at a rate dependent on a discharge coefficient and the volume of water stored in the reservoir.

The model was calibrated to streamflow data collected at each of the Environment Canada gauges in the study area. Estimates of baseflow (assumed to be mainly groundwater discharge to streams) were also compared to simulated baseflow as part of the calibration process.

The PRMS model was run over a 19-year simulation period (from October 1980 to September 1999). Figure 9 shows the average annual precipitation over the CLOCA watersheds based on the 19 years of daily data used as input to the PRMS model. Highest rates occur in the Tyrone area. Figure 10 shows the net ET over the CLOCA watersheds. This includes evaporation from interception and depression storage as well as soil moisture ET. ET rates are generally lower on the sandier soils which allow rapid infiltration and percolation to depth. Figure 11 shows the annual average surface runoff from both pervious and impervious surfaces. High runoff rates occur in the urban areas and especially in the commercial/industrial areas south of Highway 401 in the Oshawa area. Very low run-off rates occur on the ORM. Annual average rates of groundwater recharge are shown in Figure 12. As can be expected, rates are highest on the ORM and lower on the till soils and urban areas.

A map showing the combined recharge distribution used in the CLOCA Groundwater Model is presented in Figure 13.

2.8 Groundwater Extraction

In addition to groundwater discharge to streams and wetlands, groundwater extraction for municipal water supply and other large users was represented. Simulated pumping rates were assigned in the CLOCA Tier 1 study based on the maximum rates listed in their permits to take water (PTTW), registered with the Ontario Ministry of the Environment (MOE). The extraction rates were multiplied by consumptive use factors to account for return of some of the extracted water back to the aquifers.

The modelling effort pre-dated the availability of data from the MOE water taking reporting system (WTRS). The self-reported data provides a better estimate of actual taking because many users do not pump continuously at their maximum permitted rates. It was beyond the scope of the present study to update the water takings but should be considered in future modelling efforts.

2.9 Groundwater Flow Model Calibration

Calibration of the CLOCA Groundwater Model was a trial-and-error process in which results of successive model runs were used to refine the initial estimates of hydraulic conductivity, vertical anisotropy, and recharge rates. The primary target for model calibration was matching observed static water levels obtained from the MOE Water Well Information System (WWIS) database. As discussed by Kassenaar and Wexler (2006), there can be significant systematic error in the static water level data. The focus instead was on matching interpolated heads and flow directions. Potentiometric surface and water table maps for each aquifer were prepared using static water levels in water wells from the MOE WWIS database supplemented with other well data from geotechnical investigations and exploratory drilling. Further adjustment of model parameters was halted once a reasonable match between observed and simulated flow patterns was achieved. Final simulated heads in the ORAC and TAC are shown in Figure 14 and Figure 15, respectively.

Data on estimated stream baseflow were compiled and analyzed to determine rates of groundwater discharge to streams as described earlier. Matching these baseflow rates (both inside and outside the CLOCA area) was a second calibration target for the groundwater model. Estimates of net lateral inflow (cross-watershed flow) from each gauged catchment were used to adjust the calibration target for net infiltration and baseflow in the PRMS model. The process was repeated until general agreement between the PRMS and MODFLOW results was achieved. Figure 16 shows the simulated groundwater discharge to cells, in litres per second (L/s). Model results indicate that the greatest amount of groundwater discharge occurs in the headwaters of the major streams on the flanks of the Oak Ridges Moraine.

2.10 Summary

The previous sections provided a brief discussion of the Tier 1 hydrologic and groundwater models developed and calibrated for the CLOCA watersheds. The Tier 1 models were developed several years ago and only minor updates were applied in this study. Of particular note is that all streams and wetlands in the CLOCA watersheds are currently represented in the CLOCA Groundwater Model.

As with all models, it must be recognized that there are inherent simplifications in the model conceptualisation of distributed hydrologic processes and in the assignment of groundwater and hydrologic model parameters. There are also limitations and uncertainty in the input and calibration target data. Accordingly, it is unlikely to achieve perfect and/or unique models. However, the results obtained with the PRMS and MODFLOW models appear reasonable. Further discussions on the model calibration, sensitivity, and uncertainty can be found in Earthfx (2008) and Earthfx (2010).

Despite the fact that further improvements can be made to the models, it was felt that the existing groundwater model, including stream and wetland boundary conditions, upper layer geometry, aquifer properties, recharge rates, and calibration were sufficient to be used to identify the portions of the landscape that contribute discharge to stream reaches and wetlands (ESGRAs) through backward and forward particle tracking analysis.

3 <u>ESGRA Delineation Methodologies</u>

Earthfx developed a general methodology for delineating ESGRAs as part of a recent ESGRA delineation study for the Barrie, Lovers and Hewitt Creek watersheds (Earthfx, 2012). Although the flow model code used in the earlier study is different than the one used in this study (FEFLOW versus MODFLOW), the ESGRA methodology was specifically developed to be model-independent. A brief summary of the approach is provided below.

3.1 Particle Tracking

Particle tracking is an accepted methodology for visualizing and understanding groundwater flow paths. It is particularly useful in areas with complex, three-dimensional groundwater flow. In this study, the simulated heads and flows across each face of each model cell in the CLOCA Groundwater Model were post-processed and analyzed with the USGS MODPATH v6.0 code (Pollock, 2012). The MODPATH code uses output from MODFLOW-NWT along with estimates of aquifer porosity to determine local groundwater velocities within each cell. Virtual particles can be released at any point within a cell and then forward tracked from one cell to the next until it reaches a model boundary or an internal discharge point (e.g., a stream or well). Utilizing the same information, particles can also be tracked backwards from any discharge point in the model to their points of origin. Pathlines are displayed by connecting the points along the flow path (see Figure 17). Particle endpoints (i.e., the location at which the flow paths intersect land surface – representing the exit points when forward tracking or the entry points when backward tracking) can also be displayed or recorded in a database for further analysis.

For forward tracking in the direction of flow, particles are usually introduced in a uniform distribution across the model area. Forward tracking can be applied to help define and visualize the regional flow system. With forward tracking it is often necessary to release an extremely large number of particles in order to clearly illustrate the discharge to ecologically significant locations.

With backward tracking, particles are introduced in a dense distribution at a point of interest (e.g., an ecological feature supported by groundwater discharge) and traced back to the point of recharge. A benefit of reverse tracking is that attention can be focused on a limited set of specific ecological features.

Practical limits to the number of particles that can be applied uniformly across the model area and limits in the number of particles that can be packed into a discharge area may cause some small variations between forward tracking and backward tracking results. Differences can also occur when simulating flow in complex flow fields. For example, if groundwater is moving through "windows" in a regional aquitard, it may be difficult to identify all the possible particle paths through the windows if only a limited number of particles are released. Figure 18 is a schematic showing a particle release density that fails to capture flow through a window in a regional aquitard.

Another advantage of backward tracking is that clusters of particle endpoints can help identify the recharge areas that are important to a specific ecological feature. The density of particle endpoints can be used as an indicator of the significance of the recharge area. This is the basis for the delineation of ESGRAs in this study.

3.2 Bivariate Kernel Density Cluster Analysis

Once the backward particle-tracking endpoints originating from ecological features have been identified, clusters of endpoints can be further analysed to delineate ESGRA boundaries. The method used to identify clusters was adopted from published, peer-reviewed cluster analysis methodologies. Earthfx tested and refined the technique so that it could be applied to other subwatersheds and ensure that delineation of ESGRAs across Southern Ontario could be conducted in a consistent manner. Details of the method developed to objectively evaluate endpoint clusters and delineate ESGRAs are presented in Earthfx (2012).

Particle tracking endpoints tend to cluster in areas of focused higher recharge; while areas of diffuse recharge may end up with widely distributed, individual, or small groups of particles. Manually distinguishing between endpoints belonging to a cluster and isolated particles (outliers) can be rather subjective. For the purpose of this paper, "clusters" are defined as areas with a relatively high density of particle track endpoints. Endpoints that lie outside of the clusters are considered of lower significance and are excluded on the basis that they do not represent an ecologically significant volume of recharge. The delineated clusters are deemed to represent ESGRAs based on the assumption that the density of particle track endpoints correlate to recharge areas that are significant to sustaining groundwater discharge within these ecological features.

A consistent and repeatable method of identifying high-density clusters was developed based on multivariate kernel density function, $(\hat{f}_h)$, as defined by Wand and Jones (1993). In its two-dimensional (bivariate) form, it is given as:

$$\hat{f}_h(d_i) = \frac{1}{2\pi n h^2} \sum_{i=1}^{n} e^{-\frac{1}{2}\left(\frac{d_i}{h}\right)^2} \qquad [1]$$

where:

n = the total number of endpoints;
h = the smoothing (or bandwidth) parameter; and
d_i = the distance between endpoint i and the point in space being evaluated.

The choice of the Gaussian kernel function is somewhat arbitrary as a uniform, triangular or inverse-squared distance kernel (amongst others) could also be used to define the distribution of particles within a cluster. The Gaussian distribution is consistent, however, with the dispersive processes typically encountered in groundwater flow due to heterogeneity and local variations in hydraulic conductivity. It is also our findings that the cluster evaluation is more sensitive to the bandwidth parameter (i.e., the smoothing parameter) than the choice of kernel. The kernel provides a weighting function; giving stronger weights to endpoints in close proximity to the point in space that is being evaluated.

A second phase of cluster processing is needed to normalize the density field and eliminate areas of relatively small density. This helps to eliminate ESGRAs of very small areal extent and to infill any "doughnut-holes" present in an ESGRA. Removing areas of small density is accomplished by first defining a delineation cut-off threshold (ε) and eliminating all areas where the calculated density is less than a ε^{th} of the maximum evaluated $\hat{f}_h$ (i.e., eliminating all areas where $\hat{f}_h < \hat{f}_{h,max} / \varepsilon$).

In Earthfx (2012), the minimum allowable ESGRA extent was set to 0.045 km², which corresponded to the average size of the triangular elements used in the finite-element model for the Barrie, Lovers and Hewitt Creek watersheds. This corresponds to an equivalent finite-difference cell size of 200 by 200 m. Doughnut-holes less than 0.045 km² were filled in to produce continuous ESGRA delineations.

In summary, delineating ESGRAs is conducted by applying the Normalized Bivariate Kernel Density Estimation (NBKDE) procedure followed by the application of appropriate thresholds and the removal of outliers and infilling of holes. The advantage of the NKBDE method is that it is unbiased compared to grid-based counting methods which are dependent on grid size, origin, and orientation.

4 Particle Tracking Analysis

As noted above, particle tracking techniques can be used to help visualize flow pathways in the simulated three-dimensional groundwater system. Although not directly related to the mapping of ESGRAs, the exercises described below helped to better understand the complex flow patterns in the study area and to verify that the CLOCA Groundwater Model correctly represented flow in the shallow aquifers as well as groundwater/surface water interaction.

4.1 Forward Tracking

In the first forward-tracking exercise, 16 particles (a 25 m by 25 m particle spacing) were released from each model cell in the CLOCA watersheds. The virtual particles were tracked forward from their release points until they reached a point of discharge. Figure 19 displays the endpoints for all particles. As can be seen, most of the particles released in the CLOCA watersheds are discharged to streams and wetlands within the CLOCA boundary. Some particles end in streams outside the CLOCA boundary, indicating that recharge in the CLOCA watersheds is helping to support these external features. Relatively few particles discharge directly to Lake Ontario. This exercise also serves to demonstrate the satisfactory function of the model, as particles terminate at logical boundary points (streams, wetlands, and Lake Ontario).

The second forward-tracking exercise looked at the fate of particles released from a specific geologic feature, in this case, the Oak Ridges Moraine deposits. Figure 20 shows the pathlines of particles released in the high recharge areas and confirms that the Oak Ridges Moraine deposits help to support the headwater tributaries of the major streams within the CLOCA watersheds. Figure 21 shows the endpoints of particles released in the ORM deposits. Some long pathlines can be observed including some that emerge, as an example, in the lower reaches of Harmony and Farewell Creeks. Figure 22 illustrates a cross section along one of these longer flow lines (the location of the section line is shown on Figure 20). It can be seen that some of the particles released on the Oak Ridges Moraine move downwards through multiple aquitards in the vicinity of the Moraine then move back upwards near the discharge zones.

The third forward-tracking exercise looked at the fate of particles released from the Iroquois beach deposits and other sandy glacial lake deposits that exist at surface within the study area (Figure 23). These glaciolacustrine deposits are also predicted to be areas of relatively high recharge (Figure 13). Figure 24 shows the endpoints of virtual particles released in these deposits. Results indicate that recharge in the Iroquois Beach deposits contributes to flow in the lower reaches of major streams and to the minor tributaries south of the Iroquois shoreline.

The results of the previous two exercises were merged to produce a single map (Figure 25) that shows the location of particle endpoints classified based on the originating surficial geologic unit. Contrasting the forward-tracking endpoint analysis of the Oak Ridges Moraine with that of the Iroquois Beach deposits, it can be noted that the latter supports local features adjacent to the Iroquois Beach shoreline. The Oak Ridges Moraine deposits, however, support headwater features well south of the Moraine ridgeline and the beach deposits.

4.2 Backward Tracking

In the backward tracking exercise, a large number of particles are released from cells that represent ecological features assumed to be receiving groundwater discharge. The particles are then tracked backwards until they reach a point of groundwater recharge. Figure 26 shows the particle release points representing all stream reaches and wetlands identified by CLOCA staff. To prepare this figure, only 16 particles per cell were released (a 25 m by 25 m particle spacing) so that individual endpoints could be distinguished. A higher density of particles was released for the formal analysis as described in 5.1.

The resulting pathlines (Figure 27) show both short and long flow paths originating in areas of local and regional recharge, respectively. The longer flow paths tend to track back to the Oak Ridges Moraine while many of the local flow paths track back to the Iroquois Beach and other glaciolacustrine deposits. Of note are the pathlines that originate in recharge areas outside the CLOCA watersheds indicating that cross-watershed flow is important to maintaining streams in the CLOCA watersheds.

5 ESGRA Delineation and Analysis

The ESGRA delineation methodology employs particle-tracking techniques to identify, visualize and quantify the groundwater flow paths between the ecological feature and the recharge area. To conduct the particle-tracking analysis, a groundwater model is first used to determine groundwater heads and fluxes between all model cells. A velocity flow field is then derived from the cell-by-cell fluxes. Next, virtual "particles" are released in the model and traced backward from areas of ecological interest through the groundwater system to locations of recharge (Section 3.1). The particle-track endpoints are grouped and analyzed to determine the particle endpoint density (Section 3.2). While particle density does not correspond directly to recharge volumes, it does help establish that a significant amount of the recharge in the area is delivered to the ecological feature. Figure 17 illustrates backward particle tracking from a typical significant ecological feature to an area of recharge.

5.1 Particle Release Points

For the purposes of this study, all mapped streams and wetlands within the CLOCA watersheds, shown in Figure 2, were assumed to be significant for the purpose of this study (regardless of cold water versus warm water stream classification). Particles were released into the model at the top of layer 1 in a manner consistent with the methodologies outlined by Earthfx (2012). All cells with a mapped stream passing through, even if a short reach, were selected for analysis. Wetland outlines were overlain on the model grid. If the centre of the cell fell within the wetland outline, the cell was selected.

Released particles were tracked backwards from the stream or wetland feature, through the groundwater system to their originating, recharging model cell. Figure 26 presents the model cell release locations for the backward tracking analysis from streams. In each model cell, particles were released on a 5 x 5 m spacing to ensure that enough particles were included to delineate the interactions between the groundwater, stream channel, and the riparian areas adjacent to the stream. Based on this distribution, a total of 400 particles were released in each 100 by 100 m model cell. A total of 5,537,200 particles were released into model cells with significant features for the backward-tracking analysis.

5.2 Backward Tracking Particle Endpoint Results

Figure 27 illustrates the pathlines from the significant features within the CLOCA watersheds. In preparing this illustration, particles were released at a sparser density of only one particle per model cell (100 by 100 m particle spacing). At the finer 5 by 5 m analysis spacing, the density of the pathlines is so high that individual pathlines cannot be distinguished on the figure. As can be seen, on Figure 27, many pathlines cross the watershed boundary and track back to recharge areas outside the CLOCA watersheds located higher up on the Oak Ridges Moraine. While the ESGRA delineation is limited to the CLOCA jurisdiction, the endpoint analysis discussed below extended to those recharge areas beyond the CLOCA boundaries that support features located within CLOCA.

The endpoints of the backward tracked particles released from cells containing streams and wetlands, respectively, are shown on Figure 28 (at a reduced particle density (25 by 25 m spacing for clarity). Of the particles released for the ESGRA analysis, approximately 2,516,184 (45%) were released in cells that the model indicated that discharge was occurring. These were used for endpoint analysis and ESGRA delineation. The remaining particles were released into cells that were found to be locally recharging the groundwater system (e.g., a headwater stream reach or a wetland segment where little or no discharge was occurring). These particles did not leave the starting cell and were therefore excluded from the endpoint analysis (because they indicated that the cell was a recharge cell not a discharge cell). Of the 2,516,184 retained endpoints, about 212,476 (8.4%) tracked backward into neighbouring watersheds.

5.3 ESGRA Delineation

ESGRAs were delineated by analyzing the particle endpoint locations using the bivariate kernel density estimation technique for cluster analysis presented in Section 3.2. The technique assesses the density and significance of the particle end point distribution allowing for areas of greatest density to be mapped as ESGRAs.

The sensitivity of cluster analysis results was assessed by varying the NBKDE smoothing parameter (h) and the delineation threshold (ε). The smoothing parameter was varied in steps from 10 to 250 m and the delineation threshold (ε) was varied in steps from 10 to 1000. Table 4 presents the percent of the endpoints within the delineated ESGRAs with respect to the number of particles released (excluding particles that did not leave their starting cell). Table 5 presents the corresponding area delineated as potential ESGRAs for various values of the NBKDE parameters (h, ε). Table 6 presents the ESGRA cluster density (i.e., the number of endpoints that are contained within a potential ESGRA divided by the total combined ESGRA coverage area).

Table 4: Percent of endpoints covered by potential ESGRAs with varying smoothing parameter (h) and delineation threshold ε.

		h (m)					
		10	**25**	**50**	**100**	**150**	**250**
ε	**10**	6.7	7.0	17.4	52	79	97
	20	17.6	22.0	***50.6***	85	96	100
	100	83.6	87.4	97.5	100	100	100
	200	95.6	97.6	99.8	100	100	--
	1000	100.0	100.0	100.0	100	100	--

Table 5: Area (km^2) of potential ESGRAs with varying smoothing parameter (h) and delineation threshold ε.

		h (m)					
		10	**25**	**50**	**100**	**150**	**250**
ε	**10**	2.1	2.8	16.1	124.7	296.9	528.4
	20	10.8	19.1	***96.3***	321.4	483.3	613.6
	100	189.3	263.4	449.9	579.8	623.0	672.4
	200	288.1	392.5	531.0	604.7	639.4	--
	1000	413.0	516.7	583.7	632.6	661.7	--

Table 6: Potential ESGRA point density (endpoints/km^2) with varying smoothing parameter (h) and delineation threshold ε.

		h (m)					
		10	**25**	**50**	**100**	**150**	**250**
ε	**10**	82385	64151	27977	10892	6926	4759
	20	42142	29790	***13632***	6830	5148	4219
	100	11468	8620	5627	4472	4167	3862
	200	8616	6459	4878	4293	4061	--
	1000	6287	5025	4448	4105	3924	--

Based on the results shown in Table 4 through Table 6 and on consultation with CLOCA staff, the optimal kernel smoothing parameter h was set to 50 m (which is equal to twice the grid cell spacing for the kernel analysis and half the grid spacing of the numerical model). A delineation threshold, ε = 20 (or 1/ε = 0.05), was chosen because it proved to consistently identify particle clusters while meeting the following criteria:

- rejection of endpoints that clearly did not belong to any cluster;
- delineation of clusters with a relatively high density of particle endpoints; while
- not incorporating areas where endpoint density is low or zero.

The final combined ESGRA mapping using these parameter values is provided in Figure 29 which shows ESGRA delineation for all ecological features (i.e., streams, and wetlands). ESGRAs having an area less than 0.045 km² (45,000 m^2) were excluded, consistent with the approach of Earthfx (2012). The total land area identified as an ESGRA within the CLOCA watersheds is 131.3 km^2.

Of the identified endpoints, only 51% are included in the ESGRA coverage. This is a lower capture ratio than obtained in some ESGRA studies in the Lake Simcoe region. This can be explained by considering the simulated annual average recharge (Figure 12). There are many areas of high but relatively uniformly-distributed recharge. These areas, while supplying large volumes, distribute this recharge over much of the study area. Many pathlines from particles released to features across the study watersheds track back to the Oak Ridges Moraine (Figure 27 and Figure 28). However, because the recharge rates were relatively uniform and because of the wide spatial distribution of the streams supplied, tight clustering of particles was not observed within the ORM area. Therefore, when applying regional-scale clustering parameters (h and ε) some portions of these high volume areas were excluded while recharge areas supplying local features were favoured (this will be discussed further in the subsequent section). The optimized values of h and ε, however, produce an ESGRA coverage with a relatively high endpoint density, which increased the confidence that the delineated areas represent ecologically significant recharge areas.

5.4 Comparison of ESGRA and HVRA Results

High volume recharge areas or HVRAs (also known as significant groundwater recharge areas) were delineated by CLOCA (2008) utilizing PRMS-based hydrologic model output (Earthfx, 2008; also discussed Section 2.7). HVRAs were delineated as per Technical Rule 44(2)(1) as: *areas where the rate of recharge is greater than a factor 1.15 of the average recharge across the area* (MOE, 2009). The HVRAs identified in the study area are shown in Figure 30. It should be noted that these HVRAs were defined based on the average recharge (158 mm/year) across all the CLOCA watersheds.

As noted earlier, the areas of higher than average recharge do not necessarily coincide with ecologically significant groundwater recharge areas (ESGRAs). Figure 31 compares the ESGRAs delineated in this study with the HVRAs identified in the study area. Within the CLOCA watersheds, which have an area of 638 km^2, 193 km^2 are defined as a HVRA while 131 km^2 have been delineated as an ESGRA. There is some correspondence between the two delineations with 49.4 km^2 of overlap, or 38% of the delineated ESGRAs. ESGRAs are identified on the Moraine, however, that serve as an important source of recharge supporting sensitive headwater features. However, as discussed above, recharge on the Oak Ridges Moraine is relatively uniform and recharge to the lower reaches of streams is more diffuse so that clusters of pathways don't necessarily emerge in these areas. Substantial differences can also be seen over the till covered areas where the HVRAs analysis misses the lower-volume local recharge systems. Better correlation is evident in the Iroquois Beach deposits (Figure 23) where recharge appears to directly support adjacent local features.

Much of the differences between the mapped extents of the HVRAs and ESGRAs are likely a result of delineating the HVRAs using only a hydrologic model (PRMS) where the ESGRAs are delineated using a linked hydrologic and groundwater model. The groundwater model demonstrates the linkages between the recharge and discharge areas and can help identify the portions of the HVRAs that provide significant recharge to specific ecological features. As an example, most areas mapped as surficial sands would likely be identified as HVRAs by the PRMS hydrologic model. In the linked hydrologic and groundwater model, only if a significant number of pathways link that recharge area to an ecological feature will it delineated as an ESGRA. In a regional context, the areas of high uniform recharge are important, as they likely contribute a portion of flow to a large number of widely distributed ecological features. The ESGRA methodology helps to identify areas with lower recharge (on a regional scale) that directly support nearby ecologically sensitive features. While both analyses are driven by, and describe, recharge patterns, each does so at differing scales. When assessing regional areas of significant recharge, both mapping effort should be considered in partnership with the other.

6 Analysis of Individual Features

In the previous sections, particle-tracking techniques were applied on a regional scale. While understanding the regional flow system is important, the model can also be applied to describe groundwater connections to local features on an individual basis. Two wetland features, shown in Figure 32, were investigated to demonstrate the utility of these methods on a more localized, feature-by-feature basis.

The first feature studied was a wetland complex sited in the Hampton Creek branch of Bowmanville Creek. CLOCA staff have noted that this area is a discharge zone, with observable upwelling during the spring months. Particles were released into this feature on a 25-m grid and tracked backward through the groundwater system to the originating point of recharge. Figure 33 illustrates the pathlines and endpoints from this analysis, which seem to affirm that this wetland feature is a discharge area. Interestingly, while these results suggest that some local recharge supports this feature, much of the groundwater discharge appears to originate atop the Oak Ridges Moraine including in areas outside CLOCA boundaries.

The second feature selected for analysis was a series of three discontinuous wetland segments (identified as swamps by CLOCA staff) located in the Harmony-Farewell Iroquois Beach Wetland Complex. As the name suggests, these wetlands sit over permeable Iroquois Beach deposits. Particles were released into this feature on a 25-m grid and tracked backward through the groundwater system to the originating point of recharge as shown on Figure 34. The particle tracks produced from this exercise are typically short and terminate within less than 1000 m of their starting locations in the three discontinuous swamp features. While several of the particle tracks extend further north, indicating some contribution from more remote areas (i.e., the glaciolacustrine deposits west of Solina), the majority of the pathlines suggest that any supporting recharge areas for these wetlands are highly localized. A number of backward pathlines terminate in the starting cell suggesting that these wetlands also serve as recharge zones, possibly supporting other nearby ecological features. This is confirmed by the ESGRA mapping, which delineated both the east and west wetlands in the group as ecologically significant recharge areas (Figure 29).

Individual features can be analyzed with the CLOCA Groundwater Model and the particle tracking and clustering techniques outlined in this report. Analyzing a large number of individual features can be time consuming, but these methods allow for local connections within the regional groundwater system to be assessed. This type of analysis may prove useful in future subwatershed-scale wetland studies, ecological surveys, or when assessing the impacts of urban development on particular ecologically sensitive features or the groundwater system in general.

7 Conclusions and Recommendations

This report represents a collation of a number different analyses, all with the intent of improving the current understanding of the movement of groundwater within the CLOCA watershed. Primarily this work focused on linking identified ecological features to the areas of groundwater recharge which support these features. The work relied heavily upon previous modelling efforts undertaken by CLOCA and by Earthfx as part of the Source Water Protection Program (SWP).

The groundwater model was first upgraded to the recently released NWT version of MODFLOW for improved stability. A discussion of these upgrades was provided and it is expected that this revised, more flexible version of the CLOCA Groundwater Model will prove useful for other projects in the near future.

The principal tool employed in this work was particle tracking. This technique allowed flow pathlines to be tracked from recharge zones at ground surface through the groundwater system to an ultimate discharge point. This method can also be reversed, to assess the origins of the groundwater that supplies wetlands and streams. Particle tracking on its own proved elucidating when considering the areas of significant recharge and the ultimate fate of groundwater recharge within the CLOCA watersheds. It was also shown that recharge areas on the Oak Ridges Moraine, outside of the CLOCA boundaries, contribute to groundwater discharge into a number of wetlands and streams in the CLOCA watersheds.

The primary task in this assessment was the reverse particle tracking from ecologically significant features to assess the origins of the groundwater that supplies these wetlands and streams. Particles were placed in and around ecologically significant surface water features and traced back to their point of recharge. For this study, all streams and mapped wetlands in the CLOCA watersheds were treated as significant. Some pathlines converged to high-volume recharge areas, but others traced back to local recharge areas or zones outside CLOCA boundaries. Cluster analysis techniques were applied to assess the density and significance of the particle endpoint distribution. Areas of greatest density were mapped as ecologically significant groundwater recharge areas (ESGRA) via the kernel density estimation technique, which provided a quantitative and repeatable method for cluster endpoint density analysis and ESGRA delineation.

The delineated ESGRAs were compared to previously published mapping of high volume recharge areas (HVRA, also referred to as significant groundwater recharge areas). Some overlap was observed; however, in areas of distributed and uniform recharge, clusters were not identified. This suggests that the HVRAs and the ESGRAs should be considered together when assessing regional recharge patterns and groundwater movement.

While it was beyond the scope of this project to analyse individual features, backward tracking was undertaking from two wetland features. This additional analysis demonstrated that the techniques presented in this report can be applied with a localized focus to study the connections of individual features within the context of the regional-scale groundwater system. An additional area of future study could include an analysis of particle travel times. Particles with long travel times such as those originating on the Oak Ridges Moraine could be analyzed separately from particles with short travel times (i.e., areas of localized recharge.) This would help to understand the relative influence of local recharge features on a regional scale.

The study noted that, as with all models, there are inherent simplifications in the model conceptualisation of distributed hydrologic processes and in the assignment of groundwater and hydrologic model parameters. There are also limitations and uncertainty in the input and calibration target data. Thus, there are opportunities for further enhancement of the model techniques, in particular for representing groundwater/surface water interaction, and collection of additional data to help improve model calibration and reduce uncertainty. With regards to the ESGRA delineation, there are recently developed techniques for volumetrically defining the recharge areas contributing to streams and wetlands (e.g., Foley and Black, 2013) that could be tested and applied to the study area.

8 Limitations

Services performed by Earthfx Incorporated were conducted in a manner consistent with the level of care and skill ordinarily exercised by members of the environmental engineering and consulting profession. This report presents the results of data compilation and computer simulations of a complex hydrogeologic setting. Data errors and gaps are likely present in the information supplied to Earthfx, and it was beyond the scope of this project to review each data measurement and infill all gaps. Models constructed from these data are limited by the quality and completeness of the information available at the time the work was performed. Computer models represent a simplification of the actual hydrogeologic conditions. The applicability of the simplifying assumptions may or may not be suitable to a variety of end uses.

This report was prepared by Earthfx Incorporated for the sole benefit of The Central Lake Ontario Conservation Authority. Any use which a third party makes of this report, any reliance thereon, or decisions made based on it, are the responsibility of such third parties. Earthfx Incorporated 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.

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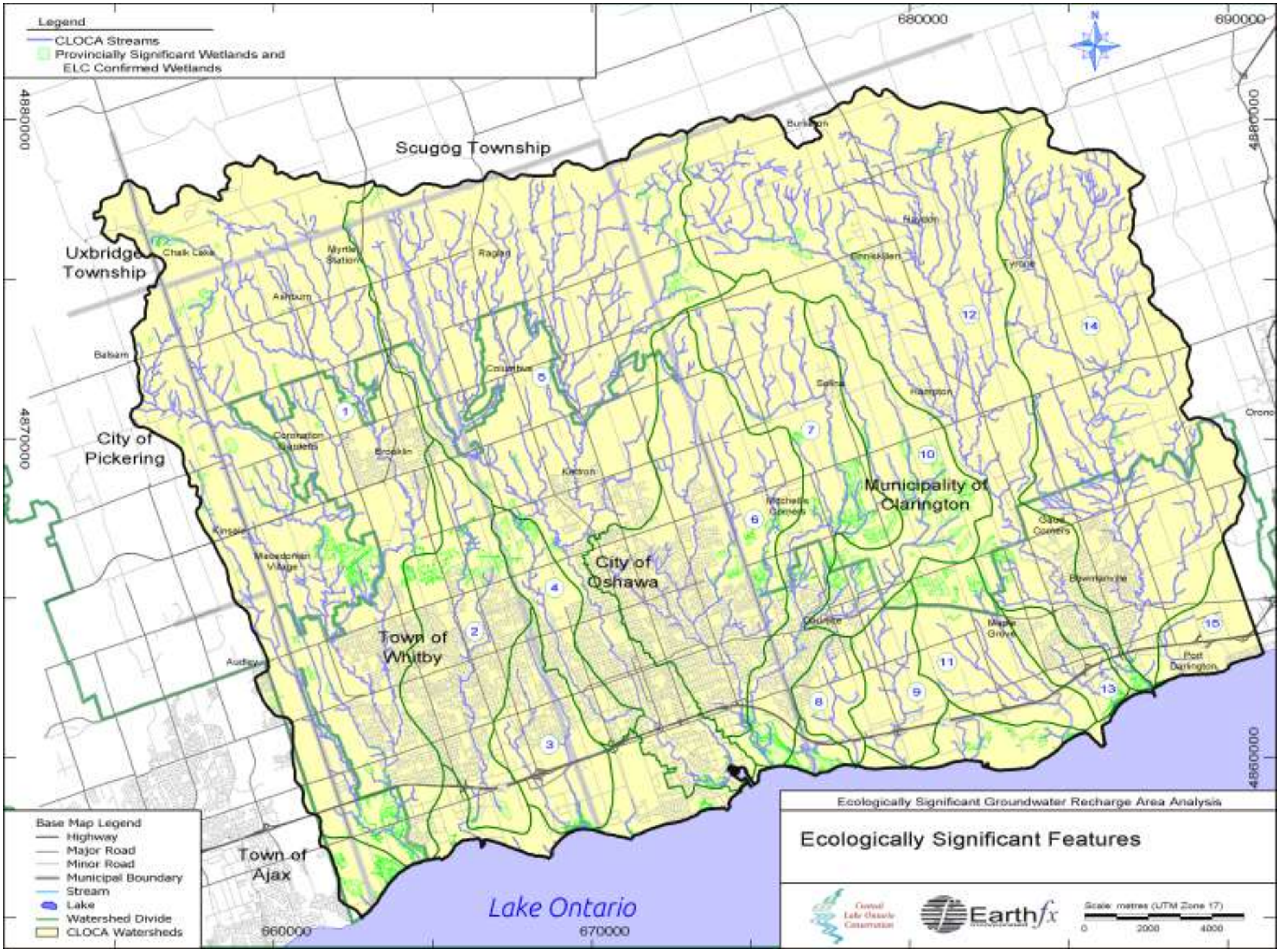
10 Figures

Figure 1: Watersheds of the Central Lake Ontario Conservation Authority.



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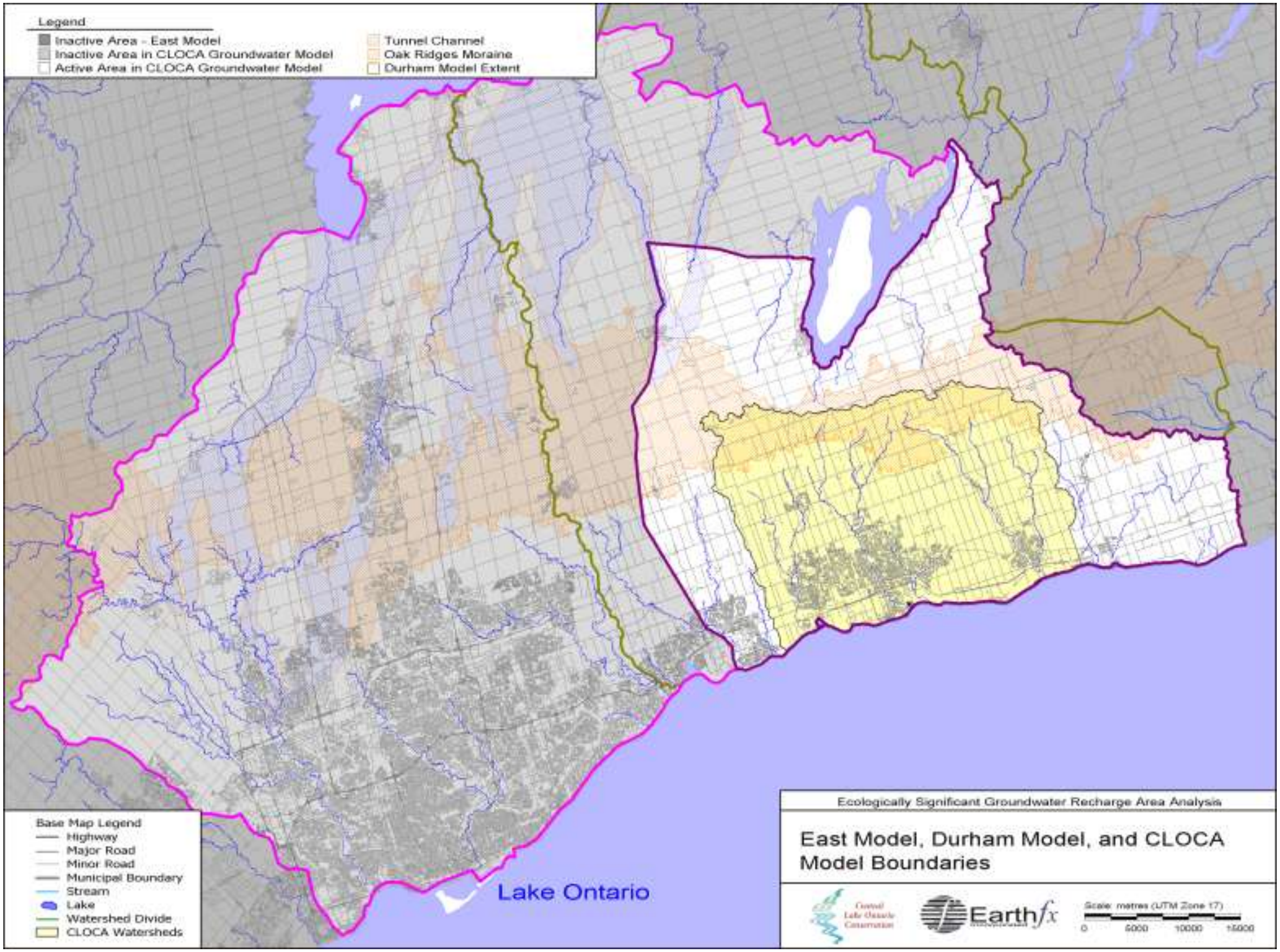

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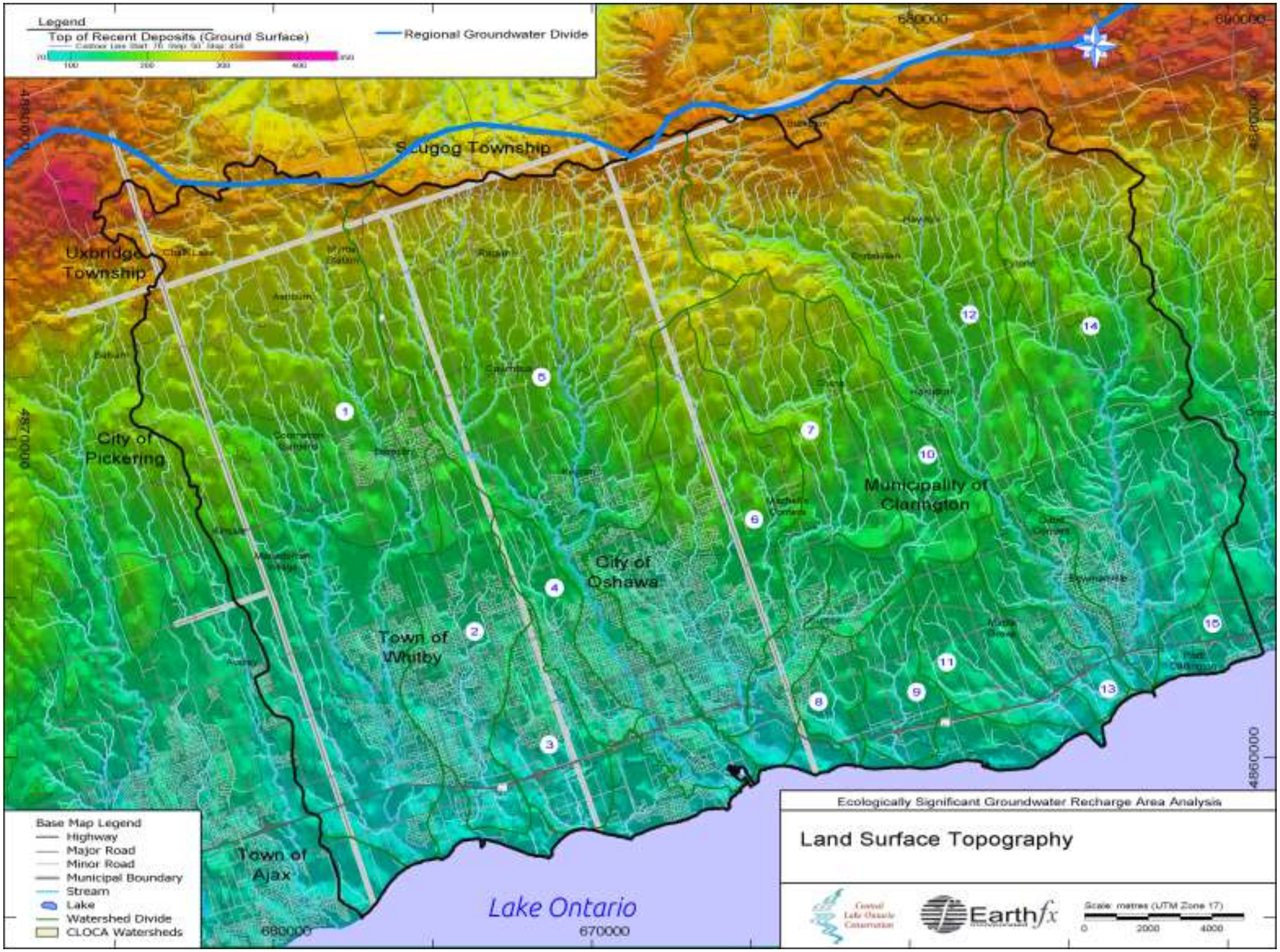

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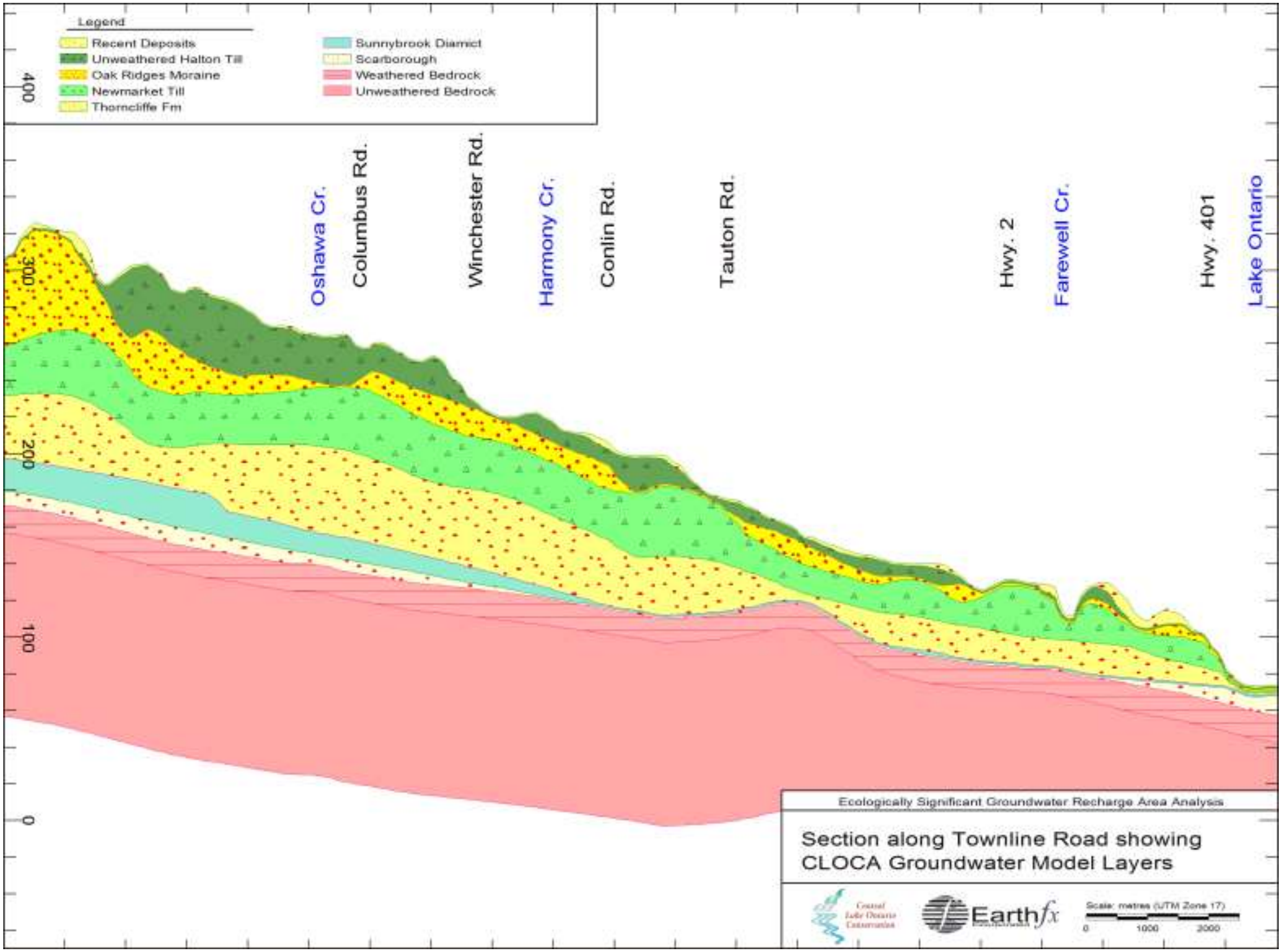

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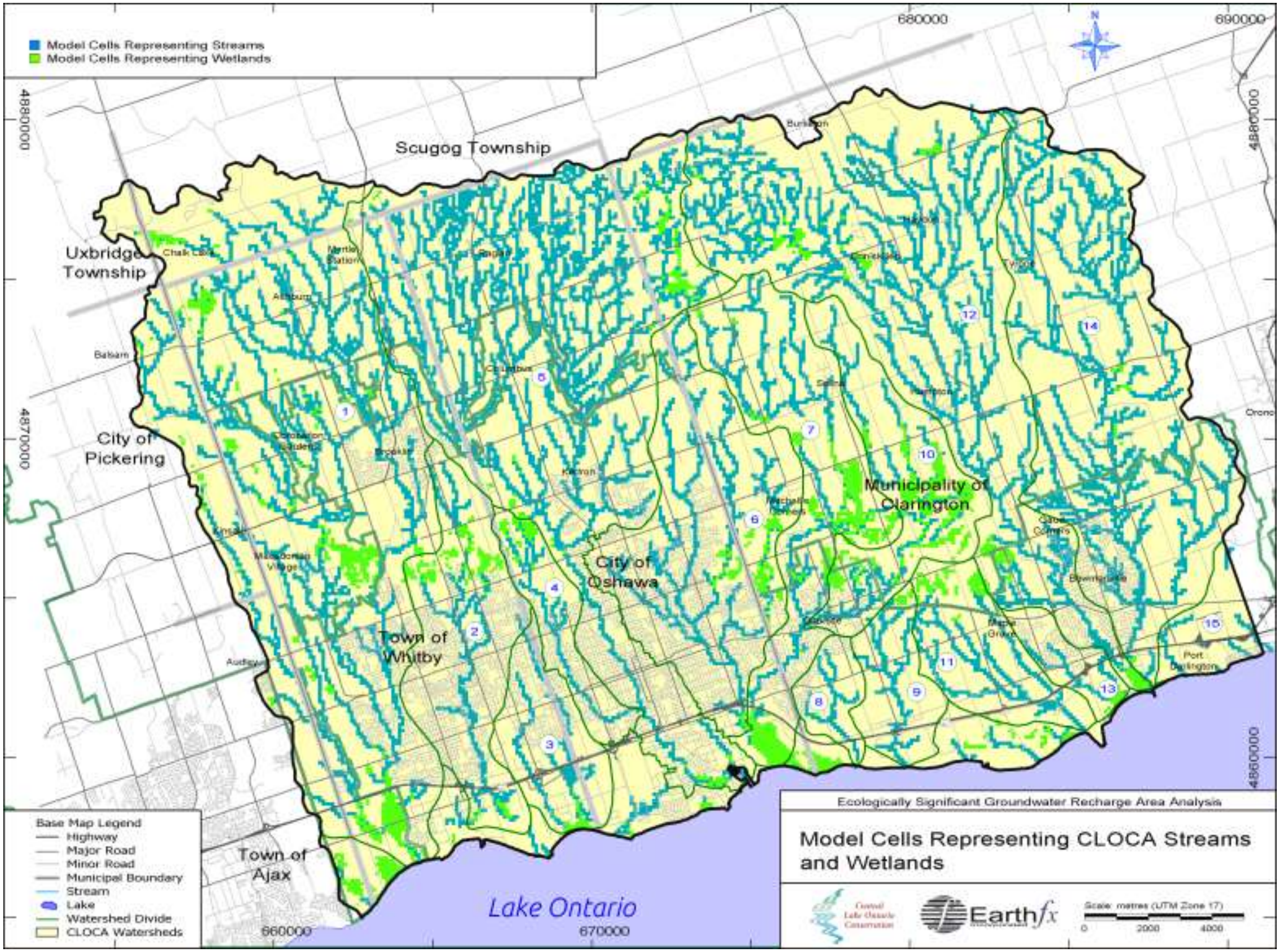

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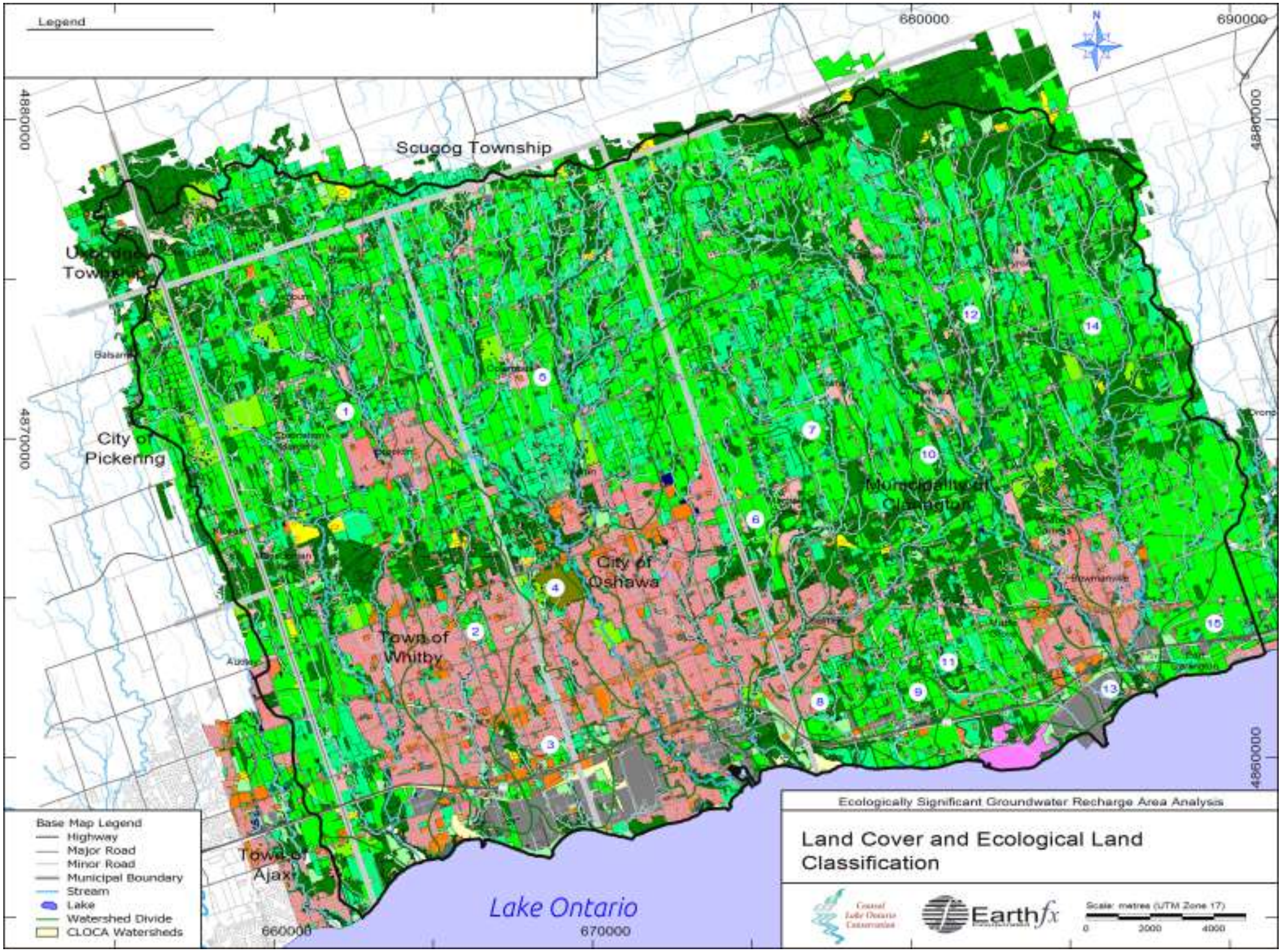

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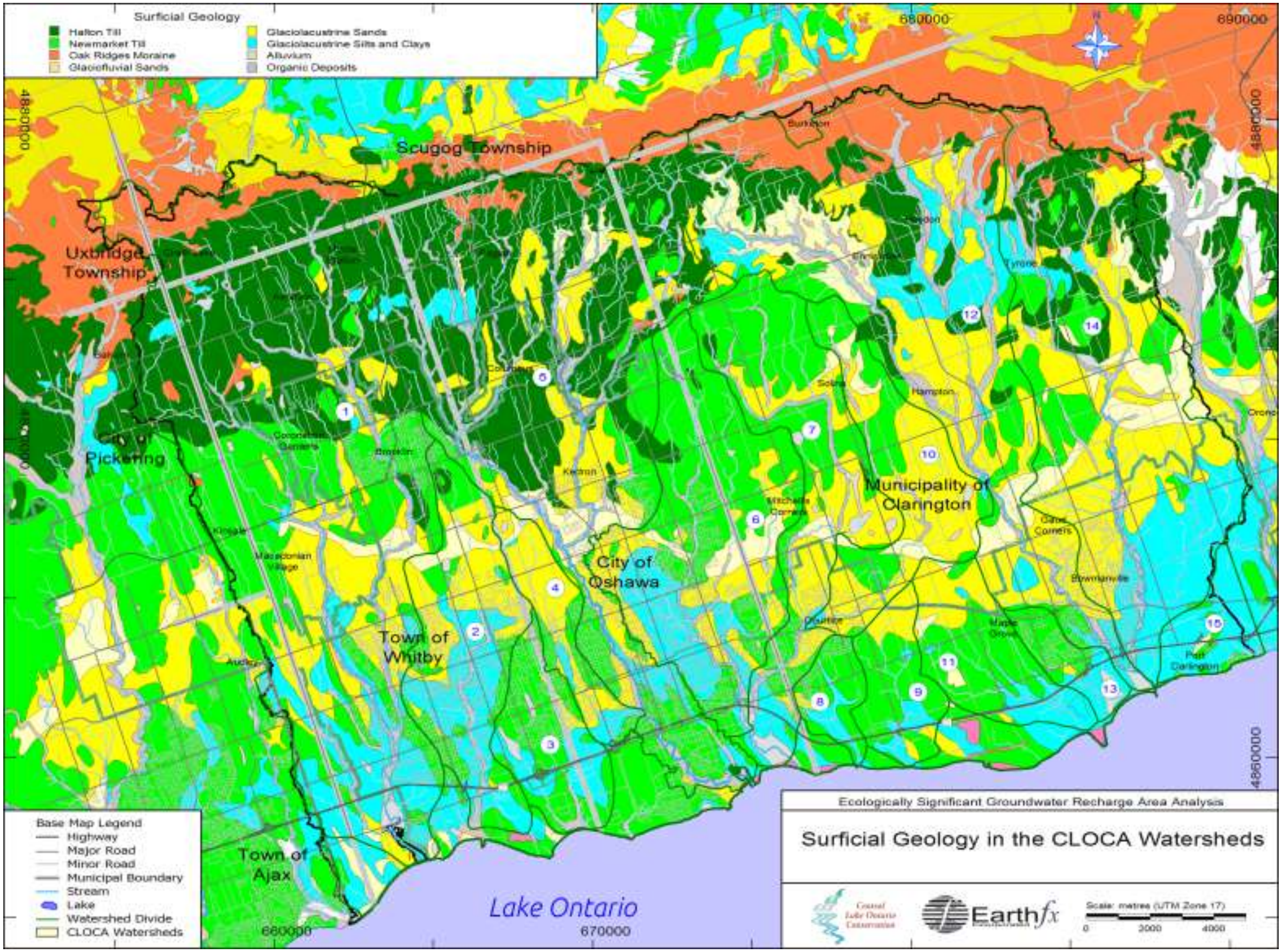

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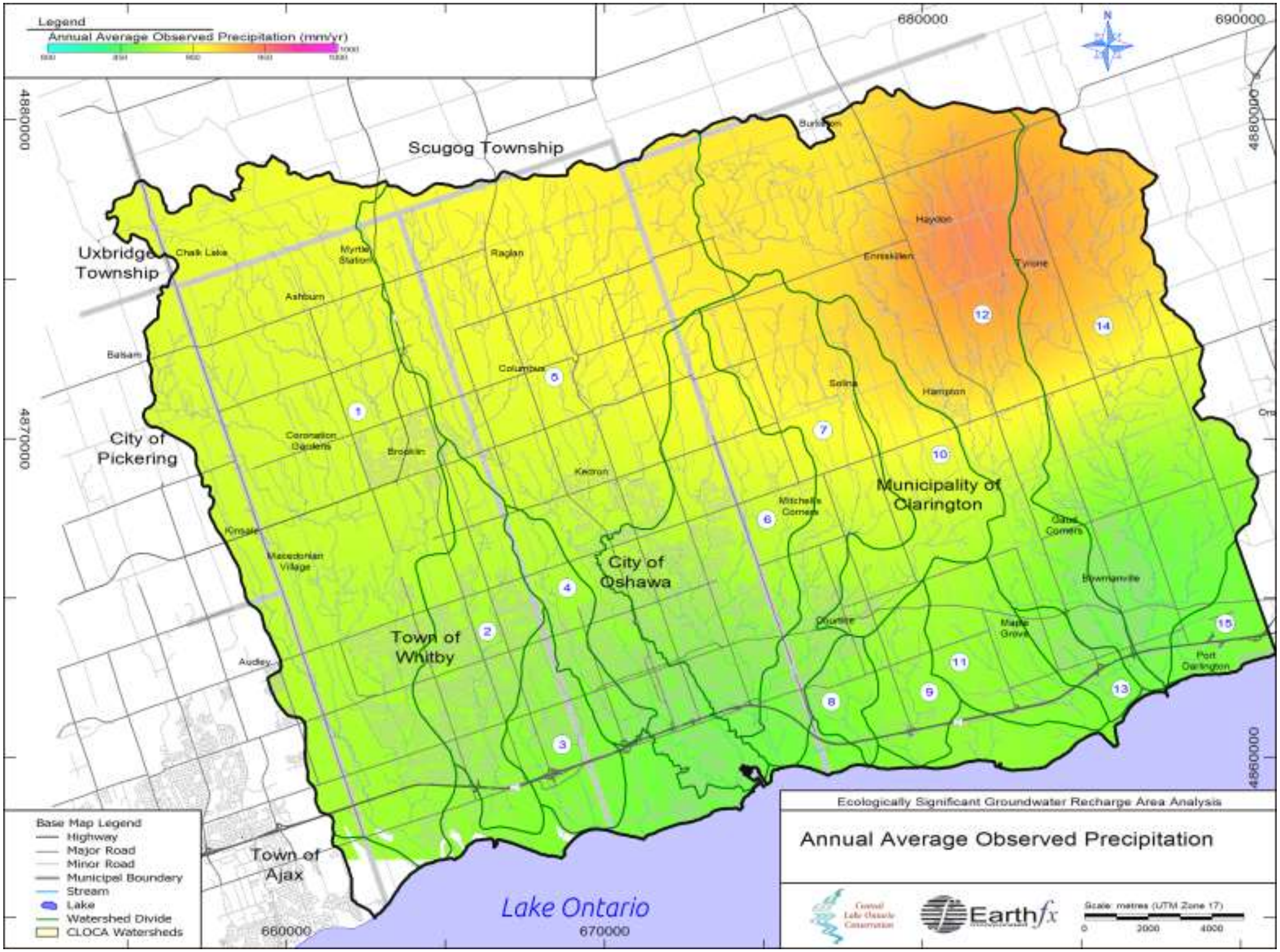

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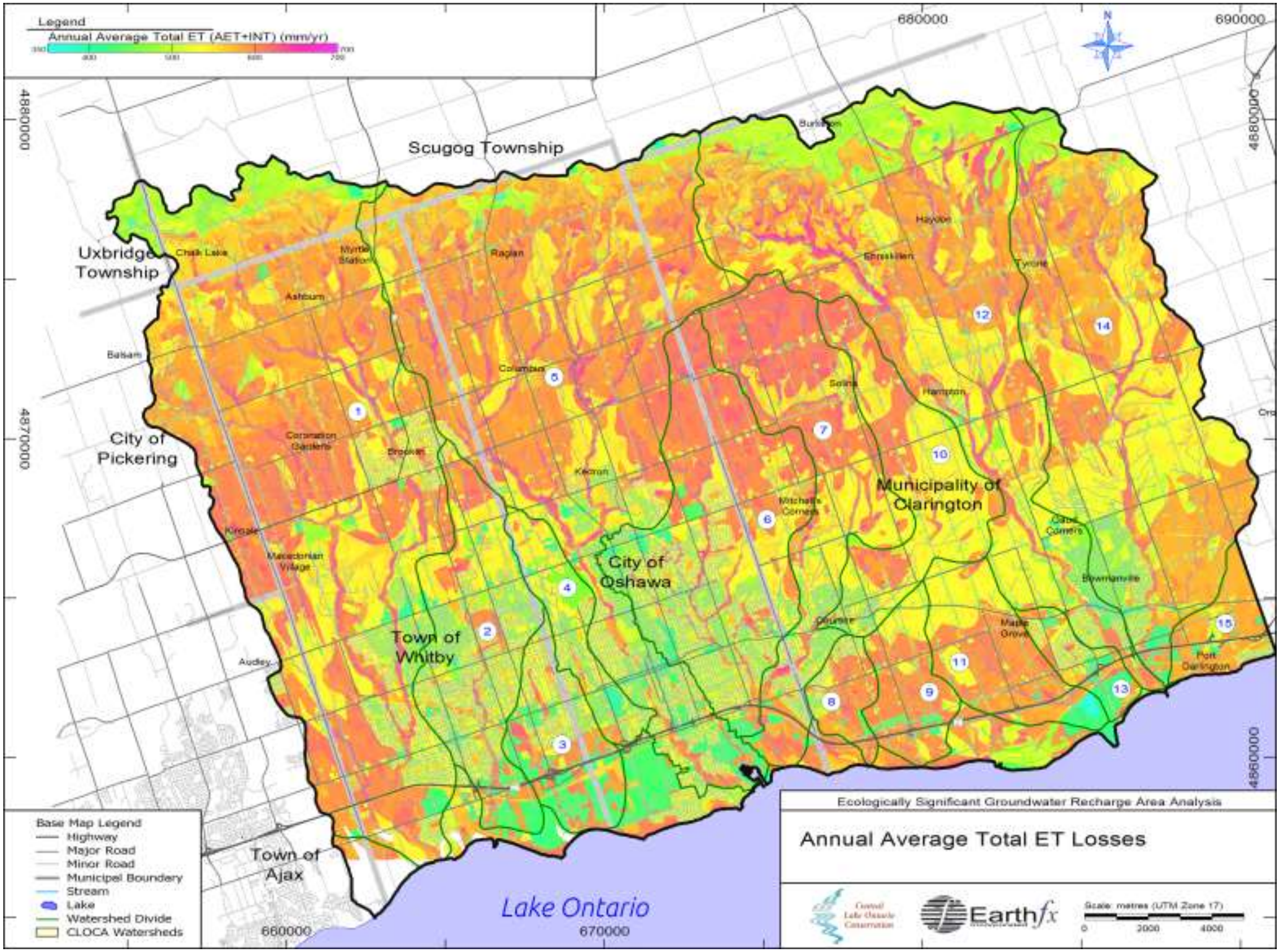

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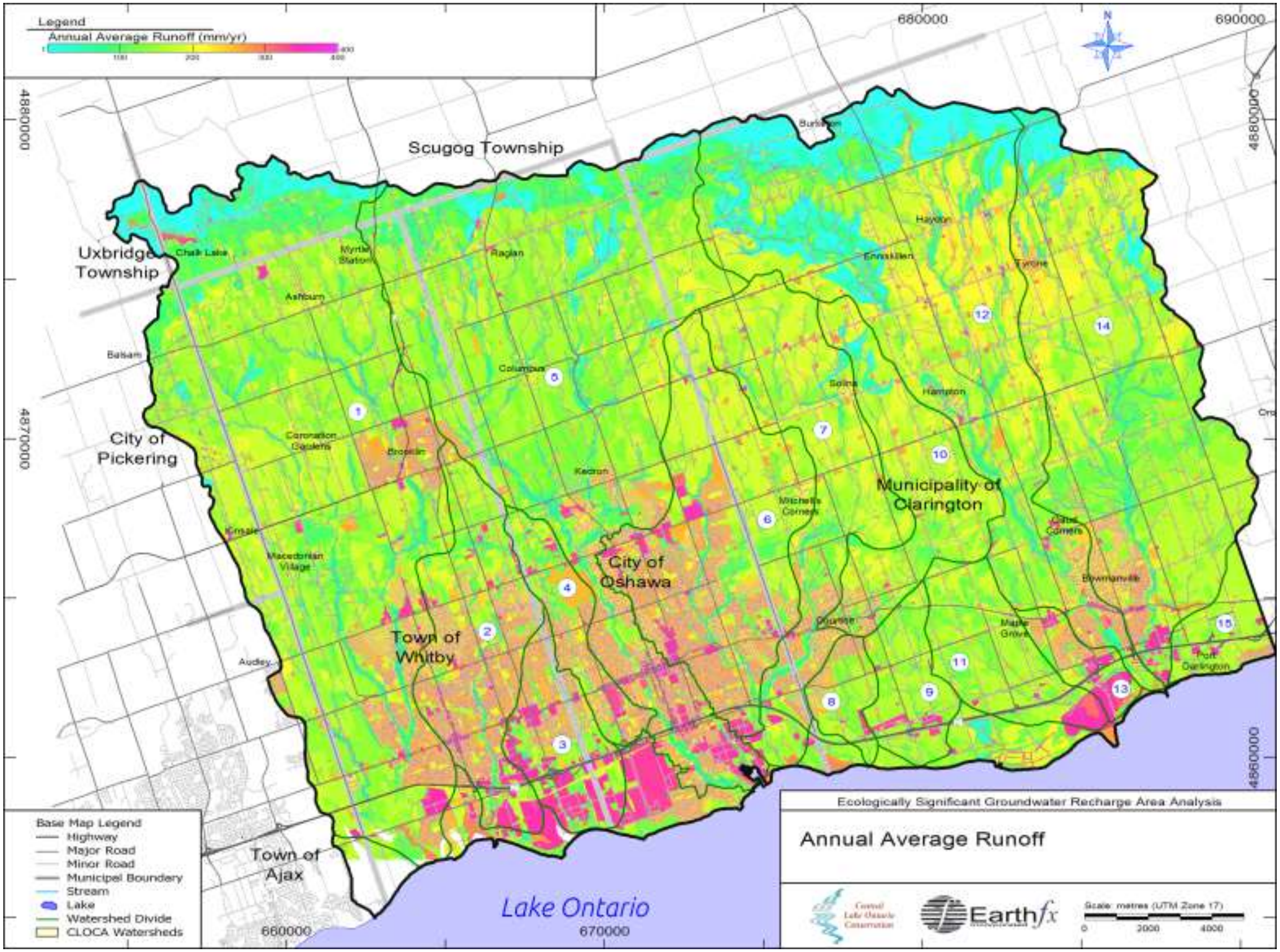

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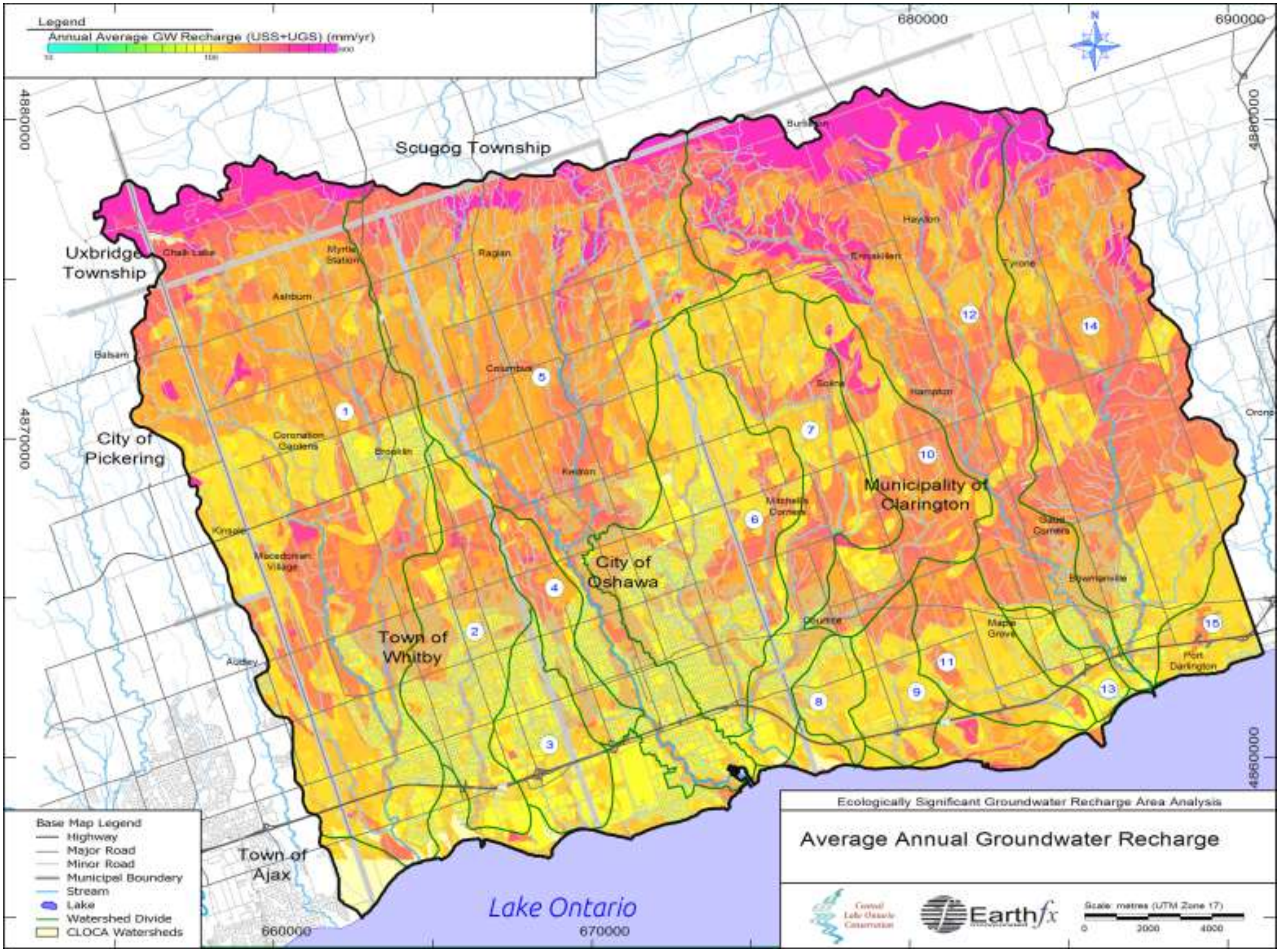

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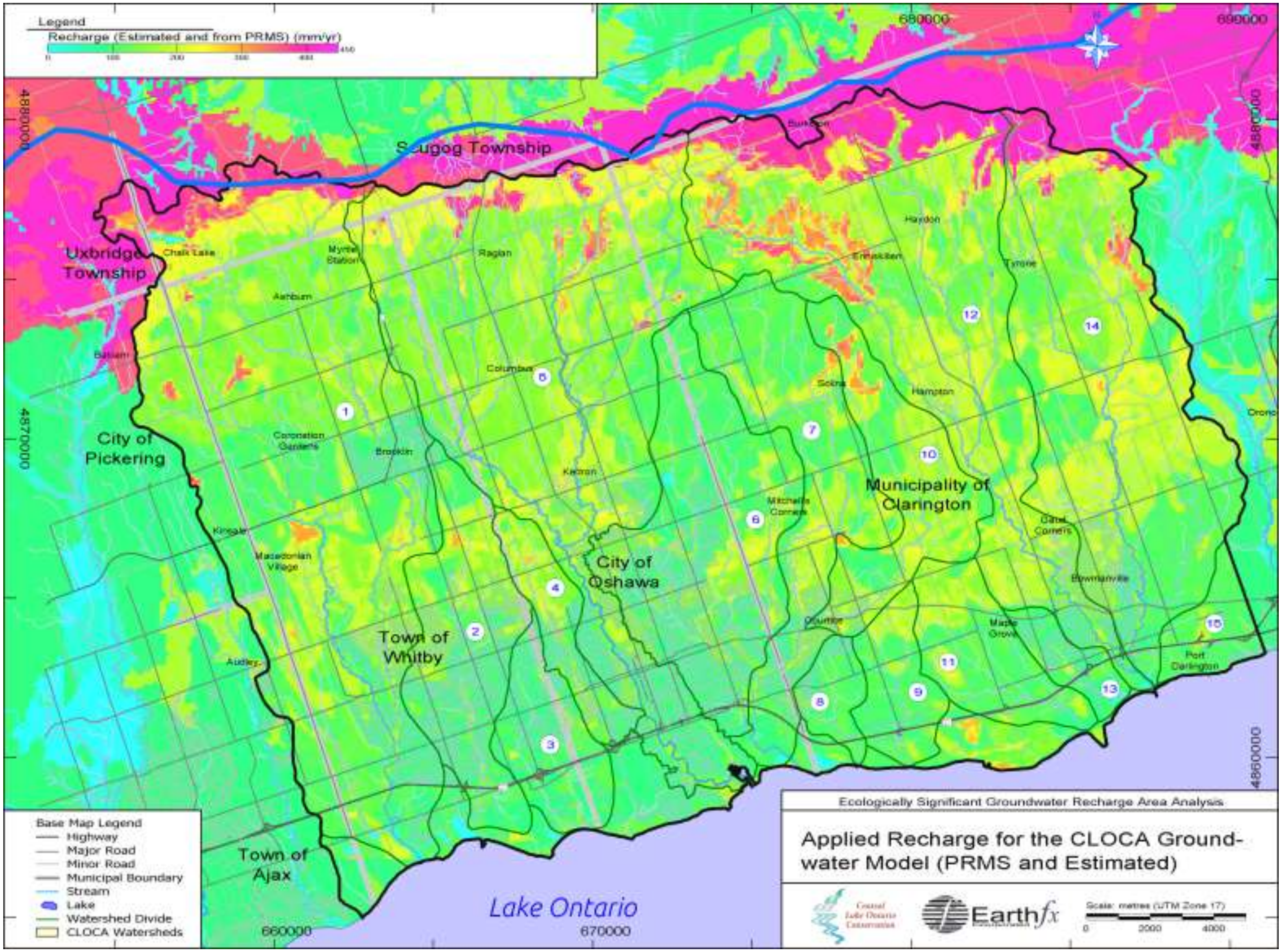

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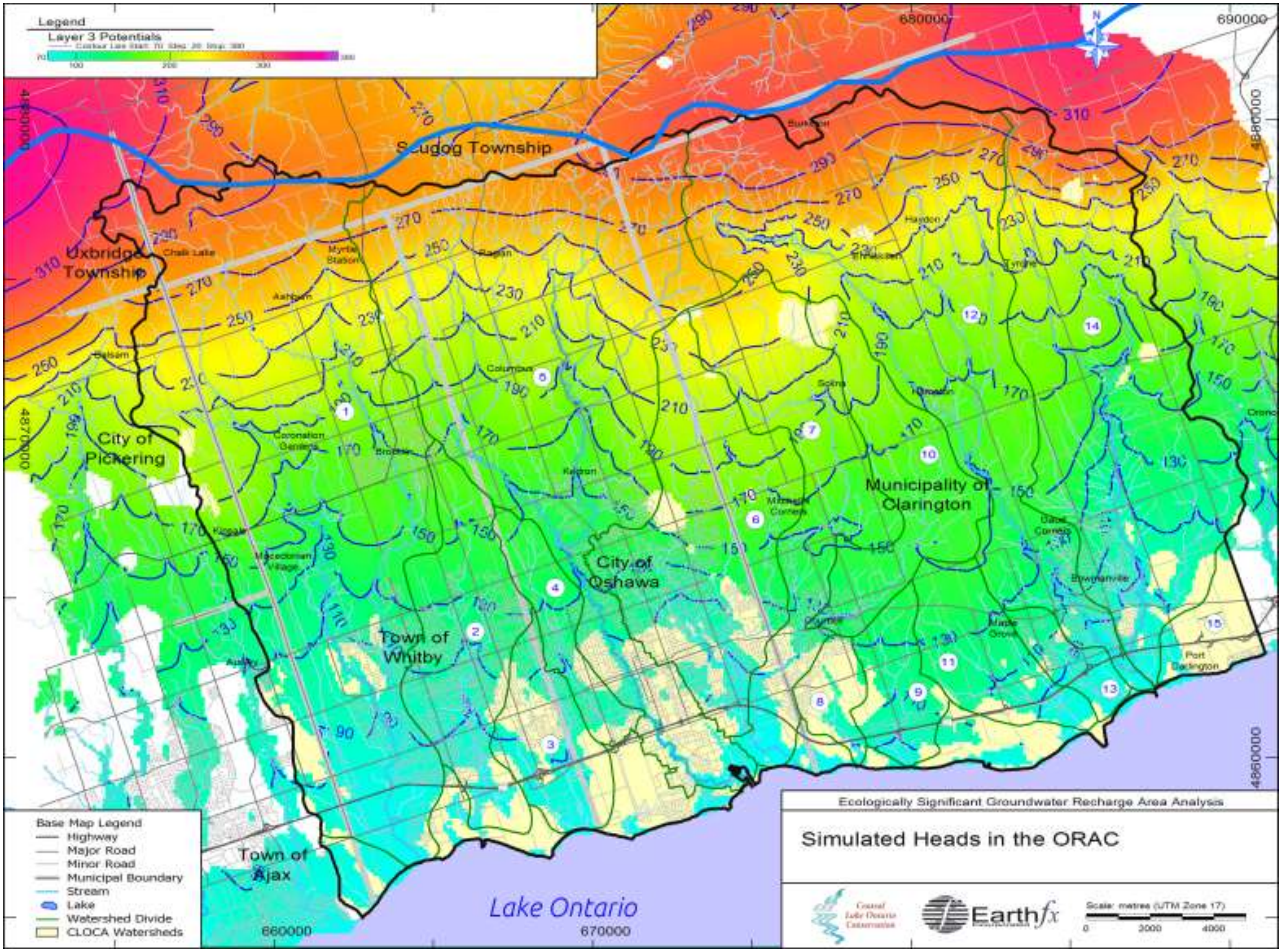

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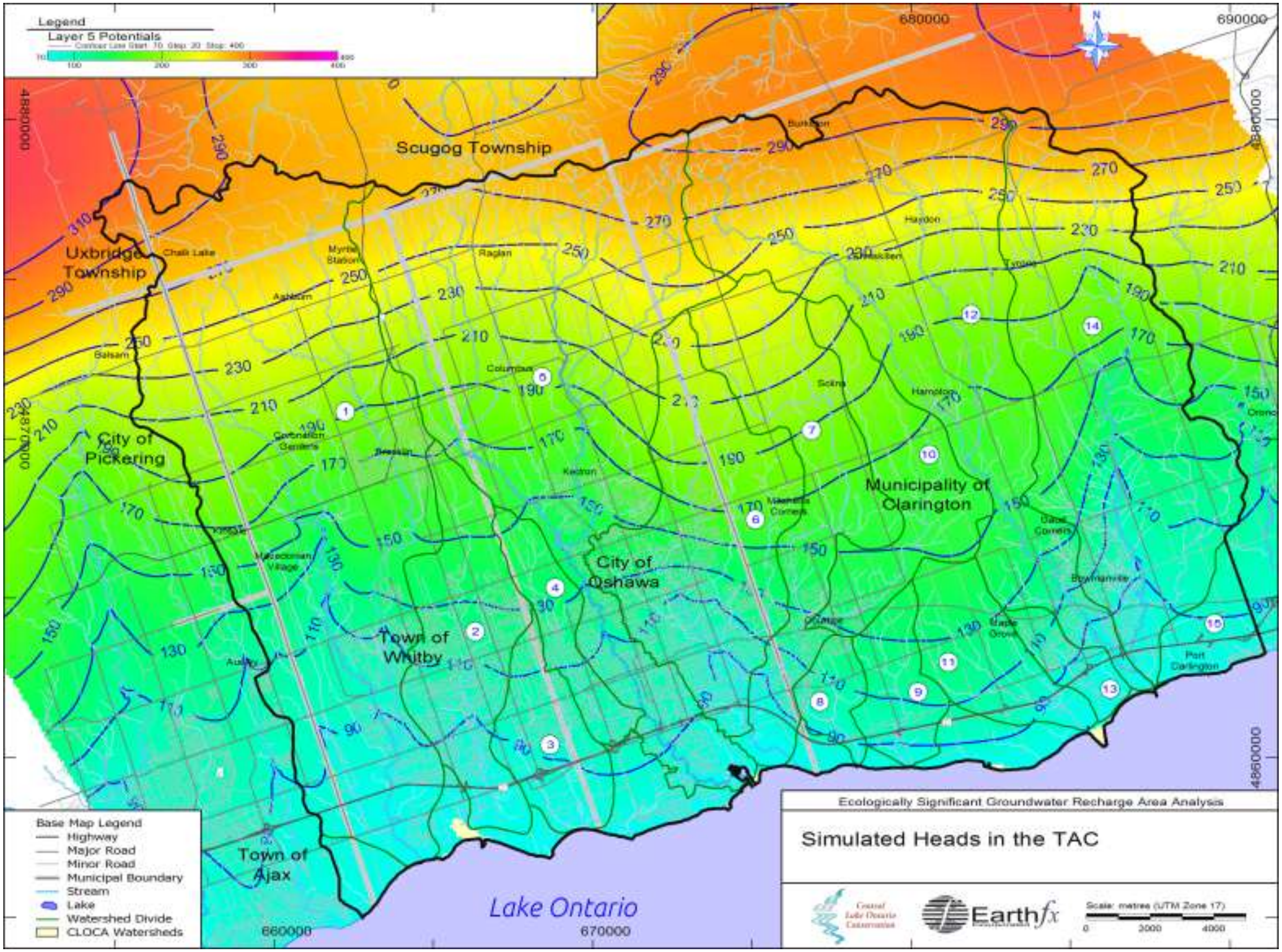

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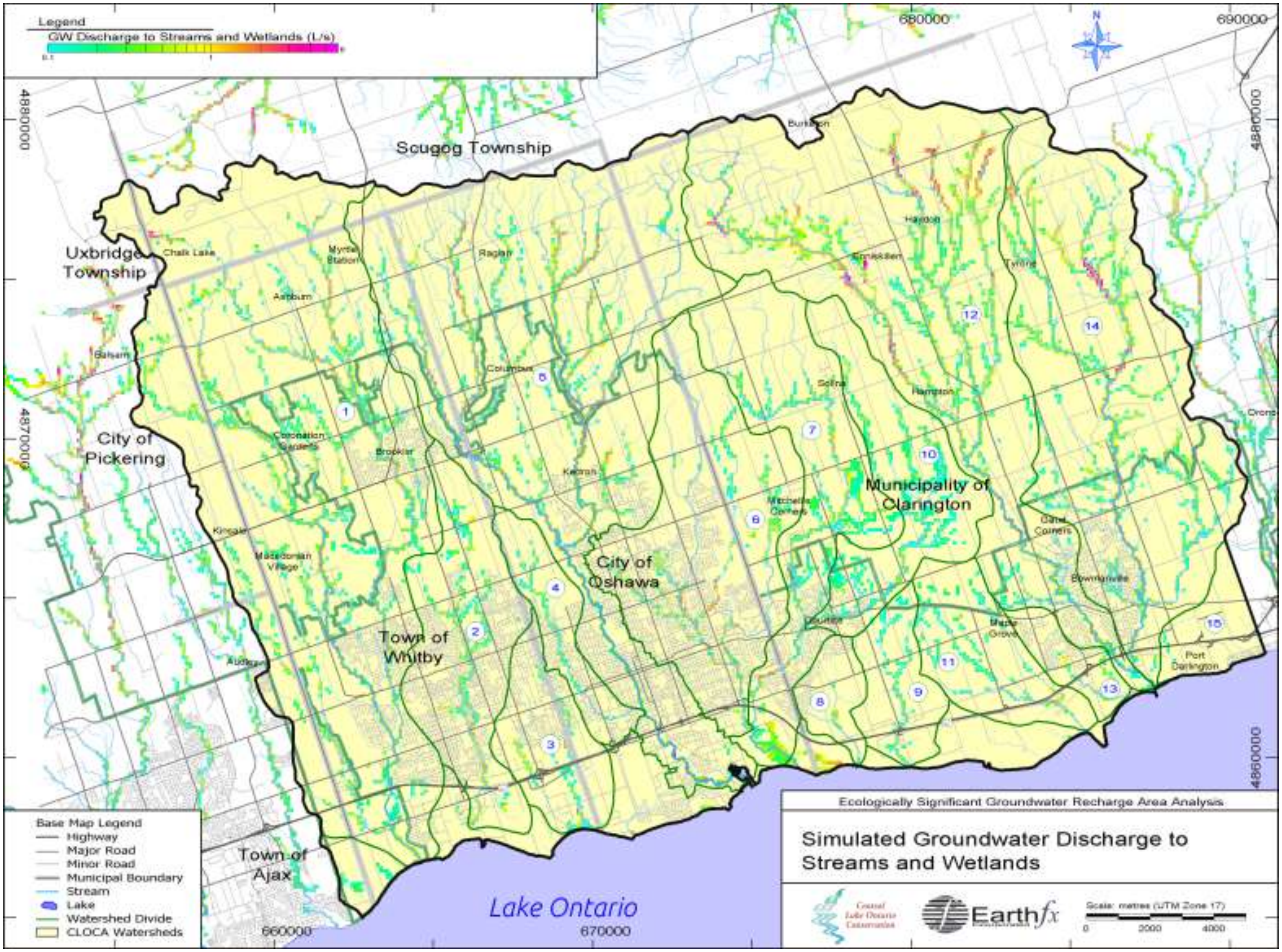

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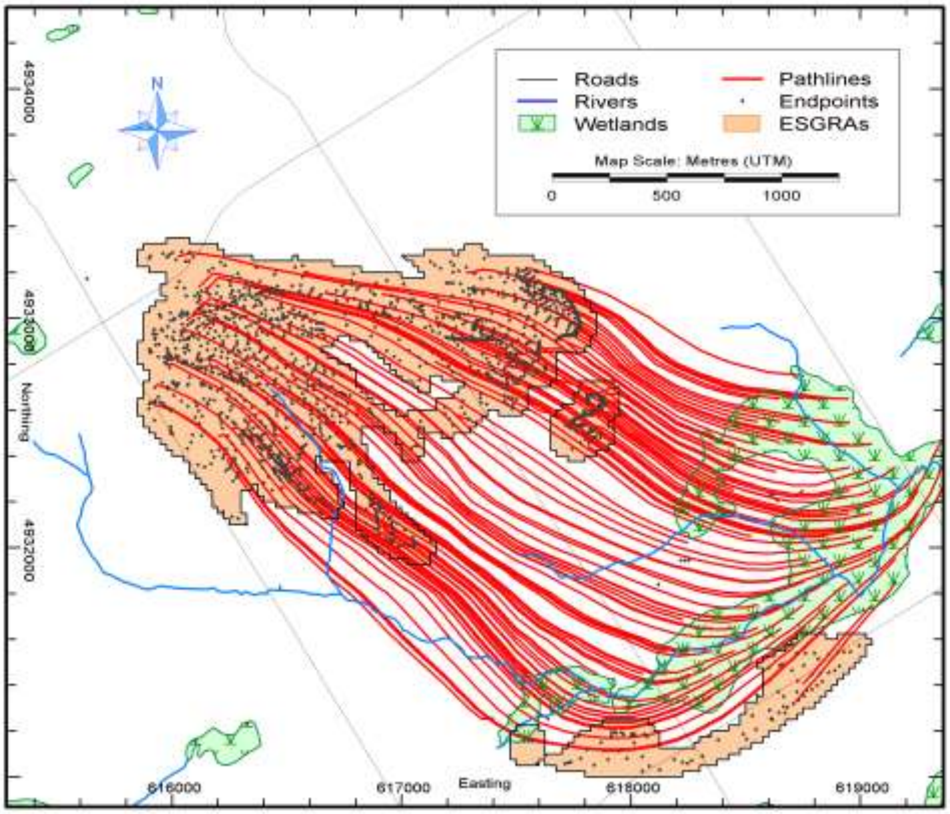

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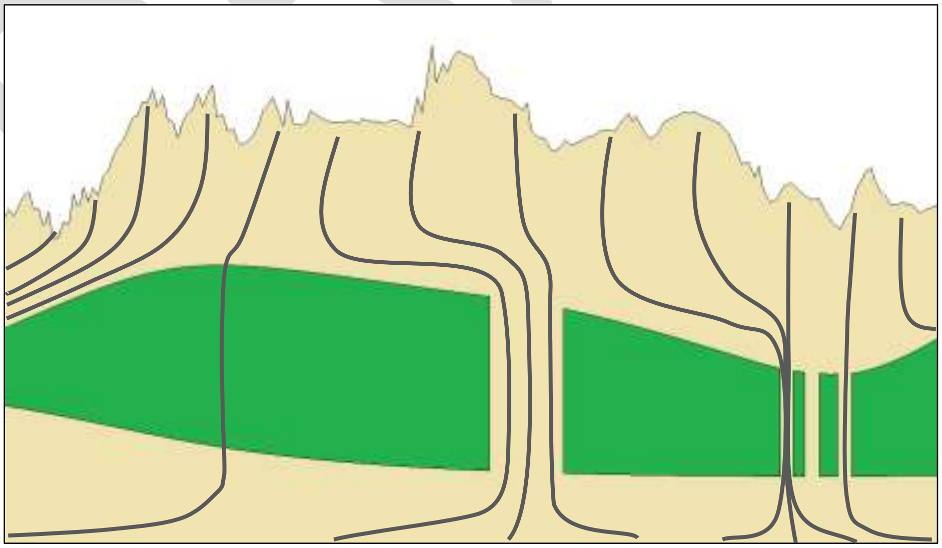

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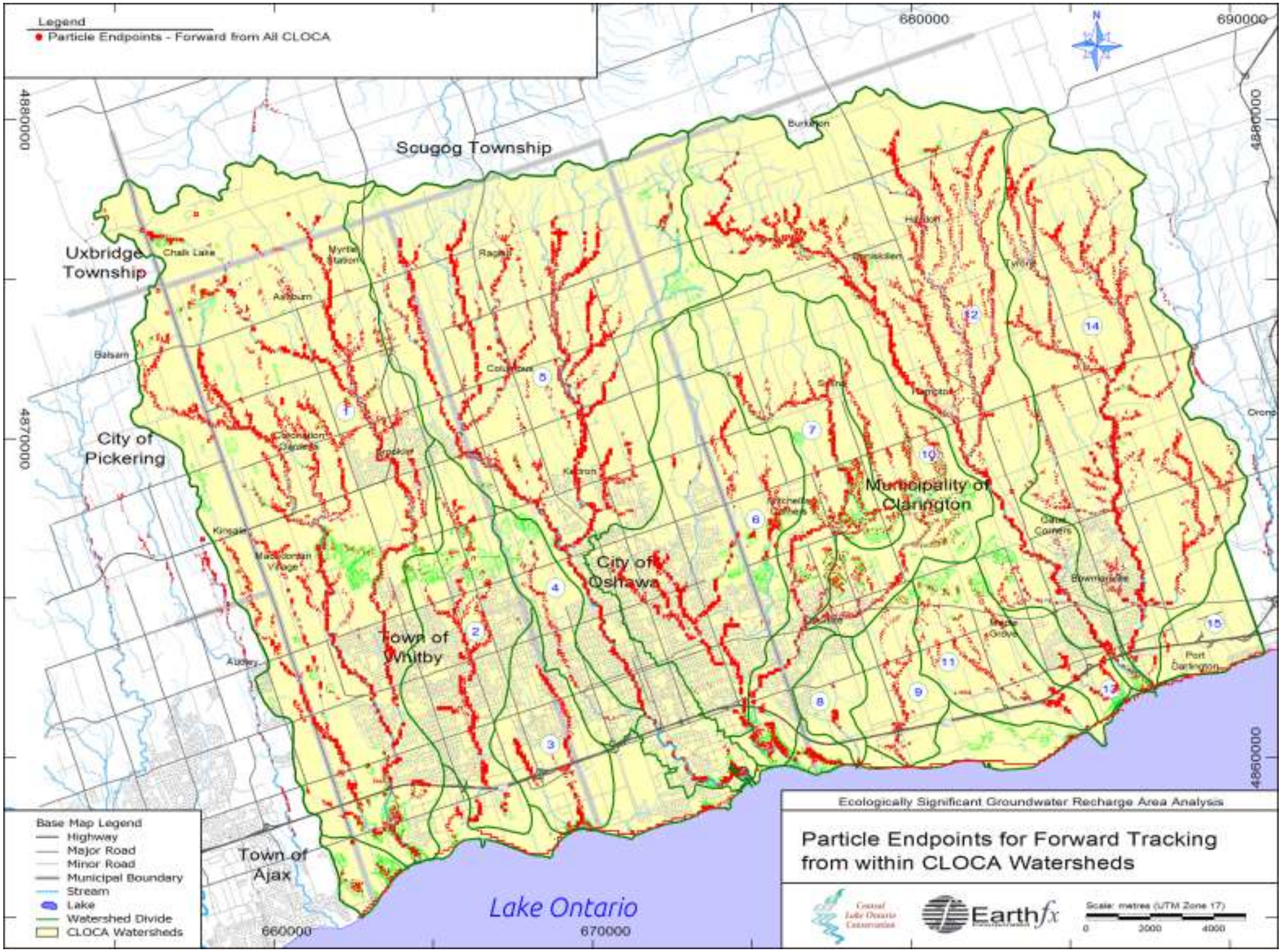

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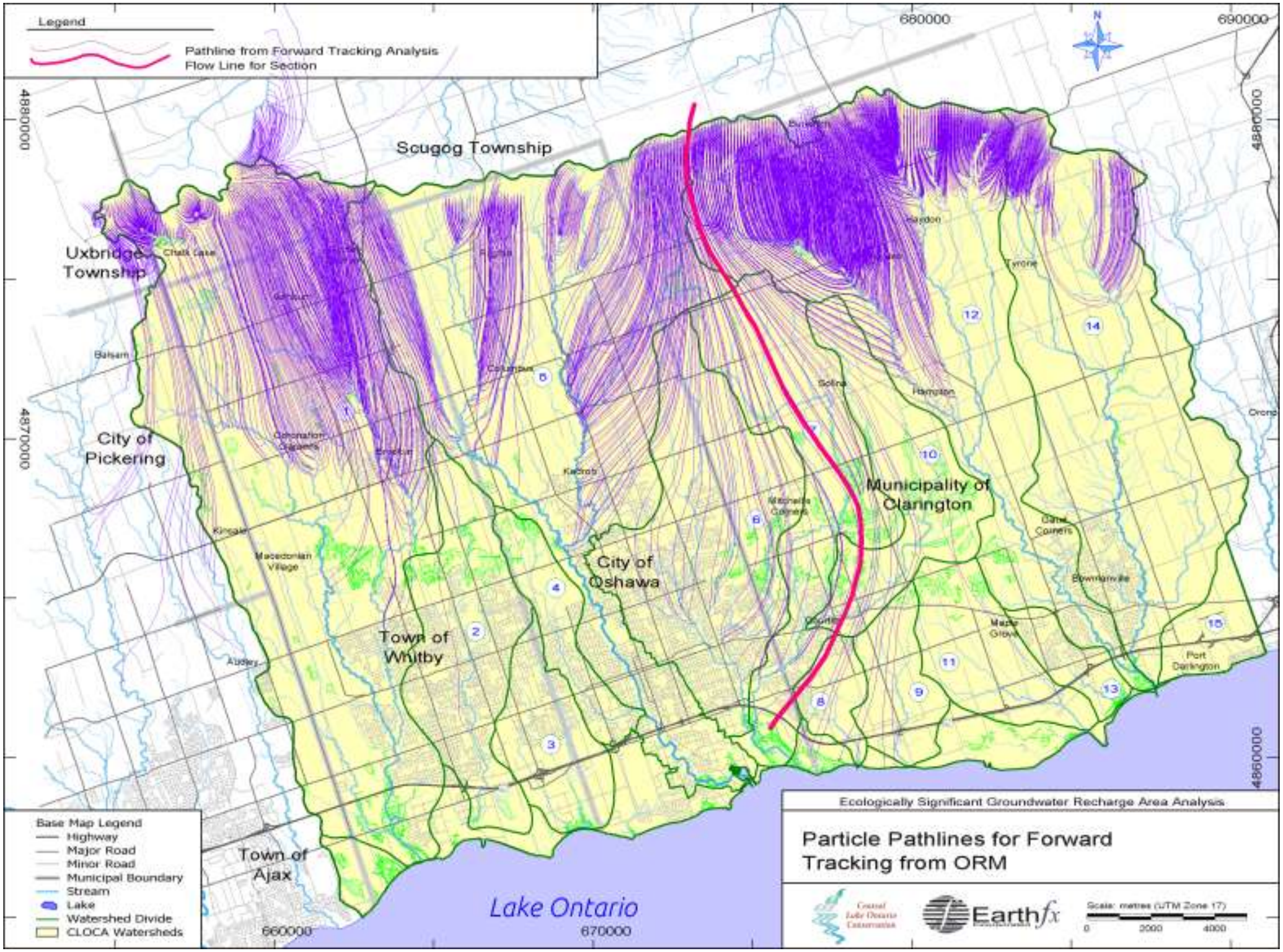

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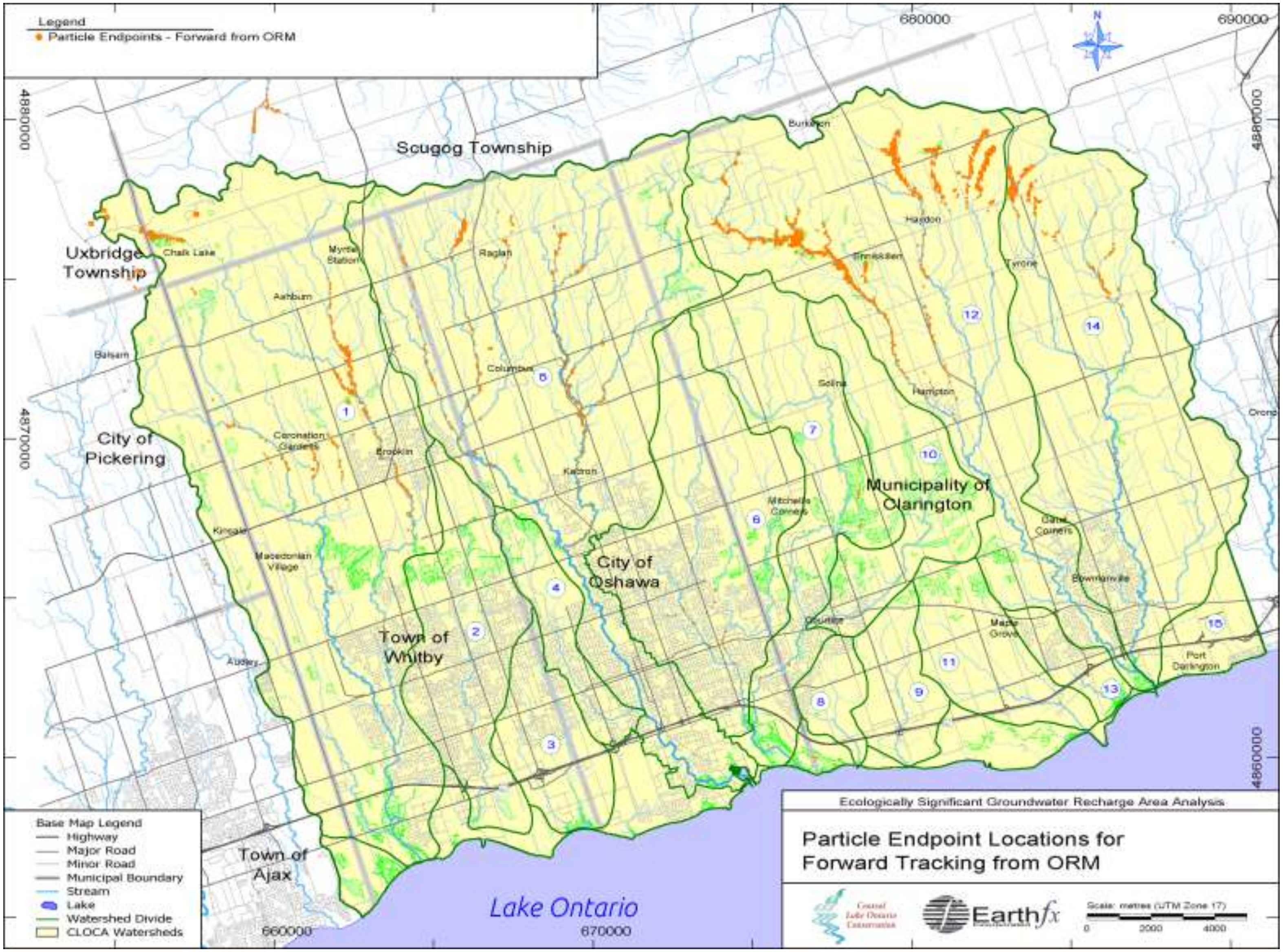

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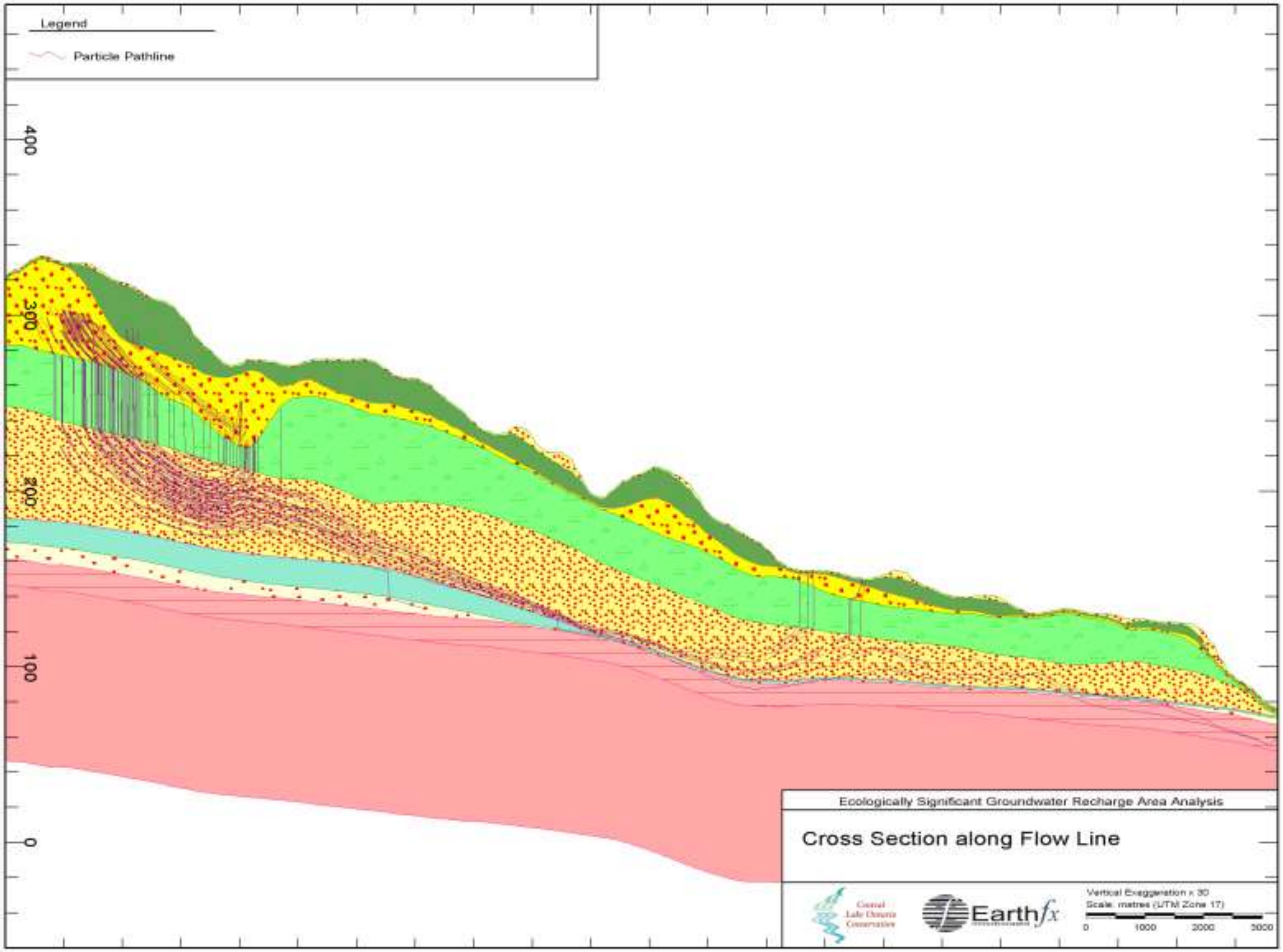

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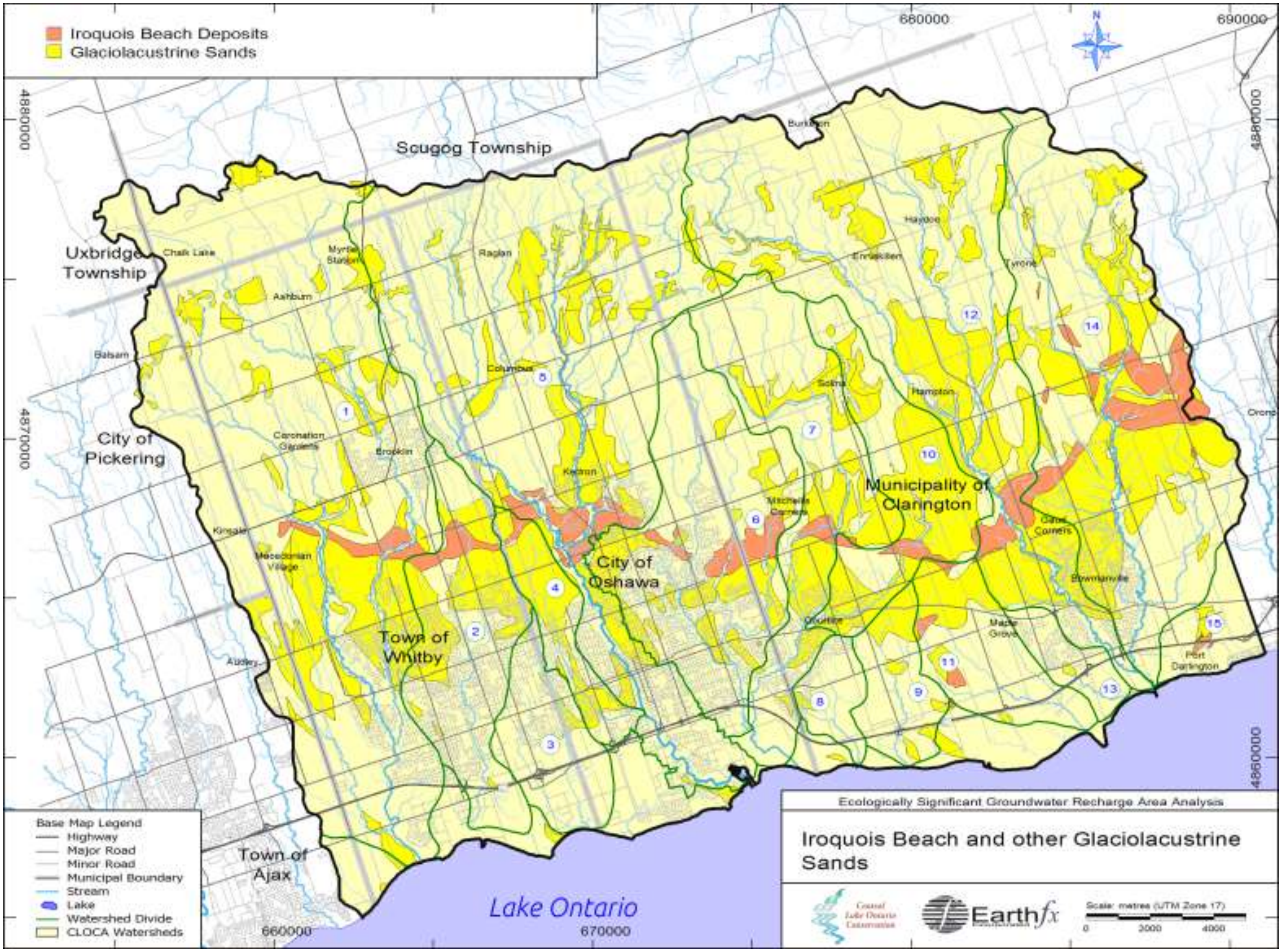

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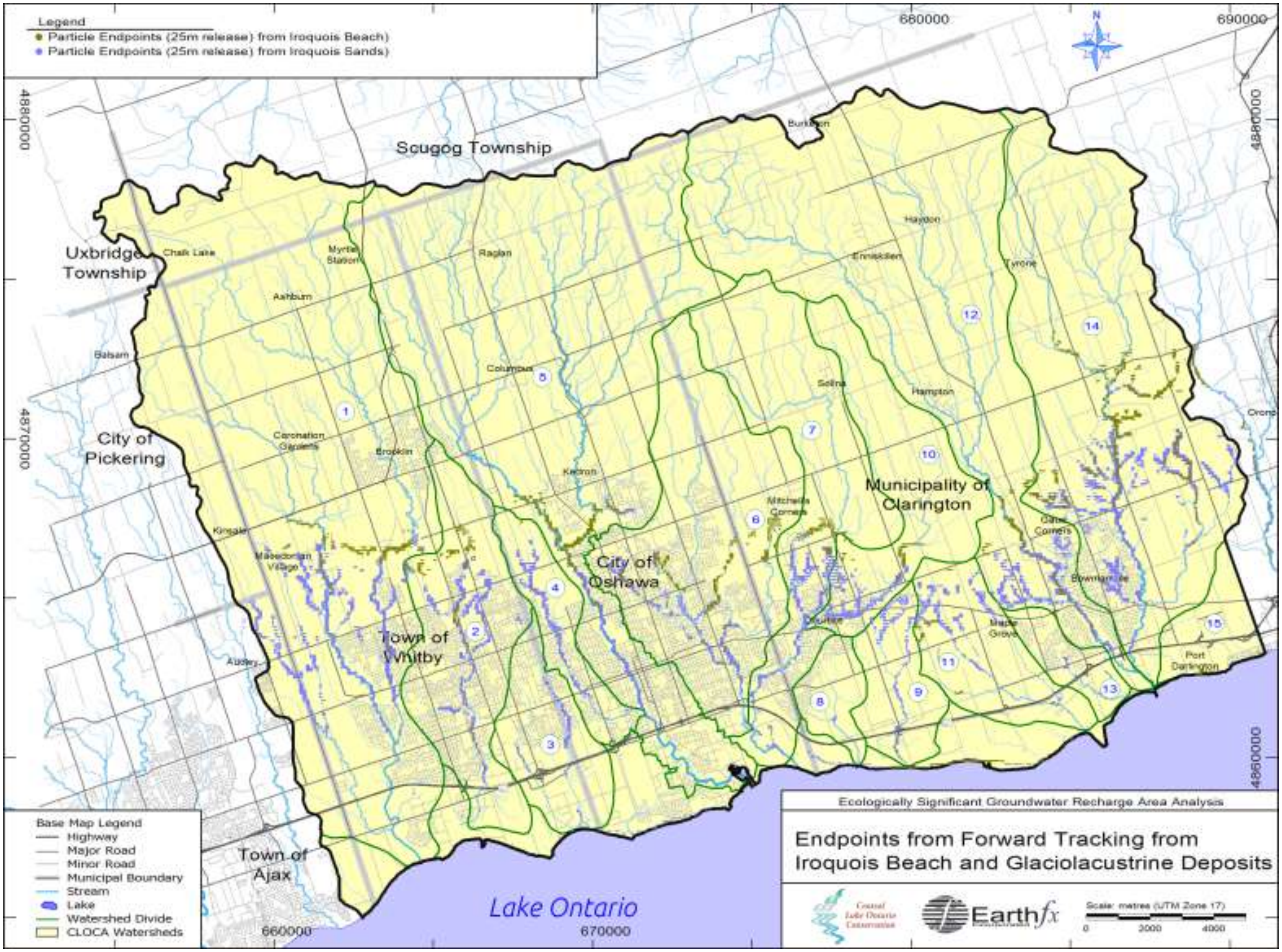

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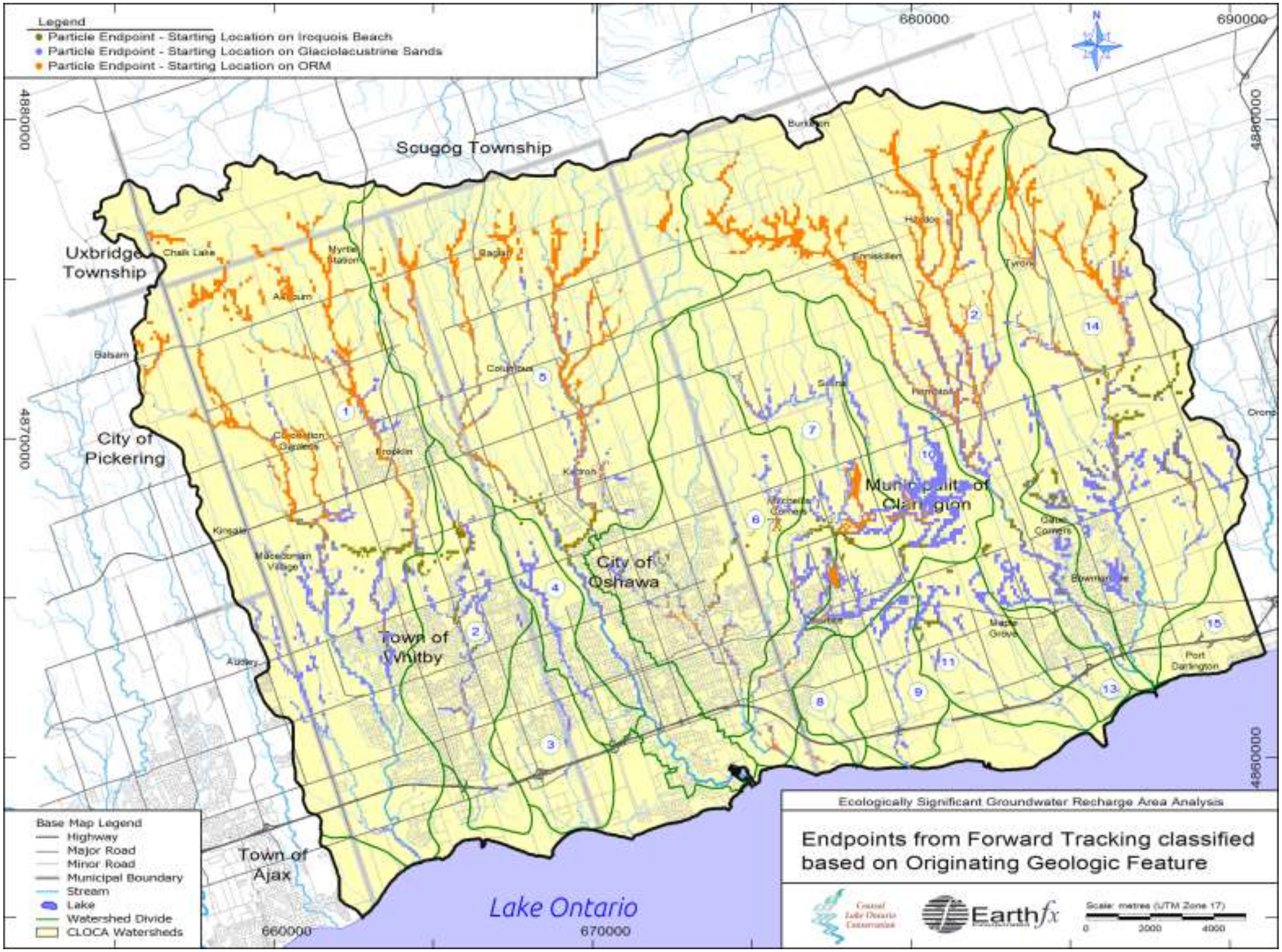

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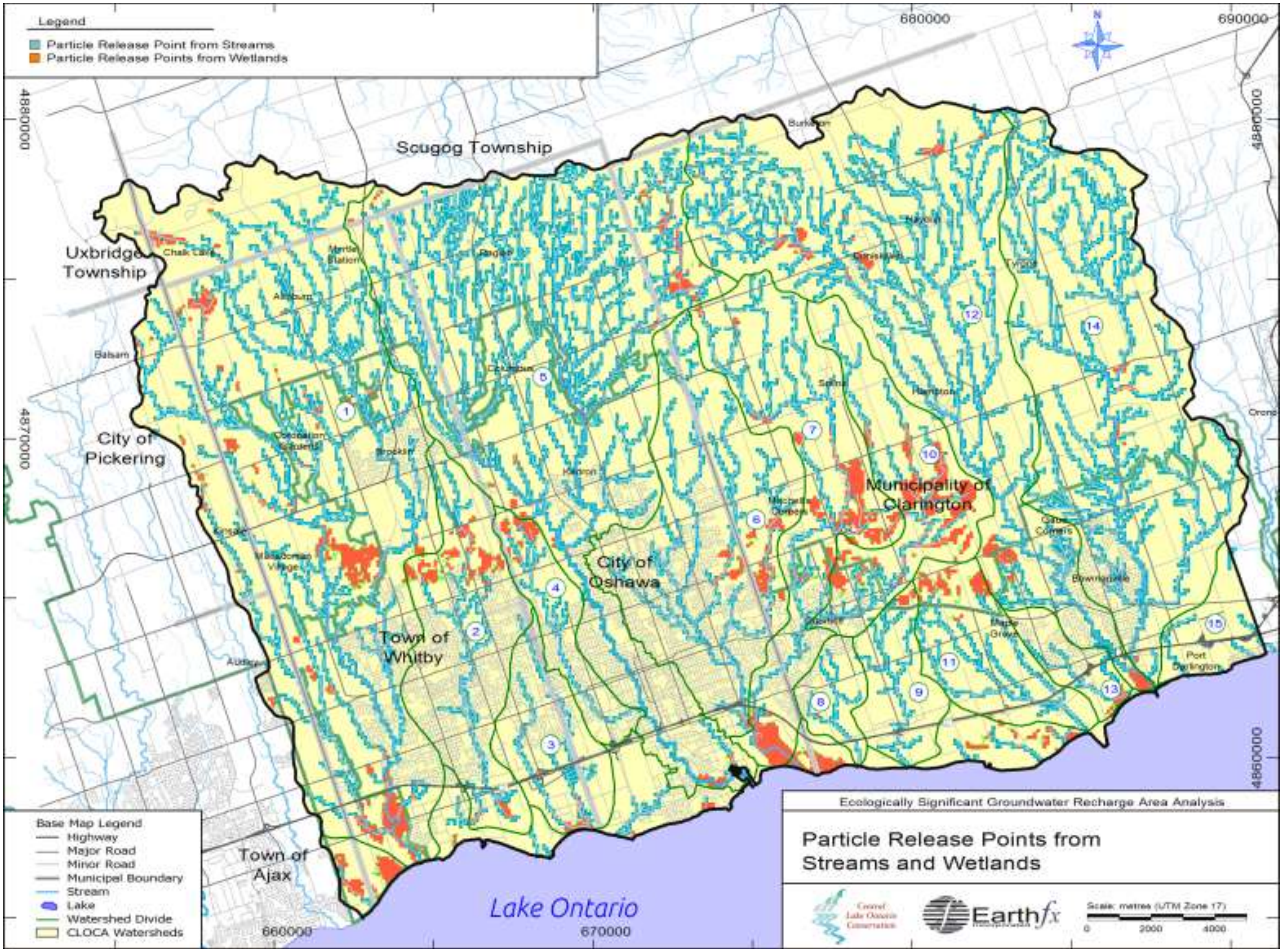

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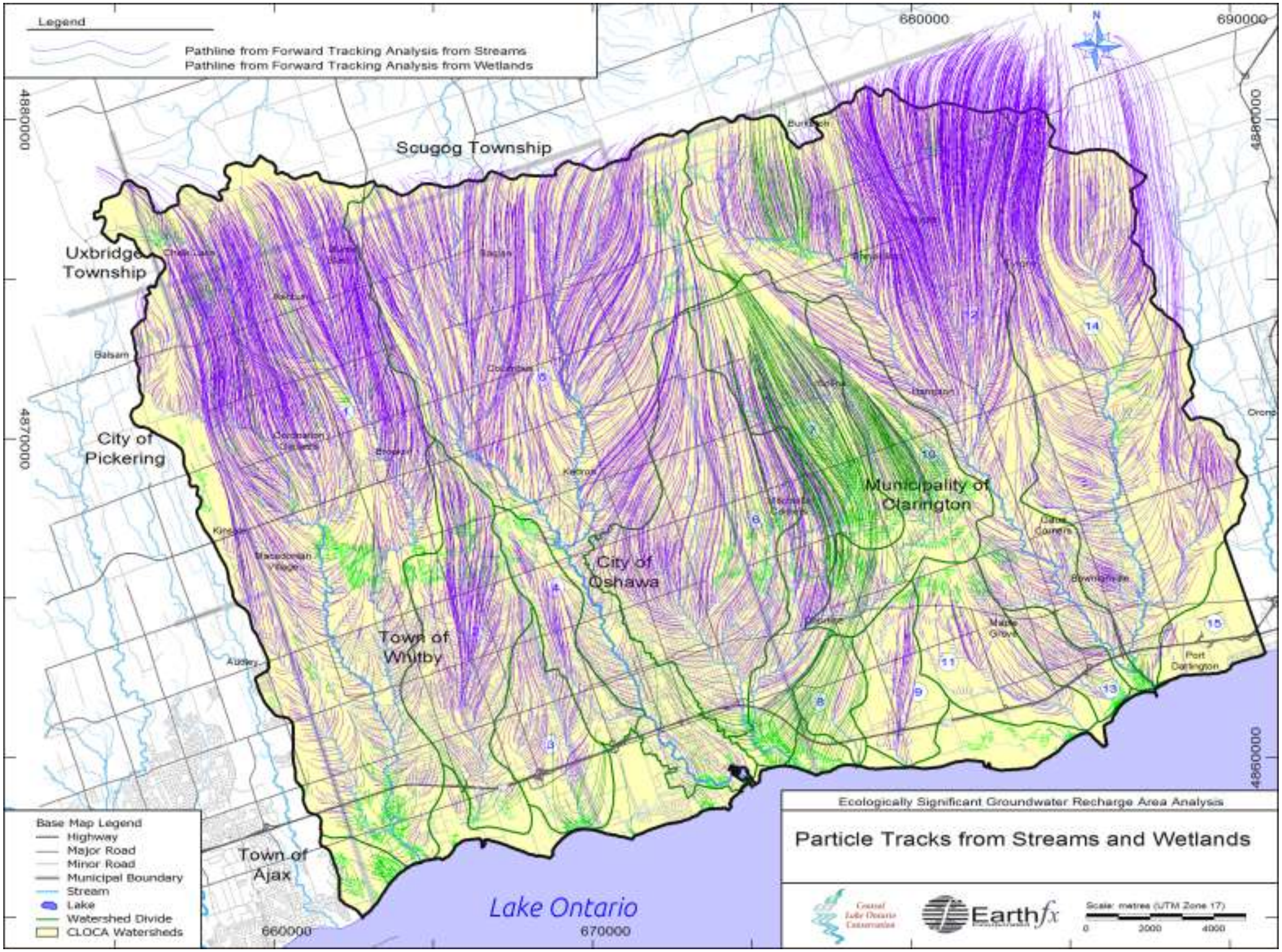

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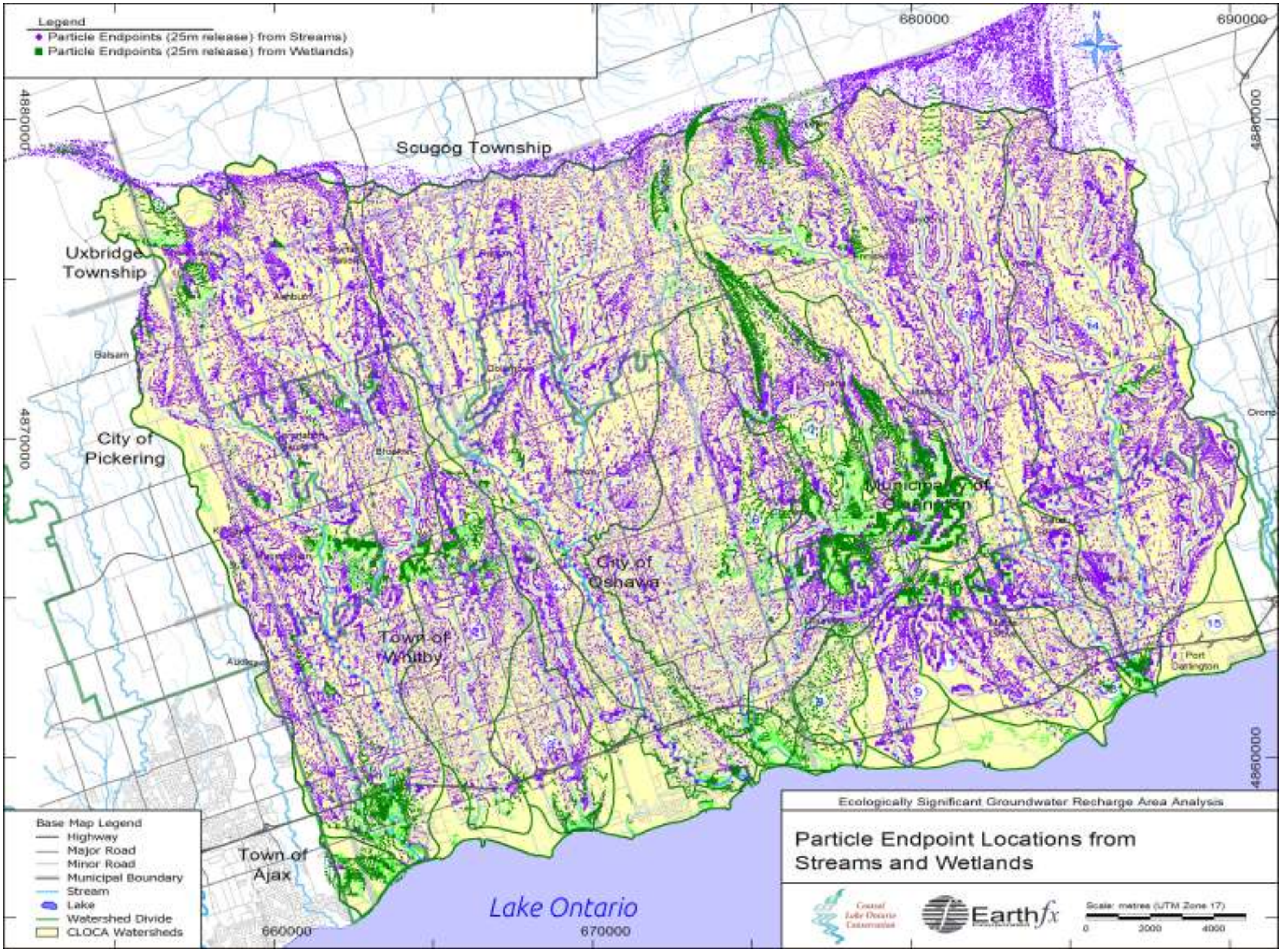

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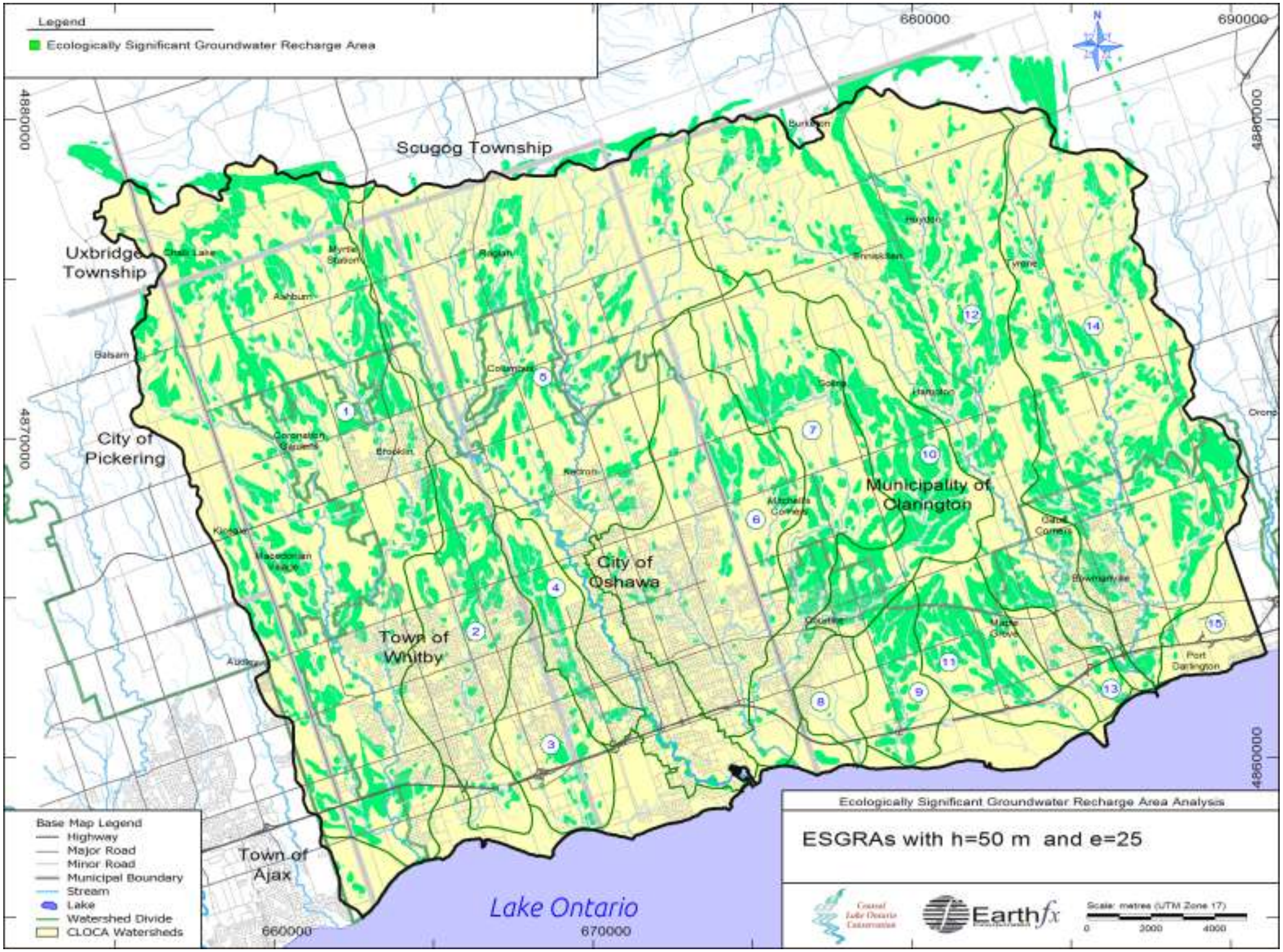

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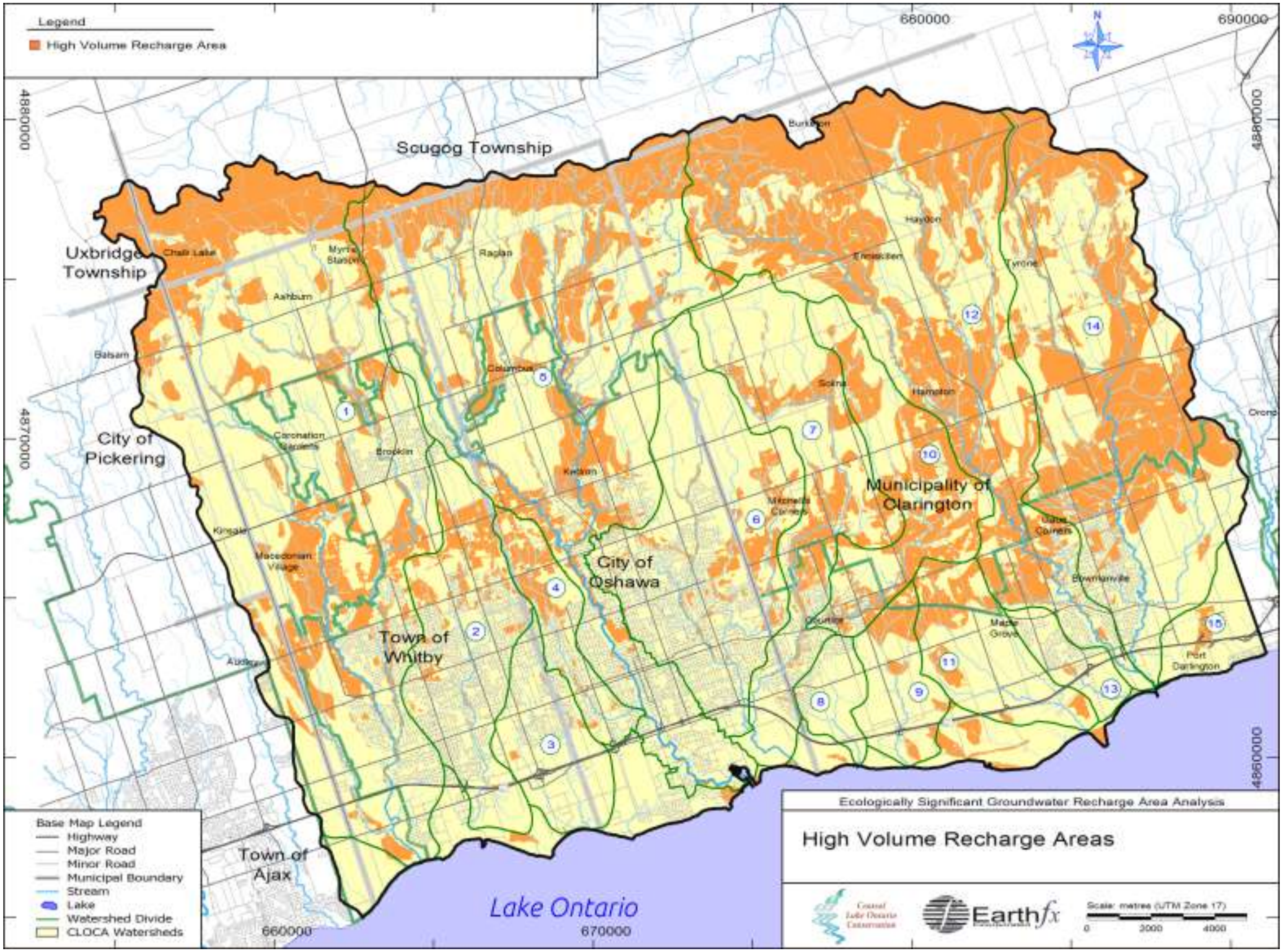

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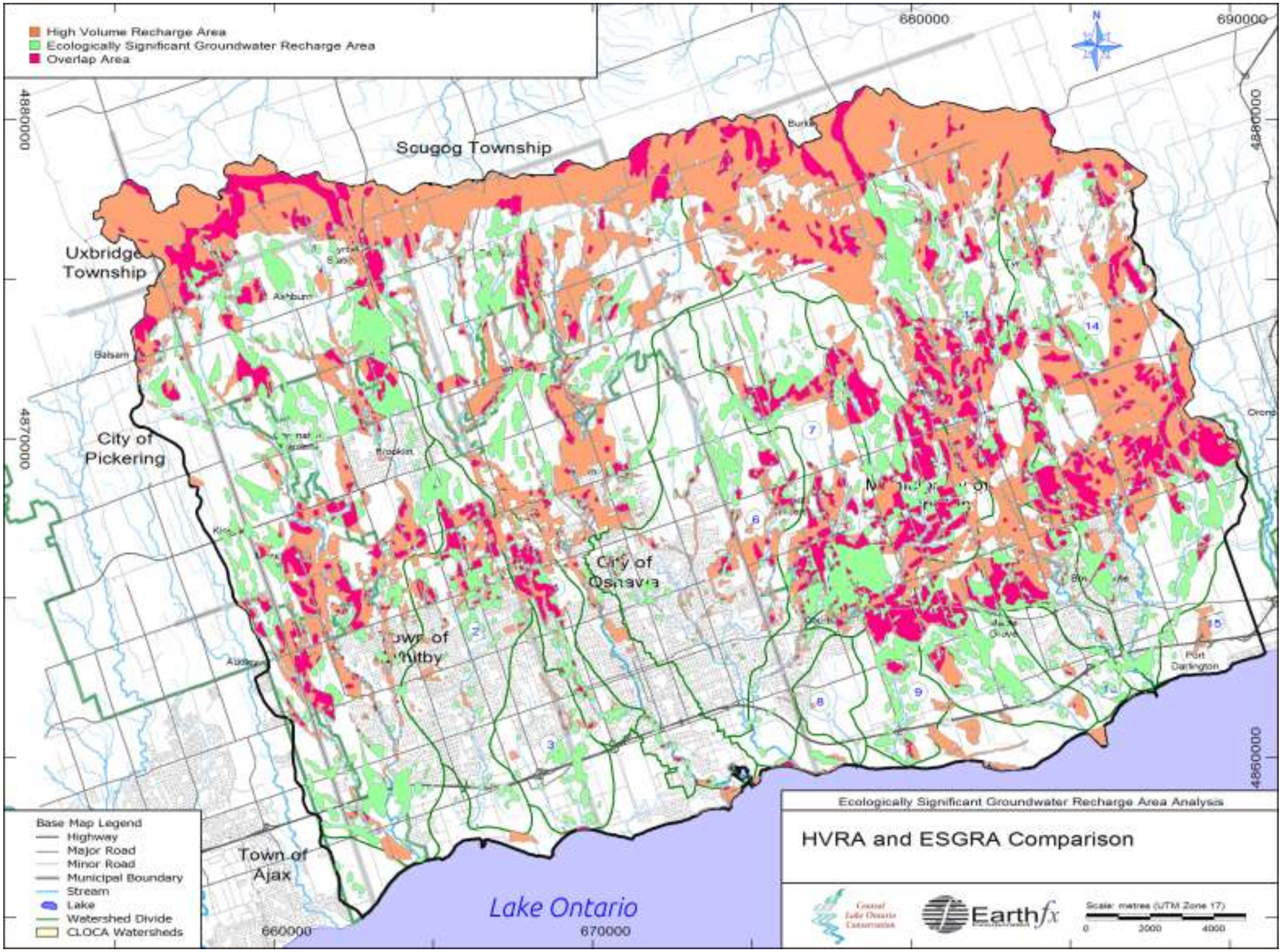

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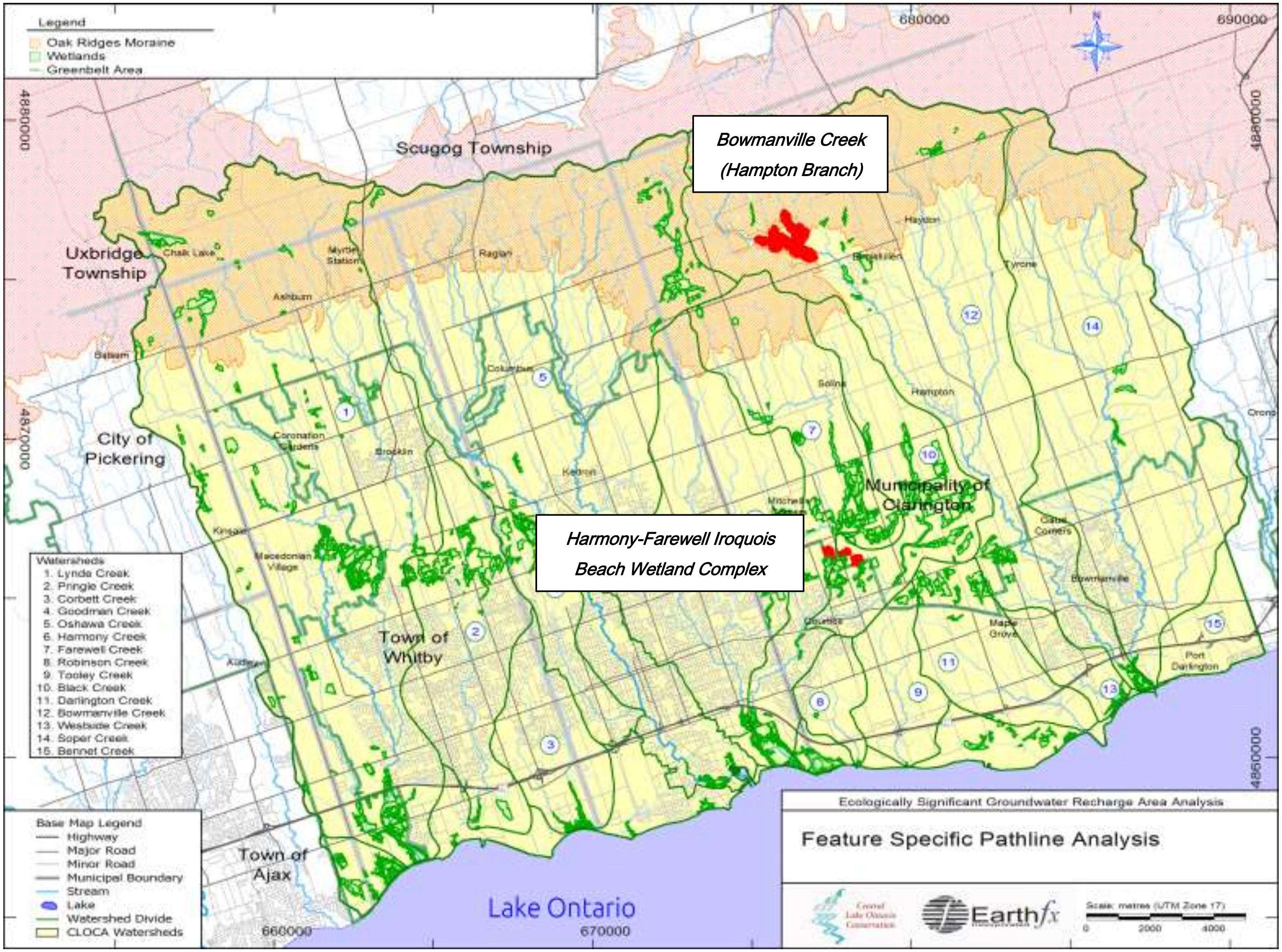

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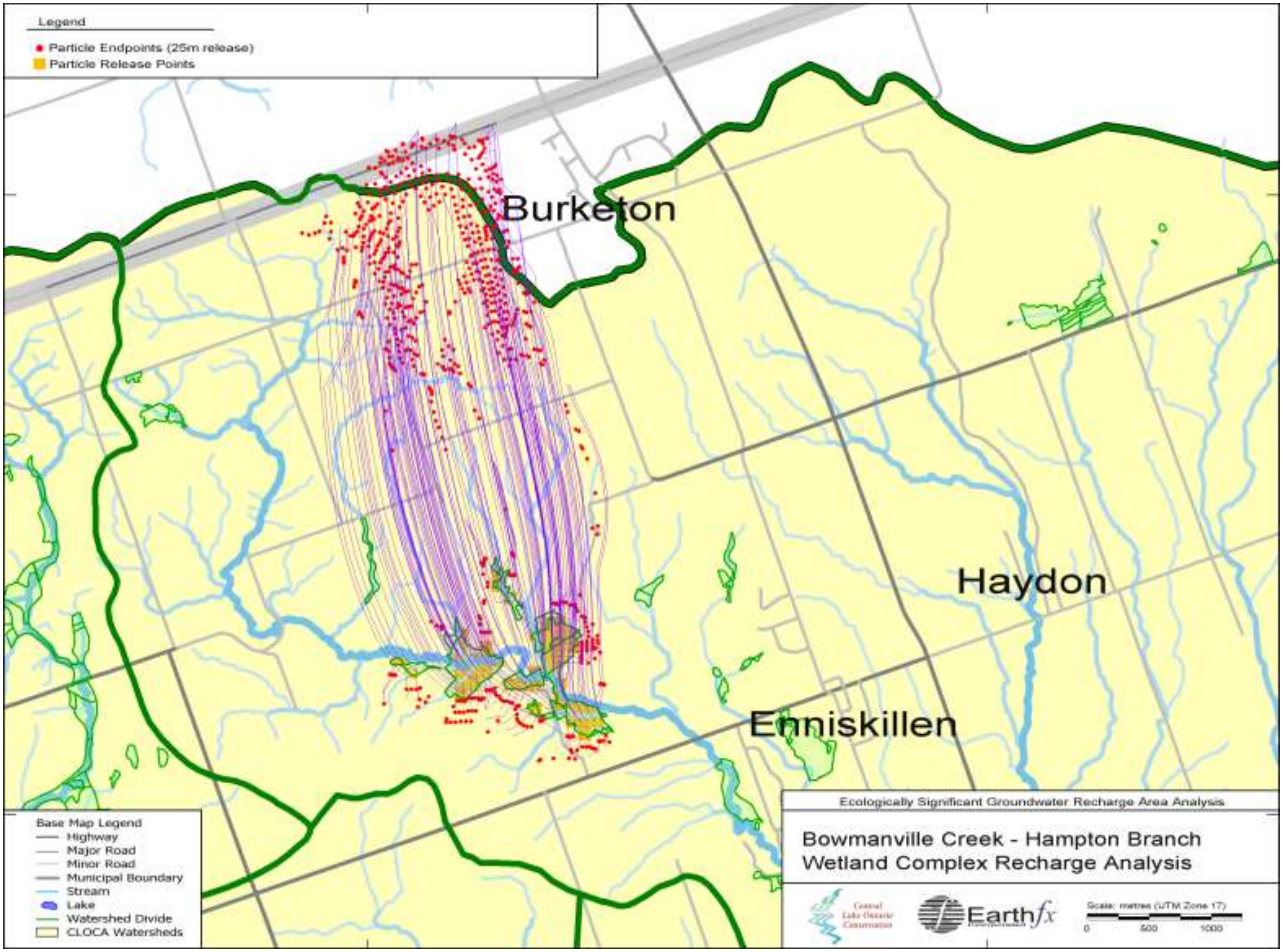

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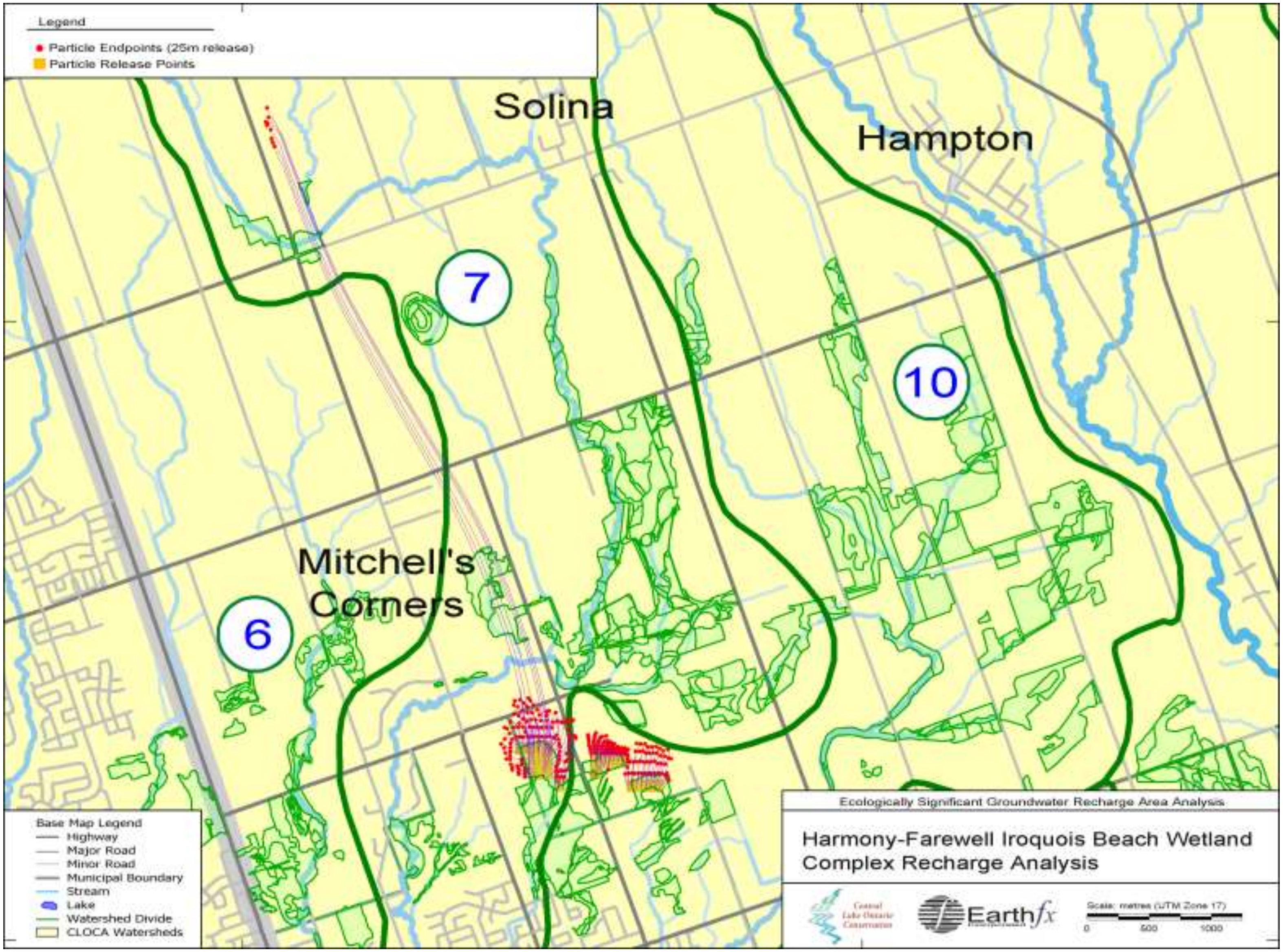

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APPENDIX B - Hydrogeological Assessment Submissions, Conservation Authority Guidelines to Support Development Applications

Hydrogeological Assessment Submissions

Conservation Authority Guidelines to Support Development Applications

June, 2013

Hydrogeological Assessment Submissions

Conservation Authority Guidelines to Support Development Applications

June, 2013

Note to Reader: This document has been provided in an attempt to standardize the hydrogeological study requirements to support development applications reviewed by Conservation Authorities and should be referred to for guidance purposes only. It is not a legal document and should not be used as such. In addition, this document has not been endorsed by all Conservation Authorities. This document has been drafted to satisfy specific requirements applicable to hydrogeologic studies that meet the needs of most Conservation Authorities and for that reason, not all content of the document may be appropriate for your hydrogeologic study or Conservation Authority. Therefore, while this document may serve as an excellent starting point for undertaking hydrogeologic studies, independent judgment and pre-consultation with your Conservation Authority and municipality is strongly recommended to determine the scope of your study.

Acknowledgements

This report was prepared by Shelly Cuddy, Gayle Soo Chan and Ryan Post. Various other Conservation Authority staff, too numerous to mention, also contributed information towards the completion of this document. The authors would also like to formally acknowledge Steve Holysh (YPDT-CAMC) and Lloyd Lemon (Genivar) for reviewing draft documents and providing constructive comments.

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1 INTRODUCTION

This guidance document has been developed by the Conservation Authorities Geoscience Group which is made up of Conservation Authority hydrogeologists. The main purpose of this document is to provide information and guidance material to Conservation Authorities, their municipalities and consultant hydrogeologists related to hydrogeological assessment requirements that can be used to ensure comprehensive evaluations of potential impacts associated with development on natural ecological features and functions that are supported by groundwater resources. The intent is that it be used as a resource to promote consistency amongst Conservation Authorities in the development of terms of reference and the Conservation Authority review of the resulting technical studies. The document may also be used as a resource to assist the consulting community in the understanding of the Conservation Authority perspective regarding potential watershed impacts and serve to increase efficiencies and reduce approval timelines.

This guidance document provides a list of recommended requirements for hydrogeological investigations. The checklist outlines specific study requirements depending on the type of development application. Short descriptions of report expectations, report components, as well as some of the resources available have also been provided. Where a Conservation Authority has adopted these guidelines, the scope of the investigation and report requirements should follow this guidance document unless otherwise agreed upon during pre-consultation with Conservation Authority staff. It should be noted, however, that this is a guideline document aimed at consistency and not a legally binding instrument. A municipality and their Conservation Authority may choose to change the scope of the analyses required within their jurisdiction.

In carrying out plan review and regulation responsibilities, Conservation Authorities can be involved in the review of hydrological assessments addressing matters such as:

1. groundwater infiltration and recharge;
2. groundwater discharge and baseflow (supporting streams and wetlands);
3. coldwater fisheries supported by groundwater discharge;
4. water quality and temperature (wetland species/fisheries);

5. groundwater elevations and flow paths (potential to divert flow, cause flooding, divert shallow flow causing impacts on shallow rooted vegetation and wetland features); and
6. cumulative watershed impacts.

In summary, this guidance document may assist Conservation Authority involvement in requirements for hydrogeological submission by:

1. establishing a consistent approach in the review of studies;
2. clarifying upfront the information that should be included in hydrogeological studies;
3. providing a clearer understanding of potential hydrogeological issues and concerns;
4. providing minimum information requirements and best management practices in the preparation of hydrogeological reports;

As indicated earlier, this document attempts to satisfy specific requirements applicable to hydrogeological studies that meet the needs of most Conservation Authorities. The guidance information is not intended to be prescriptive or to replace professional judgment and is based upon a review of current practices for hydrogeologic reviews at Conservation Authorities. Therefore, while this document may serve as an excellent starting point for undertaking hydrogeologic studies, independent judgment and pre-consultation is strongly recommended to determine the scope of a hydrogeological submission.

Where applicable, this document takes into consideration existing provincial (e.g. Oak Ridges Moraine Conservation Plan, Niagara Escarpment Plan, Lake Simcoe Protection Plan, etc.), municipal and Conservation Authority policies and guidelines for information requirements for land development applications. Information contained within this document was drawn from Ministry of Environment and Energy (MOEE) Hydrogeological Technical Information Requirements for Land Development Applications (MOEE, 1995) but simplified and focused on watershed and ecological impacts associated with development.

2 HYDROGEOLOGICAL ASSESSMENT CONTENT AND REQUIREMENTS

It is strongly recommended, that prior to the commencement of any study, the proponent and their consultant(s) undertake pre-consultation with Conservation Authority staff to confirm the scope of the required technical study.

Hydrogeological studies will vary in scope, level of detail, and methodologies depending upon project scale and the study objectives. Sufficient detail should be provided to facilitate a review of the hydrogeological analysis and conclusions.

This guidance document provides a list of recommended requirements for hydrogeological investigations. The checklist (Table 1 in Section 2.2) outlines specific study requirements depending on the type of development application. Section 3 provides a short description of report expectations, report components, as well as some of the resources available. Where a Conservation Authority has adopted these guidelines, the scope of the investigation and report requirements should follow this guidance document unless otherwise agreed upon during pre-consultation with Conservation Authority staff. It should be noted, however, that this is a guideline document aimed at consistency and not a legally binding instrument. A municipality and their Conservation Authority may choose to change the scope of the analyses required within their jurisdiction. Further, where this guideline is adopted, a staged study approach may be taken whereby a preliminary phase of a study may be initially required followed in sequence by secondary, more detailed phases over a period of time. A broader scale of investigation is generally undertaken for larger scale developments such as supporting documentation for secondary plans.

The studies are expected to provide new or updated sources of data, particularly on a local, site-specific scale and identify potential changes in environmental conditions. Data provided should be of a qualitative and a quantitative nature and be suitable to identify a linkage between impact on recharge/discharge capability, long- and short-term watershed planning and environmental quality. The information provided should be sufficient to identify areas of concern. Additionally, it will give the opportunity for developers to indicate where potential concerns can be mitigated or avoided. In this respect, developments can be accurately assessed from a site specific and broader watershed development impact perspective.

It is strongly recommended that, prior to the commencement of any study, the proponent and their consultant(s) undertake pre-consultation with Conservation Authority staff to confirm the scope of the required technical study (ies).

2.1 QUALIFICATIONS

Proponents of development applications will be required to submit reports which summarize the work completed. These reports shall be prepared by Qualified Persons (QPs). A QP is a licensed Professional Geoscientist or an exempted Professional Engineer as set out in the *Professional Geoscientists Act of Ontario.*

2.2 STUDY CHECK LIST

The general purpose of a planning application hydrogeological study is to evaluate whether the proposed application is likely to result in adverse/negative impacts to the aquifer, existing groundwater users or natural functions of the ecosystem relying on groundwater. As such, the level of detail required in the hydrogeological study is normally expected to correspond with the level of risk posed to the ground and surface water resources, and the level of uncertainty associated with the available information. Where there is a low risk of negative impacts, a QP may be able to complete their report by qualitatively applying hydrogeological principles to existing information, such as in the form of a desk-top study. Where there is a high risk of negative impacts, a detailed site investigation and monitoring program may be required.

Table 1 has been developed to serve as an easy reference resource to identify hydrogeological study requirements in support of planning applications at the Conservation Authority. Table 1 outlines the type of planning application and general requirements most commonly required by Conservation Authorities in the review of different types and scales of Hydrogeological Assessments. However, it should be noted that Table 1 is not a complete list of all types of applications dealt with by each Conservation Authority, nor are all components of the checklist appropriate for every development type/situation. The following checklist represents recommended minimum requirements. Additional information may be required in some cases.

The table is not intended to replace professional judgment. Individual Conservation Authorities should be consulted for additional specific study requirements or conversely where study components may not be required. A description of the guidance checklist components is provided in more detail within Section 3 of this document.

The expected content of a hydrogeological assessment is broken out into three sections:

1) Existing Conditions;
2) Impact Assessment; and
3) Mitigation.

Table 1: Hydrogeological Assessment Check List intended to Support Development Applications

Groundwater Assessment	**Master Environmental Servicing Plan or Equivalent**	**Environmental Assessment (EA)**	**Site Plan Commercial, Institutional, or Industrial**	**Subdivision or Condominium Development**		**Single lot Residential**	**Dewatering**
				Municipal Servicing	**Private Servicing**		
1. EXISTING CONDITIONS:							
Introduction and background	☐	☐	☐	☐	☐	☐	☐
Site location and description	☐	☐	☐	☐	☐	☐	☐
Description of: • Topography & Drainage • Physiography • Geology & Soils	☐	☐	☐	☐	☐	☐	☐
Test pits/Boreholes	☐	☐	☐	☐	☐	GNR	☐
Monitoring Wells	☐	☐	☐	☐	☐	GNR	☐
Private Well Survey	☐	☐	☐	☐	☐	GNR	☐
Hydrostratigraphy/Hydrogeology: • Aquifer properties • Groundwater Levels • Groundwater flow direction	☐	☐	☐	☐	☐	☐	☐
Description of surface water features and functions	☐	☐	☐	☐	☐	☐	☐
Water Taking Permit details	GNR	GNR	GNR	GNR	GNR	GNR	☐
Water Quality	☐	☐	☐	☐	☐	GNR	☐
D-5-5 (Water Supply)	GNR	GNR	GNR	GNR	☐	GNR	GNR

Groundwater Assessment	**Master Environmental Servicing Plan or Equivalent**	**Environmental Assessment (EA)**	**Site Plan Commercial, Institutional, or Industrial**	**Subdivision or Condominium Development**		**Single lot Residential**	**Dewatering**
				Municipal Servicing	**Private Servicing**		
2. IMPACT ASSESSMENT:							
Groundwater Levels	☐	☐	☐	☐	☐	GNR	☐
Pumping Tests*	☐	☐	GNR	GNR	☐	GNR	☐
Groundwater Discharge (Baseflow)	☐	☐	☐	☐	☐	GNR	☐
Water Balance	☐	☐	☐	☐	☐	GNR	GNR
Groundwater Quality	☐	☐	☐	☐	☐	GNR	☐
D-5-4 (Onsite Sewage Systems)	GNR	GNR	GNR	GNR	☐	GNR	GNR
3. MITIGATION MEASURES:							
Maintenance of Infiltration/Recharge	☐	☐	☐	☐	☐	GNR	GNR
Maintenance Groundwater Quality	☐	☐	☐	☐	☐	GNR	☐
Monitoring Program	☐	☐	☐	☐	☐	GNR	☐
Contingency Plans**	GNR	GNR	GNR	☐	☐	GNR	☐

NOTES: This table outlines the type of planning application and associated requirements most commonly required by Conservation Authorities in the review of Hydrogeological Assessments. This table is not a complete list of all types of applications dealt with by each Conservation Authority nor is the checklist appropriate for every development situation. Individual Conservation Authorities should be consulted with for specific requirements.

☐ - *Recommended*
GNR – Generally Not Required
** Where development is municipally serviced, these tests will be necessary on a case by case basis (sensitive aquifer/ aquatic considerations).*
***May be scoped, Contingency Plans will not be needed in most cases.*

3 HYDROGEOLOGICAL ASSESSMENT REPORT REQUIREMENTS

This section outlines the minimum requirements that should be provided in a report format for review by Conservation Authority staff. The technical requirements are based on the type of planning application as outlined in Table 1. This section should be used along with Table 1 to ensure all application study recommended requirements are being met.

3.1 EXISTING CONDITIONS

3.1.1 Introduction & Background

The following introductory information should be provided within the report:

☐ Description of the planning context and relevant policies
☐ Outline of the scope of the assessment and the specific issues
☐ Contact information for the landowner and/or person engaged in the activity or land use, if they are different people (e.g. tenant versus landlord)

3.1.2 Site Location & Description

Identification of the site location should include the following information:

☐ Site location including street address, UTM (or northing and easting, NAD83),
☐ Township/municipality, lot, concession, size of property, area to be developed/disturbed
☐ Description of the proposed undertaking or development (size and purpose)
☐ Identification of the type of site servicing
☐ Description of construction/site disturbance activities
☐ Provision of the development plan or draft plan
☐ Land use designations of the Official Plan(s) and permitted uses in the zoning of the site
☐ Present land use of the site and adjacent lands
☐ Regional map
☐ Local map showing the site, major/minor roads, environmentally sensitive areas, wetland and watercourse features within 500 metres of the site or the area of influence; whichever is greater

3.1.3 Topography & Drainage

The report should include the following information with respect to topography and drainage conditions on the site:

- ☐ Description and figure of existing surface topography and drainage patterns of the site
- ☐ Description and figure of the proposed site alteration that clearly outlines ground elevations and change in drainage patterns

3.1.4 Physiography

A description of the physiography of the study area should be presented within the report. Its purpose is to provide background information regarding the landscape and the type of landforms present.

- ☐ Description of study area physiography
- ☐ Regional (watershed or larger) physiography map of the study area showing the site

3.1.5 Geology and Soils

The description of the geology should include both regional and site-specific descriptions. This discussion should contain a description of the overburden and bedrock materials including thickness. Features such as bedrock valleys, karst, and tunnel channels should be noted where known/relevant. The consultant should reference existing relevant regional studies e.g. the Ontario Geologic Survey maps and reports, Ontario Ministry of Agriculture and Foods soils maps, Ecological Land Classification data, Watershed Management reports and Assessment Reports prepared under the Clean Water Act, 2006. An overview of the regional stratigraphy including thicknesses of the formations, and unit name is expected. This description should also include an assessment of soils and infiltration properties inferred from grain size analyses from on-site test pits/boreholes where completed.

The report should also contain a minimum of two cross-sections (along perpendicular lines) to support discussions on geology, stratigraphy and flow patterns. Ideally, the cross-sections will be oriented along the groundwater flow path and across the groundwater flow path. In some cases, the cross-sections will be constructed based on the available data (regional sections along roads, etc.). Borehole logs should be shown on the cross sections with an interpretation of geologic units encountered. For shallow construction, test pit data may be correlated where possible.

- ☐ Description of surficial and bedrock material

- ☐ Summary of on-site borehole information
- ☐ Characterization of soil stratigraphy
- ☐ Provision of detailed cross sections showing boreholes and interpolation (a min. of 2 sections are highly recommended).
- ☐ Figures:
  - Surficial and bedrock geology
  - Soils
  - Cross sections with plan

3.1.6 Test Pits and Boreholes

On-site investigations comprised of excavation of test pits with a backhoe, or shallow boreholes, are advised to determine surficial geologic and hydro-geologic conditions. While no minimum number of test pits is stipulated, the consultant is expected to construct as many test pits as required by the geo-technical regulations and to use professional judgment to determine the number and location of test pits required to adequately assess the soils and overburden materials present on the site.

Boreholes may be constructed in place of test pits and may be finished as monitoring wells. Like test pits, boreholes should be installed at strategic locations across the site so that potential impacts to sensitive groundwater dependent features can be adequately assessed.

Test pits/boreholes should be advanced to a depth to correspond with the engineering plans associated with planned development. Test pit/borehole locations should be provided on a figure and all data should be provided in an Appendix. Each test pit or borehole record should show the date of excavation and data collection. Ground elevation (masl) must be provided for each pit.

Representative soil samples shall be analysed in the laboratory to determine grain size distribution and an estimate of material percolation rates provided.

- ☐ Description of test pits/boreholes on site including date of construction/abandonment
- ☐ Grain size analysis and logs are required within the appendix of the report
- ☐ Figures:
  - Site test pit/borehole location map including historic boreholes

3.1.7 Monitoring Wells

Monitoring wells provide access to groundwater and may be required to assess short and long term changes in water levels, aquifer properties, hydraulic gradients, groundwater flow direction, connection to surface water features and impacts from dewatering.

It is recommended that a representative number of monitoring wells are constructed onsite and water levels be recorded upon well installation and at least two other occasions to determine stabilized water levels, seasonal influences and the seasonally highest (spring) and seasonally low (fall) water table elevation. A field survey should be conducted to establish reference elevations for each monitoring point and used to provide consistent elevations of soil contacts and groundwater elevations.

It may be necessary to install piezometers instead of monitoring wells where shallow groundwater levels need to be obtained and an area that is not accessible to drill rigs due to the proximity to a sensitive feature(s).

- ☐ Description of monitoring wells/piezometers on site including date of construction/abandonment
- ☐ Grain size analysis and logs are required within the appendix of the report
- ☐ Figures:
    - Site test monitoring wells/piezometers location map including historic boreholes
    - Water levels (with sample dates) and hydrographs if available

3.1.8 Private Well Surveys

In addition to boreholes installed on the site, well data from wells within 500m of site should be used to characterize the groundwater conditions. If used, all relevant/supporting information should be provided within the report.

A house-to-house water well survey within 500 m of the site should be completed to obtain well location, construction details and water levels where possible. In addition, Ministry of the Environment (MOE) water well data within 500 m of the site should be obtained to supplement and confirm the data collected through the house-to-house survey.

- ☐ Well data for private wells within 500 m of the site is to be used for the impact assessment

- Figure of the well locations Hydrogeology/Hydrostratigraphy

Hydraulic conductivity (K) of each geologic unit should be characterized or estimated. The proponent may refer to published reports regarding typical hydraulic conductivity properties for the geologic units or utilize data from field tests (single well response tests) conducted on monitoring or test wells on the site. Both K_h and K_v estimates should be provided where available.

To characterize the groundwater conditions at the site, both groundwater levels and flow patterns should be discussed along with the appropriate documentation. This should include: 1) a description of groundwater levels and seasonal fluctuations; 2) direction of groundwater flow; and 3) areas of groundwater discharge along with estimated volumes. A description of both shallow and deep (where appropriate) groundwater flow systems should be provided along with a contour plan showing flow direction. Flow system attributes such as the average horizontal hydraulic gradient, and vertical gradients between hydrogeological units should be included. An indication of seasonal fluctuations and highest seasonal water table is expected over a period of time. Where site grade alterations are anticipated, the water table should be discussed in relation to both pre-development and the finished grade.

Field work should be carried out to assess the potential impacts of the proposed development on sensitive groundwater dependent features such as surface water and wetlands. In addition, the consultant should also provide a description of regional groundwater conditions that can be summarized from regional monitoring well data (where available) and water well records within the vicinity of the site (range and average well depth, range and average pumping rate, shallowest/deepest well, any flowing well conditions, etc.) to supplement site specific data.

- Identification and characterization of hydrostratigraphic units, including local and regional aquifers
- A summary of infiltration and recharge rates associated with the site materials
- Description and characterization of hydraulic conductivity and hydraulic gradients
- General description of surface water/groundwater relationships
- Water well characteristics that may be useful in characterization of the system (well depth, pumping rate, water level, types of wells, flowing conditions etc.)
- Summary of groundwater levels, including seasonal fluctuations and highest water table evaluation

- ☐ Groundwater flow characteristics
- ☐ Characterization of hydraulic gradients
- ☐ General description of surface water/groundwater relationships
- ☐ Figures:
    - Water table figure showing shallow groundwater flow direction
    - Piezometeric surface for deeper aquifers showing groundwater flow direction (if applicable to the study)

3.1.9 Description of Surface Water Features

A description of the study area should include all stream orders (Strahler, 1952) and other surface water features (e.g. wetlands) on/or bounding the site.

Surface and groundwater interactions and associated features should be noted. Areas of groundwater discharge should be noted where anticipated; either through water table elevations generated from water well records mapped above or near ground surface elevation or observed in the field. Where groundwater models exist, figures showing simulated groundwater discharge within the gauged reach may be provided. Where tile drainage is known to exist, it should be noted.

- ☐ General description of surface water features on or near the site and their relationship to groundwater discharge and location to the water table
- ☐ Figure of watercourses and wetlands (provincially and locally significant) on or near the site

3.1.10 Water Taking Permit Details

Where a Permit to Take Water (PTTW) is required from the MOE, the proponent should provide the Conservation Authority with the supporting PTTW information as provided to the MOE (if available). This should include permitted and actual planned taking details as well as special conditions of the permit, where applicable.

- ☐ Permit to Take Water application material should to be provided

3.1.11 Water Quality

A description of water quality (ground and surface) should be provided. This is to establish a baseline to assess potential future impacts. The consultant should request monitoring data where such data are available, and comment on anticipated impacts from the development to both ground and surface water bodies in the area. Where impacts are anticipated, the consultant should suggest ways to mitigate these impacts. Even where these impacts may be unavoidable or necessary to ensure human safety (such as impacts from road salting), such considerations would allow a holistic approach to the maintenance of watershed health.

- A description of surface and groundwater quality

3.1.12 D-5-5 (Water Supply)

Where a planned development is to establish a private water supply, the Ministry of Environment D-5-5 (*Technical Guideline for Private Wells: Water Supply Assessment, 1996*) is the provincial technical guideline that a proponent is generally required to adhere to. It is noted that the health and public works departments of some Ontario municipalities set their own requirements for applications for private servicing. Per the D-5-5 guideline, the capability of the aquifer to supply a sufficient quantity of water in accordance with the requirements of Regional `Guidelines for Small Groundwater Supply Systems August 1987' (MOE, 1995) must be demonstrated. Pumping tests are required as part of the guideline and details for the number of test wells required as well as the duration of the pumping test are outlined.

D-5-5 stipulates the minimum number of test wells as well as other considerations for a given size of property and a survey of private wells within a minimum of 500m of the site. Where there are private water wells in the vicinity of the development, information should be obtained where possible to establish pre-development conditions and to assess impacts during pumping tests. Where possible, new subdivision water supply wells should be developed in deeper confined aquifers to provide protection from surface activities. In locations where a protective aquitard does not exist, or it is limited in vertical thickness and extent, recommendations and decisions associated with the location of wells should take into consideration potential sources of off-site and on-site contamination such as septic leaching beds, farming operations, industrial operations, etc., recognizing, where appropriate, the potential formation of contaminant plumes from these sources.

Regardless of the aquifer chosen for the water supply, the water quality of the upper shallow aquifer, if applicable, should be determined. The shallow aquifer assessment will also include the potential impact of the development to the overall groundwater flow system which could lead to potential impacts on nearby groundwater dependent features such as wetlands and watercourses.

3.2 IMPACT ASSESSMENT

Developments typically result in impacts including: increased runoff, reduction in infiltration potentially leading to reduced interflow and baseflow discharge, raised or lowered water levels in shallow aquifers, changes in shallow groundwater flow direction, and creation of preferential pathways that may increase susceptibility of contamination in the subsurface. Impacts may be cumulative in areas where intensive development is planned.

The proponent must provide an assessment of potential impacts. The impact assessment will vary depending on the trigger of the hydrogeological assessment (e.g. a significant recharge area may require a water balance). Therefore, each Conservation Authority should be consulted to determine specific policies and associated requirements. In addition, acceptable impacts and appropriate mitigation will require the input of a qualified ecologist and/or biologist.

The assessment of potential development impacts may include, but is not limited to, a description of the following potential impacts:

- Changes to water table elevation (including seasonal fluctuations)
- Changes in groundwater flow direction
- Reduction to infiltration/recharge/discharge rates and volumes on varying time scales (i.e., daily to annual depending upon proximal environmental features)
- Reduction in baseflow
- Impacts on water quality
- Impacts to nearby receiving surface waters (wetlands, watercourses or other significant features)
- Impacts to environmental features

The impact assessment should demonstrate a degree of understanding of site conditions such that the potential impact of the proposed development is recognized and discussed. In addition, the assessment should evaluate the potential changes to existing conditions of the recharge/discharge features and functions resulting from the proposed development. This should include a description of the estimated post-development change from existing conditions as assessed and the direct and indirect effects over short-term and long-term periods should be described. A pre-development and post-development water balance is expected for most, though not all, development applications (see Table 1). The impact assessment should discuss how pre-development infiltration, evapotranspiration, runoff and flow paths can be maintained. Groundwater quantity, quality, water level patterns (duration, frequency and spatial distribution) and the link to nearby wetlands/watercourses should all be considered.

3.2.1 Groundwater Levels

Where the pre-development shallow groundwater levels are shown to support natural features (wetland and/or discharge to another surface water feature), and where the proposed development will require dewatering or is anticipated to result in a change in the volume and/or alteration to infiltration or recharge rates, an impact assessment of the groundwater levels must be included in the report. The following information should be included:

- Where the proposed development will result in a change in the infiltration/recharge rate, information on how and where water levels will be changed (i.e. increased or decreased)
- Anticipated impacts to sensitive groundwater-dependent features (wetland and watercourse) - mitigation plans to address the impacts (see Section 3.3 Mitigation)

3.2.2 Pumping Tests

Where the proposed development requires a dewatering pumping test, the design and interpretation of the test should be done by a qualified professional. The following information should be provided:

- Rate and duration of pumping test water level data in the form of hydrographs from observation wells used to measure impacts (i.e. shallow and deep aquifer units, mini-piezometers in surface water features, nearby private wells)
- Documentation of the test and interpretations should be provided (i.e. data and output from a manual analysis or from a commercially available software e.g. AquiferTest)

3.2.3 Groundwater Discharge (Baseflow)

As part of their mandate, Conservation Authorities are concerned with the potential impact of development on groundwater contribution to baseflow. In many areas in the province, baseflow represents between 50 and 90% of summer flow in many creeks with established aquatic life and watershed species dependencies. Dewatering and tile drain or large pipe installations can significantly reduce the volume of baseflow contributions from the subsurface. Changes to shallow groundwater flow patterns induced through development have also been linked to flooding and resulting damage to private property. It is recommended that the proponent ensure that the impact assessment considers and either avoids, or sufficiently mitigates, impacts to baseflow.

- Estimate/quantify reduction to baseflow

3.2.4 Water Balance Analysis

A water balance analysis is required to estimate the pre-development and post-development infiltration and runoff for most development applications as outlined in Table 1. Many Conservation Authorities have policies related to maintaining infiltration. The maintenance of pre-development 'recharge' is a general requirement in the Oakridges Moraine Conservation Plan, Lake Simcoe Protection Plan and the Provincial Policy Statement that is often captured in municipal Official Plans. Groundwater frequently supports significant watershed features that are necessary components to the maintenance of a healthy watershed. The purpose of the water budget analysis is to reasonably estimate the current infiltration rates to the subsurface and to then determine how much this rate will change as a result of the proposed development. It is recognized that site specific water budgets are difficult to accurately estimate, the goal should be to assess the difference between pre-development and post development conditions and to mitigate for impacts on infiltration. Please see Section 3.3 for more information on mitigation measures and the example in APPENDIX A: Water Balance Example.

The terms 'infiltration' and 'recharge' are commonly used interchangeably in development application supporting documents. Infiltration relates to the capacity for the soil to allow water to enter the subsurface. Some of this infiltration results in lateral movement in the shallow unsaturated zone where interflow may predominate and some of the infiltration is directed downward to the deeper aquifer system. Recharge is considered to be primarily water that reaches the saturated zone of the aquifer and becomes part of the regional groundwater flow system. The maintenance of infiltration rates is essential to the sustainability of the groundwater flow system which may support local significant ecological features. In addition, infiltration may move to a regional deeper flow system that may be important at a regional scale from either an ecological or water supply perspective.

It is common practice and an accepted method (by most Conservation Authorities) to provide estimates of surplus using a Thornthwaite and Mather approach where surplus is estimated based on precipitation minus evapotranspiration (Steenhuis and Van Der Molen, 1986). Infiltration portion of the surplus can be estimated by applying the infiltration factors provided in the Ministry of the Environment and Energy Hydrogeological Technical Information Requirements for Land Development Applications (1995). These factors consider slope, vegetation and soils. The remainder of surplus is considered to be runoff.

The water balance should be prepared by subdividing the development site into zones that reflect drainage outlets. In a simple case, there would be one catchment and one drainage outlet, whereas a more detailed case may have multiple stream catchments and several outlets. These catchments would be further subdivided by similar infiltration properties (i.e. grades, soils and vegetations). Pre-development and post-development water balances may have different catchments depending on the change in drainage patterns, grading, soil and vegetation as a result of the development. These changes should be clearly documented in the report and within a figure.

The Ontario Ministry of the Environment Stormwater Planning and Design Manual (2003) provides representative values for evapotranspiration in Ontario and provides guidance for factors to be used (based on MOEE, 1995 guidance) in determining recharge and runoff. It should be noted that the MOE Stormwater Manual (2003) provides examples only and where possible, local estimates of evapotranspiration and water surplus are to be provided using the Thornthwaite and Mather approach and data obtained from a local climatic station.

In most cases, one surplus value may be calculated for the entire site however, it may be requested that the surplus is calculated for each catchment for both pre- and post-development.

Post-development infiltration calculations/estimations should account for changes in imperviousness, vegetation, soil conditions, grading and site design by using adjusted infiltration factors based on these changes. These calculations should take into account the change in surplus (i.e. decrease in evapotranspiration) in areas where there will be impervious surfaces (e.g. roadways, driveways and rooftops). Where an amount of evaporation is assumed to occur on impervious surfaces these assumptions should be documented and supported accordingly. Generally, a 10-20% loss of precipitation is acceptable for these areas and is highly dependant on the drainage of the site.

With the recent completion of technical studies required under The Clean Water Act, 2006, many of the Conservation Authorities now utilize numerical models to estimate, interception, evaporation, potential and actual evapotranspiration, snowmelt, runoff, infiltration, interflow, and groundwater recharge. Many of these model estimates are based on soils, surficial geology and land use mapping products but may also consider detailed vegetation attributes as well as hydrological cycle functions. These modelling output data may be available from the Conservation Authority and consultants are encouraged to liaise with staff for access to the information.

Regardless of the water balance method applied, site-specific data and estimates should be incorporated as appropriate. The water balance should provide monthly calculations based on Thronthwaite and Mather to show Potential ET, Actual ET, and then use these to determine the annual surplus. However, a monthly water balance may be requested to take into account short-term or seasonal scale in addition to long-term or annual scale effects.

As much as possible, calculations should estimate the amount of infiltration necessary to maintain pre-development conditions. Detailed information on the proposed mitigation measures should be provided to account the loss of infiltration. These details should include location of enhanced infiltration (e.g. infiltration trench), the volume/rate and condition of the soils to support water being infiltrated. Mitigation is discussed further in Section 3.3.1.

At a minimum, the following are required when conducting a water balance analysis:

- Obtain precipitation values from a reliable source such as Environment Canada Meteorological Services for the area (utilize closest station with adequate data)
- Estimate of local values for major water balance components (evapotranspiration, surplus, runoff, and infiltration) for pre-development, post-development and post-development with mitigation conditions

- Calculations of impervious areas that reflect actual conditions based on the proposed site plan or a reasonable range of impervious areas used in those cases where only a conceptual development plan is provided
- Runoff coefficients consistent with generally accepted numbers (e.g. MOE guidelines)
- The water balance is required to take into account the changes to grading/topography and land cover.
- Grain size analysis for both the fill material and on-site soils to confirm fill material is similar to existing soil conditions (maybe recommended).
- Appropriate catchments should be used within the analysis (i.e. delineate catchments based on drainage, grades, vegetation, soils and show how infiltration and runoff will change within these zones for both pre- and post-development).
- Figure of catchments used within the pre- and post-development water balance.
- All calculations should be provided in a table format which clearly demonstrates that inputs (precipitation, additional runoff, water from municipal wells, etc.) are equal to outputs (i.e. infiltration, runoff, water use).

3.2.5 Groundwater Quality

The impact of the proposed development on groundwater quality should be assessed. This may include impacts to a surface water feature from road maintenance, landscaping practices and/or chemical processing or storage. In addition, water quality should be assessed as it relates to:

- Private water supply servicing
- Discharge water as a result of dewatering activities
- Activities that can be undertaken in areas that are delineated as Highly Vulnerable Aquifers (HVAs) and Significant Groundwater Recharge Areas (SGRAs), completed as part of the Assessment Report required in support of The Clean Water Act, 2006.

The existing water quality will need to be determined by sampling and testing of the water source to understand baseline conditions. The parameters analyzed should include general chemistry, bacteriological parameters, and site specific parameters of concern relating to past, existing and proposed land use. Based on the type of proposed development, an appropriate guideline (e.g. Ontario Drinking Water Quality Standards or Provincial Water Quality Objectives) should be selected from which to compare the test results. Other water quality guidelines may be considered for comparison on a case by case basis. Regardless of the aquifer chosen for the water supply, the water quality, and the potential impacts that might arise from the proposed development, within the upper shallow aquifer, if applicable, must be assessed. This assessment will include the potential water quality impacts to the shallow groundwater flow system as well as to any sensitive groundwater dependent features such as wetlands or watercourses.

3.2.6 D-5-4 Technical Guideline for Individual On-Site Sewage Systems: Water Quality Impact Risk Assessment 1996 - Septic System Suitability Evaluation

Where a planned development is to establish individual on-site sewage systems, the Ministry of Environment D-5-4 (Technical Guideline for Individual On-Site Sewage Systems: Water Quality Impact Risk Assessment, *1996*) is the provincial technical guideline that a proponent is generally required to adhere to. The septic system study should be consistent with the minimum requirements of the MOE Manual of Policy, Procedures and Guidelines for Private Sewage Disposal Systems and any Regional Health Unit and Public Works Departments Guidelines.

The evaluation should take into consideration the hydrogeological conditions of the site and groundwater resource evaluation and integrate these with septic effluent disposal issues.

The septic system suitability evaluation will require soils investigations to determine soil profiles and to estimate percolation for each lot across the site. Soil profiles to a minimum depth of 2 meters are required for each surficial geologic material on the property. The percolation times can be determined by the following methods:

- Grain size analysis of representative soil samples, and/or
- In-situ Percolation tests, and/or
- Guelph permeameter tests

Any one method can be used to determine percolation times but it is recommended that more than one method be used to provide comparative results. Representative percolation times are required for all soil types on the property. Lot specific testing will be required prior to draft approval for the design of private sewage systems.

Percolation times will be used to determine the design of the septic system according to the details given by MOE's Manual of Policy, Procedures and Guidelines for Private Sewage Disposal Systems, and Regional Health Services and Public Works Departments guidelines. All of the limiting factors such as depth to the water table, thickness of acceptable soils, range of percolation times, and distances to wells and surface water, as set out in the MOE and Regional

Guidelines, must be considered in the design. Based on the septic system design and the design sewage flow, the hydraulic loading to the groundwater must be assessed. In determining the hydraulic loading, consideration must be given to the hydraulic properties of the soil materials in which the septic systems will be placed as well as the underlying materials. The loading must be calculated on a lot-by- lot basis as well as in consideration of the development as a whole.

Using all of the information described above, provision of a diagram(s) showing the typical lot plan, building and leaching bed envelopes is recommended for each leaching bed design. Each leaching bed must be designed specific to the conditions on each lot.

3.3 MITIGATION REQUIREMENTS

The majority of development application studies should include recommendation(s) for actions to mitigate potential impacts identified through the hydrogeological studies. Specific measures should be described to mitigate the potential impacts identified in Section 3.2. Mitigation recommendations shall address both the anticipated long-term and short-term impacts. To this end, a monitoring program to address potential impacts prior to, during and post-development may be requested by the Conservation Authority at its discretion. In this case a contingency plan may also be required (see contingency plans).

Mitigation measures might include, but are not limited to:

- Recharge or infiltration basins for urban runoff
- Preservation of setbacks (buffer areas) from recharge/discharge areas
- Sedimentation control plans to prevent siltation of recharge/discharge areas
- Spill Control Plans
- Re-vegetation plans for disturbed areas
- Re-orientation of local surface water drainage
- Provisions for land use and site control plans (e.g., tree cutting restrictions, prohibition of use or storage of specified contaminants, access restrictions, etc.)

3.3.1 Maintenance of Infiltration

The maintenance of infiltration and interflow hydraulic functions is a key target to ensure that discharge to ecological features in close proximity will not be impacted and that the overall watershed health is sustained. It is recommended that especially in areas delineated as High Volume Recharge Areas, Significant Groundwater Recharge Areas, and Ecologically Significant Recharge Areas, pre-development infiltration should be matched in the post-development scenarios utilizing low impact development solutions. In other areas, professional judgement should prevail.

There are various approaches to mitigating the impacts through Low Impact Development (LID) measures. The proponent is encouraged to plan for such measures, even in areas with low infiltration (i.e. low permeability materials) given that the cumulative impact of development even on these areas can be significant over time. Any recommended approaches should be feasible/practical given the site's surficial native soils. Please refer to the Low Impact Development Stormwater Management Planning and Design Guide, Version 1.0 for some more information (Toronto and Region Conservation Authority and Credit Valley Conservation Authority, 2011).

It should be noted that promoting infiltration from paved surfaces, such as parking lots, roadways, etc. will generally not be approved unless the water has been pre-treated to prevent groundwater contamination.

Another consideration in recommending enhanced infiltration techniques is thermal considerations. Thermal impacts are important to aquatic life in areas where shallow discharge to streams is significant. Where proposed mitigation measures to increase infiltration are identified, these can also be beneficial to creeks with cold water thermal regimes by buffering them from prolonged spikes in air temperatures or inputs of hot urban stormwater. Cold water fish community assemblages have limits to the water temperatures they can tolerate. If these limits are surpassed frequently or for prolonged periods of time, then degradation in the health and the makeup of the fish community can be expected. As such, mitigation measures that promote stormwater infiltration can be of great benefit to enhancing groundwater contributions to cold water creeks thereby protecting and enhancing the thermal stability of these fish communities.

Green infrastructure may include downspouts connected to rain water cisterns, rain gardens, green roofs, vegetated filter strips, dry and bio swales, perforated pipe, infiltration trenches, and permeable pavement. Different approaches may be combined depending on the available space, configuration, topography and soil types associated with the development. These mitigation approaches are intended to move from the more conventional approach of "pipe and convey" to one that maintains the hydrologic cycle and mitigates water quality impacts. The above is not a complete list of current approaches being applied to development. Technical documents should be reviewed for the details on appropriate approaches that may be recommended for any particular site.

Clean water (roof, walkways, parking lot and road runoff with adequate treatment) may be infiltrated through infiltration trenches that may be modular in design. Enhanced infiltration measures should not receive runoff from high traffic areas where large amounts of de-icing salts are used nor areas where there are several or large sources of pollutants. Site topography and the location of the seasonally high water table are additional considerations.

Where a proposed mitigation measure to increase infiltration has been identified, the following points should be presented/discussed:

- the mitigation method(s) selected;
- location of mitigation measures on site plan
- impacts to groundwater and surface water quality;
- the amount (or range) of the annual enhanced infiltration estimated (based on available literature for each mitigation method recommended);
- limitations - practical matters need to be considered (such as the nature of the native soil and its capacity to allow enhanced infiltration);
- the long term expected success of the measures, for example clogging or siltation of infiltration facilities is a common issue that needs to be addressed;
- long term maintenance of the measure should be discussed (i.e. will maintenance be required and who will undertake such maintenance)
- post-development monitoring - often recommended but it is uncertain whether the monitoring actually occurs and to whom the data is being provided.

The current practice of simply increasing the infiltration factor where a form of mitigation is recommended with no documentation or breakdown calculation on the expected enhancement values for each individual method or how these methods will be evaluated is unacceptable.

It is understood that some developers and or their consultants do work with municipal or Conservation Authority staff in designing and monitoring LIDs but this is not common across the province.

3.3.2 Maintenance of Groundwater Quality

The mitigation measures should address not only water quantity, but also the potential for water quality impacts on groundwater and surface water resources as a result of the development. Depending on the zoned use of the site, water quality concerns will vary. For example, in the case where shallow groundwater flow discharging to nearby streams is significant, potential temperature changes are also relevant, as aquatic life may be impacted. A discussion of potential impacts to sensitive features (i.e. wetlands, watercourses, etc.), along with recommendations for mitigation of the impacts, should be provided.

3.3.3 Monitoring Program

Pre-Development monitoring program:

A monitoring program will need to be implemented prior to development in order to assess existing conditions and to undertake an impact assessment as outlined in Section 3.2. Pre-development monitoring may also assist in addressing public concerns that could arise in the future. The proposed monitoring program should outline the following:

- Location of the proposed monitoring stations;
- Description of the monitoring locations (well type, depth and conditions, wetland, reservoir, stream, etc);
- Frequency of specific data collection;
- Chemical and other parameters to be monitored as well as frequency of monitoring.

Development monitoring program:

In certain cases where an impact assessment indicates that potential impacts may arise during construction, the developer may be required by the Conservation Authority to monitor the impact of development during construction activities. In certain situations a contingency plan may also be required to mitigate observed impacts (see below). The monitoring program would be designed to assess water levels and/or water quality impacts during development activities. Where the MOE has required a monitoring program as a condition of a Permit to Take Water (PTTW) application, these results may also be requested by the Conservation Authority.

In certain cases where an impact assessment indicates that potential impacts may arise during construction, the developer may be required by the Conservation Authority to monitor the impact of development during construction activities. In certain situations a contingency plan may also be required to mitigate observed impacts (see below). The monitoring program would be designed to assess water levels and/or water quality impacts during development activities. Where the MOE has required a monitoring program as a condition of a Permit to Take Water (PTTW) application, these results may also be requested by the Conservation Authority.

Both up gradient and down gradient monitoring wells may be required for baseline data and information. Any required monitoring program would be designed in co-operation with the Conservation Authority to meet their concerns. The program would address:

- rationale for location of the proposed monitoring well(s);
- source of water supply (i.e. communal vs. individual wells);
- zone(s) to be monitored (i.e. depth of well, aquifer receiving effluent, aquifer supplying water, receptors);
- frequency of monitoring;
- necessary parameters to be monitored (e.g. nitrate, bacteria)

Monitoring results will be provided to the Conservation Authority (and municipality) at a pre-determined interval

Post-development monitoring program:

Post-development monitoring will not be required in most cases. In some circumstances the Conservation Authority may request that the development monitoring program (above) continue for a pre-determined amount of time following development activities to assess delayed impacts to groundwater resources.

3.3.4 Contingency Plans

Where determined during pre-consultation or review of the proposed development, a contingency plan may be required. This requirement would come into effect if significant impacts are anticipated from the proposed development. This could include for example, situations where large quantities or long duration of de-watering are expected, where a significant reduction in recharge is possible, or where degradation to water quality might be anticipated.

The report must include contingency plans to address such potential impacts. Contingency plans can be requested to address short and long term impacts depending on the duration and complexity of the development and the potentiality of impacts.

3.4 SUMMARY AND RECOMMENDATIONS

Each report will summarize the study findings and provide recommendations to minimize negative impacts to the groundwater-dependent features and their functions.

3.5 FIGURES

The report should include appropriately scaled figure(s) sufficient to describe the subject property in the context of the environmental resources under discussion. Sections 3.1 through 3.3 outline the suggested minimum recommended figures to be included within the report.

- ☐ Figures as outlined in Sections 3.1 through 3.3

3.6 REFERENCES

- ☐ List references

3.7 APPENDICES

- ☐ Well records and borehole logs
- ☐ Pumping test and associated water level information
- ☐ In-situ hydraulic conductivity testing results
- ☐ Soil analysis results
- ☐ Water balance calculations – Table format
- ☐ Laboratory water quality results
- ☐ Copies of relevant planning policies, agency guidelines

4 REFERENCES

Low Impact Development Stormwater Management Planning and Design Guide, Version 1, Toronto and Region and Credit Valley Conservation, 2010.

Ministry of Environment and Energy. 1995, MOEE Hydrogeological Technical Information Requirements for Land Development Applications.

Ministry of Environment and Energy. 1995, MOEE Hydrogeological Technical Information Requirements for Land Development Applications. Appendix C2: D-5-5 Technical Guideline for Private Wells: Water Supply Assessment, 1996.

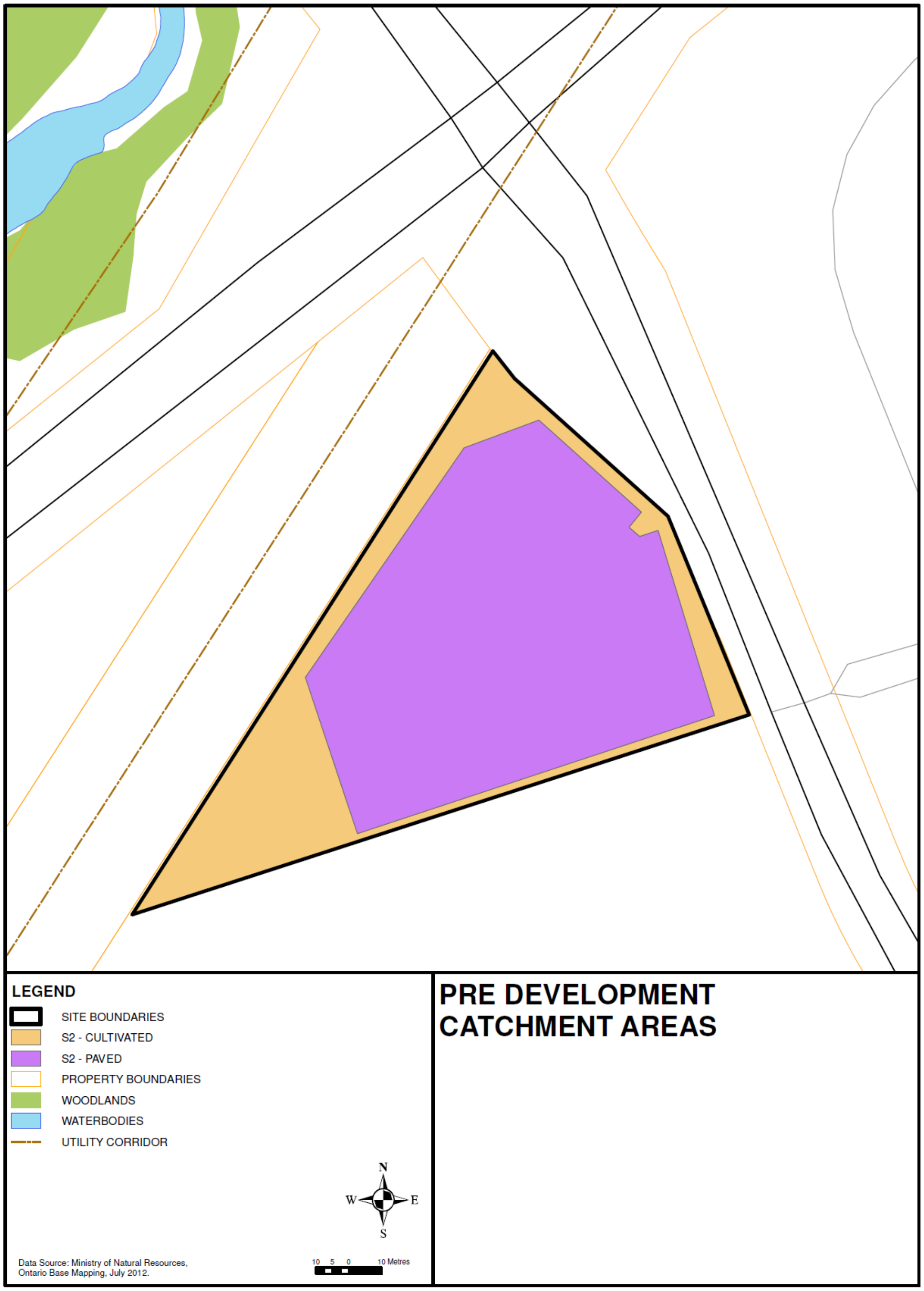
Ministry of Environment and Energy. 1995, MOEE Hydrogeological Technical Information Requirements for Land Development Applications. Appendix C3: D-5-4 Technical Guideline for Individual On-Site Sewage Systems: Water Quality Impact Risk Assessment, 1996.

Strahler, A. N. (1952). "Dynamic basis of geomorphology". Geological Society of America Bulletin 63: 923–938.

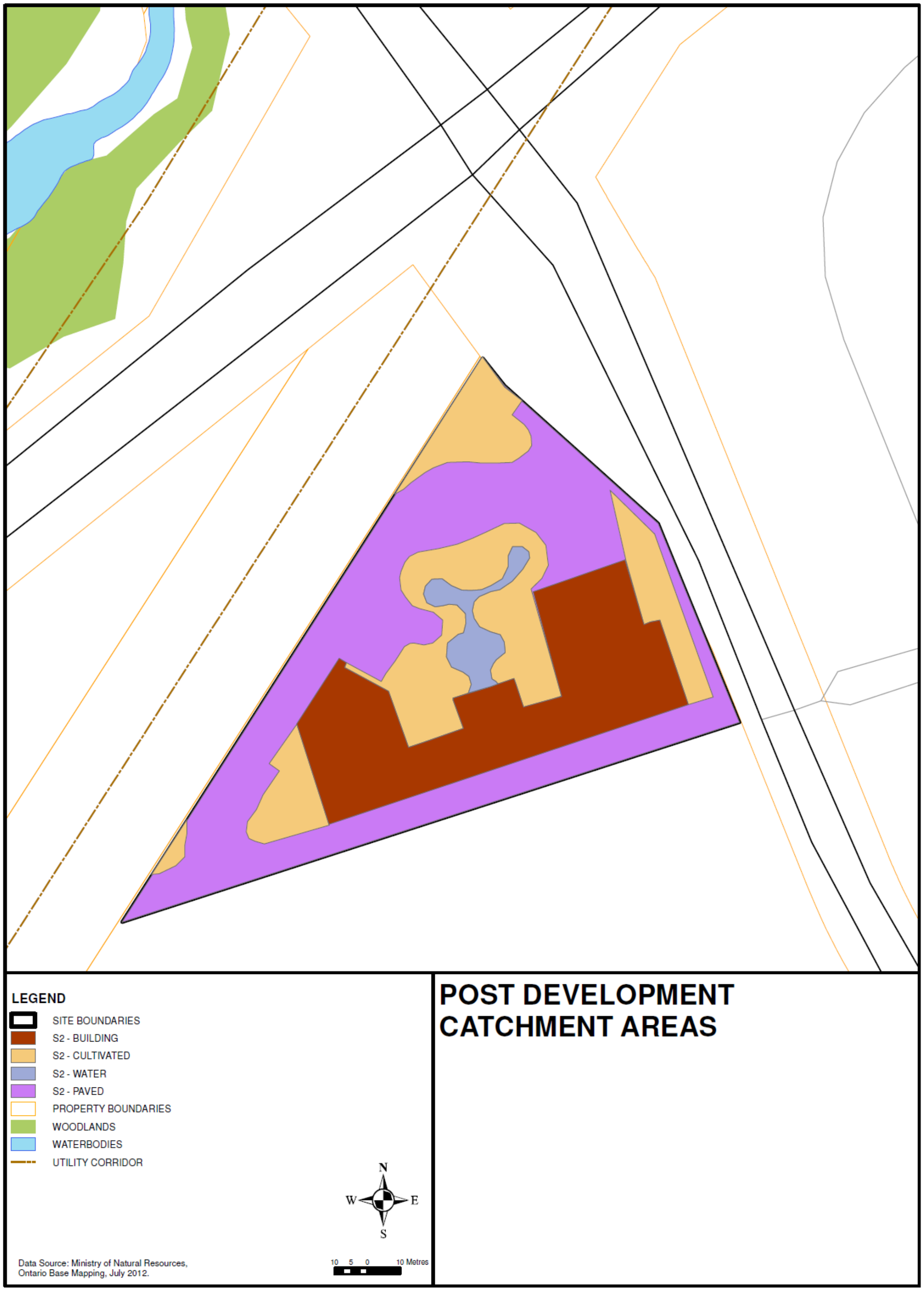
Strahler, A. N. (1952). "Hypsometric (Area-Altitude) analysis of erosional topography". Geological Society of America Bulletin 63: 1117–1142

T.S. Steenhuis, W.H. Van Der Molen, The Thornthwaite-Mather procedure as a simple engineering method to predict recharge, Journal of Hydrology, Volume 84, Issues 3–4, 30 May 1986, Pages 221-229, ISSN 0022-1694, 10.1016/0022-1694(86)90124-1

APPENDIX A: Water Balance Example



Data Source: Ministry of Natural Resources, Ontario Base Mapping, July 2012.



POST DEVELOPMENT CATCHMENT AREAS

Data Source: Ministry of Natural Resources,
Ontario Base Mapping, July 2012.

TABLE 1
CLIMATIC WATER BUDGET: CLIMATE NORMAL 1971-2000 (TORONTO LESTER B. PEARSON INT'L AIRPORT
Potential Evapotranspiration
TRILLIUM HEALTH CENTRE

	Thornthwaite (1948)							
Month	**Mean Temperature (°C)**	**Heat Index**	**Potential Evapo-transpiration (mm)**	**Daylight Correction Value**	**Adjusted Potential Evapo-transpiration (mm)**	**Total Precipitation (mm)**	**Surplus (mm)**	**Deficit (mm)**
January	-6.3	0.0	0.0	0.81	0.0	52.2	52.2	0.0
February	-5.4	0.0	0.0	0.81	0.0	42.6	42.6	0.0
March	-0.4	0.0	0.0	1.02	0.0	57.1	57.1	0.0
April	6.3	1.4	28.4	1.12	31.8	68.4	36.6	0.0
May	12.9	4.2	61.8	1.27	78.5	72.5	0.0	6.0
June	17.8	6.8	87.7	1.29	113.1	74.2	0.0	38.9
July	20.8	8.7	103.8	1.30	134.9	74.4	0.0	60.5
August	19.9	8.1	98.9	1.20	118.7	79.6	0.0	39.1
September	15.3	5.4	74.4	1.04	77.4	77.5	0.1	0.0
October	8.9	2.4	41.3	0.95	39.3	64.1	24.8	0.0
November	3.2	0.5	13.6	0.80	10.9	69.3	58.4	0.0
December	-2.9	0.0	0.0	0.74	0.0	60.9	60.9	0.0
TOTALS		**37.5**			**604.6**	**792.8**	**332.8**	**144.6**

TOTAL WATER SURPLUS **188.2** **mm**

NOTES:

1) Water budget adjusted for latitude and daylight.
2) (°C) - Represents calculated mean of daily temperatures for the month.
3) Precipitation and Temperature data from the Toronto Lester B. Pearson Int'l Airport located at latitude 43°40'38.0" N, longitude 79°37'50.0" W, elevation 173.40 m.
4) Total Water Surplus (Thornthwaite, 1948) is calculated as total precipitation minus adjusted potential evapotranspiration.
5) Total Moisture Surplus (Thornthwaite and Mather, 1957) is calculated as total precipitation minus actual evapotranspiration for 2007 and 2008.

TABLE 2
WATER BUDGET - PRE-DEVELOPMENT
WATER BALANCE/ WATER BUDGET ASSESSMENT

Catchment Designation	Site		
	S2 - Cultivated	**S2 - Paved**	**S2 - Totals**
Area (m^2)	4,229	9,427	**13,656**
Pervious Area (m^2)	4,229	9,427	**13,656**
Impervious Area (m^2)	4,229	9,427	**13,656**
Infiltration Factors			
Topography Infiltration Factor	0.15	0.15	
Soil Infiltration Factor	0.1	0.1	
Land Cover Infiltration Factor	0.1	0	
MOE Infiltration Factor	0.35	0	
Actual Infiltration Factor	0.35	0	
Run-Off Coefficient	0.65	1	
Runoff from Impervious Surfaces*	0	0.8	
Inputs (per Unit Area)			
Precipition (mm/yr)	793	793	**793**
Run-On (mm/yr)	0	0	**0**
Other Inputs (mm/yr)	0	0	**0**
Total Inputs (mm/yr)	**793**	**793**	**793**
Outputs (per Unit Area)			
Precipitation Surplus (mm/yr)	188	634	**496**
Net Surplus (mm/yr)	188	634	**496**
Evapotranspiration (mm/yr)	605	159	**297**
Infiltration (mm/yr)	66	0	**20**
Rooftop Infiltration (mm/yr)	0	0	**0**
Total Infiltration (mm/yr)	66	0	**20**
Runoff Pervious Areas	122	0	**122**
Runoff Impervious Areas	0	634	**1,413**
Total Runoff (mm/yr)	122	634	**476**
Total Outputs (mm/yr)	**793**	**793**	**793**
Difference (Inputs - Outputs)	**0**	**0**	**0**
Inputs (Volumes)			
Precipition (m^3/yr)	3,354	7,476	**10,829**
Run-On (m^3/yr)	0	0	**0**
Other Inputs (m^3/yr)	0	0	**0**
Total Inputs (m^3/yr)	**3,354**	**7,476**	**10,829**
Outputs (Volumes)			
Precipitation Surplus (m^3/yr)	795	5,977	**6,772**
Net Surplus (m^3/yr)	795	5,977	**6,772**
Evapotranspiration (m^3/yr)	2,559	1,499	**4,057**
Infiltration (m^3/yr)	278	0	**278**
Rooftop Infiltration (m^3/yr)	0	0	**0**
Total Infiltration (m^3/yr)	278	0	**278**
Runoff Pervious Areas (m^3/yr)	517	0	**517**
Runoff Impervious Areas (m^3/yr)	0	5,977	**5,977**
Total Runoff (m^3/yr)	517	5,977	**6,494**
Total Outputs (m^3/yr)	**3,354**	**7,476**	**10,829**
Difference (Inputs - Outputs)	**0**	**0**	**0**

* Evaporation from impervious areas was assumed to be 20% of precipitation

TABLE 3
WATER BUDGET, POST-DEVELOPMENT
WATER BALANCE/ WATER BUDGET ASSESSMENT

Catchment Designation	Site				
	S2 - Cultivated	S2 - Paved	S2 - Building	S2 - Water	S2 - Totals
Area (m^2)	3,609	5,977	3,655	415	13,656
Pervious Area (m^2)	3,609	0	0	0	3,609
Impervious Area (m^2)	0	5,977	3,655	415	10,047
Infiltration Factors					
Topography Infiltration Factor	0.15	0.15	0.15	0.15	
Soil Infiltration Factor	0.1	0.1	0.1	0.1	
Land Cover Infiltration Factor	0.1	0	0	1	
MOE Infiltration Factor	0.35	0	0	0	
Actual Infiltration Factor	0.35	0	0	0	
Run-Off Coefficient	0.65	1	1	1	
Runoff from Impervious Surfaces*	0	0.8	0.8	0.8	
Inputs (per Unit Area)					
Precipition (mm/yr)	793	793	793	793	793
Run-On (mm/yr)	0	0	0	0	0
Other Inputs (mm/yr)	0	0	0	0	0
Total Inputs (mm/yr)	**793**	**793**	**793**	**793**	**793**
Outputs (per Unit Area)					
Precipitation Surplus (mm/yr)	188	634	634	634	516
Net Surplus (mm/yr)	188	634	634	634	516
Evapotranspiration (mm/yr)	605	159	159	159	277
Infiltration (mm/yr)	66	0	0	0	17
Rooftop Infiltration (mm/yr)	0	0	0	0	0
Total Infiltration (mm/yr)	66	0	0	0	17
Runoff Pervious Areas	122	0	0	0	122
Runoff Impervious Areas	0	634	634	634	1,765
Total Runoff (mm/yr)	122	634	634	634	499
Total Outputs (mm/yr)	**793**	**793**	**793**	**793**	**793**
Difference (Inputs - Outputs)	**0**	**0**	**0**	**0**	**0**
Inputs (Volumes)					
Precipition (m^3/yr)	2,862	4,740	2,898	329	10,829
Run-On (m^3/yr)	0	0	0	0	0
Other Inputs (m^3/yr)	0	0	0	0	0
Total Inputs (m^3/yr)	**2,862**	**4,740**	**2,898**	**329**	**10,829**
Outputs (Volumes)					
Precipitation Surplus (m^3/yr)	678	3,789	2,317	263	7,048
Net Surplus (m^3/yr)	678	3,789	2,317	263	7,048
Evapotranspiration (m^3/yr)	2,183	950	581	66	3,781
Infiltration (m^3/yr)	237	0	0	0	237
Rooftop Infiltration (m^3/yr)	0	0	0	0	0
Total Infiltration (m^3/yr)	237	0	0	0	237
Runoff Pervious Areas (m^3/yr)	441	0	0	0	441
Runoff Impervious Areas (m^3/yr)	0	3,789	2,317	263	6,370
Total Runoff (m^3/yr)	441	3,789	2,317	263	6,811
Total Outputs (m^3/yr)	**2,862**	**4,740**	**2,898**	**329**	**10,829**
Difference (Inputs - Outputs)	**0**	**0**	**0**	**0**	**0**

* Evaporation from impervious areas was assumed to be 20% of precipitation

TABLE 4
WATER BUDGET, POST-DEVELOPMENT WITH MITIGATION
WATER BALANCE/ WATER BUDGET ASSESSMENT

Catchment Designation	**Site**				
	S2 - Cultivated	**S2 - Paved**	**S2 - Building**	**S2 - Water**	**S2 - Totals**
Area ($m^{2)}$	3,609	5,977	3,655	415	**13,656**
Pervious Area (m^2)	3,609	0	0	0	**3,609**
Impervious Area (m^2)	0	5,977	3,655	415	**10,047**
Infiltration Factors					
Topography Infiltration Factor	0.15	0.15	0.15	0.15	
Soil Infiltration Factor	0.1	0.1	0.1	0.1	
Land Cover Infiltration Factor	0.1	0	0	1	
MOE Infiltration Factor	0.35	0	0	0	
Actual Infiltration Factor	0.35	0	0	0	
Run-Off Coefficient	0.65	1	1	1	
Runoff from Impervious Surfaces*	0	0.8	0.8	0.8	
Inputs (per Unit Area)					
Precipition (mm/yr)	793	793	793	793	**793**
Run-On (mm/yr)	0	0	0	0	**0**
Other Inputs (mm/yr)	0	0	0	0	**0**
Total Inputs (mm/yr)	**793**	**793**	**793**	**793**	**793**
Outputs (per Unit Area)					
Precipitation Surplus (mm/yr)	188	634	634	634	**516**
Net Surplus (mm/yr)	188	634	634	634	**516**
Evapotranspiration (mm/yr)	605	159	159	159	**277**
Infiltration (mm/yr)	66	0	0	0	**17**
Rooftop Infiltration (mm/yr)	0	0	10	0	**3**
Total Infiltration (mm/yr)	66	0	10	0	**20**
Runoff Pervious Areas	122	0	0	0	**122**
Runoff Impervious Areas	0	634	624	634	**1,755**
Total Runoff (mm/yr)	122	634	624	634	**496**
Total Outputs (mm/yr)	**793**	**793**	**793**	**793**	**793**
Difference (Inputs - Outputs)	**0**	**0**	**0**	**0**	**0**
Inputs (Volumes)					
Precipition (m^3/yr)	2,862	4,740	2,898	329	**10,829**
Run-On (m^3/yr)	0	0	0	0	**0**
Other Inputs (m^3/yr)	0	0	0	0	**0**
Total Inputs (m^3/yr)	**2,862**	**4,740**	**2,898**	**329**	**10,829**
Outputs (Volumes)					
Precipitation Surplus (m^3/yr)	678	3,789	2,317	263	**7,048**
Net Surplus (m^3/yr)	678	3,789	2,317	263	**7,048**
Evapotranspiration (m^3/yr)	2,183	950	581	66	**3,781**
Infiltration (m^3/yr)	237	0	0	0	**237**
Rooftop Infiltration (m^3/yr)	0	0	37	0	**37**
Total Infiltration (m^3/yr)	237	0	37	0	**274**
Runoff Pervious Areas (m^3/yr)	441	0	0	0	**441**
Runoff Impervious Areas (m^3/yr)	0	3,789	2,281	263	**6,333**
Total Runoff (m^3/yr)	441	3,789	2,281	263	**6,774**
Total Outputs (m^3/yr)	**2,862**	**4,740**	**2,898**	**329**	**10,829**
Difference (Inputs - Outputs)	**0**	**0**	**0**	**0**	**0**

* Evaporation from impervious areas was assumed to be 20% of precipitation

Approximately 6% of total roof runoff is to be infiltrated to match pre-development infiltration

TABLE 5
WATER BUDGET SUMMARY
WATER BALANCE/ WATER BUDGET ASSESSMENT

Characteristic	**Site**				
	Pre-Development	**Post-Development**	**Change (Pre- to Post-)**	**Post-Development with Mitigation**	**Change (Pre- to Post- with Mitigation**
Inputs (Volumes)					
Precipition (m^3/yr)	10,829	10,829	0.0%	10,829	0.0%
Run-On (m^3/yr)	0	0	0.0%	0	0.0%
Other Inputs (m^3/yr)	0	0	0.0%	0	0.0%
Total Inputs (m^3/yr)	**10,829**	**10,829**	**0.0%**	**10,829**	**0.0%**
Outputs (Volumes)					
Precipitation Surplus (m^3/yr)	6,772	7,048	4.1%	7,048	4.1%
Net Surplus (m^3/yr)	6,772	7,048	4.1%	7,048	4.1%
Evapotranspiration (m^3/yr)	4,057	3,781	-6.8%	3,781	-6.8%
Infiltration (m^3/yr)	278	237	-14.7%	237	-14.7%
Rooftop Infiltration (m^3/yr)	0	0	0.0%	37	0.0%
Total Infiltration (m^3/yr)	278	237	-14.7%	274	-1.5%
Runoff Pervious Areas (m^3/yr)	517	441	-14.7%	441	-14.7%
Runoff Impervious Areas (m^3/yr)	5,977	6,370	6.6%	6,333	6.0%
Total Runoff (m^3/yr)	6,494	6,811	4.9%	6,774	4.3%
Total Outputs (m^3/yr)	**10,829**	**10,829**	**0.0%**	**10,829**	**0.0%**