FIGURES

TABLES

3.0 WATER BUDGET AND STRESS ASSESSMENT

Developing a source protection plan requires organizing and understanding data about water flow through the watershed. This can be accomplished by preparing a water budget. Water budgets show each part of a watershed's hydrologic system and uses data to describe the pathways that water takes through that watershed. A water budget looks at how much water enters a watershed, how much water is stored in it, and how much water leaves it (through both natural and human processes). This information helps determine how much water is available for human use while ensuring enough is left for natural processes. The watershed must have enough water to maintain streams, rivers, and lakes, and to support aquatic life and wetlands.

The Ministry of the Environment, Conservation and Parks has prepared the *Technical Rules,* which outline the steps required to:

- Estimate the quantity of water flowing through a watershed;
- Describe the significant processes that affect flow;
- Characterize the general movement of water; and
- Assess the sustainability of drinking water supplies.

The *Technical Rules* which guide the completion of the tiered water budgets are designed as a screening mechanism for gaining a progressive understanding of the characteristics of a watershed, the dynamics of surface water and groundwater interaction, and the impacts of water takings on municipal water supplies within the watershed.

The higher the tier, the more complex the science involved and the narrower the geographic focus. Moving from one tier to another helps those involved in source protection planning to understand where sources of water are located and how much water is being used in order to focus attention where it is most needed. The level of investigation required in the tiered approach depends on the severity of local water quantity issues.

While the water budget analysis primarily targets municipal drinking water sources, the knowledge gained and tools developed through the process are applicable to other areas of water resource and watershed management.

The framework includes up to four levels of analysis depending of the level of stress determined at each consecutive level. These tiers include:

- Conceptual Water Budget;
- Tier 1 Water Budget;
- Tier 2 Water Budget; and
- Tier 3 Water Budget.

This work was initiated following technical guidance distributed by the Province (Guidance Module 7) and was later modified to meet the requirements outlined in the *Technical Rules (2009).* In accordance with the *Technical Rules*, this water budget analysis does not include demand from Lake Ontario water. Water budgeting analyses are not required for the Great Lakes sources of drinking water. All levels of water budget analyses (as with all of the technical studies contained in this Assessment Report) were peer-reviewed by technical consultants, as well as provincial and municipal staff.

All comments and suggestions were considered in the final documentation, and sign-offs from the peer reviewers were obtained. A separate and more detailed peer review process was required by the Province as part of the water budget and Significant Groundwater Recharge Area analyses. This process and all associated documentation were provided to the Province as part of the approval process.

The conceptual level is the lowest tier, and Tier 3 the highest. A conceptual water budget provides a basic understanding of the key components of the water budget while the higher tiers attempt to refine the knowledge base regarding the competing demands vis-à-vis natural water availability. The higher the tier, the more complex the analysis becomes and the narrower the geographic focus. All source protection areas must complete a conceptual water budget and Tier 1 water budget analysis, but only watersheds which identify potential stress are required to complete Tier 2 and Tier 3 water budget studies.

3.1 CONCEPTUAL WATER BUDGET

Generally, the basic concepts of the hydrologic cycle, or the water budget, are familiar and understood by watershed stakeholders. The most commonly understood components are precipitation, evaporation, and streamflow within a given watershed. In scientific circles these have been further subdivided to account for plant transpiration, groundwater recharge, and groundwater flow. The measurements of precipitation and streamflow are comparatively straightforward, and data for these two parameters have been recorded for many decades by Environment Canada as well as, more recently, by Central Lake Ontario Conservation Authority (CLOCA) staff.

A conceptual water budget is the first of the four possible tiers of water budget analysis. It looks at the flow paths (runoff, and discharge and recharge zones), the amount of water within the system, and its movement through the various components of the hydrologic cycle.

The goal of the conceptual water budget is to understand the sensitivities of the system. It incorporates rough measures of the watershed's natural inputs and outputs, including:

- Precipitation, evaporation, and transpiration;
- Infiltration (water that becomes part of the *aquifer* system) and recharge (rainwater that soaks into the ground and either infiltrates or flows laterally before discharging); and
- Runoff.

Aquifer: An underground layer of water-bearing sediments (e.g., sand, gravel) or permeable rock from which groundwater can be usefully extracted via a water well.

As a basis for understanding the hydrologic regime, a conceptual water budget must also describe:

- Surface water and groundwater features;
- Land cover (e.g., the proportion of urban versus rural uses);
- Human-made structures (e.g., dams, channel diversions, water crossings); and
- Water takings.

A conceptual water budget will also present a qualitative understanding of the potential local impacts of climate change on the water budget over a 25-year period, based on observed trends. See **Figure** 3.1 for a depiction of groundwater recharge and discharge in the CLOSPA jurisdiction.

CLOSPA prepared a quantitative conceptual understanding of the hydrologic system, as required by *Technical Rule (19)*. To generate the estimates, CLOSPA:

- Described of the watershed conditions, including a summary of streamflow, total precipitation from local gauging stations, and all other hydrological components;

- Estimated the groundwater discharge component by utilizing a streamflow hydrograph separation methodology (which serves to differentiate between and quantify ground and surface water inputs);
- Used available regional geology models to determine potential areas of discharge, assuming that the amount of groundwater discharge and recharge were equal where the change in catchment area's storage is considered to be negligible (interflow is included either as runoff or groundwater discharge);
- Compared (where possible) evapotranspiration calculations and estimates provided in existing subwatershed, drainage, or development plan proposals for sensitive areas; and
- Prepared water budget output, composed of a watershed-based quantification of hydrological components.

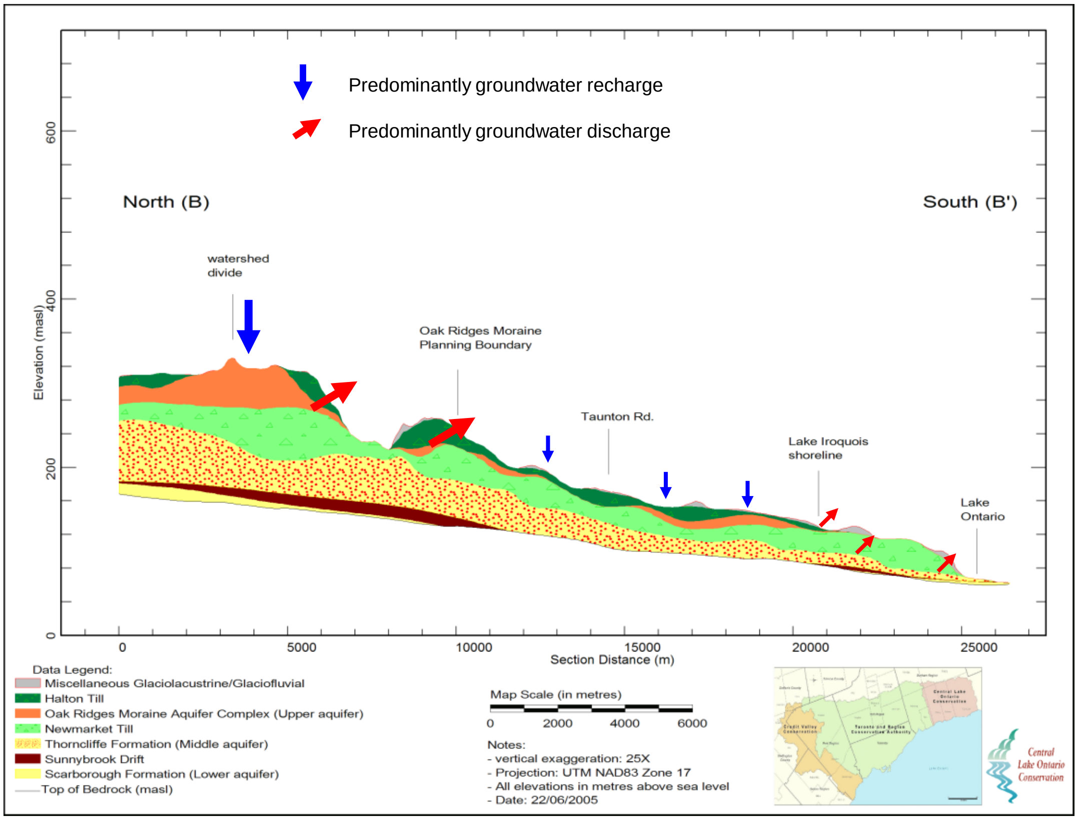

Figure 3.1: CLOSPA Conceptual Model of Flow System

Chapter 2 of this document provides details of the geological and hydrostratigraphic framework vital for the development of the hydrological components and drainage network in the study area. It also describes ecological features, fisheries, land cover, and land use. Please refer to **Chapter 2** for an in-depth description of the study area for this water budget.

The following section summarizes the key components of the hydrologic system in the study area in order to create a basis for understanding the findings documented in this chapter.

3.2 PHYSICAL GEOGRAPHY

3.2.1 Topography

Figure 3.2 shows CLOSPA's topography**.** Higher elevations occur along the Oak Ridges Moraine, which runs across the top of the study area, forms the northern surface water divide, and gradually slopes towards the Lake Ontario shoreline.

Till: A term applied to a mixture of different grain sizes ranging from clay to boulders deposited directly by glacial ice.

Surface elevations are at their highest near Chalk Lake, in the northwest of CLOSPA's jurisdiction, at 400 metres above sea level (mASL). At the Lake Ontario shoreline and in the deeply incised stream valleys, that trend north-south, surface elevations are 75 mASL, with an elevation decline of approximately 324 m over 23 km from north to south. There are broad areas of hummocky topography (**Figure 3.3**) associated with the Oak Ridges Moraine deposits and thin Halton *Till* deposits over the Oak Ridges Moraine deposits. The depressions in the hummocky areas act as zones of focused recharge and were given special consideration in the hydrologic model.

3.2.2 Physiography

The study area falls within three major physiographic regions (**Figure 3.4**) including (from north to south) the Oak Ridges Moraine, the South Slope, and the Iroquois Plain (Chapman and Putnam, 1984).

The Oak Ridges Moraine

The Oak Ridges Moraine contains four major wedge-shaped sediment deposits that are connected by narrower bands of sediments. The two middle wedges—the Uxbridge wedge to the west and the Pontypool wedge to the east—are located near the northwestern and northeastern corners of the study area, respectively. The Oak Ridges Moraine represents the most significant groundwater recharge area in the watersheds and serves as the headwaters for Lynde, Oshawa, Bowmanville, and Soper creeks.

Drumlinized: A landscape that is characterized by scattered elongated, low hills that are believed to have been formed under the glacial ice.

Lacustrine: in geology, a sedimentary environment of a lake.

The South Slope

The South Slope physiographic region extends southward from the base of the Oak Ridges Moraine towards Lake Ontario. It is a *drumlinized* plain, consisting of areas of thin aeolian sand deposits underlain by glacial deposits, mainly till. The South Slope is characterized by south trending drainage with sharply incised valleys. Harmony, Farewell, Black, and Pringle creeks and some tributaries to the larger streams have their headwaters on the South Slope.

The Iroquois Plain

The Iroquois Plain is a remnant of Glacial Lake Iroquois. The region can be separated into the following two areas:

- The Iroquois Beach: a northerly, east-west trending band of sandy beach and shallow water *lacustrine* deposits (approximately 2 km in width); and
- Iroquois Plain: a southerly plain formed by fine-grained lacustrine deposits.

The Iroquois Beach region is marked by low-lying bluffs and gravel bars. These beach sand deposits are an easily accessible source of groundwater for domestic use, and provide supplementary groundwater discharge to streams.

The Iroquois Plain region deposits are flatter and are composed of much finer grains. The smaller streams that discharge directly to Lake Ontario, such as Corbett and Tooley creeks, have their headwaters on the Iroquois Plain.

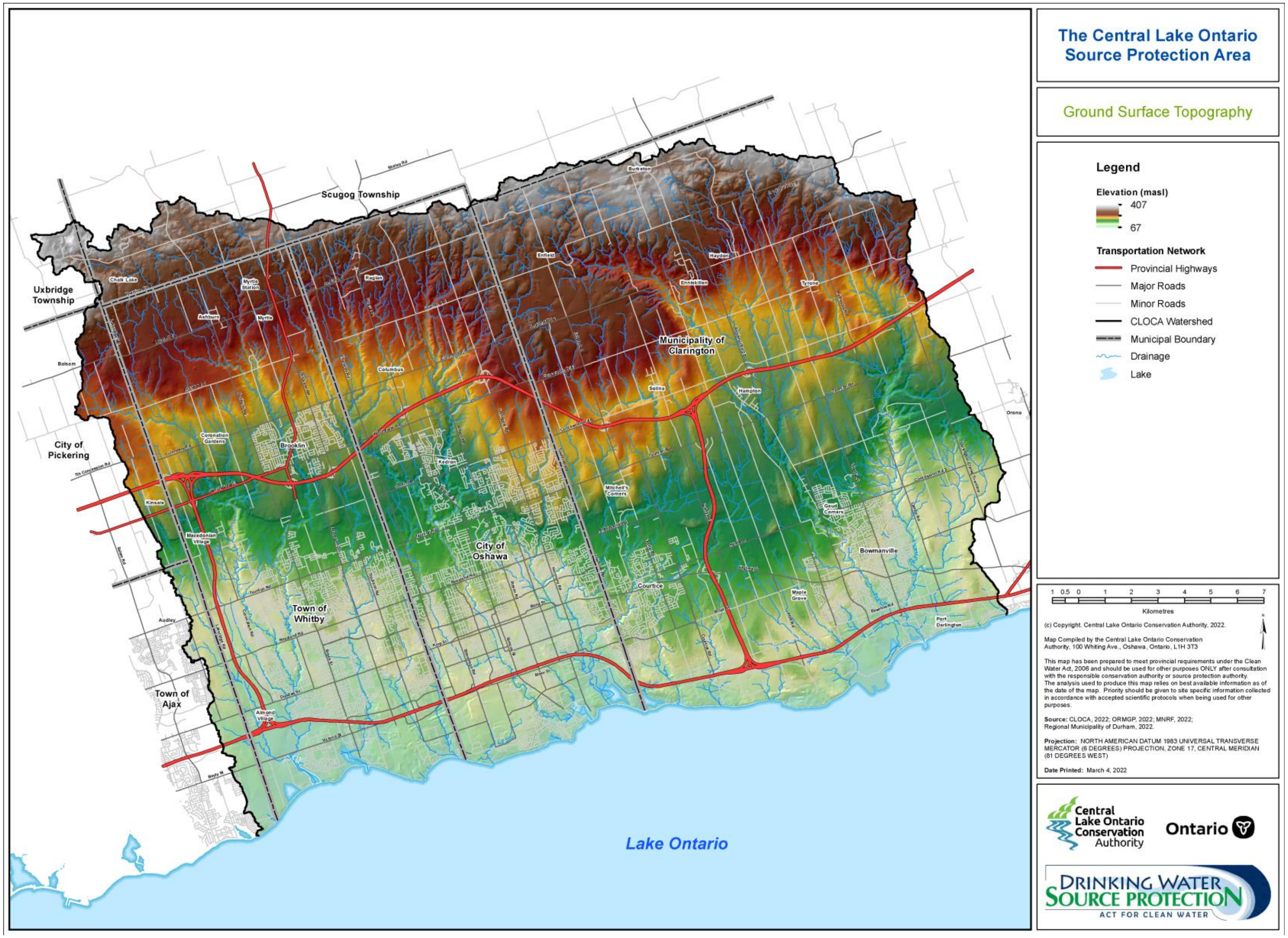

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Figure 3.2: Ground Surface Topography (from 30-m Digital Elevation Model (DEM) Data from MNR)

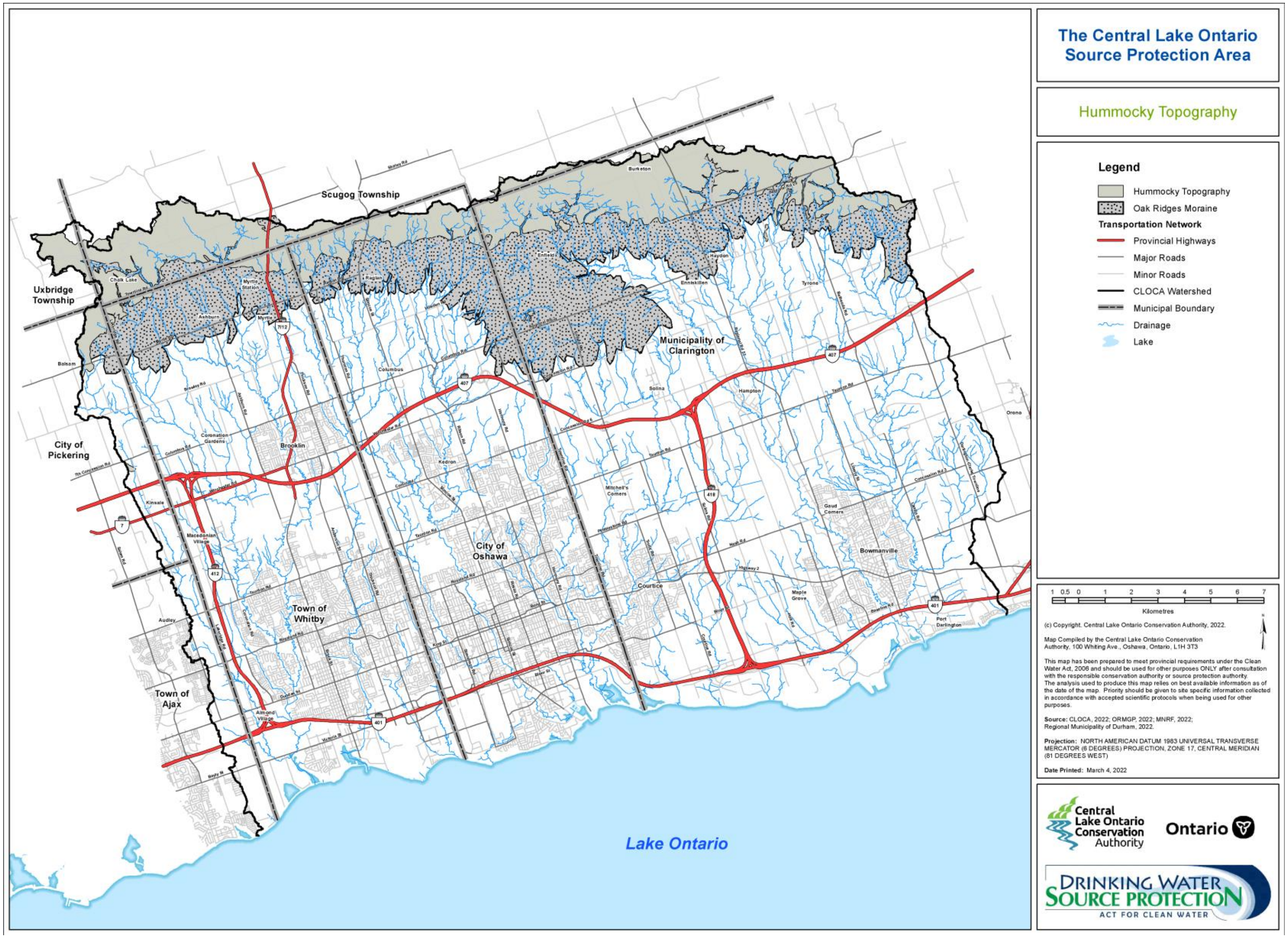

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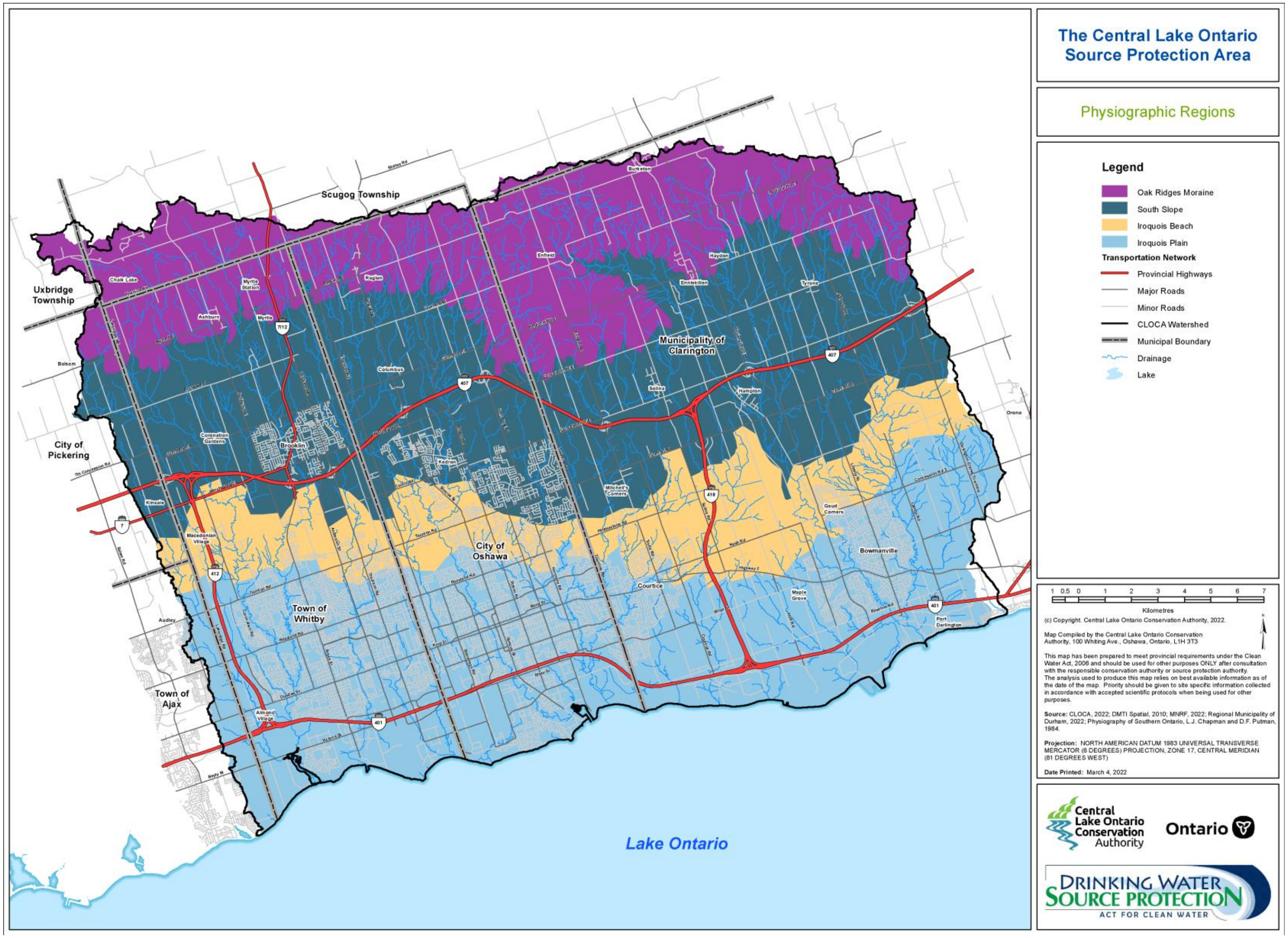
Figure 3.3: Hummocky Topography



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Source: CLOCA, 2022; DMTI Spatial, 2010; MNRF, 2022; Regional Municipality of Durham, 2022; Physiography of Southern Ontario, L.J. Chapman and D.F. Putman, 1984.

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Figure 3.4: Physiographic Regions (Chapman and Putnam, 1984)

3.3 GEOLOGY

For the most part, the study area consists of Quaternary sediments of variable thickness overlying Ordovician bedrock. The Quaternary sediments are made up of a sequence of glacial and interglacial lacustrine and *fluvial* units that record deposits made over approximately the last 135,000 years. These deposits form a sequence of aquife*r* and *aquitard* units in the study area. An understanding of these units as part of a stratigraphic framework is important to the fundamental conceptualization of water flow in watersheds.

Fluvial: processes associated with rivers and the deposits and landforms they create.

Aquitard: A layer of geological material that prevents or inhibits the transmission of water in a confined aquifer.

3.3.1 Stratigraphic Framework

To understand the geologic setting, the stratigraphic framework must be established. The stratigraphic framework is a conceptual description of the individual geologic units and the sedimentological (erosion and sedimentation) processes that affected the distribution and layering of the deposits. The stratigraphic framework for the study area has been very well established in previous work (Karrow, 1967; Dreimanis and Karrow, 1972; Sharpe *et al.*, 2002b; and Kassenaar and Wexler, 2006). The geology of the area can be characterized as consisting of sedimentary bedrock units overlain by unconsolidated overburden materials that have been deposited and modified by glacial, fluvial and lacustrine processes (Kassenaar and Wexler, 2006). The stratigraphic framework for the study area is outlined below and consists of (from oldest to youngest), see **Figure 3.5.**

1. Canadian Shield
2. Paleozoic Bedrock (550 to 350 million years ago)
    i. Simcoe Group Limestone
    ii. Georgian Bay Shale
    iii. Queenston Shale
3. Regional Unconformity “The Big Gap” (350 million to 135,000 years ago)
4. Pleistocene Overburden (135,000 to 20,000 years ago)
    iv. Scarborough Formation (or equivalent)
    v. Sunnybrook Drift (or equivalent)
    vi. Thorncliffe Formation (or equivalent)
    vii. Newmarket Till (also referred to as the Northern Till)
5. Regional Unconformity (channel infill deposits) (After approx. 20,000 years ago)
    viii. Oak Ridges Moraine/Mackinaw Interstadial Deposits (Approx. 13,300 years ago)
    ix. Halton/Kettleby Till (or equivalents, including Wentworth Till)
6. Glaciolacustrine Deposits (sand, silt and clay) (Approx. 12,500 years ago)

Details regarding the major bedrock and overburden units present in the CLOSPA are provided in the following sections.

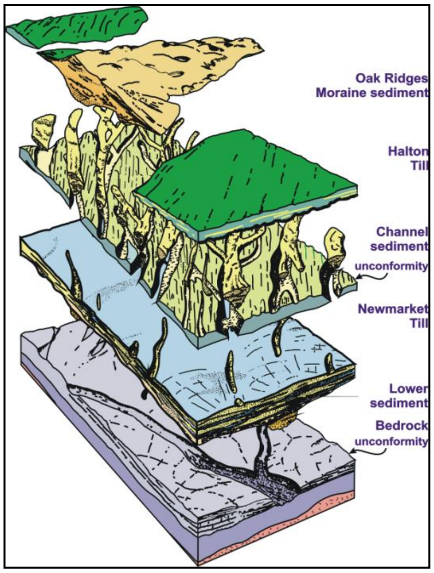

Figure 3.5: GSC Stratigraphic Framework for the Oak Ridges Moraine and South Flank

(Figure from Sharpe *et al.*, 2002)

3.3.2 Bedrock Geology

The bedrock that underlies the study area consists of limestone and shale from the Middle Ordovician (approximately 470 million years old) Lindsay Formation, and shale from the Upper Ordovician (approximately 45 million year old) Blue Mountain Formation (see **Figure 3.6**).

Regionally, the bedding dips gently toward the southwest. Bedrock exposure is limited to a few quarries, along some stream beds, and the Lake Ontario shoreline. The topographic lows are likely the result of erosion related to fluvial drainage systems that originated at higher bedrock elevation, north of the study area (see **Figure 3.7**)

Paleozoic: Geologic Era dating from about 250 to 650 million years before present.

Pleistocene: Geologic Epoch dating from about 10,000 to 2.6 million years before present.

Diamicton: A till-like material that may or may not have been deposited by glacial ice.

Glaciolacustrine: Sediments deposited in a lake associated with glacial ice.

3.3.3 Quaternary Sediments

The Quaternary sediments are from the Late *Pleistocene* geologic time period. They unconformably overlie *Paleozoic* bedrock. These sediments are up to 220 m thick, and consist of glacial and interglacial deposits that were formed within the last 135,000 years (Eyles, 2002; Karrow, 1989).

The sediment sequence is well exposed in the southern part of the study area along the Lake Ontario bluffs. This complex sedimentary package generally consists of the following:

- Till
- *Glaciolacustrine* sand
- Silt
- Clay
- *Diamicton*

It also includes Illinoian-age till and warm-climate interglacial sediments at the base of the Quaternary sequence (Karrow, 1967). **Figure 3.8** summarizes the Quaternary deposits found within the CLOSPA watersheds.

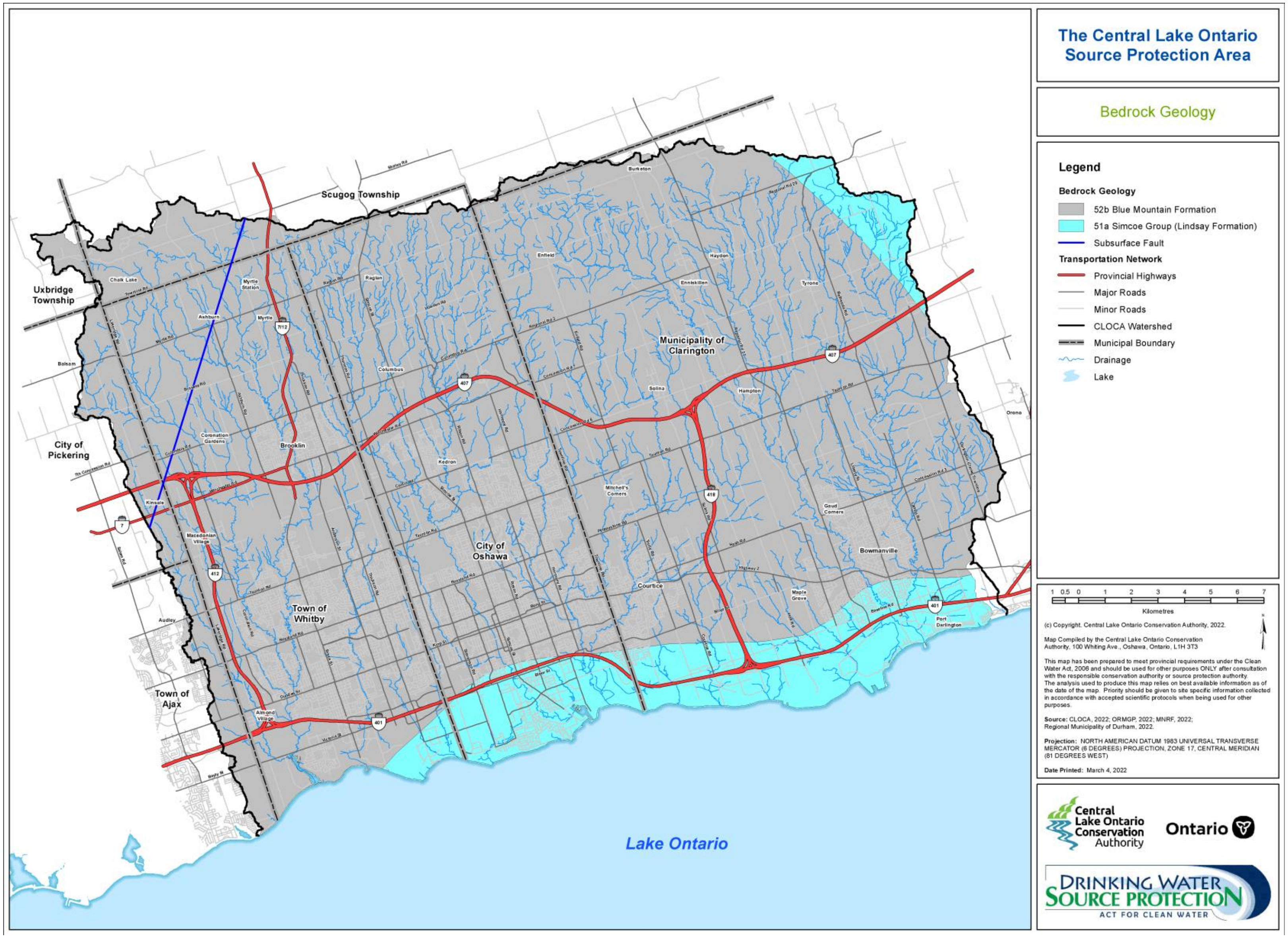

Figure 3.6: Bedrock Geology

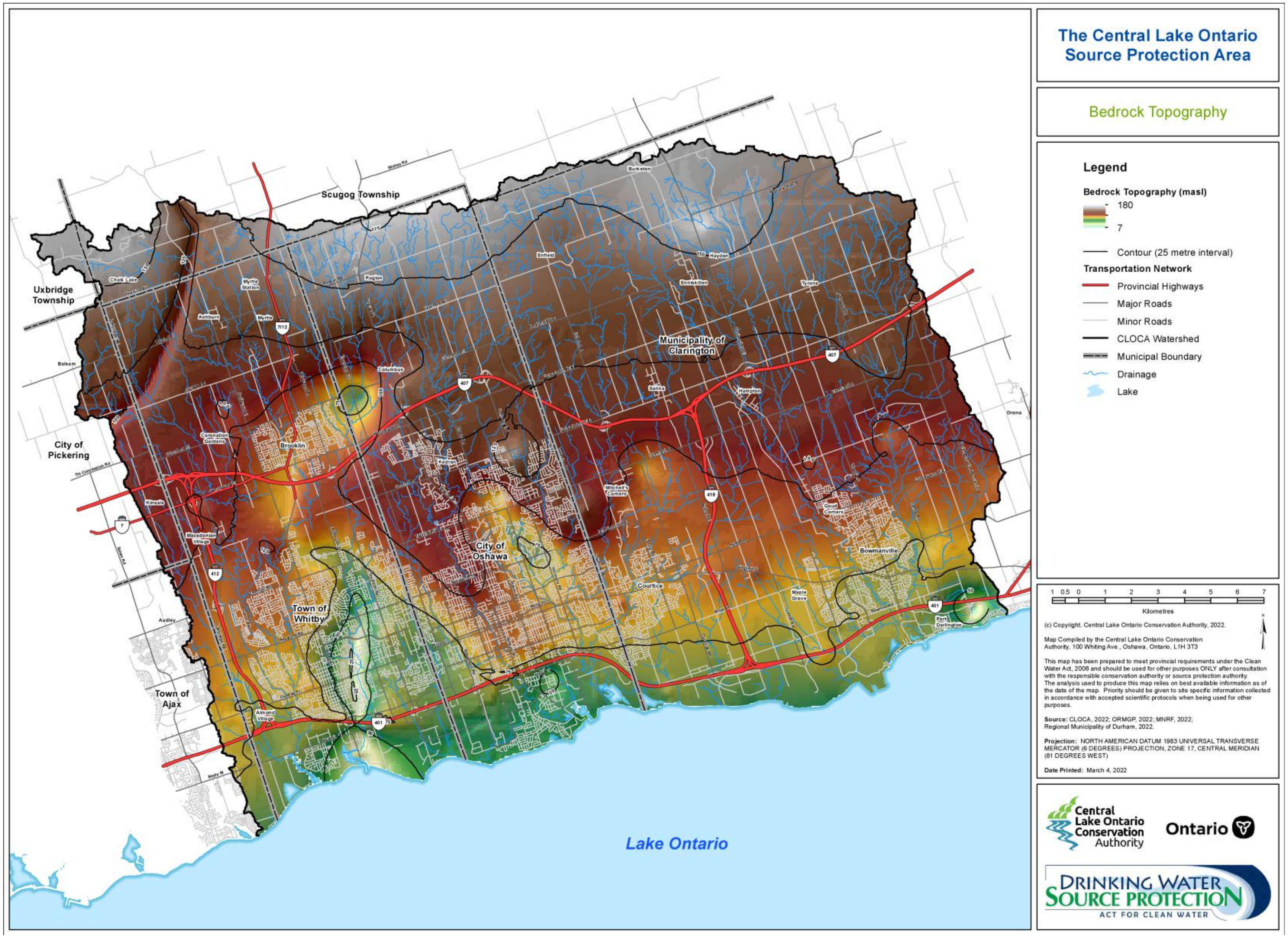

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Figure 3.7: Bedrock Topography

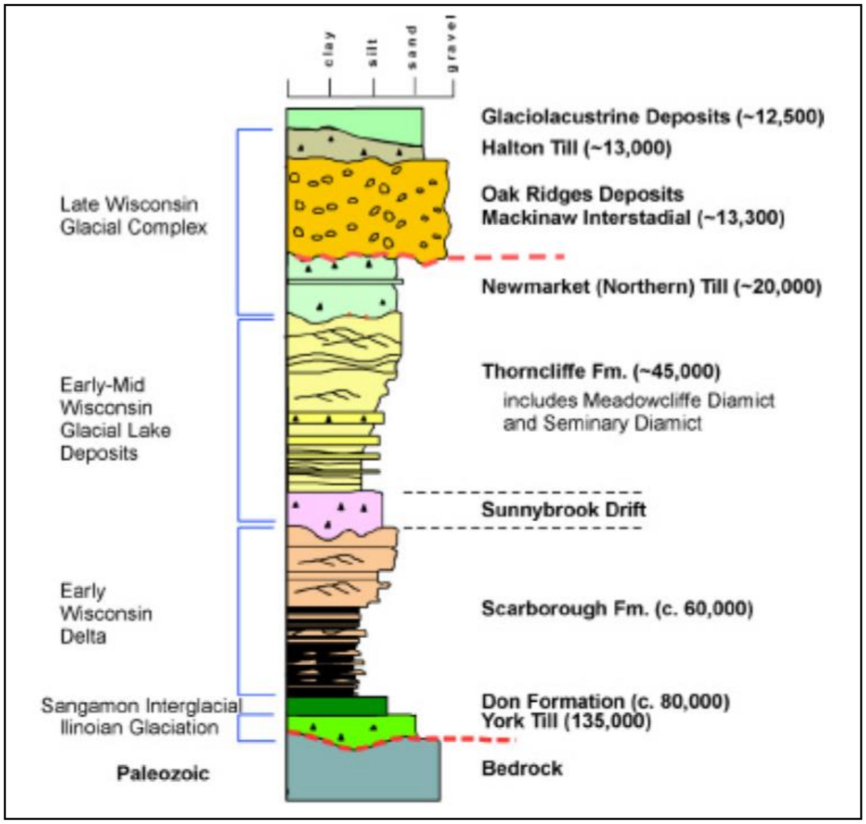


Figure 3.8: Quaternary Deposits Found within CLOSPA's Boundaries (modified from Eyles, 2002).

Scarborough Formation

The Scarborough Formation marks the start of the Wisconsinan glaciations, which took place approximately 100,000 years ago. These deposits consist of organic-rich (peat) sands that overlie silts and clays. The latter were deposited in a *fluvial-deltaic* system fed by large braided melt-water streams (Karrow, 1967; Eyles, 1997). The lower *prodelta* silts and clays are up to 60 m thick along the Scarborough Bluffs, and are likely in transitional contact with the muds of the underlying Don Formation (Eyles, 1987).

Fluvial-deltaic: Alluvial deposit at the mouth of a river.

Prodelta: The part of a delta lying beyond the delta front, and sloping gently down to the basin floor of the delta; it is

Sunnybrook Drift

The Sunnybrook Drift unit was deposited about 45,000 years ago and consists mainly of silt, but can also contain silty clay diamicton. It is generally less than 10–20 m thick, but is thicker over bedrock lows and in the northern part of the Lynde Creek watershed. The unit has been partially removed either by erosion or simply was never deposited over much of the southern half of the study area (CLOCA and MNR, 2007).

Thorncliffe Formation

The Thorncliffe Formation deposits consist of the following:

- Stratified sand;
- Silty sand;
- Rhythmically stratified silt and clay;
- Minor local pebbly silt; and
- Clay diamicton units.

This unit is present throughout most of the study area, and the interpreted thickness is shown in CLOCA and MNR (2007). The unit thickens considerably to the northwest of Lynde Creek (under the Oak Ridges Moraine) and to the northeast of Bowmanville and Soper Creeks.

The Thorncliffe Formation is often exposed on the edges of the deeper ravines near Lake Ontario and along the shoreline. These exposed areas receive direct recharge from precipitation. The water that discharges from the overlying aquifers at the edges of the valleys may also re-infiltrate the Thorncliffe Formation. Much of the recharge likely discharges locally to the stream reach within the valleys.

Newmarket Till

The Newmarket Till is a dense, over-consolidated diamicton. It was deposited by the Laurentide ice sheet when it was at its maximum extent, approximately 18-20,000 years ago. It is a massive diamicton, composed of 3–10% stony material and dense, silty sand up to 60 m thick. It contains thin interbeds of sand and silt (2–5 cm), boulder pavements, and fractures and joints. The till can be traced as a stratigraphic marker across the entire study area. The upper surface of the Newmarket Till was affected by widespread erosion, and forms a regional unconformity (Sharpe *et al*., 2002a).

The Newmarket Till separates the upper aquifer systems associated with the Oak Ridges Moraine from the lower aquifer systems that occur within deposits of the Thorncliffe and Scarborough formations. The till has been breached where it was eroded by rigorous meltwater activity (“tunnel channels”) in the northern part of the study area.

Locally, the Newmarket till is up to 65 m thick, but generally, it is less than 40 m thick. In the tunnel channel areas north of the study area (for example, south of Lake Scugog), the till is quite thin. The till is also thin in the southern part of the study area, where it may have been eroded by wave action in Glacial Lake Iroquois and by fluvial processes during subsequent lower lake stages.

Regional Unconformity (Tunnel Channels)

A network of south-southwest-oriented channels has been cut into the Newmarket Till, particularly to the north of the Oak Ridges Moraine. The channels are between one to four km wide at surface levels, and tens of metres deep. As noted, the channels cut into the Newmarket Till but, in some cases, they may penetrate into the Lower Sediments.

The infill sediments in the channels consist mainly of sandy and silty sediments. However, some channels contain 10–15 m thick cross-bedded gravels (Shaw and Gorrell, 1991; Pugin *et al*., 1999; Russell *et al*., 2002). Upward-fining of these sediments is caused by waning flow (e.g. Shaw and Gorrell, 1991). Locally, coarse channel fill sediments may be hydrogeologically significant as high-yield aquifers (Sharpe *et al*., 1996). More importantly, the erosion of the intervening Newmarket Till allows for direct hydraulic connection between the upper and lower aquifers.

There are two possible tunnel channel locations within the study area:

1. North of the headwaters of Oshawa Creek; and
2. Near the ORMGP Grasshopper Road borehole, located in the northeast Bowmanville Creek headwater area.

Oak Ridges Moraine Deposits

The Oak Ridges Moraine is an extensive stratified sediment complex. Its thickest deposits (up to 90 m) are located along a narrow east-west ridge at the top of the CLOSPA watersheds, see Conceptual Water Budget (CLOCA, 2007).

Along the south flank of the moraine, the deposits become much thinner (less than 30 m) and are covered by surface tills. Rhythmically interbedded fine sands and silts are the dominant sediments here, but coarse, diffusely-bedded sands and heterogeneous gravels are also prominent at the apex of fans and at depth in channels. Clay laminae are also present.

The deposits are interpreted as glaciofluvial, transitional to glaciolacustrine subaqueous fan, and delta sediments. They were deposited in a glacial lake ponded between two glacial ice lobes (Simcoe and Ontario) and the Niagara Escarpment during the Mackinaw Interstade, approximately 12,000–13,000 years ago.

Halton Till

The latest glacial ice advance over the southern part of the study area originated from the Lake Ontario Basin about 13,000 years ago, depositing the Halton Till. Halton Till is the youngest known till unit in the area, and possibly extends as far south as the Lake Iroquois shoreline.

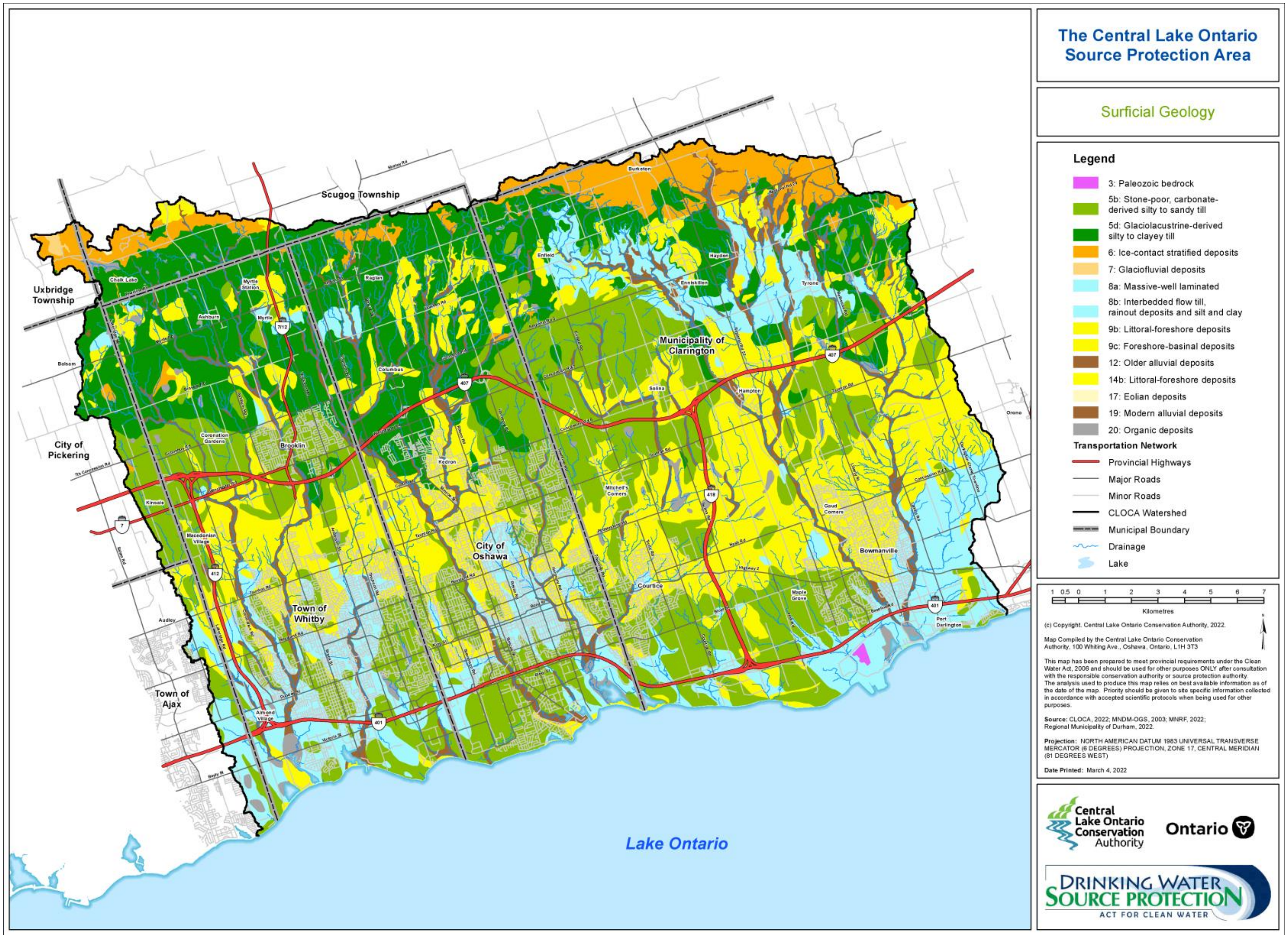
The Halton Till is texturally variable, but is generally a sandy silt to clayey silt till that is interbedded with silt, clay, sand, and gravel (Russell *et al*., 2002). The Halton Till is typically 3–6 m thick, but exceeds 15–30 m in thickness in certain local regions, such as in the headwater areas of Oshawa, Farewell, and Bowmanville creeks.

The till is generally considered a low recharge unit; however, where it is thin and weathered, and where it retains some of the hummocky features of the Oak Ridges Moraine, recharge through the till may be significant.

Surficial Glaciolacustrine Deposits

The uppermost surficial geologic unit is composed of a sequence of glaciolacustrine deposits, and occurs over the study area with the Iroquois Beach glaciolacustrine deposits; existing in an east-west band midway through the jurisdiction, they are the most continuous of these materials. These deposits represent local ponding of water, or higher water levels in Lake Ontario and Lake Simcoe, following the retreat of the glaciers approximately 12,500 years ago.

The extent of these deposits is shown on the surficial geology map featured in **Figure 3.9**. High rates of infiltration can occur through the beach deposits; however, because they are thin and underlain by till, the water table is shallow and subject to high evapotranspiration losses. Net recharge to groundwater is less than at the Oak Ridges Moraine deposits.



The Central Lake Ontario Source Protection Area

Surficial Geology

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Figure 3.9: Surficial Geology (Sharpe *et al.*, 1997)

3.3.4 Hydrogeologic Units

Stratigraphic Unit: A body of rock forming a discrete and definable unit characterised by lithology, fossil content and age.

Stratigraphy: The soil and rock layers within a study area and the layering process that created them.

Hydraulic conductivity (k) is the ability of a *stratigraphic unit* to transmit water through pores or fractures. This factor is extremely variable in Quaternary sediments and Bedrock. Methods were developed to represent spatial variations in hydraulic conductivity, because these variations influence the lateral and vertical movements of groundwater. The distribution of this parameter was estimated 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 Oak Ridges Moraine Groundwater Program (ORMGP) Groundwater Study Core Model (covering York Region) calibration process, as described in Kassenaar and Wexler (2006).

A hydrogeologic unit is a part of a stratigraphic unit. It is characterized by its porosity and hydraulic properties, which form a distinct hydrostratigraphic unit with respect to the flow of ground water (Maxey, 1964). Delineation of these units subdivides the formation material into more or less permeable portions, which helps to define the flow system.

The stratigraphic units are based on the Oak Ridges Moraine groundwater study's current interpretation, which was conducted for ORMGP study team. They are built into the three-dimensional groundwater flow model that was used for this water budget analysis (Kassenaar and Wexler, 2006).

The discussion here focuses on the link between geology, groundwater systems, and surface water systems. The ORMGP study subdivided the stratigraphic units into eight hydrostratigraphy layers to provide the detail needed to develop a groundwater flow model. Names for these eight units were selected based on the *stratigraphy* along the Lake Ontario shoreline. They are described below and summarized in **Table 3.1**.

The flow of groundwater through the unconsolidated sediment system is largely controlled by two main geologic features of the stratigraphic framework:

- The orientation and connection of the bedrock valleys—sand and gravel deposits often occur upon bedrock lows, and can form productive aquifers.
- The framework of the Newmarket Till that separates the "upper" and "deeper" parts of the flow system—where this unit has been completely eroded by melt water, or tunnel channels, the nature of the infill sediments will control the amount of leakage to the deeper aquifer system.

The nature of the infill materials is known for only a few locations situated to the west of the study area. The infill for one tunnel channel system near King City and Nobleton is described by Russell *et al*. (2002) as consisting of thick gravel deposits and diffusely graded fine sand. Further north, in the Aurora-Vandorf area, coarse sediments, including significant gravel aquifer intervals, are an important part of the channel sediments (Sharpe and Russell, 2001).

The infill material for the erosional channels is quite variable and may, in some cases, contain significant quantities of fine-grained sediments. This appears to be the case in portions of the tunnel channel near King City. In many areas, the nature and extent of the infill material within the tunnel channels remains uncertain due to the lack of deep borehole or well information. Where the Newmarket Till is present, the flow of groundwater through this aquitard is described in Gerber *et al*., 2001; Gerber, 1999; Gerber and Howard, 1996. The thickness and location of the granular deposits of the Oak Ridges Moraine form the major recharge area within the northern part of the study area.

	Stratigraphic Unit	Hydrostratigraphic Layers (HGUs)		Hydraulic Conductivity (k) (m/s)		Groundwater Flow System
		Aquifer	Aquitard	Horizontal	Vertical	
1	Glaciolacustrine and Recent		Recent Aquitard			Shallow
2	Halton Till		Halton	5.0E-07	1.5.0E-07	
3	Oak Ridges Moraine, Mackinaw Interstadial and/or Tunnel Channel Infill	Oak Ridges Aquifer Complex (ORAC)		5.0E-07 to 2.4.0E-04	Variable	
4	Newmarket Till and/or Channel silt		Newmarket	5.0E-08	1.0E-08	
5	Thorncliffe Fm. (or equivalent) and/or Tunnel Channel Infill	Thorncliffe Aquifer Complex (TAC)		1.0E-05 to 1.0E-03	Variable	Deep
6	Sunnybrook Drift (or equivalent)		Sunnybrook	5.0E-08	5.0E-09	
7	Scarborough Fm. (or equivalent)	Scarborough Aquifer Complex (SAC)		1.0E-05 to 3.0E-04	Variable	
8	Bedrock	Weathered Limestone and/or Shale		7.0E-06	7.0E-06	

Table 3.1: The Classification of the Stratigraphic Units into Eight Hydrostratigraphic Layers

3.4 SURFACE WATER FLOW SYSTEM

3.4.1 Surface Water and Drainage

Understanding the hydrologic characteristics of CLOSPA's watershed helps improve the understanding of the surface water bodies, their flows, and their levels. This section starts with a description of the drainage system and then goes on to:

- Describe the fluvial forms (fluvial geomorphology);
- Define stream size based on a hierarchy of tributaries (stream order);
- Identify surface water divides (surface water control structures);
- Identify surface water temperatures (thermal classification); and
- Identify surface water flows and levels.

The natural drainage system within CLOSPA includes five major watersheds that begin in the Oak Ridges Moraine and many smaller watersheds that begin in the southern part of the study area. Numerous small streams that drain directly into Lake Ontario have been grouped into the "Lake Ontario Catchments."

From west to east, the following creeks drain the major watershed areas of CLOSPA:

- Lynde;
- Oshawa (including the Goodman);
- Farewell;
- Black;
- Harmony;
- Bowmanville; and
- Soper.

The following are smaller streams originating in the southern portion of the study area:

- Pringle;
- Corbett;
- Robinson;
- Tooley;
- Darlington;
- Westside; and
- Bennett.

Several unnamed smaller watersheds also drain directly into Lake Ontario.

3.4.2 Fluvial Geomorphology

The geomorphology of creeks in the CLOSPA watershed area is typical of moraine-fed streams that drain to Lake Ontario. The moraine itself is generally able to hold and infiltrate precipitation into groundwater, and does not produce sufficient surface water to form streams.

The headwater streams begin on the south slope of the moraine. There, groundwater discharges to the surface along lithologic contacts. As these small streams flow through the Till Plain, the topography becomes much more uniform, with a significant north-to-south slope. The till soils are subject to erosion, and steep gullies and valleys have developed over time.

Many small streams begin in the Iroquois Beach as a result of groundwater discharge from the area. South of the beach, very few small tributaries exist, and the established creeks convey the flow.

Streams in the urban part of CLOSPA's jurisdiction have a significant history of alteration and do not reflect a natural form, but rather an impact and adjustment form.

3.4.3 Stream Order

Streams are classified using a stream order system, which assigns streams a number depending on their location in the network's branching pattern.

More than two-thirds of these streams originate within the Oak Ridges Moraine, which attests to the area's importance for groundwater discharge. First and second-order streams also receive almost half of the groundwater discharge for much of the Oak Ridges Moraine area (Earthfx, 2004). Accurate mapping of low-order streams is, therefore, critical in assessing the spatial distribution of groundwater discharge for water budgets and resource modelling.

3.4.4 Surface Water Control Structures

CLOSPA's topography is an important part of flow surface water control. For more information, please see the **Section 3.2**.

The current inventory of barriers in CLOSPA's jurisdiction identifies most of the barriers that are typically classified as either man-made (e.g., mill pond dams, culvert installations) or natural (e.g., log jams, beaver dams), **Figure 3.10.**

Most barriers in CLOSPA's watersheds are natural and do not have significant long-term effects on fish and fish habitat. Man-made barriers are of greater concern to the aquatic resources because of their impact on fish habitat and fish passage. These barriers also influence, among other things, streamflow and evaporation rates.

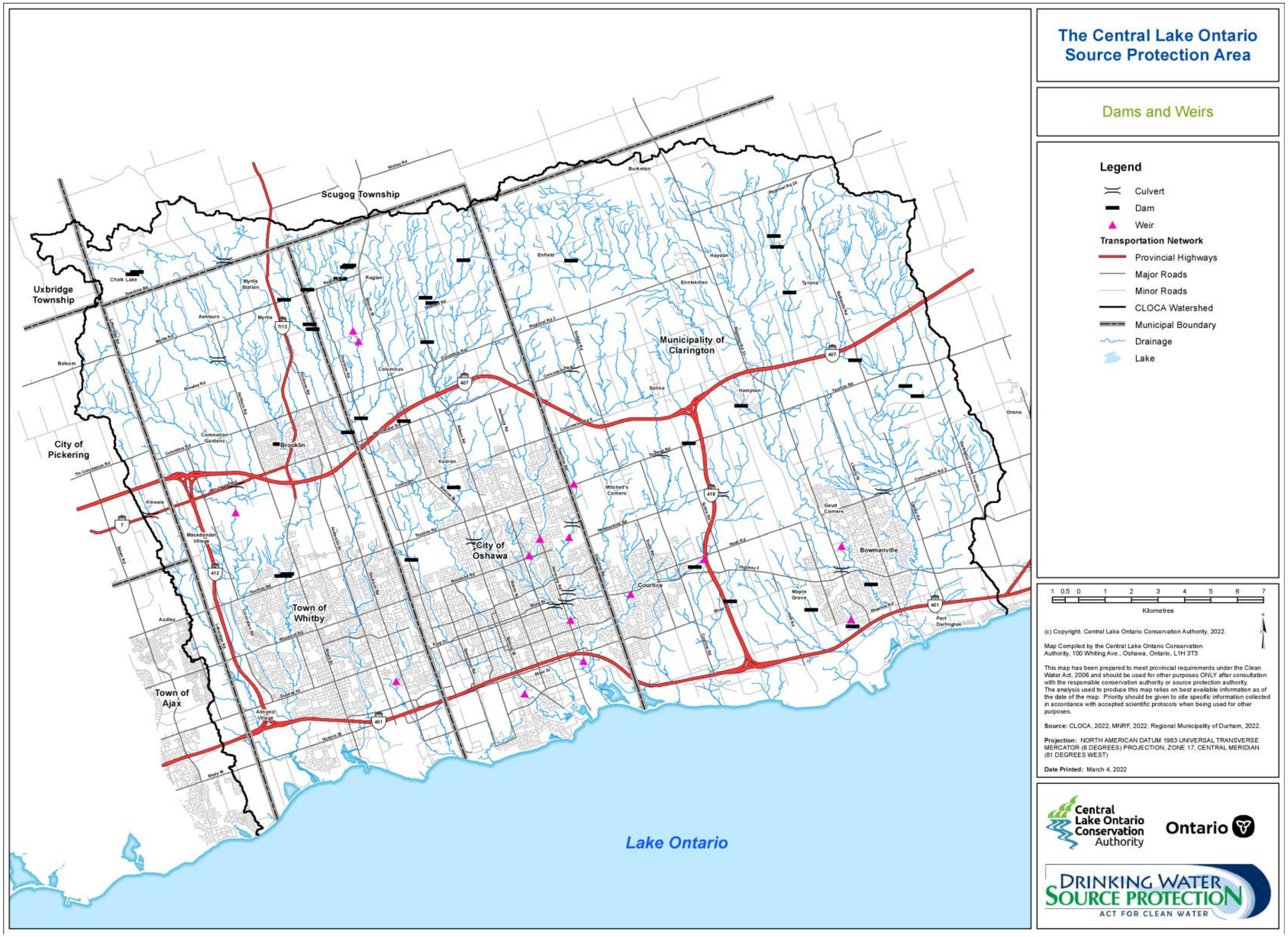
This information is highly relevant to water budget assessments, specifically:

- To identify model sensitive areas as potential recharge sinks;
- To identify stream diversion; and
- To analyze evapotranspiration.

3.4.5 Thermal Classifications

Each site's thermal classification was determined by analyzing data provided by the Stream Temperature Analysis Tool and Exchange (STATE)(Jones and Chu, 2007). Temperature loggers are deployed into the stream in the spring to record temperatures every half hour until they are retrieved in the winter. This creates a robust dataset and a good understanding of the stream's thermal regime. Also, by recording stream temperatures in the winter, CLOSPA can better understand groundwater contributions (Conant, 2004).

CLOSPA watersheds are generally classified as cold to cool water systems, with the exception of a few warm water reaches. These are typically located in degraded urban areas or headwater areas with little natural cover, and in areas where the groundwater contribution is not enough to moderate the impact of scarce riparian vegetation (**Figure 3.11**).



Map Compiled by the Central Lake Ontario Conservation Authority, 100 Whiting Ave., Oshawa, Ontario, L1H 3T3

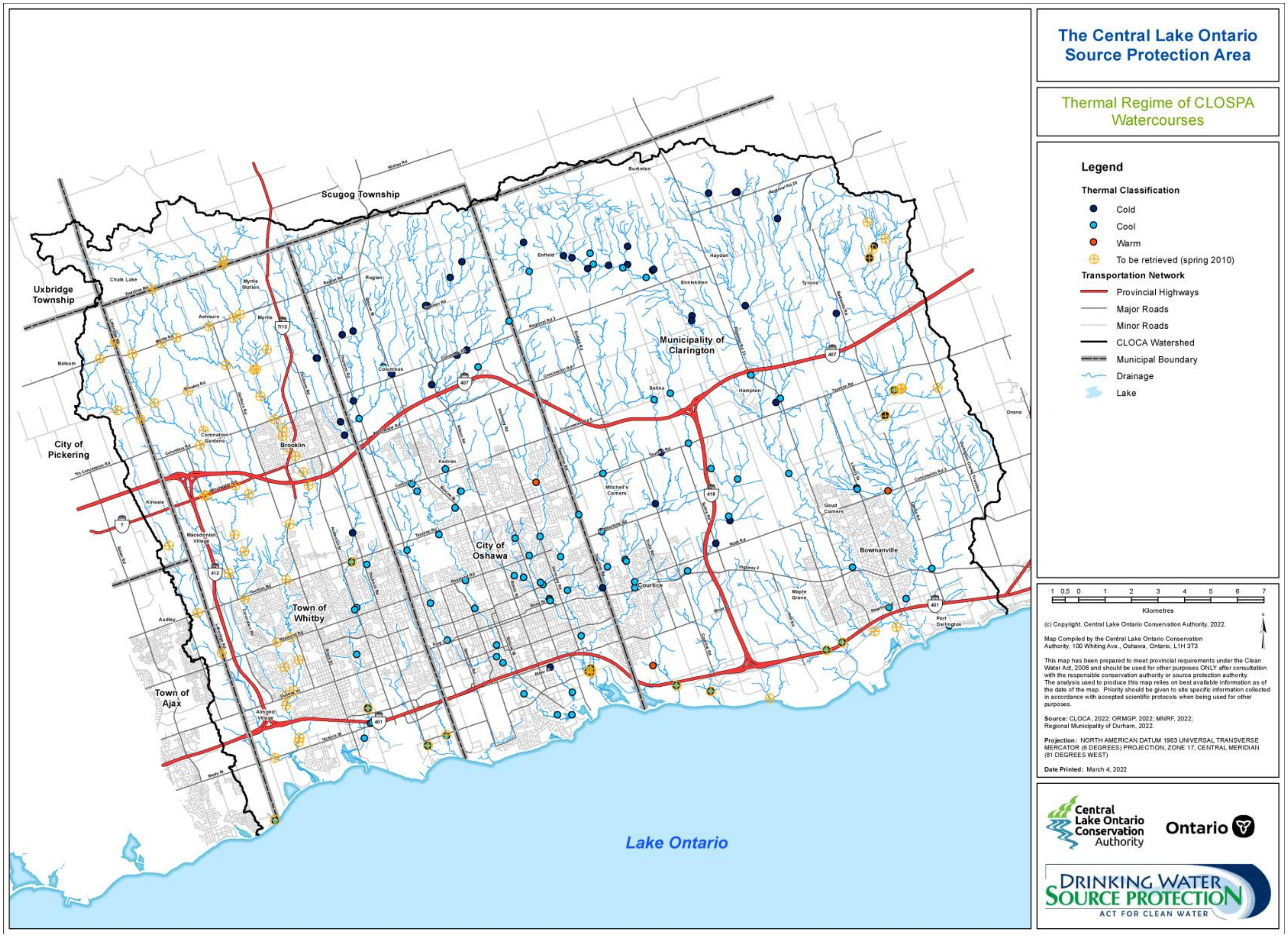
This map has been prepared to meet provincial requirements under the Clean Water Act, 2006 and should be used for other purposes ONLY after consultation with the responsible conservation authority or source protection authority. The analysis used to produce this map relies on best available information as of the date of the map. Priority should be given to site specific information collected in accordance with accepted scientific protocols when being used for other purposes.

Source: CLOCA, 2022; MNRF, 2022; Regional Municipality of Durham, 2022.

Projection: NORTH AMERICAN DATUM 1983 UNIVERSAL TRANSVERSE MERCATOR (6 DEGREES) PROJECTION, ZONE 17, CENTRAL MERIDIAN (81 DEGREES WEST)

Date Printed: March 4, 2022

Figure 3.10: Dams and Weirs



(c) Copyright. Central Lake Ontario Conservation Authority, 2022.

Map Compiled by the Central Lake Ontario Conservation Authority, 100 Whiting Ave., Oshawa, Ontario, L1H 3T3

This map has been prepared to meet provincial requirements under the Clean Water Act, 2006 and should be used for other purposes ONLY after consultation with the responsible conservation authority or source protection authority. The analysis used to produce this map relies on best available information as of the date of the map. Priority should be given to site specific information collected in accordance with accepted scientific protocols when being used for other purposes.

Source: CLOCA, 2022; ORMGP, 2022; MNRF, 2022; Regional Municipality of Durham, 2022.

Projection: NORTH AMERICAN DATUM 1983 UNIVERSAL TRANSVERSE MERCATOR (6 DEGREES) PROJECTION, ZONE 17, CENTRAL MERIDIAN (81 DEGREES WEST)

Date Printed: March 4, 2022

Figure 3.11: Thermal Regime of CLOSPA Watercourses (2005–2008)

3.4.6 Surface Water Bodies, Flows, Levels, and Trends

Lynde Creek

The watershed drains southerly towards Lake Ontario from its headwaters in the Oak Ridges Moraine. The watershed is divided into the following five subwatersheds:

- Lynde Main;
- Heber Down;
- Kinsale;
- Ashburn; and
- Myrtle Station.

The conservation authority maintains a network of monitoring stations (Environment Canada Water Survey Stations) that monitor water quantity parameters, including rainfall and stream water level. The average monthly stream flow (m^3/s) for each year was queried, averaged, and the corresponding annual discharge was computed from five years of complete data. The average annual volume of water that flows through the creek at each station is presented in **Table 3.2** below. The average monthly streamflow for the period of record for each of these stations is presented in the following graph. See **Figure 3.12**.

Station	Description	Average Annual Discharge Volume (million m^3)
02HC055	Heber Down Conservation Area	15
02HC018	Dundas St.	44
02HC054	Brooklin	68

Table 3.2: Lynde Creek, Average Annual Discharge Volume

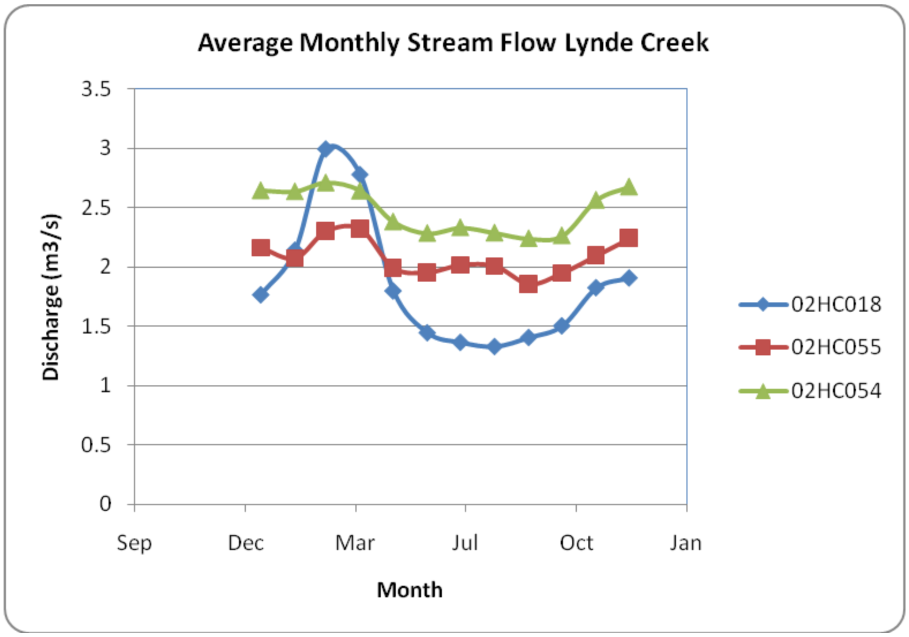


Figure 3.12: Average Monthly Streamflow, Lynde Creek

The graph shows that all three stations have similar seasonal trends, experiencing an annual maximum discharge in February and/or March and an annual minimum in July and/or August. The annual trends for the discharge at the Lynde Creek monitoring stations at Heber Down Conservation Area (02HC055) and Brooklin (02HC054) are nearly identical, paralleling the other.

Lake Ontario

Lake Ontario is the receiving body of water for all of CLOSPA's creek systems. CLOSPA does not monitor water level, or any other parameters, in Lake Ontario. The Canadian Hydrographic Services—part of the Department of Fisheries and Oceans—has a coordinated network of gauging stations for all of the Great Lakes that record water levels on an hourly basis.

The following stations are located on Lake Ontario:

- Port Weller;
- Toronto;
- Cobourg;
- Kingston;
- Rochester; and
- Oswego.

These stations have been recording hourly water levels from 1918 to present. The average monthly water level for Lake Ontario is displayed on the following graph (**Figure 3.13**).

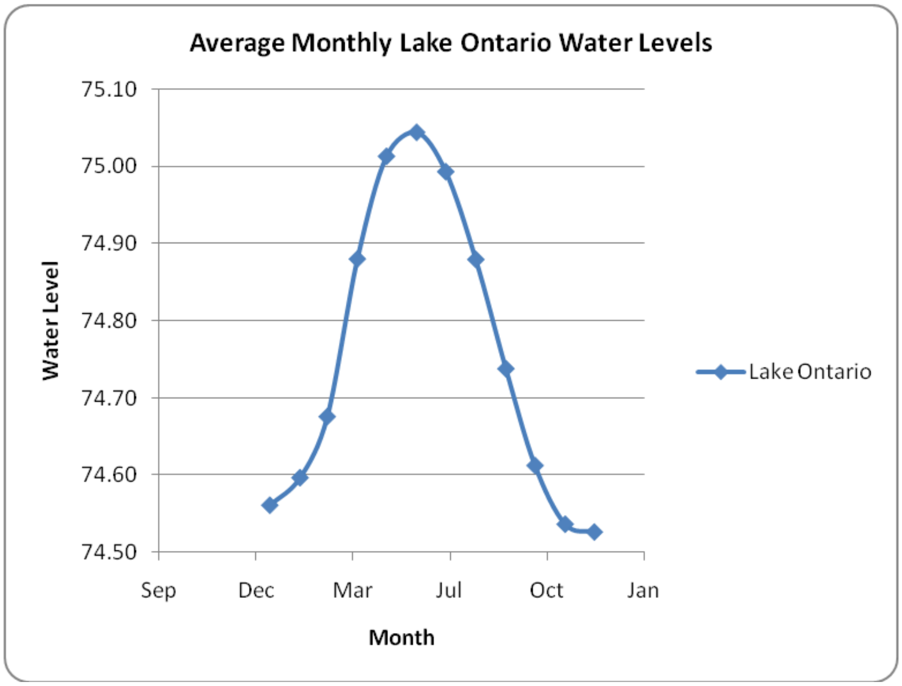


Figure 3.13: Average Monthly Water Levels, Lake Ontario

The graph shows seasonal fluctuations, with annual maximum water levels in June and annual minimums in December. The average water level for the entire period of record is 74.75 mASL.

Lake Ontario average monthly water levels vary over the long term, through a range of almost two metres since 1960 when the current St. Lawrence Seaway outflow regulation regime was established. Within the year, Lake Ontario monthly levels can vary a metre or more with the low of the year usually occurring in November or December. The maximum monthly mean Lake Ontario level observed since 1960 was elevation 75.7 metres above sea level in 1973, and the minimum was elevation 73.8 metres in 1963, all measured with respect to the 1985 International Great Lakes Levels Datum. Slightly more extreme high and low monthly levels were observed before completion of the seaway in the late 1950s.

Superimposed on top of monthly average water levels are daily fluctuations driven by climatic conditions and more significantly by short term storm surge and set-down variations that vary in degree around Lake Ontario shores.

There are no well-documented observations or information on storm set-down impacts on lake levels as there is for storm surges. Set-downs are considered to be less severe than surges.

For drinking water source protection purposes in identifying potential extreme low Lake Ontario level conditions over municipal intakes, a good estimate is the historic 1963 observed monthly low of elevation 73.8 metres (with respect to the 1985 International Great Lakes Levels Datum) less a site specific set-down equivalent to the observed surge figures in Lewis *et al.* (1990).

Historical trends and climate change projections discussed in this chapter suggest that there will be an increase in the incidence of drought and extreme weather patterns that could result in more frequent and more severe low water level conditions on the Great Lakes. A real possibility is that Lake Ontario monthly still water levels could drop below historical record low elevations under future climate change/climate variation conditions by in the order of three to four tenths of a metre as mentioned in **Chapter 5.8**.

Small Watersheds

The following are the six small watersheds within CLOSPA that are ungauged creek systems:

- Corbett;
- Robinson;
- Tooley;
- Darlington;
- Westside; and
- Bennett.

All six creeks drain directly to Lake Ontario and have relatively small drainage areas. The drainage areas of each small watershed and its total percentage of the CLOSPA watershed area is represented in the **Table 3.3**.

Watershed	Area (ha)	Percentage of Watershed Area (%)
Corbett	1455	2%
Robinson	570	1%
Tooley	1050	2%
Darlington	1636	3%
Westside	572	1%
Bennett	742	1%

Table 3.3: Small Watersheds Area

Table 3.3 indicates that each of the small watersheds comprises less than 3% of the total area of the CLOSPA jurisdiction.

Black, Harmony, Farewell Creek

This watershed drains southerly towards Lake Ontario from its headwaters in the south slope till plain of the Oak Ridges Moraine. The Black/Harmony/Farewell Creek watershed is divided into the following three primary subwatersheds:

- Black Creek;
- Harmony Creek; and
- Farewell Creek.

The Harmony Creek subwatershed is further divided into the following subwatersheds:

- Ritson;
- Wilson;
- Grandview;
- Taunton; and
- Mitchell.

The conservation authority maintains a network of monitoring stations that observe water quantity parameters, including rainfall and stream water level. These stations are permanent gauges that record information at set intervals. The average annual discharge volumes for each station are presented in **Table 3.4** below. The average monthly streamflow for the period of record for the Harmony Creek station is presented in the following graph (**Figure 3.14**).

Station	Description	Average Annual Discharge Volume (million m^3)
02HC013	Harmony Creek at Bloor Street	14

Table 3.4: Black, Harmony, and Farewell Creek Average Annual Discharge Volume

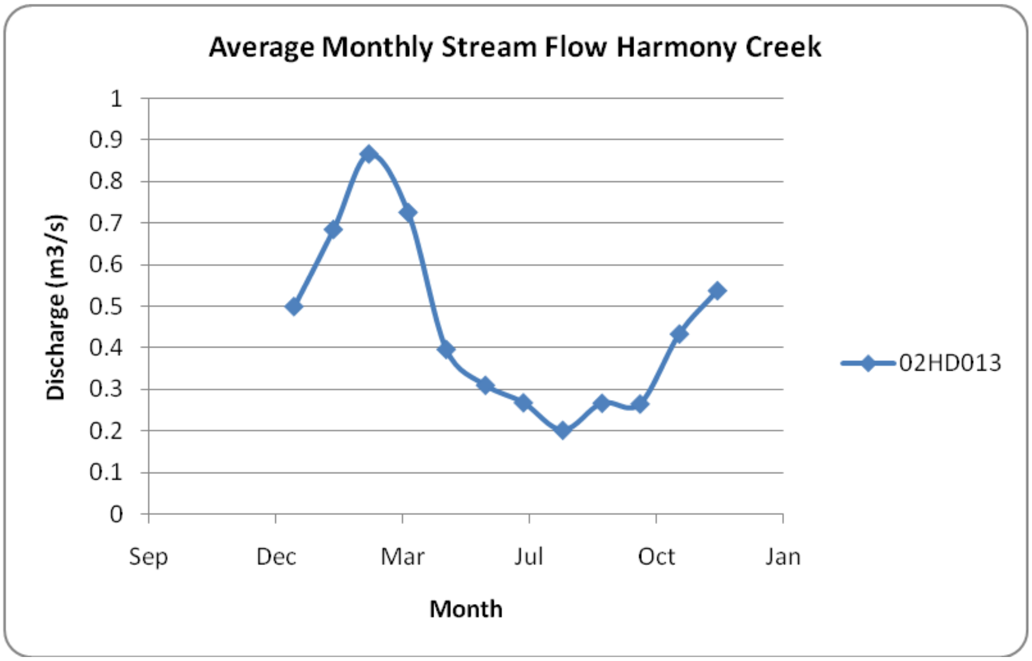


Figure 3.14: Average Monthly Streamflow, Harmony Creek

Figure 3.14 shows a seasonal trend, with annual maximum discharges in March and annual minimums in August.

Bowmanville and Soper Creeks

This watershed drains in a southerly direction towards Lake Ontario and from its headwaters in the Oak Ridges Moraine. The watershed is considered to be two main watersheds—Bowmanville and Soper—each having four subwatersheds of their own and one additional subwatershed that they share after the two streams merge—Coastal watershed. The subwatersheds within the Bowmanville watershed are:

- Bowmanville Main;
- Hampton;
- Haydon; and
- Tyrone.

The subwatersheds within the Soper watershed are:

- Soper Main;
- Soper East;
- Soper North; and
- Mackie.

The conservation authority maintains a network of monitoring stations that observe water quantity parameters, including rainfall and stream water level. These stations are permanent gauges that record information at set intervals. The average annual discharge volumes for each station are presented in **Table 3.5**. The average monthly streamflow for the period of record for Bowmanville and Soper creeks is presented in the following two graphs (**Figure 3.15** and **Figure 3.16**).

Station	Description	Average Annual Discharge Volume (million m^3)
Hampton	Bowmanville at Hampton Conservation Area	23
Bow-EB	Bowmanville at 57 Rd	101
02HD006	Bowmanville at Jackman Rd	45
Sop-EB	Soper at Taunton Rd East	12
02HD023	Soper at Taunton Rd West	8

Table 3.5: Bowmanville and Soper Creek Average Annual Discharge Volume

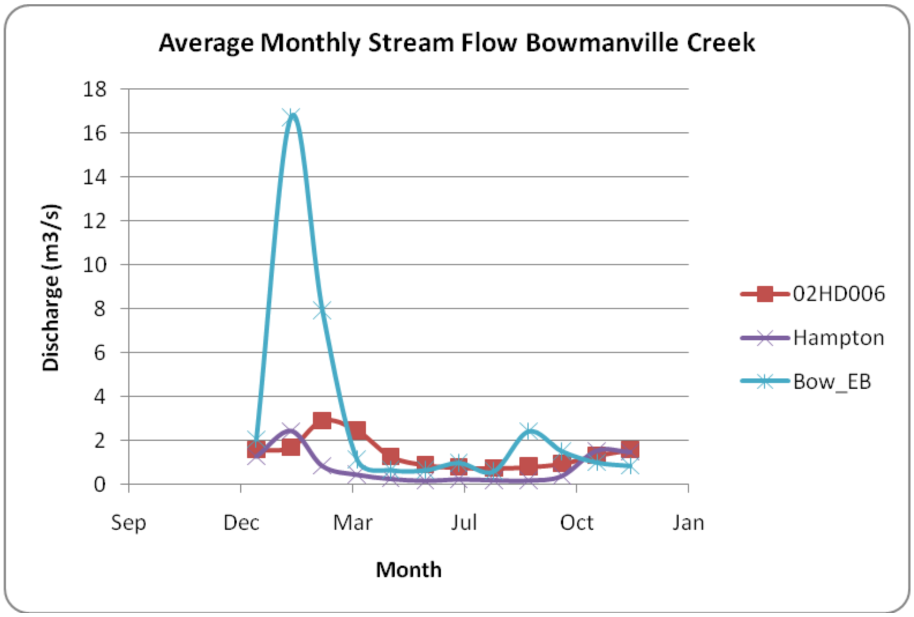


Figure 3.15: Average Monthly Streamflow, Bowmanville Creek

Figure 3.15 shows that all three stations experience similar seasonal trends, with annual maximum discharges in February and/or March and annual minimums during the summer months.

It is noted that the Bowmanville (East Branch surface water gauging station) peaks significantly higher than the other two stations during February. The period of record for this station in very short, so the abnormally high peak could be due to lack of historical data, and may not be representative of the actual monthly trends.

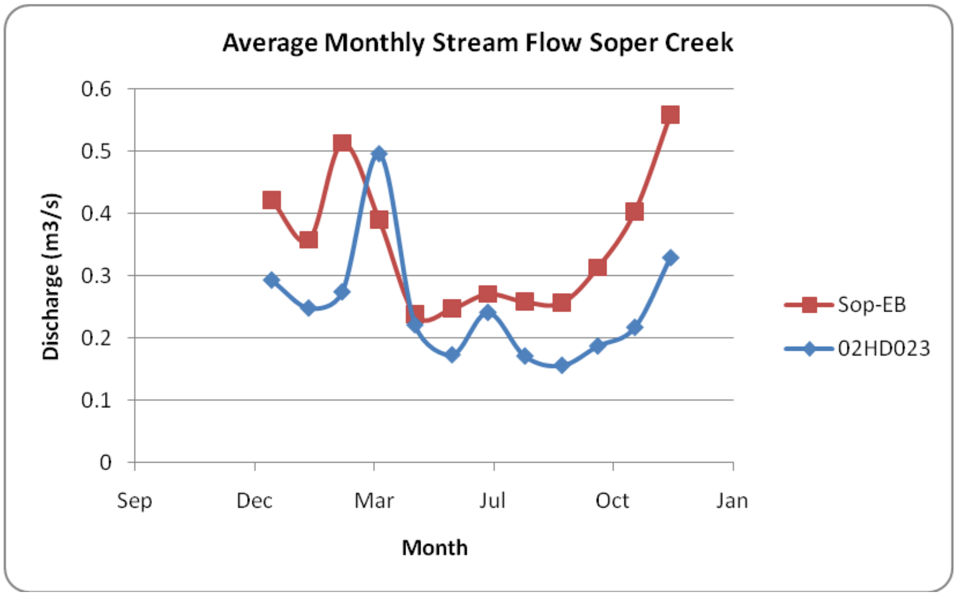


Figure 3.16: Average Monthly Streamflow, Soper Creek

Figure 3.16 shows that both stations experience similar seasonal trends, with annual maximum discharges in February and/or March and annual minimums during the summer months.

Both stations on Soper Creek experience a slight peak during the month of July that is not seen in any of the other stations. This peak could be due to the short periods of records of these stations, which could cause several summer storms to artificially raise the monthly average discharge.

Oshawa Creek

This watershed drains in a southerly direction towards Lake Ontario from its headwaters in the Oak Ridges Moraine. The conservation authority maintains a network of monitoring stations that observe water quantity parameters, including rainfall and stream water level. These stations are permanent gauges that record information at set intervals. The average annual discharge volumes for each station are presented in **Table 3.6**.

Station	Description	Average Annual Discharge Volume (million m^3)
02HD008	Oshawa at Oshawa	34
OshEast	Oshawa at Conlin Rd East	33
OshWest	Oshawa at Conlin Rd West	19
OshMain	Oshawa at Thomas St	90

Table 3.6: Oshawa Creek, Average Annual Discharge Volume

The average monthly streamflow for the period of record for these stations is presented in **Figure 3.17**. The graph shows that all four stations experience similar seasonal trends, with annual maximum discharges in February and/or March and annual minimums during the summer months.

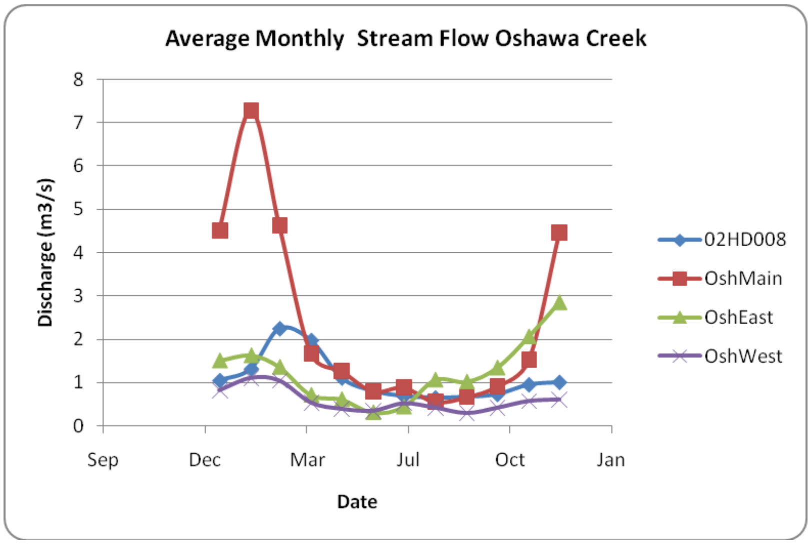


Figure 3.17: Average Monthly Streamflow, Oshawa Creek

3.4.7 Wetlands

There are 19 provincially and three locally significant wetlands and wetland complexes within the CLOSPA jurisdiction. Most of these wetlands are located on the Lake Iroquois and Lake Ontario shorelines. Most of the wetlands in this region are either swamps or marshes. **Table 3.7** lists the evaluated wetlands and their corresponding status in the study area as of April, 2008.

Wetland Name	Significance	Description
Bowmanville Coastal Wetland Complex	Provincial Area: 29 ha	Bowmanville is a coastal wetland in the municipality of Clarington. This wetland receives flows from Soper and Bowmanville creeks, which drain into the wetland from the north. Water levels in the marsh are comparable to those of Lake Ontario because the marsh is kept open to the lake through a maintained channel for boaters.
Carruthers Creek Wetland Complex	Provincial Area: 146.7 ha	The Carruthers Creek Wetland Complex is in the Town of Ajax, on the north shore of Lake Ontario. It was first evaluated in 1983. The wetland is primarily located at the mouth of Carruthers Creek, and was complexed with the previously locally significant Ajax Warbler Swamps in 1998. A great deal of field work has been undertaken for the Ajax A3 planning area in support of the wetland re-evaluation.
Chalk Lake Wetland Complex	Provincial Area: 13.1 ha	The Chalk Lake Wetland Complex is on the Oak Ridges Moraine. It is in the southeast corner of the Town of Uxbridge and the southwest corner of Scugog Township. The complex is comprised of two wetlands that are linked by a headwater reach of the Lynde Creek. All of the wetlands in the complex occur on organic deposits underlain by marl deposits. There are fen-type wetlands within this complex, which are rare within the conservation authority jurisdiction.
Corbett Creek Coastal Marsh	Provincial Area: 21 ha	Corbett Creek is a coastal wetland at the junction of the east and west branches of Corbett Creek in the Town of Whitby. The water levels at this marsh are affected by inputs from Corbett Creek and the condition of the barrier beach. When the barrier beach is closed, the wetland accumulates water from the watershed and the water level rises above the lake level. As the water level rises, it increases pressure on the barrier beach, eventually causing the beach to break open. When the barrier beach is open, water levels in the wetland are similar to those in the lake. As the flow of water slows, waves re-establish the barrier beach and the process is repeated.

Cranberry Marsh	Provincial Area: 47 ha	Cranberry Marsh is a coastal wetland in the Town of Whitby. Historic land records indicate that this marsh once received stream inflow from an upland watershed. However, agricultural development has since severed any stream connections to the marsh. In 2001, a water-control structure was installed at the outlet of the marsh along the barrier beach to manage water levels within the wetland. Water levels are now managed by the conversation authority to promote biodiversity by maintaining an equal amount of emergent vegetation and open water habitat.
Dagmar Station Wetland	Local Area: 13.2 ha	Dagmar Station Wetland is a small treed swamp in the Town of Whitby, approximately 15 km north of the town centre. Dagmar Station is a palustrine wetland that drains into Lynde Creek. The wetland is bisected by the Canadian Pacific Railway, which provides easy access to it.
Enfield Wetland Complex	Provincial Area: 102 ha	The Enfield Wetland Complex is on the Oak Ridges Moraine in the Municipality of Clarington, with two of the twenty-four individual wetlands in the City of Oshawa. Most of the wetlands are linked to one another by headwater reaches of Oshawa Creek. The complex is also part of an Area of Natural and Scientific Interest and contains kettle wetlands. The Enfield Wetland Complex is composed of 92% swamps and 8% marsh.
Gold Point Coastal Wetland	Provincial Area: 4 ha	Gold Point Coastal is a wetland in the City of Oshawa. A creek flows through the wetland from the north and outlets at Lake Ontario. Water levels in the wetland change depending on flows and whether the barrier beach is open to the lake.
Harmony-Farewell Iroquois Beach Wetland Complex	Provincial Area: 685.7 ha	The Harmony-Farewell Iroquois Beach Wetland Complex is located within the municipalities of Oshawa and Clarington, on the shoreline of Glacial Lake Iroquois. It is bounded by Harmony Road to the west, Conlin Road to the north, Green Road to the east, and Nash Road to the south. It is comprised of 70 individual wetlands, both swamp and marsh. The wetland was re-evaluated in 1999 and now includes two formerly separate wetlands— Harmony Valley Wetland and Golf Course Wetland—and many previously unevaluated wetlands. Many uncommon and rare species have been noted within this complex, largely attributed to its size and connectivity.
Heber Down Wetland Complex	Provincial Area: 85 ha	The Heber Down Wetland Complex is in the centre of the Town of Whitby, on the shoreline of Glacial Lake Iroquois. Heber Down has 16 wetlands that cover a total of 85 hectares. The complex is composed of 96% swamp area and 4% marsh area. Heber Down sustains large wetland swamps and associated upland forests, noteworthy seepage slope swamps, variegated horsetail meadows, and a concentration of significant plants and animals. Most of the wetland complex is within the Heber Down Conservation Area, owned and managed by the conservation authority.

Lynde Creek Coastal Wetland Complex	Provincial Area:130 ha	Lynde Creek is a drowned river-mouth coastal wetland at the outlet of the Lynde Creek watershed in the Town of Whitby. This wetland receives flows from the east and west branches of Lynde Creek, which enter the marsh from the north. Water levels in this marsh are similar to those of Lake Ontario, as the barrier beach is typically open to the lake.
Maple Grove Wetland Complex	Provincial Area: 149.1 ha	The Maple Grove Wetland Complex is located in the Municipality of Clarington around the Hamlet of Maple Grove. It is situated on the shoreline of Glacial Lake Iroquois. It is composed of 17 individual wetlands that are made up of swamp and marsh habitats. The wetland complex crosses the headwater reaches of Tooley Creek, Darlington Creek, and Bowmanville Creek.
McLaughlin Bay Wetland Complex	Provincial Area: 42 ha	McLaughlin Bay is a coastal wetland in the City of Oshawa and Municipality of Clarington. The wetland receives water from overland flows from the surrounding landscape, and from two small streams that collect runoff from the agricultural and urban areas to the north. The wetland is mostly shallow, open water and is separated from Lake Ontario by a well-established barrier beach. The barrier beach is rarely open to the lake, keeping water levels in the wetland perched above Lake Ontario.
Oshawa Creek Coastal Wetland Complex	Provincial Area: 20 ha	Oshawa Creek Costal Wetland is in the City of Oshawa. The wetland is separated by Oshawa Harbour into two areas, one to the west of the harbour, and the other to the northeast. Oshawa Creek flows through the wetland to the west, and Montgomery Creek flows through the wetland to the northeast. Water levels in the wetland are similar to Lake Ontario because the wetland is connected to the lake through the harbour.
Oshawa Second Marsh	Provincial Area: 133 ha	Oshawa Second Marsh is a coastal wetland in the City of Oshawa. Historically, Farewell Creek—which collected drainage from the Harmony and Farewell Creek watersheds—emptied directly into Oshawa Second Marsh. However, over the last several decades, restoration efforts have been made to eliminate carp, reduce sediment deposition, and re-establish aquatic vegetation in the marsh. Farewell Creek is now diverted directly into Lake Ontario and is separated from the marsh by an extensive berm. The marsh is also separated from Lake Ontario by a well-established barrier beach. A water-level control structure was installed to control and periodically draw down water levels to allow aquatic vegetation to germinate.

Pumphouse Coastal Wetland Complex	Provincial Area: 7 ha	Pumphouse Marsh is a semi-circular coastal wetland in the City of Oshawa. This wetland is separated from Lake Ontario by a well-established barrier beach and is connected to the lake only by seepage through the beach. Historical land records suggest that this marsh was once open to Lake Ontario, and received stream inflow from an upland watershed. However, urban development has severed any stream connections to the marsh, and the wetland now receives almost all of its water from storm sewer outlets.
Raby Head Wetland #1	Local Area: 4.3 ha	This small wetland is in the Municipality of Clarington, on the north shore of Lake Ontario, adjacent to St. Mary's Cement. It is composed of 35% swamp and 65% marsh.
Solina Wetland	Provincial Area: 11.3 ha	The Solina Wetland is in the Municipality of Clarington, bounded by Courtice Road to the west, Taunton Road to the south, Washington Road to the east, and Conlin Road to the north. Solina is a headwater wetland for a tributary of Farewell Creek. The wetland is in an oval-shaped depression, or kettle, with a moat along the wetland margin. Thick, fibrous peats more than one metre deep have accumulated through the wetland. Solina Wetland is remarkable for having 11 wetland types in just 11.3 ha and for supporting one of the few kettle peatlands in the GTA. Solina further supports 12 significant vascular plant species that are considered rare in site district 6–7.
Tooley Creek Coastal Wetland	Local Area: 0.35 ha	Tooley Creek Coastal Wetland is at the mouth of Tolley Creek, on the north shore of Lake Ontario, within the Municipality of Clarington. It is bounded by Darlington Provincial Park to the west, Highway 401 to the north, and Courtice Road to the east. Though the wetland is only 0.35 ha, it was evaluated because coastal wetlands are rare in the western part of Lake Ontario. In addition, it supports two plant species that are rare in Durham Region, and it is considered a locally significant fish habitat.
Westside Beach Marsh	Provincial Area: 27 ha	Westside Beach is a coastal wetland in the Municipality of Clarington. The wetland was once double its current size and received outflow from Westside Creek, which entered the wetland from the west. However, much of the wetland is now being quarried for limestone, and Westside Creek has been re-routed to enter the marsh from the east. Water levels in the wetland are typically higher than those of Lake Ontario early in the season, when water flows from Westside Creek are high and the barrier beach is intact. If the barrier beach breaks open from the pressure of the water, water levels fall to those of Lake Ontario.
Whitby Harbour Wetland Complex	Provincial Area: 8 ha	Whitby Harbour is a coastal wetland in the Town of Whitby. It receives flows from Pringle Creek, which drains into the wetland from the north and flows through the wetland to Whitby Harbour. Water levels in the wetland are similar to Lake Ontario because the wetland is connected to the lake through the harbour.

Whitby-Oshawa Iroquois Beach Wetland Complex	Provincial Area: 198.5 ha	This wetland complex is located in the Town of Whitby and the City of Oshawa. It is situated on the shoreline of Glacial Lake Iroquois and is comprised of 81 individual wetlands made up of marsh and swamp habitats. The wetlands are grouped into one complex centred on the headwater reaches of the Pringle Creek and Oshawa Creek watersheds. Several wetlands flow into the Lynde Creek watershed.

Table 3.7: Central Lake Ontario Conservation Authority Wetlands

3.5 GROUNDWATER FLOW SYSTEM

Generally, shallow groundwater flow in the study area mimics the ground surface topography. Regionally, groundwater flows southward from the Oak Ridges Moraine towards Lake Ontario. The water table gradient decreases significantly south of Taunton Road in Whitby and Oshawa, and east of Bowmanville.

The *depth to water table* helps to assess vulnerability. With the exception of some areas within the Oak Ridges Moraine, the water table is generally shallow throughout the CLOSPA watershed. South of the Oak Ridges Moraine, the depth to water table ranges from 1–20 m below ground surface. Within the Oak Ridges Moraine, the average water table is approximately 30 m below ground surface. The water table is deepest in the area north of Chalk Lake, where it is approximately 40 m below ground surface. Generally, the deepest water table coincides with the thickest sand and gravel materials in the study area.

Depth to Water Table: the depth between the ground surface and the top of the saturated portion of the shallowest aquifer.

Figure 3.18 was generated from the corrected ORMGP database well logs, where the records were subdivided into the wells screened in shallow aquifer systems and those screened in deeper aquifer systems. Records were categorized according to depth to separate the water table (less than 20 m for the shallow system) from the potentiometric wells (20m or more for the deeper system).

The water level elevation information captured from the shallow aquifer dataset was then kriged. The *kriging* process may produce erroneous results in areas where there is sparse data interpolating water table data across valleys and topographic lows where the water table does not actually exist above the ground surface. Hence, the derived water table surface was adjusted to ground surface wherever the water table surface was mapped above the ground surface.

Kriging: a method of interpolating between points of data (such as its elevation) from observations of nearby locations.

The water level maps were then further refined to show the directional flow of each aquifer in the study area. This provided a more detailed view of flow direction within individual aquifer systems. To generate the maps in **Figure 3.19, Figure 3.20, Figure 3.21** and **Figure 3.22** the screened intervals of the water wells in the database were marked to the interpreted geological aquifer formation in the ORMGP geologic model. The water level surfaces were then kriged from each aquifer individually.

The water level in the Oak Ridges Moraine has an average elevation of 295 mASL. It has a measured maximum elevation of 328 mASL in the area northwest of Chalk Lake. South of the Lake Iroquois Beach region, the water table elevation is approximately 115 mASL, but it drops to 75 mASL at the Lake Ontario shoreline. West of Bowmanville, water table elevations at the shoreline are relatively higher—100 mASL—which reflects the ground surface topography in this area **(Figure 3.20).**

The regional model north of the study area shows increasing hydraulic heads, which indicate some cross-boundary flow, particularly in the northwest part of the study area. It is important to consider this during water budget calculations.

The Thorncliffe Formation is one of the commonly tapped aquifers in the area, and has many wells—these were completed in only its uppermost portion. Nonetheless, groundwater movement in this aquifer shows a general south and southeast direction of flow **(see Figure 3.21).**

The Scarborough Formation water levels, like those of the aquifers above it, broadly reflect the overall shape of the Oak Ridges Moraine and the major watersheds **(see Figure 3.22).**

This reflection, however, is muted with depth. There is a subtle indication of the influence the bedrock valley systems have on the water levels and flow directions. The lack of a clearer influence on water levels may be partly due to the scarcity of wells in the deeper valleys.

Figure 3.23 is a potentiometric surface map prepared for the area. It shows a regional pattern of groundwater flow from the Oak Ridges Moraine towards Lake Ontario that is similar to the water table. Potentiometric surface elevations range from 300 mASL in the Oak Ridges Moraine to 75 mASL at the Lake Ontario shoreline.

The potentiometric surface elevations continue to rise in the northwest part of the study area, outside of the CLOSPA jurisdictional boundary. This suggests that some deeper groundwater crosses the watershed divide from the Lake Simcoe Region Conservation Authority watershed (northwest of the CLOSPA study area) and from significant areas along the northeast boundary.

In several areas north of the Lake Iroquois Beach region, the potentiometric surface is at a higher elevation than the water table. This suggests upward groundwater flow (see **Section 3.5.2**).

In some cases where the elevation of the potentiometric surface is above the ground surface, *artesian* flowing wells are present. Numerous flowing wells have been recorded within the CLOSPA study area (**Figure 3.24**) and many of them are associated with deeper wells. These deep-flowing wells are most common in the south slope region of the eastern part of the watershed. Most of these wells tap the Lower Sediments beneath the low-permeability Newmarket Till.

Artesian: groundwater under sufficient pressure to rise above the top of the aquifer containing it**.**

A number of flowing wells are present in the Hampton, Brooklin, and Columbus areas. Based on the regional potentiometric surface, potential areas of artesian flow also exist north of Stephen's Gulch Conservation Area, in the Haydon area, and just east of Brock Street north of Taunton Road. In some of these areas, river valleys intersect the Lower Sediments, and groundwater from these aquifers contributes to streamflow (SooChan, 2006).

Areas of potential downward vertical gradients are areas where the interpolated water table is at a higher elevation than the interpolated potentiometric surface. **Figure 3.25** shows potential downward vertical gradients and a potential area of deeper groundwater vertical gradient.

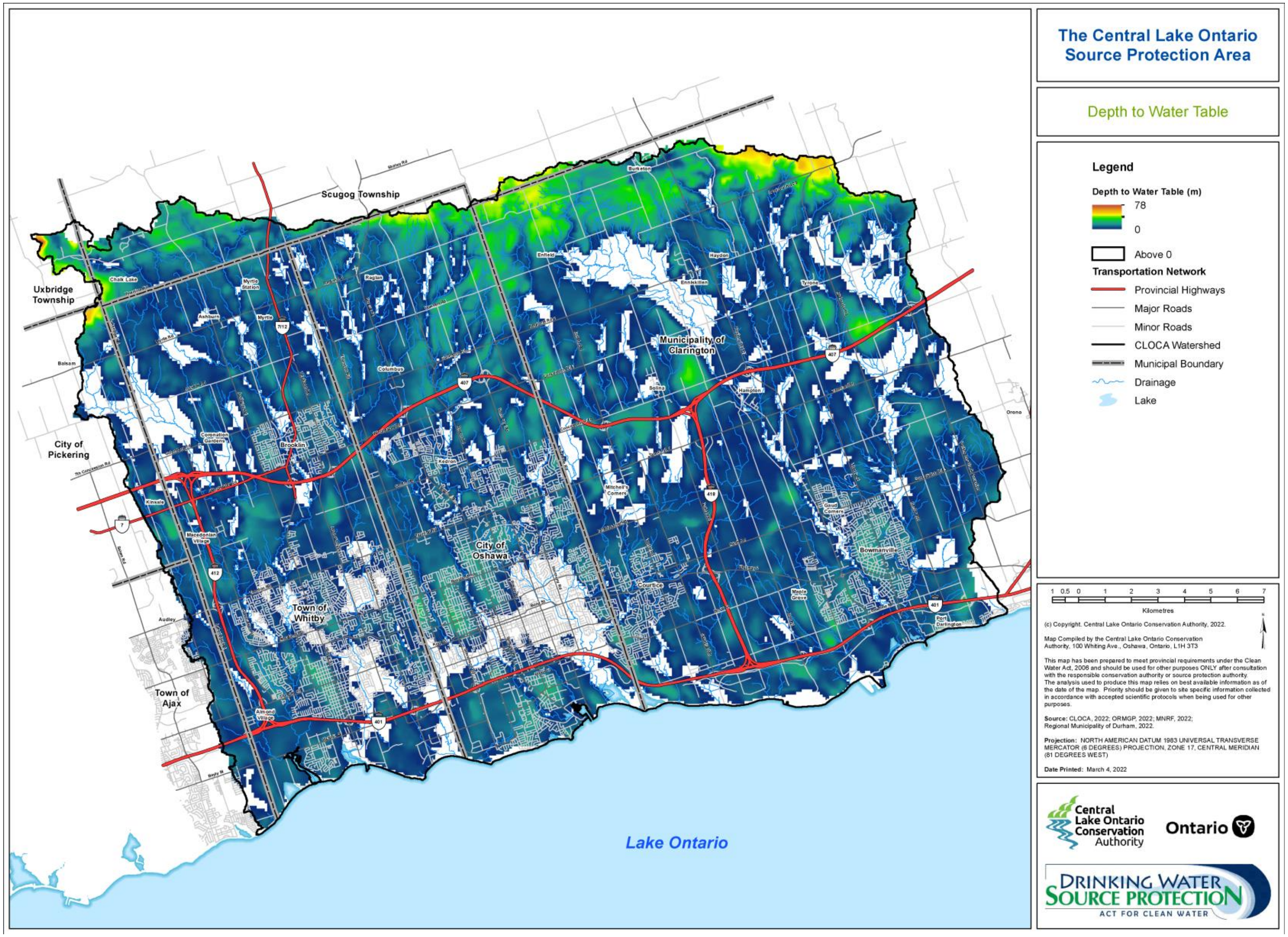


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Figure 3.18: Depth to Water Table

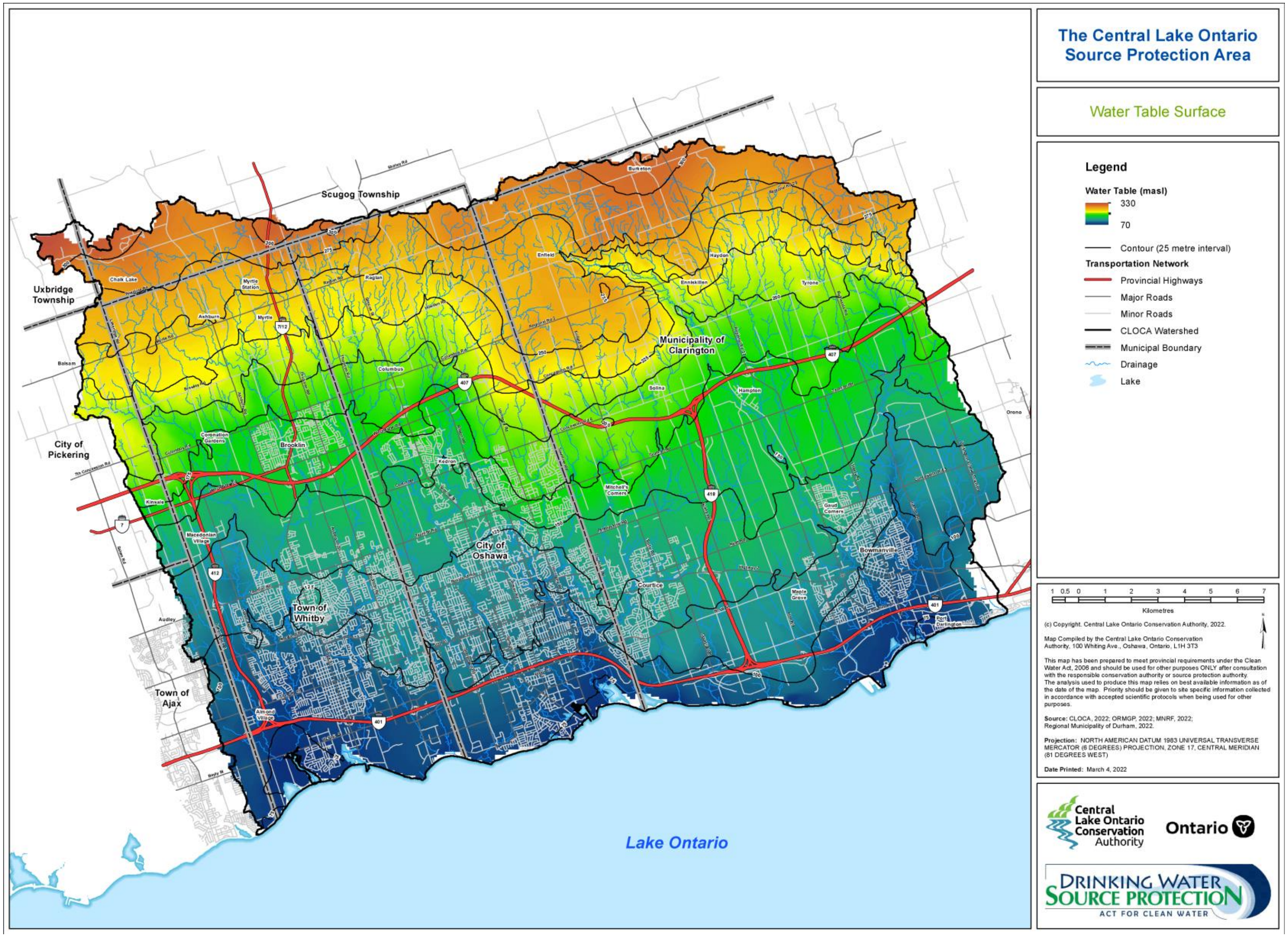

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Figure 3.19: Water Table Surface

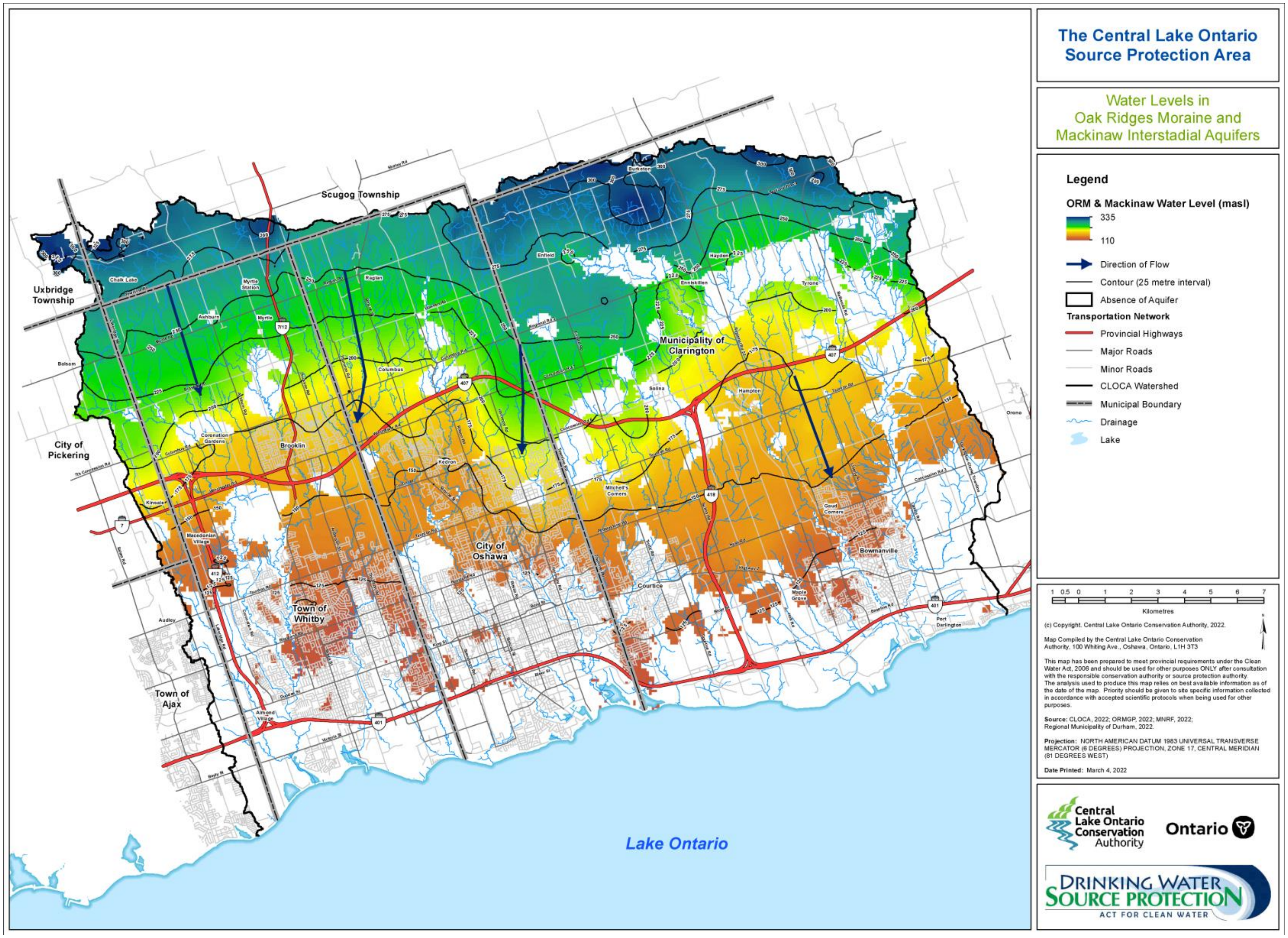

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Figure 3.20: Water Levels in Oak Ridges Moraine and Mackinaw Interstadial Aquifers

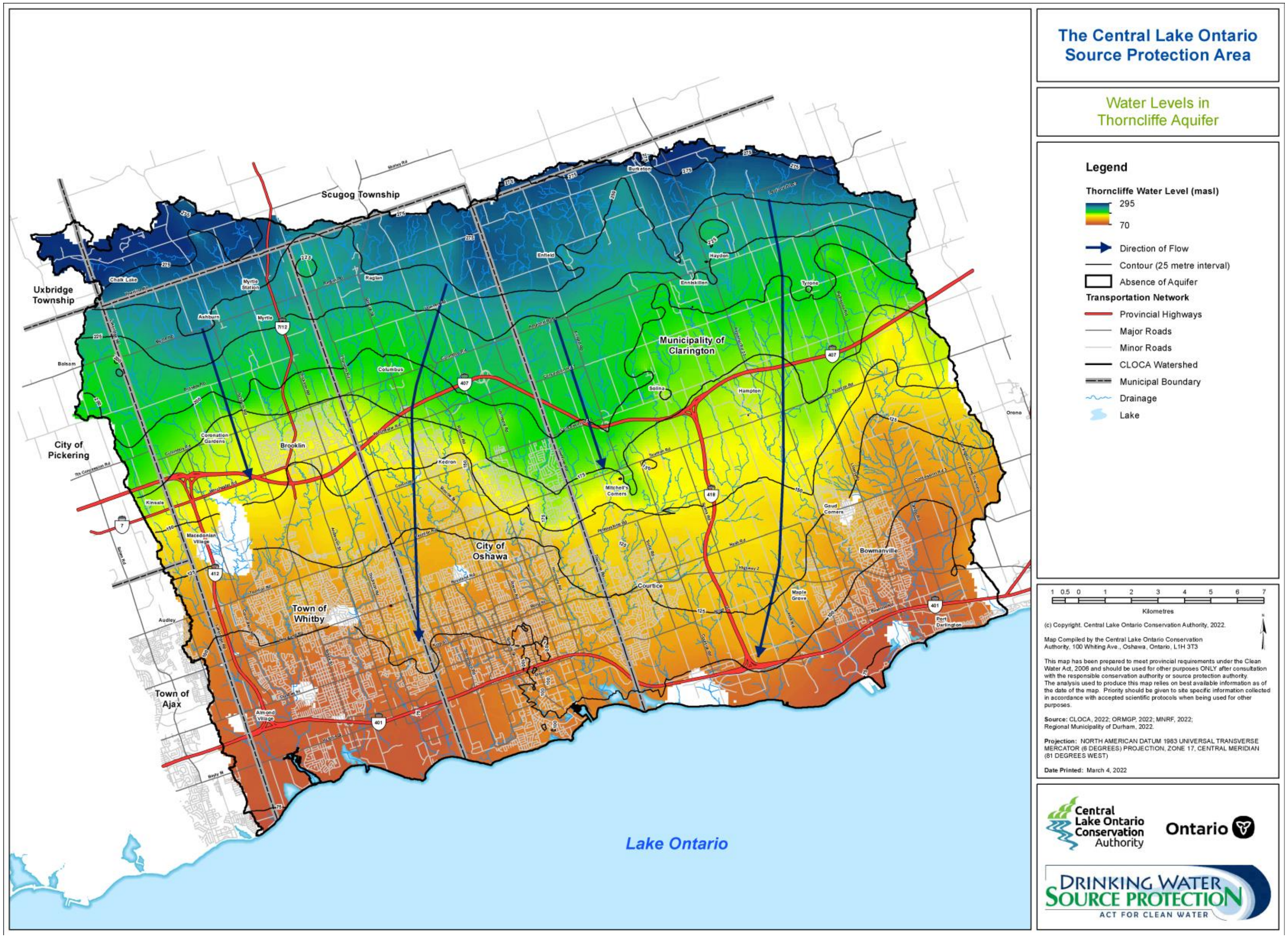

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Figure 3.21: Water Levels in Thorncliffe Aquifer

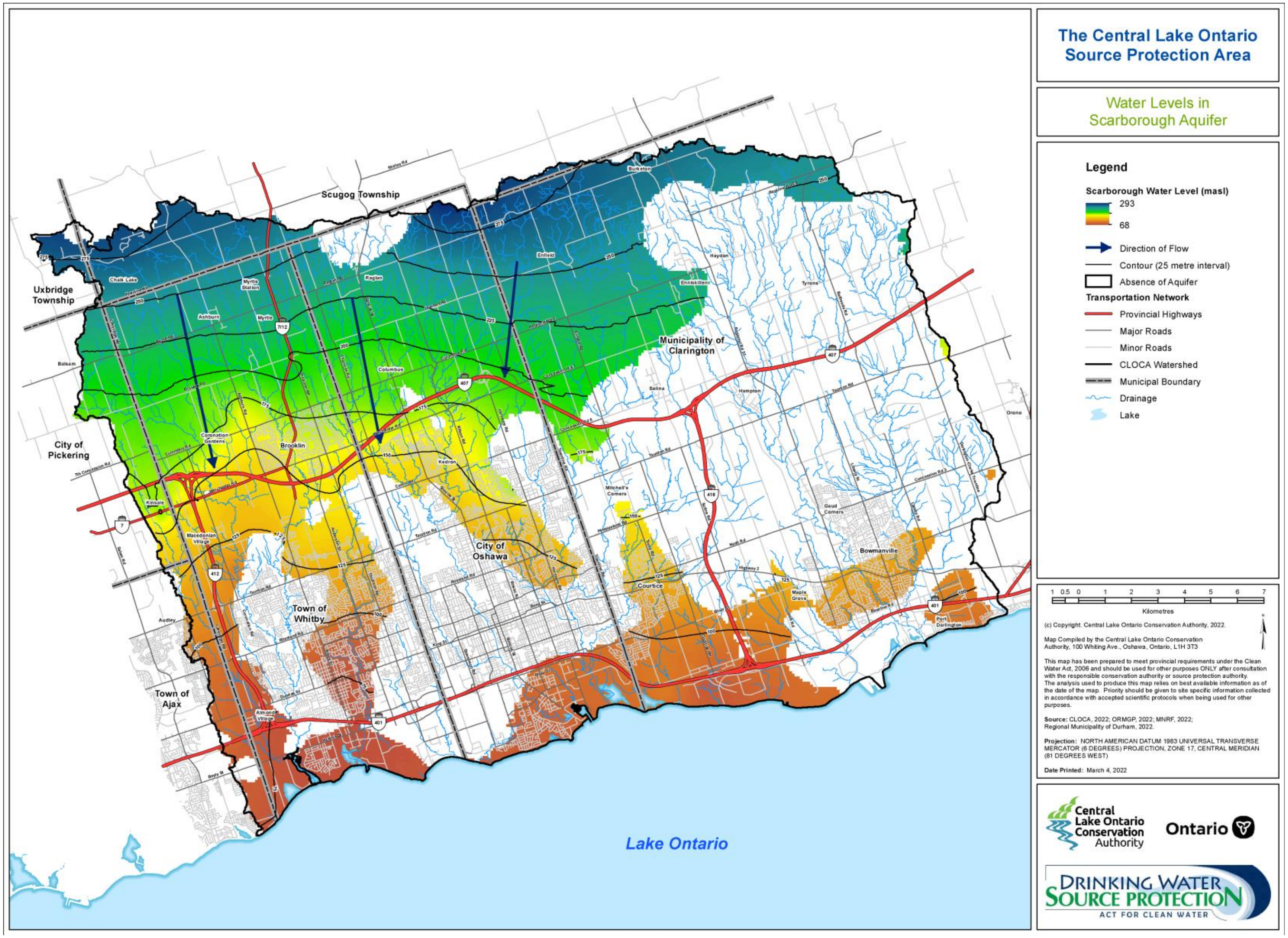

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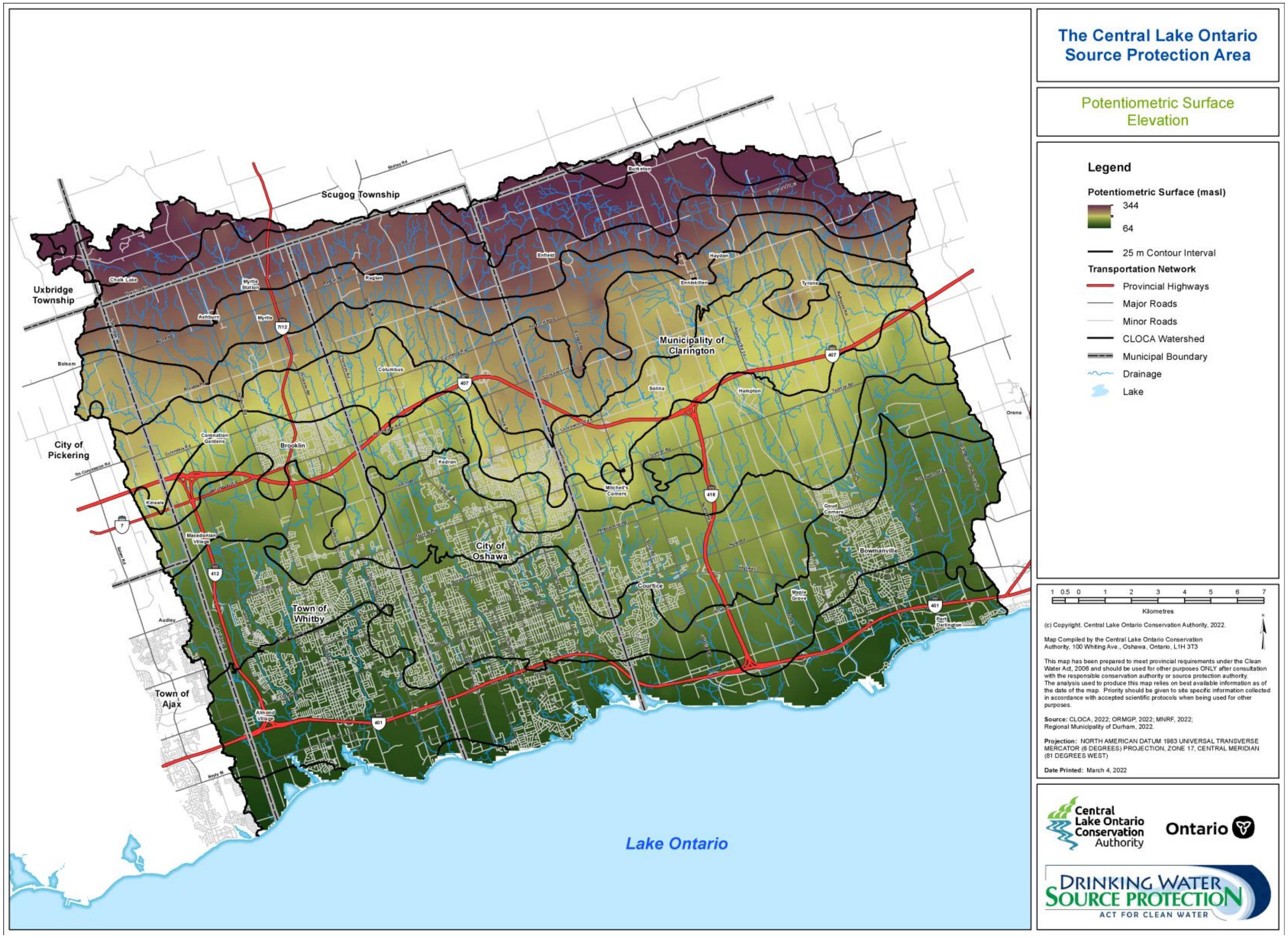
Figure 3.22: Water Levels in Scarborough Aquifer



The Central Lake Ontario Source Protection Area

Potentiometric Surface Elevation

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Figure 3.23: Potentiometric Surface Elevation

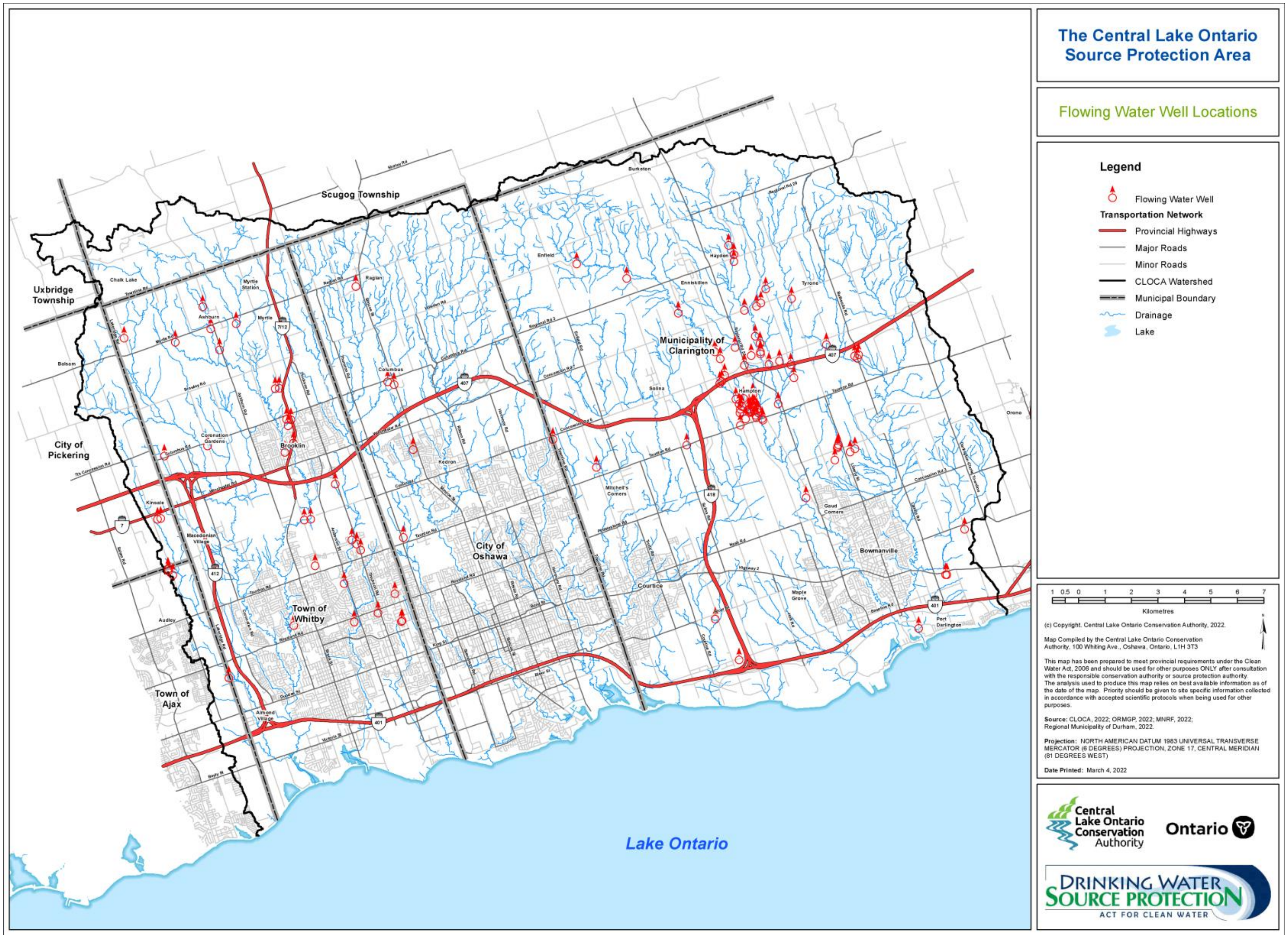

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Figure 3.24: Flowing Water Well Locations

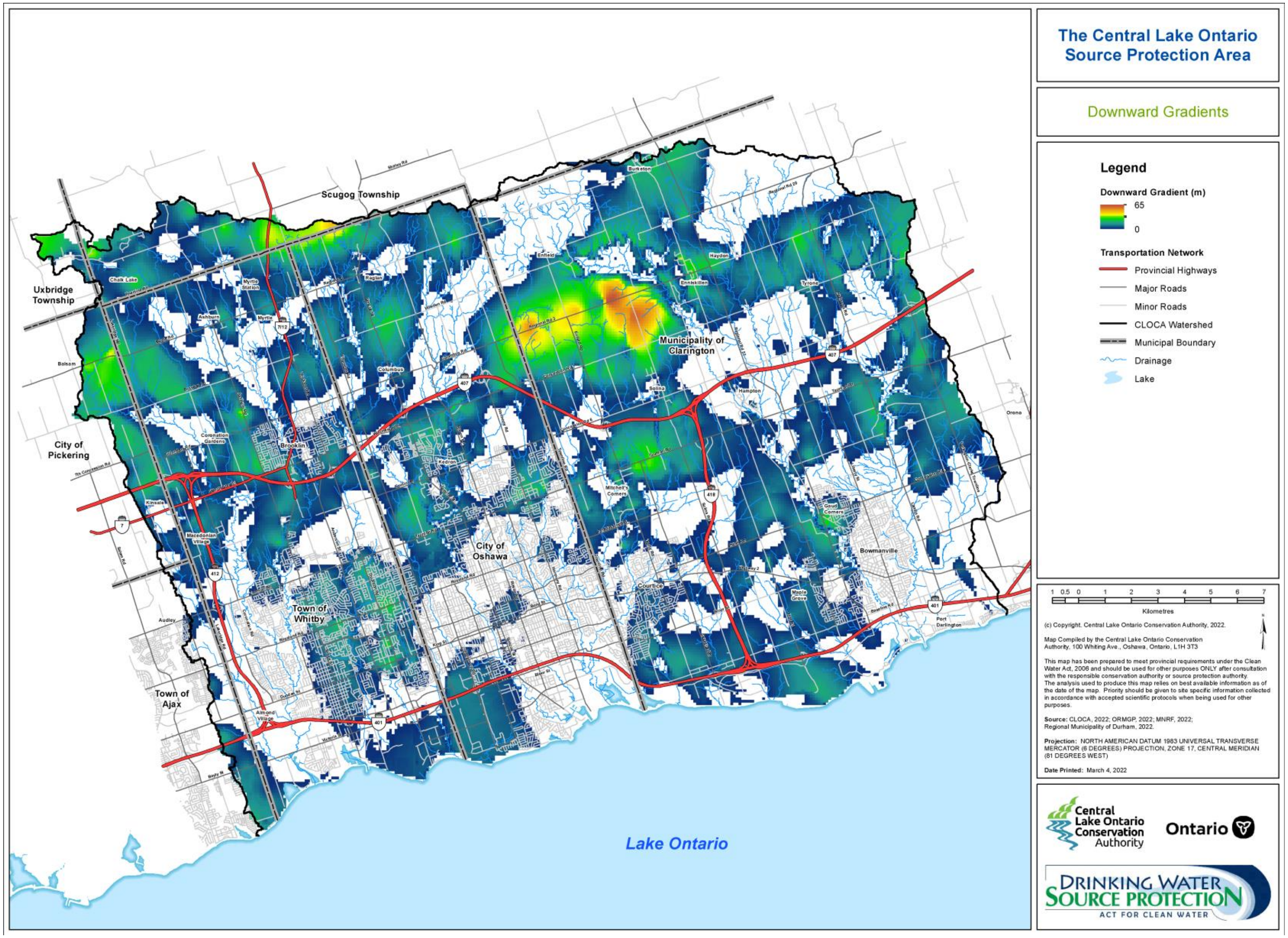

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Figure 3.25: Downward Gradients

Interaction between Groundwater and Surface Water

The interaction of shallow groundwater with surface water drainage features (such as streams and stream channels) is reflected in the water table surface. When surface water drainage features are projected onto the study area, they coincide with the deflection and closer spacing of water table contours. As indicated earlier, a more regional view shows that there is groundwater contribution from the northeast and west into the CLOSPA study area.

3.5.1 Groundwater Recharge

The Oak Ridges Moraine is the most significant area of groundwater recharge within the watershed. The amount of groundwater recharge is approximately 300 mm/yr, or 40% of the area's annual precipitation. The Lake Iroquois Beach deposits are the second most important recharge area within the CLOSPA study area (CLOCA Watershed Inventory, 1979; SooChan, 2006).

Recharge within, and near, the study area has been estimated using a number of different methods that have yielded a wide range of values. As stated above, the major recharge area occurs along the Oak Ridges Moraine. The hummocky terrain with estimates of 360 mm/yr in recharge that is present over much of this feature generates numerous stream channels.

Any precipitation that does not evapotranspire or evaporate will predominantly penetrate the ground, or form local runoff that collects in hummocks; ultimately, though, much of this water also infiltrates.

Much of the south flank of the Oak Ridges Moraine is covered by till, or till with a lacustrine veneer. Unit recharge rates for these deposits are less than half of those on the Oak Ridges Moraine. Groundwater recharge through the surficial till is enhanced where the topography is hummocky along the Oak Ridges Moraine, but is reduced to negligible levels along the Oak Ridges Moraine south flank (where the Oak Ridges Aquifer Complex (ORAC) is confined by the overlying till). In these areas, there are upward vertical hydraulic gradients between the ORAC and the water table, with minor recharge to sand bodies contained within the till.

The southern part of the study area contains Glacial Lake Iroquois deposits that exhibit different unit recharge rates, depending on the deposits, which range from lacustrine gravel to clay and till. The Lake Iroquois Beach deposits of sand and gravel will have the highest unit recharge rates for this area, except where upward vertical gradients occur along the break in topographic slope.

Data on land use, climate, and soil properties were analyzed to provide the initial estimates of the spatial distribution of groundwater recharge. It is assumed that the primary influence on the recharge distribution is the surficial geology, as mapped by the Geological Survey of Canada. Estimates for recharge in the CLOSPA watersheds, were initially obtained from the values in **Table 3.8**. They were later updated in an iterative manner using the PRMS model and the spatial distribution of applied recharge during the more advanced Tier 1 analysis.

Surficial Material	Recharge (mm/yr)
Bedrock	60
Lower Sediments	120
Newmarket Till	90
Halton/Kettleby Till	90
Moraine Deposits	360
Glacial River Deposits	320
Glacial Lake Deposits - Silt and Clay	60
Glacial Lake Deposits – Sand and Gravel	240
Organic Deposits	60
River Deposits – Sand and Gravel	60
Other Recent Deposits	60
Unclassified Surficial Geology	60

Table 3.8: Annual Average Recharge Values Used in the Calibrated Regional Model (MODFLOW: Earthfx, 2004)

3.5.2 Groundwater Discharge

Discharge areas are places where groundwater discharges to surface water bodies, either as seeps and springs, or as baseflow. These areas are characterized by upward vertical hydraulic gradients.

Recent studies in the CLOSPA study area identified potential discharge areas where the interpreted water table surface is within 1 m of the ground surface, as represented by the digital elevation model (see **Figure 3.26**). The existence of these potential discharge areas is supported by the observation of seeps, springs, or wetland areas. The most prominent potential discharge areas are along the southern fringe of the Oak Ridges Moraine and along the courses of the watershed streams.

Groundwater levels are strongly influenced by the surface water system, and when contours bend around streams, this indicates groundwater discharge to streams. A map of simulated groundwater discharge to streams is presented in **Figure 3.27.**

Two methods were used to verify the location of key areas of groundwater discharge:

- Aerial thermography survey data were used to define significant seepage areas on the south flank of the moraine. They appeared to correlate well with brook trout occurrence data.
- Reverse particle tracking, using results of the MODFLOW model, identified where significant functional zones were recharged.

In an alternative approach, CLOSPA assessed stream reaches that exhibited more than 1 litre/second (L/s) of groundwater discharge per 100 m reach (as predicted by the groundwater model). Particle tracking was used to determine their associated points of recharge.

These preliminary input estimates were used to create several preliminary maps from the regional 100 m grid model (recharge, runoff, evapotranspiration, etc.). These maps were created during the conceptual water budget analyses that were subsequently updated and refined in the Tier 1 work presented in this chapter.

Estimation of Discharge

Preliminary water budgets were calculated at specific locations where there was sufficient streamflow data. Data is considered sufficient if there is at least five years of continuous streamflow data (this may or may not include minor data gaps). Past and current streamflow data gaps are outlined in the characterization section of this Assessment Report. Data gaps are usually the result of inadequate monitoring. For the most part, these gaps have been addressed through gauge installation over the past five years.

There is no current gauging for the Black and Farewell creeks or small watersheds, though limited historical information has been identified. Black Creek and Farewell Creek watersheds are both significant to the overall water budget of CLOSPA, as both have headwaters originating in the Oak Ridges Moraine and both extend through Lake Iroquois Beach physiographic units.

These gaps were addressed through the Tier 1 source protection budget activities using 3D numerical models (explained later in this chapter). **Figure 3.28** depicts the general trends in daily mean streamflow for six Water Survey Canada stream gauge stations (either active or inactive). These gauge stations are all located within CLOSPA's watersheds, and have long-term data sets.

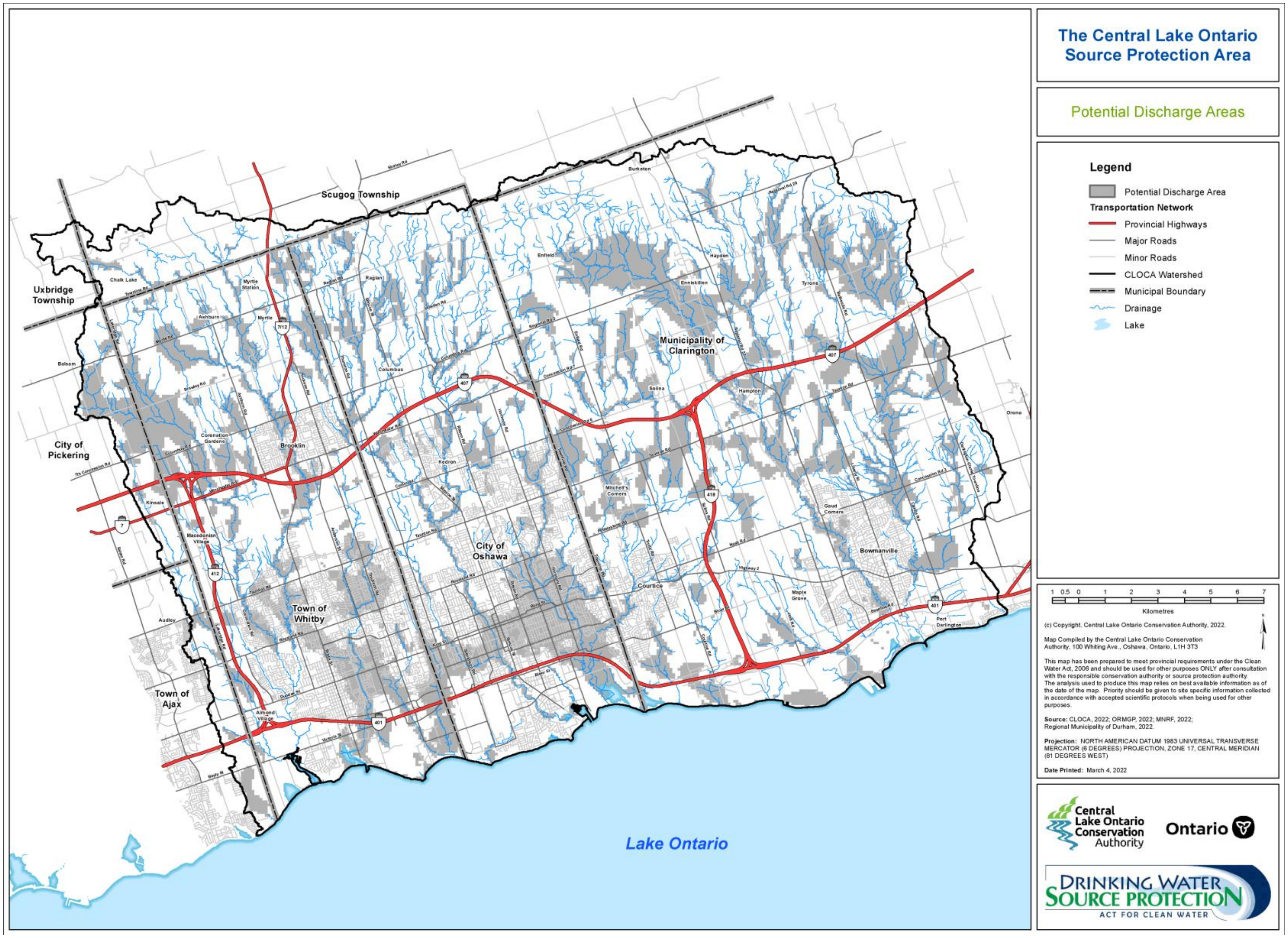

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Figure 3.26: Potential Discharge Areas

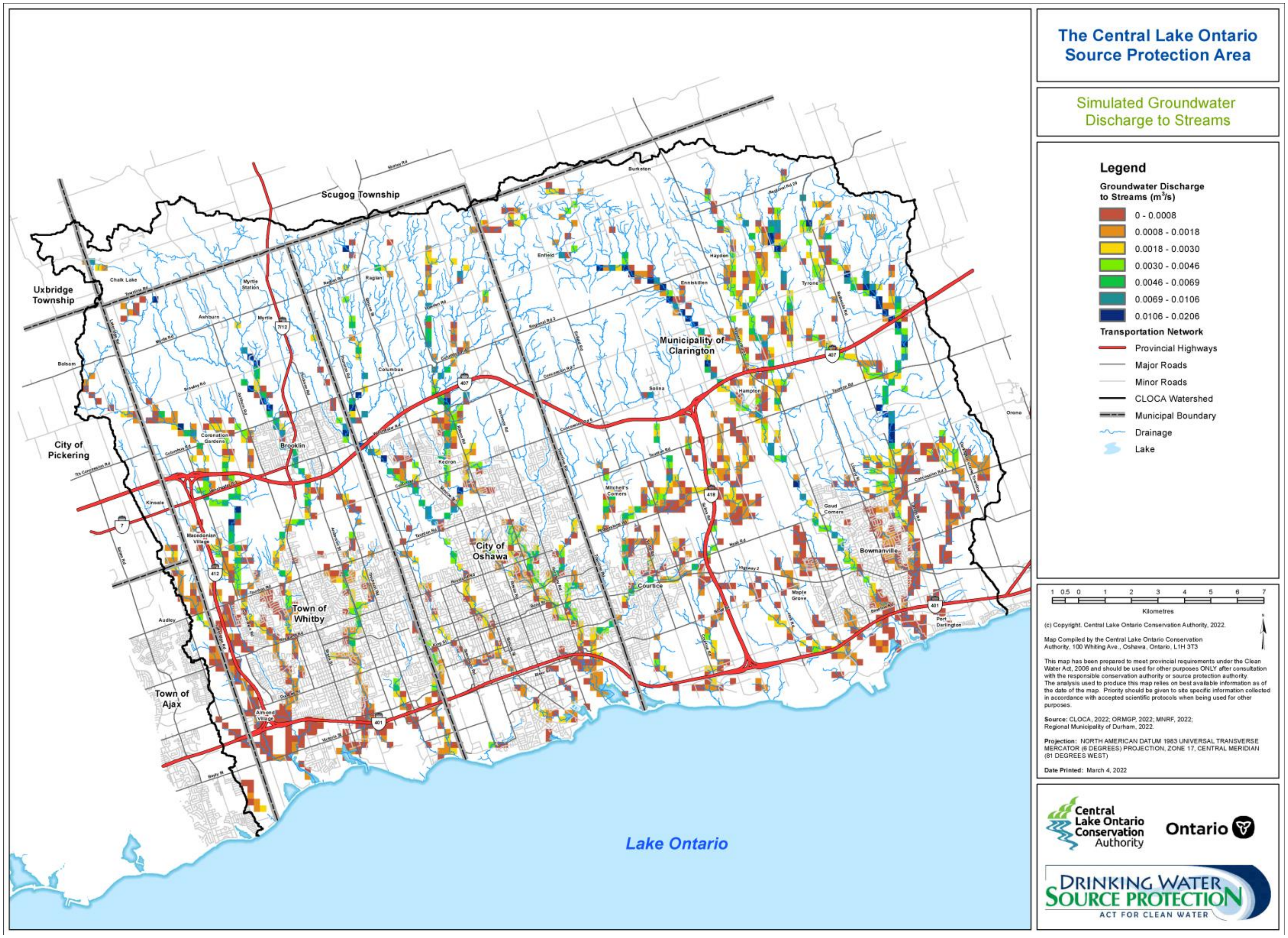

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Figure 3.27: Simulated Groundwater Discharge to Streams

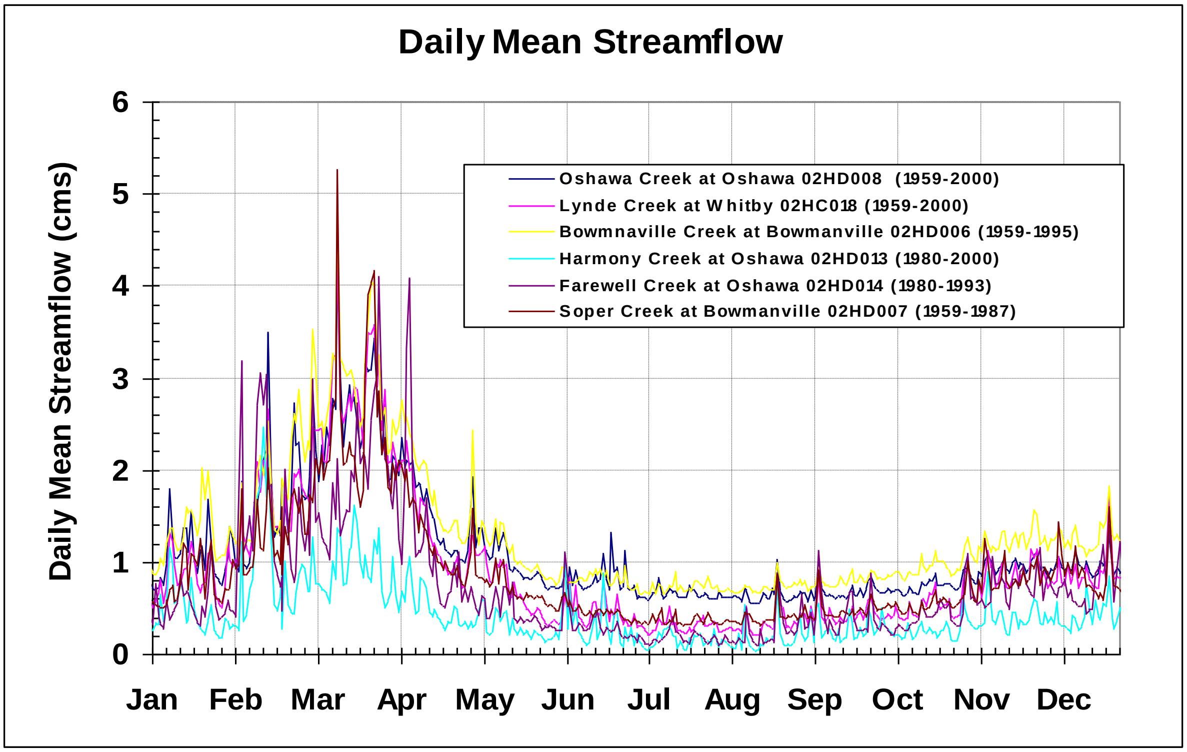


Figure 3.28: Daily Mean Streamflow Calculated at Six WSC Hydrometric Data (HYDAT) Sites

In the conceptual water budget approach, analysts subtracted total streamflow from total precipitation to estimate regional annual evapotranspiration, where change in storage is considered negligible (when there is a steady state in a closed system). Analysts used the following data:

- Precipitation data—Long-term average of the precipitation data from the Orono climate station (Stn. # 6155854); and
- Streamflow data—Long-term average of streamflow data from the HYDAT stations in each of the watersheds analyzed.

The water budgets represent the average annual conditions of the drainage area above the streamflow gauge location for the period of record. Note that this approach does not include a quantitative assessment of the groundwater underflow at the gauge site.

Preliminary estimates, consistent with the provincial *Technical Rule, Nov 2009* regarding water budget calculations, were based on the following:

- Local climate station data;
- Hydrograph separation methodology; and
- Total streamflow for six Water Survey of Canada stations (either existing or abandoned) located within each major watershed.

These estimates have limitations. For example, some are based on too little data. In some cases, large areas are simulated based on single values, so that it becomes impossible to scale the information down to a local area, or to distribute water reservoir estimates spatially (Ely, 2006). The estimates assume steady state conditions and no changes in long-term storage.

The ORMGP database has baseflow estimates that were generated using six different hydrograph separation methods for HYDAT stations in the study area. This has resulted in some long-term average baseflow estimates being as low as 0.54L/s, and others as high as 0.77 L/s for stream gauge 02HC013 on Lynde Creek. Because of these variations, it would be wise to use a range of baseflow estimates for future model calibration. For this conceptual analysis, analysts used a conservative baseflow separation method (5-day average of 7-day min), see **Appendix C** for discussion.

The summary of precipitation (P), total streamflow (STRM), runoff (RO), and groundwater discharge (GWD) estimates represent initial water budget estimates for the contributing drainage areas. Similarly, the quantifications of actual evapotranspiration (AET) described herein (P minus STRM) are estimates only, and may be also be considered as inferred values of evapotranspiration.

Current initiatives for integrated watershed management use a similar simplified water budgeting approach, though data manipulation and analytical techniques may be slightly different. For instance, hydrograph separation methodology has evolved, and can now better estimate groundwater discharge (baseflow). Additionally, as mapping techniques improve and they are better able to delineate boundaries, the contributing drainage area inputs are altered.

To estimate groundwater discharge from streamflow hydrograph separation, analysts remove the runoff or storm/melt events that form peaks on the hydrograph over short periods—hours or days. The groundwater component contributes most consistently to streamflow, with annual fluctuations appearing as gradual changes in the hydrograph.

Additionally, a 3-D numerical groundwater flow model (MODFLOW) was being constructed for the ORMGP groundwater study. MODFLOW used groundwater discharge estimates from hydrograph separation as one of its flux calibration targets. From daily average streamflow measurements, groundwater discharge was estimated from the streamflow separation methodology.

This methodology creates rough estimates of the parts of the water budgets for the various watersheds. It meets the requirements of the *Technical Rules (2009)* for a conceptual water budget.

Table 3.9 features estimates of the following for the drainage areas for the six HYDAT streamflow stations.

- Total precipitation (P);
- Total streamflow (STRM);
- Groundwater discharge (GWD); and
- Actual evapotranspiration (AET).

These data represent the initial water budget estimates, averaged over drainage areas refined during the Tier 1 analysis that is presented later on this chapter. An important part of this refinement was determining the spatial distribution of the different parts of the hydrologic cycle. Though it may not affect drinking water, the conceptual water budget identified potential localized stress on water quantity in some watersheds. It detected low supply and recharge based on information provided in existing local groundwater use studies.

Also, many areas are currently under considerable pressure to develop and significantly change land use, in spite of legislation for the Oak Ridges Moraine and Greenbelt. The level of growth in urban centres, and beyond, means that there will likely be a reduction in recharge and related ecological impacts. For example, several communities use groundwater as their primary source of drinking water. Though there are appreciable groundwater supplies in this area, some communities that rely on shallow aquifer supplies in watersheds with limited recharge and storage might feel the impact on a seasonal basis.

The following table breaks down the coarse water budget component estimates for the various gauged watersheds within CLOSPA's jurisdiction. This is done as part of the Conceptual Water Budget requirements, as outlined in the *Technical Rules (2009).* There are no estimates for the ungauged watersheds (**Table 3.9**).

Station	Period of Record	# full years	Elev masl	Drainage Area km²	Average annual estimates P mm	~AET mm	STRM mm	GWD mm	GWD %¹	~RO mm	~RO %¹
Climate Stations											
6156561 Pontypool	1999-present	2	373		1005						
6151042 Burketon McLaughlin	1969-present	27	312		902						
6159048 Tyrone	1967-1999	31	206		943						
6155854 Orono	1923-1996	59	148		880						
6150830 Bowmanville Mostert	1966-present	31	99		844						
6155878 Oshawa WPCP	1969-present	30	84		870						
6152605 Frenchmans Bay	1959-present	38	76		844						
Streamflow Stations											
02HC018 Lynde Creek near Whitby	1959-present	39		106.0	880	612	268	136	51%	132	49%
02HD008 Oshawa Creek at Oshawa	1959-present	43		95.8	880	520	360	227	63%	133	37%
02HD013 Harmony Creek at Oshawa	1980-present	21		41.6	880	569	311	101	32%	211	68%
02HD014 Farewell Creek at Oshawa	1980-1993	10		58.5	880	500	380	161	42%	219	58%
02HD006 Bowmanville Creek at Bowmanville	1959-1995	34		82.9	880	390	490	311	63%	179	37%
02HD007 Soper Creek at Bowmanville	1959-1987	22		77.7	880	531	349	210	60%	139	40%

Note:
Elev = elevation; P = precipitation; STRM = streamflow; GWD = groundwater discharge (5d average of 7d minimum daily average flow).
~AET = actual evapotranspiration = P-STRM; ~RO = runoff = STRM - GWD.
Assume Orono average total precipitation for AET calculations.
[1] percentage of total streamflow (STRM).

Table 3.9: Summary of Total Conceptual Water Budget

*GWD=Recharge in a Closed System. Models in T1 can simulate conditions and results based on gauged watershed results and calibration to include ungauged watersheds.

Surface Water Intakes and Private Wells

Lake Ontario Water Systems and Water Demand

This water budget analysis does not include demand from the Lake Ontario source. Water budgeting analyses are not required for the Great Lakes sources of drinking water. There are no inland municipal surface water intakes within CLOSPA. For a description of the Lake Ontario intakes see **Chapter 2**.

Private and Cluster Wells and Water Demand

Not all drinking water within the study area comes from the Great Lakes. From a quantity perspective, we should also consider current and projected private use (as per Ontario's *Clean Water Act, 2006* provisions), as there are many cluster situations and communal drinking water systems. Under the *CWA, 2006,* a municipality may also "designate" a drinking water system (or cluster of systems) as defined under the *Safe Drinking Water Act*; the Act includes all drinking water systems established for the purpose of proving drinking water, and private wells. Once designated by a municipality, the system is subject to the same requirements under the *CWA* that apply to the municipal residential drinking water systems for assessment, monitoring, and policy. Designated systems must be identified in the provincially approved Terms of Reference for the source protection authority. There are no designated or elevated clusters or wells in the CLOSPA jurisdiction to date.

Permitted water uses in the watershed, including drinking water, recreation, ecological purposes, agriculture, and industry, were assessed in the conceptual water budget and refined further during the Tier 1 analyses. Though most of the urban settlements in the CLOSPA region are serviced by water from Lake Ontario, groundwater still remains an important source of potable water to hamlets and rural areas. According to the MOECC Water Well Information System (WWIS), there are approximately 5,500 privately owned domestic water wells within the CLOSPA study area at the time of this Assessment Report.

Water takings in Ontario are governed by the Water Taking and Transfer Regulation under the *Ontario Water Resources Act*. Section 34 of the Act requires anyone taking more than a total of 50,000 litres in a day, with some exceptions, to obtain a Permit to Take Water (PTTW). Provincial guidance refers to specific water use definitions regarding the analysis of the PTTW information:

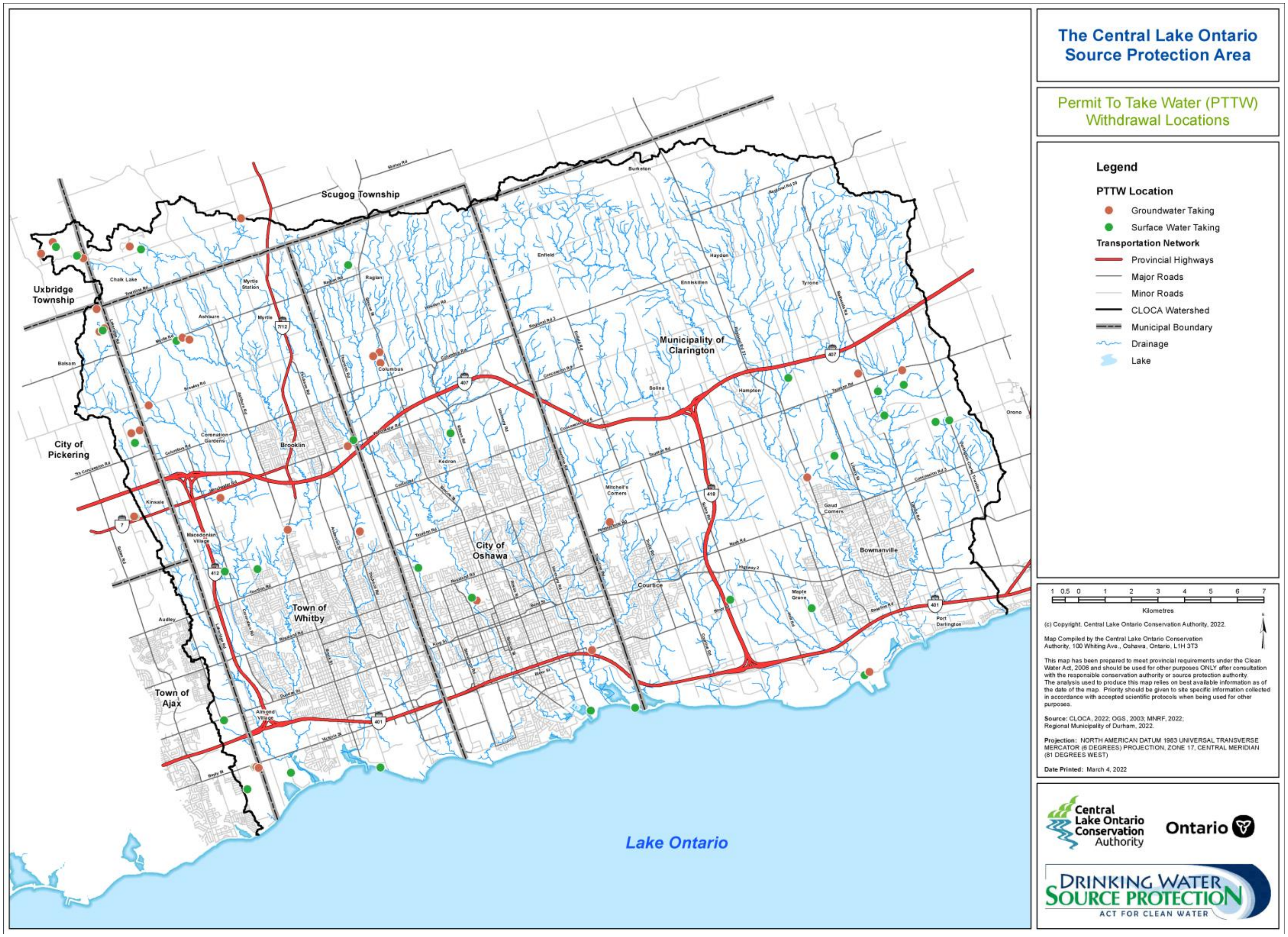
- Water Demand—water taken as a result of an *anthropogenic* activity, expressed as a ratio of consumptive demand to the difference between source supply and reserve; and
- Consumptive Demand—water taken from a groundwater or surface water source and not returned locally in a reasonable time period.

Anthropogenic: Human-created, as opposed to natural.

Table 3.10 represents a volume assessment of groundwater and surface water takings, as calculated from provincial water taking data provided by the Province. This data was further refined in the Tier 1 analysis presented later in this chapter. **Figure 3.29** shows the groundwater and surface water takings locations.

Watershed	Permitted Water Takings (L/day)	
	Groundwater Source	Surface Water Source
Bowmanville	1,309,248	4,919,872
Soper Creeks	None on record	9,874,080
Darlington Creek	5,952,465	13,358,840
Lynde Creek	33,631,688	47,978,115
Oshawa Creek	538,560	1,987,400
Pringle Creek	98,194	9,874,080
Lake Ontario	N/A	192,946,250

Table 3.10: Permitted Water Takings



(c) Copyright. Central Lake Ontario Conservation Authority, 2022.

Map Compiled by the Central Lake Ontario Conservation Authority, 100 Whiting Ave., Oshawa, Ontario, L1H 3T3

This map has been prepared to meet provincial requirements under the Clean Water Act, 2006 and should be used for other purposes ONLY after consultation with the responsible conservation authority or source protection authority. The analysis used to produce this map relies on best available information as of the date of the map. Priority should be given to site specific information collected in accordance with accepted scientific protocols when being used for other purposes.

Source: CLOCA, 2022; OGS, 2003; MNRF, 2022; Regional Municipality of Durham, 2022.

Projection: NORTH AMERICAN DATUM 1983 UNIVERSAL TRANSVERSE MERCATOR (6 DEGREES) PROJECTION, ZONE 17, CENTRAL MERIDIAN (81 DEGREES WEST)

Date Printed: March 4, 2022

Figure 3.29: Permit To Take Water (PTTW) Withdrawal Locations

Potential Future Drinking Water Sources

Most of the region's water and wastewater customers are serviced by Lake Ontario-based systems, including the urban areas of Whitby, Oshawa, Courtice, and Bowmanville. Approximately 320,000 customers live within the urban and rural areas of the CLOSPA jurisdiction that also fall within Durham Region (Statistics Canada, 2006). Approximately 95% of them receive service from the water and wastewater systems that the region owns and operates. The region is responsible for treating water and distributing it to the customer. The development of these systems is currently guided by water and wastewater servicing plans that were completed in 1995.

It is important to note that although most of the region's drinking water comes from Lake Ontario, there are appreciable good quality groundwater supplies within the region's jurisdiction. These remain untapped and represent a potential future supply. The Oak Ridges Moraine, Thorncliffe, and deep-buried channel aquifers have been very important in other areas currently experiencing water quantity stress. These aquifers represent a potential future supply for municipal and other drinking water, and should be understood and managed accordingly. Ongoing water budgeting work will serve towards the quantification of these supplies.

Durham Region's population and employment levels have grown significantly since they completed their servicing plans, and this growth is expected to continue. The region is updating the comprehensive Water and Wastewater Master Plan study to develop a long-term servicing strategy for the design and operation of all municipal water and wastewater systems in Durham Region. The study will update and/or incorporate previous servicing plans and studies as required, and will satisfy Phases 1 and 2 of the Municipal Class Environmental Assessment (Class EA) process.

Growth within Durham Region is currently guided by the Durham Regional Official Plan (ROP), which establishes the parameters for development within Durham Region. The Durham ROP outlines growth within the region as amended by Amendment No.114. CLOSPA is completely within the boundary of Durham Region, and population projections for CLOSPA can be estimated based on projections provided in the ROP, recognizing that these projections will be revised to conform to the Growth Plan. The ROP projects a combined population of 585,000 for the urban centres of Whitby, Oshawa, Bowmanville, and Courtice by year 2021. This reflects a 51% increase over the next 16 years, which is more or less consistent with the reported annual growth rate.

Ultimately, the Source Protection Plan will incorporate the details of the 25-year (2031) and 50-year (2056) water supply plans.

3.6 CLIMATE

3.6.1 Climate: Historical and Projections

Climate change is affecting average and extreme climate conditions in Ontario, and will continue to do so. Recent droughts, flooding, heat waves, and warmer winters have had various effects in Ontario, including water shortages, forest fires, lower water levels in the Great Lakes, declines in agricultural production, power outages, and outbreaks of water-borne diseases (Chiotti and Lavender, 2008). The *CWA* requires a discussion of climate change, as it could impact estimates of water supply in the water budget analysis.

The Great Lakes have a large influence on the region's climate. They cause higher autumn and winter precipitation (including very heavy snowfalls), and mitigate extreme hot and cold temperatures.

Ontario experiences a variety of extreme weather events and associated natural disasters. Major storms hit most parts of Ontario at least once or twice per year, with high winds, rain, freezing rain, or snow. In spring, rapid snowmelt or ice jamming can lead to flooding, especially in northern communities. Tornados can be experienced in southern Ontario, which has the highest frequency of tornadoes in Canada, in the spring and summer months. Remnants of hurricanes also occasionally produce high winds and excessive rainfalls. In recent years, Ontario has experienced some exceptionally severe weather events, including the 1998 ice storm.

3.6.2 Climate Trends

During the last half of the twentieth century (1948–2006), the annual average temperature in Ontario increased between 0–1.4°C, with larger increases observed in the spring (Chiotti and Lavender, 2008).

Since 1999, annual precipitation in southern Canada has increased by about 5–35% (Zhang *et al*., 2000), and the number of days with precipitation (rain or snow) has increased significantly (Bruce *et al*., 2000, Chiotti and Lavender, 2008).

Autumn snowfalls have been increasing in the area, but snowfalls have declined in spring and winter. Snowfall trends in the south subregion are not statistically significant, although there is evidence of an increase in snow (Chiotti and Lavender, 2008).

3.6.3 Climate Projections

Projections for changes in temperature and precipitation were estimated from several Global Circulation Models (GCM) using seven different greenhouse gas emission scenarios. The results range from conservative to aggressive assumptions regarding future emission rates. They indicate an increase in annual temperature and most models also predict an increase in annual precipitation levels within the next 20–50 years.

The range of results increases over time and indicates that maximum warming will occur in winter. Also, changes in extreme warm temperatures are expected to be greater than changes in the annual mean temperature (Chiotti and Lavender, 2008). The number of days exceeding 30°C in the south subregion is projected to more than double by 2050 and severe heat days could triple in some cities by 2080 (Chiotti and Lavender, 2008). Projections of precipitation vary more significantly than those of temperature. However, some of the projections indicate a slight decrease (<2.5%) in annual precipitation for most of the province in the next 50 years.

Aanalysts predict summer and fall decreases of up to 10% by 2050. Warmer temperatures and longer growing seasons will impact net moisture availability, resulting in increased evaporation and evapotranspiration rates. Winter projections show increases in precipitation, increasing from south to north and ranging from 10% to more than 40%.

Changes in extreme daily precipitation are expected to be greater than the changes projected in the annual mean precipitation (Chiotti and Lavender, 2008). This means that rain or snowfall events will become both more intense and more frequent (Chiotti and Lavender, 2008). Lake-effect snow will likely increase over the short to medium term, as lake temperatures rise and winter air temperatures remain cool enough to produce snow. By the end of the twenty-first century, however, snowfall may be replaced by heavy lake-effect rainfall events (Chiotti and Lavender, 2008).

Unseasonal temperatures, more frequent periods of lower than average precipitation, and peak storms resulting in flooding events have been observed and documented in the last decade. Impacts such as lower water levels in wells and flooding have been recorded. It is expected that these types of climatic events will continue to affect the study area. Management strategies that include climate change adaptation components will become increasingly important. Additional discussions regarding potential climate change impacts and threats to drinking water sustainability are presented in **Chapter 5** (Drinking Water Threats Assessment).

3.7 TIER 1 WATER BUDGET

The Tier 1 Water Budget is the second tier of the four possible water budgets (Conceptual Water Budget, Tier 1, Tier 2, and Tier 3). It considers whether a water source can meet water use demands in a subwatershed without being stressed. It uses spreadsheets and GIS maps to look at *consumptive demand.* It also calculates how quickly a natural water source replenishes (recharges) itself. This calculation depends on several factors, including land use, topography, and geology. If there is a possibility that a subwatershed could be stressed, a Tier 2 Water Budget is required.

The primary purpose of the Tier 1 analysis is to quantitatively describe the movement of water within the various elements (such as soils, aquifers, streams, and lakes) that make up the hydrologic cycle within each subwatershed. Tier 1 analyses are more detailed than those conducted through the conceptual water budget process, providing a spatial analysis of all the water budget components in the jurisdiction, including watersheds where no gauge stations exist.

Under the source protection initiative, a second purpose of the Tier 1 analysis is to estimate the hydrologic stress from a water quantity perspective within each subwatershed. A water quantity stress situation occurs where there is more estimated demand for than supply of the water in the watershed. To screen out areas of potential stress, water supply volumes represented by the formula ($Q_{SUPPLY} = (Q_R + Q_{IN})$) are compared to consumptive demand. The ratio of demand to supply defines the degree of subwatershed stress. Further efforts and resources could then be focused on areas that serve municipal supplies found to be under hydrologic stress, or those that will likely be in the future.

Consumptive Demand: Amount of water taken from a surface water or groundwater system without being returned to that system.

The hydrologic cycle estimates the following:

- Precipitation (QP);
- Evapotranspiration (QE);
- Recharge (QR);
- Runoff (QRO);
- Groundwater and surface water takings (QST and QGT);
- Groundwater discharge to streams (QGD); and
- Lateral groundwater inflow and outflow (QIN and QOUT).

A steady-state water budget assumes that the amount of water stored in the various surface and subsurface reservoirs will vary only slightly over the time scale considered. The parts of such a water budget are shown schematically in **Figure 3.30**. **Table 3.11** is a summary of the primary components of the water budget, organized by watershed, on an annual basis.

Climatic data was further processed to support the quantification of inputs to the system. This process is described below.

The climate across the study area varies appreciably, both spatially and temporally. There is some local variation caused by topography, prevailing winds, and proximity to Lake Ontario. Long-term climate data—including daily maximum and minimum temperature, precipitation, and solar radiation—were obtained from Environment Canada for the 20-year period from January 1, 1980 to December 31, 1999.

Eight stations have long-term records that cover this period. Four of these stations—the ones that had joint precipitation and temperature measurements were selected (Bowmanville-Mostert, Oshawa WPCP, Burketon-McLaughlin, and Tyrone). The station in Orono was excluded because of the many breaks in the precipitation record. Because the PRMS model works in "water years" (which begin in October of the previous calendar year), the data sets were pared down to the 19-year period from October 1, 1980 to September 30, 1999.

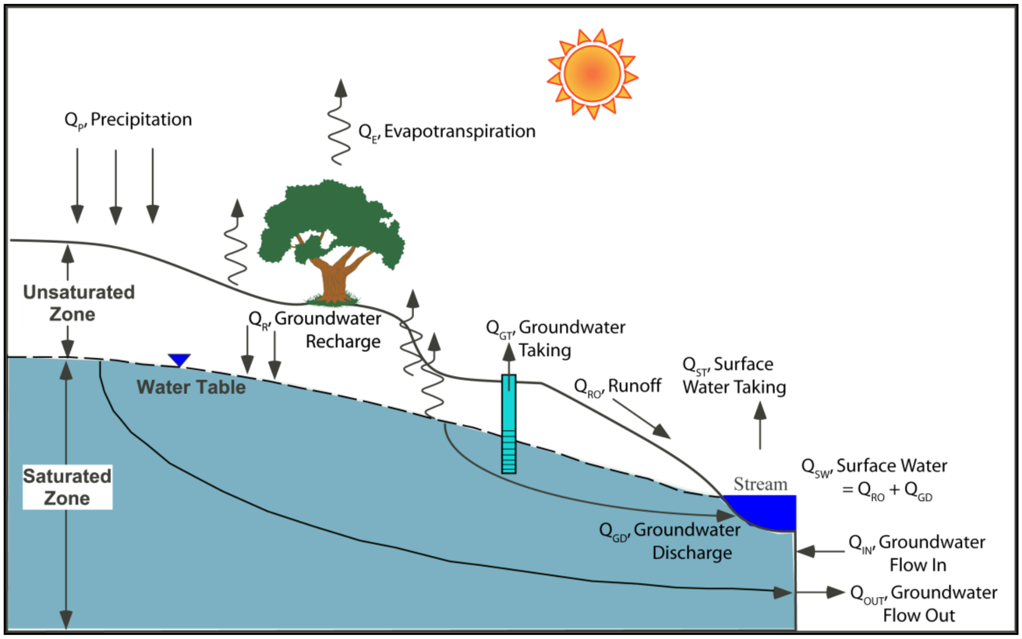


Figure 3.30: Components of a Steady-State Water Budget (after MOE, 2007)

Before processing the daily data, analysts examined data on climate normals (30-year averages) between 1971–2000 to search for obvious patterns. Data for stations within or near the study area were obtained from Environment Canada.

Watershed	Watershed	Imperviousness		Total Annual Average Precipitation	Annual Average Surface Runoff		Annual Average Groundwater Infiltration		Annual Average Evapotranspiration		Annual Average Interception	
	(km^2)	(km^2)	(%)	(mm/yr)	(mm/yr)	(%)	(mm/yr)	(%)	(mm/yr)	(%)	(mm/yr)	(%)
Lynde	132.2	12.2	9.2	887.9	168.7	19.0	161.0	18.1	398.1	44.8	160.1	18.0
Pringle	28.5	9.7	34.1	878.7	240.9	27.4	123.2	14.0	425.8	48.5	88.8	10.1
Corbett	14.6	6.5	44.5	867.2	257.4	29.7	100.4	11.6	434.6	50.1	74.9	8.6
Goodman	10.3	3.7	36.3	874.6	230.0	26.3	141.4	16.2	406.4	46.5	96.8	11.1
Oshawa	110.2	11.7	10.6	896.8	169.0	18.8	168.1	18.7	396.9	44.3	162.9	18.2
Harmony	46.7	11.5	24.7	885.4	227.2	25.7	118.4	13.4	429.2	48.5	110.6	12.5
Farewell	36.3	3.2	8.9	894.9	192.9	21.6	136.7	15.3	405.8	45.3	159.6	17.8
Robinson	5.7	1.1	18.4	868.1	203.1	23.4	106.8	12.3	423.8	48.8	134.4	15.5
Tooley	10.5	1.4	13.2	871.8	184.3	21.1	127.0	14.6	401.2	46.0	159.3	18.3
Black	24.2	1.4	5.9	895.2	183.1	20.5	161.3	18.0	386.4	43.2	164.3	18.4
Darlington	16.4	1.8	11.2	871.5	184.6	21.2	135.0	15.5	393.0	45.1	158.9	18.2
Bowmanville	90.5	4.5	5.0	913.5	149.3	16.3	213.8	23.4	372.2	40.7	178.2	19.5
Westside	5.7	2.3	40.1	865.1	255.4	29.5	98.9	11.4	435.9	50.4	75.0	8.7
Soper	75.4	4.6	6.2	895.3	174.2	19.5	172.8	19.3	374.7	41.9	173.6	19.4
Bennett	7.4	0.8	10.6	860.9	191.8	22.3	115.0	13.4	406.2	47.2	147.9	17.2
Lake Ontario Catchments	24.0	7.4	30.9	827.9	217.6	26.3	109.8	13.3	413.3	49.9	87.1	10.5

Table 3.11: Primary Components of the Water Budget by Watershed on an Average Annual Basis

Mean annual precipitation ranged from 858 millimetres per year (mm/yr) at Bowmanville-Mostert to 1001 mm/yr at Leskard. Annual average precipitation is higher in the northeast part of the study area, although the spatial coverage of data, particularly to the northwest, is limited. The findings are consistent, however, with the observation that Soper and Bowmanville Creeks had higher annual average streamflow rates than the other gauged watersheds. While it appears that this likely has to do with elevation within the study area, analysis of precipitation normals on a larger scale (e.g., Kassenaar and Wexler, 2006) shows that, while the high values are not anomalies, they are localized to this area. Kassenaar and Wexler (2006) noted two other consistent patterns: low values in the urban areas of the GTA (possibly due to heat island effects), and higher values south and west of Georgian Bay, Lake Simcoe, and Lake Scugog (possibly due to lake effects). The lowest values for monthly average precipitation occur in February, while high precipitation rates occur in August, September, and November.

Monthly averages of maximum daily temperatures for 1971– 2000 ranged from 10.8–12.0 °C, while the monthly averages of minimum daily temperatures ranged from 1.9– 3.6 °C. Mean daily temperature is not shown in the table because it is simply computed as the average of the reported minimum and maximum daily temperatures. The mean daily temperature for January (typically the coldest month) ranged from -8.1°C at Burketon McLaughlin to -5.3°C at Oshawa WPCP, showing the warming effect of Lake Ontario. The mean daily temperature for July (typically the warmest month) ranged from 19.8–20.3°C.

Agriculture and Agri-food Canada calculates mean annual potential evapotranspiration for “ecodistricts” across Canada by using climate normals. Ecodistrict 553 covers most of the study area as well as several conservation areas to the north and east. Annual estimates of potential evapotranspiration calculated for Ecodistrict 553 were calculated using both the Thornthwaite method, which calculates precipitation from May to August, and the Penman method, which calculates precipitation from June to August only.

Comparison with average precipitation for Ecodistrict 553 shows that potential evapotranspiration exceeds available precipitation in both the Thornthwaite and Penman timeframes. Actual evapotranspiration in those months depends on the availability of soil moisture and other factors previously discussed. These estimates were calculated for a very large area and do not take into account local variation in soils, land use, and solar radiation. The numbers were used to confirm the estimates of potential evapotranspiration obtained with the PRMS model.

Daily climate data that was used as an input to the PRMS hydrologic model were nearly complete, although some infilling of missing data was required. The PRMS code provided methods to infill solar data, but this was unnecessary because the solar data were complete. Earthfx developed data pre-processors to infill precipitation and temperature. These pre-processors were built on procedures developed by Schroeter *et al*., (2000).

To fill in missing daily precipitation records, analysts identified the 12 stations nearest the one with the missing record. Next, each measured precipitation value at the 12 nearby stations was adjusted. To do this, the measured value for that day was multiplied by the ratio of the mean monthly precipitation at the nearby station. This determined the mean monthly precipitation at the station with the missing record.

Finally, analysts used an inverse-distance weighting method to determine a weighted average of the adjusted measured values. If daily precipitation values were missing, but an accumulated amount was provided at the end of a number of days, the method described above was first applied to each of the missing values. The sum of the estimates was determined, and then each daily value was scaled so that the sum equaled the reported accumulated value.

If the maximum temperature value was missing for a particular day, analysts calculated the difference between the average monthly maximum temperature and the average monthly mean temperature for the station, then added this number to the reported mean temperature.

Similarly, if the minimum temperature value was missing for a particular day, analysts calculated the difference between the average monthly minimum temperature and the average monthly mean temperature, then subtracted this number from the reported mean temperature.

Where all temperature data for a particular day were missing, analysts identified the 12 stations nearest the one with the missing records. Next, the measured mean temperature value at each of the 12 stations was adjusted. To do this, analysts calculated the difference between the mean monthly temperature at the nearby station and the mean monthly temperature at the station with the missing record (as per Schroeter *et al*., 2000), then subtracted this number from the measured mean temperature.

Finally, analysts used inverse-distance weighting to determine a weighted average of the adjusted measured mean temperature values. They then estimated the values for the missing maximum and minimum temperatures from the infilled mean temperature data, using information about the differences between the monthly average temperature values.

This Tier 1 analysis uses data that has been collected routinely over the years by the conservation authority and other government agencies, such as the Ontario Ministry of the Environment and Climate Change, and Environment Canada. Two numerical models were available to CLOSPA for this study, so analysts combined the two. The models assessed groundwater recharge, interaction between the groundwater and surface water systems, and groundwater movement across watershed boundaries. The groundwater model extended beyond the CLOSPA boundary and was used to estimate inflow from recharge areas outside of the CLOSPA study area.

The first model was based on the U.S. Geological Survey (USGS) Precipitation-Runoff Modelling System (PRMS) (Leavesley *et al*., 1983). This model represented surface water. Earthfx modified the model so that it could conduct the water balance on a cell-by-cell basis.

The PRMS model estimated levels of precipitation, interception, evaporation, potential and actual evapotranspiration, snowmelt, runoff, infiltration, interflow, and groundwater recharge for all the CLOSPA watersheds. PRMS model calibration aimed to match measured surface water flows and estimated baseflows at Environment Canada surface water gauges with long-term records.

It is significant that the PRMS model application used distributed data on soil properties, topography, vegetative cover, land-use classes, daily rainfall, and temperature. Analysts chose these consistent model parameters for each land-use/soil-type/vegetation combination across all the watersheds within the CLOSPA boundaries. This way, the hydrologic response of each watershed depended on the relative coverage and distribution of each land-use/soil-type/vegetation combination. This also helped overcome the limitations of having a small number of gauges with long-term records relative to the number of catchments modelled, see Tier 1 Water Budget report (CLOCA, 2009).

The second model, based on the U.S. Geological Survey's MODFLOW numerical groundwater flow code (MacDonald and Harbaugh, 1988), represented the groundwater system. The groundwater model, which includes the study area, was developed as an extension to the previous Oak Ridges Moraine groundwater model development project (Kassenaar and Wexler, 2006). The groundwater model provided the following information:

- Estimated groundwater potentials;

- Groundwater budget items (such as the exchange of water between shallow and deeper aquifers);
- Lateral inflows and outflows from the catchments; and
- Groundwater discharge to streams.

Results from the groundwater modelling, described later on, established that significant volumes of groundwater were entering the CLOSPA watersheds from high-recharge areas to the northeast and northwest. Groundwater pathway and flux analyses also showed that significant amounts of groundwater were moving across subwatershed boundaries. The groundwater model was calibrated to observed groundwater potentials and estimated baseflows.

To link the hydrologic and groundwater models, analysts used the groundwater recharge output from the PRMS hydrologic model, averaged over a 19-year simulation period, as input to the MODFLOW groundwater model. Then, to constrain the PRMS calibration targets, analysts used net lateral inflows and estimated groundwater discharge to streams from the MODFLOW model. They then used an iterative calibration procedure in which recharge and baseflow estimates were refined until the two models agreed. By integrating the surface water and groundwater analysis and accounting for inter-catchment groundwater flow, analysts achieved a better calibration and obtained a consistent (and more insightful) assessment of the overall hydrologic system.

As expected, runoff is high in the urbanized areas, especially along roads, and in commercial and industrial areas. Runoff is low over the Oak Ridges Moraine and over the exposed Lower Sediment sands in the Enniskillen area. Runoff is moderate to high on the South Slope and Iroquois Plain areas due to the predominantly till soils. Runoff for the Iroquois Beach deposits is higher than for the Oak Ridges Moraine, because of the shallow water table and underlying tills.

This study identified the different ways that water enters and leaves the watersheds, the amount of water that enters or leaves, and flow levels. It also showed that groundwater inflow across watershed boundaries was a significant component of the water budget. In most catchments, Q_{IN} was balanced by Q_{OUT}, but Bowmanville Creek and Oshawa Creek watersheds had significant net lateral inflows (i.e., Q_{IN} – Q_{OUT}). Many of the small watersheds had small net lateral outflows. Lateral groundwater inflow ranged from 22–69% of Q_{SUPPLY} (Q_R + Q_{IN}). As expected, watersheds that include significant portions of the Oak Ridges Moraine had the largest overall Q_{SUPPLY}.

The water demand portion of the water budget analysis was determined from the following sources:

- The MOECC PTTW;
- Estimates of unserviced population water consumption;
- Agricultural water use; and
- Other potential water users identified by CLOSPA.

There are no groundwater-based municipal water systems presently operating in the CLOSPA study area. The results of the water supply and water use analyses were used to evaluate the cumulative stress within each subwatershed. Analysts completed a screening assessment that included an estimated percentage of the water supply that water users demand consumptively. This percentage is referred to as the percent water demand.

According to the *Technical Rules (2009)*, subwatersheds with significant consumptive takings may jeopardize the reliability of the well or intake. As a result, subwatersheds that experience a significant-to-moderate degree of stress, and that contain municipal drinking water systems, will move on to the

Tier 2 Water Budget and Stress Assessment to refine estimates. Subwatersheds that experience a significant-to-moderate degree of stress, but do not contain municipal drinking water systems, will be highlighted, but will not automatically move on to Tier 2 unless as directed by the Province. Subwatersheds that experience a low degree of stress will not be required to undergo any further steps in the Water Budget—Water Quantity Risk Assessment process for source protection.

Analysts summarized the daily outputs from the hydrologic model to produce tables and maps showing the water supply portion of the water budget. This included estimates of precipitation (P), evapotranspiration (ET), recharge (Q_R), and runoff (RO), on a monthly and annual basis.

Analysts also summarized the outputs from the steady-state groundwater model to produce tables and maps showing lateral groundwater inflow and outflow (Q_{IN} and Q_{OUT}), and groundwater discharge to streams (G_D) on a long-term average basis (see **Table 3.12**).

The PRMS model indicated large variations in seasonal and year-to-year groundwater recharge, with near-zero recharge in the summer months and highly variable recharge throughout the other months of the year. This depended on ET processes, snowpack accumulation, and snowmelt events. The sum of the annual average recharge (Q_R) and the lateral inflow (Q_{IN}) were used as the groundwater supply (Q_{SUPPLY}) in subsequent groundwater stress assessments.

Analysts used usage descriptions in the PTTW database to estimate monthly corrections for the consumptive demand. Overall, permitted water demand in the CLOSPA watersheds was 1.3 times higher in the spring and summer than in the fall and winter months.

The conservation authority is working to confirm permit status and actual water use for permits in the PTTW database. Because that work is still ongoing, maximum permitted rates (as recommended in the *Technical Rules (2009))* were used in the Tier 1 demand analysis. Finally, the demand estimates were adjusted to account for water pumped, but locally returned to the watershed (consumptive use correction).

The water demand analysis calculated a total groundwater demand equal to 18,249 m^3/d. Lynde, Oshawa, Bowmanville, Soper, and Darlington watersheds have the highest total groundwater demand, with Lynde alone accounting for 39% of the total. Similarly, the Lynde watershed accounts for over 56% of the total surface water consumptive demand (excluding demand from Lake Ontario). Golf course irrigation and snowmaking are the two most significant permitted groundwater uses in the CLOSPA watersheds. However, un-permitted agricultural demand (water takings that require no permit) exceeds both golf course irrigation and snowmaking. Population growth is estimated to increase the overall groundwater demand (for direct human consumption) by about 3% over the next 25 years.

Initially, analysts used streamflow data to estimate the water reserve sections of the groundwater and surface water budgets. Because the areas that contribute to the gauges do not cover the entire CLOSPA region, water reserve was computed using the simulated streamflow from the calibrated numerical models. Groundwater reserve ($Q_{RESERVE}$) was estimated as 10% of the groundwater model simulated baseflow (G_D). The surface water reserve was estimated on a monthly basis by using the simulated lower decile flows (Q_{P90}) from the hydrologic model.

Watershed	Q Recharge (m^3/s)	Q In (m^3/s)	Q Supply (m^3/s)	Q Reserve (m^3/s)	Q Demand Current Condi-tions (m^3/s)	% Water Demand Current Condi-tions	Stress Level Current Conditions
Lynde Creek	0.6765	0.2020	0.8785	0.0679	0.0819	10.10	Moderate
Pringle Creek	0.1115	0.0420	0.1535	0.0106	0.0043	2.98	Low
Corbett Creek	0.0463	0.0170	0.0633	0.0041	0.0001	0.19	Low
Goodman Creek	0.0462	0.0150	0.0612	0.0024	0.0009	1.48	Low
Oshawa Creek	0.5892	0.1970	0.7862	0.0650	0.0300	4.17	Low
Harmony Creek	0.1756	0.0810	0.2566	0.0175	0.0095	3.95	Low
Farewell Creek	0.1577	0.1100	0.2677	0.0168	0.0100	4.00	Low
Robinson Creek	0.0193	0.0150	0.0343	0.0004	0.0023	6.89	Low
Tooley Creek	0.0423	0.0200	0.0623	0.0028	0.0038	6.30	Low
Black Creek	0.1243	0.0670	0.1913	0.0106	0.0062	3.44	Low
Darlington Creek	0.0702	0.0220	0.0922	0.0043	0.0149	16.97	Moderate
Bowmanville Creek	0.6149	0.3050	0.9199	0.0816	0.0239	2.85	Low
Westside Creek	0.0180	0.0220	0.0400	0.0013	0.0015	3.76	Low
Soper Creek	0.4152	0.2000	0.6152	0.0407	0.0170	2.97	Low
Bennet Creek	0.0272	0.0210	0.0482	0.0018	0.0018	3.82	Low
Lake Catchments	0.0747	0.1100	0.1847	0.0086	0.0032	1.79	Low

Table 3.12: Groundwater Stress Assessment Summary —Current Conditions

3.7.1 Stress Assessment Subwatersheds

As indicated above, according to the *Technical Rules (2009)*, subwatersheds with significant consumptive takings may jeopardize the reliability of the well or intake. As a result, subwatersheds that experience a significant-to-moderate degree of stress, and that contain municipal drinking water systems, will move on to the Tier 2 Water Budget and Stress Assessment for refinement of estimates. There are no groundwater municipal supplies located in CLOSPA. Stress identified in the Tier 1 Water Budget process is not required to be further studied per the *Technical Rules (2009).*

3.7.2 Tier 1 Methodology

Groundwater Calculation

The *Technical Rules (2009)* provides the following equation for calculating the percent water demand for groundwater:

$$\text{\% Water Demand (Groundwater)} = \frac{Q_{DEMAND}}{Q_{SUPPLY} - Q_{RESERVE}} \times 100$$

The *Technical Rules (2009)* defines the terms of the equation as follows:

Term	Definition	Calculation
Q_{DEMAND}	Groundwater Consumptive Demand	Groundwater demand is calculated as the estimated average annual and monthly rate of groundwater takings in a subwatershed.
Q_{SUPPLY}	Groundwater Supply	Groundwater supply is calculated as the estimated annual recharge rate plus the estimated groundwater inflow into a subwatershed. For monthly volumes these annual numbers are divided by 12 months.
$Q_{RESERVE}$	Groundwater Reserve	Component of baseflow discharge: suggest 10% of the total groundwater discharge should be maintained as a reserve.

For the CLOSPA watershed analysis, Q_{DEMAND} was calculated in the manner prescribed above. Though detailed monthly groundwater recharge estimates were available from the PRMS model, the monthly Q_{SUPPLY} was calculated using the average annual rate divided by 12 as directed by the *Technical Rules (2009)*.

Average Annual Groundwater Supply Calculation Methodology

For consistency with other studies, Q_{SUPPLY} was calculated in accordance with the *Technical Rules (2009)* as follows:

$$Q_{SUPPLY} = Q_{RECHARGE} + Q_{IN}$$

Monthly Groundwater Supply Calculation Methodology

While the PRMS model can be used to estimate average monthly recharge rates, the *Technical Rules (2009)* requires that monthly supply be estimated as 1/12th of the annual average Q_{SUPPLY} for simplicity.

Surface Water Calculation

The prescribed approach for determining the surface water quantity stress in the *Technical Rules (2009)* considers seasonal variability and is therefore evaluated using an estimated monthly streamflow. Percent water demand is calculated for each month and the largest monthly stress is compared against the threshold values. Percent water demand is calculated on a monthly basis as:

$$\%\ \text{Water Demand (Surface Water)} = \frac{Q_{DEMAND}}{Q_{SUPPLY} - Q_{RESERVE}} \times 100$$

The terms of the equation are determined as follows:

Term	Definition	Calculation
Q_{DEMAND}	Surface Water Consumptive Demand	Surface water demand is calculated as the estimated rate of consumptive takings from streams, ponds, and lakes in a subwatershed.
Q_{SUPPLY}	Surface Water Supply	Monthly surface water supply is calculated as the median monthly flow in a stream or into a lake or reservoir. Where median flow conditions cannot be obtained, best available monthly baseflow measurements or estimates should be used.
$Q_{RESERVE}$	Surface Water Reserve	As a minimum, surface water reserve is estimated using the 10th percentile monthly flow.

For the CLOSPA watershed analysis, Q_{DEMAND} was calculated in the manner prescribed above. Q_{SUPPLY} was calculated using the median monthly flows as determined in the PRMS model while $Q_{RESERVE}$ was estimated using the simulated lower decile monthly flow.

Stress Assessment Criteria

Groundwater Stress Assessment: Current and Future Conditions

Groundwater stress assessments calculate percent water demand on an annual and monthly basis. Q_{SUPPLY} and $Q_{RESERVE}$ were estimated from the models, and annual and average monthly demand values were determined from the water demand analysis.

The *Technical Rules (2009)* prescribes that the stress be determined by calculating the average annual and maximum monthly percent water demand for each subwatershed and then comparing them to the following thresholds.

Groundwater Stress Thresholds Current and Future Scenarios:

Groundwater Quantity Stress Level Assignment	Average Annual	Monthly Maximum
Significant	> 25%	> 50%
Moderate	> 10%	> 25%
Low	0 – 10%	0 – 25%

The thresholds for monthly maximum conditions are higher than average annual thresholds because groundwater supplies can typically tolerate short-term water demands that may not be sustainable over the entire year. The resultant groundwater stress level assignment is the maximum of the current and future assessment values for both annual and monthly conditions.

The thresholds are intended to be conservative, to ensure that areas potentially under hydrologic stress will be identified for additional work. As an example, the combined thresholds and water reserve values ensure that where the annual consumptive demand is more than 9% of the annual recharge into a subwatershed, that subwatershed will be assigned a moderate level of hydrologic stress (assuming that lateral inflows are a minor component of Q_{SUPPLY}).

The groundwater stress assessment that used annual average demand indicated that, under current conditions (see **Table 3.12** and **Figure 3.31**), Lynde Creek and Darlington Creek watersheds have moderate stress levels, and the remaining watersheds have low stress levels. The assessment that used monthly demand indicated that Lynde Creek and Darlington Creek watersheds have elevated stress levels, but were still below the monthly threshold values. The maximum stress levels from the two analyses were combined to determine the final stress levels and, again, Lynde Creek and Darlington Creek watersheds had moderate stress levels, while the remaining catchments had low stress levels.

The analyses were repeated using estimates of future demand (see **Table 3.13** and **Figure 3.32**)

This scenario resulted in no changes to the stress assessment levels. Unless significant land-use changes are anticipated, only increased demand is to be considered in the Tier 1 future stress analyses. No change in imperviousness is considered. With development restrictions afforded by the *Oak Ridges Moraine Conservation Act, 2001* and Greenbelt legislation in the study area, future land-use change is not considered to be significant. Future drinking water demand from groundwater sources estimated as increasing by only 3%.

Surface Water Stress Assessment: Current and Future Conditions

As noted, the percent water demand is calculated for each month and the largest monthly stress is compared against the following thresholds.

Surface Water Stress Thresholds Current and Future Scenarios:

Surface Water Quantity Stress Level Assignment	Maximum Monthly % Water Demand
Significant	> 50%
Moderate	20% - 50%
Low	<20 %

These thresholds apply to both current and future scenarios. The resulting surface water stress level assignment is the maximum of the current and future assessment values.

Analysts conducted a surface water stress assessment to calculate percent water demand on a monthly basis. To do this, they used simulated median flows (Q_{P50}) for Q_{SUPPLY} and lower decile flows (Q_{P90}) for $Q_{RESERVE}$. Results showed that Lynde, Goodman, Oshawa, Darlington, and Soper creeks watersheds all had significant stress levels during summer months (**Table 3.14** and **Figure 3.32)**

This is not uncommon in the smaller watersheds in Southern Ontario, because groundwater recharge happens mostly in the spring and fall with little recharge in the summer.

Watershed	Q Recharge (m^3/s)	Q In (m^3/s)	Q Supply (m^3/s)	Q Reserve (m^3/s)	Q Demand Future Conditions (m^3/s)	% Water Demand Future Conditions	Stress Level Future Conditions
Lynde Creek	0.6765	0.2020	0.8785	0.0679	0.0832	10.27	Moderate
Pringle Creek	0.1115	0.0420	0.1535	0.0106	0.0043	2.98	Low
Corbett Creek	0.0463	0.0170	0.0633	0.0041	0.0002	0.29	Low
Goodman Creek	0.0462	0.0150	0.0612	0.0024	0.0009	1.48	Low
Oshawa Creek	0.5892	0.1970	0.7862	0.0650	0.0309	4.29	Low
Harmony Creek	0.1756	0.0810	0.2566	0.0175	0.0099	4.15	Low
Farewell Creek	0.1577	0.1100	0.2677	0.0168	0.0105	4.19	Low
Robinson Creek	0.0193	0.0150	0.0343	0.0004	0.0024	6.93	Low
Tooley Creek	0.0423	0.0200	0.0623	0.0028	0.0039	6.56	Low
Black Creek	0.1243	0.0670	0.1913	0.0106	0.0065	3.57	Low
Darlington Creek	0.0702	0.0220	0.0922	0.0043	0.0154	17.49	Moderate
Bowmanville Creek	0.6149	0.3050	0.9199	0.0816	0.0253	3.02	Low
Westside Creek	0.0180	0.0220	0.0400	0.0013	0.0015	3.77	Low
Soper Creek	0.4152	0.2000	0.6152	0.0407	0.0176	3.07	Low
Bennet Creek	0.0272	0.0210	0.0482	0.0018	0.0018	3.87	Low
Lake Catchments	0.0747	0.1100	0.1847	0.0086	0.0032	1.82	Low

Table 3.13: Groundwater Stress Assessment Summary—Future Conditions

Watershed	Percent Water Demand = $Q_{DEMAND}*100/(Q_{SUPPLY}-Q_{RESERVE})$												Max. Monthly Water Demand (%)	Stress Level
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		
Lynde Creek	11	10	7	2	9	25	123	78	18	8	8	9	123	Significant
Pringle Creek	0	0	0	0	0	0	0	0	0	0	0	0	0	Low
Corbett Creek	0	0	0	0	0	0	0	0	0	0	0	0	0	Low
Goodman Creek	0	0	4	6	12	35	92	135	15	7	0	0	135	Significant
Oshawa Creek	0	0	0	2	5	15	49	58	12	4	1	0	58	Significant
Harmony Creek	0	0	0	0	0	0	0	0	0	0	0	0	0	Low
Farewell Creek	0	0	0	0	0	0	0	0	0	0	0	0	0	Low
Robinson Creek	0	0	0	0	0	0	0	0	0	0	0	0	0	Low
Tooley Creek	0	0	0	0	0	0	0	0	0	0	0	0	0	Low
Black Creek	0	0	0	0	0	0	0	0	0	0	0	0	0	Low
Darlington Creek	0	0	0	9	18	57	185	514	37	16	7	0	514	Significant
Bowmanville Creek	0	0	0	1	1	3	6	5	2	1	0	0	6	Low
Westside Creek	0	0	0	0	0	0	0	0	0	0	0	0	0	Low
Soper Creek	0	0	0	3	18	58	207	286	25	3	1	0	286	Significant
Bennet Creek	0	0	0	0	0	0	0	0	0	0	0	0	0	Low
Lake Catchments			Not Applicable – Demand is only from Lake Ontario											
	Note: Q_{SUPPLY} is the median flow (Q_{P50}) for the month. $Q_{RESERVE}$ is the lower decile flow (Q_{P90}) for the month.													

Table 3.14: Surface Water Stress Assessment—Current and Future Conditions

All other catchments, with the exception of Bowmanville Creek, have low stress levels because they have no surface water demand. Bowmanville Creek has low stress levels because of a relatively high water supply (which included significant lateral groundwater inflow from parts of the Oak Ridges Moraine outside the CLOSPA boundaries) and a relatively low surface water demand compared to the other large catchments.

Analysts used cumulative flow analyses to verify the Tier 1 stress assessment results. These analyses, conducted with long-term data for the two watersheds (Lynde and Oshawa creeks), suggest a decrease in streamflow since the late 1990s. These changes may be due to an increase in watershed stress. However, factors like climate change, changes in stream hydraulics, and an increase in permitted water demand may also be contributing factors. Further investigation is recommended to ascertain potential ecosystem impacts. Given that this is not a drinking water concern, these further analyses should be conducted under other conservation authority watershed protection programs.

There are no operating municipal groundwater supply wells in the CLOSPA watersheds. Therefore, according to the *Technical Rules (2009)*, a Tier 2 stress assessment will not be necessary. The Conservation Authority, however, is committed to protecting watersheds and to improving of their understanding of watersheds, and as such, has developed a list of data and knowledge gaps for their watersheds, see CLOCA Conceptual Water Budget (CLOCA, 2007), and summary table in **Chapter 6: Summary, Conclusions and Next Steps**). The Q_{DEMAND} component of the water budget is key among these. CLOSPA would like a more comprehensive understanding of this part of the water budget, which would include updating permit data and assessing actual water use. Additional surface water gauges and wells have been installed, and with time, their records will allow an improved assessment and understanding of the watersheds.

On a more general level, this study has demonstrated the benefits of an integrated assessment of groundwater and surface water resources. Lateral groundwater movement between catchments is significant, and in particular, lateral inflows from outside the CLOSPA watersheds form an important part of the flow system, regarding both water volume and the protection of significant groundwater recharge areas.

It was particularly notable that particle tracking suggested that groundwater recharge northeast of CLOSPA flows in deep aquifers under Soper Creek before discharging to Bowmanville Creek. The quantitative insight into the variability in groundwater recharge is also important, both on a yearly and monthly basis. Many of the CLOSPA watersheds produce a net outflow of water during the summer months, which indicates that groundwater storage plays a significant role in maintaining groundwater supply. Understanding the role of storage through the use of transient groundwater models should be considered when monitoring groundwater levels over the long term.

All calculations and models used in this study involve simplifications and assumptions. However, the results provide a clear understanding of watershed behaviour on a seasonal and annual basis and of the interaction between the surface water and groundwater systems. The linked groundwater and surface water models developed in the Tier 1 analyses will greatly improve the management of CLOSPA's water resources and the understanding of the hydrology and hydrogeology of the CLOSPA watersheds.

Detailed Monthly Groundwater and Surface Water Stress Assessments are show in **Table D.1** to **Table D.6 (Appendix D).**

3.7.3 Uncertainty

Uncertainty is inherent in the water budget estimation process. The accuracy of estimates relies on the:

- Quantity and quality of the input data (e.g., related to streamflow, climate, groundwater well records);
- Conceptual understanding of the watersheds; and
- Modelling calculation methodology.

Overall, the issues related to uncertainty, as well as data and knowledge gaps, are complex and highly qualitative. There is a degree of uncertainty associated with the water budget analyses. However, it is impossible to provide a quantitative assessment of the level of uncertainty. Rather, one can only say (in very general terms) that the level is low, moderate, or high.

The *Technical Rule, (2009)* suggests that it would be reasonable to expect a low level of uncertainty in areas where data density is high, where hydrogeologic studies have been conducted, or where numerical models have been developed. This study generally satisfies all three criteria. It is recognized, however, that all hydrogeologic analyses have an intrinsic level of uncertainty, because one can never have enough data to fully know how conditions vary in the subsurface.

Development of the ORMGP Core Model entailed a comprehensive process of:

- Collecting and filtering the large amount of water well, monitoring well, and other geologic data;
- Interpreting the geologic logs as best as possible;
- Building a conceptual geologic model;
- Assigning initial estimates of aquifer properties and recharge rates, then refining the estimates through model calibration; and
- performing statistical and sensitivity analyses to demonstrate the validity of the model calibration.

The report by Kassenaar and Wexler (2006) documents the procedures and focuses a great deal of attention, on answering the questions related to assessing model uncertainty.

While these independent review comments increase the comfort level with the results of the modelling process, there is still the recognition that geologic data are always incomplete. It is also acknowledged that the WWIS data that, in a large part, was used to develop the models has a high degree of error and uncertainty. Data obtained from municipal monitoring networks and other high-quality sources have less uncertainty, and have provided useful information in the vicinity of the municipal wellfields. The number of wells and spatial coverage of high-quality data are limited compared to the WWIS data. It is recommended that CLOSPA continue to improve its monitoring network over time and incorporate the available high quality data, especially within the higher stressed watersheds, thereby reducing the level of uncertainty associated with the numerical models.

One task at the end of Tier 1 is to identify and list data gaps that will require further assessment as part of Tier 2. Without operating municipal wells, a Tier 2 assessment will not be necessary in the CLOSPA watersheds. CLOSPA, however, is committed to improving their understanding of the watersheds, and as such has developed a list of data and knowledge gaps for their watersheds (CLOCA, 2007). The most significant of these, from a water budget perspective, is a more comprehensive understanding of the Q_{DEMAND} components of the water budget, including assessing the permits and actual water use.

Computer models are a simplification of the real world, built from limited and potentially erroneous data, so their results should be considered with care and verified independently. It should be recognized that the passage of time affects the information provided. Environmental conditions can change, and computer simulations are based upon information that existed at the time the data was collected, and a model that was formulated accordingly.

As a result of these uncertainties, the assumptions made in the Tier 1 Water Budget tend to overestimate actual stress in order to identify areas where water quantity stress for municipal drinking water supplies may exist. Where potentially stressed watersheds are identified, further analysis is required. The findings from the Tier 1 Water Budget should not be used to make decisions for other water management purposes without consideration of the objectives, scale and assumptions of the Tier 1 study as well as inclusion of site-specific data where available. Consultation with the conservation authority technical staff is also advised.

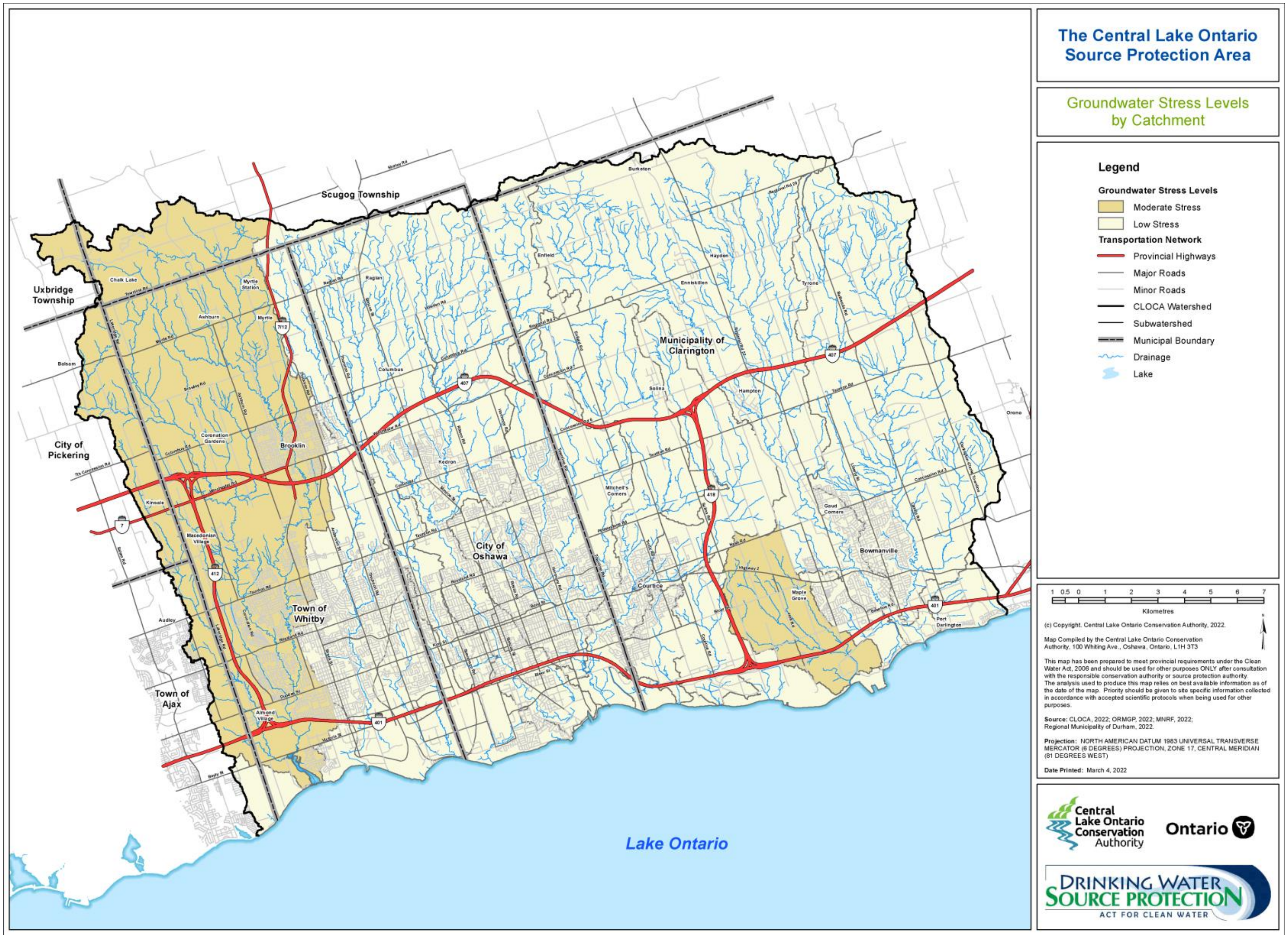
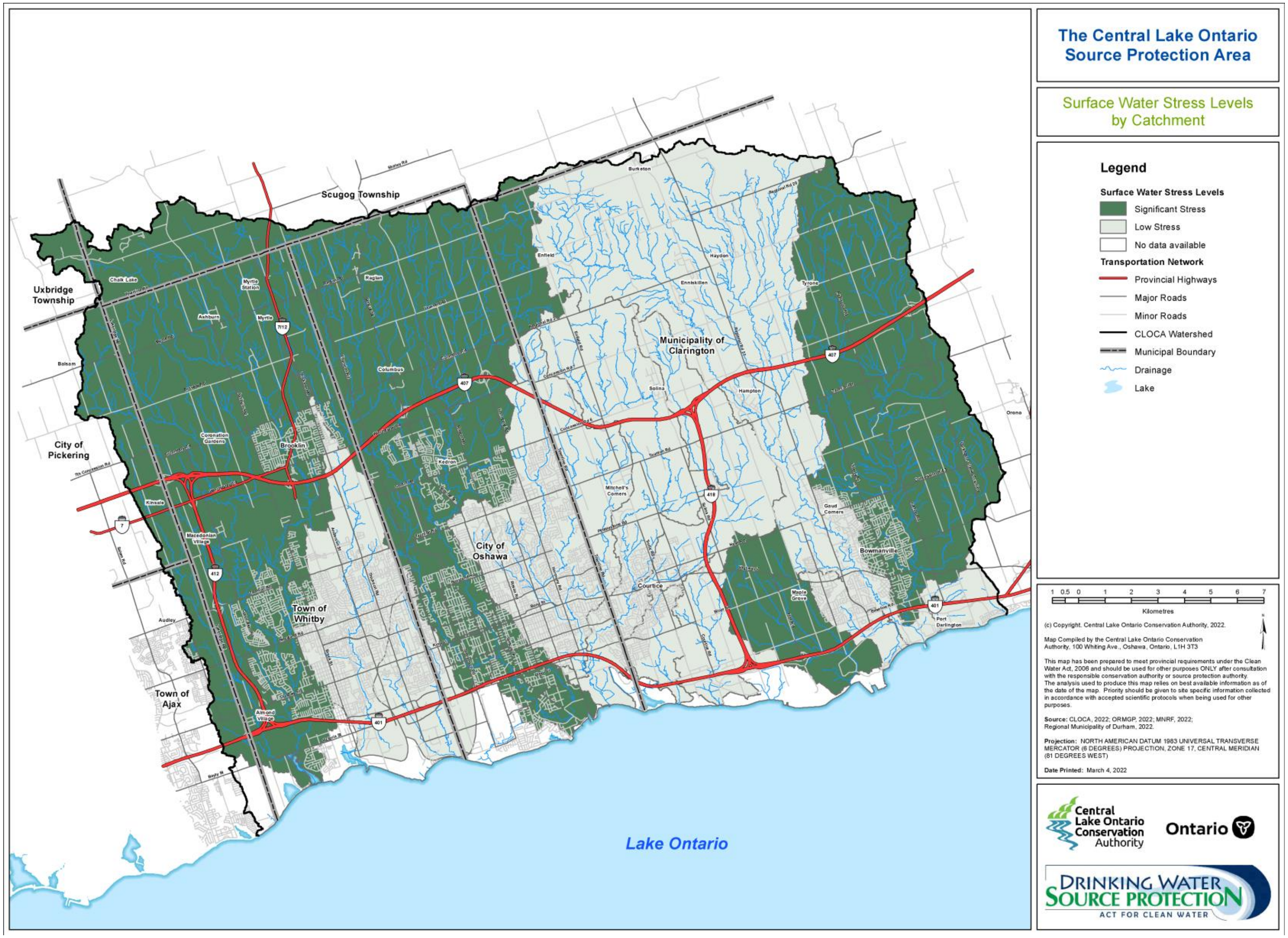


Figure 3.31: Groundwater Stress Levels by Catchment (Current and Future Conditions)



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Map Compiled by the Central Lake Ontario Conservation Authority, 100 Whiting Ave., Oshawa, Ontario, L1H 3T3

This map has been prepared to meet provincial requirements under the Clean Water Act, 2006 and should be used for other purposes ONLY after consultation with the responsible conservation authority or source protection authority. The analysis used to produce this map relies on best available information as of the date of the map. Priority should be given to site specific information collected in accordance with accepted scientific protocols when being used for other purposes.

Source: CLOCA, 2022; ORMGP, 2022; MNRF, 2022; Regional Municipality of Durham, 2022.

Projection: NORTH AMERICAN DATUM 1983 UNIVERSAL TRANSVERSE MERCATOR (6 DEGREES) PROJECTION, ZONE 17, CENTRAL MERIDIAN (81 DEGREES WEST)

Date Printed: March 4, 2022

Figure 3.32: Surface Water Stress Levels by Catchment (Current and Future Conditions)

3.8 TIER 3 WATER BUDGET PROCESS

3.8.1 Overview

The water budget analyses were concluded at a Tier 1 level as part of the 2012 CLOSPA Assessment Report submission with no municipal groundwater systems located within CLOSPA's jurisdiction. A Tier 3 analysis conducted in York Region where stressed watersheds with municipal groundwater supplies exist (for quantity), however, shows impacted areas that extend into a small part of CLOSPA's jurisdiction where source protection plan water quantity policies will apply. The following Tier 3 discussion is thus presented here as part of updates to the CLOSPA Assessment Report and is consistent with the Tier 3 discussion in the TRSPA updated report.

Note that the contents of this section have been excerpted from: *Tier 3 Water Budget and Local Area Risk Assessment for the Region of York Municipal Systems* prepared for the Regional Municipality of York in November, 2013 (EarthFx Inc., 2013a). This foundation report contains additional details regarding the methodology, data, mapping, and risk assessment process and has been extensively peer reviewed by a panel of provincial, municipal, Conservation Authority, and outside experts.

The overall objective of a Tier 3 Water Budget Assessment is to determine whether a municipality is able to meet its planned water quantity requirements, considering increased municipal water demand, future land development, drought conditions, and other water uses. The Tier 3 Water Budget Assessment is required to:

- Estimate the likelihood that a municipal drinking water source is able to sustain its allocated (existing plus committed or planned) pumping rates, while maintaining the requirements of other water uses (e.g. ecological requirements and other water takings); and
- Identify water quantity threats that may influence a municipality's ability to meet their allocated and planned pumping rates.

The Technical Rules requires that Tier 3 Water Budget Assessments be completed in subwatersheds where the groundwater and/or surface water are sources for municipal drinking water supplies that show moderate or significant water quantity stress. Based on the results of the TRSPA Tier 2 water budget study, moderate groundwater quantity stresses were identified in the Little Rouge (RO02) and Stouffville/Reesor Creek (DU06) subwatersheds. The Region of York operates supply wells in both subwatersheds, while the Region of Durham operates supply wells in the Stouffville/Reesor Creek subwatershed. The following sections describe the findings of the Tier 3 Water Budget analyses for municipal wells located in both subwatersheds. Note that other municipal wells are present within the study area, but were not the focus of the Tier 3 assessment.

The two prescribed activities which are drinking water quantity threats are defined in the Ontario Regulation 287/07 under the *Clean Water Act, 2006*. These activities are:

- Any consumptive use of water (demand for water); or
- Any activity that reduces recharge to an aquifer.

The information used to assess these water quantity threats include detailed characterization of current and future municipal and non-municipal consumptive uses (demand), the amount of water available for use in the aquifer or surface water body, as well as potential reduction in recharge from future changes in land use based on the current Official Plan and zoning.

The two major components of a Tier 3 Water Budget Assessment are:

1. The Tier 3 Water Budget Model - Developed using numerical groundwater and surface water models, which are used to evaluate localized hydrologic or hydrogeologic conditions at a water supply well or surface water intake. The Tier 3 Water Budget represents improvements over the Tier 1 and 2 Water Budgets in terms of the model simulation and representation of groundwater movement between and across subwatershed boundaries. This is made possible by collecting and assessing data that reflects in the surface flow system, and in the subsurface characterization in the study area, notably in the vicinity of municipal wellheads and surface water intakes.
2. The Local Area Risk Assessment - The evaluation of a series of risk scenarios within the *Local Areas*. Local Areas are the vulnerable areas that are delineated to protect the quantity of water required by a municipality to meet their current or future water needs. The Tier 3 Water Budget Model was used to delineate the Local Area for municipal groundwater wells in the Study Area.

Local Areas: For a surface water system, it is the drainage area that contributes surface water to an intake, or an area that contributes groundwater recharge to the drainage area. For a well, it is the area created by combining the cone of influence of the well; the cones of influence resulting from other water takings where those cones of influence intersect that of the well; and the areas where a reduction in recharge would have a measurable impact on the cone of influence of the well.

Once the Tier 3 models have been calibrated and validated, the Local Areas are delineated and Local Area Risk Assessments are undertaken within these areas. Part IX.1 to Part IX.4 of the *Technical Rules* (MOE, 2009) and Ministries of the Environment and of Natural Resources Bulletin (MOE and MNR, 2010) set the requirements and deliverables for the risk assessment process and enumeration of moderate and significant drinking water quantity threats. The primary steps in this process are:

1. Identification of the Study Area and model domain through the evaluation of the interaction of the cones of influence of municipal wells and other water users, with a threshold set based on natural water level fluctuations in the aquifer(s) involved.
2. Municipal Water Use Assessment - detailed characterization of wells and intakes, specifically existing, committed, and planned demand as well as low water operating constraints.
3. Other Water Use Assessment – identification of other uses that might be influenced by municipal pumping and identify water quantity constraints according to those other uses.
4. Characterization of Future Land Use - comparison of Official Plans with current land use and incorporates assumptions relating to additional imperviousness from future developments.
5. Development and calibration of a Tier 3 Water Budget Model – Numerical surface water and groundwater models created to simulate the movement and extraction of surface water and groundwater in the Study Area.
6. Refinement of the water budget parameters within the modelled area.
7. Delineation of vulnerable areas for water quantity. These areas are delineated using the Tier 3 Water Budget Model.
8. Evaluation of the Risk Scenarios within the Local Area to establish the overall Risk Level for each of the vulnerable areas for water quantity. The risk ranking (low, moderate, or significant) is assigned to each of the vulnerable areas independently based on the results of the scenarios.
9. Enumeration of Drinking Water Quantity Threats and the associated risk level for the threat activity (based on the risk level assigned to the *Local Area*).

10. Confirmation of Significant Groundwater Recharge Areas from the Tier 1 and 2 (conducted for York Region) studies.

The Tier 3 Water Budget represents improvements to the Tier 1 and Tier 2 Water Budgets in terms of the model simulation and more accurate estimates of groundwater movement between and across sub watershed boundaries. This is made possible by refinements in the geological conceptualization and subsurface characterization of the Study Area, particularly in the vicinity of municipal wellheads. The model is used to map the area around each well or group of wells where the water comes from to supply that well(s) – called the Local Area.

Wellhead Protection Areas – Quantity (WHPA-Qs) are the vulnerable areas that are considered as most important to protect the quantity of water required by a municipality to meet their current or future water needs. There are two types of WHPA-Qs:

1. The *cone of influence* of the municipal supply wells (WHPA-Q1); and
2. The areas where a reduction in recharge would have a measurable impact on the cone of influence of the well(s) (WHPA-Q2).

Cone of Influence: For one or more wells that draw water from an aquifer, this is the area within the depression created in the water table or potentiometric surface when the wells are pumped at a rate equivalent to their allocated plus planned quantities of water.

The combination of the WHPA-Q1 and the WHPA-Q2 are called a ***Local Area***. The drinking water threats within the *Local Area* are classified as low, moderate or significant depending on the risk level assigned to the *Local Area*. If the risk level is significant, then all consumptive water uses and activities which reduce recharge are classified as significant drinking water threats. If the risk level is moderate, current consumptive water uses and recharge reductions are moderate threats, while future such activities would be significant threats.

Where the risk scenarios identify the potential that a well will not be able to supply its allocated or planned supply, the Local Area is assigned a 'moderate' or 'significant' water quantity risk level. Once the risk level is assigned to the *Local Area*, any activity within the Local Area, that reduces recharge to the aquifer, or that removes water from an aquifer without returning it to the same aquifer (demand) is identified as being a drinking water quantity threat.

The CTC SPC is required to develop policies in the Source Protection Plan to manage or avoid significant drinking water quantity threats, and may develop policies for moderate or low water quantity threats.

3.8.2 Tier 3 Methodology

Study Area and Model Domain

The Study Area model domain for this Tier 3 study considered the surface water and groundwater divides as well as the geographic distribution of municipal water supplies, radii of influence of the wells, and hydrogeologic boundaries (i.e., Lake Simcoe and Lake Ontario). With the large withdrawals from confined aquifers such as the Yonge Street Aquifer combined with the relative proximity of other municipal wells in Simcoe, York, Peel, and Durham regions, a large model domain was required to fully encompass the WHPA Q1 and Q2 areas. Another consideration was physical extent of the underlying Tier 1 and 2 models. Normally, a Tier 3 model domain is smaller than the previous tiers, but in this case it was larger. In particular, underlying model data were not available east of Uxbridge and northwest of Bradford.

Municipal Water Use Characterization

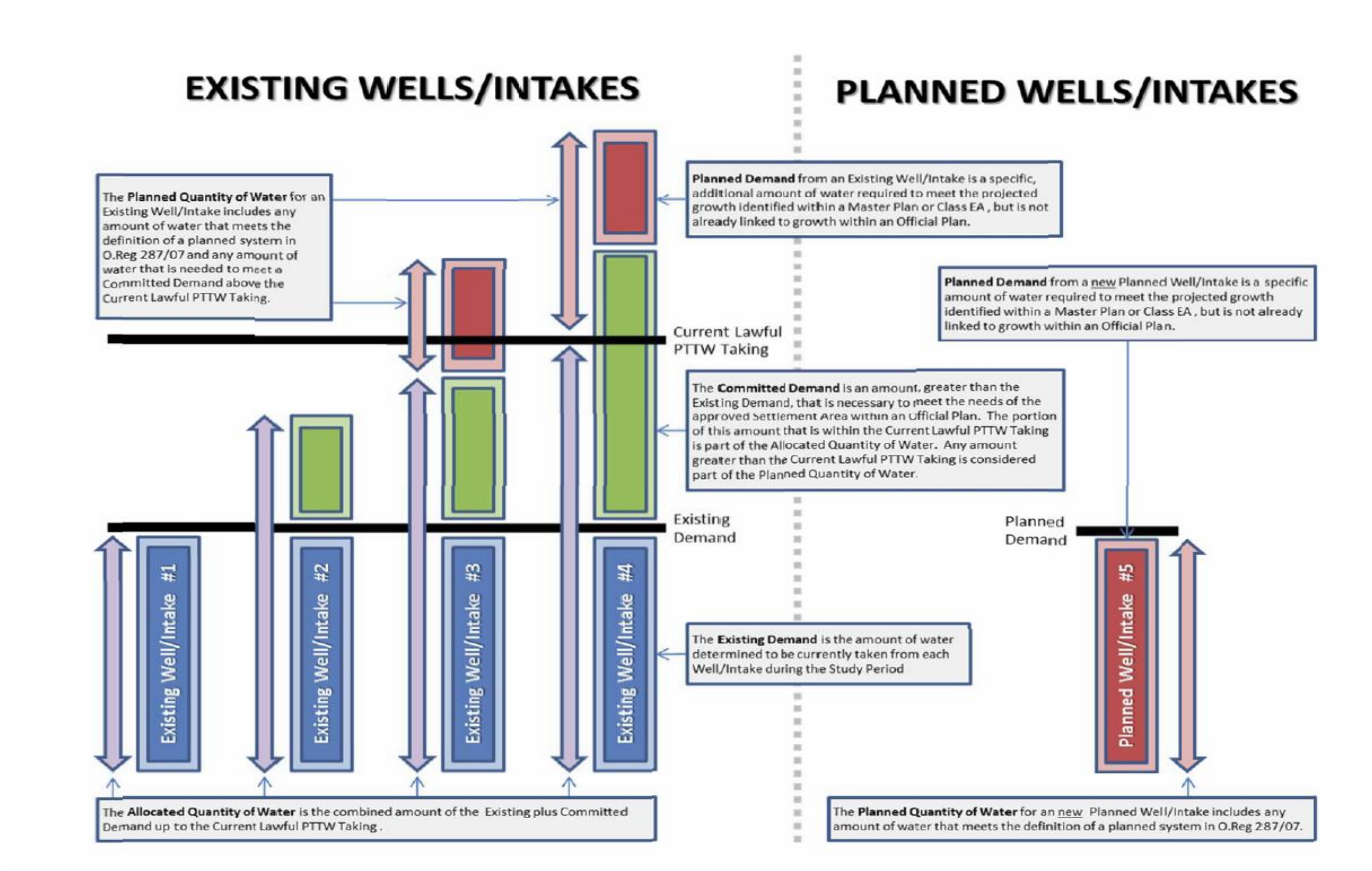
To characterize water demand in the study area, the following data were collected and assessed for each municipal well:

- Permit Details - where possible, original copies of Permits to Take Water was compiled;
- Historical pumping records and water level monitoring data;
- Well completion details - open hole depth, well screen top and bottom depth, position of well screen with respect to the aquifer, casing and screen construction, casing survey data;
- Maintenance records - typical pre- and post-rehabilitation well yields, rehabilitation frequency;
- Safe Water Level at each well or intake was estimated or calculated based on the minimum groundwater or surface water elevation that can be sustained while pumping at the intake;
- Maximum Yield or Sustainable Yield Estimates were estimated for each well (may be less than the permitted rates); and
- Operational procedure and maintenance information.

The *Technical Rules* require that the existing, committed and planned quantity of water be estimated for each existing and planned groundwater well or surface water intake. These terms were first defined through the *CWA, 2006*, and later refined through Interim Guidance issued by the MOE in December 2013:

- **Existing Demand** - amount of water determined to be currently taken from each well / intake. For this study, existing demand has been estimated as the average annual pumping during the study year (2008). Maximum monthly and maximum daily demands are also estimated based on historical trends.
- **Committed Demand** - an amount, greater than the existing demand that is necessary to meet the needs of an approved Settlement Area within an Official Plan. The portion of this amount that is within the current lawful PTTW taking is part of the allocated quantity of water. Any amount of usage greater than the current lawful PTTW taking is considered part of the Planned Quantity of Water.
- **Planned Demand** – a specific additional amount of water required to meet the projected growth identified within a Master Plan or Class EA, but is not already linked to growth within an Official Plan.
- **Allocated Quantity** - in respect of an existing surface water intake or an existing well, the existing demand of the intake or well plus any additional quantity of water that would have to be taken by the intake or well to meet its committed demand, up to the maximum quantity of water that can lawfully be taken by the intake or well under the current PTTW.
- **Planned Quantity** - (a) in respect of an existing surface water intake or existing well, any amount of water that meets the definition of a planned system in O.Reg. 287/07 and any amount of water that is needed to meet a committed demand above the maximum quantity of water that can lawfully be taken by the intake or well under the current PTTW. (b) in respect of a new planned surface water intake or planned well, any amount of water that meets the definition of a planned system in O.Reg. 287/07.

These parameters are shown graphically on **Figure 3.33**. Estimating consumptive water use under existing demand and under allocated demand (existing plus committed plus planned demand) pumping conditions is a key element of the Tier 3 Water Budget Assessment. The term “consumptive” is used to describe the portion of water taken from a surface or groundwater source that is not returned directly to that source. While the focus of the risk assessment is on evaluating the sustainability of the municipal wells in catchments identified as potentially stressed in the Tier 2 assessment, water demand estimates from all surface and groundwater takings across the entire model area has been compiled and simulated in the Tier 3 model. None of the municipal wells in the study area located in CLOSPA's jurisdiction and thus no risk assessment is required.



The **Planned Quantity of Water** for an Existing Well/Intake includes any amount of water that meets the definition of a planned system in O.Reg 287/07 and any amount of water that is needed to meet a Committed Demand above the Current Lawful PTTW Taking.

Planned Demand from an Existing Well/Intake is a specific, additional amount of water required to meet the projected growth identified within a Master Plan or Class EA , but is not already linked to growth within an Official Plan.

Planned Demand from a new Planned Well/Intake is a specific amount of water required to meet the projected growth identified within a Master Plan or Class EA , but is not already linked to growth within an Official Plan.

The **Committed Demand** is an amount, greater than the Existing Demand, that is necessary to meet the needs of the approved Settlement Area within an Official Plan. The portion of this amount that is within the Current Lawful PTTW Taking is part of the Allocated Quantity of Water. Any amount greater than the Current Lawful PTTW Taking is considered part of the Planned Quantity of Water.

The **Existing Demand** is the amount of water determined to be currently taken from each Well/Intake during the Study Period

The **Allocated Quantity of Water** is the combined amount of the Existing plus Committed Demand up to the Current Lawful PTTW Taking.

The **Planned Quantity of Water** for an new Planned Well/Intake includes any amount of water that meets the definition of a planned system in O.Reg 287/07.

Figure 3.33: Characterization of Existing and Planned Systems

A key component of the municipal water use assessment was the identification of the “safe additional drawdown” for the municipal wells. This parameter is defined as the additional depth that the water level within a pumping well could fall and still maintain that well’s allocated pumping rate. The additional drawdown is calculated by considering the amount of drawdown available beyond the drawdown created by the existing conditions and pumping rate (herein referred to as the ‘baseline’ level).

A key aspect of the determination of the “safe additional drawdown” is whether the constraint on the well’s operation is related to either in-well conditions (i.e., related to a pump or well screen elevation) or to in-aquifer conditions (i.e., related to prevent dewatering of a confined aquifer). Another example of an in-well limit might be, for example, a change in casing diameter that prevents the pump from being lowered.

To determine the safe additional drawdowns at each well, the following components were evaluated for each of the municipal wells in the York Tier 3 assessment area:

1. **Existing (baseline) pumped water elevations.** The baseline water levels are based on the average annual observed water levels for the period of normal pumping operations during the study period (2010 to 2011). The existing pumped water elevations (either in-well or in-aquifer) are considered to represent long-term average water levels under current pumping conditions.
2. **Safe Water Level elevations.** The Safe Water Level is the lowermost elevation within the pumping well (or aquifer) to which water levels can be depressed. This elevation is dependent upon a number of factors (e.g., well screen elevation, pump intake setting, or top of confined aquifer) and is evaluated on a well-by-well basis.
3. **Estimated Non-Linear Head Losses and Convergent Head Loss Corrections.** Non-linear head loss refers to drawdown in the pumped well caused by turbulent flow in the well casing, resulting in an increase above the predicted theoretical drawdown. Convergent head loss corrections are applied to account for the difference between the simulated average water level in a model cell and that in the pumping well.

In summary, the “safe additional drawdown”, is selected based on the lesser of:

a) Additional available drawdown in the well, as determined by the difference between the operating level in the well (during the study period) and the top of the well screen. (This is based on the assumption that water levels should not be drawn down into the well screen during operations.)

or

b) Additional available drawdown in the aquifer nearby the well, as determined by the difference between the aquifer water levels (during the study period) and the top of the aquifer. (This is based on the assumption that the confined aquifer should not be dewatered in the vicinity of the well.

If the safe additional drawdown is selected based on *in-well* conditions, the Safe Water Level threshold is defined by the lower limit of the in-well condition (e.g., the top of casing). If the safe additional drawdown is based on *in-aquifer* conditions, the Safe Water Level is based on the lower limit of the in-aquifer threshold (e.g. the top of the aquifer).

A well is considered to be at risk if the “Risk Scenario Minimum Simulated Water Level” (i.e., the lowest predicted water level in the well under various Tier 3 assessment scenarios) is below the Safe Water Level.

Identification of Other Water Uses

One of the goals of the Tier 3 assessment process is to develop a better understanding of the effects of the municipal wells on other water uses. Specifically, the analysis must consider whether the allocated municipal water demand can be met while maintaining the requirements of other water uses in the area. These water uses, as defined in the Clean Water Act, include:

- Municipal wells outside of stressed subwatersheds (RO02 and DU06);
- Other water takings including agricultural, commercial and industrial water takings;
- Waste water assimilation;
- Navigation;
- Recreation;
- Aquatic habitat; and
- Provincially significant wetlands.

Municipal wells outside of subwatersheds identified as stressed in the Tier 2 analysis have the potential to be affected by wells inside the stressed subwatersheds. Therefore, these wells were active in the modelling process, but were not subjected to the safe water level threshold evaluation.

Extensive data compilation and analysis of all non-municipal water use (including agricultural, commercial and industrial, and recreational water takings) was included in Section 9 and Appendix E of the Development and Calibration Report (Earthfx, 2013b). Recreational water use for golf courses, snowmaking, and recreational fishing from stocked fish ponds were identified along with the other permitted takings. While no specific guidelines are provided for the assessment of risks related to “other takings”, an incremental drawdown threshold of 1-m was selected based on the natural fluctuations observed in the study area.

Wastewater assimilation requirements were considered for all sewage treatment plant discharges to watercourses. Each Environmental Compliance Approval within the model domain was reviewed to determine if any low flow minimums were specified.

The model domain was assessed for the presence of navigable waterways that could have minimum water flow requirements.

There are no takings active in the York Tier 3 Model used to represent water demands related to maintaining aquatic habitat. Instead, the Technical Rules specify that impacts to aquatic habitat be addressed in terms of “reduction to the flow or level of water that constitutes an unacceptable impact to other water uses”.

The major watersheds, streams, lakes, and wetlands which drain the study area were mapped and classified using the latest Ontario Ministry of Natural Resources (MNR) Version 2 stream coverage. A total of 4450 km of mapped streams are found within the study area, and each stream reach was represented in the flow model. Streamflow data for the study area were obtained from the Water Survey of Canada, a division of Meteorological Service of Canada, Environment Canada. There are approximately 75 active and inactive (historical) stream gauges proximal to the study area. A total of 23 Water Survey of Canada gauges within the study area were selected for use during model calibration based on their period of record, data quality, and catchment size (between 10 and 800 km^2). Daily mean stream discharge data at these stations were employed to calibrate the integrated surface water/groundwater model.

Groundwater exchange between the aquifer systems and each stream reach was computed by the SFR2 module in the York Tier 3 model. The rate of groundwater discharge to a stream reach is proportional to the difference in head between the aquifer and the water level (stage) in the stream. Unlike the earlier

Core Model (Kassenaar and Wexler, 2006), which used a fixed estimate of stream stage based on the DEM, the Tier 3 model stage in the stream is calculated based on the baseflow accumulated (routed) from all upstream tributaries.

Characterization of Future Land Use

The type of land cover has a strong influence on the water balance. Interception and evapotranspiration are directly controlled by vegetation type and cover density, which, in turn, affect runoff and infiltration rates. Conversion of natural or agricultural land forms to urban types of land use (e.g., residential, commercial, industrial, or institutional) often increases the amount of impervious cover (e.g., roofs and pavement) leading to increased evaporation from depression storage and increased overland runoff, reducing recharge potential. While at the same time, evapotranspiration and evaporation from interception and soil zone storage are decreased as the vegetative and pervious cover is changed, increasing the recharge potential. These competing factors make assessing the net impact to groundwater recharge more difficult to predict.

The Tier 3 analysis characterized projected land use changes following the following steps from the MNR Water Budget Guide:

1. Existing land use was mapped based on data from the municipalities.
2. Projected land use was mapped based on approved Official Plans.
3. Areas of land use change were identified by comparing projected to existing land use.
4. The projected change in imperviousness for each area of land use change was mapped based on assumptions relating to the imperviousness of each land use category.
5. A map of projected change in imperviousness was generated for areas with projected land use alterations.

The MNR Water Budget Guide states that potential impacts of stormwater management and low impact development measures are not accounted for when estimating imperviousness changes for future land use. Additionally, future non-municipal water demands due to land use change (e.g., increases in self-supplied domestic use) should not be speculated.

Detailed land use and land cover data for entire study area were provided by the municipalities, MNR, and the Conservation Authorities. This information was used to develop the PRMS recharge model inputs, as descried in detail in Chapters 8 and 12 of the Model Development and Calibration Report (see Earthfx, 2013b). Official land use plans for the York, Peel, Durham and the Bradford regions were compiled. These land use plans include future urban settlement boundaries, however, specific land use within the boundaries is not known at this time. A methodology was developed to reasonably adjust model inputs to represent future conditions.

Model Development and Calibration

The Tier 3 Water Budget includes key enhancements to the Tier 1 and 2 numerical models. These include improvements in the simulation of the surface flow system, and in the geological conceptualization of the area, particularly in proximity to municipal wellheads. These updates enabled a more localized representation of the subsurface and its flow systems near the wellheads as compared to the regional-scale representation created for the previous assessments.

The GSFLOW code used for this project is based on the integration of two main “sub-models” used to simulate the surface water and groundwater flow processes. Within each of these submodels additional processes are represented, including snow pack accumulation and snowmelt, unsaturated flow, evapotranspiration, etc. All of these processes are represented in a “distributed” manner, i.e., the study area is subdivided into small representative blocks, or cells, each having unique properties and characteristics.

For the York Tier 3 Water Budget, the processes and unique response of each cell was simulated as well as the interaction between cells and the collective response of all the cells in the model area. The result was a spatially-varied response to the inputs (e.g., precipitation, temperature, and solar radiation) and withdrawals (e.g., well pumping and groundwater discharge to streams).

The GSFLOW sub-models covered the following main processes:

1. Surface water processes including climate, vegetation uptake, land use, soils and flow in streams, wetlands, and riparian areas; and
2. Sub-surface processes, including unsaturated flow and saturated groundwater flow.

The Tier 1 and 2 water budget assessments used separate hydrologic and groundwater flow models that were manually integrated and analyzed. In particular, outputs from the hydrologic model provided the estimate of groundwater recharge to the groundwater model while the groundwater model provided estimates of cross-watershed flows needed to be added to the simulated flows at the catchment outlet. The GSFLOW model used in this study, on the other hand, was a fully-integrated groundwater and surface water model, which modelled the surficial and sub-surficial processes simultaneously, allowing for the responses from each sub-model to interact as they do naturally. This provides for a wide range of modelling improvements and feedback mechanisms that were beyond the capabilities of the loosely-coupled approach. This integrated approach proved particularly necessary in this study because of the significant interactions between the surface water and groundwater processes.

For example, wetlands were represented as one-way outflow drains in the Tier 1 and 2 models. This means that wetlands are always assumed to be points of groundwater discharge, even though they can seasonally serve as groundwater recharge points under varying hydrologic conditions. With a fully-integrated approach, no limiting assumptions about wetland function are needed, as water movement into or out of the wetland is simulated based on the actual flow and head-dependant leakage conditions on each day in the simulation period.

The surface water portion of GSFLOW is based on the Precipitation-Runoff Modelling System (PRMS) developed by the USGS (Leavesley *et al.*, 1983). PRMS itself is composed of many hydrologic process component models, including:

1. A climate sub-model that distributes precipitation types and determines potential evapotranspiration rates based on temperature and solar radiation data;
2. An energy-balance snowmelt model that simulates snowpack dynamics and accounts for snowmelt quantities;
3. A vegetation canopy interception model;
4. A soil moisture accounting algorithm that computes runoff, storage, actual evapotranspiration (AET), and recharge; and
5. An overland flow module that routes runoff downslope until a stream feature or water body is reached.

The GSFLOW version of PRMS also improves on the original PRMS code with the inclusion of a cascading overland flow algorithm that routes surface runoff along flow pathways toward streams and lakes, thus allowing for run-on and re-infiltration; and the ability to communicate with the groundwater model to account for water table feedback mechanisms that may reject potential recharge and add groundwater discharge to the surface water system.

Groundwater processes in GSFLOW are simulated by MODFLOW-NWT (Niswonger, *et al*., 2011), a well-established groundwater modelling code. MODFLOW-NWT's sub-models include saturated and unsaturated flow processes, lake and wetland water balance and groundwater interaction, and streamflow routing. Lake stage is determined based on stage/area/volume relationships for each water body. The MODFLOW-NWT model is specifically designed to represent complex, fluctuating, shallow water-table conditions that are essential to properly simulating interaction between the surface and subsurface.

Calibration targets for the Tier 3 GSFLOW model included flows recorded at streamflow gauges, and continuous water-level data from PGMN and York Region monitoring wells. Other secondary sources included MOE WWIS static water levels and wetland mapping. The integrated modelling approach has the benefit that the model must be calibrated to both groundwater and surface water data simultaneously; thus reducing the level of uncertainty typically associated with separate models that make simplifying assumptions regarding the processes not explicitly represented. The integrated calibration also means that artificial or empirical data processing techniques such as baseflow separation are not needed because the model is calibrated to total measured flow at the stream gauges.

To facilitate model construction and evaluation, GSFLOW's sub-models can be run independently during calibration, scenario or sensitivity analysis. For example, the PRMS model was first used to provide an estimate of long-term average recharge. This recharge estimate was then used to develop an initial long-term steady-state groundwater flow model calibration. Once the long-term average sub-models were developed, the final integrated calibration was completed and tested against the more detailed transient water levels and streamflow discharge measurements.

All municipal and non-municipal groundwater takings were represented in the model on a daily basis (rather than monthly) using reported information and consumptive use factors. The surface water model accounted for all surface takings in the study area. The results of model calibration and the insights gained were presented in detail in Earthfx, 2013b.

The GSFLOW code can produce maps showing the distribution of model outputs on a daily basis. Outputs include groundwater levels, groundwater discharge to streams, the separate components of overland runoff, potential and actual evapotranspiration, snow pack, soil moisture, etc. for every model cell in the study area.

Water Budget Parameter Refinement

The Tier 3 GSFLOW model produces estimates of model outputs on a daily basis. Outputs include groundwater levels, groundwater discharge to streams, the separate components of overland runoff, potential and actual evapotranspiration, snow pack, soil moisture, etc. for every model cell in the study area.

Maps of each parameter, averaged over the modelling period are provided in the foundation report (Earthfx, 2013a).

Delineation of Vulnerable Areas for Water Quantity

The WHPA-Q1 is defined in the Technical Rules for the Assessment Report (MOE, 2009), as:

> "*…the combined area that is the cone of influence of the [municipal] well and the whole of the cones of influence of all other [municipal and non-municipal] wells that intersect that area*".

The cone of influence for a single well can be determined by subtracting the simulated steady-state potentiometric heads (heads) in the production aquifer under pumping conditions from the simulated steady-state heads with no pumping. The difference in heads is referred to as the well drawdown. To determine the combined cones of influence needed to define the WHPA-Q1, the simulated steady-state heads in the production aquifer with all wells pumping were subtracted from the simulated steady-state heads with no wells pumping.

As per the Technical Rules, the model used to prepare the water budget analyses was used to conduct the simulations needed to delineate WHPA-Q1 and WHPA-Q2 areas. As with Scenarios C and G, the WHPA-Q1 analysis is completed using the steady-state groundwater model and a long-term estimate of average groundwater recharge. It should be noted that under the *steady state condition*s, many of the dynamic surface water processes, such as rainfall/runoff partitioning, cascading overland flow, and groundwater feedback (rejected recharge) are not active and only the baseflow (groundwater discharge) component of the streamflow is routed through the stream network. Groundwater recharge rates used in the steady-state model simulation were determined through a long-term (20-year) simulation with the PRMS sub-model assuming current land use. The model period was from October 1986 to September 2009. The first three years were assumed to be affected by model start up and were not used in the averaging.

Steady-State Condition: assumes that the amount of water stored in surface water and subsurface reservoirs will vary negligibly over the time scale considered.

The rates of pumping used in the WHPA-Q1 simulations were based on the allocated quantities of water (existing plus committed plus planned municipal demands). In theory, the cone of influence of a well will grow until inflows into the drawdown cone (i.e., recharge, stream leakage, or inflows from natural hydrologic boundaries such as Lake Simcoe) balance the pumping withdrawals. However, because the drawdown decreases exponentially away from the pumping centre, the drawdown at distance may not be measurable and/or may not be distinguishable from natural variation due to precipitation events and other water takings. Accordingly, a drawdown threshold of 1.0 m was selected as the practical limit of the cone of influence for the York Tier 3 WHPA-Q1 delineation. This threshold value was established by a thorough review of seasonal variations in monitoring wells with continuous data. (Earthfx Inc., 2011).

The WHPA-Q2 is defined in the Technical Rules for the Assessment Report (MOE, 2009) as the WHPA-Q1 plus:

> *"...any area where a future reduction in recharge would significantly impact that area".*

This statement has been interpreted in the MNR Water Budget Guide to mean that the WHPA-Q2 includes the map outline of future land developments, identified in a municipality's Official Plan (OP), that are:

1. outside of or straddle the WHPA-Q1 boundary; and
2. could decrease natural groundwater recharge to a point that it would have a measurable impact on water levels at the municipal pumping wells (MNR, 2011).

For new land developments that straddle the WHPA-Q1 boundary, the WHPA-Q1 would expand to include the outline of the proposed development. For land developments outside the WHPA-Q1, separate WHPA-Q2 areas would be delineated.

The impact of recharge reduction was determined by subtracting the simulated steady-state heads with the adjusted recharge rate for the new land development areas from the simulated steady-state heads using recharge based on current land use. Adjusted groundwater recharge rates were determined through long-term (20-year) simulations with the PRMS sub-model using the percent imperviousness and other changes in vegetative cover properties associated with the new land developments. A drawdown threshold of 1.0 m was selected as the practical limit for the "measurable" impact at nearby municipal wells. It should be noted that this simulation is similar to conditions under Scenario G (1), except those developments within the WHPA-Q1 area were not simulated.

Risk Assessment Scenario Evaluation
The risk assessment scenarios include ten scenarios, as described in **Table 3.15**. These scenarios are based on the requirements outlined in the ***Technical Bulletin: Part IX Local Area Risk Level***. They include both existing and future land use, average and drought climate; combined with existing and committed municipal water demand. Note that Scenarios A, B, E, and F relate to surface water systems, and were therefore not considered in York (groundwater supply stresses only).

Scenario	Time Period	Model Scenario Details			
		Land Cover	Municipal Pumping	Model Simulation	
C	Period for which climate and stream flow data are available for the Local Area (1987-2009)	Existing	Existing	Steady-state, Average Annual Recharge	
D	10 year drought period (1956-1966)	Existing	Existing	Transient (1960-2006); Monthly recharge rates	
G(1)	Period for which climate and stream flow data are available for the Local Area (1987-2009)	Projected Demand and Reduction in Recharge	Committed	Groundwater Recharge Reduction and Increase in Demand	Steady-state, Average Annual Recharge
G(2)		Existing	Committed	Groundwater Discharge Reduction from Increase in Demand	
G(3)		Recharge Reduction	Existing	Groundwater Recharge Reduction from Land Cover	
G(4)		Existing	Committed	Per (G)2; Impacts on other users	
G(5)		Existing	Planned	Per (G)2; Impacts on other users	
H(1)	10 year drought period (1956-1966)	Projected Demand and Reduction in Recharge	Committed	Groundwater Recharge Reduction and Increase in Demand	Transient (1960-2006); Monthly recharge rates
H(2)		Existing	Committed	Groundwater Discharge Reduction from Increase in Demand	
H(3)		Recharge Reduction	Existing	Groundwater Discharge Reduction from Increase in Demand	

Table 3.15: Risk Assessment Scenarios for the York Tier 3 Water Budget

The risk scenarios used the calibrated surface water and groundwater flow models to estimate changes in water levels in the municipal supply aquifers, and to estimate the impacts to groundwater discharge and base flow to streams under average and drought climate conditions. Note that most of the scenarios were evaluated using the steady-state model, but the 10-year drought scenarios (D and H) required transient simulations.

Cell-by-cell discharge was used to identify stream reaches where there is significant groundwater discharge. The SFR2 module model accumulates the cell-by-cell groundwater discharge and routes it downstream, providing an estimate of baseflow at any point in the network. The accumulated baseflow can, if a downward gradient exists between the stream and the aquifer, leak back into the aquifer. Changes in pumping can lower aquifer levels, induce leakage, and reduce baseflow in the stream. The change in the accumulated baseflow in the stream was selected as the best means to estimate the impact on aquatic habitat.

Where the scenarios identify the potential that a well will not be able to supply their allocated rates, the Local Area is assigned a 'moderate' or 'significant' water quantity risk level. Once the risk level is assigned to the Local Area, activities within the Local Area that reduce recharge to the aquifer, or that removes water from an aquifer without returning it to the same aquifer (consumptive use), are enumerated as drinking water threats.

Part IX.1 to Part IX.4 of the *Technical Rules* and MOE and Ministry of Natural Resources Bulletin (MOE and MNR, 2010) set the requirements and deliverables for the Local Area Assessment and Risk Level. It is important to note that the assignment of a significant risk to a local area, based on the evaluated impacts to "other water uses" using the appropriate scenarios, can only occur when a ***Planned Quantity of Water*** has been identified within the Tier 3 assessment (MOE, 2013), which is NOT the case in the York Tier 3 Local Area. Impacts to "other water uses" from municipal drinking water use were assessed in the Local Area, as required by the *Clean Water Act, 2006* and the *Technical Rules*, including:

- Groundwater discharge to streams;
- Groundwater discharge to wetlands; and
- Other permitted groundwater takings.

The Technical Rules provide specific thresholds to be used in evaluating the impact of pumping to meet allocated demand on cold water stream reaches. A reduction by an amount that is greater than either of the following two criteria is deemed a moderate risk within the York Tier 3 Local Area, since there is no Planned Quantity of Water in the York Tier 3 Local Area:

- 20% of the existing estimated streamflow that is exceeded 80% of the time (Q_{p80}); or
- 20% of the existing estimated average monthly baseflow of the stream.

The first criterion can be used where the Q_{p80} values are estimated from gauged flows. The second criterion is more applicable to ungauged reaches of streams and was selected for use in this study because it is more is compatible with the steady-state analyses completed for the risk assessment scenarios discussed.

While no specific thresholds are provided for the evaluation of impacts to warm water streams the impacts on these streams must still be evaluated. A decrease of 50% of the existing estimated monthly average baseflow of the stream was selected as a reasonable threshold for "unacceptable impacts" for the purpose of this study. This assumed that there is some groundwater discharge to warm water streams and that a measurable decrease in that amount could cause an unacceptable impact.

The methodology and thresholds for the evaluation of risks related to provincially significant wetlands (PSW) were not specified in the Technical Rules other than that the municipal takings should not "result in a reduction to the flow or level of water that constitutes an unacceptable impact to other water uses". An approach that identified wetlands subject to more than a 1-m drawdown in groundwater levels beneath that wetland was selected for two reasons:

1. Model representation: The complexity of wetland function, and model representation of wetlands, suggests that a simplified approach based on the change in the underlying aquifer water levels would be a direct and consistent means of assessment.
2. Understanding of natural seasonal fluctuations: The evaluation of water level fluctuations undertaken for the WHPA-Q1 assessment indicated that a 1-m seasonal fluctuation in

groundwater levels is considered normal in the study area. Accordingly, an incremental drawdown threshold of 1 m was selected for wetland risk consideration.

Despite the above discussion on significant impacts, new proposed revisions to the Technical Rules (written communication York Region, October 21, 2013) state that impacts to "other water uses" can only result in a moderate risk level being assigned to the *Local Area* when there is no planned demand within the *Local Area*.

Enumeration of Drinking Water Quantity Threats

Two broad categories of water quantity threats are identified in the MOE Technical Rules, which are to be considered in assessing Drinking Water Threats:

1. Consumptive water demand; and
2. Reductions in recharge from land development.

Confirmation of Significant Groundwater Recharge Areas

The Technical Rules require that the SGRAs delineated during the Tier 1 and Tier 2 water budget processes (**within the model domain**) must be reconfirmed based on the results of Tier 3 models. Accordingly, results from the integrated GSFLOW model were used in this analysis. As discussed in the model development report, the GSFLOW model takes into consideration topography, surficial geology, and how land cover (vegetative cover and imperviousness) affects groundwater recharge. The GSFLOW model has the added benefit of taking into consideration groundwater feedback, such as:

1. Saturation-excess rejected recharge (i.e., where infiltration rates are limited by soil saturation, including when the water table is seasonally at or near surface, or where soil moisture is elevated due to unsaturated zone process feedback);
2. Groundwater discharge feedback (i.e., where groundwater discharge to the soil zone can move downslope, or as overland runoff); and
3. Routing of total flow such that leakage from the stream raises water levels in riparian or wetland areas to the point that recharge is prevented.

In summary, groundwater feedback occurs in complex three-dimensional processes, and only a fully integrated model can account for those mechanisms in the recharge estimate.

For this assessment, because the Tier 3 area only extends into a very small portion of the CLOSPA, the jurisdictional average that was used to delineate SGRAs in the Tier 1 analysis was not changed or recalculated for the whole of CLOSPA. The T3 recharge grid however, was used to re delineate the SGRA in the area that the model covers CLOSPA using the T1 jurisdictional average of 182mm. This use of a single value for all catchments is consistent with the methodology selected by CLOSPA for its Tier 1 study.

Owing to the cell-based nature of the Tier 3 model and because the parameters that affect recharge are spatially variable, the map of estimated groundwater recharge is also spatially variable and shows relatively small parcels of land that are above the SGRA threshold. It is understood that it will likely be difficult to develop workable policies for the management of small, isolated SGRA zones. However, to maintain consistency with the Tier 1 work, these small areas were maintained in the Tier 3 analysis.

CLOCA staff interpreted Rule (45) (delineation of SGRAs) to exclude all parts of the watershed that are municipally sourced by Lake Ontario supplies and with the exception of the Village of Brooklin, have no down-gradient private drinking water systems that were determined during the Tier 1 analysis. As the Tier 3 study only covers a small area in the northwest corner of CLOCA where private water wells are used for drinking water purposes, no additional areas were required to be clipped out.

3.8.3 Study Area and Model Domain

The York Tier 3 study was exceptional because of its geographical scope. In the early stages of the project, it became clear that the modelled drawdown cones of many different municipal systems intersected. Therefore, the model domain for the York Tier 3 study extended beyond the TRSPA jurisdiction, into CLOSPA, Kawartha Region Source Protection Area, South Georgian Bay Lake Simcoe, Trent Coalition Conservation) and includes 12 distinct watersheds from Lake Simcoe to Lake Ontario, as shown on **Figure 3.34**.

The model domain includes the following communities with municipal wells within the TRSPA:

- Caledon East and Palgrave in the Region of Peel;
- Nobleton, Kleinburg, King City, and Whitchurch-Stouffville in the Region of York; and
- Uxville in the Region of Durham.

In addition, the model domain includes the following communities with municipal wells outside of the TRSPA:

- Schomberg, Bradford, Ansorveldt, Holland Landing, Aurora, Newmarket, Ballantrae, and Mt. Albert in the Region of York; and
- Uxbridge in the Region of Durham.

3.8.4 Municipal Water Usage and Requirements

York Region and the Region of Durham operate well-based municipal drinking water systems within the York Tier 3 model domain. The Region of Peel operates wells in the model domain (Caledon East and Palgrave), but the subwatersheds containing these wells were not calculated to be stressed. Therefore, the Peel wells were included in the model, but were not evaluated as part of the stress assessment scenarios, except as “other uses”. The existing and committed extraction rates that were used for the York and Durham wells in the Tier 3 analysis are summarized in **Table 3.16**. Further details of this water use by municipality are provided below.

York Region Municipal Water Use

A long period of record is available for many of the York Region supply wells (see Earthfx, 2013b). The records show that groundwater taking generally increased through the 1990’s, stabilized in the early 2000’s, and then declined significantly in 2008 due to an increase in the amount of Lake Ontario sourced water piped into York Region from Toronto and Peel Region. The years 2010 and 2011 were selected for quantifying existing demand as they are most representative of current and future groundwater takings. York Region operates 11 municipal wells in four towns within the TRSPA portion of the York Tier 3 Study Area (one additional well exists in Nobleton, but has not yet been placed in active service). Some of the permits have restrictions on the operations of individual wells along with restrictions on the maximum daily volumes that can be extracted. A summary of the wells and their associated water taking permits are provided in **Table 3.17**. This table also includes notes on the operating conditions listed in the permits.

(c) Copyright. Toronto & Region Source Protection Area, 2014.

Source: TRCA, 2014; DMTI Spatial, 2010; MNR, 2010.

This map has been prepared to meet provincial requirements under the Clean Water Act, 2006 and should be used for other purposes ONLY after consultation with the responsible conservation authority or source protection authority. The analysis used to produce this map relies on best available information as of the date of the map. Priority should be given to site specific information collected in accordance with accepted scientific protocols when being used for other purposes.

Figure 3.34: York Tier 3 Water Budget Model Domain

Municipal Well	Existing Demand (m^3/d)	Existing plus Committed Demand (m^3/d)	Existing plus Committed plus Planned Demand (m^3/d)	Notes
King City PW3	359.7	359.7	359.7	No change
King City PW4	851.0	851.0	851.0	
Kleinburg PW3	627.8	627.8	627.8	No change
Kleinburg PW4	1,050.4	1,050.4	1,050.4	
Nobleton PW2	487.2	590.0	766.7	Future pumping allocated equally between old and new wells
Nobleton PW3	446.7	590.0	766.7	
Nobleton PW5	0	590.0	766.7	
Stouffville PW1	611.8	611.8	611.8	No change
Stouffville PW2	530.6	530.6	530.6	
Stouffville PW3	973.5	973.5	973.5	
Stouffville PW5	950.1	950.1	950.1	
Stouffville PW6	801.2	801.2	801.2	
Uxville MW1	43.8	115.8	115.8	Future usage increase distributed uniformly to both wells
Uxville MW2	1.6	4.1	4.1	

Table 3.16: Simulated Average Municipal Pumping Rates within the CTC (TRSPA)

Municipal Well	MOE PTTW No.	Permit Issued	Permit Expiry	Maximum Permitted Taking (L/min)	Maximum Permitted Taking (L/d)	Comment
King City PW3	8634-67HR9L	20-Dec-04	31-Jan-15	1,364	1,963,915	There are no conditions placed on this system. In 2011, King City was converted to a Lake Ontario supply. The wells will be retained for back-up purposes, however, and included in the risk scenario modeling.
King City PW4		20-Dec-04	31-Jan-15	1,818	2,618,554	

Kleinburg PW3	2411-789N8E	22-Jan-08	31-Jan-14	3,637	5,237,000	Kleinburg PW3 and 4 are located on the same site and are operated as a single source. Kleinburg will be serviced primarily through surface water in future, although the wells will be retained for back-up sources, and therefore included in the risk scenario modeling.
Kleinburg PW4		22-Jan-08	31-Jan-14			
Nobleton PW2	0747-7SXHU5	26-Jun-09	30-Jun-19	1,364	1,964,000	This permit will be amended; Nobleton PW 4 has been replaced by Nobleton PW 5. The Permit restricts the simultaneous operation of Nobleton PW 2 & 3.
Nobleton PW3		26-Jun-09	30-Jun-19	1,734	2,496,000	
Nobleton PW5	New well not listed in PTTW					
Stouffville PW1	3671-8P9NK5	12-Dec-11	31-Mar-17	2,046	2,946,240	No changes from the previous Permit (Ref. No. 5722-74LPXE). No operational restrictions. Future demand will be serviced from surface water supplies.
Stouffville PW2		12-Dec-11	31-Mar-17	2,046	2,946,240	
Stouffville PW3		12-Dec-11	31-Mar-17	2,046	2,946,240	
Stouffville PW5		12-Dec-11	31-Mar-17	1,590	2,289,600	
Stouffville PW6		12-Dec-11	31-Mar-17	2,160	3,110,400	
Uxville MW1	2835-8MXRAR	27-Oct-11	30-Sep-21	1,318	1,898,000	MW1 is the primary well, with MW2 serving as the backup. The permit governs total pumping from both wells.
Uxville MW2						

Table 3.17: Municipal Permit to Take Water Summary within the CTC (TRSPA)

The existing water demand for York Region is included in **Table 3.18**. The York Region data provided in this table were obtained from Permits to Take Water, 2010 and 2011 pumping data, and the approved Water and Wastewater Master Plan (York Region, 2009), which summarizes future water allocation across York Region based upon approved growth projections through to 2031. Graphs of the water use over time with the measured and safe water levels are provided and can be found in **Appendix C3 of the TRSPA Updated Approved Assessment Report, 2014**.

Table 3.19 includes the committed demand for the municipal water systems within the *Local Area*. The values shown are the difference between the existing demand and the 2016 groundwater taking projections in the approved Water and Wastewater Master Plan as per **Table 3.18**. These values reflect anticipated growth that is contained within the York Region Official Plan and plans for the local municipalities. The calculated safe additional drawdown values are presented in **Table 3.20**.

A number of communities in the York Tier 3 Study Area have no committed demand, including Kleinburg, King City, and Stouffville. Although some future growth is anticipated in Kleinburg, King City and Stouffville through 2016, the additional population will be serviced through surface water supplies piped from Lake Ontario.

The system serving Stouffville is a blended system with mixed surface water and groundwater. The system in King City was converted to Lake Ontario supply in July 2011. The system in Kleinburg is being converted to surface water (Lake Ontario) supply and groundwater will cease to be the primary supply. The wells in King City and Kleinburg will be maintained as back-up supplies in the event of a surface water supply disruption, such as that which occurred in 2009, where lake-based supply from Peel was interrupted for a period of several months. Reverting to existing groundwater supplies minimized the disruption to local residents as the surface water pipeline was repaired. To similarly avoid interruptions in service to residents from surface water delivery issues in future, groundwater supplies will be retained for back-up wherever lake-based supplies are introduced. Taking from the wells were included in the Tier 3 risk scenarios to be conservative.

Region of Durham Municipal Water Use

Twelve municipal supply systems are operating in Durham Region. Of these, the two municipal wells (MW1 and MW2) that supply potable water to the Uxbridge Industrial Park (Uxville) are within a watershed identified as potentially stressed at the Tier 1/Tier 2 level. The system is classified as a “Small Drinking Water System”. The wells are operated under PTTW 2835-8MXRAR which expires in September 2021 with maximum permitted rate of 1,898 m^3/d.

The Uxbridge Industrial Park consists of 29 serviced lots in Phase 1 and 37 serviced lots in Phase 2 (total 66 lots) spread over 92.1 ha. At present, the park is 50% developed. Existing demand values, presented in **Table 3.18**: Current and Future Municipal Water Use (TRSPA) reflect average daily extraction from each well for the system for 2010 and 2011 and were equal to 43.8 m^3/d for MW1 and 1.55 m^3/d for MW2, or a total of 45.4 m^3/d. These years were selected to be consistent with the values used for York Region. The data used in the table were obtained from WTRS pumping data and information supplied by Durham Region.

Information used to determine allocated water in **Table 3.19** was provided by Durham Region (written communication from Beata Golas to Don Goodyear on April 9, 2013). Pumping is triggered based on water levels in the on-site 1,134 m^3 reservoir. The pumping rates are relatively small and show seasonal variation but no longer-term trend, as shown on the graphs in **Appendix C3 (TRSPA Proposed Updated Approved Assessment Report, 2014)**. One short-term spike in pumping was noted in November 2008.

Wells within the Town of Uxbridge, located about 13 km northeast of Uxville, were also represented in the York Tier 3 integrated surface water/groundwater model but are not located in a watershed identified as potentially stressed at the Tier 1/Tier 2 levels and are not within the TRSPA jurisdiction. The Lynde Creek watershed located within CLOSPA and which covers a very small portion of Uxbridge was identified as only moderately stressed under Tier 1 level.

Municipal Well	Well Maximum Permitted Extraction (m^3/d)	Water System Maximum Permitted Extraction (m^3/d)	Existing Demand (2010-2011)		2016 and 2031 Master Plan		Water Sources for Demand Increases	Notes
			Well Annual Average (m^3/d)	System Annual Average (m^3/d)	2016 Water System Demand (m^3/d)	2031 Water System Demand (m^3/d)		
King City PW3	1,963.9	4,582.5	359.7	1,210.6	0.0	0.0	Lake Ontario	King City water supply was converted from a groundwater to a Lake Ontario supply in 2011. The wells will be retained for back-up / redundancy purposes only.
King City PW4	2,618.6		851.0					
Kleinburg PW3	5,237.0	6,187.4	627.8	1,680.2	0.0	0.0	Lake Ontario	Kleinburg water supply is being converted from a groundwater to a Lake Ontario supply.
Kleinburg PW4			1,050.4					
Nobleton PW2	1,964.0	6,956.0	487.2	933.9	1,770.0	2,300.0	Groundwater	Water system is designed and constructed to meet 2031 build-out. Increases can be accommodated with current infrastructure and permitted water taking.
Nobleton PW3	2,496.0		446.7					
Nobleton PW5	2,496.0		Not in service					
Stouffville PW1	2,946.2	14,238.7	611.8	3,867.2	3,867.2	3,867.2	Lake Ontario	Stouffville is a blended groundwater and surface water system. Demand increases in Stouffville are to be accommodated using Lake Ontario water. Current groundwater takings are to be maintained in the future.
Stouffville PW2	2,946.2		530.6					
Stouffville PW3	2,946.2		973.5					
Stouffville PW5	2,289.6		950.1					
Stouffville PW6	3,110.4		801.2					
Uxville MW-1	1898.0	1898.0	43.8	45.4	1898.0	1898.0	Not applicable	Combined pumping from MW-1 and MW-2 cannot exceed 1,898 m^3/d
Uxville MW-2			1.6					

Notes: *Planned average demand for 2031 is based on population, employment data, and water consumption unit rates (252 L/capita/d and 225 L/d for employment use per the 2008 Unit Rates study completed for the master plan). York Region Master Plan average day demand is the PTTW maximum permitted taking divided by the peaking factor. The demand data presented are annual average day values. King City existing demand based on 2010 data - Community was converted to Lake Ontario supply July 2011.*

Table 3.18: Current and Future Municipal Water Use (TRSPA)

Municipal Well	Water Demand Water System Classification	System Max. Permitted Pumping (m^3/d)	Existing Demand (m^3/d)	Committed Demand (m^3/d)	Planned Demand (m^3/d)	Allocated Quantity of Water (m^3/d)	Notes
King City PW3 King City PW4	No Committed and No Planned	4,582.5	1,210.6	0.0	0.0	1,210.6	King City water supply is being converted from a groundwater to a Lake Ontario supply.
Kleinburg PW3 Kleinburg PW4	No Committed and No Planned	6,187.4	1,680.2	0.0	0.0	1,680.2	Kleinburg water supply is being converted from a groundwater to a Lake Ontario supply.
Nobleton PW2 Nobleton PW3 Nobleton PW5	Committed and Planned	6,956.0	933.9	836.1	530.0	2,300.0	Water system is designed and constructed to meet 2031 build-out. Increases can be accommodated with current infrastructure and permitted water taking.
Stouffville PW1 Stouffville PW2 Stouffville PW3 Stouffville PW5 Stouffville PW6	No Committed and No Planned	14,238.7	3,867.2	0.0	0.0	3,867.2	Stouffville is a blended groundwater and surface water system. Demand increases in Stouffville are to be accommodated using Lake Ontario water. Current groundwater takings are to be maintained in the future.
Uxville MW-1 *	Committed and No Planned	1,898.0	43.8	74.6	0.0	120.0	Combined pumping from MW-1 and MW-2 cannot exceed 1,898 m^3/d. * Uxville MW-1 is used as the main supply well in this system.
Uxville MW-2			1.6				

Notes: *Values presented are annual daily averages. Existing demand calculated as the average daily demand for 2010 and 2011. Planned average demand for 2031 is based on population, employment data and per capita water consumption unit rates (252 L/capita/d and 225 L/d for employment use per the 2008 Unit Rates study completed for the master plan). King City existing demand based on 2010 data - Community was converted to Lake Ontario supply July 2011.*

Table 3.19: Municipal Allocated Extraction Rates

Municipal Well	Safe Water Level (mASL)		Existing Water Level (mASL)		Safe Additional Drawdown (m)	
	Lowest Pump Intake	Top of Aquifer	Average In-well Level	Average Aquifer Level	In-well Drawdown	Aquifer Drawdown
Stouffville PW1	184.16	189.34	230.10	229.77	45.94	**40.43**
Stouffville PW2	182.04	186.31	233.00	229.77	50.96	**43.47**
Stouffville PW3	266.74	270.40	279.63	282.12	12.89	**11.73**
Stouffville PW5	301.91	303.43	305.75	306.68	3.84	3.25
Stouffville PW6 [1]	291.26	302.85	299.50	303.11	8.24	0.26
Uxville MW-1 *	293.9	291.7	315.3	320.3	**21.5**	28.6
Uxville MW-2	291.1	307.5	319.9	320.3	22.5	**12.8**

Notes: - *Safe additional drawdown for each well emphasized in bold. Corresponds to the more conservative value (smaller safe additional drawdown value) provided by considering the in-well drawdown and the aquifer drawdown.*

[1] Stouffville PW#6 in-well safe additional drawdown used because the Lower ORAC behaves as an un-/semi-confined aquifer in this area

Table 3.20: Safe Additional Drawdown for Municipal Wells (TRSPA)

The Uxville Water Supply system does not provide water to domestic residents. The system is located within the Oak Ridge Moraine planning area and no further rural residential development is permitted. There is no official plan designation for Uxville development in the future, and population growth estimates for this area are not considered in the Durham Official Plan or in the water use master plan. Therefore, Durham Region does not plan to increase the quantity of water beyond that required to service the industrial park. At most, infilling of the existing industrial park (100% development) would increase demand to approximately 120 m^3/d. As indicated in **Table 3.20**, the committed demand (based on the increase from 45.4 m^3/d to 120 m^3/d) is 74.6 m^3/d and there is no planned demand for this system. The calculated safe additional drawdown values are presented in **Table 3.20**.

Tolerance

The Tier 3 assessment also considers a municipal water system's tolerance to risk. The Technical Rules state that "tolerance is evaluated to determine whether an existing system is capable of meeting peak demand". *Technical Rule 100* states:

> *For the purposes of evaluating the groundwater scenarios C and D in Table 4B, a tolerance level shall be assigned to the existing type I, II or III system which the local area relates that is the subject of evaluation in accordance with the following:*
>
> - *A tolerance level of high if the existing system is capable of meeting peak demand during all assessment periods; and*
> - *A tolerance level of low if sub-rule (1) does not apply to the existing system.*

The PTTW for the Yonge Street wellfield allows for increased takings in peak demand periods (up to 67,200 m^3/d on average for May through August and up to 87,656 m^3/d on any given day). However, the yearly average production is still limited to 42,000 m^3/d as simulated in the model for Scenario C.

Scenarios D and H however, used the actual takings or scaled takings that reflect peak pumping and show that the wells are capable of meeting peak demands even under extreme drought conditions. The tolerance of the York Region wells are generally high because of the ability to reallocate pumping to other nearby wells and/or wellfields that have additional available drawdown. Finally, the ability for York Region to supplement groundwater takings in the Yonge Street wellfields and the Stouffville wellfield with surface water supplies from Lake Ontario provides York Region with a high degree of tolerance under any water taking and drought scenario.

The tolerance of the Uxville system is high, given the low water use (less than 10% of the PTTW) and high well capacity.

3.8.5 Other Water Uses and Requirements

Other Permitted Groundwater Takings

A total of 272 permitted groundwater and combined groundwater/surface water takings are represented in the model, as listed in the Model Development and Calibration Report. Municipal wells located outside of the assessment watersheds (e.g., wells for the towns of Uxbridge, Palgrave, and Caledon East) were also simulated in the model. These municipal wells and the other permitted takings were simulated at their estimated consumptive rate. The effects of future increases in other water takings were not considered in the risk assessment scenario analyses.

Non-permitted water use was also compiled and 8 additional wells in CLOCA and 5506 in TRCA watersheds respectively were considered during model development and calibration. Non-permitted use includes wells pumping less than 50 m^3/d mainly for private domestic and agricultural use and livestock watering. Takings from non-permitted and domestic wells were not represented in the risk assessment scenario analyses because the takings are small and assumed to be non-consumptive (the water is generally returned to the shallow aquifer).

Surface Water Takings

As outlined in the Model Development and Calibration Report (Earthfx 2013b), 432 surface water takings were identified and incorporated into the model (including agricultural, commercial and industrial water takings). The total surface water consumptive use was estimated at 47,120,000 m^3/yr. Agricultural demand represents the largest surface water use at 50% of permitted takings. Golf course takings are significant at 21%. A number of surface water permits (20) for wildlife conservation have been issued by the MOE. These were assumed to have no consumptive use and were not represented in the model.

Estimates of the available drawdown were made based on the static water level at the time of drilling and the top of well screen (as reported in the WWIS or estimated where the data were not available). Data on available drawdown in the wells under pumping conditions were not available. As noted earlier, proposed revisions to the *Technical Rules* state that if the allocated demand at the municipal wells does not exceed the current permitted amount, then only a moderate risk level can be assigned to the *Local Area*.

Wastewater Assimilation

Wastewater generated in Kleinburg and Nobleton is collected and treated at individual water pollution control plants (WPCP), then discharged into local watercourses where it eventually flows into Lake

Ontario. Wastewater generated in Aurora, King City, Richmond Hill, Vaughan, Markham, and Stouffville is collected at the York-Durham Sewage System which is a large trunk sewer that runs to the Duffins Creek WPCP in Ajax. This wastewater is treated and discharged directly into Lake Ontario. In addition, a small portion of the wastewater generated in Vaughan is treated in Peel Region.

None of the Certificates of Approval for these systems specify a condition relating to the flow rates of receiving watercourses. The issue of assimilative capacity is addressed through specifications of the quality of the effluent discharged, which is closely monitored and reported to the MOE on a regular basis. Impacts of future pumping on wastewater assimilation were therefore not considered further in the Tier 3 analysis.

Navigation Requirements

No specific water use requirements for navigation have been identified within the TRSPA. Therefore, no impacts are expected.

Recreational Requirements

The Tier 3 analysis included a large number of artesian wells and groundwater-fed ponds in the Lemonville area (northwest of Stouffville) with water use purpose classified as "recreational/aesthetic". However, no impacts were identified to these ponds through the Tier 3 analysis.

Aquatic Habitat Requirements

The Oak Ridges Moraine bisects the Local Area, with half of the watercourses arising and flowing north towards Georgian Bay, and the other half arising and flowing south to Lake Ontario. Groundwater discharge creates significant stretches of cold-water habitat in the headwater areas of the TRSPA, as was discussed in **Section 2.2.2** and shown on **Figure 2.5**. Potential impacts to these aquatic habitat requirements were assessed through the various scenarios described in **Section 3.9.2**, and the results are provided in **Section 3.9.10**.

Provincially Significant Wetlands

There are a large number of wetlands and wetland complexes within the study area, most of them located in the hummocky topography of the Oak Ridges Moraine and in the low lying areas in the northeastern portion of the study area near Lake Simcoe. Potential impacts to these wetlands are discussed in **Section 3.9.10**.

3.8.6 Future Land Use

For the future condition risk assessment scenarios, the GSFLOW cell-based land use input parameters were modified to include locally representative levels of urbanization within the proposed development areas. Under current conditions 32% of the land use is designated as urbanized in the York Tier 3 model area, and within that area the average percent imperviousness is 65%. For the future land development scenarios, the land use model inputs were modified so that the imperviousness was a minimum of 65% within the future urban settlement boundary areas. The increase in imperviousness was only applied to cells where this resulted in an increase over the existing level. This new input condition was used for all future land development scenarios.

3.8.7 Model Development and Calibration

The details regarding the model development and calibration process are presented in the foundation report prepared by Earthfx Inc. (Earthfx, 2013a). An excerpt of the model development/calibration approach is provided below.

Calibration targets for the Tier 3 GSLOW model included flows recorded at streamflow gauges, and continuous water-level data from PGMN and York Region monitoring wells. Other secondary sources included MOE WWIS static water levels and wetland mapping. The integrated modelling approach has the benefit that the model must be calibrated to both groundwater and surface water data *simultaneously*; thus reducing the level of uncertainty typically associated with separate models that make simplifying assumptions regarding the processes not explicitly represented. The integrated calibration also means that artificial or empirical data processing techniques such as baseflow separation are not needed because the model is calibrated to total *measured* flow at the stream gauges.

To facilitate model construction and evaluation, GSFLOW's sub-models were run independently during calibration, scenario or sensitivity analysis. For example, the PRMS model was first used to provide an estimate of long-term average recharge. This recharge estimate was then used to develop an initial long-term steady-state groundwater flow model calibration. Once the long-term average sub-models were developed, the final integrated calibration was completed and tested against the more detailed transient water levels and streamflow discharge measurements.

All municipal and non-municipal groundwater takings were represented in the model on a daily basis (rather than monthly) using reported information and consumptive use factors. The surface water model accounted for all surface takings in the study area. The results of model calibration and the insights gained were presented in detail in Earthfx 2013b. The replicated the normal seasonal variation of 1 to 2 m in the ORAC, TAC and SAC aquifer units.

3.8.8 Water Budget Parameter Refinement

The Tier 3 water budget resulted in updates to the estimates provided in the TRSPA Tier 1 and 2 water budgets and shown in Chapter 3 of the **TRSPA Updated Approved Assessment Report, 2014**. As noted, traditional definitions of the surface water and groundwater components of the water budget are somewhat limited, because water moves between those systems in complex and highly varied pathways. In addition, some takings, such as takings from ponds and streams, are now specifically simulated in the model and no longer can be classified as either traditional groundwater or surface water takings.

The integrated nature of this model produces water budget results that require a slightly different interpretation when compared to uncoupled models. While mass is conserved within the model, water can discharge and re-infiltrate multiple times through the model. For example, groundwater can discharge to a stream reach, flow downstream in the channel, and then re-infiltrate into the groundwater system through the streambed, lake-bottom or wetland. Total inflow into the groundwater model cannot therefore be taken as only net recharge plus lateral groundwater inflows because leakage from streams and wetlands must also be considered. As explained above, stream leakage to the groundwater system may be mostly supported by groundwater discharge in upstream areas (especially in the catchment headwaters).

3.8.9 Delineation of Vulnerable Areas for Water Quantity

The WHPA-Q1 was delineated by determining the change in simulated heads within the production aquifers between the following two model scenarios:

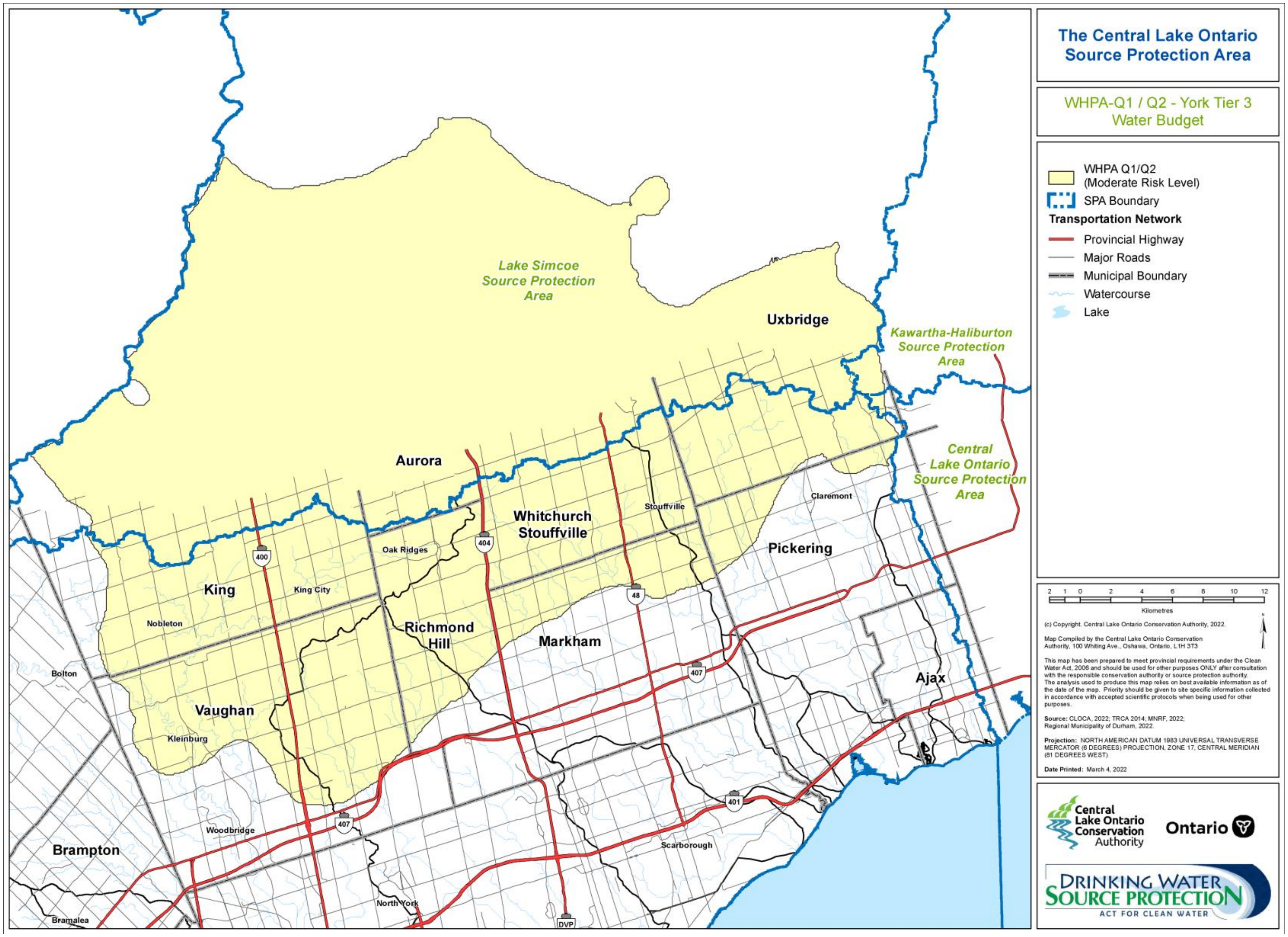
1. Steady-state baseline model using existing land use and no municipal or non-municipal pumping to determine "pre-development" conditions; and
2. Steady-state model using existing land use and allocated demand rates for municipal pumping and consumptive use rates for all other water uses.

Municipal pumping wells are typically completed in one of the three major aquifers (the lower ORAC, TAC/Tunnel Channel Sediments, and the SAC). In delineating the WHPA-Q1 area, the cones of influence for the municipal wells within each aquifer was calculated and compared. To be conservative, the furthest extent of the cone of influence in each aquifer was considered when delineating the final WHPA-Q1. The cones of influence for each of the aquifers were superimposed to delineate the final WHPA-Q1 area shown on **Figure 3.35**. This WHPA-Q1 area covers approximately a quarter of the model domain, extending from Richmond Hill/Markham in the south to north of Queensville in the north and from Maple in the west to beyond Uxbridge in the east. For clarity, a second map showing the extent of the WHPA-Q1 within the CLOSPA only is provided as **Figure 3.36**.

As mentioned in **Section 3.9.6**, future land use changes were considered in terms of potential recharge reduction for each municipality in the study area. According to the Official Plans, proposed changes to land use include infilling of both high and low intensity urbanized land. Only those areas with change in land use that straddle or are outside of the WHPA-Q1 boundary were considered in delineating the WHPA-Q2. It should be noted that the cumulative effect of all proposed land use changes were considered in risk assessment Scenarios G(1), G(3), H(1), and (H3).

Inputs to the PRMS sub-model were adjusted to account for increased surface imperviousness and changes in vegetative cover associated with urbanization of rural land. In accordance with the MNR Water Budget Guide (MNR, 2010), no best management practices to enhance recharge and manage stormwater (e.g., low impact development strategies (LIDS)) were considered in the simulations. A future annual average groundwater recharge rate was determined through a 20-year PRMS simulation and applied to the steady-state groundwater model.

Simulated heads under the WHPA-Q2 simulation were subtracted from simulated heads generated in the WHPA-Q1 simulation. The additional drawdowns in the Lower did not intersect the Stouffville municipal pumping wells (the nearest municipal wells completed in the Lower ORAC aquifer) and, therefore, future land use change has no “measurable” impact on the municipal wells. Smaller areas of drawdown were obtained in the TAC and SAC and did not impact any municipal wells.



🟨 WHPA Q1/Q2 (Moderate Risk Level)
SPA Boundary
Transportation Network
Provincial Highway
Major Roads
Municipal Boundary
Watercourse
Lake

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Map Compiled by the Central Lake Ontario Conservation Authority, 100 Whiting Ave., Oshawa, Ontario, L1H 3T3

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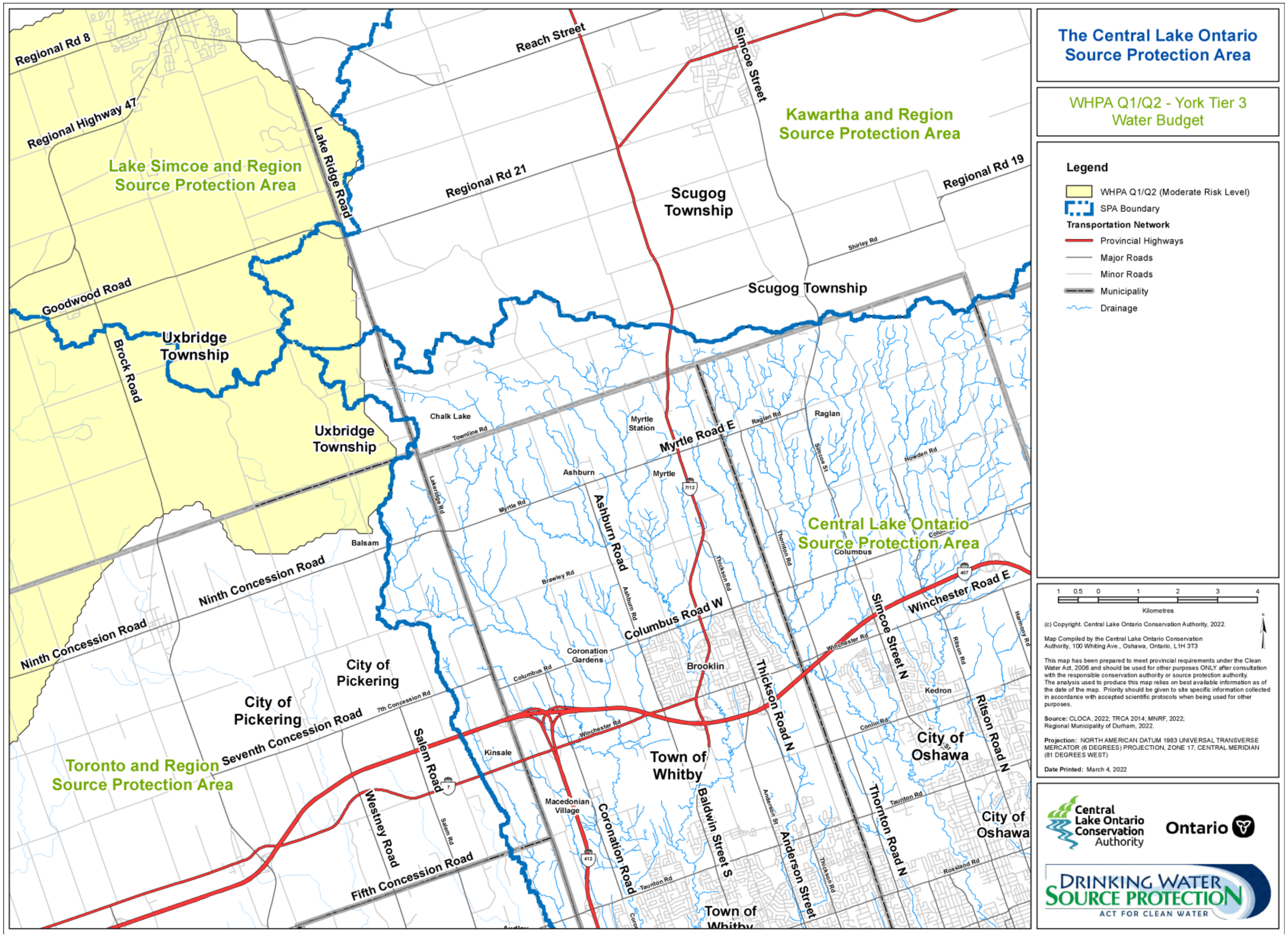
Source: CLOCA, 2022; TRCA 2014; MNRF, 2022; Regional Municipality of Durham, 2022.

Projection: NORTH AMERICAN DATUM 1983 UNIVERSAL TRANSVERSE MERCATOR (6 DEGREES) PROJECTION, ZONE 17, CENTRAL MERIDIAN (81 DEGREES WEST)

Date Printed: March 4, 2022

Figure 3.35: WHPA-Q1 / Q2 - York Tier 3 Model



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Source: CLOCA, 2022; TRCA 2014; MNRF, 2022; Regional Municipality of Durham, 2022.

Projection: NORTH AMERICAN DATUM 1983 UNIVERSAL TRANSVERSE MERCATOR (6 DEGREES) PROJECTION, ZONE 17, CENTRAL MERIDIAN (81 DEGREES WEST)

Date Printed: March 4, 2022

Figure 3.36: WHPA Q1 / Q2 – York Tier 3 in CLOSPA

The area of predicted drawdown near the Kleinburg municipal water supply wells (south of Nobleton) straddled the WHPA-Q1, but the WHPA-Q1 was not expanded to include this drawdown for two reasons: first, the Kleinburg wells are not in a stressed watershed, and second, the Kleinburg wells were completed in the deeper TAC and SAC aquifers, which did not show a measureable drawdown from the proposed developments in this area.

The results of the WHPA-Q2 assessment confirmed that the proposed future land uses that straddle or are located outside of the WHPA-Q1 area do not produce a significant impact on heads at the municipal pumping wells. The WHPA-Q2 area is therefore coincident with the WHPA-Q1 area.

3.8.10 Risk Assessment Scenario Results

The results of the risk assessment scenarios are tabulated in **Table 3.21** and **Table 3.22 and** have also been added to the Well System Characterization graphs included in **Appendix C3 of the TRSPA Updated Approved Assessment Report**.

York Region has considerable operational flexibility in allocating demand between individual wells and even between nearby wellfields. In addition to multi-well wellfield limits, system-wide permits covering the Yonge Street Aquifer allow pumping to be re-allocated between wellfields. Model test simulations indicated that the shallow wells in Stouffville are relatively more drought sensitive. York Region staff have indicated that pumping at these wells would be shifted to deeper wells under drought conditions. Accordingly, 40% of the daily takings at Stouffville PW5 and PW6 were re-allocated to the deeper wells PW1 and PW2 to reflect operations under drought conditions. It is important to note that, under these Scenario D drought re-allocation rates, the total combined takings for Stouffville reflected the actual 2010-2011 Study Period totals.

The model simulations proceeded as follows:

1. Step 1: The first iteration of the GSFLOW simulation is a steady state run identical to the Scenario C conditions (long term average recharge and water takings). This initializes the water levels in the aquifers.
2. Step 2: After this first iteration, two years of average transient conditions (Oct. 1, 1954 to Oct 1, 1956) are then simulated to set up antecedent soil and unsaturated zone conditions, groundwater feedback and GW/SW interaction processes in the fully-integrated GSFLOW model. During this two year period all municipal wellfields are pumped at the average daily (2010-2011 Study Period) operational rates.
3. Step 3: On Oct 1, 1956 (the start of the 10-year drought) the pumping rates in Stouffville are switched to the drought re-allocation rates. All other municipal wells and surface water and groundwater takings continue to be operated at Study Period rates.
    a. The average water levels in the aquifers in September, 1956 (the start of the drought) are used as a reference for drawdown calculations.
    b. The maximum simulated daily drawdown in each well is determined from within 10-year drought period.

Well	Aquifer	Safe Additional Drawdown (m)	Additional Drawdown (m)							
			Scenario C	Scenario D	Scenario G(1)	Scenario G(2)	Scenario G(3)	Scenario H(1)	Scenario H(2)	Scenario H(3)
Stouffville PW1	TAC	40.43	6.27	5.66	0.78	0.10	0.70	5.86	5.74	5.79
Stouffville PW2	TAC	43.47	6.06	5.66	0.78	0.10	0.70	5.86	5.74	5.79
Stouffville PW3	Lower ORAC	11.73	6.12	3.65	2.25	0.01	2.24	4.54	3.67	4.52
Stouffville PW5	Lower ORAC	3.25	5.59	2.30	0.86	0.14	0.73	2.50	2.41	2.34
Stouffville PW6	Lower ORAC	8.20	5.82	2.30	0.86	0.14	0.72	2.50	2.42	2.35
Uxville-MW1	ORAC	21.50	2.06	4.82	1.62	0.56	1.07	6.19	5.91	5.14
Uxville-MW2	ORAC	12.70	1.82	4.63	1.27	0.22	1.07	5.38	5.06	4.92

Notes:

Additional drawdowns for Scenario C expressed relative to no-pumping conditions.
Additional drawdowns for Scenario G expressed relative to Scenario C heads.
Highlighted text indicates wells that are significantly affected by changes in land use.

Table 3.21: Predicted Drawdowns at the Municipal Wells in the Stressed Watersheds

Well	Aquifer	Additional Drawdown (m)							
		Scenario C	Scenario D	Scenario G(1)	Scenario G(2)	Scenario G(3)	Scenario H(1)	Scenario H(2)	Scenario H(3)
Nobleton PW2	TAC	2.99	4.57	4.06	3.05	0.97	9.34	9.23	4.69
Nobleton PW3	TAC	3.01	4.45	3.93	2.92	0.96	8.96	8.84	4.57
Nobleton PW4	TAC	2.49	4.04	4.85	3.83	0.98	17.85	17.74	4.16
King City PW3	TAC	7.68	6.88	3.02	0.60	**2.30**	7.66	7.27	7.29
King City PW4	TAC	8.15	6.88	3.02	0.60	**2.30**	7.66	7.27	7.29
Kleinburg PW2	TAC	0.62	2.14	0.81	0.17	0.63	2.35	2.29	2.21
Kleinburg PW3	SAC	3.06	4.11	0.77	0.11	0.65	4.32	4.22	4.21
Kleinburg PW4	SAC	3.54	4.11	0.77	0.11	0.65	4.32	4.22	4.21
Palgrave PW1	Lower ORAC	1.80	2.14	0.04	0.02	0.02	2.15	2.15	2.14
Palgrave PW2	Lower ORAC	13.4	13.29	0.04	0.03	0.02	13.31	13.31	13.29
Palgrave PW3	Lower ORAC	12.3	6.27	0.00	0.00	0.00	6.27	6.27	6.27
Caledon East PW3	Lower ORAC	40.9	6.95	0.01	0.00	0.00	6.95	6.95	6.95
Caledon East PW4	TAC	1.34	3.56	0.01	0.00	0.01	3.51	3.58	3.54

Notes:

Additional drawdowns for Scenario C expressed relative to no-pumping conditions
Additional drawdowns for Scenario D and H are expressed relative to October 1956 heads.
Additional drawdowns for Scenario G expressed relative to Scenario C heads.
Highlighted text indicates wells that are significantly affected by changes in land use.

Table 3.22: Predicted Drawdowns at Other Municipal Wells

The drought simulations, and drought re-allocation rates, reflect the operational flexibility available to York Region. The simulations reflect the changes in operations that could be implemented at the onset of a drought. Additional study and simulations are necessary to determine the triggers (e.g., decrease in precipitation or decline in groundwater levels), and to optimize drought response needed to maintain safe available drawdown.

Scenario C Results: Current Conditions and Climate

This scenario provides the baseline conditions for evaluation of the other scenarios. Best estimates of current water use were applied, and recharge was based on current (2010) land use.

Scenario D Results: Existing Pumping Rates, Current Land Use, and Drought Conditions

Results from the transient drought simulation in Scenario D, in terms of simulated stage, heads, and numerous other water budget components, were produced by the model on a cell-by-cell basis for each day. For presentation purposes, and to facilitate trend analysis and comparisons, these values were also accumulated on a monthly basis to produce monthly average results.

As noted earlier, for transient stress scenario analyses the simulated monthly average aquifer heads and streamflow for September 1956 were taken to represent reference conditions prior to the start of the drought.

The maximum drawdowns under transient drought conditions (Scenario D) were compared to the safe additional drawdown and were found to be less than the safe additional drawdown at all municipal wells. Drawdowns were calculated relative to the average monthly head for September 1956. Values were corrected for convergent head losses and non-linear head losses.

The transient model produces other useful information relevant to the surface water and groundwater system response to drought. Total simulated streamflow includes contributions from overland runoff as well as from groundwater inflow. The maximum change in total streamflow was determined by subtracting the simulated flows for August 1965, the most severe period of the drought, from flows in September 1956. The results showed that the largest relative change in streamflow occurs in the upper (headwater) reaches of most streams with less change in the main stems.

Scenario G Results: Allocated Water Demand, Future Land Use, and Average Climate

Scenario G evaluates the ability for the municipal wells to sustain the allocated water demand pumping rates under average climate conditions. This scenario was simulated using the Tier 3 model in steady-state mode with long-term average annual groundwater recharge rates reflecting long-term average climate conditions.

As per the MNR Water Budget Guide, Scenario G was subdivided into three scenarios to better isolate the impacts due to increased municipal pumping from impacts due to future changes in land use.

Scenario G (1): Allocated Water Demand and Future Land Use – This simulation evaluates the combined impact of increased municipal pumping rates to meet allocated water demand and reductions in recharge due to future land use change. Scenario G (1) is similar to the WHPA-Q2 scenario discussed previously although all future land development within the study area was simulated in Scenario G (1) rather than just those areas outside the WHPA-Q1.

Inputs to the PRMS submodel were adjusted to account for increased surface imperviousness and changes in vegetative cover in the all future development areas. A new future annual average groundwater recharge rate distribution was determined through 20 years of PRMS simulations.

The simulated drawdowns at the municipal are less than the safe additional drawdown at all municipal wells. The scenario predicts large areas of drawdown that centre on the municipal wells due to increased pumping. The areas of drawdown extend further south due to projected changes in land use.

Scenario G (2): Allocated Water Demand and Current Land Use – This simulation evaluates only the impact of increased municipal pumping to meet allocated water demand. The average annual groundwater recharge rate represented current land use conditions.

The simulated drawdowns at the municipal wells for Scenario G (2) are smaller than for Scenario G (1) and are less than the safe additional drawdown. As discussed above, the effects of increased pumping to meet allocated demands are centered around the Yonge Street area wells and some of the other municipal wells with significant increases in pumping. Drawdowns are more pronounced in the deeper aquifers, where the majority of the municipal supply wells are screened.

Scenario G (3): Existing Pumping and Future Land Use – This simulation evaluates only the impact of reductions in recharge associated with the future land use change. Existing pumping rates for municipal wells and the average annual groundwater recharge rate for future land use were used in this scenario.

With few exceptions (e.g., Stouffville, King City and Kleinburg), the drawdowns are less than those for Scenario G (2). The additional drawdowns are not centered on the municipal wellfields but occur mainly in the south and southeast parts of the study area, corresponding to locations of projected land use change. The projected changes in future land use have a more direct impact on the shallow groundwater system.

Scenario H Results: Allocated Water Demand, Future Land Use, and Drought Conditions

Results from the Scenario H transient drought simulations include stream stage, aquifer heads, and numerous other water budget components calculated on a on a cell-by-cell basis for each day. While daily hydrographs and animation results were reviewed during calibration, and daily values were used for the risk assessment drawdown analysis, for presentation and trend discussion purposes the daily values were processed into monthly average results.

The maximum drawdowns under transient drought conditions (Scenario H) were compared to the safe additional drawdown at each of the municipal wells. Drawdowns were calculated relative to the average monthly heads for September 1956 from the Scenario D simulation which served as a reference condition at the start of the drought. As in Scenario G, three different simulations were run to identify the separate and combined contributions of increased pumping to meet allocated demand and projected land use change impacts on the simulated drawdowns.

Scenario H (1): Allocated Water Demand, Future Land Use, and Drought Conditions – This scenario simulates drought conditions and considers both allocated demand and projected land use change. As in Scenario D, maximum decrease in simulated head occurred in August 1965 although local variations in the low-point date were found.

In much of the study area, the drought scenarios can be seen as a superposition of two independent problems: (1) the response to increased pumping and change in recharge and (2) the response to drought. Monthly average heads during August 1965 were taken to represent the most severe drought conditions. The maximum changes were predicted in the ORAC and SAC. The drawdowns are larger than those for Scenario D because of the additional effects of increased pumping and land use change superimposed on the drought response. Areas of high change occur at the wellfields and in areas of proposed land use change as in Scenario G (1) but also at the regional divide in the ORM and near inter-stream divides as in Scenario D.

A direct comparison made by subtracting the simulated heads in the TAC for Scenario H (1) from those in Scenario D indicates that the difference in response between the two scenarios is due mainly to the increased pumping at the municipal wells. The drawdowns differ from those between Scenario G (1) and Scenario because the steady-state simulations compare average response and have limited groundwater feedback while Scenarios D and H (1) simulate at a more realistic response and account for aquifer storage and non-linear effects such as reduction in leakage to and from streams.

The maximum simulated additional drawdowns for the 10-year drought at the municipal wells are presented in Error! Reference source not found. and are less than the safe additional drawdown at all municipal wells. This indicates that the wells are capable of sustained pumping to meet allocated water demand under drought conditions and projected land use.

Scenario H (2): **Allocated Water Demand, Existing Land Use, and Drought Conditions** – This scenario simulates the response of the municipal wells under drought climate conditions and considers only increased pumping to meet allocated demand and not projected land use change. The predicted drawdowns are nearly identical to those observed for Scenario H (1), suggesting that the impact of land use change on the overall drought response is relatively minor.

The maximum additional drawdowns at the municipal wells for Scenario H (2) were found to be less than the safe additional drawdown values at all of the municipal wells. The simulated drawdowns at the wells are very close to those for Scenario H (1) confirming that the effect of recharge reductions due to land use change are muted during a drought.

Scenario H(3): Existing Pumping, Future Land Use, and Drought Conditions - This Scenario simulates the response of the municipal wells under drought conditions and considers only projected land use and not increased pumping to meet allocated demand. The small change in heads between Scenario H (3) and Scenario D indicates that the municipal wells are relatively insensitive to land use change under drought conditions.

Results from the Scenario H transient drought simulations include stream stage, aquifer heads, and numerous other water budget components calculated on a on a cell-by-cell basis for each day. While daily hydrographs and animation results were reviewed during calibration, and daily values were used for the risk assessment drawdown analysis, for presentation and trend discussion purposes the daily values were processed into monthly average results.

The maximum drawdowns under transient drought conditions (Scenario H) were compared to the safe additional drawdown at each of the municipal wells. Drawdowns were calculated relative to the average monthly heads for September 1956 from the Scenario D simulation which served as a reference condition at the start of the drought. As with Scenario G, three different simulations were run to identify the separate and combined contributions of increased pumping to meet allocated demand and projected land use change impacts on the simulated drawdowns.

Risk Assessment Scenario Result Summary

No impacts to aquatic habitats were predicted within the TRSPA or CLOSPA; although a limited number of individual cold water reaches with moderate to significant decreases in flow were found in TRSPA, mostly in proximity to the Yonge Street wells. As noted in **Section 3.92**, proposed revisions to the Technical Rules state that if the allocated demand does not exceed the current PTTW amount, then only a moderate risk level can be assigned to the *Local Area*.

Few provincially significant wetlands are located within the area defined by the predicted 1-m drawdown cone and only one wetland that is located within the TRSPA could potentially have reduced outflows or water level due to increases in pumping at nearby municipal wells. In addition, two other wetlands were identified within the 1-m drawdown cone north of the TRSPA boundary (Earthfx, 2013a). As noted above, proposed revisions to the Technical Rules state that if the allocated demand does not exceed the current PTTW amount, then only a moderate risk level can be assigned to the local area. No aquatic habitats or wetlands are affected in the CLOSPA area of the *Local Area*.

Three Non-Municipal Permitted Wells Located in CLOSPA – York Tier 3 Study		
4687-77VQZS [PW1 – Snowmaking]	4687-77VQZS [PW2 - Snowmaking]	4687-77VQZS –PW3 – Snowmaking]

List of Permitted Consumptive Water Uses (CLOSPA)

A list of permitted consumptive water uses for the TRSPA area is listed in Chapter 3 of the TRSPA Updated Approved Assessment Report. The following table provides a count of all water takings considered in the Tier 3 assessment. These represent water quantity threats under the CWA (*2006*) and are further reported in Chapter 5 (Drinking Water Threats Assessment) of this Assessment Report.

Type	**Source Protection Area**				**Total for Local Area**
	TRSPA	**LSCBRSPA**	**CLOSPA**	**KHSPA**	
Municipal *Count of individual point takings*	15	38	0	0	**53**
Non-Municipal Permitted *Count of individual point takings*	62	81	3	0	**146**
Non-Municipal Non-Permitted *Count of individual point takings*	5506	9,032	8	6	**14,552**
Total Takings	**5,583**	**9,151**	**11**	**6**	**14,745**

Note:
TRSPA – Toronto and Region Source Protection Area
LSCBRSPA- Lakes Simcoe and Couchiching/Black River Source Protection Area
KHSPA – Kawartha- Haliburton Source Protection Area

Table 3.23: Summary of Consumptive Water Quantity Threats

Uncertainty Assessment

It is estimated that there is a low uncertainty in the assignment of the moderate risk level to the local area for the following reasons:

1. The factors contributing to uncertainty indicated a low underlying uncertainty for the risk assignment.
2. The moderate risk level is due in part to the potential significant impact on baseflow, PSWs and other permitted water takings. Although there is only limited baseflow discharge measurements in the area and limited data on wetland stage, the areas affected are relatively distant from the municipal wells and impacts are likely to be less significant than those simulated under steady-state conditions.

3. Another important factor to consider is that the 2010-2011 municipal water takings represent a reduced taking compared to historic conditions. Total pumping was closer to maximum permitted takings in the 2007 to 2009 period, for example. Thus, Scenarios G and H represent a return to historic conditions.

There is low uncertainty in the assignment of high tolerance to the local area. The high tolerance is due to the metres of additional drawdown in most wells, the integrated nature of the York municipal supply system, and the fact that a water supply pipeline from Lake Ontario is also available to meet municipal needs.

3.8.11 Tier 3 Significant Groundwater Recharge Areas

As discussed above, the Tier 3 model produced different estimates of the various water budget parameters as compared to the Tier 1 and 2 models. As the Tier 3 area only extends into a very small portion of the CLOSPA, however, the jurisdictional average that was used to delineate SGRAs in the CLOSPA Tier 1 analysis was not changed or recalculated for the whole of CLOSPA. The T3 recharge grid was used to re delineate the SGRA in the area that the model covers CLOSPA using the T1 jurisdictional average of 182mm. This use of a single value for all catchments is consistent with the methodology selected by CLOSPA for its Tier 1 study.

The differences are shown and discussed and presented in new mapping in Chapter 4 (Vulnerability) **Section 4.1.4**.

3.9 WATER BUDGET SUMMARY

Water budget analyses are required to determine the sustainability of drinking water supplies. The CWA (2006) is primarily concerned with “stress” (more demand than supply) as it relates to municipal drinking water supplies. Water budget analyses are nonetheless required to assess water quantity sustainability for all sources within the jurisdiction. These analyses for CLOSPA are done on a watershed basis where demand is reviewed against supply to determine where potential stress exists.

3.9.1 Tier 1 Water Budget

The Tier 1 **Water Budget** analysis in this Assessment Report assessed potential water quantity stress in both surface water (not including Lake Ontario) and groundwater.

Groundwater supplies in CLOSPA are used as a source of drinking water for private wells (5% of the population in the study area), and to support ecosystem functions. The surface water in streams in the study area is important for supporting the ecosystem, and is also used for irrigation and other non-drinking water purposes.

Lynde Creek and Darlington Creek watersheds were found to have moderate groundwater stress levels, and the Lynde, Goodman, Oshawa, Darlington, and Soper Creeks watersheds have significant surface water stress levels during summer months. All other catchments in the study area have low stress levels for both groundwater and surface water. Given that these stresses are not associated with municipal drinking water supplies, which are the focus of the *CWA* (*2006*), additional investigation and management will take place under the Conservation Authority Watershed Protection programs.

Since the *Technical Rules (2009)* exclude consideration of the Great Lakes in water budget stress assessment, Lake Ontario was not included in the water budget studies.

3.9.2 Tier 3 Water Budget

A York Region Tier 3 study conducted in 2013 for stressed watersheds where municipal wells are located however, identified a small area in CLOSPA that is within the delineated WHPA Q1/Q2 combined area as discussed in this Assessment Report. The summary for this study is as follows:

The water budget presented in the Tier 3 assessment provides an update to the estimates for TRSPA and other affected areas that were reported in the respective simplified Tier 1 and 2 assessments, including a small area in CLOSPA along its northwest boundary. The new analysis indicates that traditional definitions of the surface water and groundwater components of the water budget are limited because of the highly interconnected nature of the systems. Some takings, groundwater-fed ponds and golf course ponds (supported by a well), cannot be classified as either groundwater or surface water takings because they begin as an integrated capture of surface and groundwater, and often contribute to aquifer recharge downstream through stream leakage.

The numerical modelling indicates that cross-watershed groundwater flows are significant; suggesting that water management policies must include the broader areas surrounding the stressed watersheds.

Water demand in the study area is varied, complex and there is considerable uncertainty in many of the permitted and non-permitted uses. Continued efforts to quantify and monitor actual water use is essential.

The Tier 3 integrated GSFLOW model represents a significant improvement over previous Tier 1 and Tier 2 modelling efforts in the study area. The Model Development and Calibration Report (Earthfx, 2013b) covers all aspects of data compilation, conceptualization, model construction and calibration of the fully integrated SW/GW model used in this risk assessment. Significant improvements include:

- Construction of a comprehensive and updated SQL Server database;
- Extensive “data mining” to compile relevant information from numerous field investigations and measurements completed since the development of the Core Model;
- Significant improvements to the subsurface conceptual model including the sub-division of both the Newmarket Till and ORAC units;
- Representation of groundwater interaction and surface water routing throughout the entire 4,450 km York Region stream network;
- Improved representation of wetlands, lakes and the interaction between the shallow water table and soil zone infiltration processes;
- Full simulation of cascading overland runoff and interflow, including the effects of urbanization and focused recharge in the hummocky topography of the ORM;
- Extensive compilation, assessment and model representation of all daily surface water and groundwater takings in the study area; and
- Full transient calibration to both groundwater levels and total measured streamflow, spanning a period of average (2006), drought (2007) and wet year conditions (2008).

Of particular note is the extensive work to understand water use in the study area. Much time was devoted to cross-referencing permits, water takings and other water use information so as to best estimate and represent the water takings in the area. Municipal groundwater use dominates, but agricultural and golf course water takings are significant. Despite these efforts, additional measured actual takings are needed as the consumptive use estimates are still subject to many assumptions. Accurate estimates of water demand are essential to the overall water budget.

The Tier 3 GSFLOW model represents a truly integrated assessment of the surface water and groundwater processes in the study area. The individual forcing functions of long-term climate (dry year/wet year), seasonal: variation (particularly snowmelt response) and change in water demand on both a seasonal and longer-term basis are very complex and cannot be assessed independently. The GSFLOW model response indicates that each of the forcing functions, both individually and, in many areas, in a combined manner, produce significant local and regional scale changes in water levels, streamflows and the overall water budget.

The Risk Assessment indicates that the York Tier 3 Local Area is classified at a moderate risk because increases in pumping to meet allocated demand are predicted to create a greater than 1 m incremental drawdown in other permitted wells and under provincially significant wetlands.

The Tolerance of the Local area is classified as high. The uncertainty in the risk classification is low and the uncertainty in tolerance assignment is also low.

No model is, of course, perfect, and the following improvements could be implemented:

1. Long term fully integrated GSFLOW simulations could be undertaken as an improvement over the estimates from the uncoupled steady state simulations. Steady-state uncoupled analysis is limited.
2. Additional refinements to the representation of urbanization, including sewer lines, could be added.
3. A move towards an ecologically driven groundwater recharge assessment (ESGRA) is suggested in the Tier 3 study to complement ESGRA studies already completed in CLOCA under C.A. programs (outside of the SWP initiative). Every effort should be made to eliminate the use of general consumptive use factors. Major takings, including irrigation, should be quantified and fully simulated.
4. Other long term water level and pumping tests, such as the 16th Avenue Sewer Construction program, could be assessed as a verification of the model.
5. The water quality WHPA assessment should be updated to reflect the improved understanding of the local geology and interconnected groundwater/surface water system.
6. The drought simulations, and drought re-allocation rates, reflect the operational flexibility available to York Region. The simulations reflect the changes in operations that could be implemented at the onset of a drought. Additional study and simulations are necessary to determine the triggers (e.g., decrease in precipitation or decline in groundwater levels), and to optimize drought response needed to maintain safe available drawdown.

It should be noted that the area of concern is very small in CLOSPA.