Graham Creek Background Report: Abiotic, Biotic and Cultural Features

for preparation of the
Graham Creek Watershed Plan

October 2009

Prepared by Ganaraska Region Conservation Authority

The Graham Creek Background Report: Abiotic, Biotic and Cultural Features was written to document the historical and current conditions of the Graham Creek watershed, and creates the foundation of the Graham Creek Watershed Plan. The Ganaraska Region Conservation Authority would like to thank the many seasonal staff that provided field assistance and the landowners who granted permission to collect data from their property.

This document was written by Ganaraska Region Conservation Authority (GRCA) staff members Pam Lancaster, B.Sc., Jenny Dai, M.Eng., Brian Morrison, B.Sc., Mark Peacock, P.Eng., Mike Smith, B.Sc., Ken Towle, M.E.S., and Magdi Widaatalla, M.Sc., P.Geo. for the residents, communities, municipalities and stakeholders of the Graham Creek watershed. Maps were created by the GRCA GIS Department, Brian Curran, B.Sc., Steve Nowak, B.A. and Jeff Moxley. This document represents the first of its kind for the Graham Creek watershed and complements the 1966 and 1976 Ganaraska Region Conservation Reports (Department of Energy and Resources Management 1966, Ontario Ministry of Natural Resources 1976). Certain sections of this report have been summarized from peer reviewed or consultant documents, and review and input into this document by committee members, stakeholders and residents has occurred in 2009.

The Ganaraska Region Conservation Authority envisions that this document will serve to aid in the conservation, enhancement and sustainable management of the Graham Creek watershed and its resources.

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Ganaraska Region Conservation Authority. 2009. Graham Creek Background Report: Abiotic, Biotic and Cultural Features. Ganaraska Region Conservation Authority. Port Hope, Ontario.

The Graham Creek Background Report: Abiotic, Biotic and Cultural Features Executive Summary

The Graham Creek Background Report: Abiotic, Biotic and Cultural Features documents historic and current conditions of the Graham Creek watershed. This document creates the foundation for the Graham Creek Watershed Plan. It is envisioned that the Graham Creek Background Report and the forthcoming Graham Creek Watershed Plan will serve to aid in the conservation, enhancement and sustainable management of the Graham Creek watershed and its resources.

The Graham Creek watershed flows through Ward 2 of the Municipality of Port Hope in Northumberland County and Ward 4 of the Municipality of Clarington in the Regional Municipality of Durham (Figure 1). Historic events have shaped the watershed into present-day condition. Most notable are the effects of settlement patterns caused by the location of road and rail corridors. Today, the watershed supports a population of 3,538 people, a productive agriculture community, and a mix of natural resources and recreational uses. In addition, residents depend on water from the watershed for domestic and economic use, although the residents in Newcastle rely on Lake Ontario for its source of water.

Shaped thousands of years ago by glacial activity, the Graham Creek watershed lies on Paleozoic bedrock, and its topographic and hydrogeological features include the Oak Ridges Moraine, the South Slope and the Iroquois Plain physiographic regions (Figure 2). Corresponding surficial geology and soils help dictate where groundwater flows, where aquifers lie, and where groundwater is recharged and discharged (Figures 3 and 4).

The Graham Creek watershed drains an area of 78 square kilometers (km^2). Mulligan Creek is the largest tributary of Graham Creek; however other tributaries such as Crooked Creek and Lytle Creek also exist. Protection of the Graham Creek watershed has been influenced by surface water studies such as floodplain mapping and hydraulic studies. Regulations are also in place to protect people and property from flood waters, and to protect some of the natural features of the watershed.

Surface water quality as a whole in is generally good, with only localized problems. Physical parameters (dissolved oxygen, pH, conductivity and alkalinity) indicate that surface water quality can be resilient to acidification, eutrophication and chemical additions. Chloride has been increasing since 1965, as indicated at a long-term provincial monitoring station. Nutrients such as total phosphorus and nitrate-N can be considered the surface water quality parameter most capable of fluctuating beyond recommended guidelines. However, there has been a decline in total phosphorus since 1965 at the long-term provincial monitoring station, and exceedances may be related to high runoff due to storm events or land use. Groundwater quality data is limited in the Graham Creek watershed, however quality is influenced by geology and land uses in the area.

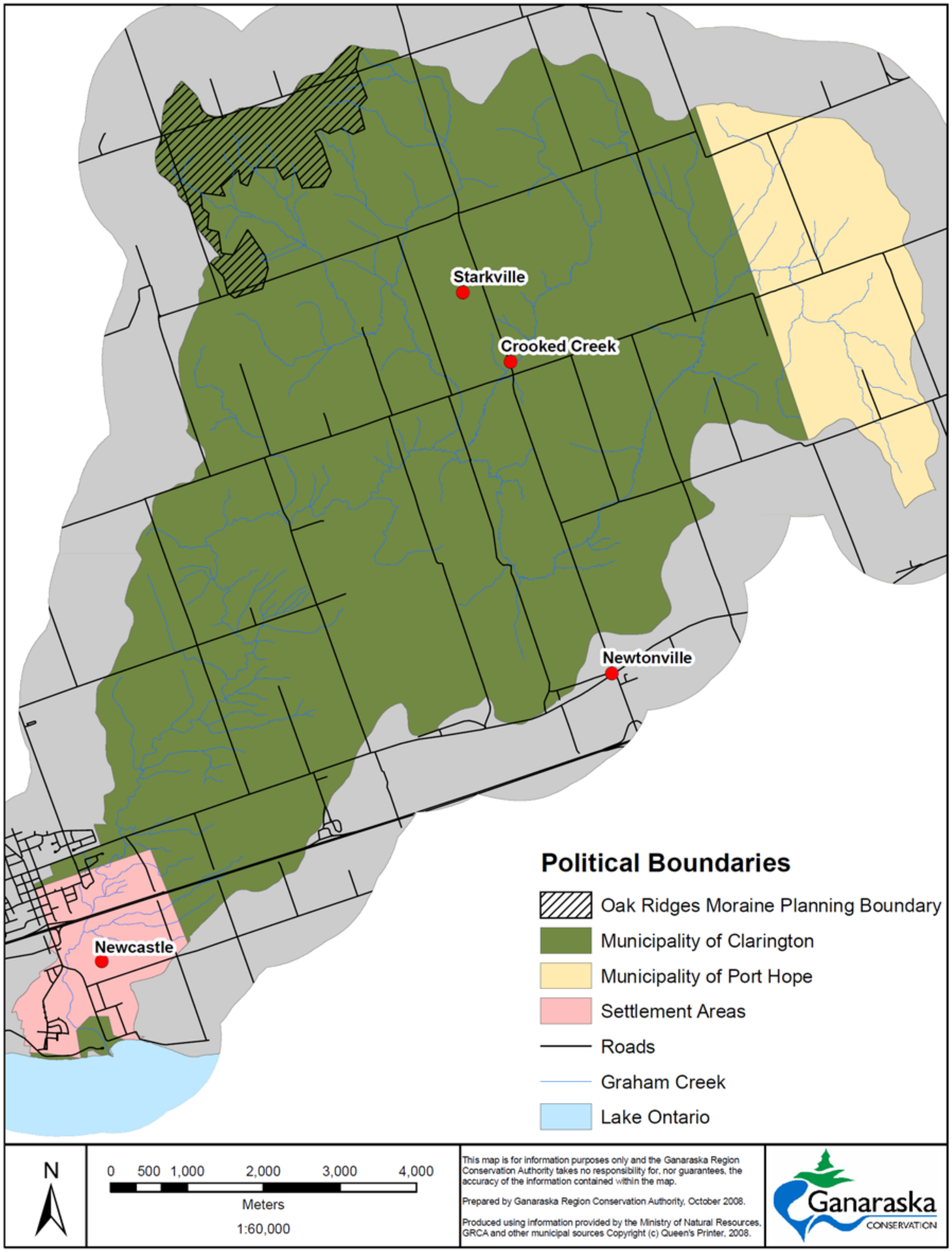


Figure 1: Graham Creek watershed

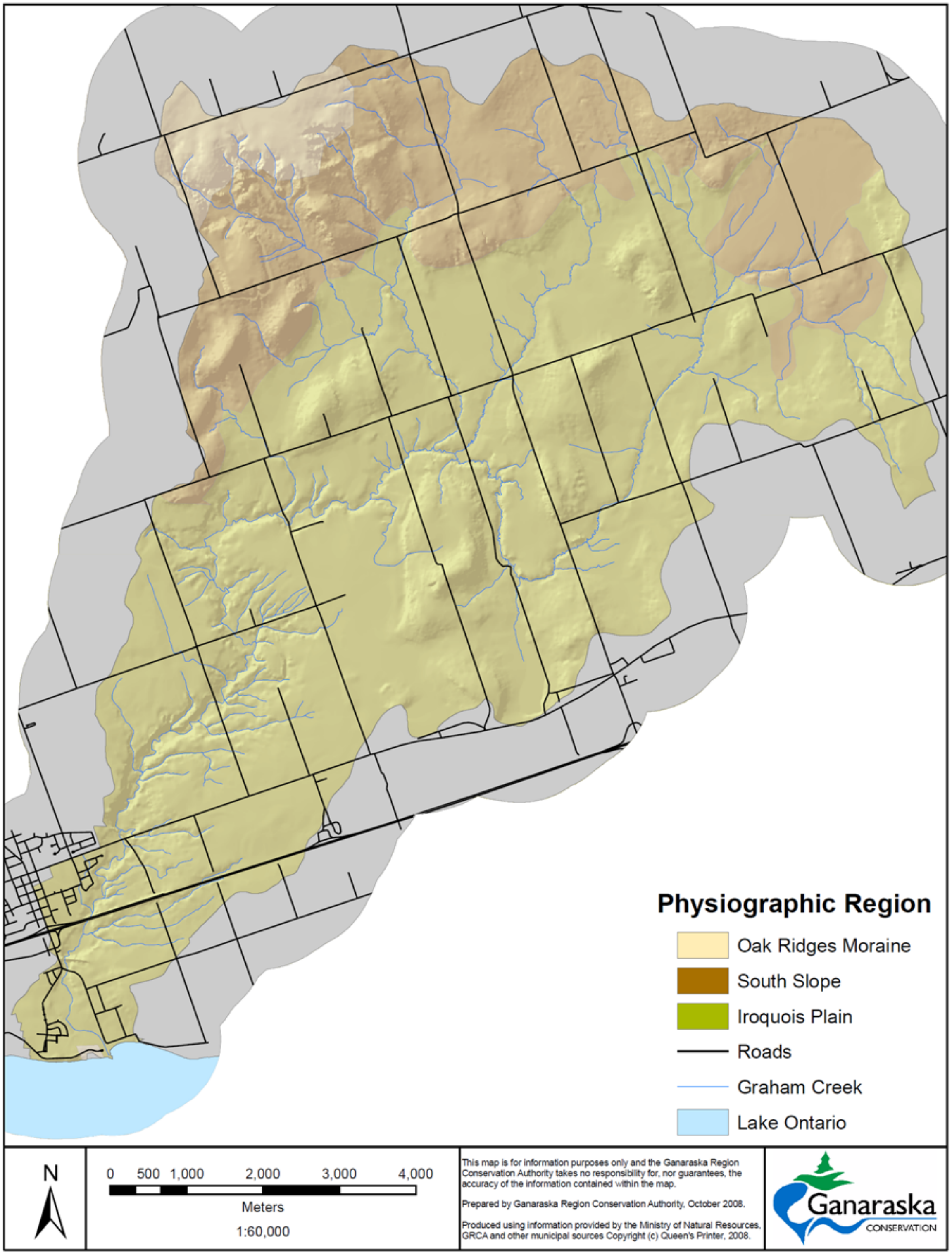


Figure 2: Physiographic regions

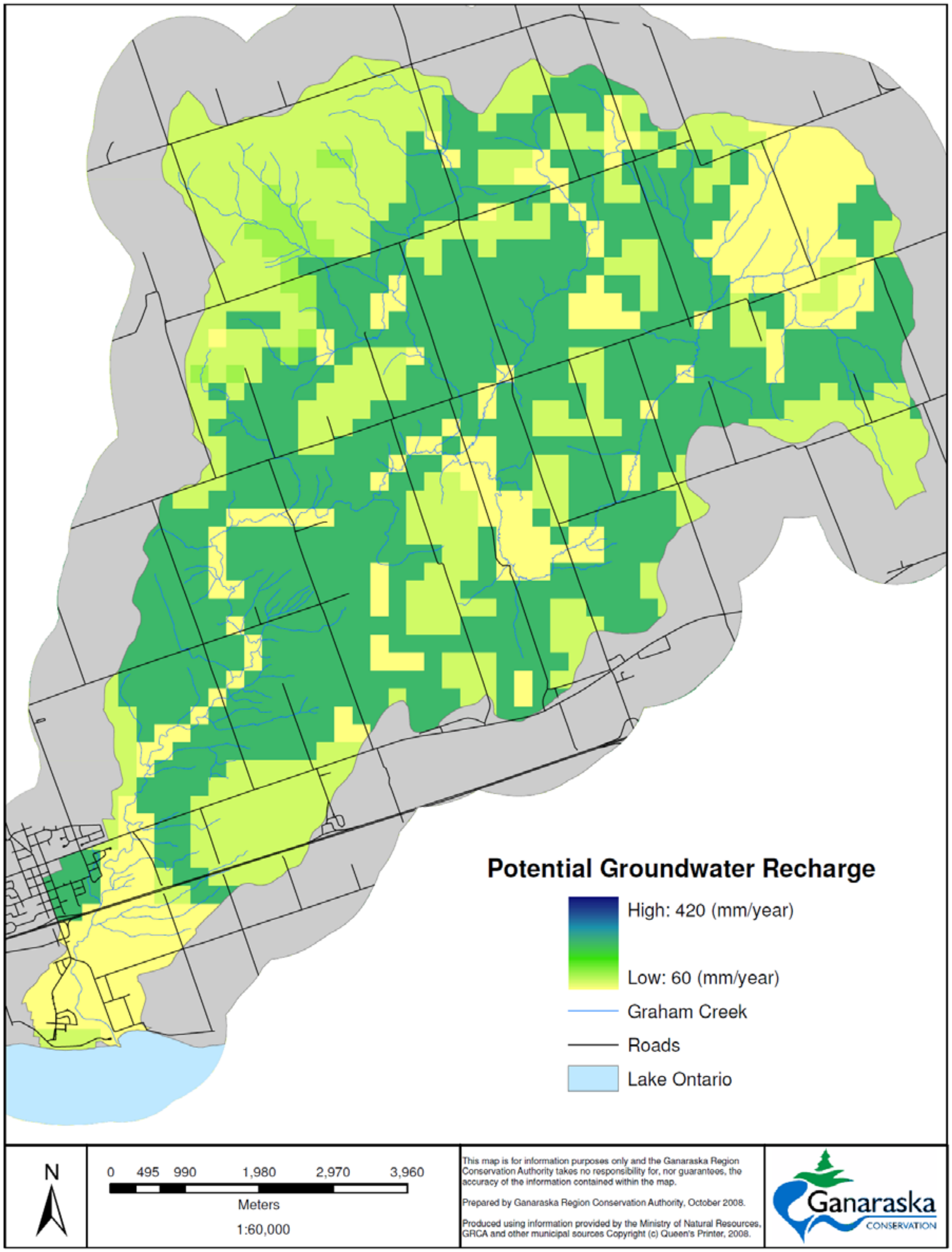


Figure 3: Potential groundwater recharge

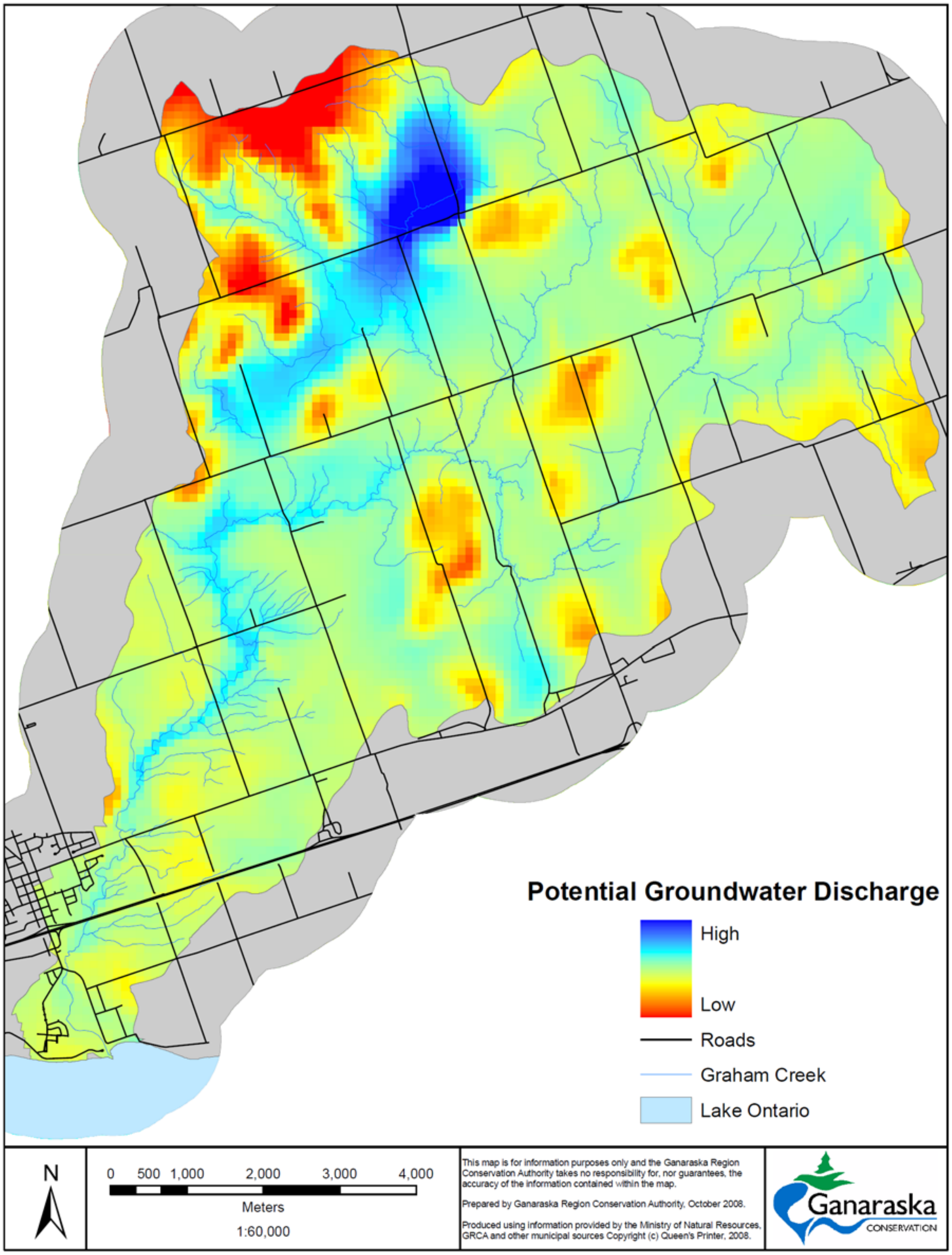


Figure 4: Potential groundwater discharge areas

40 species of fish have been sampled in the Graham Creek watershed. Five or 13% of the species are not native to the Lake Ontario basin. Stream quality based on Steedman's IBI calculated one site being excellent (6%), 11 sites good (69%), four sites fair (25%), and zero (0%) poor sites (Figure 5).

The terrestrial natural habitat of the Graham Creek watershed includes forest, meadows and wetlands (Figure 6). At 35%, forest cover, which includes treed wetlands, exceeds the commonly used guideline of 30%. However, higher quality interior forest habitat is found in only about 23% of the watershed. In addition, much of these natural heritage features are in private ownership. Indicator species such as birds and frogs can indicate the health of forest and wetland habitats. Numerous Species at Risk may inhabit the Graham Creek watershed and therefore should be considered in management planning. Invasive species such as Dog-strangling Vine (*Cynanchum rossicum)*, European Buckthorn (*Rhamnus cathartica)*, and Garlic Mustard (*Alliaria petiolata)* pose a threat to terrestrial habitat health.

The Graham Creek watershed is not only an important environmental feature to the communities of the Municipality of Clarington and Municipality of Port Hope; it also plays an important role in a larger context. For example Graham Creek contributes to the health and resources of Lake Ontario. In addition, Lake Ontario is a drinking water source for thousands of Ontario residents. However, the watershed has the potential to be influenced by future stresses such as climate change.

The Graham Creek watershed is recognized for its aquatic habitat, terrestrial natural heritage, and recreational opportunities. In addition, the watershed provides drinking water to the majority of watershed residents. The development of a watershed plan will aim to conserve and sustainably manage the Graham Creek watershed for current and future generations.

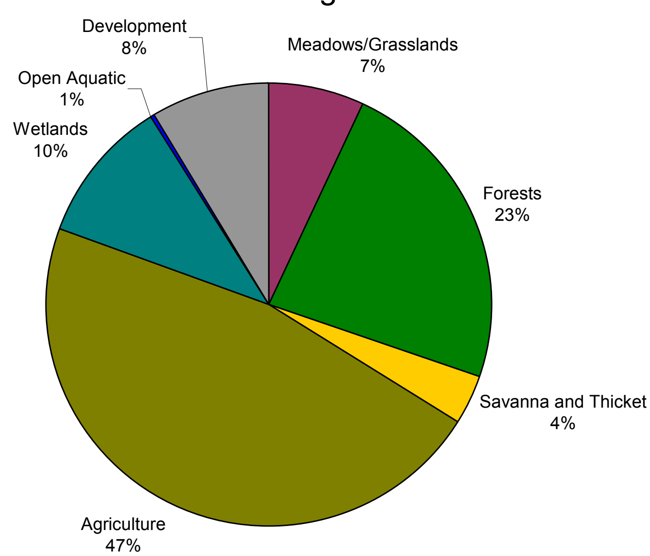
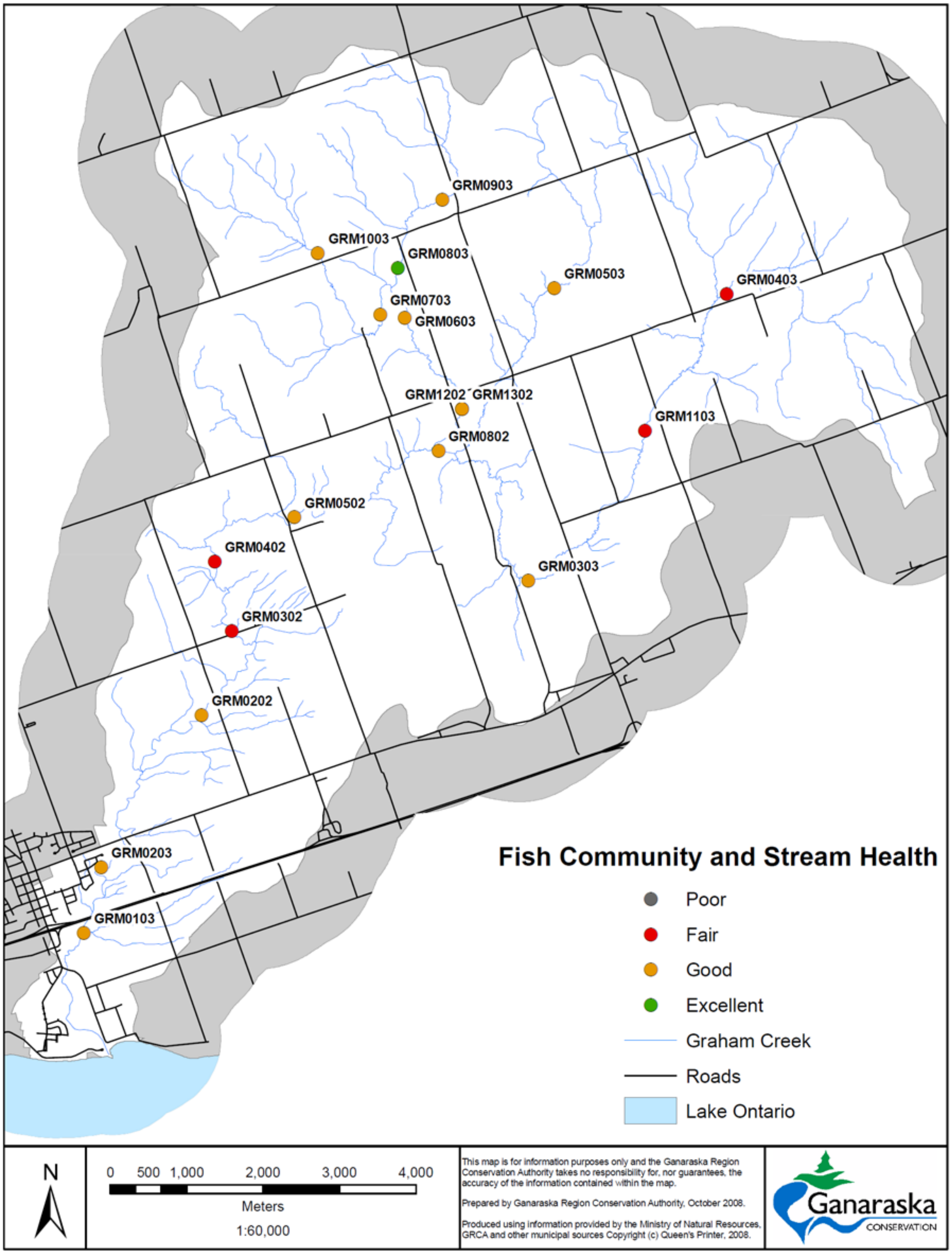


Figure 6: Land cover based on ecological land classification



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1.0 GRAHAM CREEK WATERSHED PLAN

Throughout the Province of Ontario there is a need to manage and plan for the appropriate use of our natural environment and its resources. As development continues across the landscape, sustainable management and planning of human settlement is required to ensure that current and future actions do not degrade, alter or destroy the natural environment. A watershed plan is one way to ensure that current and future generations are able to progress while acknowledging and addressing effects on the local ecosystem.

The study area of a watershed plan is a watershed: an area of land that drains to a common body of water. Watersheds are defined by topographical boundaries and may cross political jurisdictions. The Ganaraska Region Conservation Authority (GRCA), formed in 1946, was established to manage local watersheds including Wilmot Creek, Graham Creek, Ganaraska River, Gages Creek, Cobourg Creek, and smaller streams draining to Lake Ontario and Rice Lake (Figure 1.0).

The Graham Creek watershed in the Ganaraska Region Conservation Authority drains to Lake Ontario (Figure 1.0) as it passes through the Municipality of Port Hope and Municipality of Clarington. The Graham Creek watershed has been delineated by the topography. Heights of land form the drainage basin in the rural areas of the watershed. In the lower reaches, urban drainage that discharges through storm sewers and along roads into Graham Creek is considered part of the watershed (Figure 1.1). A watershed is a logical environmental planning area, given that many natural functions are interconnected. Natural cycles in a watershed need to be protected for the benefit of our local environment and community.

In 2001 the Province of Ontario enacted the *Oak Ridges Moraine Conservation Act*, which in 2002 established the *Oak Ridges Moraine Conservation Plan*. The purpose of the *Oak Ridges Moraine Conservation Plan* is to provide land use and resource management planning direction to provincial ministers, ministries, agencies, municipalities, municipal planning authorities, landowners and other stakeholders on how to protect the Moraine's ecological and hydrological features and functions (Ontario Ministry of Municipal Affairs and Housing 2002).

As a result of the legislated requirements of the *Oak Ridges Moraine Conservation Plan*, the Regional Municipality of Durham and Municipality of Clarington require a watershed plan to be created for the Graham Creek watershed, which originates on the Oak Ridges Moraine. Graham Creek in the Municipality of Port Hope does not originate on the Oak Ridges Moraine; however the municipality is engaged in active watershed management, requiring a watershed plan to be created to aid in local planning and management decisions.

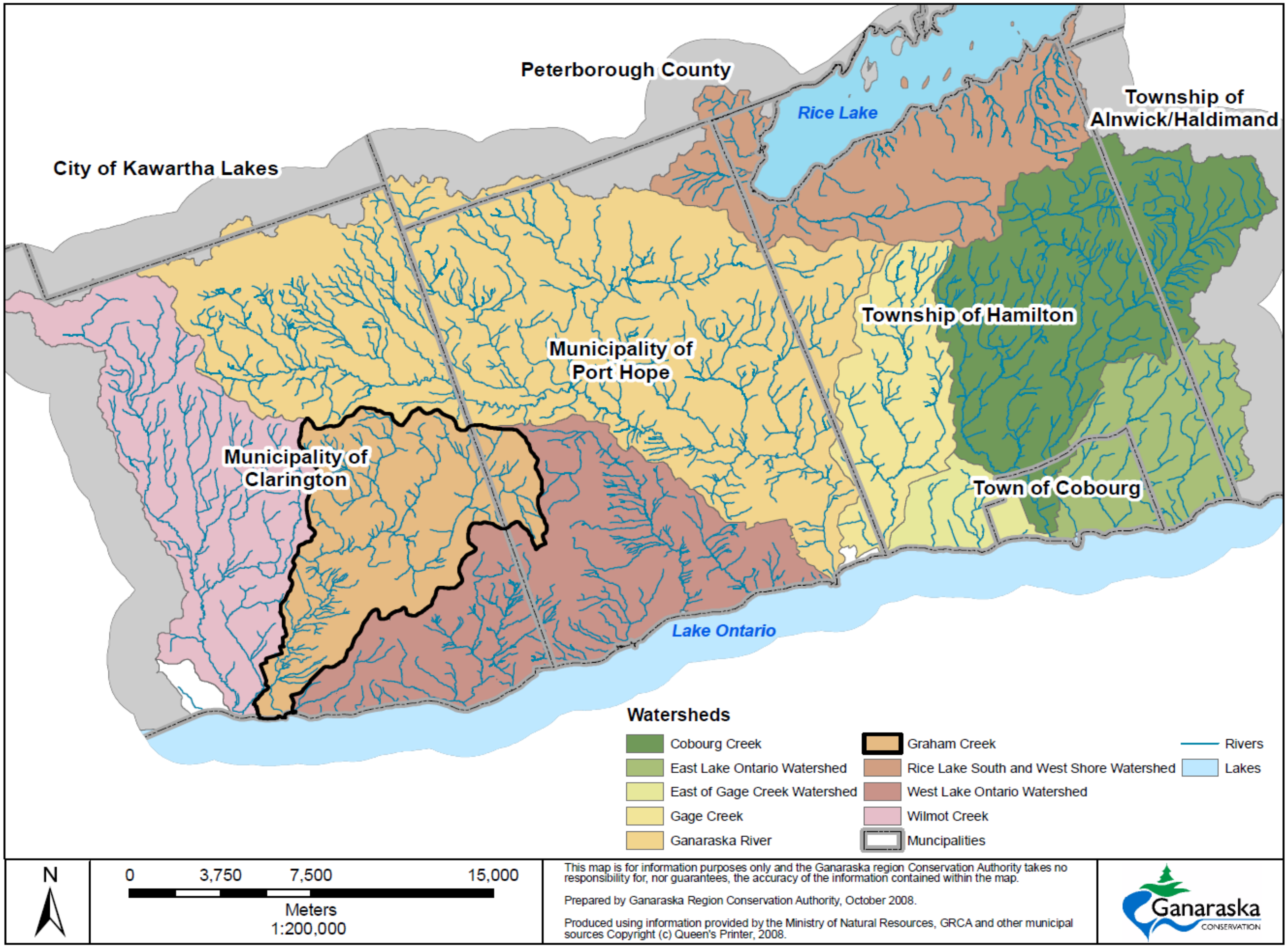


Figure 1.0: Graham Creek watershed in the Ganaraska Region Conservation Authority

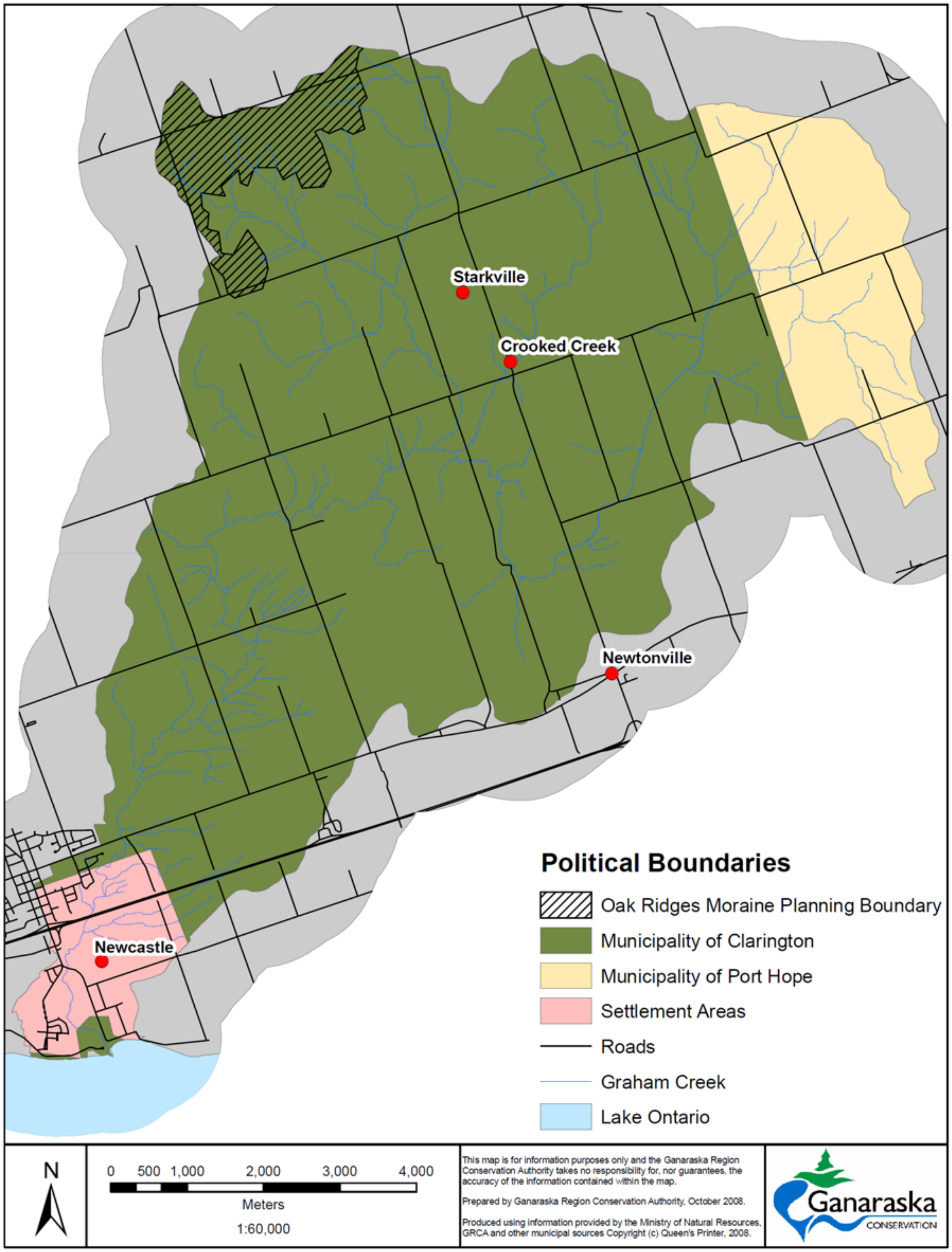
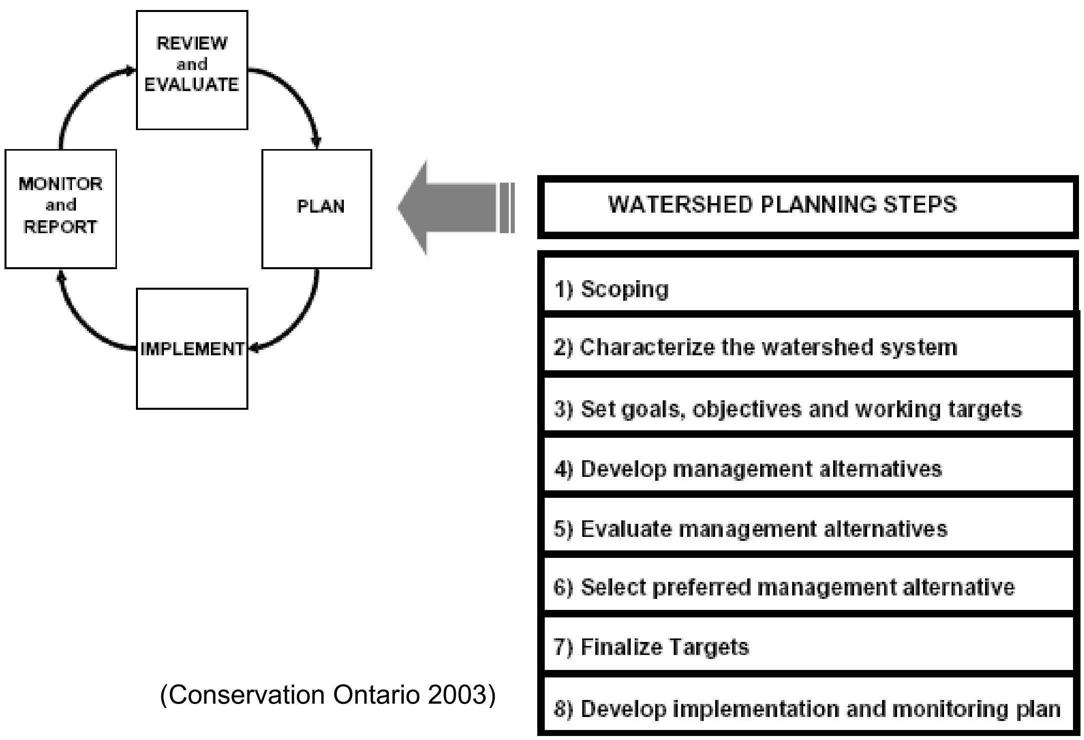


Figure 1.1: Graham Creek watershed

1.0.1 Watershed Planning Process

The watershed planning process is one stage in the ongoing process of watershed management. The basic principles of watershed management have changed little since formally described in the early 1990s (Ontario Ministry of Environment and Energy and Ministry of Natural Resources 1993). As illustrated in Figure 1.2, the process of watershed management has four phases, including plan development; plan implementation; monitoring and reporting; and reviewing, evaluating and updating the plan. Conservation authorities in Ontario commonly follow this process, although each authority may have slightly different terminology associated with individual steps, suited to local watershed needs.

Watershed plans are usually prepared in response to a trigger, such as public concern about environmental conditions, a municipal Official Plan requirement, or, as in this case, the requirements set out by the *Oak Ridges Moraine Conservation Act*.



(Conservation Ontario 2003)

Figure 1.2: Watershed management phases and watershed planning steps

The “plan” phases can be described according to eight steps as shown in Figure 1.2. The key to success is public, community and stakeholder input into milestone steps (e.g., characterization and alternative steps). Steps 1 and 2 have been completed. Scoping requires choosing a study area, creating a terms of reference and managing data. A Terms of Reference has been created for the Graham Creek Watershed Plan process (Ganaraska Region Conservation Authority 2005, updated in 2009).

Characterizing the watershed describes the history and current conditions of the study area. This document reflects the characterization step of the Graham Creek watershed plan process. It contains current information for making informed management decisions regarding the conservation and environmentally sound management of the watershed, and creates the foundation for the Graham Creek Watershed Plan.

The Graham Creek Watershed Plan will address steps 3 to 8. Based on the information presented in this document, as well as computer models used to evaluate the watershed's response to alternative land use management scenarios, the Graham Creek Watershed Plan can be created. Current information and model results will be used to develop the plan containing recommendations, implementation strategies, and roles and responsibilities. The plan will also address requirements of the *Oak Ridges Moraine Conservation Act*. The watershed plan will be completed in late 2009 or early 2010.

1.0.2 Graham Creek Fish Habitat Management Plan

While the Graham Creek watershed plan is being created, a Fish Habitat Management Plan is being developed. The Fish Habitat Management Plan, the Graham Creek Watershed Plan and respective background documents will be created simultaneously. This will make certain that results and information presented in the documents will complement each other and avoid unnecessary duplication. In addition to ensure that public and stakeholder consultation and involvement is effective, public meetings and consultation of both background documents and plans will occur at the same time. The end result of both plans will be the conservation, enhancement and proper management of the Graham Creek watershed and its resources, with emphasis and focus on the biotic aquatic resources in the Fish Habitat Management Plan.

1.0.3 Lake Ontario Shoreline

In the late 1980s focus was given on the Lake Ontario shoreline in relation to land use, hazard land identification and proper management. Sandwell Swan Wooster Incorporated (1990) completed a Lake Ontario Shoreline Management Plan for the Central Lake Ontario, Ganaraska Region and Lower Trent Region Conservation Authorities. The overall objective of the study was to develop a comprehensive shoreline management plan to allow the Conservation Authorities to implement long-term development objectives. Sandwell Swan Wooster Incorporated (1990) listed specific objective of the study that were intended to:

- Establish a program for the prevention of flooding and erosion damages and the protection of existing development from flooding and erosion.
- Evaluate hazard areas, investigate littoral processes, and to identify and assess potential damage centres and protection strategies along the shoreline.

- Provide background information useful to planning authorities in developing waterfront plans.
- Assess the characteristics of the shoreline including sensitive areas, recreational opportunities, wildlife habitat and the Lake Ontario fishery in terms of potential use or preservation of these resources.
- Determine the optimum management strategy for the shoreline in terms of flood and erosion mitigation and other resource management concerns.
- Identify the role of Conservation Authorities and that of other relevant agencies in managing the shoreline.

Along with the identification of erosion setback limits, 100-year flood lines, erosion rates, sediment characteristics, damage centres and erosion monitoring stations, Sandwell Swan Wooster Incorporated (1990) recommended the following actions, many of which have been enacted:

- Municipalities should recognize shoreline hazard lands in appropriate official plan and zoning provisions.
- Measures should be taken to protect environmentally sensitive areas along the shoreline.
- Acquisition of the shoreline should be considered in order to protect the environmental characteristics, and acquired lands should include the limits of erosion and/or flooding setbacks.
- Implementation of shoreline protection structures should be examined on a site-specific scale, and carried out using coastal engineering studies.
- Conservation Authorities should operate existing shoreline monitoring stations and establish additional sites.

Specific and additional information regarding the Lake Ontario shoreline in the Graham Creek watershed is found in Sandwell Swan Wooster Incorporated (1990) and in section 4.1.7 of this document.

Massey Building, Newcastle

Chapter 2 – History of Graham Creek Watershed

2.0 CULTURAL HISTORY OF THE GRAHAM CREEK WATERSHED

Historical settlement patterns, communities and natural resource uses play an important role shaping current communities, land resources and natural environments. Understanding historical events will aid in understanding current land uses and settlement areas. This understanding will guide management decisions while appreciating local history.

2.0.1 Settlement

Prior to European settlement, numerous aboriginal groups inhabited the region around and in the Graham Creek watershed. The Hurons resided in the region from Lake Ontario to Georgian Bay until the late 1600s, when the Iroquois forced the Hurons to move as far north as Lake Superior (Martin et al. 1986). After 1660 the Cayuga tribe of the Iroquois established outposts in the Rice Lake area and at Ganaraska (Port Hope), thus controlling the fur trade in the area. In the early 1700s the Iroquois were forced out of the surrounding area by the Mississaugas, a stem of the Ojibwa-Algonkins from the Lake Superior region (Martin et al. 1986). The Mississaugas did not settle in any one place, and were nomadic in the area (Schmid and Rutherford 1976).

Clarke Township was first surveyed in 1791, followed by the first settlers arriving in the late 1790s (Schmid and Rutherford 1796). The main settlement areas in Graham Creek included Newcastle, Newtonville, Starkville and Crooked Creek. Newcastle was settled in the early 1800s, yet merged with the neighbouring community of Bond Head in 1851 (Schmid and Rutherford 1976). Newcastle was founded on industry, with the most prominent business being Newcastle Agricultural Works. The Newcastle Agricultural Works in 1849 manufactured plows, scufflers, harrows, potash, and sugar kettles (Schmid and Rutherford 1976). In 1864 the business burnt down, but being a necessary employer in the community was rebuilt. By 1868 the Massey family employed more than 100 men and established 20 agencies in Ontario (Schmid and Rutherford 1976). In 1891 the company amalgamated with Harris Implement to become Massey Harris and latter Massey-Ferguson.

In 1872, the Newcastle Woollen Manufacturing Company, one of the largest woollen mills in Upper Canada was located in Newcastle, and employed 60 people (Schmid and Rutherford 1976). However times changed, the woollen mill burned, the Massey family moved to Toronto, and the loss of Northrop and Lyman, which later become the largest dealers in patent medicines (Schmid and Rutherford 1976). The most populous settlement area of Clarke Township slowly declined due to the numerous setbacks faced by the community.

Newtonville was settled in 1839, and was called Clarke Village from time to time (Schmid and Rutherford 1976). The population of Newtonville increased to 450 people in 1863, but by 1869 the population declined to 200, with the emigration of resident to western Canada (Schmid and Rutherford 1976). Newtonville was an important travel route stopover with taverns, store and blacksmiths.

Starkville is located in the centre of the Graham Creek watershed and was named after its first settlers, the Stark Family, who among others settled there in 1842 (Schmid and Rutherford 1976). This village contained a post office, store, and school. The Canadian Northern Railway passed one mile south of Starkville, and was the location of the Starkville station (Schmid and Rutherford 1976). Crooked Creek is located on the crossroads between Newtonville and Starkville. It contained a general store, and was the site of the last sawmill in Clarke Township (Schmid and Rutherford 1976).

2.0.2 Historical Natural Resources

When settlers arrived in Clarke Township, black walnut grew along the shores of Lake Ontario, cedar swamps lined the wet lowlands, and the uplands were covered with maples, beech, white pine, and oaks (Schmid and Rutherford 1976). Among the forests and swamps, wildlife was abundant and fish were plentiful in the streams. Large predators were also inhabited the Graham Creek watershed including bears and wolves (Belden and Company 1974). Once settlers harvested their shelter and food requirements from the plentiful flora and fauna in the area, they moved onto harnessing water power for milling. In 1848, five mills were located on Graham Creek (Figure 2.0).

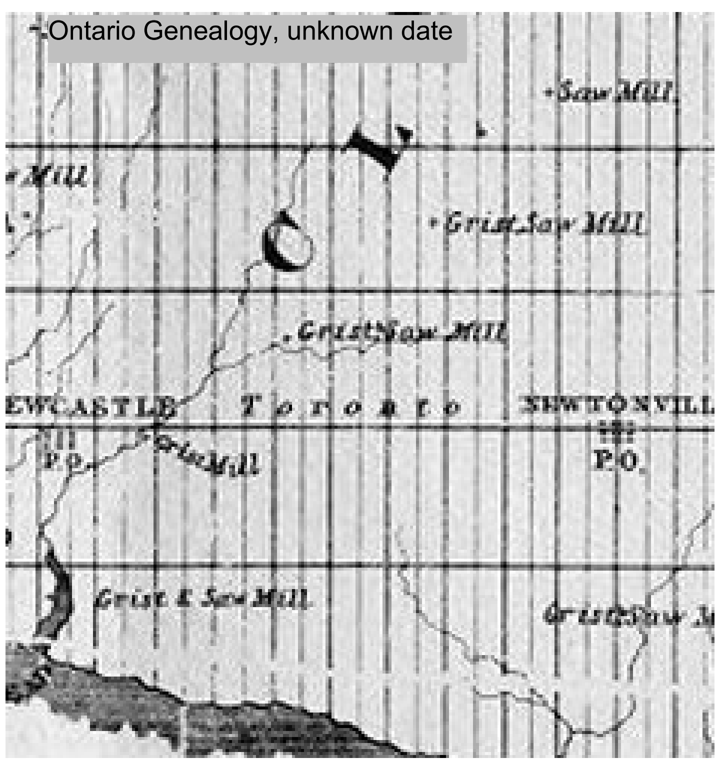


Figure 2.0: Locations of dams on Graham Creek in 1848

Forestry was also a large economic component of Clarke Township. In order to clear the land for agriculture, which was the main motivation of the settlers, large tracts of land were harvested for timber. In fact Newcastle was one of the chief wood depots east of Toronto with thousands of cords of wood loaded on boats at the Port of Newcastle every year for use in Toronto (Schmid and Rutherford 1976). As forests were removed and replaced with wheat and fruit trees, the landscape was altered and forced to adapt. Deforestation created open land on the high ridges of the area, however, over the years, the erosion and the leaching of nutrients from the fields cause the farms on the ridge [Oak Ridges Moraine] to be abandoned (Schmid and Rutherford 1976).

2.0.3 Changing Landscape

Rail travel helped shaped the current day natural landscape. In 1856 the Grand Trunk Railway connected Toronto to Cobourg (Richardson 1944), thus changing the travel corridor to the south end of Graham Creek. The railway provided for diverse employment in Clarke Township. Much of the timber harvested was used to fuel the steam locomotives. Today the Canadian National Railway operates on in the same track corridor, moving freight and passengers on two sets of tracks through Newcastle, and the south end of Graham Creek.

The Canadian Northern Railway company constructed a railway that ran through the middle of the Graham Creek watershed. In October of 1911 the Canadian Northern Railway opened passenger services, with the Orono Station in Wilmot Creek being a prominent stop, and by 1917 the boom of freight and passenger service was realized (Schmid and Rutherford 1976). A second station occurred at Starkville in the Graham Creek watershed, but after 20 years of operation, the station was closed (Schmid and Rutherford 1976). In 1919 the Canadian Northern and Grand Trunk Railway companies amalgamated, causing the lakeshore route to be the main passenger service line, and the construction of a second track along the lakeshore route (Schmid and Rutherford 1976).

As with any settlement, the natural environment is changed through the use and exploitation of natural resources and the transformation of land from forests to agriculture, or wetlands to towns and villages. Figure 2.1 depicts a timeline of the events that transformed the wetlands and forests of the Graham Creek watershed to the towns and villages we se today. Today the Graham Creek watershed is different from the pre-settlement days, both in appearance and in the natural resources that exist.

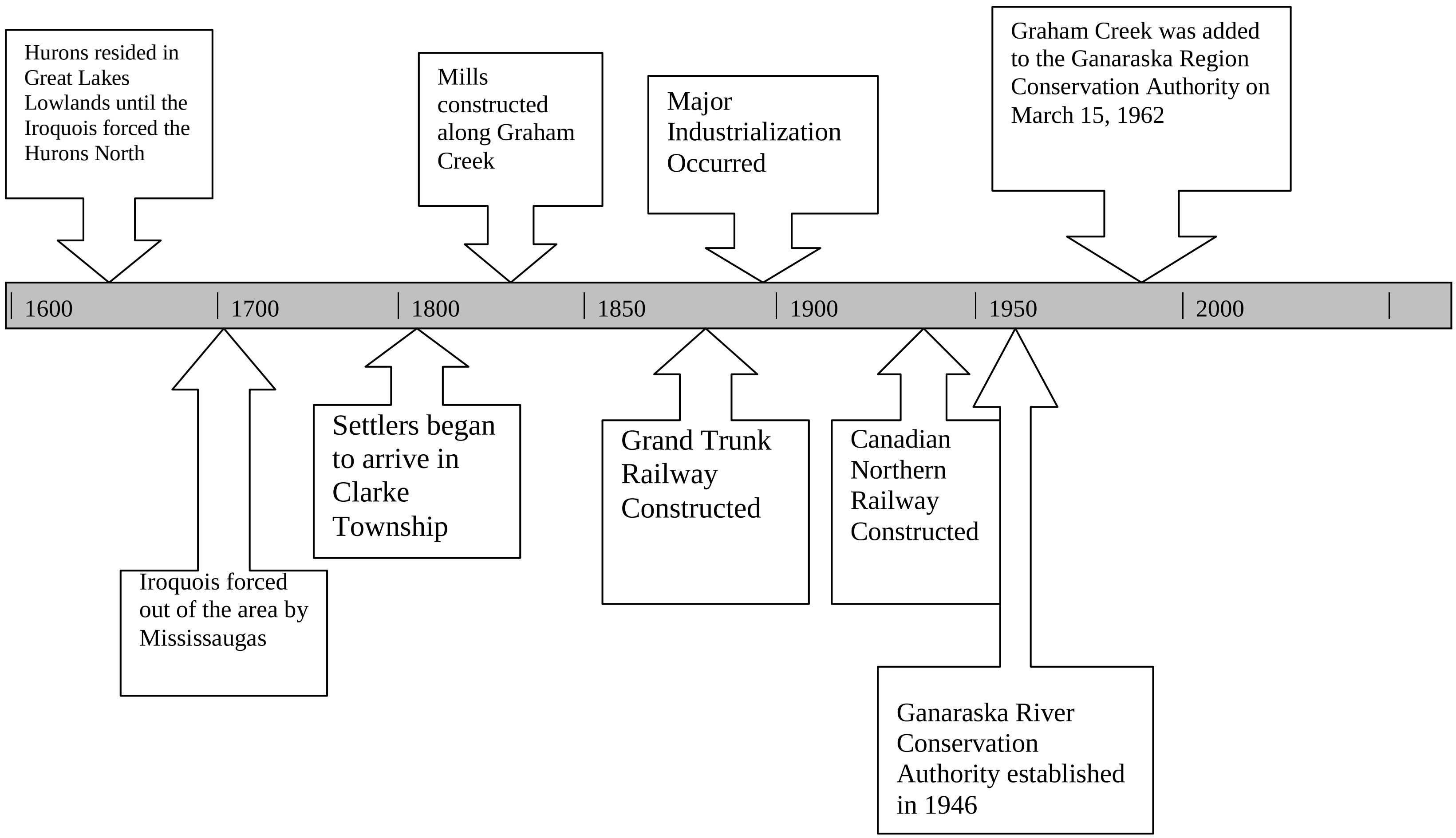


Figure 2.1: Post settlement events in the Graham Creek watershed

Chapter 3 - Abiotic Features

3.0 Regional Climate

Climatic elements such as precipitation (rain and snow), evaporation and temperature have a dominant effect on various components of the hydrologic cycle (Figure 3.0). Understanding these elements and their patterns plays a key role in developing water budgets and understanding how natural systems will respond to changes in climate and drought conditions. The climate of an area depends on its location within the worldwide circulation of the atmosphere. Local climates may also be profoundly affected by the proximity of an area to large water bodies and local topographic relief.

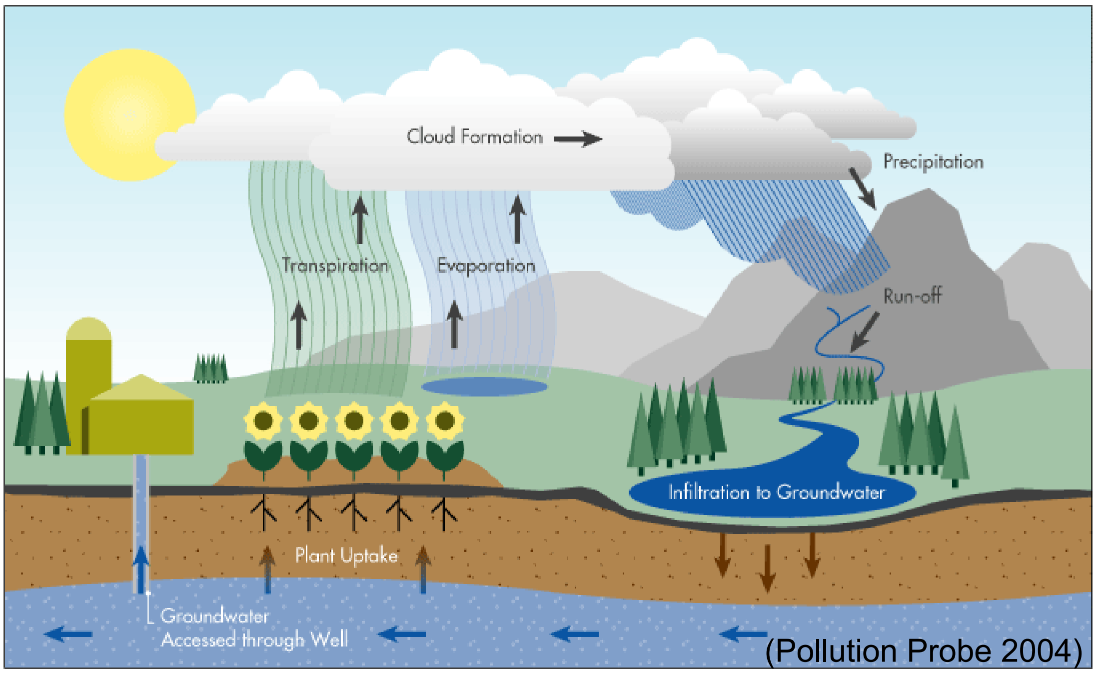


Figure 3.0: Hydrologic cycle

Topography influences local temperature and precipitation. Average annual temperature and precipitation show only minor variation across the Ganaraska Region Conservation Authority due to the small geographic scale. The climate in the Ganaraska Region Conservation Authority is continental, with cold winters and warm summers. The most significant factor affecting the climate is Lake Ontario. A definite moderating effect due to lake influence is seen in the immediate vicinity of the Lake Ontario shoreline, while the modification in climate diminishes as one ascends the northern inland slopes. On the Oak Ridges Moraine the climate is colder, exhibiting harsher winters and later springs than the rest of the drainage area.

Climate data from Environment Canada is available from 20 stations in (four stations) and nearby the Ganaraska Region Conservation Authority and can be used to determine precipitation and temperature and estimate infiltration and evapotranspiration. In addition to the climate data from Environment Canada, the

Ganaraska Region Conservation Authority operates five meteorological stations (Figure 3.1 and Table 3.0) that provide 15-minute interval climatic data. In 2008 rain gauges were installed on three Provincial Groundwater Monitoring Network wells. These wells are located near Leskard in Wilmot Creek, on Newtonville Road in Graham Creek and in the Rice Lake Conservation Area (Figure 3.1). Data is not yet available for these rainfall stations.

According to the climatic information provided (Table 3.1), the mean annual daily temperature in the Ganaraska Region Conservation Authority ranges from about 5.9 to 7.3° Celsius (C). January is the coldest month with mean daily temperatures in the -8°C range. July is the warmest month, with a mean daily temperature of approximately 20°C.

According to climate data from several local Environment Canada climate stations, precipitation in the Ganaraska Region Conservation Authority shows local variation (Figure 3.2). In the lakeshore region the mean annual precipitation varies from 755 to 830 millimetres (mm), while on the northern upland slopes it varies from 875 to 900 mm. There is greater precipitation (up to 1000 mm) on the Oak Ridges Moraine upland area than on the slope and low regions of the Ganaraska Region Conservation Authority.

Precipitation varies seasonally, with the September to December period generally being the wettest. Between December and March most precipitation falls as snow, whereas in the months of November and April precipitation is mixed, with most being rain. Depending on location, either February or July is typically the driest month of the year, however in 2009, the month of February received more rainfall than normal. The mean annual precipitation ranges from about 830 mm/year at Port Hope in the south to about 880 mm/year in Orono in the west. About 70 to 85% of precipitation falls as rain. Figure 3.3 and Figure 3.4 show the annual meteorological trends based on the records of two meteorological stations in and near the Ganaraska Region Conservation Authority.

Table 3.0: GRCA-operated climate stations

Station Name	Location	Year Established	Type of Measurements
GRCA Main Office	2216 County Road 28, Port Hope	2002	Rainfall, Air Temperature, Wind Speed and Direction, Relative Humidity
Cobourg Creek*	609 William Street, Cobourg	2003	Rainfall, Air Temperature
Wilmot Creek	Concession Road 3, Newcastle	1999	Rainfall
Forest Centre	10585 Cold Springs Camp Road, Campbellcroft	2001	Rainfall, Snowfall, Air Temperature, Wind speed and Direction
Baltimore Creek	4494 County Road 45, Baltimore	1999	Rainfall, Air Temperature, Wind Speed and Direction

*Replaced the Cobourg Pump Station climate station that operated since 2000.

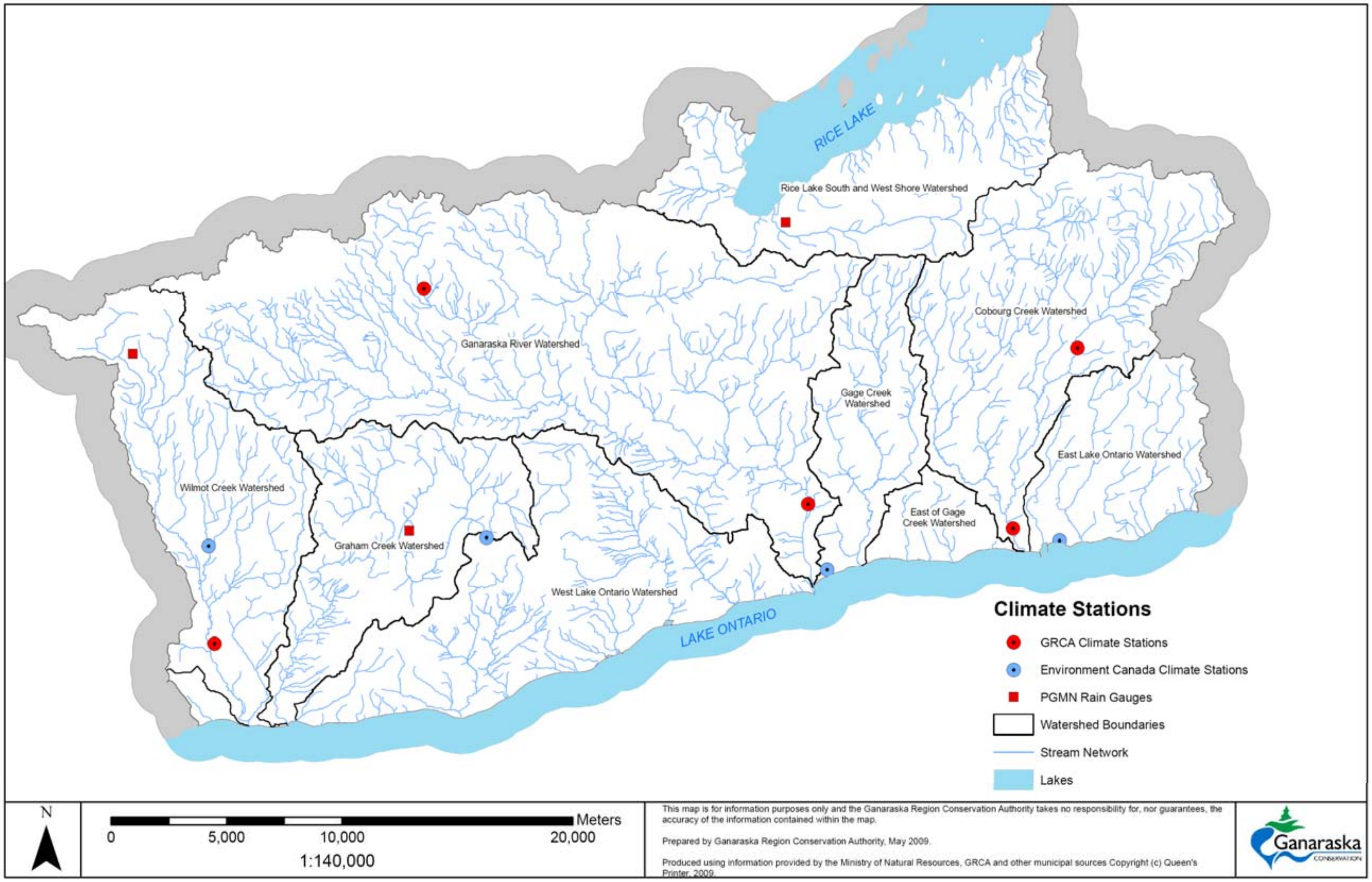


Figure 3.1: Climate stations

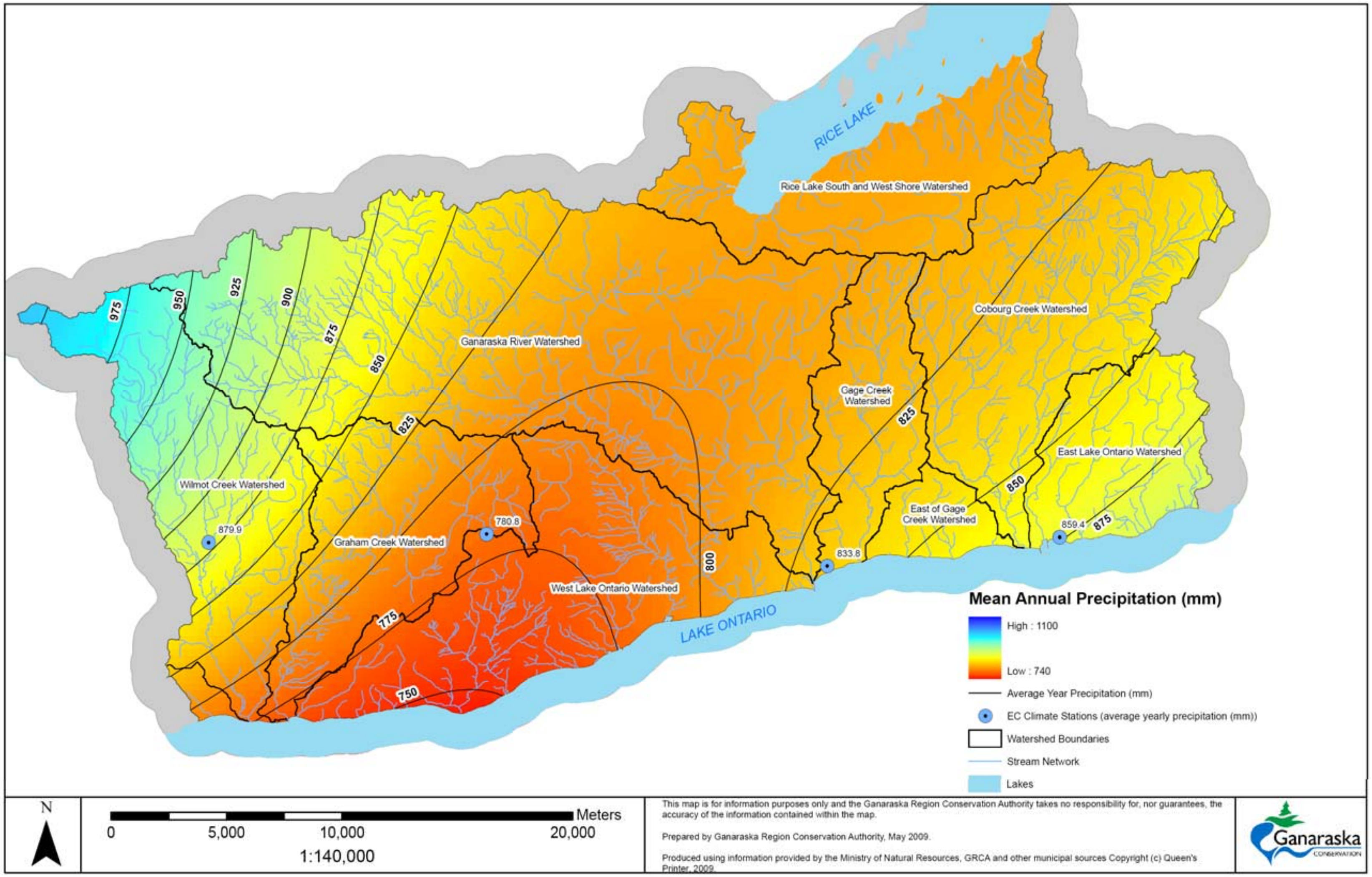


Figure 3.2: Precipitation distribution

Table 3.1: Precipitation and temperature data summary

	Campbellford*	Cobourg	Port Hope	Orono	Peterborough*
Elevation (masl)	146	79.2	80.8	148	191.4
Total Precipitation (mm)	836.7	871.1	832.0	879.9	840.3
Rain (mm)	684.1	765.8	709.0	724.5	682.0
Snow (mm)	149.3	106.0	122.0	152.6	162.0
Wettest Month (mm)	December, 82.1	September, 90.0	December, 80.5	September, 76.3	August, 83.2
Driest Month (mm)	July, 58.3	February, 54.0	July, 53.3	February, 63.8	February, 50.6
Mean Year Temperature (^oC)	--	7.1	7.3	6.8	5.9
Warmest Month (^oC)	--	July, 19.6	July, 20.0	July, 20.1	July, 19.4
Coldest Month (^oC)	--	January, -6.0	January, -5.8	January, -6.9	January, -8.9

* Stations located outside of the Ganaraska Region Conservation Authority, but near enough to have relevant data. Data range from 1971 to 2000 from selected weather stations.

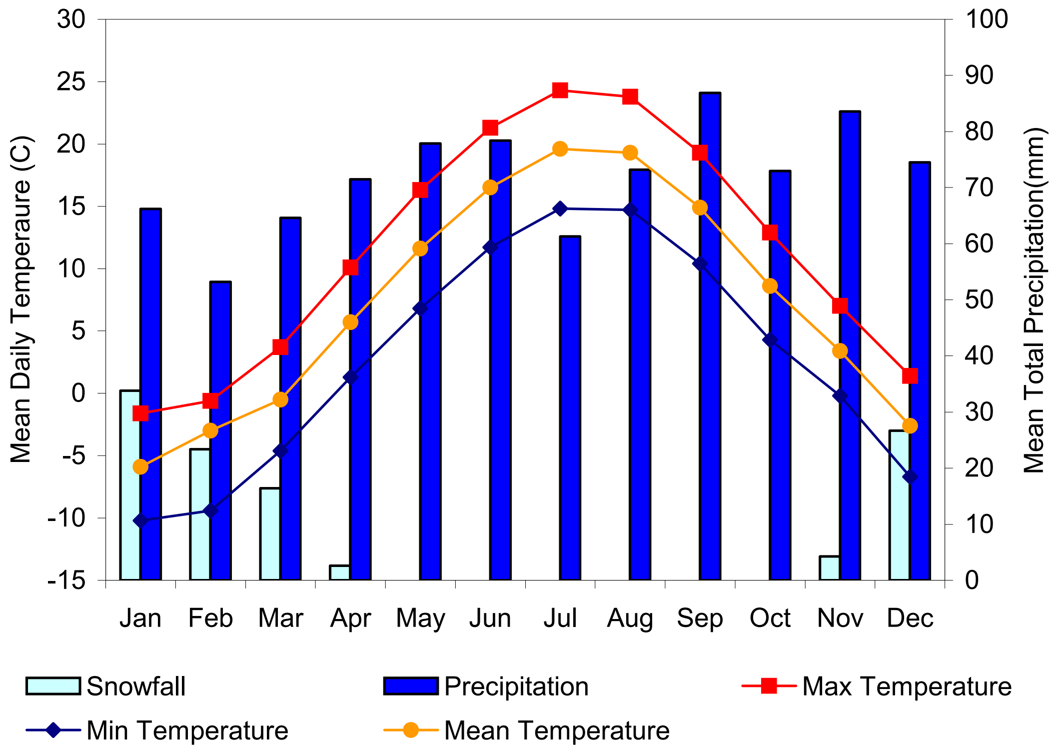


Figure 3.3: Cobourg STP meteorological station (6151689), 1970 to 2003

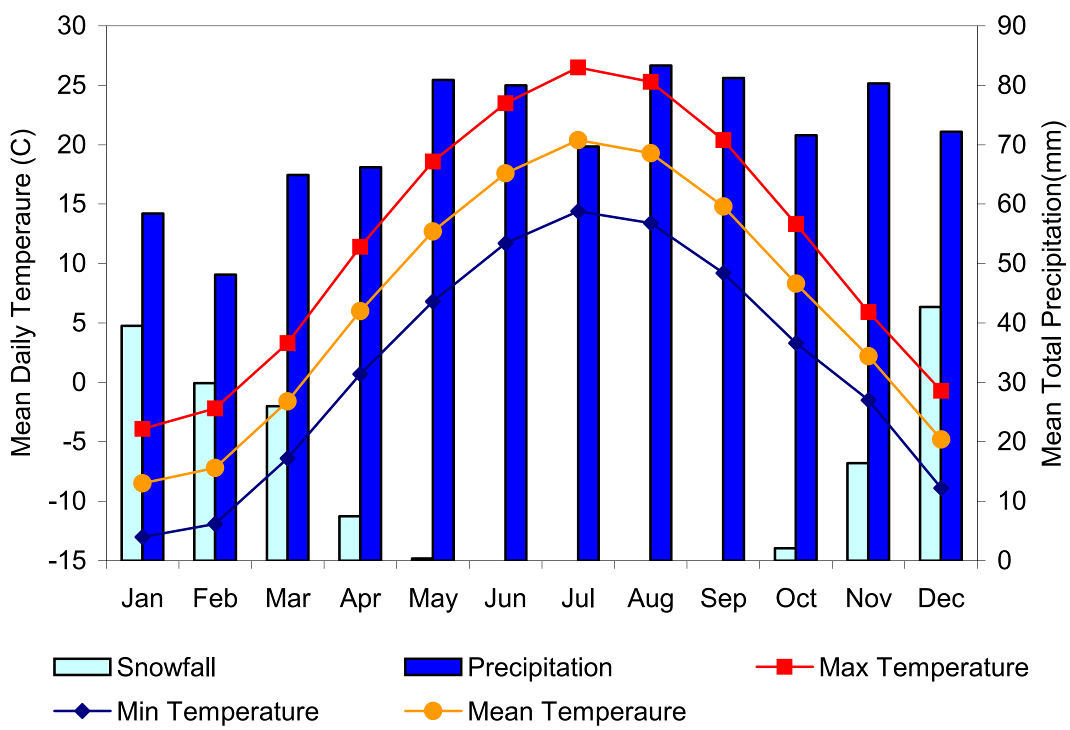


Figure 3.4: Peterborough, Trent University meteorological station (6151689), 1968 to 2000

3.1 GEOLOGIC CHARACTERISTICS

Geology is the scientific study of the Earth, its origins and evolution, the materials it is comprised of, and the processes that act on it. The following section defines the bedrock, glacial deposition, topography, physiographic regions, surficial geology and soils of the Graham Creek watershed.

3.1.1 Bedrock

The bedrock beneath the Graham Creek watershed is Palaeozoic bedrock that is 550 to 350 million years old (Earthfx Incorporated 2006). Palaeozoic bedrock was created from the eroded materials of mountains being lithified on top of the Canadian Shield. Across southern Ontario there are five Palaeozoic Bedrock types. The bedrock unit that represents the lower geologic formation in the Graham Creek watershed is the Lindsay Formation from the Simcoe Group, composed of coarse-grained limestone. Limestone bedrock, which can be highly fractured, has the potential to create productive aquifers or aquitards when it is poorly fractured with low permeability (Earthfx Incorporated 2006).

The surface of the bedrock was created as a result of historical erosion. Erosion created depressions and channels in the bedrock surface, and topographic highs were created from rocks that were not eroded. The bedrock in the Graham Creek watershed is completely covered by a mantle of Quaternary deposits. Bedrock elevation ranges from about 50 to 75 metres above sea level (masl) along the shore of Lake Ontario to about 100 to 125 masl below the Oak Ridges Moraine (Figure 3.5).

3.1.2 Glacial Depositions

Geological activity during the Wisconsin Glaciation period formed the major deposits that sit on limestone bedrock. The Late Wisconsinan ice advance occurred 25,000 to 12,000 years ago, in which the Laurentide ice sheet deposited a thick sheet of till, known locally as Bowmanville Till (Brookfield et al. 1982), which has a regional correlation with Newmarket Till or Northern Till in the western part of the Oak Ridges Moraine (Earthfx Incorporated 2006). The Bowmanville Till lies on the thick lower sediments comprised of Port Hope Till, Clarke Deposits, and a thin layer equivalent to the Scarborough Formation (Brookfield et al. 1982, Earthfx Incorporated 2006, YPDT-CAMC Groundwater Study [website] 2006, Ganaraska Region Conservation Authority 2007).

The sediments of the Oak Ridges Moraine, which formed approximately 12,000 to 13,000 years ago, are found in the northern end of the Graham Creek watershed. The sediments of the Oak Ridges Moraine, deposited as glacial meltwaters, travelled through a glacial lake between the Simcoe and Ontario ice lobes that covered southern Ontario (Earthfx Incorporated 2006).

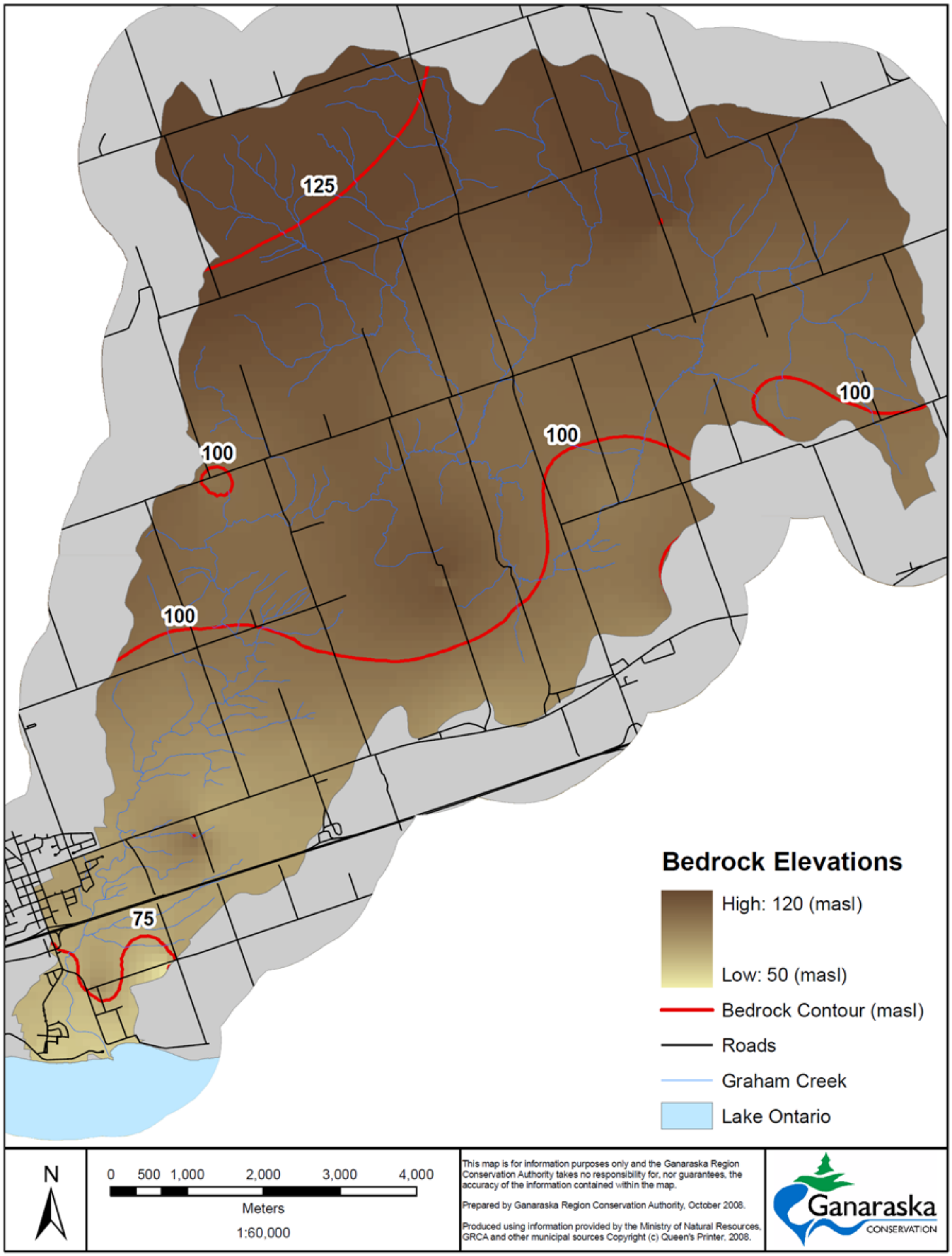


Figure 3.5: Bedrock elevation

The youngest glacial deposits in the Graham Creek watershed consist of glaciolacustrine sediments (glacial till, river deposits and Lake Iroquois Deposits), left behind from glacial lakes that form a thin layer over the Bowmanville Till and Oak Ridges Moraine sediments (Earthfx Incorporated 2006). Many regional and local names of the geological characteristics exist. Table 3.2 lists the names of the geological layers in the Graham Creek watershed.

Table 3.2: Geologic units in order of youngest to oldest deposition

Geologic Units Derived from the Regional Model (Based on 5 layers)	Geologic Units Derived from the Core Model (Based on 8 layers) Figure 3.7 (Earthfx Incorporated 2006)	Geologic Units Derived from Brookfield et al. 1982, and Singer 1981 (used in GRCA studies)	Description
	Late stage sediments (glacial/fluvial)		Aquifer or Aquitard
Halton Till	Halton Till or equivalent (upper glacial unit)	Halton (Bouchette) Till	Aquitard
Oak Ridges Moraine Complex	Oak Ridges Moraine Deposits	Oak Ridges Moraine Complex	Aquifer
Newmarket Till	Bowmanville Till (middle glacial unit)	Bowmanville Till	Aquitard
Lower Sediments	Clarke Deposits or equivalent	Clarke Deposits	Upper Aquifer
	Port Hope Till (lower glacial unit)	Port Hope Till	Aquitard
	Scarborough Formation or equivalent	Scarborough Formation or equivalent	Lower Aquifer
Bedrock	Weathered Bedrock	Fractured (Weathered) Bedrock Unweathered Bedrock	Aquifer Aquitard

A vertical cross-section of the geological characteristic of the Graham Creek watershed can be viewed using data from the Ministry of the Environment water well records. Using Viewlog software, one representative cross-section was generated from north-east to south-west (Figure 3.6). Eight geological layers are seen in the cross-sections (Figure 3.7) and are in chronological order as described in Table 3.2. The thickness of the overburden deposits increases from south to north, with the thickest deposits occurring in the Oak Ridges Moraine area, and the thinnest near the Lake Ontario shoreline. Each geological layer is described in more detail below. It should be noted that geological units across southern Ontario vary considerably in structure and therefore local geological units exist throughout Ontario. In this document the localized names referenced from many studies completed in the area will be used.

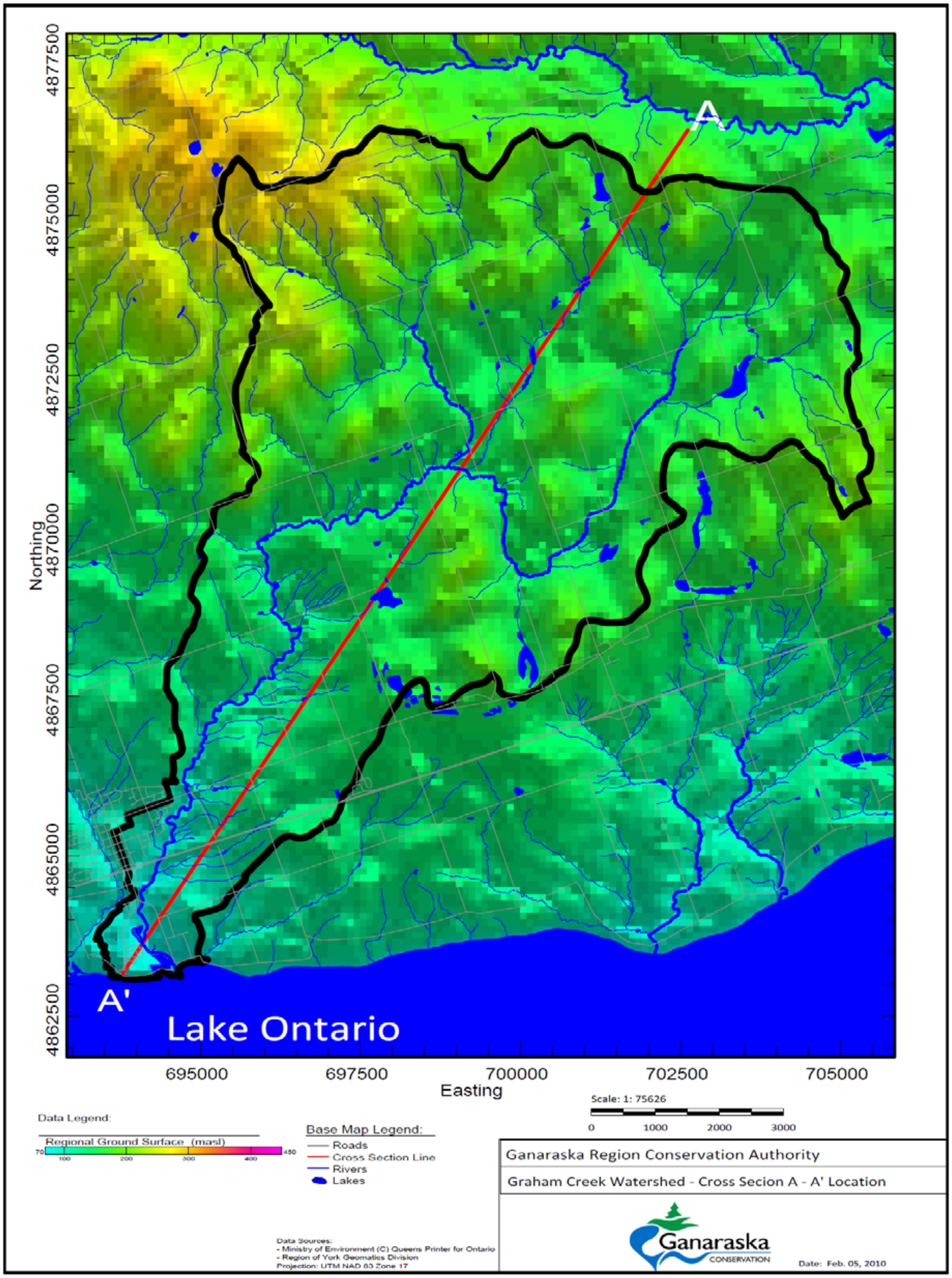


Figure 3.6: Graham Creek watershed cross-section location

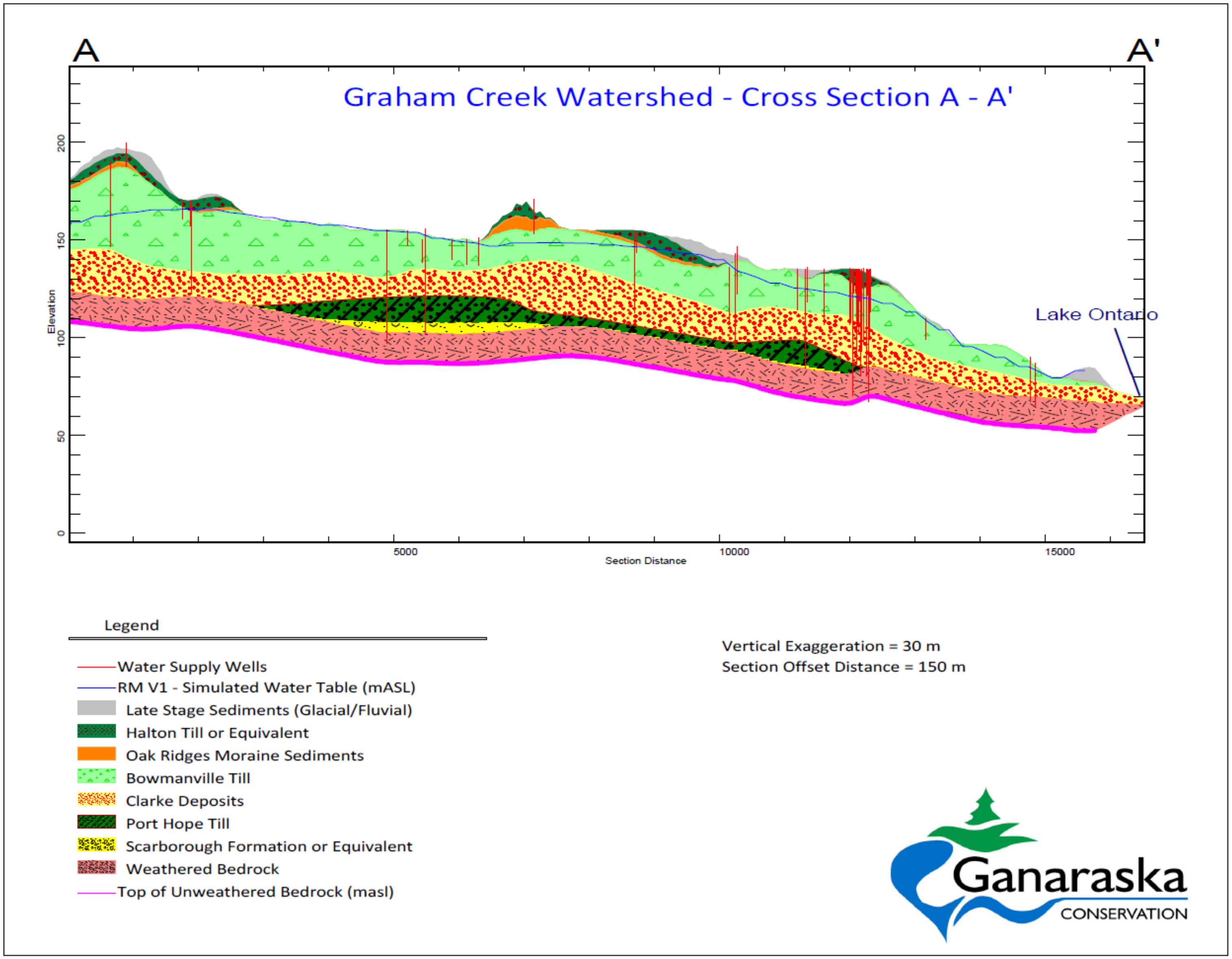


Figure 3.7: Graham Creek watershed cross-section A – A'

Scarborough Formation or Equivalent

The Scarborough Formation or its localized equivalent sits on top of the bedrock and was formed by a deltaic deposit at the mouth of a very large historic river (Eyles 2002). It is described as a sequence of sediments ranging from fine clay/silts to channelized coarse cross-bedded sands that become vertically coarser (Jagger Hims Limited 2007). As a result of the coarse-grained sediments in this formation, deep overburden aquifers are found in some localized areas.

Geologists feel that the regionally known Scarborough Formation does not extend into the Graham Creek watershed, however an equivalent formation does sit on top of the bedrock. As shown in Figure 3.7 the Scarborough Formation or equivalent unit is very thin and is not seen in the northern or southern areas of the watershed. This geological unit, equivalent to the Scarborough Formation, creates a highly productive sand and gravel aquifer.

Port Hope Till (Lower Glacial Unit)

The Port Hope Till (equivalent to the regional Sunnybrook Drift) was deposited in glacial and proglacial lacustrine areas (Jagger Hims Limited 2007). Sediments that form the Port Hope Till were deposited as mud on the floor of a cold, deep glacial lake and pebbles were dropped into the sediments by floating ice (Eyles 2002; Earthfx Incorporated 2006). These fine, compactable sediments cause the Port Hope Till to act as an aquitard. Brookfield et al. (1982) correlated the regional Sunnybrook Drift to a localized Port Hope Till that contains less clay and more silt than the Sunnybrook Drift. Figure 3.7 shows that the Port Hope Till declines in thickness toward the south end of the Graham Creek watershed.

Clarke Deposits or Equivalent

The Clarke Deposit (regionally correlated to the Thorncliffe Formation) includes glaciofluvial deposits of sand, silty sand, silt and pebbly silt, and clay. This geological unit was deposited by glacial meltwaters entering a deep, ice-dammed ancestral Lake Ontario (Earthfx Incorporated 2006). The Clarke Deposit is highly variable and serves as an aquifer (Jagger Hims Limited 2007). Singer (1981) correlated the regional Thorncliffe Formation to a localized Clarke Deposit, which contains less clay and more silt (Brookfield et al. 1982). Figure 3.7 show that the Clarke Deposit is found beneath the Bowmanville Till.

Bowmanville Till (Middle Glacial Unit)

The Bowmanville Till is a distinct, dense glacial deposit of fine sediments (Jagger Hims Limited 2007) left behind by the Laurentide Ice Sheet. This till unit is dominant in the Graham Creek watershed. The Bowmanville Till is correlated to the regionally known Newmarket or Northern Till (Earthfx Incorporated 2006; YPDT-CAMC Groundwater Study [website] 2006). With variable pavement layers in the Bowmanville Till, this geological unit acts as an aquitard. Brookfield et al. (1982) correlated the Newmarket Till to the localized Bowmanville Till, which contains less clay and more silt.

Oak Ridges Moraine Deposits
The sediments of the Oak Ridges Moraine are complex and contain predominantly coarse-grained glacialfluvial and terminal outwash materials (Jagger Hims Limited 2007); however are limited in the Graham Creek watershed. These deposits were left behind between two lobes of the Laurentide Ice Sheet when they retreated, therefore the Oak Ridges Moraine can be referred to as an interlobate moraine, meaning between two lobes (Eyles 2002). The Oak Ridges Moraine is a well-known physiographic feature that contains sediments with variable thickness, texture and distribution, all of which function as regional aquifers and aquitards.

Halton Till or Equivalent (Upper Glacial Unit)
Halton Till is a fine-grained, clay-rich till and contains few stones (Jagger Hims Limited 2007). Found on the southern flanks of the Oak Ridges Moraine, the Halton Till was laid down by the last glacial ice advance over the Oak Ridges Moraine (Earthfx Incorporated 2006). This variable cap of finer sediments over the Oak Ridges Moraine causes the Halton Till to act as an aquitard.

The regionally known Halton Till does extend into the Graham Creek watershed, but is mainly covered by post-glacial sediments. As shown in Figure 3.7, the Halton Till or equivalent unit sits on top of Oak Ridges Moraine Deposits in a few areas in the north end of the watershed. The Halton Till does act as an aquitard where it exists.

Late Stage Sediments (Glacial/Fluvial)
Following the Wisconsinan deglaciation, deposits formed in the glacial lakes and rivers. These sediments occur in lower elevations and floodplains, creating many of the wetlands in the watershed. In Graham Creek the late stage deposits include gravelly beach deposits formed along the former shores of Lake Iroquois.

3.1.3 Topography

Topography refers to the shape, form and physical features of the Earth's surface (Eyles 2002). In the Graham Creek watershed, the land generally slopes from north to south. The maximum topographic elevation is approximately 275 masl and it declines to 75 masl at Lake Ontario. Topography is best understood when observed in the field. Figure 3.8 displays the topographic features (using a five-metre grid) of the Graham Creek watershed along with differing elevations. Topographic features are important in promoting groundwater recharge and minimizing surface water runoff.

3.1.4 Physiographic Regions

Physiography refers to areas of similar geological form and includes the physical features of the Earth's surface. The three physiographic regions found in the Graham Creek watershed from north to south are the Oak Ridges Moraine, the South Slope and the Iroquois Plain (Figure 3.9).

Oak Ridges Moraine

The Oak Ridges Moraine is located in the north-west corner of the watershed and it occupies 2.7 km^2 or 3.5% of the Graham Creek watershed. The Oak Ridges Moraine extends regionally over 160 km from the Niagara Escarpment to the Trent River. As described in Chapman and Putnam (1966), the Oak Ridges Moraine is hilly with a knob-and-basin relief comprised of sandy or gravelly materials. This coarse, permeable material of the Oak Ridges Moraine provides for recharge. Water drains vertically through the sand and gravel, moving laterally until it reaches less pervious material, and reappears as springs along the slopes of the moraine (Chapman and Putnam 1966). However, given the small area in Graham Creek that is considered moraine deposits, the recharge potential is minimal.

South Slope

The South Slope lies between the Oak Ridges Moraine and the Iroquois Plain and it occupies 19.2 km^2 or 25% of the watershed area. The South Slope is found in a band to the south of the moraine, with a regional elevation range between 140 and 190 masl (Ganaraska Region Conservation Authority 2007). The South Slope area is a rolling till plain that contains spillway channels from glacial melt waters, of which Graham Creek is an example. Till plains (mainly Bowmanville Till) as well as ice-contact stratified drift and outwash deposits (generally comprised of older sediments exposed by erosion) occur in the South Slope region. The presence of the till materials at the surface represents a major factor in the distribution of groundwater recharge in the watershed as described below. Three regional till deposits have been identified in the Ganaraska Region Conservation Authority.

- Halton Till (or the equivalent Bouchette Till) is a sheet of clayey silt till deposited by the last major glacial advance in the area.
- Bowmanville Till (equivalent to Newmarket Till) is a deposit of sandy silt till that lies beneath the Oak Ridges Moraine.
- Port Hope Till (Sunnybrook Till equivalent) is a deposit of fine silt and clay sediments found beneath the Clarke Deposits.

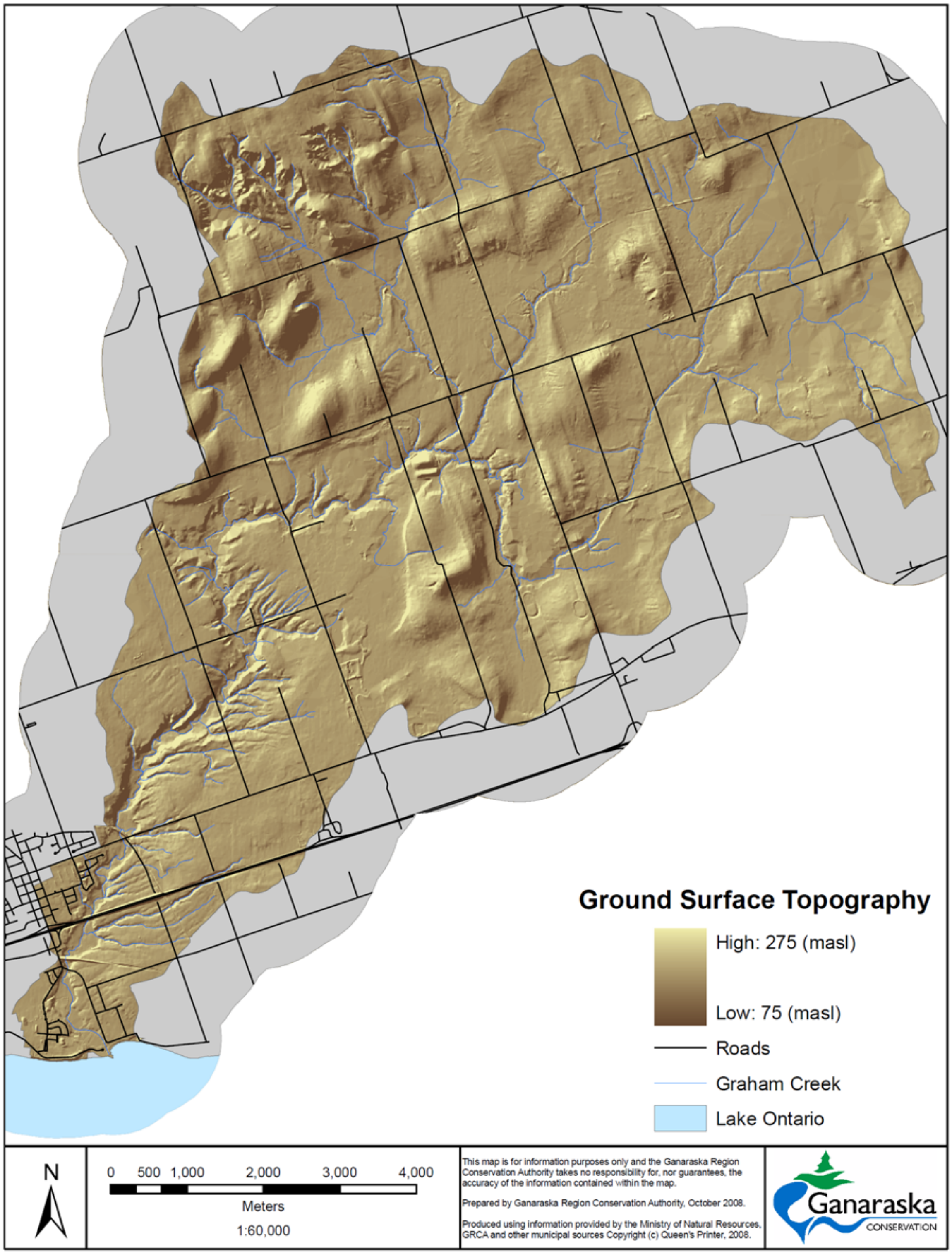


Figure 3.8: Ground surface topography

Iroquois Plain
The Iroquois Plain is located south of the South Slope and occupies 56.4 km^2 or 72% of the watershed. The Iroquois Plain is a relic of the lowland bordering Lake Ontario that was inundated with water during the late Pleistocene period by Lake Iroquois (Chapman and Putnam 1966). The Iroquois Plain contains many large drumlins that would have been islands in Lake Iroquois. Today these former islands look like terraces, formed by historic wave action (Chapman and Putnam 1966).

Bluffs or gravel bars running east to west frequently mark the northern boundaries of the Iroquois Plain. These represent the ancient shoreline of glacial Lake Iroquois, following the recession of the last glacial advance. This beach line runs from 6.4 to 10.3 km to the north and nearly parallel to Lake Ontario (Gartner Lee Limited 1976). The beach sits approximately 75 m above the current shoreline, and the plain extends to the current lake level. At its northern limits, the plain has an irregular formation, which levels to a clay plain. This has created a terrain, which, below the beach line, is similar to the south slope. However, different materials were deposited in each area, with a different glacial history (Gartner Lee Limited 1976).

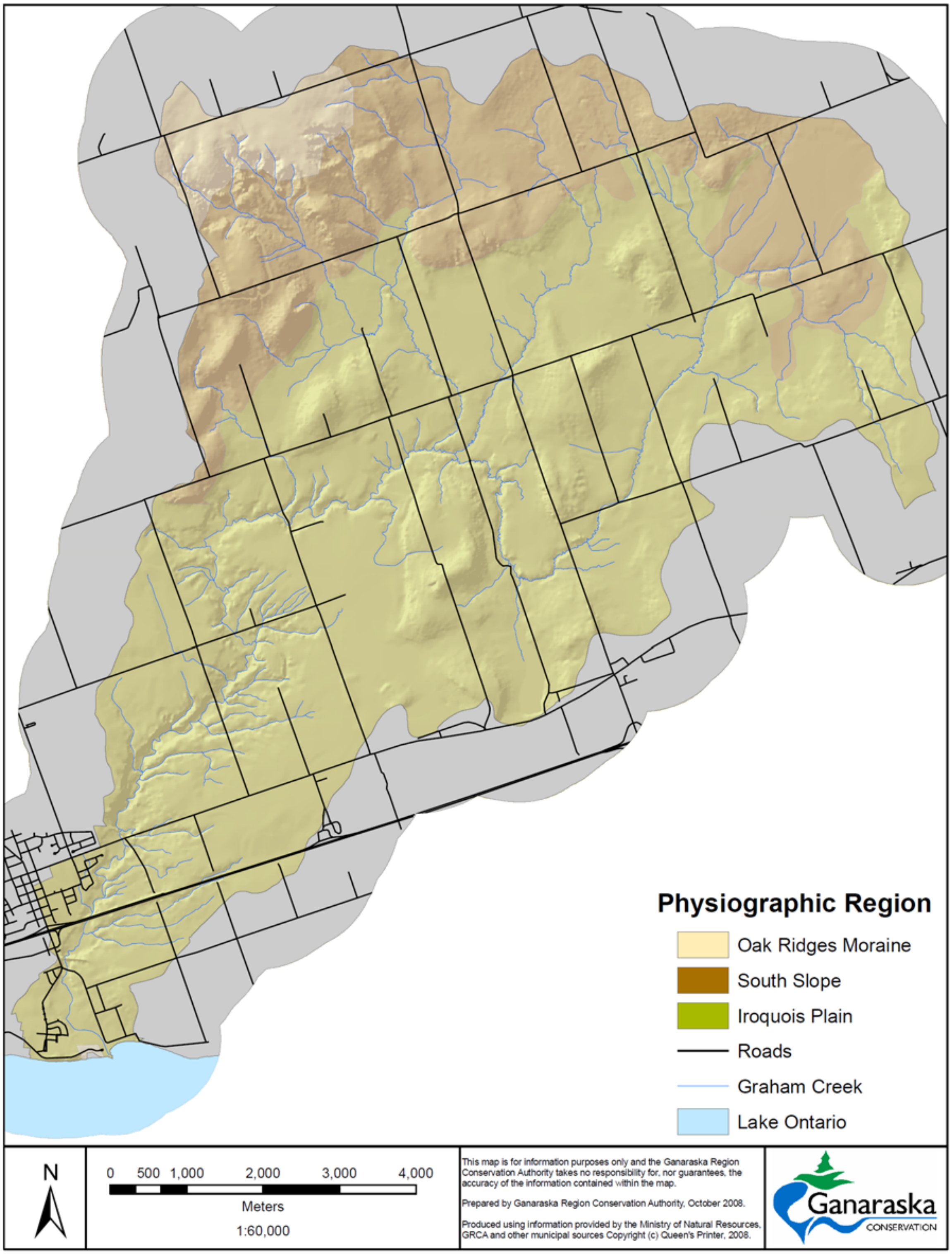


Figure 3.9: Physiographic regions

3.1.5 Surficial Geology

Surficial geology refers to the upper layer or exposed layer of geological deposits. In the Graham Creek watershed there are 10 surficial geological units (Table 3.3; Figure 3.10). The majority of these deposits on the surface of the land were created during the Pleistocene epoch when massive ice formations and the resulting meltwaters shaped the surface.

Glacial lake silt and sand deposits form the dominant uppermost exposed geological layer, acting as both aquifers and aquitards. This geological layer helps to form many of the wetlands found in the watershed. Bowmanville Till (regionally equivalent to Newmarket Till) forms another dominant upper most exposed geological layer, especially in the north-west corner of the watershed, and acts as an aquitard. Other glacial lake deposits are found throughout the Graham Creek watershed with compositions ranging among silt, sand, gravel and clay. River deposits are located in the current and postglacial river valleys and beds.

Table 3.3: Surficial geology

Surficial Geology Unit	**km^2**	**Percent of Watershed**
Glacial Lake Deposits: sand and gravel	4.5	5.7
Glacial Lake Deposits: silt and clay	3.9	4.9
Glacial Lake Deposits: silt and sand	36.5	46.5
Glacial River Deposits: sand and gravel	0.003	0.004
Halton Till	0.6	0.8
Bowmanville (Newmarket) Till	22.3	28.5
Organic Deposits	2.7	3.4
River Deposits: Early postglacial deposits	0.5	0.7
River Deposits: Late Stage (Modern) Deposits	6.3	8.0
Sand	1.1	1.4

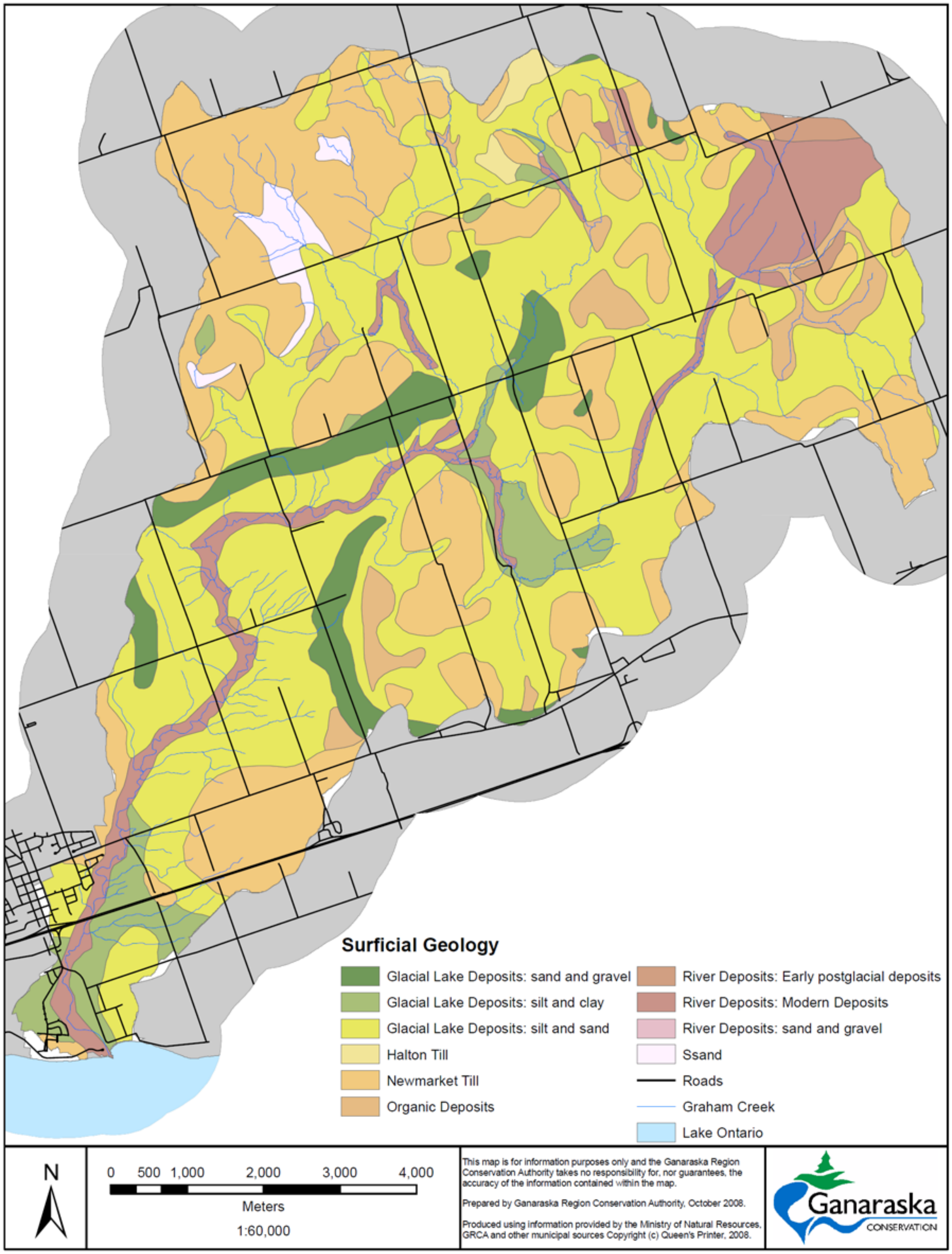


Figure 3.10: Surficial geology

3.1.6 Soils

Soil is defined as the unconsolidated organic material on the immediate surface of the Earth that serves as a natural growing medium for vegetation (Hoffman 1974). Figure 3.11 shows the different soils found in the Graham Creek watershed as defined by the Ontario Ministry of Agriculture, Food and Rural Affairs. The dominant soil type in Graham Creek is the Bondhead Series. This soils group is formed from limestone till and is commonly associated with drumlins or elongated hills (Webber et al. 1991). Bondhead soils provide good drainage and therefore are suitable for agriculture. Other soils found in Graham Creek that are associated with limestone till are Otonabee and Guerin soils. Otonabee soils provide good drainage whereas Guerin soils provide imperfect drainage (Webber et al. 1991).

Percy loam soil, which also provides good drainage yet susceptible to erosion are found in the bottom end of Graham Creek. Imperfect drainage and unproductive soils are also found, including muck. Muck soils occur in depressions or along streams underlain by clay (Webber et al. 1991).

In hydrologic calculation, soils may be classified into four main groups (A, B, C, D) and three interpolated groups (AB, BC, CD). These classifications depict how soils move water. Table 3.4 describes the features of the hydrologic soils group. Figure 3.12 shows the location of the hydrologic soil types.

Table 3.4: Hydrologic soils group

Hydrologic Soils Group	Run-off Potential	Infiltration when Wet	Typical Soils
A	Low	High	Excessively drained sands and gravels
B	Moderate	Moderate	Medium textures
C	Medium	Slow	Fine texture or soils with a layer impeding downward drainage
D	High	Very slow	Swelling clays, clay pan soils or shallow soils over impervious layers.

(Hudson 1981)

Soil types and their corresponding characteristics help dictate land uses in a particular area. In the South Slope and Iroquois Plain, sandy loam soils are typical. As a result, agricultural practices in these two physiographic regions prevail. The only limiting factors that these soils have for agricultural purposes are imperfect drainage and the presence of muck soils. The land cover characteristics of productive agricultural land interspersed with wetlands is a result of the watersheds' soil composition. Wetlands in the Graham Creek watershed are usually the result of clay underlying the water, in which surface water creates the wetlands, not groundwater discharging to the surface to create wetlands.

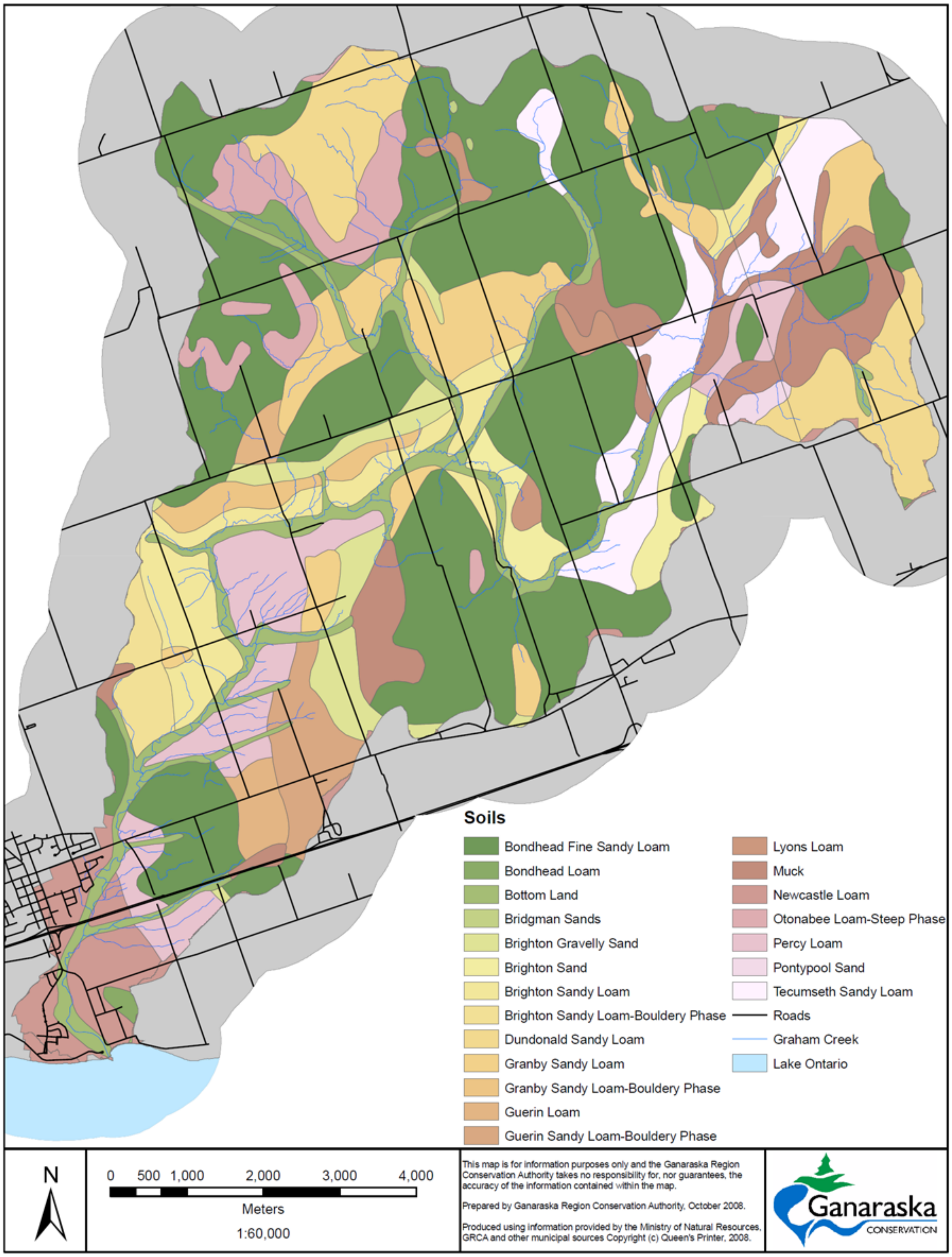


Figure 3.11: Soils

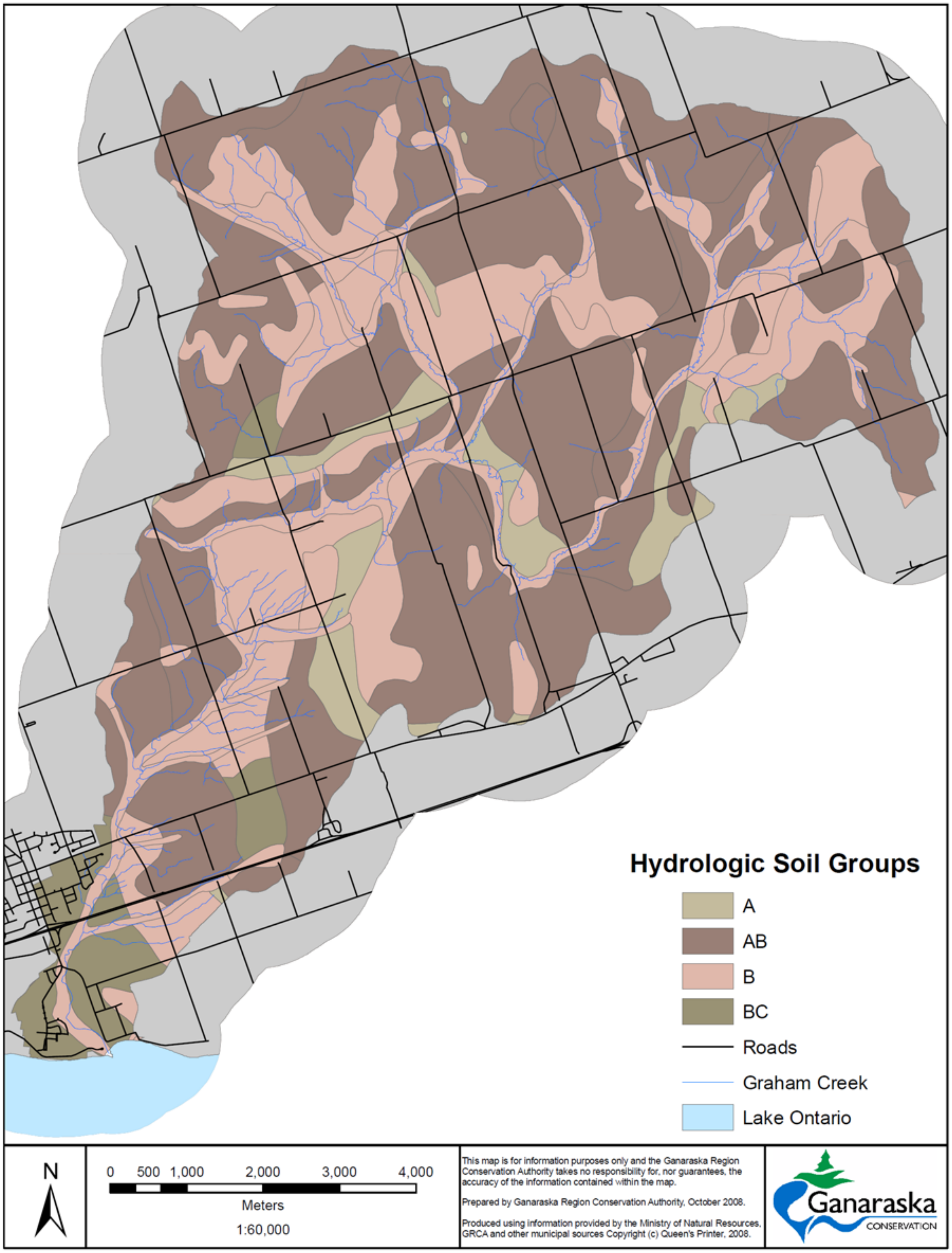


Figure 3.12: Hydrologic soils group

3.2 GROUNDWATER

The movement and location of groundwater in the subsurface are controlled by land cover, sediment types and topography. Porous surficial materials generally comprise groundwater recharge areas. Rainfall and snowmelt percolate through these sediments and replenish the aquifers that form important groundwater supply sources for many watershed residents. In addition these aquifers contribute water to streams of the Graham Creek watershed through groundwater discharge. Groundwater discharge contribution during periods of time without precipitation and during critical summer low-flow periods is essential in sustaining the ecosystem of the watershed. Areas of the watershed that lack porous surficial materials experience higher surface runoff than groundwater recharge.

3.2.1 Aquifers and Groundwater Flow

Overburden deposits in the Graham Creek watershed play an important role in the regional drainage and groundwater recharge patterns. Bedrock valleys and bedrock topography do not control the Graham Creek's drainage and groundwater flows in the area. Similar to other watersheds of the area, the thickness of the overburden dictates the distribution of the overburden and bedrock aquifers and the specific importance of each type of deposit as a source of water supply. Grouped as hydrostratigraphic units, geologic units are categorized based on their relative capacity to store and transmit different amounts of water. As outlined by Widaatalla and Peacock (2007), the following geological units are defined with their respective hydrostratigraphic units.

- Glacial Lake Deposits comprised of sand and gravel that form a discontinuous unconfined shallow aquifer at surface
- Oak Ridges Moraine sediments consisting of ice-contact and outwash deposits that form an aquifer/aquitard complex
- Glacial till aquitards comprised of Halton Till (aquitard) and Bowmanville Till (leaky aquitard)
- Clarke Deposits that are mainly sand and gravel (aquifer)
- Port Hope Till that is mainly a clayey silt till (aquitard)
- Deep coarse sand and gravel aquifer (equivalent to Scarborough Formation)
- Fractured limestone of the Simcoe Group (in some areas, fractured shale from the Georgian Bay Group) that forms the weathered bedrock aquifer.

Higher rates of infiltration generally occur in the more permeable and thick coarse-grained deposits associated with the glacial lake and moraine sediments in the north. The depth to the watertable in the northern area of the watershed varies and is generally deep beneath the surface. Aquifer thickness and the depth to the watertable can vary depending on location, though the watertable is generally found at depths of less than 5 m below ground surface in the southern portion of the watershed (Morrison Environmental Limited 2004).

The movement of groundwater in the area is a subtle reflection of local topography and drainage as interpreted from the Ministry of the Environment well record data. The lateral movement of groundwater in the watershed occurs from topographic highs to topographic lows. The dominant regional groundwater flow direction is southerly, off the Oak Ridges Moraine toward the Lake Ontario basin. Figure 3.13 shows the watertable contour elevations in the watershed. This figure was generated as an output from the regional Oak Ridge Moraine groundwater model (Earthfx Incorporated 2006).

The Oak Ridges Moraine is likely a source area for groundwater recharge for aquifers buried beneath the till plain to the south. Local areas of groundwater recharge are associated with sandy and till deposits such as the one that occurs about three kilometres northwest of Starkville (Gartner Lee Limited 1976). The sand and gravels of upper Iroquois Plain form a shallow aquifer, which represents a potential source of well water into the majority of central and southern watershed areas. These sands probably contribute significantly to the flow regime of local streams (Gartner Lee Limited 1976). Streams flow in the larger valleys such as the main branch likely receives an appreciable contribution from groundwater discharge that may trend either in an upward direction into the valleys or originate as springs along valley walls.

A number of wells located in the Iroquois Plain get their water from sand and gravel aquifers buried at depth in the glacial till. In most cases these aquifers only appear to be lenses and are not very extensive in size. The majority of these wells were drilled in the till layer and most like in sand lenses in the Bowmanville till. In some cases these saturated confined sand and lenses in the till may be under flowing artesian conditions, such as areas along Golf Course Road (Rannie 1989) and in Lots 16 and 17, Concession Road 3 (Associated Geotechnical Services Limited 1966). Some wells also penetrate the upper part of the lower sediments (Clarke Deposits). In the south, wells are screened in fractured bedrock aquifer.

Recharge values in the Graham Creek watershed can be extrapolated from the regional recharge estimations of the Ganaraska Region Conservation Authority. Recharge rates in the relatively permeable glacial lake sand and gravel, and Oak Ridges Moraine deposits were estimated to be in the order of 250 to 350 mm/year (Morrison Environmental Limited 2004). Infiltration rate of 100 mm/year or less was estimated in the till plains in the South Slope, and the glaciolacustrine clays and silts of the Iroquois Plain (Morrison Environmental Limited 2004).

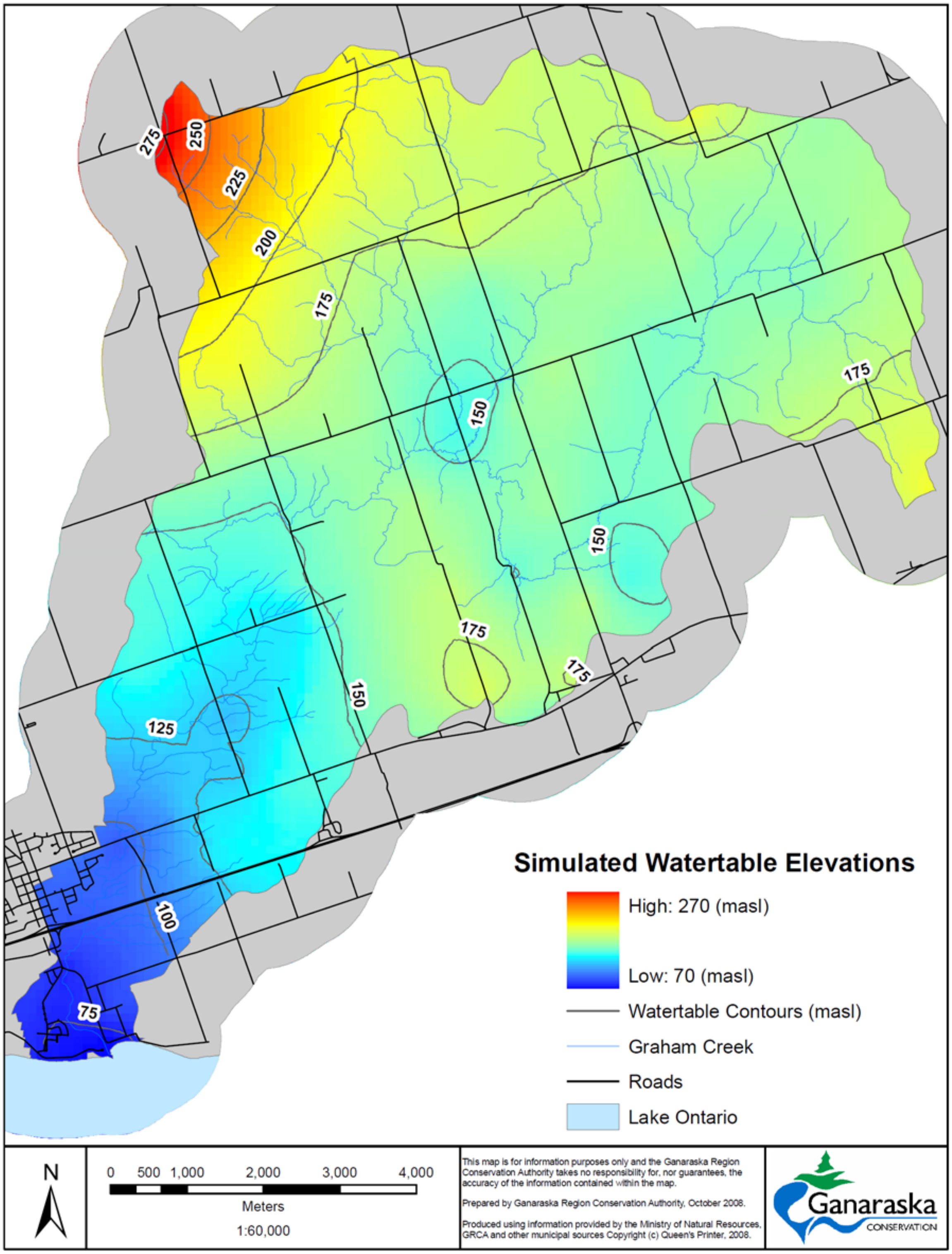


Figure 3.13: Simulated watertable elevation

3.2.2 Groundwater and Surface Water Interactions

Understanding groundwater and surface water interactions at both a regional and watershed scale has recently seen an increase in interest from all areas of watershed science. Gains and losses of water in a stream can be analyzed using stream temperature, baseflow, fish communities, and the presence of stream vegetation and aquatic organisms. However, certain techniques are more appropriate at various spatial scales or in order to answer certain questions.

Groundwater Recharge and Discharge

Recharge is the process by which groundwater is replenished, and it occurs through the vertical seepage of water through soil and unsaturated soils to an area of saturation. Rain and snowmelt are the major sources of recharge, however amounts of recharge and the rate at which it occurs depend on surficial soil composition, land use and topography (Widaatalla and Peacock 2007). Discharge is the opposite of recharge; in this process, groundwater is normally found in an upward gradient leaving the system through porous materials as springs or flow into surface water features such as streams, rivers, lakes and wetlands.

The northern uplands of the South Slope in the watershed represent the highest recharge areas. There are many factors affecting the distribution groundwater recharge rates in the watershed.

- The presence of coarse sand and gravel sediments at the surface.
- Distribution of thick overburden mainly in the northern and eastern parts of the watershed also contributes to higher recharge rates. Figure 3.15 shows the overburden thickness with thick sediments areas mainly in the northern parts of the watershed.
- The sharp topographic changes which created steep slopes that favour runoff in the central part of the watershed.
- Upwards groundwater flow directions in the central part of the watershed where little (or no recharge) is expected to occur.

The spatial distribution of applied recharge to the Oak Ridges Moraine regional groundwater model in the Graham Creek watershed is shown in Figure 3.16. Moderate recharge rates were shown to be in the South Slope and Iroquois Plan. The lowest recharge rates are mainly associated with steep slope and the till covered areas in the northern part of the watershed (Earthfx Incorporated 2006; Figure 3.16). These areas are generally characterized by the presence of till at the surface and glacial silt and clay in the south.

Figure 3.17 shows the potential discharge areas in the Graham Creek watershed. This figure was created by comparing the digital elevation model (DEM) and the groundwater level from wells tapping into the first aquifer encountered in different parts of the watershed. These potential groundwater discharge locations are mainly located in the valley areas and areas of geological transition of the watershed. These discharge areas provide baseflow to Graham Creek, which is critical in maintaining stream flows during times where precipitation is minimal or does not occur.

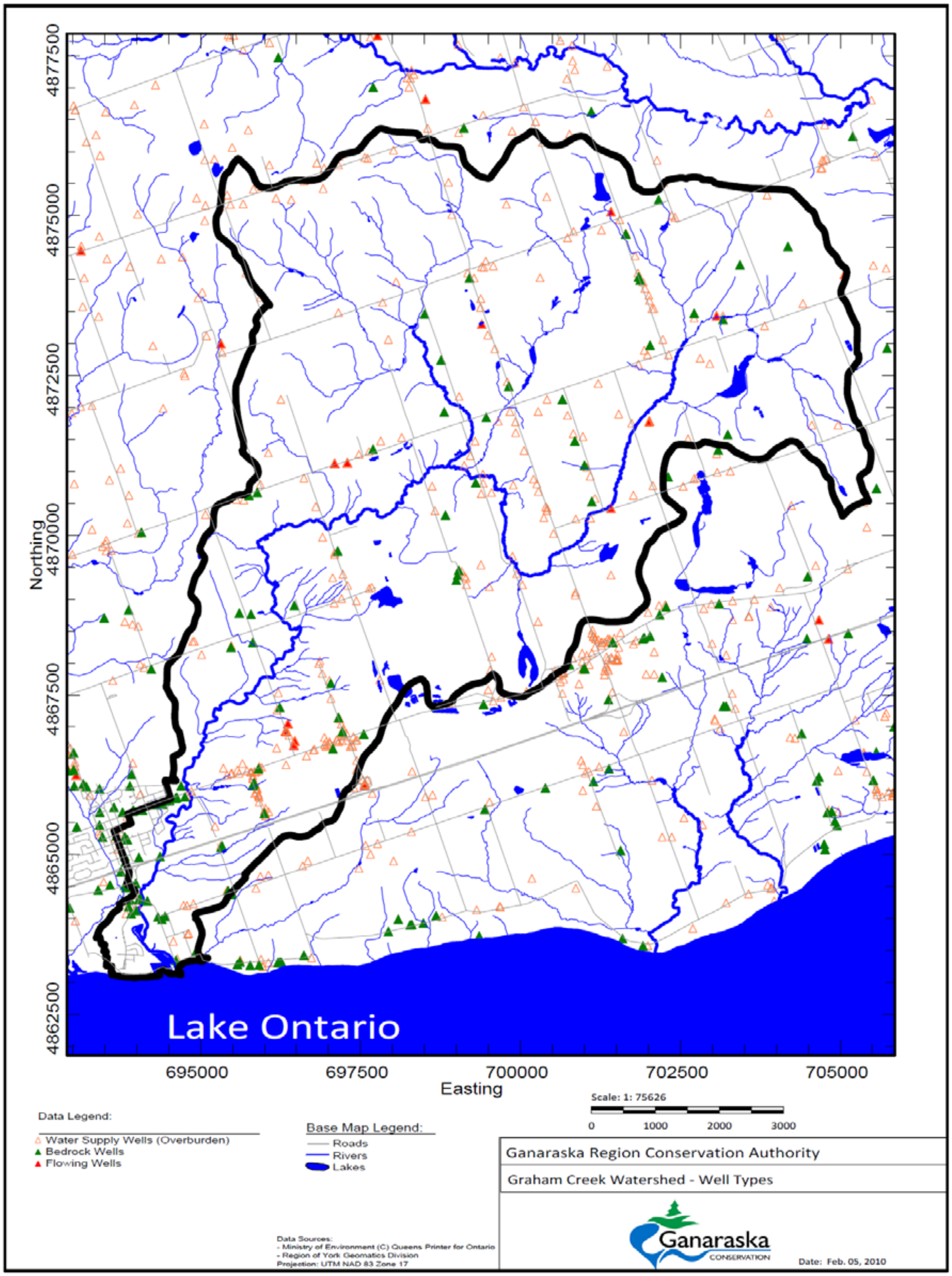


Figure 3.14: Water well types

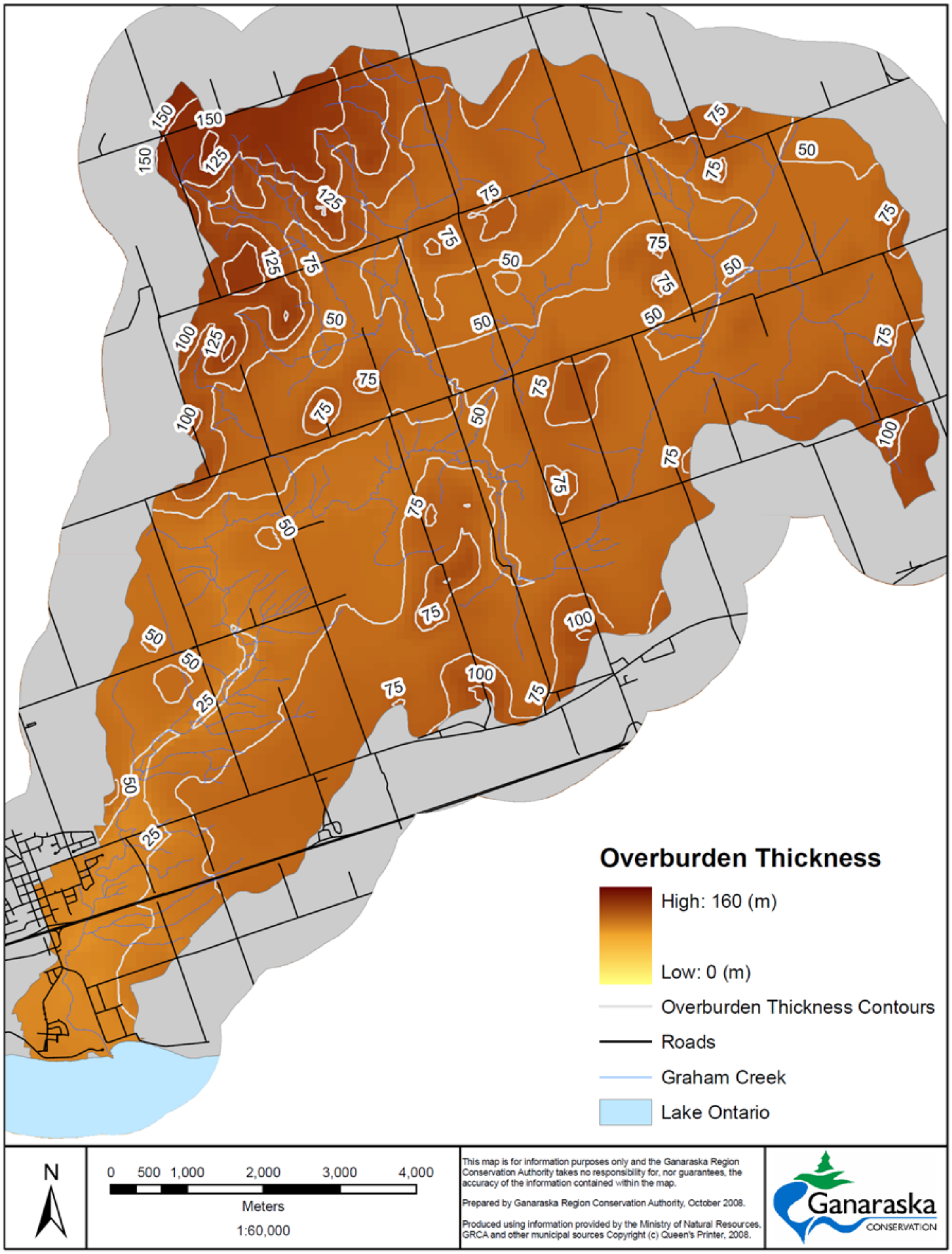


Figure 3.15: Overburden thickness

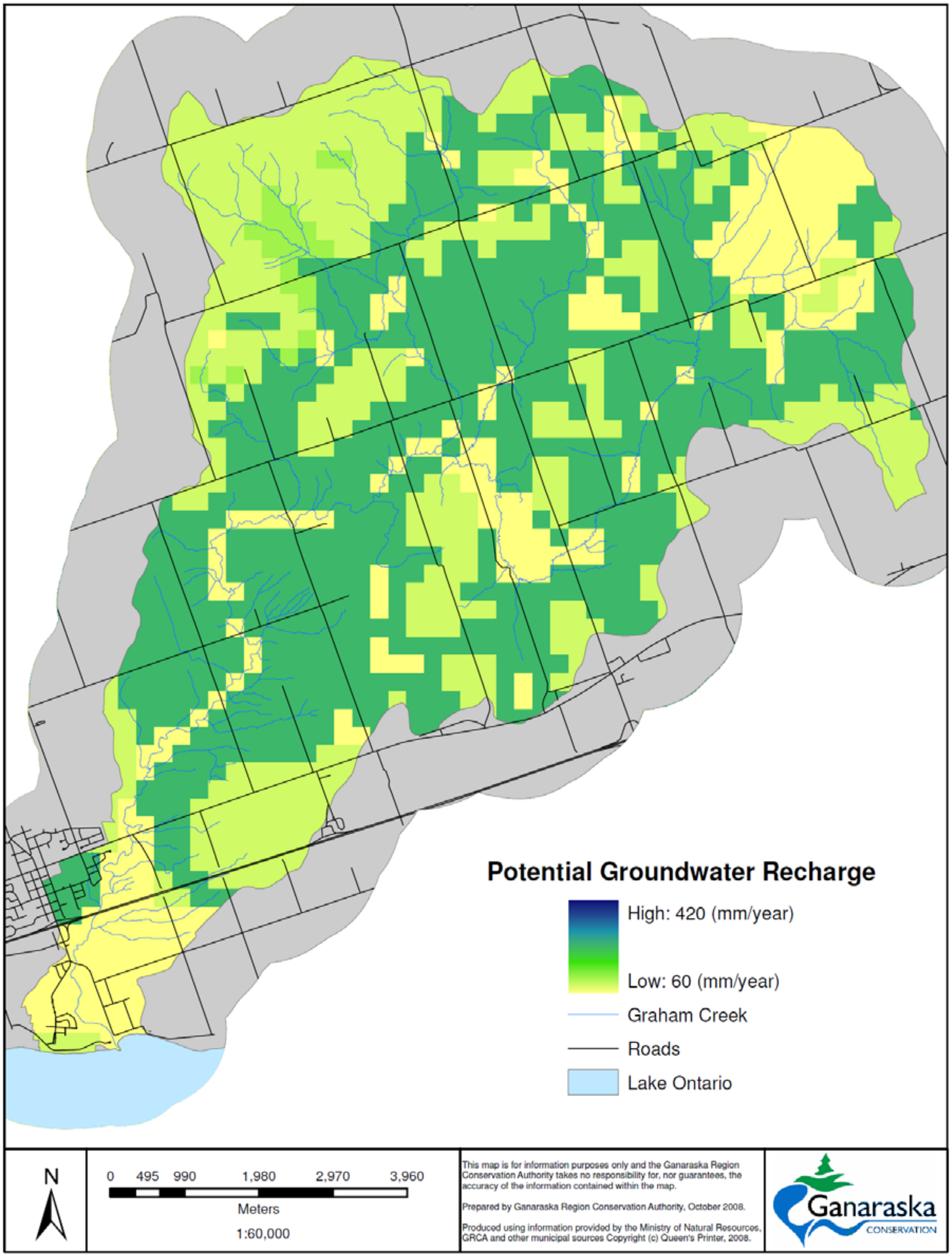


Figure 3.16: Potential groundwater recharge

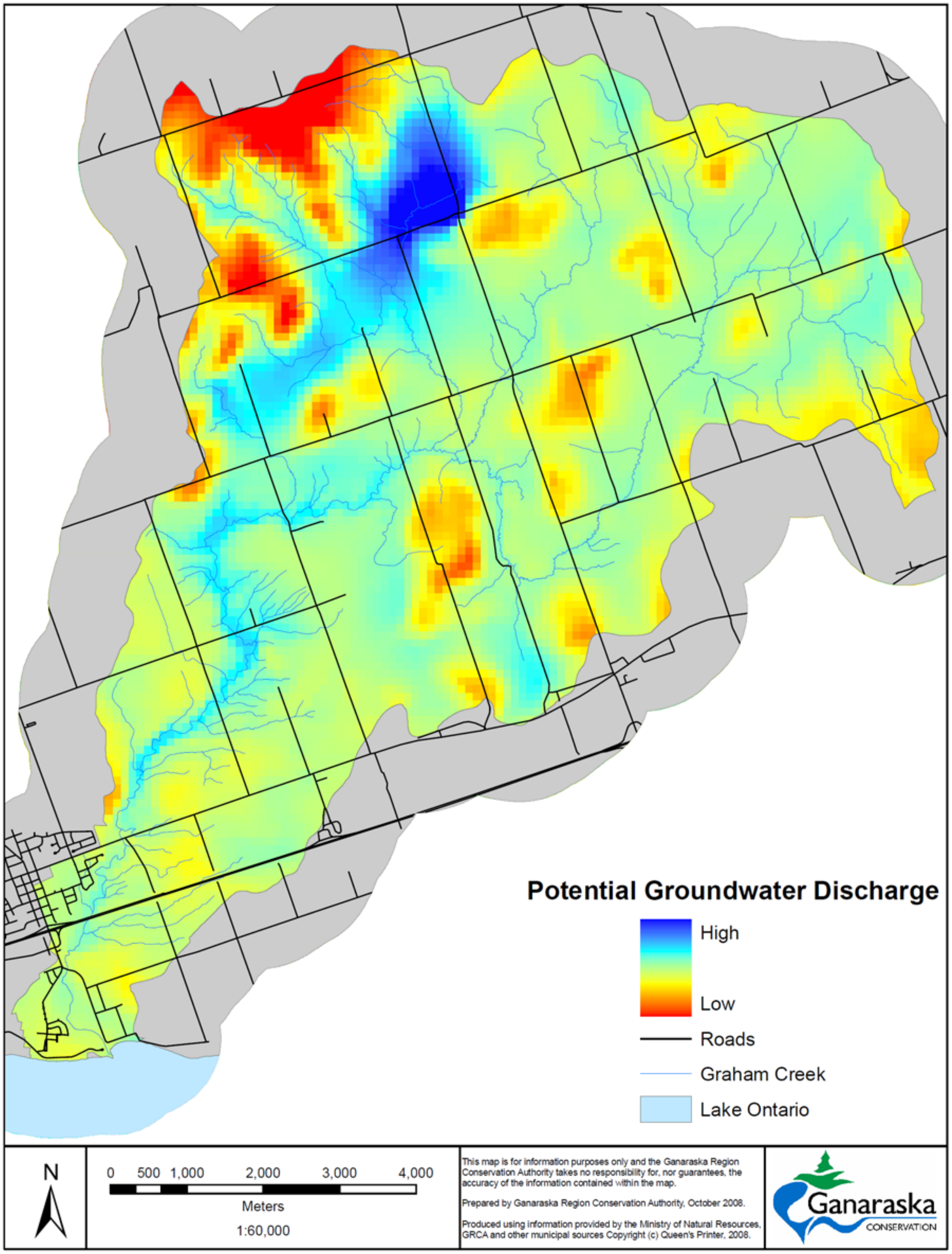


Figure 3.17: Potential groundwater discharge areas

Significant Groundwater Recharge Areas

Potential groundwater recharge and discharge areas have been identified for the Graham Creek watershed. However, groundwater recharge areas can be evaluated based on methodologies used to define their significance. In 2009 this evaluation was done under the Drinking Water Source Protection program, directed by the *Clean Water Act, 2006.* The evaluation of significant groundwater recharge areas was done in the Trent Conservation Coalition Source Protection Region, referred to as the study area herein, and is described in a report entitled *Trent Source Water Protection Study Recharge Study* (CAMC-YPDT 2009). Note that the study was completed at a scale larger than the Ganaraska Region Conservation Authority and the Graham Creek watershed.

Methodology

The Technical Rules (Ontario Ministry of the Environment 2009) used in the Drinking Water Source Protection program define significant groundwater recharge areas by one of the following two criteria. A significant groundwater recharge area is where:

- The annual recharge rate is at least 1.15 times the annual recharge rate of the area under consideration; or

- The annual recharge volume is at least 55% of the annual water budget surplus (precipitation minus actual evapotranspiration) of the area under consideration.

Significant groundwater recharge areas in the study area were delineated using the second (water budget surplus) method. The delineation process consisted of an analysis of climate, estimation of recharge rates, and calculation of the water budget surplus and the threshold recharge volume.

Climate Analysis

Climate affects groundwater recharge because precipitation and evapotranspiration rates affect the amount of water available to recharge the groundwater system. Data from 71 climate stations across the study area were used to illustrate the interpolated 30-year precipitation and temperature averages. Given the significant variability observed in the precipitation and temperature averages, it was deemed inappropriate to calculate the water budget surplus using a set of climate data from a single station. Thus, taking into account the location of climate stations, the interpolated precipitation and temperature data, general physiography, and the location of watershed boundaries, the study area was divided into northern, central and southern climate zones. The Ganaraska Region Conservation Authority lies in the south climate zone, represented by the Cobourg Sewage Treatment Plant climate station.

Recharge Rates
Recharge rates across most of the Paleozoic Area of the study area were estimated from a three-dimensional regional groundwater flow model developed by the Conservation Authorities Moraine Coalition (Earthfx Incorporated 2006). The model provided estimates of annual recharge rates for most of the quaternary soil types in the study area. These estimates were related to the surficial geology in the study area using surficial geology mapping from the Ontario Geological Survey.

Water Budget Surplus
The water budget surplus is the difference between the precipitation and actual evapotranspiration plus runoff in a given area over a particular time period; this value represents the amount of water that is available to recharge groundwater. The water budget surplus was calculated by subtracting the annual actual evapotranspiration - calculated using Thornthwaite-Mather (1957) and available soil moisture - from the precipitation averages in each of three climate zones in the study area. The water budget surplus for the south climate zone is 353.7 mm/year.

Delineation of Significant Recharge Areas
Significant groundwater recharge areas were delineated by calculating a threshold recharge rate, above which an area would be considered a significant groundwater recharge area. In accordance with the selected approach, this threshold value was calculated as 55% of the water budget surplus for each climate zone. The threshold value for the south climate zone is 194.5 mm/year. Significant groundwater recharge areas in the study area were delineated using the threshold values. However, two further methodologies were considered to refine the delineation of significant groundwater recharge areas, shown in Figure 3.18.

Areas with shallow groundwater, typically found in low-lying valleys, are unlikely to contribute any significant groundwater recharge. Any recharge occurring in these lower-lying areas would move laterally in the shallow groundwater system and discharge in adjacent streams and wetlands. Thus, areas where the water table was less than 2 m below the ground surface were removed from the delineation of significant groundwater recharge areas. After removing areas with shallow groundwater, a number of small areas (less than 0.01 km^2) remained in the delineation. These areas were removed in consideration of the resolution of the input data (i.e., surficial geology mapping and water table mapping) used in the delineation.

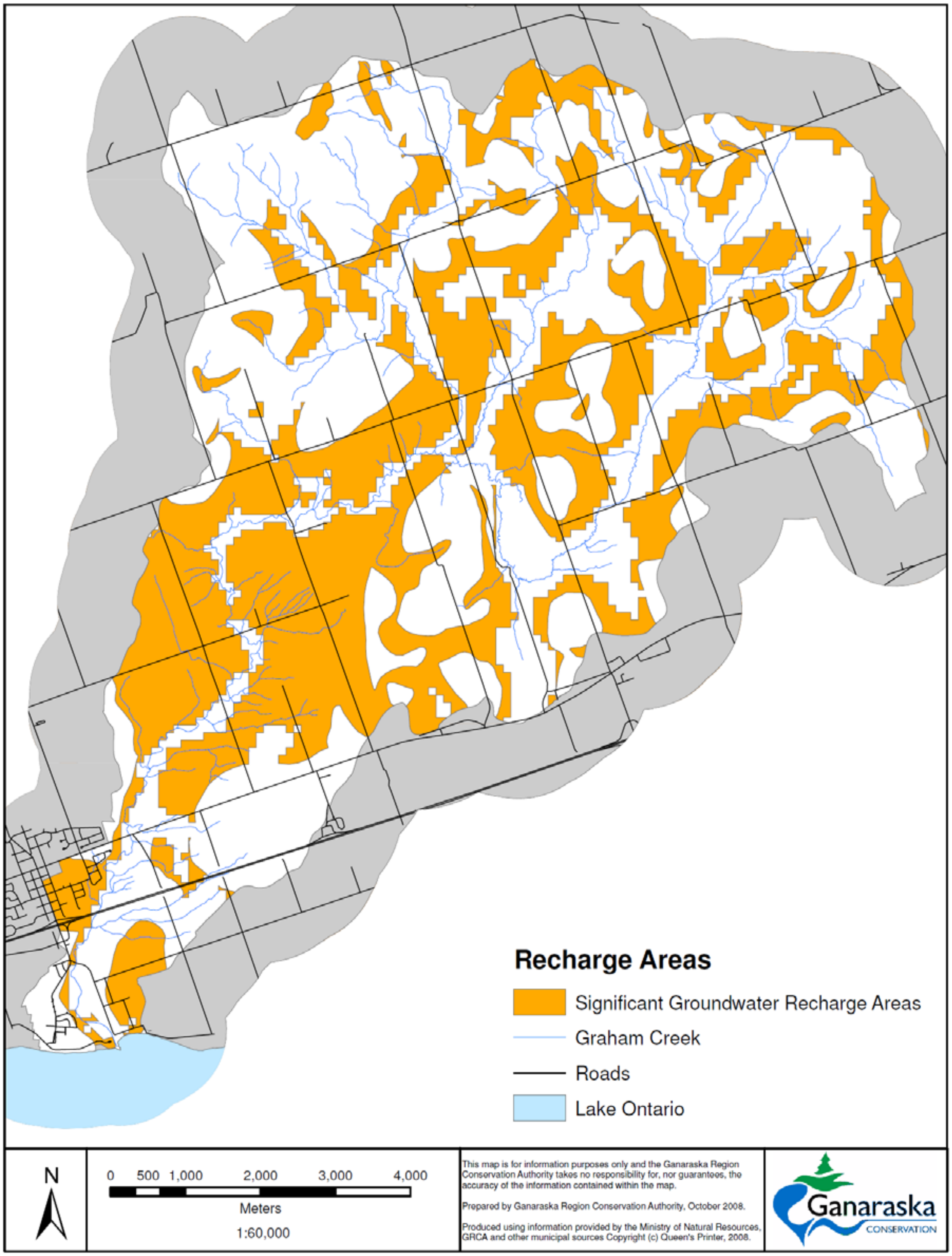


Figure 3.18: Significant groundwater recharge areas

Baseflow
The study and understanding of baseflow in a watershed is important in watershed management since water demand during these low flow periods can cause stress on aquatic ecology. Baseflow for the purpose of this document is defined as stream discharge during periods when storm flow has ceased and stream flow consists entirely of delayed sources of flow. However, depending on the purpose of the study, baseflow or low flow can also be interpreted more narrowly as the flow during a defined period of prolonged dry weather (Hinton 2005).

Baseflow is a result of groundwater discharge to a stream, and it is controlled by topography and the geological characteristics of the area. Baseflow provides all of the flow to streams during dry periods and therefore has a significant effect on the quantity and quality of surface waters. Streams are under baseflow conditions 70% of the time. Areas where groundwater discharges to streams provide cooler water temperatures. Groundwater discharge areas provide places of refuge from warm stream temperatures, and fish tend to take advantage of these locations (Power et al. 1999). Surface water quantity and quality is also affected by baseflow since the amount of water in a system is founded by its baseflow condition, and the quality of water is controlled by the quality and quantity of the groundwater entering the stream.

The Ganaraska Region Conservation Authority attempted to conduct baseflow surveys in 2008 and 2009. Due to the wet summer conditions experienced during what would normally be baseflow conditions the surveys were not able to be carried out. The high dominance of wetlands in the Graham Creek watershed (10% of the entire drainage area) causes a slower release of surface water after rainfall. Therefore a longer period of dry weather is required to achieve baseflow conditions in Graham Creek. It is recommended that baseflow surveys are carried out during the next period of prolonged dry weather to understand baseflow conditions in the Graham Creek watershed.

3.3 Groundwater Analysis
Groundwater analysis allows watershed managers to understand groundwater systems, and where and how it contributes to surface water systems. In addition, by understanding the groundwater system, drinking water sources and non-potable water uses can be maintained in a manner that protects the natural environment and the groundwater resource.

3.3.1 Groundwater Vulnerability

Groundwater vulnerability has been evaluated for the Graham Creek watershed through the Drinking Water Source Protection program, directed by the *Clean Water Act, 2006.* The evaluation of groundwater vulnerability was carried out in the Trent Conservation Coalition Source Protection Region and is described in a report entitled *Groundwater Vulnerability Assessment - TCC Source Protection*

Region (AECOM 2009). Note that the study was completed at a scale larger than the Ganaraska Region Conservation Authority and the Graham Creek watershed.

The objective of identifying groundwater vulnerability is to address groundwater source protection. Delineations are also intended to recognize different uses of water in a regional setting, including shallow and deep private wells, ecological resources and recharge/discharge areas. Such delineations also serve as the basis for protection efforts for these water resources. Preliminary aquifer vulnerability areas in the Ganaraska Region Conservation Authority have been delineated through earlier municipal groundwater studies (Morrison Environmental Limited 2004).

Methods

The Technical Rules (Ontario Ministry of the Environment 2009) used in the Drinking Water Source Protection program list four acceptable methods to be used for the assessment of groundwater vulnerability. Two of the four acceptable methods were selected for use and these have been used in previous studies throughout the Ganaraska Region Conservation Authority.

- Intrinsic Susceptibility Index (ISI) – A score or index value is given to each well (e.g., Ministry of the Environment Water Well Record Database). This index or score at each well is then interpolated between wells to produce a vulnerability map. This method takes into account the soil type and thickness above the aquifer, and the static water level in the well.

- Aquifer Vulnerability Index (AVI) – A score or index value is assigned based on mapping products (e.g., depth to aquifer, soil type and thickness) that reflects the relative amount of protection provided by physical features that overlie the aquifer. This method, unlike the ISI, does not take into account water table or water level information.

Scoring of groundwater vulnerability is as follows:

	ISI or AVI Range
High Vulnerability	0 to < 30
Medium Vulnerability	30 to < 80
Low Vulnerability	> 80

Results for the Palaeozoic Study Area

Using the ISI method, shallow aquifers in areas north of the Oak Ridges Moraine are generally of high or medium vulnerability. Shallow aquifers in the centre of the Oak Ridges Moraine and the Iroquois shoreline appear to be slightly more vulnerable than in the north and south flanks of the Oak Ridges Moraine. This is expected since the deposits are largely unconfined coarse-textured material. However, the AVI method produced more conservative results along the centre of the Oak Ridges Moraine, whereas the ISI method produced results more conservative in the rest of the Palaeozoic Study Area.

In general, the AVI method produced more conservative results in the Oak Ridges Moraine since the method is based on geological characteristics, whereas the ISI method created results less conservative given there are fewer wells, which are needed for analysis, in the area of study on the Oak Ridges Moraine. As a result, and after Ontario Ministry of the Environment approval (for the purpose of the Drinking Water Source Protection program), the resulting ISI and AVI maps were merged to create a conservative groundwater vulnerability map for the Ganaraska Region Conservation Authority that can be used to determine groundwater vulnerability for the Graham Creek watershed (Figure 3.19).

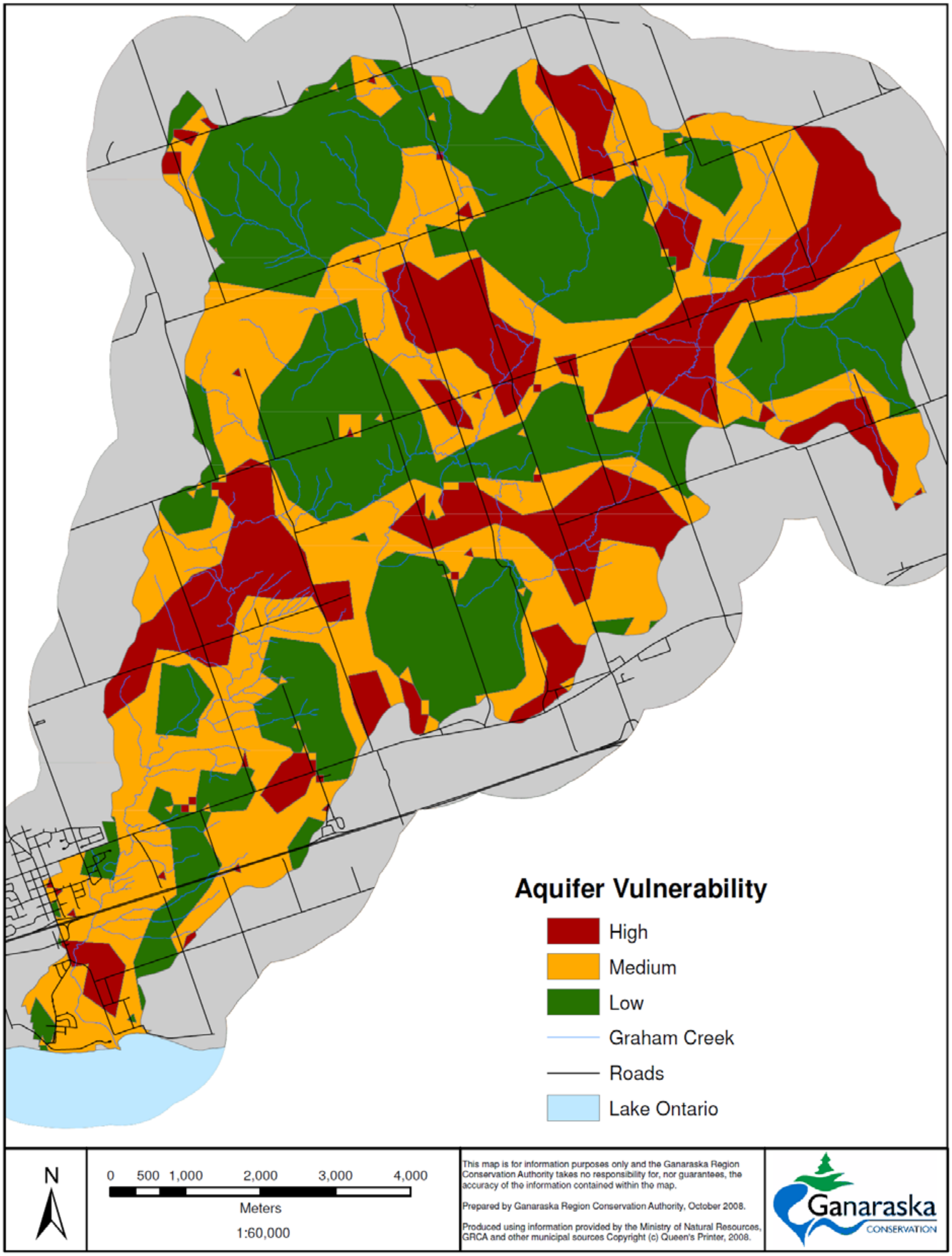


Figure 3.19: Groundwater vulnerability

3.4 SURFACE WATER

Surface water flows and occurs on the surface of the ground. Water enters onto the surface via precipitation and groundwater discharge, and it moves via water flow, groundwater recharge or transpiration. The following section describes surface water characteristics, surface water flows and water quantity.

3.4.1 Drainage Basin Characteristics

The Graham Creek watershed originates in the Oak Ridges Moraine and South Slope at an elevation of approximately 275 masl in its northwest corner, and drains a land base of 78.2 square kilometres (km^2). It flows southwest for about 20.4 km and discharges to Lake Ontario at an elevation of 105 masl. Graham Creek has a total fall of about 51 m with an average slope of about 2.5 m/km.

Mulligan Creek is the largest tributary of Graham Creek and originates in the till plains of Concession 5. The stream gradients are very steep, and at one point the stream gradient reaches 71 m/km (Ontario Ministry of Natural Resources 1976). In contrast the headwaters in the east and along the main branch to Concession Road 3 are generally flat. Downstream of Concession Road 3 the creek valley becomes incised and the gradient steeper. Crooked Creek drains an area of 8.5 km^2 and Lytle Creek an area of 3.8 km^2. Figures 3.20 and 3.21 show the main branch and its tributaries. The wetlands, having a flat gradient, have the combined effects of lowering runoff rates and reducing peak flows. Several of the small tributary streams are intermittent and have poorly defined channels.

Graham Creek is drained by tributary streams that combine into a main channel. Several methods have been used for ordering the tributary streams in a drainage network; however the Horton-Strahler method is widely used (Wetzel 2001). The smallest permanent stream is designated as the first order, and the confluence of two first-order streams creates a second order stream. This increase by confluence occurs until the system outlets to a specified point, in this case, Lake Ontario. Graham Creek, as defined by the Horton-Strahler method, consists of five stream orders that in total travel a distance of 148 km. Stream order lengths are as follows: first order 82 km, second order 28 km, third order 10 km, fourth order 13 km, and fifth order 15 km (Figure 3.22). In addition, many intermittent and ephemeral streams contribute to the flows and habitat of Graham Creek during differing times of the year.

As Graham Creek flows through the landscape, it is easily influenced. Imperviousness is one such landscape characteristic that alters the drainage response of a watershed. Impervious areas are hardened through and development. These land cover prevent water from infiltrating through the ground, increase surface runoff rates, and alters pathways of surface water (e.g., drainage through storm sewers to a stream). Areas of increased imperviousness are located primarily south of Regional Road 2 and in Newcastle. However, according to Ecological Land Classification, imperviousness as it relates to urban areas, roads and rural development is limited throughout the watershed.

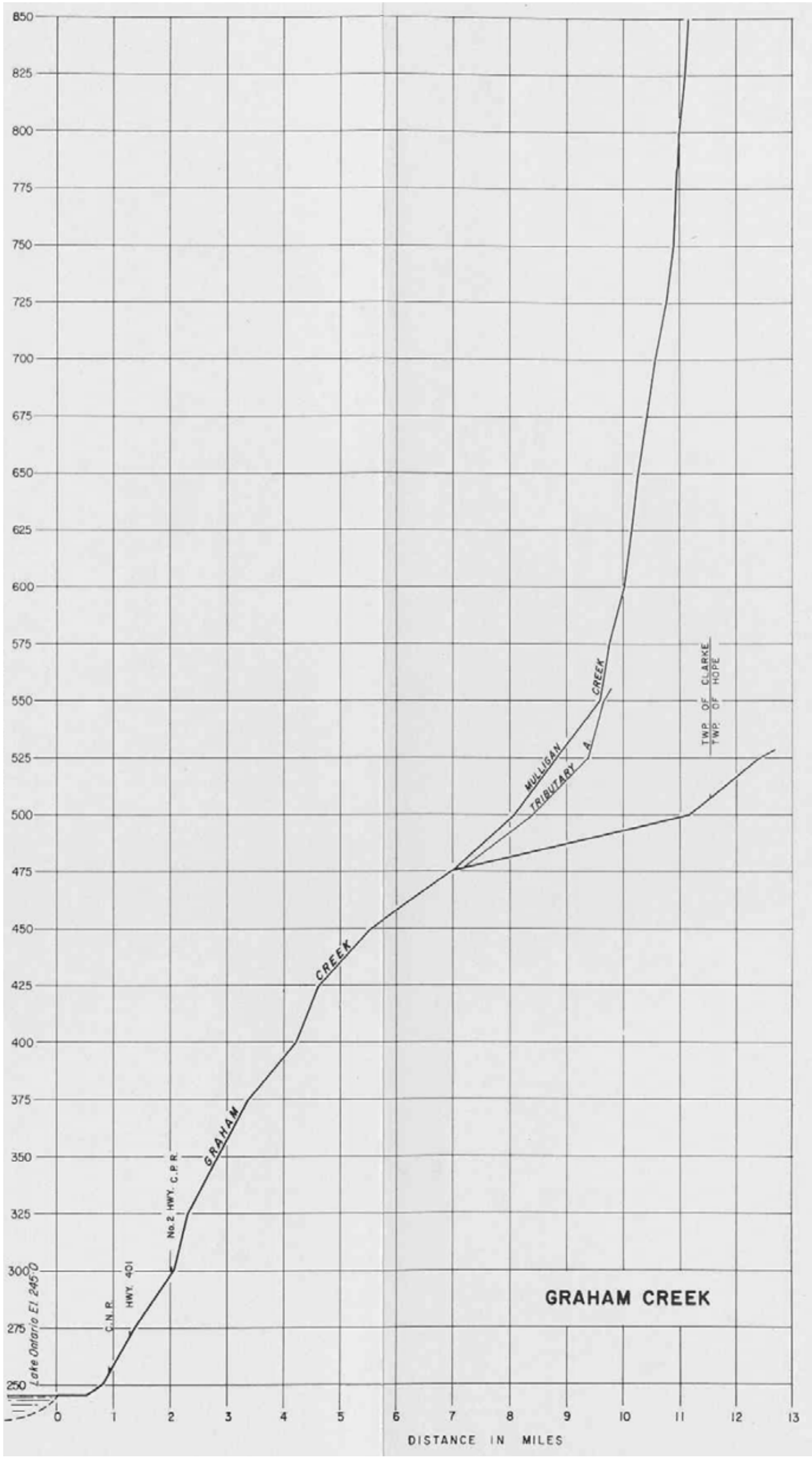


Figure 3.20: Historical cross-section of Graham Creek

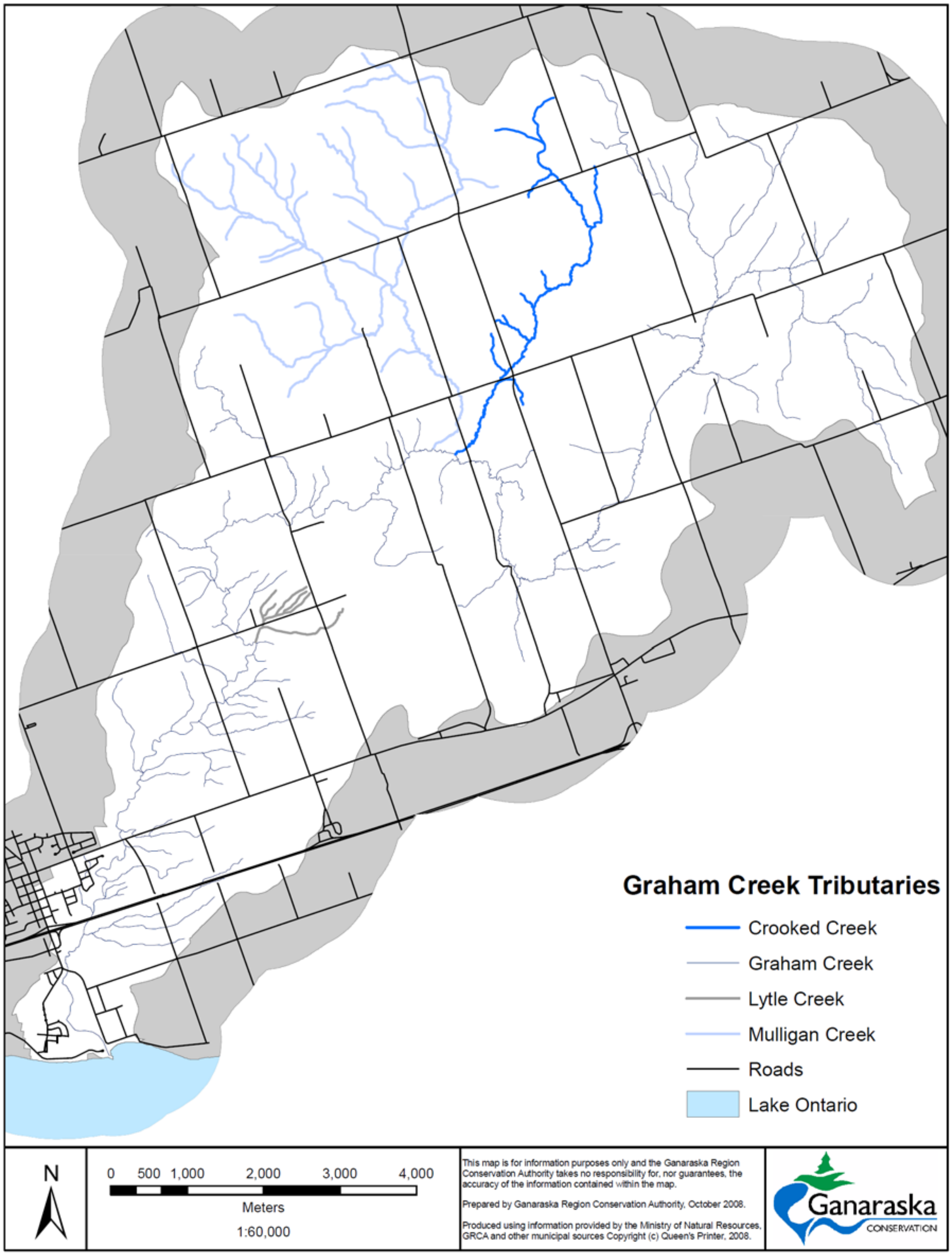


Figure 3.21: Graham Creek tributaries

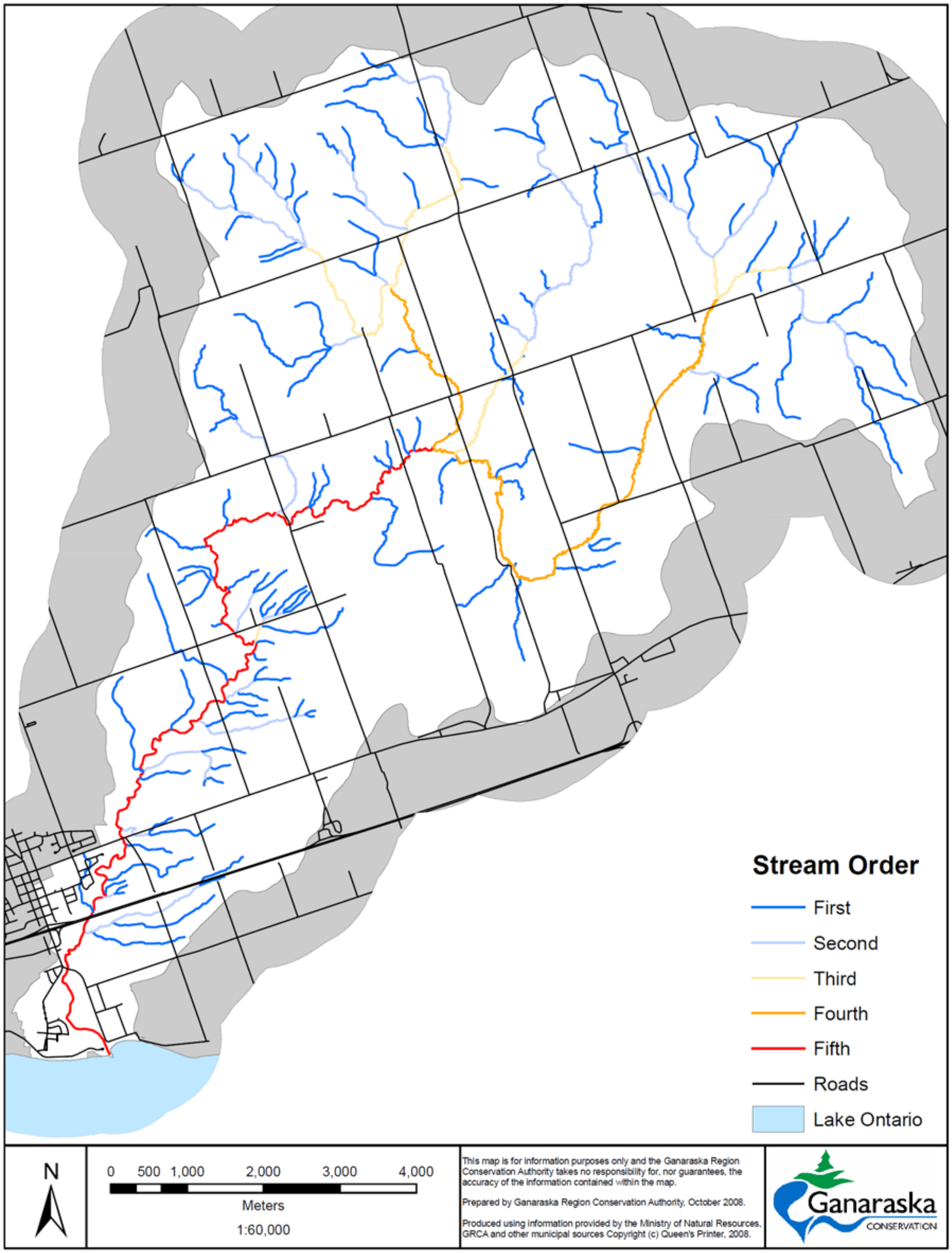


Figure 3.22: Stream order

3.4.2 Dam and Water Control Structures

It is unknown how many private dams and water control structures are on Graham Creek. Historically 5 grist or sawmills existed in Graham Creek, therefore remnant foundations may exist. Figure 3.23 shows the locations of known dams and water control structures in Graham Creek and in Northumberland County. Online ponds would have associated dams in order to impound the water. The lamprey barrier south of Mill Street acts as a barrier to non-jumping species of fish.

In 1966, the Conservation Authorities Branch prepared preliminary engineering report on the Graham Creek Reservoir. Anticipated benefits from the reservoir, located in Lots 12 to 17, Concession 3 of the Municipality of Clarington, included minor flood control, low flow augmentation, irrigation water supply and recreational use (Ontario Ministry of Natural Resources 1976). Costs for the project caused delays, and a new evaluation in the preceding years caused the project to be cancelled. Today there is little need for such as reservoir.

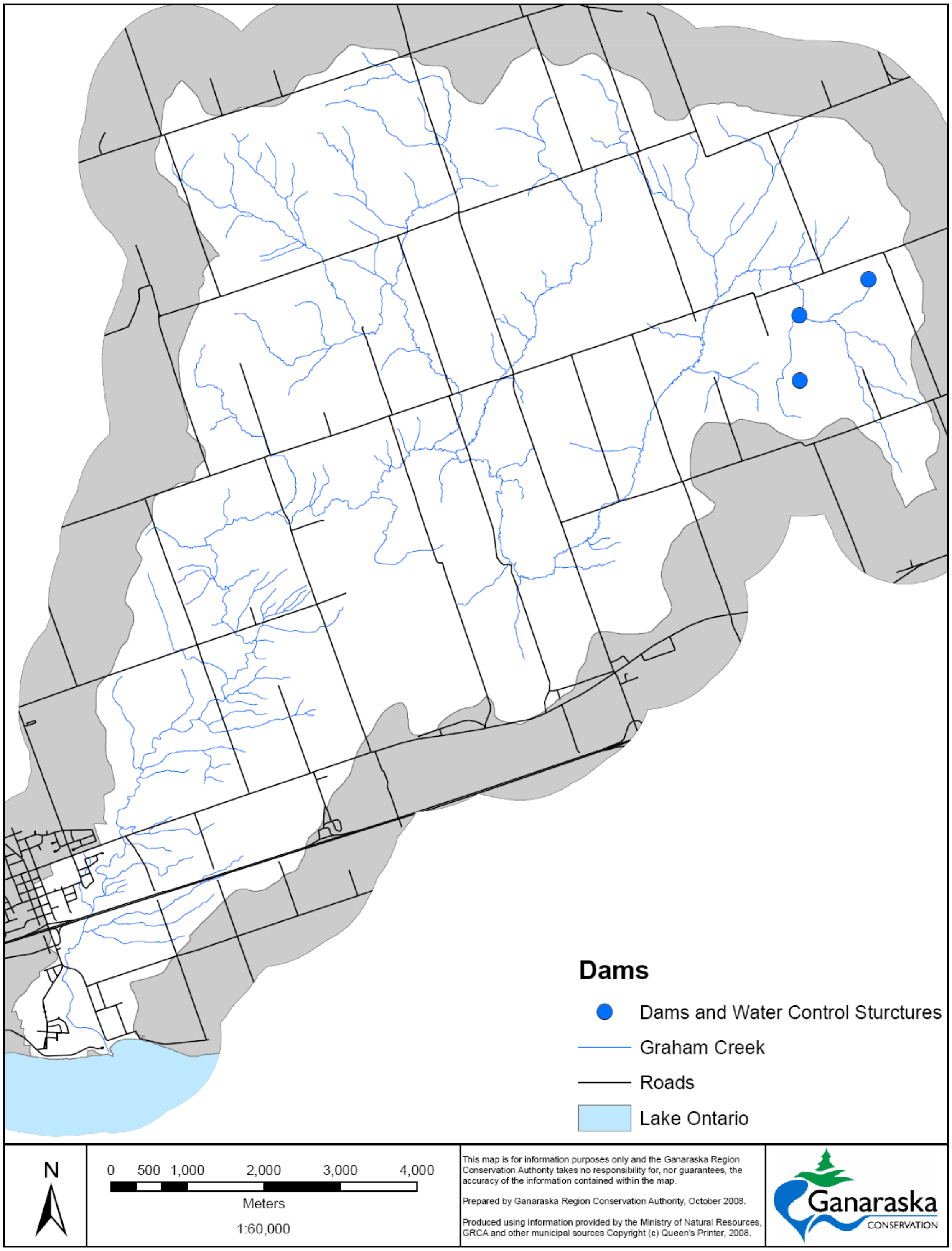


Figure 3.23: Dams and water control structures[1]

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[1] Inventory only conducted in Northumberland County

3.4.3 Stream Gauge Stations

Graham Creek has not historically been monitored through the Water Survey of Canada stream gauge system. As a result historic or long-term water flow information is lacking. However in late 2009 a stream gauge was installed at Mill Street to allow for data collection.

3.4.4 Ontario Low Water Response

The Ontario Low Water Response (formerly Ontario Water Response) program was developed in 1999/2000 to prepare and coordinate a provincial response plan in the event of a drought. The program recognizes that water management must be approached at both the provincial and local levels. The provincial role is to provide overall direction through policies and guidelines, central information storage and analysis, and emergency support (Ganaraska Region Conservation Authority 2007b). At the local level, monitoring of water levels, information collection and program delivery can be accomplished.

As part of this program, and in response to low water conditions, a Ganaraska Region Water Response Team has been established to assist with implementing the response. Members include local municipalities, the Ontario Ministry of Natural Resources, the Ontario Ministry of the Environment, the Ontario Ministry of Agriculture, Food and Rural Affairs, and the Federal Department of Fisheries and Oceans.

The indicators to the Ontario Low Water Response program are the amount of precipitation and streamflow conditions. Different threshold levels for precipitation and streamflow are used to categorize the level of low water conditions (Table 3.6). Methods used to determine threshold levels are defined in Ganaraska Region Conservation Authority (2007b).

Table 3.6: Summary of threshold levels for low water response

Condition	Precipitation		Stream Flow
Level 1	3 or 18 month precipitation < 80%	or	Spring: - < 100% of lowest monthly average flows Other months: - < 70% lowest monthly average flows
Level 2	1,3, or 18 month precipitation < 60% or 3 weeks of < 7.6 mm per week	or	Spring: - < 70% of lowest monthly average flows Other months: - < 50% lowest monthly average flows
Level 3	1,3 or 18 month precipitation < 40%	or	Spring: - < 50% of lowest monthly average flows Other months: - < 30% lowest monthly average flows

(Ganaraska Region Conservation Authority 2007b)

Once a low water condition has been identified, an appropriate response is carried out. The following, as defined in Ganaraska Region Conservation Authority (2007b), are the responses that will take place in relation to each condition.

- Level 1 Response: Communication will occur between the Water Response Team and the Ministry of Natural Resources. Each Water Response Team member is responsible for communicating water conservation messages in their sector. The message will consist of a media release, which will focus on current watershed conditions and promote a 10% voluntary water use reduction.

- Level 2 Response: When a watershed moves from Level 1 to Level 2 conditions, notification is given to members of the Water Response Team and the Ministry of Natural Resources. Each member is responsible for communicating water conservation messages in their sector with the target of a further 10% water use reduction. Municipalities may consider restrictions on non-essential use as appropriate. The provincial agencies on the Water Response Team will contact the Ontario Water Directors' Committee Low Water Committee Coordinator. The Coordinator will activate the Low Water Committee to reinforce cross-ministry program support. The Coordinator will also notify the Provincial Emergency Response Coordinator and request regular briefings with Emergency Measures Ontario.

- Level 3 Response: When a watershed moves from Level 2 to Level 3 conditions, notification is given to members of the Water Response Team and the Ministry of Natural Resources. The Ontario Water Directors' Committee Low Water Committee is responsible for declaring a Level 3 condition. At the Level 3 condition water restrictions may be necessary and will be implemented through the appropriate government agency.

Since the Ontario Low Water Response program was initiated in 2000, the Graham Creek watershed has experienced a Level 1 low water condition in 2005 and 2007. Therefore, a voluntary reduction in water use by 10% was encouraged.

3.5 SURFACE WATER ANALYSIS

Analyzing surface water can be done from a flow and a use perspective. Understanding the quantity and flow characteristics allows for protection of surface water, people and property. The following sections discuss hydrology, hydraulics, floodplains and water budgeting in the Graham Creek watershed.

3.5.1 Graham Creek Hydrology

Hydrology determines the amount of flow generated by a particular storm. The storm examined is defined in terms of the worst event that would statistically happen in a certain number of years. Computer models are used to determine flows and do so by examining rainfall, land area and cover, infiltration, and evaporation to determine the runoff associated with a rainfall.

3.5.2 Hydraulics Analysis

Hydraulics models take runoff results from the hydrology models and convey them down the river system estimating the extent of the area flooded by (or needed to carry) the flow. Simply put, hydrology calculates how much of the water will become runoff, and hydraulics calculates how high the river will rise.

In the Graham Creek watershed many settlement areas were built around water courses that provided power and transportation. Analysis is required to scientifically define floodplains for both the protection of existing land uses and the prevention of introducing new uses into hazardous areas.

Flood Flows

As stated in the *Technical Guide - River and Stream Systems: Flooding Hazard Limit* (Ontario Ministry of Natural Resources 2002), "*The group of flood standards referred to in the Natural Hazard Policy is the basis by which floodplains are delineated. It is designed to accomplish the main objectives of floodplain management: to prevent loss of life and to minimize property damage and social disruption*." There are three types of flood events used in defining the flood standard in Ontario: synthetic storms developed from the two large historical events (Hurricane Hazel and the Timmins storm), observed and documented historical events (if larger than the 100-year event), and statistically derived 100-year events. The magnitude of the flood which defines the floodplain limits in a particular area of the province is largely dependent upon the susceptibility of that area to tropical or thunderstorms, rainfall, snowfall or a combination of these meteorological events (Ontario Ministry of Natural Resources 2002).

The Graham Creek watershed lies within Zone 1, as defined in technical guides, and as such the Regulatory Flood is defined by the greater of:

- The flood level corresponding to the peak flow generated by the Regional Storm (Hurricane Hazel)
- An observed and well-documented flood level
- The 100-year flood level.

All watersheds in the Ganaraska Region Conservation Authority have their Regulatory Flood defined using a Hurricane Hazel-based event.

Graham Creek Hydrologic Model

This section has been summarized from Ganaraska Region Conservation Authority (2008b).

The Ganaraska Region Conservation Authority updated hydrologic model was developed based on the standardized methodology prepared by Greenland International. The new model was enhanced by using updated GIS data and modeling programs. Graham Creek at the time was an ungauged creek, however Wilmot Creek to the west is gauged and the hydrologic model was calibrated using five summer events and verified by two events selected from 2000 to 2008. The Wilmot Creek hydrology model was calibrated to gauged flow data. Since Graham Creek is so close to Wilmot Creek, the same calibration factors were applied to the Graham Creek model.

The calibration adjustment factors obtained from the Wilmot Creek hydrology study were applied to the Graham Creek hydrologic model. Four types of design storms (AES 12 hour, SCS 12 hour, SCS 24 hour and Chicago 12 hour) were used on the calibrated model to see which theoretical storm would produce the highest peak runoff. The Chicago storm was found to be the critical storm event that caused the highest runoff.

The simulated results also were compared with previous studies (M.M. Dillon Limited 1977, D.G. Biddle and Associates Limited 1995, and Greenland International Consulting Limited 2003). The updated model results were significantly higher than Greenland's in the range of 5 to 154%. As compared to M.M. Dillon Limited (1977), the regional flows (Hurricane Hazel) simulated from the updated model are about 2 to 26% lower except Mulligan Creek in which updated model simulated higher flow due to a larger drainage area delineated. All the discrepancies from previous studies can be explained.

Peak flows for future conditions were further estimated by applying the calibrated model on the future land use which was extracted from the Municipality of Clarington Official Plan. The differences in peak flows between existing land use and future land use are minimal. The detailed recommended flow rates for developing flood line in Municipality of Clarington in the LiDAR covering are listed in the Table 3.7 and the location of key nodes is illustrated in Figure 3.24.

The results of the new hydrologic model for Graham Creek are reasonable and provide the best estimate of flow and therefore should be input into a hydraulic model to establish new regulatory floodlines for the Municipality of Clarington. It is recommended that the simulated peak flow rates adjusted by calibration factors for the 100-year Chicago 12-hour storm and Hurricane Hazel, be used as input the Graham Creek floodplain mapping. It is further recommended that the existing scenario be used as input to the hydrology model as this model produces slightly greater peaks than the peak flows generated from future land use.

Table 3.7: Recommended flow rates for creating flood lines

Key node	NHYD in VO2 Model	Drainage area (ha)	100 yr (m^3/s) Existing Chicago	Regional (m^3/s) Existing
A	342	113	1.5	7.8
B	980	6808	45.8	326.7
C	981	7094	48.1	341.6
D	907	7424	49.5	357.9
E	339	223	4.3	17.4
F	902	7647	51.2	370.2
G	900	7840	53.2	375.8

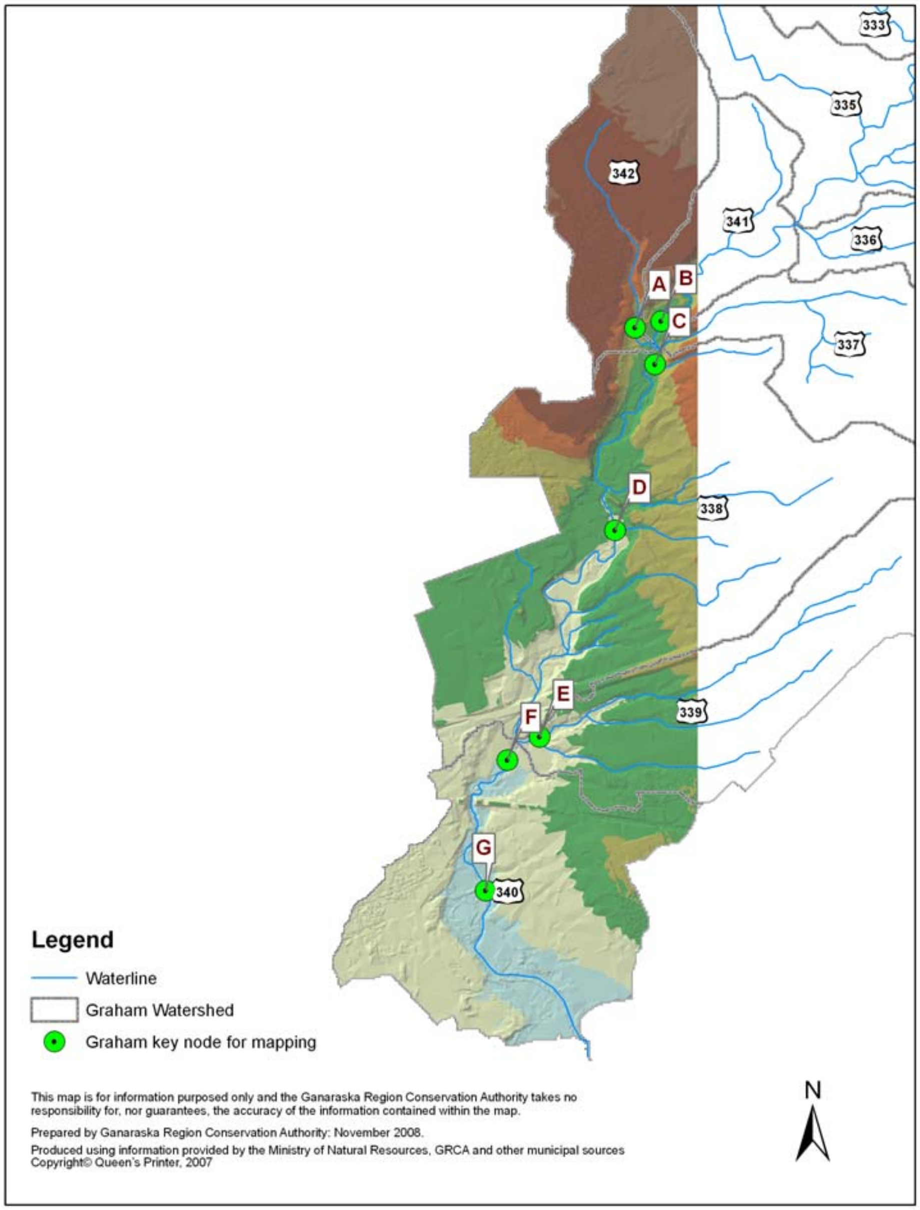


Figure 3.24: LiDAR mapping coverage and key nodes location

3.53 Natural Hazards

Natural Hazard Limits are boundary lines that delineate areas where there is a concern for public health and safety associated with natural hazards. Generally these hazards are a result of flooding, erosion or unstable organic soils. The Province of Ontario has developed criteria for defining these Natural Hazard Limits (Ontario Ministry of Natural Resources 2002), which are implemented both through the *Provincial Policy Statement, 2005* and *Ontario Regulation 97/04*. Criteria is also outlined in the *Development, Interference with Wetlands, and Alterations to Shorelines and Watercourses Regulation*, implemented by Conservation Authorities throughout the province. These regulations are empowered by Section 28 of the *Conservation Authorities Act*, and the Ganaraska Region Conservation Authority administers *Ontario Regulation 168/06*, in the Graham Creek watershed.

The Ganaraska Region Conservation Authority has developed hazard limits for the riverine, coastal and wetland systems (organic soils), for the purpose of provincial policy and regulations implementation. These limits have been used to create a single mapping product for all hazard areas in the watershed (Figure 3.25). Lake Ontario hazards, which are also delineated, are not being addressed in this background report.

General Objectives of Hazard Lines

The general objective of hazard mapping is to develop background information that will satisfy data requirements of the municipal zoning by-laws and the natural hazards component of the *Provincial Policy Statement*. The Ganaraska Region Conservation Authority has established objectives which form the basis of the decision-making process associated with regulation implementation. These objectives include an Authority program designed to "*prevent loss of life and/or property damage resulting from flooding and/or erosion on lands subject to the Regulation by minimizing hazardous and unnecessary development of lands within Regulatory floodplains*" (Ganaraska Region Conservation Authority 2005b). Other objectives include the following.

- To promote the conservation and wise use of watercourses and their associated valleylands
- To require mitigating measures to be undertaken for work within regulated areas, which singly or cumulatively may cause an increase in flooding or erosion, or a decrease in the environmental quality of the stream and its associated valleylands
- To reduce the necessity for public and private expenditures for emergency operations, evacuation and restoration of properties subject to flooding
- To regulate uses of floodplains and any development in them that in future years may require emergency operations and expensive protective measures
- To regulate development on or adjacent to potentially dangerous slopes
- To reduce soil erosion from valley slopes

- To regulate the draining or filling of wetlands which may reduce natural water storage capacity and protect provincially and/or locally significant wetlands
- To minimize water pollution associated with filling and construction activities. The Ganaraska Region Conservation Authority will liaise with other agencies regarding pollution matters and promote wise use of water resources to help improve water quality throughout the watershed
- To make information available regarding erosion prone areas to interested parties.

Provincial Policy Statement

The Provincial Policy Statement*, 2005* (PPS) defines development as *"new lot creation, a change in land use or construction which requires approval under the Planning Act"* (Ontario Ministry of Municipal Affairs and Housing 2005). The PPS protects public health and safety through the land use planning process by directing development away from these hazardous areas, and only permitting development where hazards can be safely addressed. Section 3.0 of the PPS contains the natural hazard policies that form the basis for comments the Ganaraska Region Conservation Authority provides to municipalities on applications circulated in the Graham Creek watershed.

Hazard Types and Limits

Riverine Hazards

Riverine hazards result from the proximity of a structure to a river, creek, or stream. Natural hazards relating to riverine systems may include flooding, stream erosion, slope instability, and the shifting tendencies of meandering riverine systems. Riverine hazard limits address these hazards. To account for the variation present in the shape of riverine systems, two basic categories have been developed to facilitate the determination of the erosion-related components of the Natural hazard limit: confined and unconfined riverine systems. The following sections outline the methods that have been developed to set the boundaries within which development is susceptible to hazards.

Flooding Hazard Limit

The Flooding Hazard Limit, or Regulatory Floodline, is generally based on the greater of the Hurricane Hazel storm event (the Regional Storm) or the 100-year return period storm or an observed flood. Floodlines for the Regional Storm are calculated using precipitation data from Hurricane Hazel, which occurred in 1954, while the 100-year floodlines are based on a storm that statistically occurs once every one hundred years.

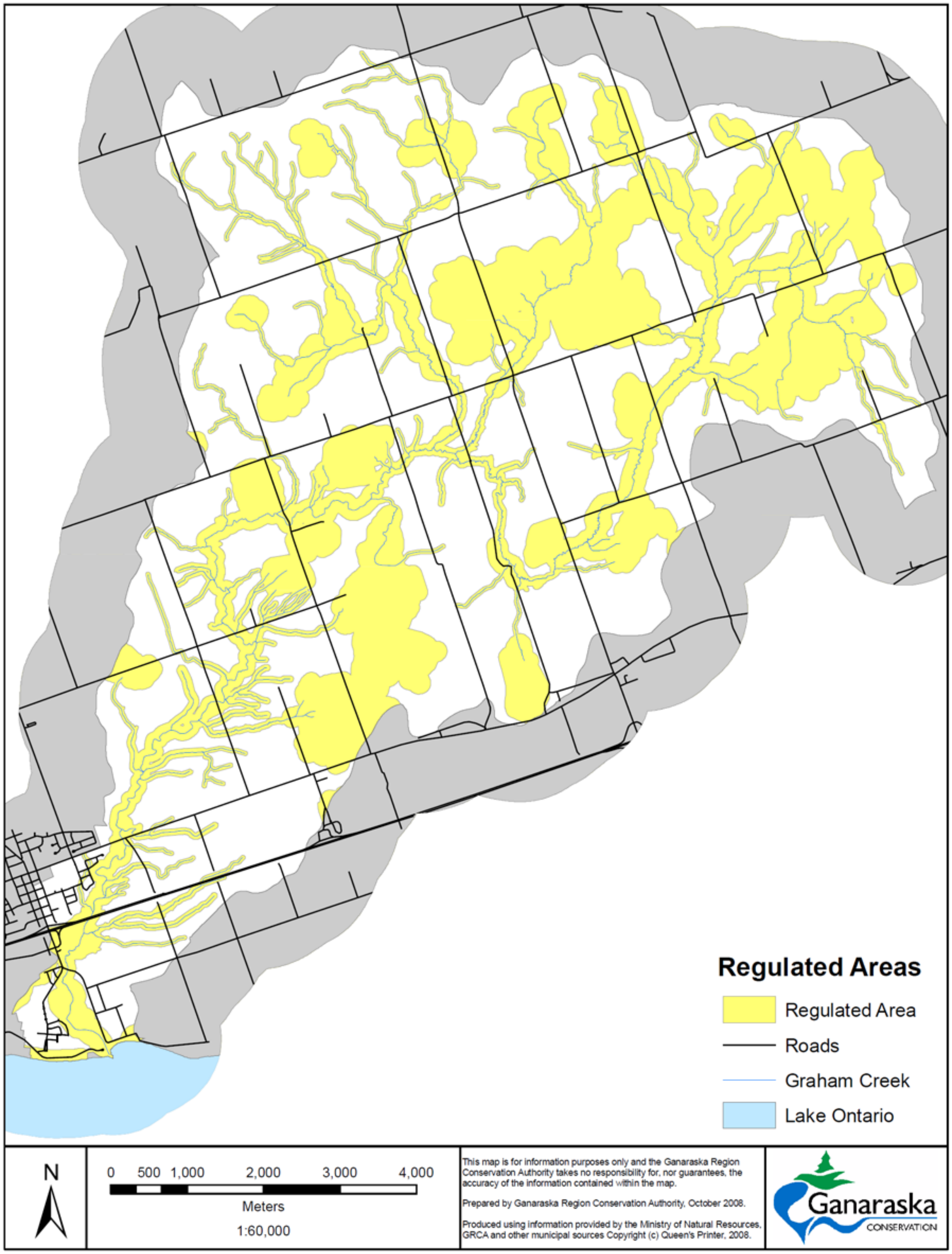


Figure 3.25: Regulated areas

The Regulatory Floodline is determined through a computer simulation of the specified storm centred over the watershed in question. There are two types of computer models involved: (1) the hydrology model calculates how much water will flow into the river and (2) the hydraulic model calculates how high the water will rise in the river. These models takes into account watershed features including soils (type and degree of saturation), vegetation, grades, and existing land uses, and defines the water surface elevations that will be produced by the storm. Figures 3.26 and 3.27 display the application of this model in delineating the Regulatory Floodline.

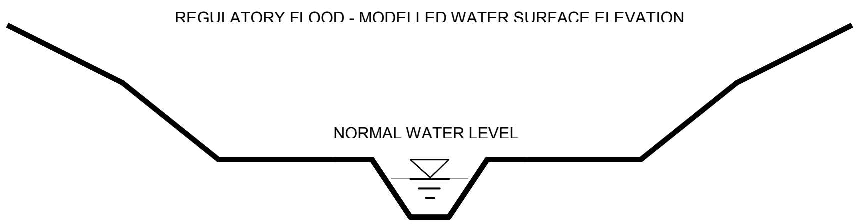


Figure 3.26: Watercourse cross-section with a Regulatory Floodline

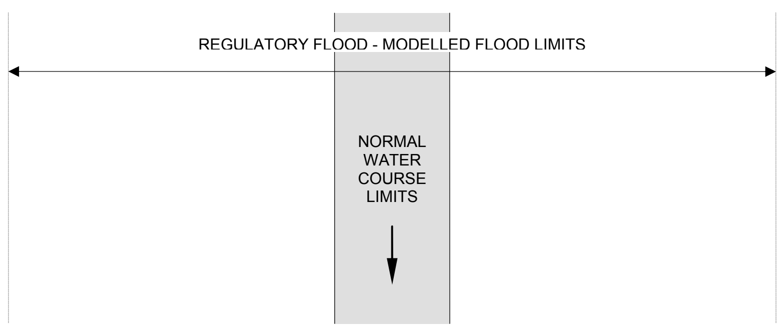


Figure 3.27: Plan view of a watercourse with a Regulatory Floodline

Erosion Hazard Limit - Confined Systems

The Erosion Hazard Limit for a confined system consists of the Toe Erosion Allowance, the Stable Slope Allowance, and the Erosion Access Allowance. A confined system, for this purpose, is defined as a watercourse within a clearly visible valley that is impacting on the valley walls, and is shown in Figure 3.28.

Stream Erosion

Stream bank erosion is an important cause of valley slope instability, and is ultimately responsible for the presence of valleys. Stream erosion directly at the toe of a valley slope can steepen and undercut the slope, leading to the eventual failure of the bank. The Toe Erosion Allowance has been implemented to buffer development from the hazardous effects of toe erosion, and also to buffer the natural river processes from the influences of development. This allowance is based on a minimum distance of 15 metres between the edge of a river system and the toe of its confining valley wall. Figures 3.28 and 3.29 show the application of the Toe Erosion Allowance. On a reach to reach basis, a determination is made as to whether the stream impacts on the valley wall at any location. If so, the Toe Erosion Allowance is expanded to include all lands between the top of bank and the toe of slope (valley floor).

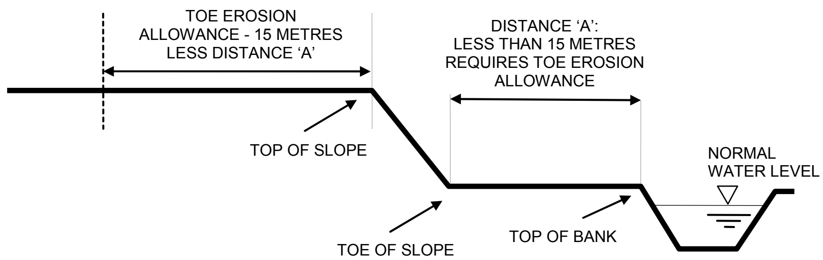


Figure 3.28: Watercourse cross-section with Toe Erosion Allowance

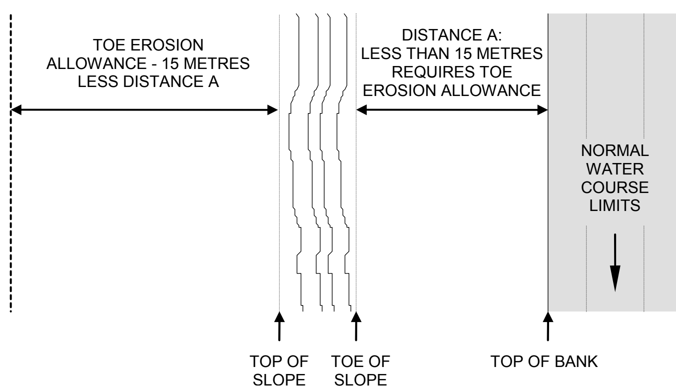


Figure 3.29: Plan view of watercourse with Toe Erosion Allowance

Slope Stability Allowance

Slopes are also naturally subject to movement and failure. The Stable Slope Allowance has been implemented to buffer development from the hazards of slope instability, and also to prevent the influence of development on the rate of slope movement. This allowance is based on an assumed stable slope gradient of 3 horizontal units to 1 vertical unit (3:1). For slopes at steeper gradients, the allowance is equal to the distance between the actual valley top of slope and the point at which a slope at a 3:1 gradient, rising from the same toe position, would intersect the ground surface. Figure 3.30 shows the application of the Stable Slope Allowance.

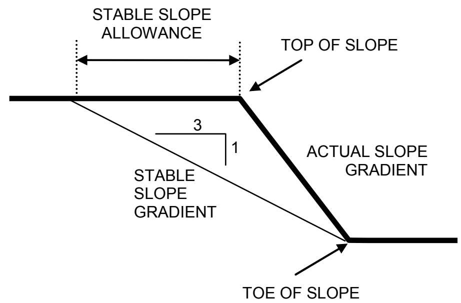


Figure 3.30: Stable Slope Allowance

Access Allowance

In addition to the above-mentioned Toe Erosion and Stable Slope Allowances, a minimum 5-metre Erosion Access Allowance is also applied to maintain sufficient access for emergencies, maintenance and construction activities. This allowance is analogous to a factor of safety, providing protection against unforeseen conditions that may adversely affect the natural processes of an erosion prone area. Figure 3.31 shows a typical application of the Erosion Access Allowance in conjunction with the Toe Erosion and Stable Slope Allowances. The Erosion Hazard Limit for a confined system is comprised of these three allowances (Erosion Access, Toe Erosion and Stable Slope).

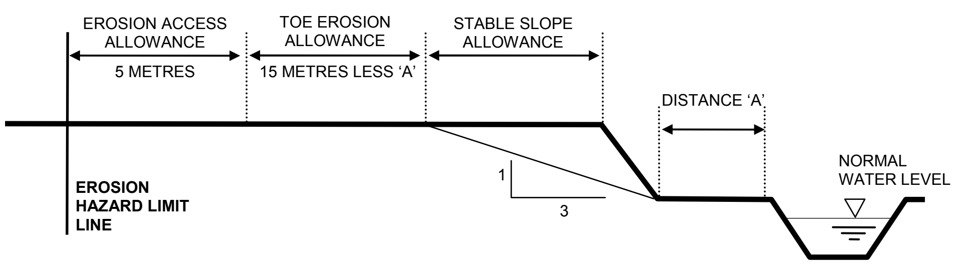


Figure 3.31: Erosion Hazard Limit (for a confined system)

Erosion Hazard Limit - Unconfined Systems

The Erosion Hazard Limit for unconfined systems consists of the Meander Belt Allowance and the Erosion Access Allowance. Unconfined systems occur where a watercourse is not contained within a clearly visible valley section. If the stream sits in a large valley section, but does not impact on the valley wall, the stream is considered unconfined.

Meander Belt

In unconfined systems, the watercourse is not contained within a visible valley, rather the flow of water is free to shift across the land. As a result, the watercourse of an unconfined system does not impact on the valley walls.

Meandering tendencies of the watercourse, areas of confluence and areas of geographical change must be thoroughly examined to accurately designate representative reaches along the watercourse. For this purpose, a reach is defined as areas of similar topography along the watercourse, and regions between confluences.

The Meander Belt Allowance provides a limit to development in the areas where the river system is likely to shift. This allowance is based on 20 times the bankfull channel width, where the bankfull channel width is measured at the widest riffle section of the reach. A riffle is a section of shallow rapids where the water surface is broken by small waves. Measurements of the bankfull width have been determined for each reach, or groups of reaches, by observing existing aerial photographs, maps and field data. Where on-line ponds are located in unconfined systems, the meander belt width is increased by the width of the open water in the pond.

Erosion Hazard

The Erosion Hazard Limit for an unconfined system is comprised of the Meander Belt Allowance and the 6-metre Erosion Access Allowance. Figure 3.32 shows a typical application of the Meander Belt Allowance and the Erosion Access Allowance to define the Erosion Hazard Limit.

Access Allowance

As with confined systems, the 5-metre Erosion Access Allowance is also applied in unconfined systems to maintain sufficient access for emergencies, maintenance and construction activities. This allowance is shown in conjunction with the Meander Belt Allowance in Figure 3.32.

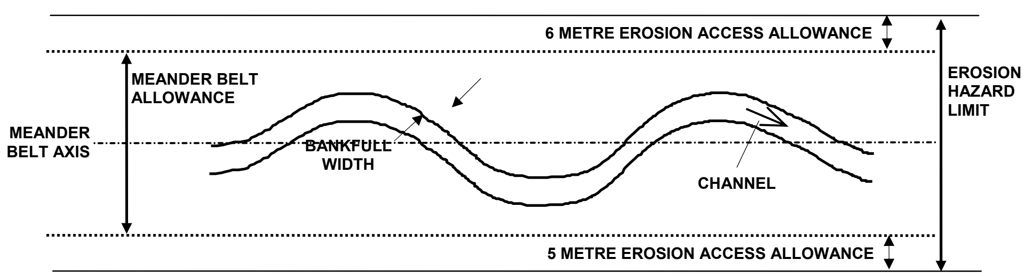


Figure 3.32: Erosion Hazard Limit (for an unconfined system)

Natural Hazard Limit - Riverine Hazards

The Toe Erosion Allowance, Stable Slope Allowance, Erosion Access Allowance and Meander Belt Allowance (where applicable) are applied in combination to every riverine system in the Graham Creek watershed. The result of these allowances is the final Erosion Hazard Limit. The Flooding and Erosion Hazard Limits are drawn out for each riverine system, and the furthest landward limit of these two lines is taken to be the Natural Hazard Limit.

Wetland Natural Hazards
Wetlands are defined in the *Provincial Policy Statement* as follows.

> *Lands that are seasonally or permanently flooded by shallow water, as well as lands where the watertable is close to or at the surface. In either case the presence of abundant water has caused the formation of hydric soils and has favoured the dominance of either hydrophytic plants or water tolerant plants. The four major types of wetlands are swamps, marshes, bogs, and fens.* (Ontario Ministry of Municipal Affairs and Housing 2005)

Section 28 under the *Conservation Authorities Act* acknowledges the same wetland definition as the *Provincial Policy Statement*.

Wetlands are included as a natural hazard because they exhibit two hazards: flooding and instability due to organic soils. To satisfy requirements of both the Natural Hazard Policy and the Generic Regulation, provincially significant wetlands and unevaluated wetlands (identified through Ecological Land Classification) are defined as part of the wetland natural hazards.

In order to map wetlands for natural hazard purposes, provincially significant wetlands, wetland complexes, and locally significant wetlands were mapped. Once the wetland boundary was determined, the wetland was classified as either provincially significant or locally significant. For provincially significant wetlands a buffer of 120 m was added to the wetland to define the Natural Hazard Limit. Locally or regionally significant wetlands were mapped and a 30 m buffer was added to define the Natural Hazard Limit.

3.5.4 Water Budget and Stress Assessment

The following section was modified from the Tier 1 water budget process, prepared for the Drinking Water Source Protection program. Please refer to Ganaraska Region Conservation Authority (2008) for further detail.

A water budget is a computer-based, scientific tool used to define a watershed's hydrologic system. Results of a water budget provide understanding of how water flows onto and on the surface, and through and below the ground. Water budgets will expand beyond the quantification of components in the water balance equation (precipitation, evapotranspiration, groundwater and surface water flow), to include water use. Water budget analyses are undertaken in a watershed to quantify water entering and leaving the watershed, and to characterize the contribution of each component to the overall hydrologic system.

Stress analysis identifies the functional relationships among water budget components and produces a foundation that can be used to evaluate future watershed stresses. Stresses (e.g., development activities, water taking or climate change) in a watershed can modify the relative contribution and characteristics of the components of the hydrologic system, and alter the overall water budget. This may threaten the health of ecosystems that have become established under the current hydrologic cycle. Stresses include increased peak flows or significant reduction in groundwater discharge that sustains a river baseflow. A water budget analysis can be carried out to predict the effect of newly induced stresses on components of the hydrologic cycle such as peak flows, and groundwater recharge and discharge.

Water Budget Equations and Components

A water budget is an estimation or account of the various hydrologic cycle processes for a given study area, and it consists of inputs, outputs and changes in storage. The inputs are precipitation, groundwater or surface water inflows, and anthropogenic inputs such as waste effluent. Outputs are evapotranspiration, water supply removals or abstractions, surface or groundwater outflows, as well as any changes in storage in the area of interest. The inputs must equal the outputs if the system is to remain in equilibrium. The individual inputs and outputs of a water budget can be expressed as follows.

Equation 1

$$P + SW_{in} + GW_{in} + ANTH_{in} = ET + SW_{out} + GW_{Out} + ANTH_{out} + \Delta S$$

Where:

- P = precipitation
- SWin = surface water flow in
- GWin = groundwater flow in
- ANTHin = anthropogenic or human inputs such as waste discharges
- ET = evaporation and transpiration
- SWout = surface water flow out
- GWout = groundwater flow out
- ANTHout = anthropogenic or human removals or abstractions
- ΔS = change in storage (surface water, soil moisture, groundwater)

(Ontario Ministry of the Environment 2007)

For this study, the recent version of the model CANWET 3 was used to run the water budget. The current version gives an opportunity to use monthly curve numbers, evapotranspiration coefficient, recession coefficient and seepage coefficient. The seepage coefficient facilitates the discharge to and recharge from neighbouring watersheds. In addition Geographic Information System (GIS) layers were used in the model (Table 3.8). Since Graham Creek is an un-gauged system the calibrated model parameters of neighbouring gauged Wilmot Creek was used for estimating necessary water budget components.

Table 3.8: GIS layer sources used for surface water budget

Data Layer and Summary of Preparation
Physiographic Regions (MNR and YPDT-CAMC 2006) recession constant is 0.06, which was calculated from recession segments of hydrographs at gauge stations.
Soils (OMAFRA 2004) defined textures guided by Soils Layer Development for CANWET (Greenland, 2006). Assigned values of unsaturated water capacity according to CANWET User's Guide.
Basins (Delineated by ArcHydro (V. 1.2) on the basis of DEM, V2 from MNR)
County (MNR 2002)
Streams (MNR 2002)
Weather (Environment Canada Website) selection of two stations on the basis of locations, correlation, data quality and fitness with corresponding stream flow data.
Elevation (MNR, Version 2)
Land use (GRCA ELC 2006) re-classified according to CANWET User's Guide (Version 1.0). Revised to future land use layer based on *Municipality of Clarington Official Plan* (2007) and the *Municipality of Port Hope Official Plan* (2008).
Tile Drainage analyzed and determined that recorded tiles are not significant in modeled watersheds.
Point source discharge to Lake Ontario, not necessary to be modeled.
Permit to Take Water (PTTW) (MOE 2007) consider consumptive factor (Aqua Resource Inc. 2004). Remove the permits of takings from Lake Ontario temporary extractions and permits expired before 2003.

Stress Assessment Methodology

A stress assessment looks at the amount of water in a watershed in relation to water uses. Through drinking water source protection, the province has developed stress rankings to determine if a watershed is stressed based on water supplies and water uses. In the Graham Creek watershed, the water supply estimation constitutes two components, surface water supply, which is the water available as stream flow, and groundwater supply, which is the water available in the aquifers.

Surface Water Supply and Study Approach

Five methods have been suggested through drinking water source protection (Ontario Ministry of the Environment 2007) to calculate monthly surface water supply.

1. Calibrated continuous surface model results: Q_{p50} (monthly median flow)
2. Stream flow monitoring from Hydroclimatological Data Retrieval Program (HYDAT): Q_{p50} (monthly median flow)
3. Stream flow monitoring (manual): monthly/bi-monthly measurements of baseflow
4. Prorated stream flow monitoring: prorated stream flow dataset from nearby gauge stations with similar physiographic and land use setting

5. Ontario Flow Assessment Technique (OFAT) 30_{Q2} estimated average annual baseflow.

This study follows approaches 1 and 2 to estimate the surface water supply for the Graham Creek watershed. Since Graham Creek is not gauged, the CANWET model was setup using the calibrated parameters of the Wilmot Creek watershed which has similar physiographic and land use features. The model simulated stream flow was then used to estimate Q_{p50} to determine the monthly surface water supply. Three scenarios were then run to estimate surface water supplies. These include the current (existing) scenario, the future scenario and a future scenario under climate change.

Current Scenario

The current scenario implies estimating surface water supply for the existing climate and the current land use scenario. The CANWET model was run using long-term climate data from 1976 to 1995 and the existing land use features. The simulated stream flow data for the 20-year period was then used to estimate Q_{p50} to determine the monthly surface water supply.

Future Scenario

The future scenario implies estimating surface water supply for the existing climate and the future land use scenario. The CANWET model was run using climate data from 1976 to 1995 and the land use scenario expected after 25 years. The 25-year future scenario assumes full build-out of the Municipality of Clarington official plan designated lands (Figure 3.33). The Q_{p50} was then estimated from the 20-year simulated stream flow to predict the future monthly water supply.

Future Scenario with Climate Change

Climate is expected to change in the future with the increasing levels of greenhouse gases in the atmosphere. A number of groups around the world have been involved in predicting how much the change might be. To depict the climate change scenario, Global Climate Models (GCM) have been developed at different geographical locations. The Canadian Centre for Climate Modeling and Analysis under the umbrella of Environment Canada has also come up with a series of Canadian Global Climate Models (CGCM) for climate prediction, study of climate change and variability, and to better understand the various processes that govern our climate system.

The CGCM divides the globe into 3.75^{o} x 3.75^{o} grids and models climate data for each of these grids at a varied time series. For this study, CGCM2 IPCC SRES "A2" GHG was used and future climate data was generated for the years 2021 to 2040. The CANWET model was then run using future climate data and future land use features to simulate stream flow under this changed climate scenario.

The future climate generated by CGCM seemed to overpredict precipitation. The average annual precipitation for 20 years was 1276 mm, which is about 42% more than the average annual precipitation observed between 1976 and 1995. Therefore the CGCM model simulations need further investigation. However, for the present study the CGCM simulations were used to estimate water supply.

Further, the simplistic modeling approach used for water budget and stress assessment has been found limiting for handling groundwater flows under changed climatic conditions. This is due to some inherited limitations in the SCS-CN approach and single tank sub-surface structure of the CANWET model.

Groundwater Supply and Study Approach

As indicated through drinking water source protection guidance documents (Ontario Ministry of the Environment 2007), in the "analysis of groundwater supplies, aquifer storage is not considered and the watershed water supply terms are therefore assumed to be constant on an average annual basis. As such, recharge estimation methods applied should determine recharge estimates as the average annual rates."

Ontario Ministry of the Environment (2007) lists the following methods for estimating groundwater recharge.

- Baseflow separation/water balance
- Calibrated continuous surface water model or groundwater model
- Calibrated soil moisture balance
- Experience.

In this study, calibrated surface water model CANWET was used to estimate annual average groundwater recharge. The calibrated models were run for the 20-year simulation period (1976-1995) and estimated annual groundwater recharge was then averaged to predict groundwater supply.

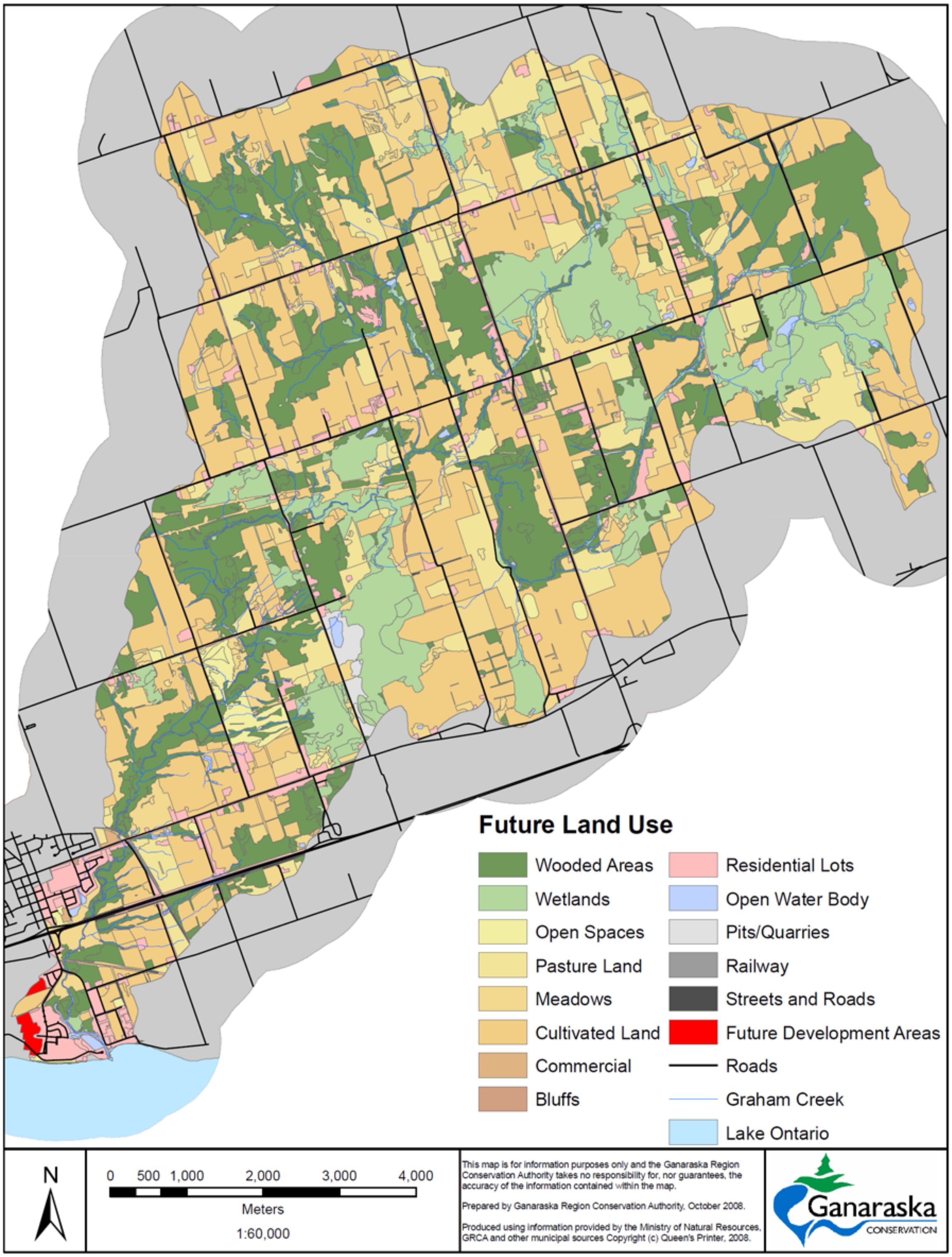


Figure 3.33: Future land use

The observed stream flow was also partitioned into baseflow and surface flow using two approaches: digital filter strip and base sliding interval. The base sliding interval technique was found more appropriate for the Graham Creek watershed. The baseflow separation results were compared with the model simulated results. The modeled groundwater recharge was slightly higher than estimated values using the base flow separation technique; however it realistically represented the characteristics of the watershed under study and therefore was used. Three scenarios were then run to estimate groundwater supplies: current (existing) scenario, the future scenario and a future scenario under climate change.

Current Scenario

The current scenario implies estimating groundwater recharge values using the existing climate data and current land use scenario. The CANWET model was run using long-term climate data from 1976 to 1995 and the existing land use features. The simulated annual groundwater recharge was then averaged to estimate the groundwater supply. According to the Ontario Ministry of the Environment (2007), the monthly groundwater supply is to be calculated simply by dividing the annual numbers by 12 months.

Future Scenario

The future scenario implies estimating groundwater supply using the existing climate data and the future land use scenario. The CANWET model was run using climate data from 1976 to 1995 and land use features expected after 25 years. The simulated annual groundwater recharge was then averaged to estimate the groundwater supply under future conditions.

Future Scenario with Climate Change

The groundwater supply for future land use scenario under climate change was estimated by running the CANWET model using land use features expected after 25 years and change in climate predicted for years 2021 to 2040 by the CGCM2 model. The simulated annual groundwater recharge was then averaged to estimate the annual groundwater supply under future conditions and changed climate. A monthly supply was estimated by dividing the annual estimate by 12.

Water Demand Estimation

In this water budget and water quantity stress assessment, the estimation of monthly consumptive demand for surface and groundwater is a critical element. Water demand needs to be calculated as “consumptive” use, which refers to water taken from groundwater or surface water and not returned locally in a reasonable time period. From the calculation perspective, total consumptive demand estimation comprises the permitted water use estimation and non-permitted water use estimation, which includes non-permitted agricultural and non-permitted residential water use. The groundwater and surface water demands were calculated separately for further stress assessments. It should be noted that the non-consumptive returns are not considered as per Ontario Ministry of the Environment (2007).

Permitted Water Use

The primary source of information for water demand estimation is the MOE Permit to Take Water (PTTW) database. Water users that take more than 50,000 litres/day (L/d) are required to obtain a PTTW from the Ministry of the Environment, with the exception of agricultural and livestock uses. However, the PTTW database does not contain any direct information about the amount of water actually taken and no detailed information about when the water consumption occurs for each permitted use.

The new PTTW management database, containing data up to 2005, was developed by MOE to supplement the old PTTW database by accounting for multi-site permits, consumptive use and seasonal variability. Therefore, the new PTTW management database was selected as a basis for permitted water demand estimation. For the purpose of water demand estimation, the database was carefully screened and updated by Ganaraska Region Conservation Authority staff through the following steps.

- Screened the validity of all permits that expired before December 31, 2002. Expired permits were not considered in the water demand calculation. In addition, permitted takings from Lake Ontario and temporary takings, were not considered in water demand calculations.
- Updated database with new permits issued from 2005 to 2007
- Replaced maximum water taking rate by actual pumping rates where the actual records were available
- Reviewed all multiple sources and multiple factors in permits
- Applied default monthly adjustments on PTTW and adjusted by reviewing individual permits
- Applied consumptive factors: the default consumptive factors in Ontario Ministry of the Environment (2007) are applied, except those uses that removed water from original sources (study unit) and did not return the water to same unit within a reasonable time period (e.g., water bottling).

The locations of PTTW sites considered in the Graham Creek watershed water budget are shown in Figure 3.34 and detailed information regarding these takings is listed in Table 3.9.

Table 3.9: PTTW data

Permit	Source	General Purpose	Specific Purpose	Demand Proportion	Consumptive Factor	Max Per Day (L/day)	Consumptive Annual Taking (m^3)
7578-6C5NRC	Surface	Commercial	Other - Commercial	1	1	22,73,045	69,328
1652-645RX7	Ground	Commercial	Bottled Water	1	1	218,869	79,878
02-P-4058	Surface	Agricultural	Field and Pasture Crops	1	0.8	572,796	13,075
02-P-4058	Surface	Agricultural	Field and Pasture Crops	1	0.8	286,398	6,538
65-P-388	Surface	Commercial	Golf Course Irrigation	1	0.7	49,968	67,264
5288-6GDQ4T	Ground	Agricultural	Nursery	1	0.9	900,000	23,112
5288-6GDQ4T	Ground	Agricultural	Nursery	1	0.9	102,200	2,625

In the Graham Creek watershed, non-permitted water use generally includes groundwater takings from private water supply wells in municipally unserviced areas, and surface water takings from streams and ponds for agricultural use. This was determined upon review of land use and local water use patterns.

Non-serviced Residential Water Demand

As prescribed in Ontario Ministry of the Environment (2007), water demand for non-serviced residential areas is calculated by combining population density with typical per-capita water use rates. It is recommended to use Statistics Canada Census data at the dissemination area (DA) level to estimate total population and then estimate non-serviced population by removing municipally serviced populations. When the non-serviced population distribution is generated, non-serviced residential demand can be calculated using the typical water usage rate of 335 litres per day per person (L/d/person).

Review of local water use determined that in the Graham Creek watershed, non-serviced residents take their water from the groundwater system. The consumptive factor was designated to be 0.2 because most of the removed water will be returned to the groundwater system through septic systems.

Total and serviced population estimation

The population in the Graham Creek watershed is 3,583 based on Statistics Canada 2006, with a population density of 46 people/km^2. In the watershed 69% of population is serviced by the Newcastle Water Treatment Plant, a municipal drinking water system (Table 3.10).

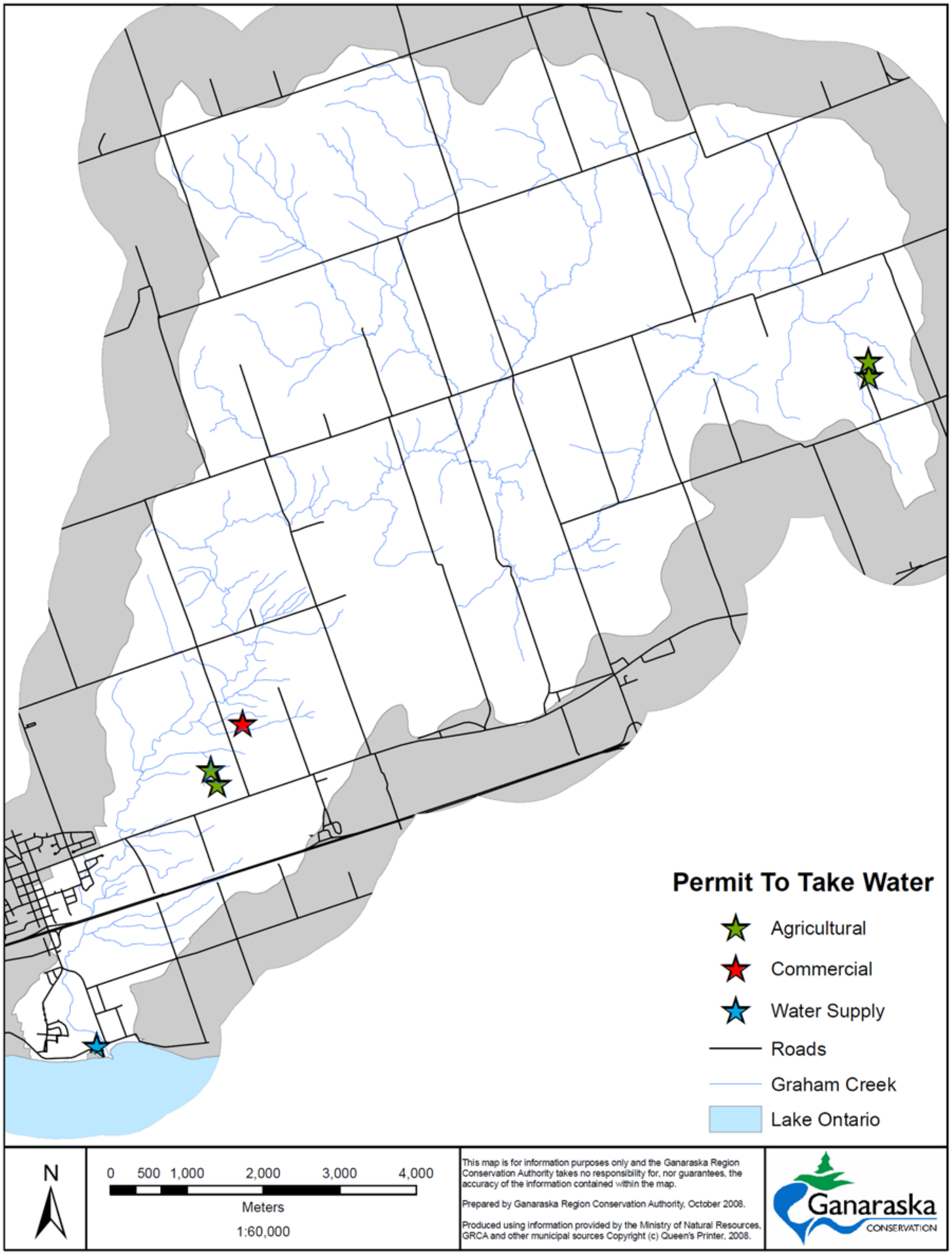


Figure 3.34: Permit to Take Water

Non-serviced water demand

Non-serviced water demand is calculated by combining non-serviced population and the recommended water usage rate of 335 litres per day per person. The results are presented in Table 3.14.

Table 3.10: Existing serviced and non-serviced residential water use

Watershed population	Serviced Population	Non-serviced Population	Percent Serviced	Non-serviced Residential Water Demand	
3583	2482	1101	69	134,641 m^3	1.72 mm

Non-permitted Agricultural Water Demand

Ontario Ministry of the Environment (2007) recommends the use of the De Loë (2002) method that estimates agricultural water use based on the Statistics Canada 2001 agricultural census data at Census Consolidates Subdivision (CCS) level. Considering the fact that land use in the Graham Creek watershed has not experienced measurable changes in the past five years, the results from the De Loë method (2002) were used directly. This was done by overlaying the De Loë layer on the Graham Creek watershed polygons and aggregating the data. Non-permitted agricultural water use was estimated by subtracting permitted takings of water for agricultural purposes. The following three assumptions were applied during the calculation.

Non-permitted agricultural uses are assumed to be exclusively surface water takings. The applied consumptive factor is 0.78. The seasonal water use occurs in summer (July and August). The non-permitted agricultural demand is reported in Table 3.11.

Table 3.11: Surface water non-permitted agricultural water use (m^3)

January to June	July	August	September to December	Annual
2,736 each month	22,945	22,945	2,736 each month	73,252

Future Scenario

For 25-year future scenarios, water demand was estimated by taking into account the increase in population serviced by inland water source (e.g., groundwater). The water demand for the municipal areas serviced by Lake Ontario is assumed to be a constant. 13.2% and 25.2% was estimated to represent the increases over the 25-year time frame in the rural areas of the Municipality of Clarington and the Municipality of Port Hope respectively.

Water Reserve Estimation

The concept of “water reserve” is designed to set aside water for purposes other than uses that are currently permitted (Ontario Ministry of the Environment 2007), such as natural ecosystem uses (e.g., in-stream needs, springs and wetlands) and other human uses (e.g., waste assimilation, power generation, navigation and recreation). The reserve quantity is subtracted from the total water source supply prior to evaluating the percent water demand.

Upon review of the current situation and future developments in the Graham Creek watershed, there are no significant water reserve requirements for waste assimilation or navigation. Recreational uses are primarily limited to Lake Ontario. Other activities such as canoeing, kayaking, and navigation on local streams were assumed to be negligible. Therefore, the main function of reserved water in the Graham Creek watershed is to maintain the health of the natural ecosystem.

Surface Water Reserve

The Ontario Ministry of the Environment (2007) recommended two methods to estimate water reserve for surface water stress assessments.

- Calculation of lower decile flow (Q_{p90}) on a monthly basis
- Calculation of reserve values using the Tessman method

Due to limited monitoring data (only two years available), simulated streamflow from the CANWET model was used for surface water reserve estimation. Both Q_{p90} and the Tessman method were applied on simulated stream flows and monitoring data over the simulation period of 1976 to1995 at two gauge stations, 02HD012 in Ganaraska River and 02HD009 in Graham Creek. After comparison, it was found that the monthly water reserve based on simulated stream flows and monitoring data are in better agreement when using the Tessman method. Therefore, the Tessman method was believed to be more reliable on simulated data since:

- Q_{p90} is determined by one ranked position at lower decile after ranking streamflow from the largest value to the smallest value. It was less reliable when this method was used in simulated streamflows instead of observed streamflows.
- The Tessman method estimates water reserve based on mean values, and the reserve values are not easy to be effected by simulation errors.

Under the future scenario with climate change prediction, the Tessman method is not appropriate for calculations of watershed reserve values, because during the dry months, the monthly water reserve is larger than water supply. Due to this situation, Q_{p90} was used. More investigation is required to determine the effect of climate change on water reserve.

Groundwater Reserve

The Ontario Ministry of the Environment (2007) recommends that a simplified estimation method be applied for analysis, whereby the reserve is estimated as 10% of the existing groundwater discharge. However, there is no theoretical basis for this value and it may be low considering that in Ganaraska Region Conservation Authority watersheds, baseflow represents 40 to 60% of stream flow. Therefore, the required reserve for the Graham Creek watershed was estimated, and simplified as 10% of the average annual and monthly groundwater supply however this assumption is questionable.

<u>Stress Assessment Calculation</u>

The objective of the stress assessment is to screen the Graham Creek watershed and indicate whether there is a significant or medium stress level. The Ontario Ministry of the Environment (2007) indicates that the stress assessment is evaluated by percent water demand, which is the ratio of the consumptive water demand to water supplies, minus water reserves. Using a comparison between thresholds and estimated percent water demand, the Graham Creek watershed is then assigned a stress level.

In the Drinking Water Source Protection program, a low level of stress requires no further water budgeting and assessment work, but monitoring, database maintenance and assessment updating are encouraged. A moderate to significant level of stress, plus the presence of municipal drinking water systems, requires a Tier 2 assessment. A moderate to significant level of stress, without the presence of municipal drinking water systems is highlighted for more consideration under other regulatory programs (e.g., PTTW, *Fisheries Act,* etc.).

The Graham Creek watershed stress assessments evaluate surface water and groundwater independently and for three different scenarios: current scenario, future scenario and climate change scenario. The resulting assigned stress level is the maximum of the three scenarios.

Surface Water Stress Assessment Current Scenario

Water supply and water reserve were calculated based on monthly simulated stream flows and monitored flows. Water demands were distributed to each month, considering the seasonal usage to investigate typical peak demand situations in the summer. Then the percent water demands were calculated as a relative indicator for each month by using the following equation (Eq.1). The largest monthly percent water demand was used to classify the stress level by comparing calculated values with surface water stress thresholds (Table 3.12).

$$\text{\% Water Demand (Surface Water)} = \frac{Q_{\text{DEMAND (SW)}}}{Q_{\text{SUPPLY (SW)}} - Q_{\text{RESERVE (SW)}}} \times 100 \qquad \text{[Eq.1]}$$

Table 3.12: Surface water stress thresholds

Surface Water Quantity Stress Level Assignment	All Scenarios Maximum Monthly Percent Water Demand
Significant	> 50%
Moderate	20% to 50%
Low	< 20%

Future Scenario and Future Scenario with Climate Change

The goal of the current scenario is designed to identify stress as a result of existing water use, while the goal of the 25-year future scenario is to identify watersheds that may become stressed as a result of future urbanization and/or additional drinking water requirements. The surface water percent water demand equation (Eq. 1) was also used in the future scenario. Finally, the stress level was determined by comparing results with the default surface water stress thresholds in Table 3.16. The percent water demand calculation and stress assessment for the climate change scenario use the same methodology, equation and thresholds described above.

Groundwater Stress Assessment Current Scenario

Following similar procedures in surface water stress assessment, the concept of percent water demand for groundwater was calculated by the following equation (Eq.2). The stress level was determined by comparing results with groundwater stress thresholds listed in Table 3.13. Because groundwater sources and demand tend not to demonstrate significant seasonal variability, annual supply values are deemed to be more appropriate for this exercise. However, peak monthly groundwater demand was also assessed to determine if the groundwater source could be temporarily over-stressed in the specific months. The resulting groundwater stress level assigned is the maximum of the current and future assessment values for both annual and monthly conditions.

$$\textbf{\%}\text{ Water Demand (Groundwater)} = \frac{Q_{\text{DEMAND (GW)}}}{Q_{\text{SUPPLY (GW)}} - Q_{\text{RESERVE (GW)}}} \times 100 \qquad \text{[Eq.2]}$$

Table 3.13: Groundwater stress thresholds

Groundwater Quantity Stress Level Assignment	All Scenarios	
	Average Annual	Monthly Maximum
Significant	>25%	>50%
Moderate	>10%	>25%
Low	0 to10%	0 to 25%

Future Scenario and Future Scenario with Climate Change

The equation (Eq.2) of percent water demand for groundwater was also used for the future scenario and the future scenario with climate change. Finally, the stress level was classified by comparing results with the stress thresholds in Table 3.13.

Uncertainty

Uncertainty is inherent in the water budget estimation and stress assessment process. The accuracy of estimates is reliant on the quality of input data, methodology, modeling, and conceptual understanding of the watershed. Overall, the issues related to uncertainty, and data and knowledge gaps are complex and highly qualitative. There is a degree of uncertainty associated with every aspect of the water budget analyses, however, it is impossible to provide a quantitative assessment of this level of uncertainty. Rather one can only say, in very general terms, that the level is low, moderate or high.

It is quite difficult to quantify the uncertainty. However, uncertainty can be evaluated as "low" in watersheds where,

- A long-term historical record is available
- High quality dense monitoring data with good quality are provided
- Complex numerical modeling is applied
- Relative studies and research have been conducted to enhance the understanding of the water system.

According to the Ontario Ministry of the Environment (2007), the uncertainty becomes particularly important if a watershed has been assigned a low stress level and the percent water demand estimate is near the threshold of moderate stress. For that situation, estimates should be checked to make sure that they are conservative.

Graham Creek is an un-gauged watershed. Although a few spot flow measurements have been taken by GRCA staff, there is no permanent gauge station to provide long term historical data needed to set up and verify a numerical model. The Q_{supply} is simulated by using parameters from the calibrated model in the neighbouring watershed. The understanding of the watershed is also limited by few previous studies. The uncertainty is evaluated as "high". However, the uncertainty is not that important because the calculated percent water demand is quite low when compared to the moderate threshold.

Water Budget Results for Graham Creek Watershed

Existing Scenario

Figure 3.35 and Table 3.14 describe the elements of the water budget simulated by CANWET using long-term data for the Graham Creek watershed under the existing land use scenario. The Graham Creek watershed is an un-gauged watershed and the simulations for this watershed were conducted using the calibrated parameters of the Wilmot Creek watershed.

Future Scenario

Figure 3.36 and Table 3.15 describe the elements of the water budget simulated by CANWET for the Graham Creek watershed using long-term existing climate data under the projected future land use (Figure 3.36) scenario. The results showed no change in the stream flow compared to the existing land use scenario.

Future Scenario with Climate Change

Figure 3.37 and Table 3.16 describe the elements of the water budget simulated by CANWET for the Graham Creek watershed using long-term climate data simulated by the Canadian Global Climate Model (CGCM), considering climate change for the 2021 to 2040 period under the projected future land use scenario. The CGCM predicts considerable increase in annual precipitation (about 40%) and as a result, the CANWET model simulates significant increase in stream flow.

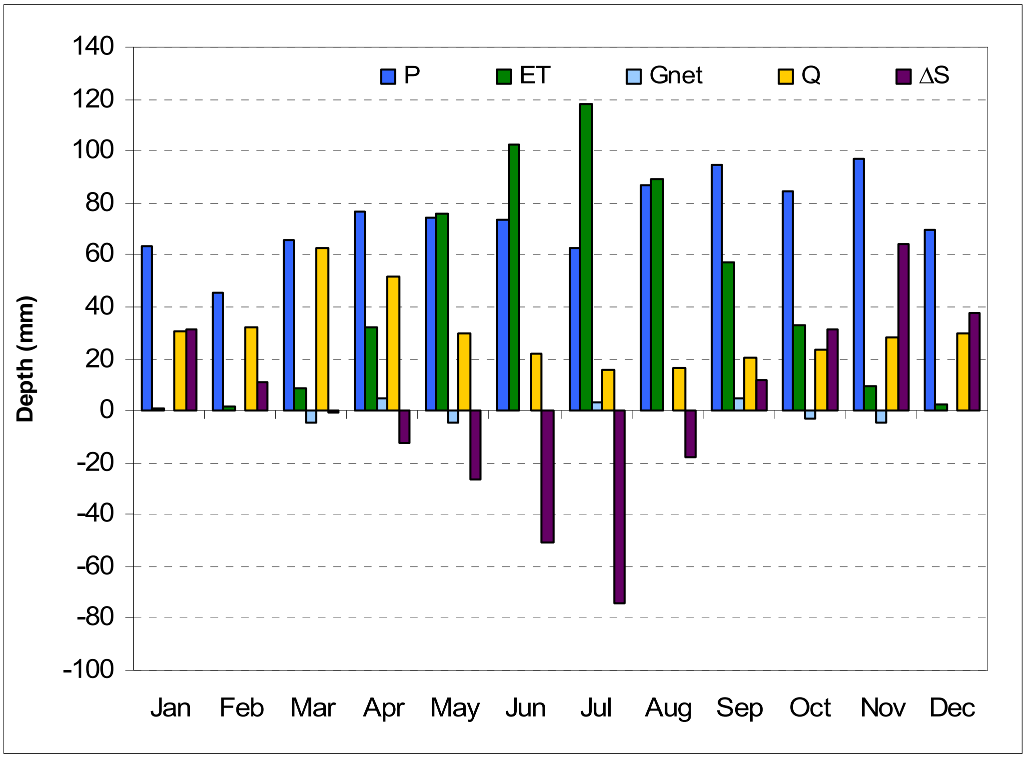


Figure 3.35: Graham Creek watershed under existing land use scenario

Table 3.14: Graham Creek watershed under existing land use scenario

Month	(P) Precipitation (mm)	(ET) Evapotranspiration (mm)	(G_{net}) Net Groundwater Flow In and Out (mm)	(Q) Stream Flow (mm)	△S Change in Storage (mm)
January	63.2	1.0	0	30.9	31.3
February	45.2	1.6	0	32.2	11.4
March	65.5	8.5	-5	62.4	-0.4
April	76.4	31.8	5	51.8	-12.2
May	74.3	75.6	-5	30.0	-26.3
June	73.7	102.2	0	22.0	-50.5
July	62.7	117.8	3	15.9	-74.0
August	87.1	88.8	0	16.3	-18.0
September	94.7	57.4	5	20.7	11.6
October	84.8	32.9	-3	23.4	31.5
November	96.8	9.4	-5	28.5	63.9
December	69.9	2.4	0	29.7	37.8
Annual	894.3	529.4	-5	363.8	

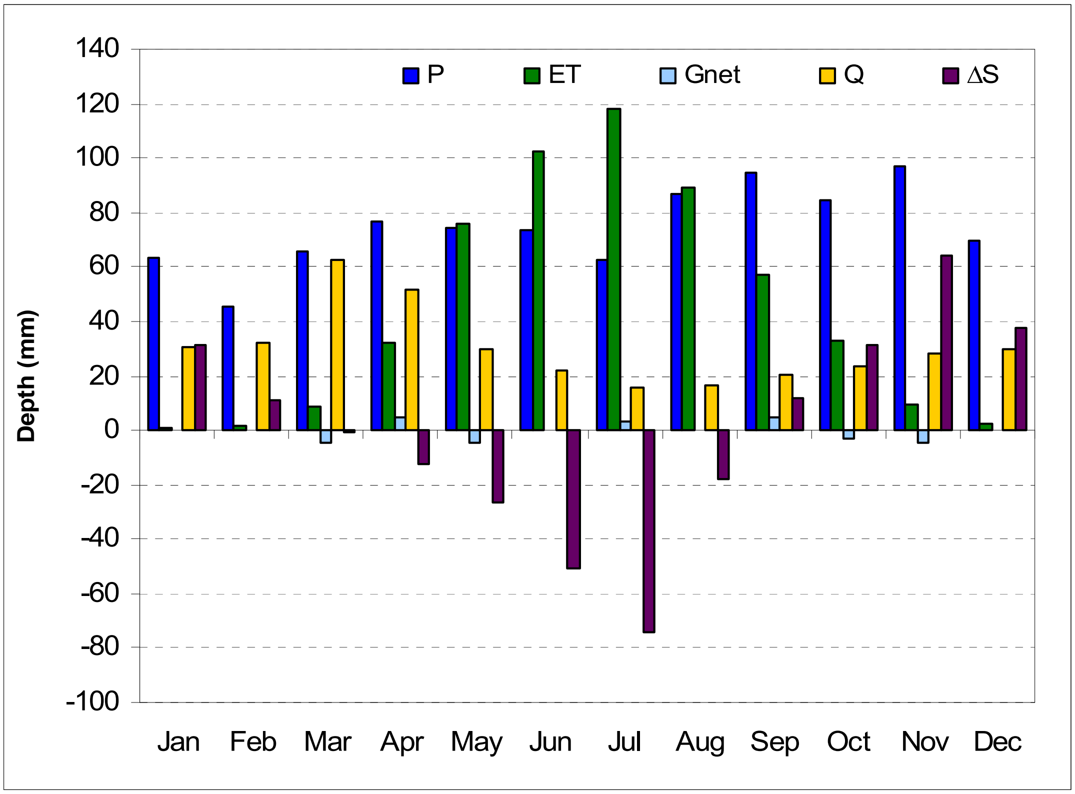


Figure 3.36: Graham Creek watershed under future land use scenario

Table 3.15: Graham Creek Watershed under future land use scenario

Month	(P) Precipitation (mm)	(ET) Evapotranspiration (mm)	(G_{net}) Net Groundwater Flow In and Out (mm)	(Q) Stream Flow (mm)	△S Change in Storage (mm)
January	63.2	1	0	30.9	31.3
February	45.2	1.6	0	32.2	11.4
March	65.5	8.5	-5	62.5	-0.5
April	76.4	31.8	5	51.8	-12.2
May	74.3	75.6	-5	29.9	-26.2
June	73.7	102.2	0	22.0	-50.5
July	62.7	117.8	3	15.9	-74.0
August	87.1	88.8	0	16.3	-18.0
September	94.7	57.4	5	20.7	11.6
October	84.8	32.9	-3	23.4	31.5
November	96.8	9.4	-5	28.5	63.9
December	69.9	2.4	0	29.7	37.8
Annual	894.3	529.4	-5	363.8	

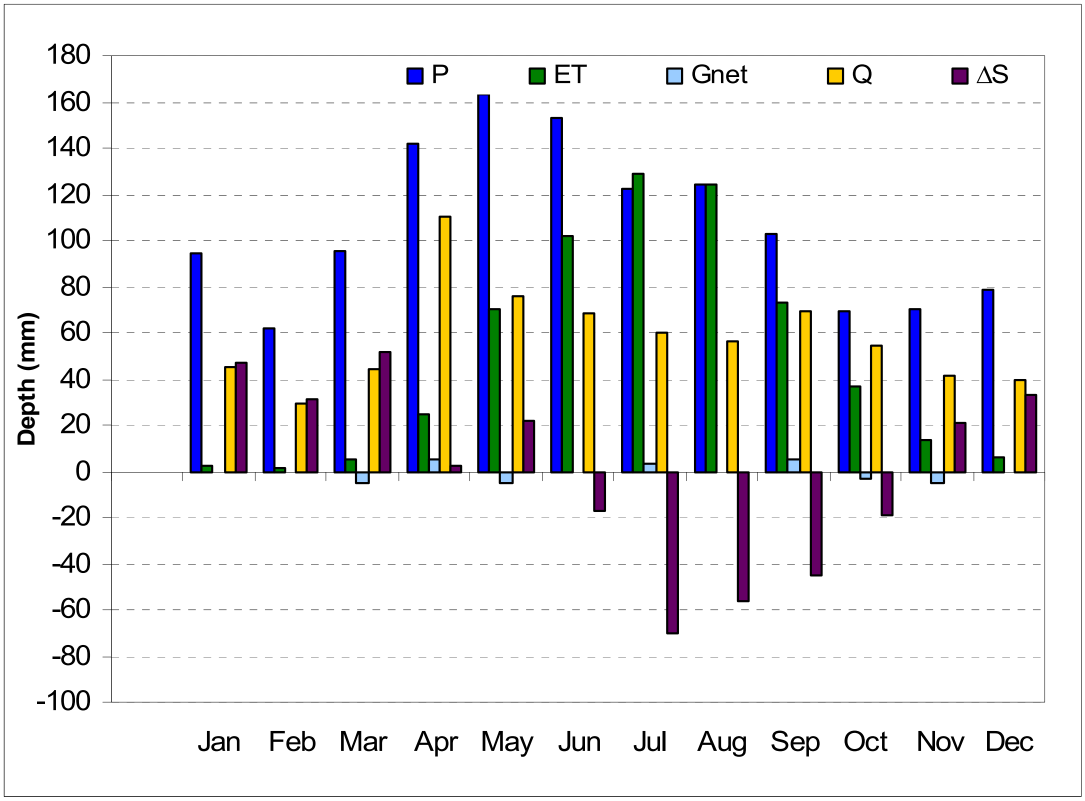


Figure 3.37: Graham Creek watershed under future land use scenario with climate change

Table 3.16: Graham Creek watershed under future land use scenario with climate change

Month	(P) Precipitation (mm)	(ET) Evapotranspiration (mm)	(G_{net}) Net Groundwater Flow In and Out (mm)	(Q) Stream Flow (mm)	△S Change in Storage (mm)
January	94.5	2.6	0	45.1	46.8
February	61.6	1.1	0	29.0	31.5
March	95.5	4.8	-5	44.1	51.6
April	141.6	24.5	5	110.1	2.0
May	163.1	70	-5	76.2	21.9
June	153.2	102.1	0	68.1	-17.0
July	121.9	128.9	3	59.9	-69.9
August	124.0	123.8	0	56.1	-55.9
September	102.6	73	5	69.3	-44.7
October	69.3	36.5	-3	54.8	-19.0
November	70.1	13.2	-5	41.3	20.6
December	78.9	6.3	0	39.7	32.9
Annual	1276.3	586.8	-5	693.7	

Stress Assessment

Water Supply and Water Reserve

Water supply and water reserve are estimated using the methodology described above and the results are reported in Table 3.19 to 3.24.

Water Demand

There are five multi-sources Permit to Take Water (PTTW) in the watershed (Figure 3.34). At the northeast corner of watershed one PTTW is issued for agricultural use; at the bottom of watershed one groundwater source is for an agricultural nursery; the other PTTW is taking water directly from Graham Creek for irrigating a golf course. There is no municipal drinking water system in the Graham Creek watershed. However 69% of watershed residents are serviced by the Newcastle Water Supply System taking water from Lake Ontario.

The total water demand for the existing scenario is 212,794 m^3 (2.72 mm) per year. This can be broken down as follows: 53% is recorded in the Permit to Take Water database, 13% estimated as non-serviced residential use, and 34% estimated as non-permitted agriculture use. The total water demand can be separated as groundwater demand (52,655 m^3, 0.67 mm) and surface water demand (160,129 m^3, 2.05 mm). The details of groundwater and surface water demand for each month are shown in Table 3.17. Both groundwater and surface water are indicated as having a significant higher usage in summer due to predominant usage for irrigation.

The water demand for the 25-year future scenario only considers the increase for non-serviced population water use, which is adjusted by a projected population increase rate. Surface water demand is the same as the existing scenario, while 7% increase is presented in groundwater demand for the future scenario (Table 3.18.).

Stress Assessment

Percent water demand calculation and stress assessment were conducted for the Graham Creek Watershed. As shown in Tables 3.19 to 3.24 there is no indication that there are stresses under all three scenarios for both surface water and groundwater.

Water Budget and Stress Assessment Summary

Three scenarios were run for the Graham Creek watershed, existing conditions, future conditions, and future conditions under climate change effects. Both the existing and future conditions show that the Graham Creek watershed receives approximately 850 mm of precipitation a year. A large portion of this water is lost through evapotranspiration which increases in April and declines in October, with peak rates occurring in July. Groundwater recharge through stream inputs happens largely in March, April, October and November, and stream flow increase in March and April due to the spring freshet. Changes in storage occur from March to August with the greatest loss occurring in July. This means that water stored in surface water, soil moisture, and groundwater is being depleted through natural cycles and water use. Water is put back to storage in the period of September to February.

Under a scenario of future conditions with climate change effects, the Graham Creek watershed is expected to receive more precipitation, experience higher evapotranspiration rates, and experience more surface flows (due to increased precipitation). However this provides a basic glimpse of a future with climate change. More work is required for modeling climate change.

In the Graham Creek watershed, the surface water and groundwater stress assessment results in a “low” level of stress from water taking reliability and water quantity perspective.

Table 3.17: Existing water demand estimation

Unit: m^3

	Annual	January	February	March	April	May	June	July	August	September	October	November	December
PTTW	**112,613**	**0**	**0**	**0**	**0**	**0**	**16,540**	**39,767**	**39,767**	**16,540**	**0**	**0**	**0**
Groundwater	25,737	0	0	0	0	0	0	12,868	12,868	0	0	0	0
Surface Water	86,876	0	0	0	0	0	16,540	26,898	26,898	16,540	0	0	0
Non-Serviced Residential (G)	**26,928**	**2,244**	**2,244**	**2,244**	**2,244**	**2,244**	**2,244**	**2,244**	**2,244**	**2,244**	**2,244**	**2,244**	**2,244**
Non-PTTW Agriculture (S)	**73,252**	**2,736**	**2,736**	**2,736**	**2,736**	**2,736**	**2,736**	**22,945**	**22,945**	**2,736**	**2,736**	**2,736**	**2,736**
Total	**212,794**	**4,980**	**4,980**	**4,980**	**4,980**	**4,980**	**21,521**	**64,955**	**64,955**	**21,521**	**4,980**	**4,980**	**4,980**
Groundwater	52,665	2,244	2,244	2,244	2,244	2,244	2,244	15,113	15,113	2,244	2,244	2,244	2,244
Surface Water	160,129	2,736	2,736	2,736	2,736	2,736	19,277	49,843	49,843	19,277	2,736	2,736	2,736

Unit: mm

PTTW	**1.44**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.21**	**0.51**	**0.51**	**0.21**	**0.00**	**0.00**	**0.00**
Groundwater	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.16	0.00	0.00	0.00	0.00
Surface Water	1.11	0.00	0.00	0.00	0.00	0.00	0.21	0.34	0.34	0.21	0.00	0.00	0.00
Non-Serviced Residential	**0.34**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**
Non-PTTW Agriculture	**0.94**	**0.04**	**0.04**	**0.04**	**0.04**	**0.04**	**0.04**	**0.29**	**0.29**	**0.04**	**0.04**	**0.04**	**0.04**
Total	**2.72**	**0.06**	**0.06**	**0.06**	**0.06**	**0.06**	**0.28**	**0.83**	**0.83**	**0.28**	**0.06**	**0.06**	**0.06**
Groundwater	0.67	0.03	0.03	0.03	0.03	0.03	0.03	0.19	0.19	0.03	0.03	0.03	0.03
Surface Water	2.05	0.04	0.04	0.04	0.04	0.04	0.25	0.64	0.64	0.25	0.04	0.04	0.04

Table 3.18: Future water demand estimation

Unit: m^3

	Annual	January	February	March	April	May	June	July	August	September	October	November	December
PTTW	**112,613**	**0**	**0**	**0**	**0**	**0**	**16,540**	**39,767**	**39,767**	**16,540**	**0**	**0**	**0**
Groundwater	25,737	0	0	0	0	0	0	12,868	12,868	0	0	0	0
Surface Water	86,876	0	0	0	0	0	16,540	26,898	26,898	16,540	0	0	0
Non-Serviced Residential (G)	**30,483**	**2,540**	**2,540**	**2,540**	**2,540**	**2,540**	**2,540**	**2,540**	**2,540**	**2,540**	**2,540**	**2,540**	**2,540**
Non-PTTW Agriculture(S)	**73,252**	**2,736**	**2,736**	**2,736**	**2,736**	**2,736**	**2,736**	**22,945**	**22,945**	**2,736**	**2,736**	**2,736**	**2,736**
Total	**216,349**	**5,277**	**5,277**	**5,277**	**5,277**	**5,277**	**21,817**	**65,252**	**65,252**	**21,817**	**5,277**	**5,277**	**5,277**
Groundwater	56,220	2,540	2,540	2,540	2,540	2,540	2,540	15,409	15,409	2,540	2,540	2,540	2,540
Surface Water	160,129	2,736	2,736	2,736	2,736	2,736	19,277	49,843	49,843	19,277	2,736	2,736	2,736

Unit: mm

PTTW	**1.44**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.21**	**0.51**	**0.51**	**0.21**	**0.00**	**0.00**	**0.00**
Groundwater	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.16	0.00	0.00	0.00	0.00
Surface Water	1.11	0.00	0.00	0.00	0.00	0.00	0.21	0.34	0.34	0.21	0.00	0.00	0.00
Non-Serviced Residential	**0.39**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**
Non-PTTW Agriculture	**0.94**	**0.04**	**0.04**	**0.04**	**0.04**	**0.04**	**0.04**	**0.29**	**0.29**	**0.04**	**0.04**	**0.04**	**0.04**
Total	**2.77**	**0.07**	**0.07**	**0.07**	**0.07**	**0.07**	**0.28**	**0.83**	**0.83**	**0.28**	**0.07**	**0.07**	**0.07**
Groundwater	0.72	0.03	0.03	0.03	0.03	0.03	0.03	0.20	0.20	0.03	0.03	0.03	0.03
Surface Water	2.05	0.04	0.04	0.04	0.04	0.04	0.25	0.64	0.64	0.25	0.04	0.04	0.04

Table 3.19: Surface water stress calculation (existing scenario)

Month	Water Supply (Q50)		Water Reserve (Tessman)		Water Supply/ Water Reserve		Water Demand (Q demand)			Stress Level	Uncertainty
	m^3/s	mm/month	m^3/s	mm/month	m^3/s	mm/month	m^3	mm/month	% Water Demand		
January	0.84	27.80	0.34	11.25	0.50	16.55	2736	0.035	0.21	Low	High
February	0.87	28.84	0.35	11.71	0.52	17.13	2736	0.035	0.20	Low	High
March	1.95	64.69	0.69	22.74	1.26	41.95	2736	0.035	0.08	Low	High
April	1.53	50.72	0.57	18.87	0.96	31.84	2736	0.035	0.11	Low	High
May	0.90	29.82	0.33	10.91	0.57	18.91	2736	0.035	0.19	Low	High
June	0.71	23.41	0.33	10.89	0.38	12.53	19277	0.247	1.97	Low	High
July	0.51	16.96	0.33	10.89	0.18	6.07	49843	0.638	10.50	Low	High
August	0.51	16.98	0.33	10.89	0.18	6.09	49843	0.638	10.47	Low	High
September	0.60	20.00	0.33	10.89	0.27	9.11	19277	0.247	2.71	Low	High
October	0.64	21.30	0.33	10.89	0.31	10.42	2736	0.035	0.34	Low	High
November	0.90	29.72	0.33	10.89	0.57	18.84	2736	0.035	0.19	Low	High
December	0.77	25.51	0.33	10.89	0.44	14.63	2736	0.035	0.24	Low	High

Table 3.20: Surface water stress calculation (future scenario)

Month	Water Supply (Q50)		Water Reserve (Q10)		Water Supply/ Water Reserve		Water Demand (Q demand)			Stress Level	Uncertainty
	m^3/s	mm/month	m^3/s	mm/month	m^3/s	mm/month	m^3	mm/month	% Water Demand		
January	0.84	27.83	0.34	11.26	0.50	16.57	2736	0.035	0.21	Low	High
February	0.87	28.84	0.35	11.72	0.52	17.12	2736	0.035	0.20	Low	High
March	1.95	64.69	0.69	22.76	1.26	41.93	2736	0.035	0.08	Low	High
April	1.53	50.65	0.57	18.86	0.96	31.79	2736	0.035	0.11	Low	High
May	0.90	29.81	0.33	10.90	0.57	18.91	2736	0.035	0.19	Low	High
June	0.71	23.40	0.33	10.89	0.38	12.51	19277	0.247	1.97	Low	High
July	0.51	16.94	0.33	10.89	0.18	6.05	49843	0.638	10.54	Low	High
August	0.51	16.98	0.33	10.89	0.18	6.09	49843	0.638	10.47	Low	High
September	0.60	19.99	0.33	10.89	0.27	9.10	19277	0.247	2.71	Low	High
October	0.64	21.29	0.33	10.89	0.31	10.40	2736	0.035	0.34	Low	High
November	0.90	29.71	0.33	10.89	0.57	18.82	2736	0.035	0.19	Low	High
December	0.77	25.57	0.33	10.89	0.44	14.68	2736	0.035	0.24	Low	High

Table 3.21: Surface water stress calculation (future scenario with climate change)

Month	Water Supply (Q50)		Water Reserve (Tessman)		Water Supply/ Water Reserve		Water Demand (Q demand)			Stress Level	Uncertainty
	m^3/s	mm/month	m^3/s	mm/month	m^3/s	mm/month	m^3/s	mm/month	% Water Demand		
January	1.52	50.35	0.39	12.99	1.13	37.36	2736	0.035	0.09%	Low	High
February	0.87	29.01	0.39	12.80	0.49	16.21	2736	0.035	0.22%	Low	High
March	1.22	40.48	0.71	23.49	0.51	16.99	2736	0.035	0.21%	Low	High
April	3.06	101.56	1.86	61.65	1.20	39.90	2736	0.035	0.09%	Low	High
May	2.06	68.44	1.39	46.25	0.67	22.19	2736	0.035	0.16%	Low	High
June	2.07	68.60	1.30	43.27	0.76	25.33	19277	0.247	0.97%	Low	High
July	1.79	59.48	1.03	34.15	0.76	25.33	49843	0.638	2.52%	Low	High
August	1.60	53.15	1.00	33.02	0.61	20.13	49843	0.638	3.17%	Low	High
September	1.95	64.70	1.28	42.49	0.67	22.21	19277	0.247	1.11%	Low	High
October	1.41	46.71	1.03	34.16	0.38	12.55	2736	0.035	0.28%	Low	High
November	1.00	33.13	0.74	24.51	0.26	8.62	2736	0.035	0.41%	Low	High
December	1.09	36.01	0.43	14.38	0.65	21.63	2736	0.035	0.16%	Low	High

Table 3.22: Groundwater stress calculation (existing scenario)

Month	Water Supply (Q50)		Water Reserve (Q10)		Water Supply/ Water Reserve		Water Demand (Q demand)			Stress Level	Uncertainty
	m^3/s	mm/month	m^3/s	mm/month	m^3/s	mm/month	m^3/s	mm/month	% Water Demand		
January	0.78	25.92	0.078	2.59	0.70	23.33	2244	0.029	0.12	Low	High
February	0.78	25.92	0.078	2.59	0.70	23.33	2244	0.029	0.12	Low	High
March	0.78	25.92	0.078	2.59	0.70	23.33	2244	0.029	0.12	Low	High
April	0.78	25.92	0.078	2.59	0.70	23.33	2244	0.029	0.12	Low	High
May	0.78	25.92	0.078	2.59	0.70	23.33	2244	0.029	0.12	Low	High
June	0.78	25.92	0.078	2.59	0.70	23.33	2244	0.029	0.12	Low	High
July	0.78	25.92	0.078	2.59	0.70	23.33	15113	0.193	0.83	Low	High
August	0.78	25.92	0.078	2.59	0.70	23.33	15113	0.193	0.83	Low	High
September	0.78	25.92	0.078	2.59	0.70	23.33	2244	0.029	0.12	Low	High
October	0.78	25.92	0.078	2.59	0.70	23.33	2244	0.029	0.12	Low	High
November	0.78	25.92	0.078	2.59	0.70	23.33	2244	0.029	0.12	Low	High
December	0.78	25.92	0.078	2.59	0.70	23.33	2244	0.029	0.12	Low	High

Table 3.23: Groundwater stress calculation (future scenario)

Month	Water Supply (Q_r+Q_{net})		Water Reserve (10% supply)		Water Supply/ Water Reserve		Water Demand (Q demand)			Stress Level	Uncertainty
	m^3/s	mm/month	m^3/s	mm/month	m^3/s	mm/month	m^3	mm/month	% Water Demand		
January	0.78	25.90	0.078	2.59	0.70	23.31	2540	0.033	0.14%	Low	High
February	0.78	25.90	0.078	2.59	0.70	23.31	2540	0.033	0.14%	Low	High
March	0.78	25.90	0.078	2.59	0.70	23.31	2540	0.033	0.14%	Low	High
April	0.78	25.90	0.078	2.59	0.70	23.31	2540	0.033	0.14%	Low	High
May	0.78	25.90	0.078	2.59	0.70	23.31	2540	0.033	0.14%	Low	High
June	0.78	25.90	0.078	2.59	0.70	23.31	2540	0.033	0.14%	Low	High
July	0.78	25.90	0.078	2.59	0.70	23.31	15409	0.197	0.85%	Low	High
August	0.78	25.90	0.078	2.59	0.70	23.31	15409	0.197	0.85%	Low	High
September	0.78	25.90	0.078	2.59	0.70	23.31	2540	0.033	0.14%	Low	High
October	0.78	25.90	0.078	2.59	0.70	23.31	2540	0.033	0.14%	Low	High
November	0.78	25.90	0.078	2.59	0.70	23.31	2540	0.033	0.14%	Low	High
December	0.78	25.90	0.078	2.59	0.70	23.31	2540	0.033	0.14%	Low	High
Annual	9.37	310.80	0.937	31.08	8.43	279.72	56220	0.719	0.26%	Low	High

Table 3.24: Groundwater stress calculation (future scenario with climate change)

Month	Water Supply (Q_r+Q_{net})		Water Reserve (10% supply)		Water Supply/ Water Reserve		Water Demand (Q demand)			Stress Level	Uncertainty
	m^3/s	mm/month	m^3/s	mm/month	m^3/s	mm/month	m^3	Mm/month	% Water Demand		
January	1.52	50.30	0.152	5.03	1.36	45.27	2540	0.033	0.07%	Low	High
February	1.52	50.30	0.152	5.03	1.36	45.27	2540	0.033	0.07%	Low	High
March	1.52	50.30	0.152	5.03	1.36	45.27	2540	0.033	0.07%	Low	High
April	1.52	50.30	0.152	5.03	1.36	45.27	2540	0.033	0.07%	Low	High
May	1.52	50.30	0.152	5.03	1.36	45.27	2540	0.033	0.07%	Low	High
June	1.52	50.30	0.152	5.03	1.36	45.27	2540	0.033	0.07%	Low	High
July	1.52	50.30	0.152	5.03	1.36	45.27	15409	0.197	0.44%	Low	High
August	1.52	50.30	0.152	5.03	1.36	45.27	15409	0.197	0.44%	Low	High
September	1.52	50.30	0.152	5.03	1.36	45.27	2540	0.033	0.07%	Low	High
October	1.52	50.30	0.152	5.03	1.36	45.27	2540	0.033	0.07%	Low	High
November	1.52	50.30	0.152	5.03	1.36	45.27	2540	0.033	0.07%	Low	High
December	1.52	50.30	0.152	5.03	1.36	45.27	2540	0.033	0.07%	Low	High
Annual	18.20	603.60	1.820	60.36	16.38	543.24	56220	0.719	0.13%	Low	High

3.6 GROUNDWATER QUALITY

Groundwater quality is spatially variable, is affected by seasonal changes and local climate, and by the types of soils and rocks through which water moves. When water from rain or snowmelt moves overland and through the ground, water dissolves minerals found in rocks and soils, percolates through organic material such as roots and leaves, and reacts with algae, bacteria, and other microscopic organisms. Each of these natural processes changes groundwater quality. In addition to natural controls over groundwater quality, human influences such as contamination can alter the quality of groundwater.

In the Graham Creek watershed, the most common dissolved substances in groundwater are minerals and salts; as a group, referred to as dissolved solids. Dissolved solids include common constituents such as calcium, sodium and chloride; nutrients such as nitrogen and phosphorus; and trace elements such as selenium, chromium and arsenic (Morrison Environmental Limited 2004). In general, the common, naturally dissolved substances are not considered harmful to human health or aquatic organisms, although some constituents can affect the taste, smell or clarity of water.

Nutrients and trace elements in water can be harmful to human health and aquatic life if they exceed standards or guidelines set out by the province through the *Ontario Drinking Water Objectives*. Dissolved gases such as oxygen and methane are common in groundwater in the Graham Creek watershed.

Groundwater quality data for the Graham Creek watershed is potentially available from a wide variety of sources including the Ministry of the Environment Water Well Records Database, the Provincial Groundwater Monitoring Network, private well sampling, municipal water sampling programs, and local and site-specific groundwater studies. The first step in reporting groundwater quality is to collect all the available data to allow a water quality comparison on a spatial scale (vertically in aquifer/aquitard units and horizontally in an individual aquifer) and temporal scale for a variety of parameters. At this time there is limited data, data gaps and other limitations affecting groundwater quality analysis. In addition, water quality data can only be inferred to a site-specific location, and not necessarily to an aquifer.

3.6.1 Groundwater Quality in Private Water Supply Wells

The majority of the residents in the Graham Creek watershed receive their water from private wells, except for areas around Newtonville and Newcastle that are serviced from the Newcastle Water Treatment Plant. Many of these private wells supply water to permanent residents, whereas other wells are used for agricultural purposes including livestock watering, irrigation, and a small number of wells are used for commercial and industrial purposes.

It is important to identify aquifer types when assessing groundwater quality, which can be done using the Water Well Record Database. The sand and gravel deposits of glaciofluvial and glaciolacustrine origins are the main aquifers in the area. In the Graham Creek watershed, overburden, bedrock, and flowing artesian wells have been identified. Overburden wells are more important as a source of private water supply wells. Generally bedrock wells are concentrated in the southern part of the Graham Creek watershed where overburden is relatively thin.

General, but limited information related to the quality of groundwater is available from the Water Well Record Database. A considerable number of wells are reported to have some natural water quality problems. For example, some bedrock wells have been reported to have salty, sulphurous or mineral water, and other well water contains gas (Singer et al. 2003). The description of groundwater quality within the overburden was given in terms of quality parameters and water type rather than in terms of specific overburden units. The parameters that were considered include sodium, iron, chloride, sulphate, nitrate, total hardness and total dissolved solids.

Most of the Ministry of the Environment Water Well Record Database includes information related to groundwater encountered such as fresh, salty, sulphurous, or containing iron or gas. The well driller, as part of the well record requirements, normally submits this information to the Ministry of the Environment. Usually the driller visually examines a water sample taken from the well for clarity. The driller then smells and tastes the water and enters appropriate observations into the well record. These observations are very useful especially when the water tastes salty or smells like a rotten egg, showing the presence of sodium chloride or hydrogen sulphide. The driller’s observations are subjective and are therefore inadequate for determining the suitability of groundwater for drinking purposes.

To provide an indication of the Graham Creek watershed groundwater quality, well records were compiled from Water Well Records. Wells screened in bedrock are observed to produce fresh water. Freshwater was interpreted to be water that has acceptable taste and odour, and is usable as a drinking water supply. Although not noted on the well records, water in this category may still require treatment such as softening or iron removal to meet Ontario Drinking Water Standards. The presence of contaminants that do not usually produce a notable taste or odour (such as bacteria and nitrate) would not normally be noted on the well records. Salty water is not frequently reported, and it is expected that these occurrences might be a result of activities at the landscape. Road salting and dust control can result in chloride contamination, as can salt/sand stockpiles and landfills.

Due to the limited data availability at this time, the above sections provide general information about regional groundwater quality in the Graham Creek watershed. In addition, it is known that site-specific groundwater quality issues occur in the Graham Creek watershed, however details of these occurrences are unknown. Many times however, it is poor private well maintenance and conditions that lead to negative groundwater quality results, rather than contaminated aquifers.

3.6.2 Provincial Groundwater Monitoring Network Groundwater Quality

Groundwater quality sampling in the Ganaraska Region Conservation Authority is being conducted as part of the Ministry of the Environment Provincial Groundwater Monitoring Network (PGMN). PGMN wells are not used for private or public drinking water supplies. They provide information on regional groundwater aquifers that supply drinking water. The information from the Provincial Groundwater Monitoring Network will provide an early warning system for changes in water levels caused by climatic conditions, as well as changes in water quality from natural or anthropogenic (man-made) causes.

There is one PGMN well in the Graham Creek watershed. This well is PGMN Well number GA 140, and is north of Concession Road 3, and has a depth of 11.79 m. Groundwater quantity and quality sampling occurs as part of the monitoring program. The location of the PGMN well is shown in Figure 3.38. Groundwater quality sampling has been completed in 2004, 2006 and 2007 2008. Samples were tested for most parameters specified in the *Ontario Drinking Water Quality Standards Regulation* (O. Reg. 169/03). All of the sampling procedures, storage and laboratory testing are carried out according to Ministry of the Environment guidelines.

Table 3.25 shows the laboratory results as well as the comparison of these results with the Ontario Drinking Water Standards at the PGMN well. Bolded results indicate samples exceeded the Ontario Drinking Water Standards for non-health related parameters. Red bolded results indicate samples exceeding the Ontario Drinking Water Standards for health related parameters. Laboratory results of groundwater samples collected to date showed no major variations from the Ontario Drinking Water Standards from both an operational and human health perspective (Table 3.25).

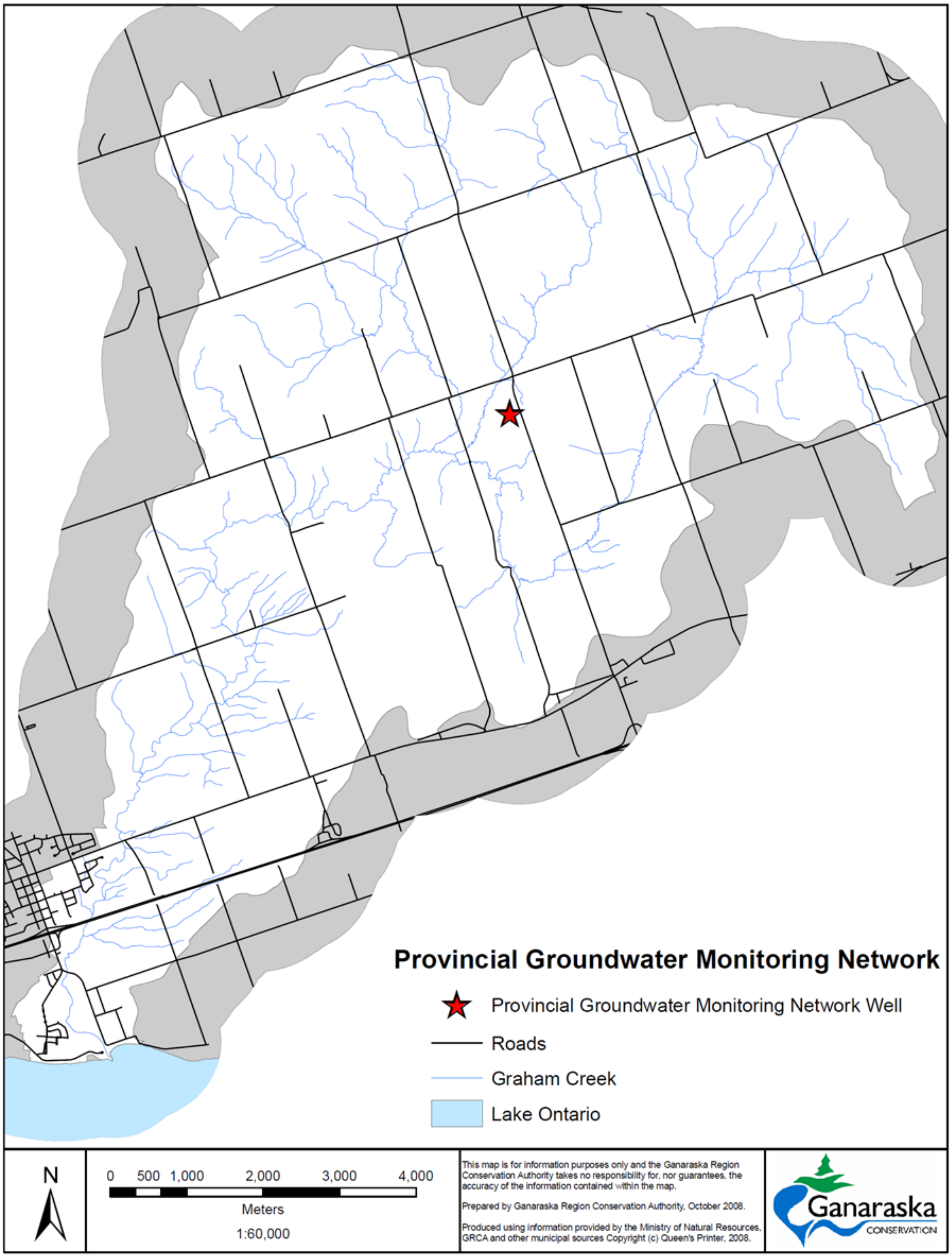


Figure 3.38: Provincial Groundwater Monitoring Network well location

Table 3.25: Groundwater quality at the PGMN Well

Parameter	Units	Ontario Drinking Water Standard	July 8, 2002	November 9, 2006	October 24, 2007	October 23, 2008
pH	None	6.5 to 8.5	NA	8.04	7.89	7.92
Alkalinity	mg/L as CaCO3	30 to 500	NA	269	274	291
Conductivity	μS/cm	800	**NA**	**2420**	**2170**	2640
Carbonate	mg/L as CaCO3		0	<2	< 2	
Bicarbonate	mg/L as CaCO3		NA	269	274	
Total Dissolved Solids	mg/L	500	**1210**	**1460**	**1400**	**1930**
Chloride	mg/L	250	**370**	**610**	**600**	**728.0**
Nitrite	as N mg/L	1.0	NA	< 0.005	<0.005	0.005
Nitrate	as N mg/L	10.0	0.00	1.70	1.66	
Nitrate + nitrite	as N mg/L	10.0	NA	1.70	1.66	1.46
Sulphate	mg/L		25.1	25	26	28
Fluoride	mg/L	1.5	0.04	< 0.06	< 0.06	0.03
Total Reactive Phosphorus	mg/L		NA	< 0.02 UAL	<0.02	0.02
Dissolved Organic Carbon	mg/L	5.0	0.7	1.0	0.7	0.8
Dissolved Inorganic Carbon	mg/L		50.6	67.8	80.3	71.3
Organic Nitrogen	mg/L	0.15	NA	< 0.05	0.12	
Ammonia + ammonium	as N mg/L		NA	0.11	<0.04	0.05
Total Kjeldahl Nitrogen	as N mg/L		0.10	0.14	0.15	0.07
Hardness	mg/L as CaCO3	80 to 100	**404**	**540**	**503**	**413**
Aluminum	mg/L	0.1	0.0144	0.0003	0.0003	0.00025
Antimony	mg/L	0.006	0.00088	< 0.0002	< 0.0002	0.00052
Arsenic	mg/L	0.025	0.0004	0.0006	0.0004	0.00003
Barium	mg/L	1	0.0132	0.225	0.217	0.237
Beryllium	mg/L		0	< 0.00004	< 0.00002	0
Boron	mg/L	5	0.0003	0.007	0.004	0.0098
Calcium	mg/L		130	179	167	129
Cadmium	mg/L	0.005	0.00001	< 0.00006	0.000008	0.00001
Cobalt	mg/L		0.00004	0.000093	0.000196	0.00028
Chromium	mg/L	0.05	0.0005	0.0010	0.0020	0.00
Copper	mg/L	1	0.0013	0.0005	0.0007	0.0008
Iron	mg/L	0.3	-2	0.16	0.20	0.198
Lead	mg/L	0.01	0.00001	0.00003	< 0.00002	0.00002
Magnesium	mg/L		19.2	22.6	20.9	22.5
Manganese	mg/L	0.05	0.000125	0.00677	0.00973	0.0103
Molybdenum	mg/L		0.00024	0.00041	0.00107	0.0002
Nickel	mg/L		0.0004	0.0022	0.0015	0.0034
Phosphorus	mg/L		0.006	0.02	< 0.01	0.002
Potassium	mg/L		1.50	2.19	2.65	2.01
Selenium	mg/L	0.01	0	< 0.003	< 0.001	0.001
Silver	mg/L		0.00001	< 0.00003	< 0.00001	0
Sodium	mg/L	200	174	**241**	**238**	**345**
Strontium	mg/L		0.269	0.402	0.434	0.478
Titanium	mg/L		0.0004	0.0005	0.0005	0.0007
Thallium	mg/L		0	< 0.0001	0.00001	0
Uranium	mg/L	0.02	0.00001	0.00067	0.000649	0.00077
Vanadium	mg/L	0.1	0.00016	0.00031	0.00072	0.00056
Zinc	mg/L	5	0.0045	0.0012	0.002	0.0007

Bold signifies parameters exceeding the Ontario Drinking Water Standard for non-health related parameters.
Red Bold signifies parameters exceeding the Ontario Drinking Water Standard for health related parameters.

3.7 SURFACE WATER QUALITY

The quality of surface water is influenced by the surrounding landscape and in stream transformations. Land use and cover in a watershed can influence water chemistry and integrity of the stream environment. Non-point sources (i.e., runoff) that enter surface water contain components of the drainage area. Surrounding land use and cover therefore play an important role in the type and amount of nutrient, bacteria, chemical and metal loading that occurs in a water system. Modes of transportation into a water body such as a stream include point sources (direct) and non-point sources (indirect), atmospheric deposition (precipitation and dust), internal transportation (nutrient cycling), and groundwater inputs. Surface water quality modeling helps to understand how the landscape and land uses contribute to surface water quality. At this time however, surface water quality modeling is not yet available for the Graham Creek watershed.

Quality water is needed for a healthy aquatic ecosystem, from an entire ecosystem perspective and from a human needs standpoint. Many guidelines exist that set out limits for certain parameters as they relate to aquatic organism toxicity levels, unsafe use of water for recreational activities, agricultural purposes and for human consumption. In Ontario the provincial government has set out *Provincial Water Quality Objectives* based on uses such as aquatic life needs and recreation (Ontario Ministry of Environment and Energy 1999).

In addition to provincial guidelines, the federal government has set out *Canadian Water Quality Guidelines* based on aquatic life, recreation and agricultural use (Canadian Council of Ministers of the Environment 2006). Both governments also have drinking water quality objectives or guidelines that set limits on water quality parameters so that drinking water is safe for human consumption (Ontario Ministry of the Environment 2003; Canadian Council of Ministers of the Environment 2006). These guidelines and objectives help to rank and understand water quality in terms of an environmental or human need.

When analyzing the surface water quality of Graham Creek, *Provincial Water Quality Objectives* related to aquatic life tolerance or recreational water usage will be used. Where provincial objectives do not exist, *Canadian Water Quality Guidelines* for aquatic life tolerance will be used. In order to characterize the surface water quality of Graham Creek, water quality parameter trends through time will be analyzed and current surface water quality will be examined.

3.7.1 Methods

Surface Water Quality Data Sets

Presently, two surface water quality programs exist in Graham Creek, the Ganaraska Region Water Quality Monitoring Network and the Provincial Water Quality Monitoring Network.

Ganaraska Region Conservation Authority staff conducts the Ganaraska Region Water Quality Monitoring Network (GRWQMN) on a yearly basis. In the Graham Creek watershed, 13 GRWQMN sample sites exist. Combinations of these sites were sampled once a month in from July to September 2002, June to August and October 2003, and July to September 2005. Table 3.26 outlines the GRWQMN sample sites and Figure 3.39 shows their locations.

Table 3.26: Locations and sampling times of GRWQMN stations

Site	Sample Frequency Dates
GR-01-02	July 25, August 21, and September 24, 2002
GR-01-03	May 27, June 16, July 14, August 18 and October 6, 2003
GR-01-05	July 19, August 30 and September 27, 2005
GR-02-02	July 25, August 21, and September 24, 2002
GR-02-03 and GR-06-02	July 25, August 21, September 24, 2002, May 27, June 16, July 14, August 18 and October 6, 2003
GR-03-02	July 25, August 21, and September 24, 2002
GR-04-02	July 25, August 21, and September 24, 2002
GR-05-02	July 25, August 21, and September 24, 2002
GR-06-03	May 27, June 16, July 14, August 18 and October 6, 2003
GR-07-02 and GR-04-03	July 25, August 21, September 24, 2002, May 27, June 16, July 14, August 18 and October 6, 2003
GR-07-03	May 27, June 16, July 14, August 18 and October 6, 2003
GR-08-02 and GR-03-03	July 25, August 21, September 24, 2002, May 27, June 16, July 14, August 18 and October 6, 2003
GR-09-02 and GR-05-03	July 25, August 21, September 24, 2002, May 27, June 16, July 14, August 18 and October 6, 2003

In 2009 a Baseflow Water Quality Monitoring Program was carried out. Since a stream or river experiences baseflow conditions (groundwater contribution only) 70% of the time, water quality should be consistent 70% of the time unless it is affected by point source contamination. On September 16th, 19 sites (Figure 3.40) were sampled throughout the watershed during a period of no rain and baseflow conditions.

The largest surface water data set exists through the Provincial Water Quality Monitoring Network (PWQMN), operated in partnership by the Ontario Ministry of the Environment (MOE) and the Ganaraska Region Conservation Authority. Throughout the existence of the program, 52 parameters have been analyzed at one time or another. One active PWQMN sample station is located in Graham Creek in the lower half of the watershed (Mill Street). Figure 3.39 shows the location of the PWQMN station and Table 3.27 outlines the years of data available.

Table 3.27: PWQMN station and sampling frequency

Station	PWMQN Station ID	Years Sampled
Graham Creek at Mill Street	06011800102	1965 to present

No sampling occurred from 1995 to 2001
Turbidity and metal sampling stopped in December 2006

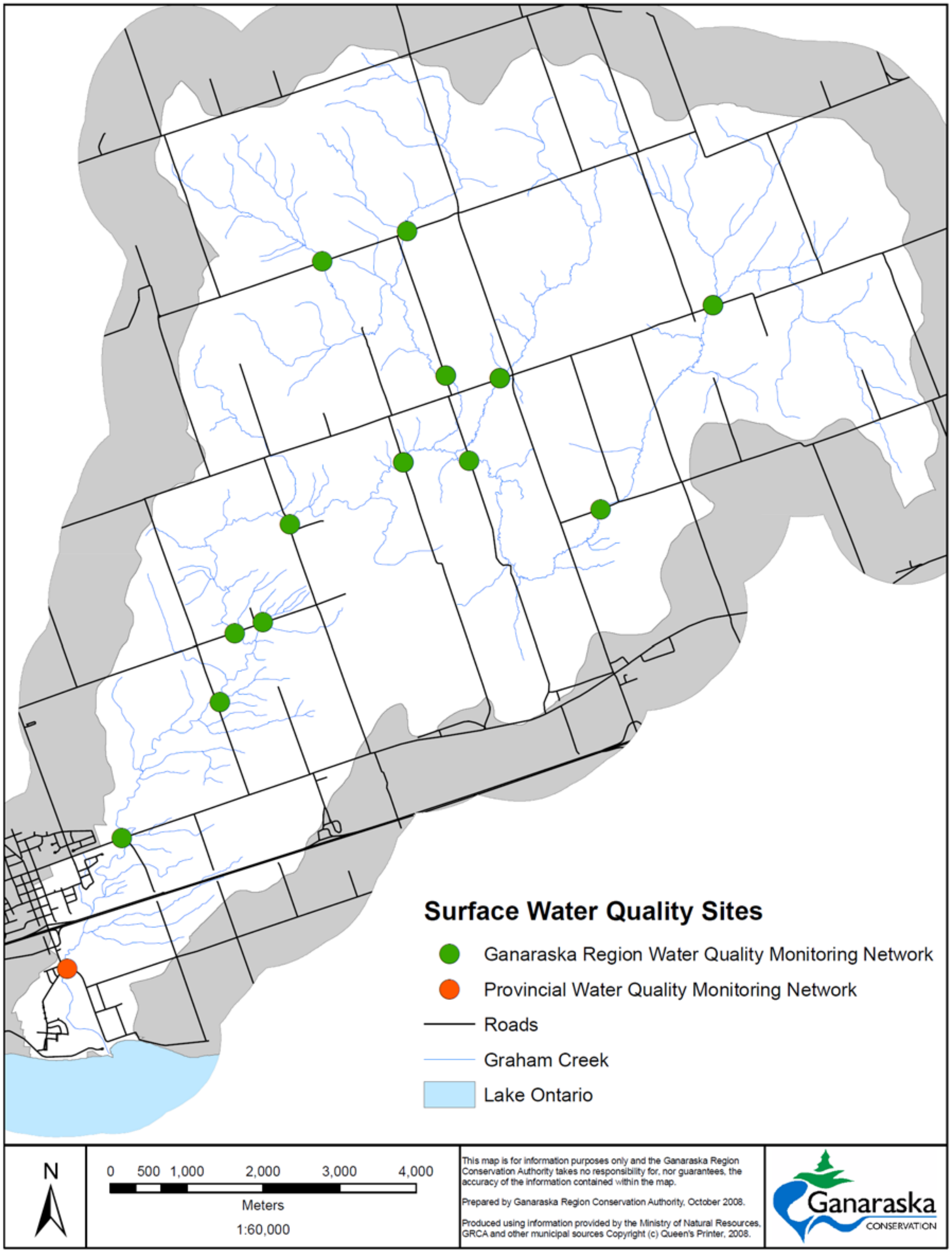


Figure 3.39: Surface water quality monitoring sites

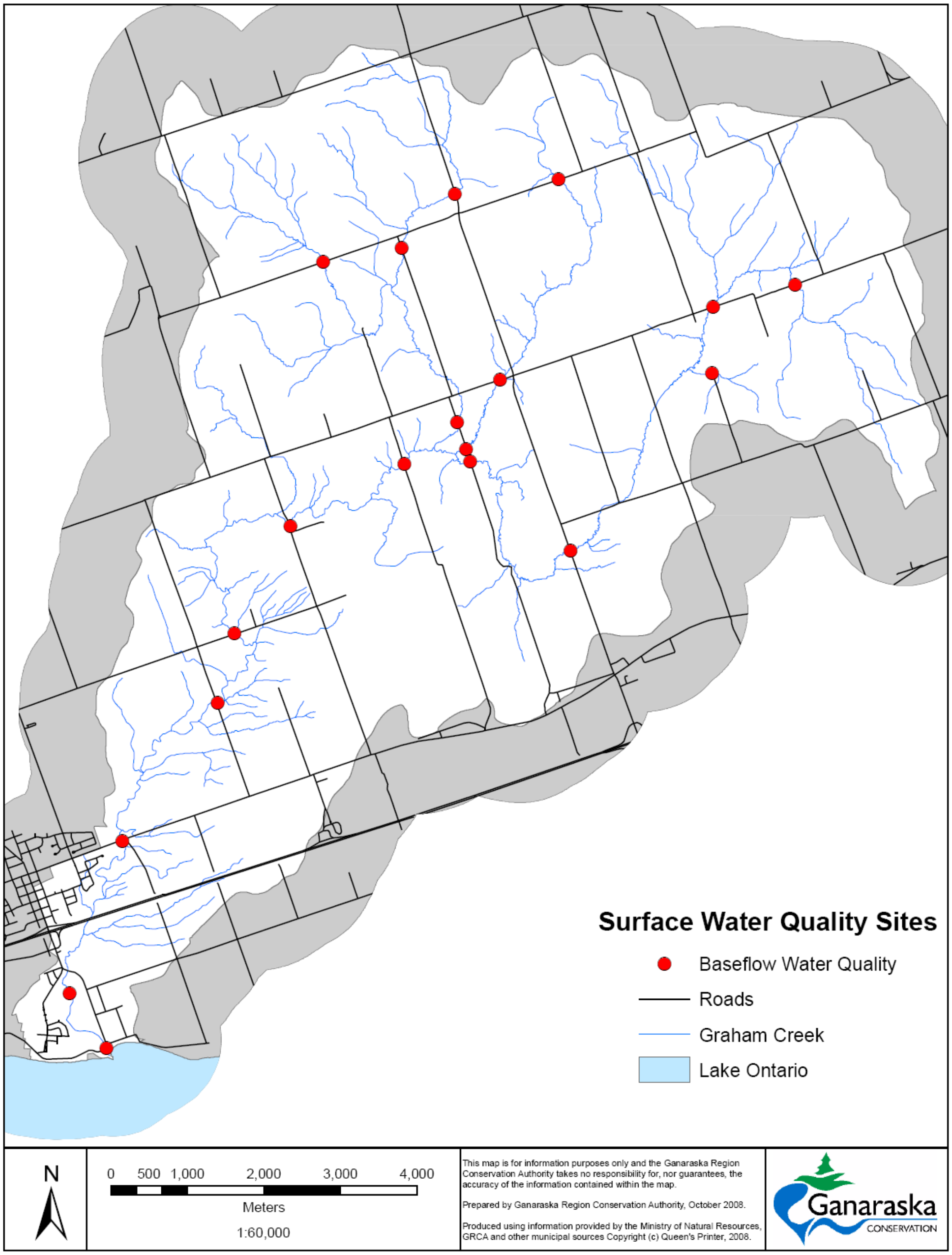


Figure 3.40: Baseflow water quality monitoring sites

Water Quality Sampling Methods

Since 2002 surface water quality sites have been monitored using a YSI™ 600QS model water quality probe. Parameters include temperature, salinity, pH, dissolved oxygen, total dissolved solids and conductivity.

For the GRWQMN program, surface water was analyzed for alkalinity, total suspended solids, nitrate, nitrite and chloride concentrations in-house using a HACH DR/2010 Portable Datalogging Spectophotometer. The Spectophotometer method used to analyze alkalinity was the sulphuric acid method with a digital titrator; total suspended solids were the photometric method, and nitrate was the calcium reduction method; nitrite was the diazotisation method (HACH Company 1989). Along with in-house analysis, samples were sent to SGS Lakefield Research Limited for analysis of total phosphorus, ammonia-ammonium, unionized ammonia, *Escherichia coli* and total coliform.

The baseflow water quality monitoring analysis was conducted by SGS Lakefield Research in 2009 for total phosphorus, nitrate, nitrite, total suspended solids, ammonia-ammonium, unionized ammonia, *Escherichia coli* and total coliform. Turbidity was sampled in the field with a HACH 2100P Turbidimetre.

Since the Provincial Water Quality Monitoring Network is run as a partnership, samples are taken by the Ganaraska Region Conservation Authority and analyzed by the MOE at a provincial lab. Surface water was taken from the sample site in 500 ml bottles, preserved if needed and shipped to the MOE lab. Parameters analyzed by the MOE lab since 1965 include those outlined in Table 3.28.

Table 3.28: List of water quality parameters sampled through PWQMN

Parameter Category	Parameters
Physical	dissolved oxygen, biological oxygen demand, conductivity, pH, alkalinity, carbon, colour, turbidity, residues, dissolved organic carbon
Major Ions/Anions	calcium, magnesium, sodium, potassium, hardness, chloride
Metals and Chemicals	aluminum, barium, beryllium, cadmium, cobalt, chromium, copper, iron, manganese, molybdenum, methoprene, nickel, lead, strontium, titanium, vanadium, zinc, phenolics, cyanide, arsenic, sulphate, mercury, methoxycitronellal, malathion
Nutrients	total ammonium, nitrite, nitrate, phosphate, total phosphorus, total kjeldahl nitrogen
Bacteria	Fecal Streptococcus, Fecal Coliforms, Total Coliforms, *Escherichia coli*, *Pseudonom Aeruginosa*

Water Quality Data Screening

Although the PWQMN data contain the most surface water quality data, not all of the 52 parameters are usable. Some parameters were sampled in a short time period and therefore are statistically irrelevant. Others were only sampled during time periods prior to 2002 when the PWQMN program was restarted after being cancelled in 1995. Therefore certain parameters and sample sites have been removed from the water quality analysis.

The following parameters were not analyzed because the data is historic and does not reflect current conditions (prior to 1995) or there are less than 30 sample points, making them statistically invalid. As a result of these conditions the following parameters were not analyzed.

- Cyanide: 2 sample in 1980
- Arsenic: 2 samples in 1980
- Sulphate: sampled in 1972, 1973 and 1994
- Phenolics: Sampled prior to 1994
- Turbidity reported in JTU: Sampled prior to 1972
- Any nitrite or nitrate sampled prior to 1984 due to differences in analysis
- Total Residue: Sampled prior to 1994
- Filtered Residue: Sampled prior to 1994
- Mercury: 2 samples in 1980
- Malathion: 10 samples in 2003 and 2004
- Methoxycitronellal: 10 samples in 2003 and 2004
- Methoprene: 21 samples in 2003 and 2004
- Colour: 1 samples in 1969
- Dissolved Organic Carbon: Sampled in 1972 and 1973
- *Pseudonom Aeruginosa* MF: 6 samples in 1994
- Fecal Streptococcus MF: Sampled prior to 1994
- Fecal Coliform MF: Sampled prior to 1994
- *Escherichia coli*: 6 samples in 1994
- Total Coliform: Sampled prior to 1986.

Trends in metals were analyzed using data from 2002 to 2007 to eliminate invalid results due to MOE laboratory detection limit changes that have occurred since the 1970s.

Surface Water Quality Guidelines

Surface water quality guidelines were used to evaluate measured water quality parameters. Table 3.29 outlines the guidelines used and the source.

Table 3.29: Surface water quality guidelines or objectives

Parameter	Guideline or Objective	Parameter	Guideline or Objective
pH *	6.5-8.5	Cobalt*	0.9 µg/L
Total Suspended Solids ⤙	25 mg/L	Iron*	300 µg/L
Dissolved Oxygen*	5 to 8 mg/L (temperature dependant)	Lead*	5 µg/L
Nitrate-N ǂ	2.9 mg/L	Molybdenum*	40 µg/L
Nitrite-N ǂ	0.197 mg/L	Nickle*	25 µg/L
Unionized Ammonia*	0.02 mg/L	Vandium*	6 µg/L
Total Phosphorus*	0.03 mg/L	Total Chromium †	2 µg/L
*Escherichia coli**	100 cfu/100 ml (recreation)	Zinc*	30 µg/L
Chloride ǂ	250 mg/L	Beryllium*	11 µg/L
Aluminum*	75 µg/L	Cadmium*	0.2 µg/L
Copper*	5 µg/L		

* Ontario Ministry of Environment and Energy (1999)
ǂ Canadian Council of Ministers of the Environment (2006)
† Pawlisz et al. (1997)
⤙ Department of Fisheries and Oceans Canada (2000)

Statistical Analysis

All statistical analysis was done using the computer statistical package Statistica using non-parametric tests.

- *GRWQMN Data Analysis*: Basic descriptive statistics on the GRWQMN data were conducted and median values were calculated due to the non-parametric nature of the data. Geometric means were calculated for bacteria data. Analysis comparing dissolved oxygen to stream temperature is described using Spearman's Ranks Correlation.

- *Baseflow Water Quality Data Analysis*: Basic descriptive statistics on the baseflow water quality data were conducted and median values were calculated due to the non-parametric nature of the data. Geometric means were calculated for bacteria data. Catchment areas contributing to each sample site were defined using Arc Hydro. Each catchment area was then evaluated for land use types with 2002 Ecological Land Classification data. These land use types were used to infer a relationship to the water quality parameters sampled at each site.

- *PWQMN Data Analysis*: Analysis of trends over time and relationships to flow using PWQMN data was done with Spearman's Ranks Correlation. Comparisons were completed for each parameter (dependent variable) compared against time (independent variable). The level of significance was set at α = 0.05. Therefore, if *$p < 0.05$ there is statistical significance* in the strength of the linear relationship (r – linear correlation coefficient) between a particular parameter and time. If significance is found in the r value, then the regression equation ($y = b0 + b1(x)$) can be used to predict future chemical concentrations or to fill in data gaps. Before predictions can be made, the coefficient of determination (r^2) must be close to 1 (preferably >0.6). This indicates that the regression line describes a significant amount of the parameter.

3.7.2 Ganaraska Region Water Quality Monitoring Network Results

The Ganaraska Region Water Quality Monitoring Network allows a watershed-wide analysis of water quality. Given the small data set of each GRWQMN station, all stations will be grouped to give an overall picture of water quality in Graham Creek.

Physical Parameters

The physical parameters of the surface water in Graham Creek indicate the base conditions of water quality. Table 3.30 describes the physical conditions of the Graham Creek surface water as sampled through the GRWQMN. All physical parameters are within acceptable ranges and concentrations are dependent on stream conditions such as flow and temperature.

Table 3.30: Range of physical parameters through the GRWQMN

Parameter	n*	Median	Minimum	Maximum	10th Percentile	90th Percentile
pH	56	7.93	6.96	8.57	7.50	8.32
Dissolved Oxygen (mg/L)	47	9.25	0.50	23.58	3.78	11.88
Conductivity (µs/cm)	55	449	0.20	760	35.0	513
Salinity (%)	56	0.21	0.00	0.40	0.00	0.25
TDS (g/L)	53	0.29	0.00	0.36	0.01	0.31
Alkalinity (mg/L as CaCO3)	56	189	144	428	154	224
TSS (mg/L)	56	5.00	0.00	387	2.00	13.0
Turbidity (mg/L)	61	1.90	0.24	95.2	1.00	5.55

*n represents the number of samples

Results show the following:

- pH levels are within the acceptable range of 6.5 to 8.5.
- Total suspended solids (TSS) rarely (9%) exceeded the recommended 25 mg/L.
- The median TSS concentration of 5 mg/L reflects the usual condition without influences of high flows.
- Dissolved oxygen ranging between 0.5 and 23.6 mg/L are within acceptable ranges during sampling.
- Dissolved oxygen is noted to decline as stream temperatures increase (n=44, r_s = -0.35, p = 0.02) (Figure 3.41)

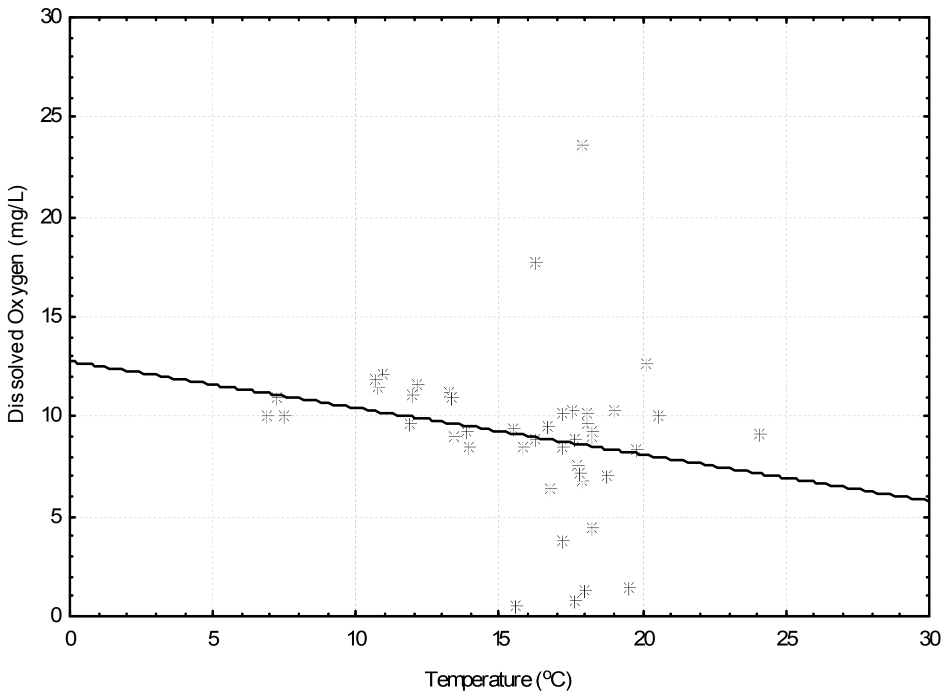


Figure 3.41: Dissolved oxygen concentrations and stream temperature

Nutrients

Five nutrient parameters have been sampled through the GRWQMN and concentration ranges are found in Table 3.31.

- Nitrate-N and nitrite-N concentrations never exceeded the Canadian Water Quality Guideline (CWQG) of 2.9 mg/L and CWQG of 0.197 mg/L respectively when sampled through the GRWQMN.
- Ammonia-ammonium limits are dependent on stream temperature and unionized ammonia has a PWQO of 0.02 mg/L. Based on this objective, unionized ammonia at sampled GRWQMN stations has exceeded the PWQO 30% of the time.
- Total phosphorus has also exceeded the PWQO of 0.03 mg/L 20% of the time.
- Unionized ammonia and total phosphorus median concentration are below the PWQO (Table 3.31).

Table 3.31: Nutrient concentrations sampled through the GRWQMN

Parameter	n	Median	Min	Max	10th Percentile	25th Quartile	75th Quartile	90th Percentile
Nitrate-N (mg/L) (CWQG = 2.9 mg/L)	56	0.60	0.10	1.9	0.20	0.30	0.75	1.10
Nitrite-N (mg/L) (CWQG = 0.197 mg/L)	56	0.007	0.00	0.06	0.003	0.005	0.012	0.02
Ammonia-ammonium (mg/L)	65	0.20	0.01	0.90	0.01	0.10	0.30	0.40
Unionized Ammonia (mg/L) (PWQO = 0.02 mg/L)	64	0.011	0.005	0.06	0.005	0.006	0.024	0.03
Total Phosphorus (mg/L) (PWQO = 0.03 mg/L)	65	0.02	0.02	4.56	0.02	0.02	0.03	0.08

Bacteria

Ranges of *Escherichia coli* frequently exceed the PWQO as sampled through the GRWQMN (Table 3.32). Concentrations give an idea of bacteria concentrations in Graham Creek. However samples are only taken once per site per sampling time and are not based on five samples per site. *Escherichia coli* concentrations have exceeded the PWQO 37% of the time throughout the entire Graham Creek watershed.

Table 3.32: Bacteria concentrations sampled through the GRWQMN

Parameter	n	Geometric Mean	Min	Max	10th Percentile	90th Percentile
Escherichia coli (cfu/100 ml)(PWQO = 100 cfu/100 ml)	65	79	8	2000	16	380
Total Coliform (cfu/100 ml)	64	1224	112	7600	320	4000

3.7.3 Baseflow Water Quality Monitoring Program Results

The Ganaraska Baseflow Water Quality Monitoring Program allows a watershed-wide analysis of water quality during baseflow conditions. Baseflow occurs 70% of the time in a year. Therefore, water quality is more likely to be a result of groundwater quality or very local land uses (e.g., point source contamination). By sampling numerous sites, a detailed picture of areas that have uniform water quality can be seen, given that surface water runoff and precipitation inputs are controlled.

Physical Parameters

The physical parameters of the surface water suggest the background conditions of the quality of water. Table 3.33 describes the physical conditions of surface water as sampled through the Baseflow Water Quality Monitoring Program. All physical parameters are within acceptable ranges, with concentrations dependent on stream conditions such as flow and temperature. TSS exceeded the recommended 25 mg/L 11% of the time; the median concentration of 3 mg/L reflects the usual condition of Graham Creek.

Table 3.33: Range of physical parameters through the Baseflow Water Quality Monitoring program

	N	Median	Minimum	Maximum	10^{th} Percentile	90^{th} Percentile
Temperature (^oC)	18	14.5	12.7	16.2	13.2	16.2
DO (mg/L)	18	13.8	1.6	16.4	2.5	15.3
Conductivity (us/cm)	18	481	385	562	402	544
Salinity (%)	18	0.23	0.19	0.27	0.2	0.26
pH	18	7.97	7.49	8.24	7.51	8.12
TDS (mg/L)	18	0.31	0.26	0.64	0.26	0.35
Turbidity (mg/L)	18	6	2.34	518	2	197
TSS (mg/L)	19	3	2	52	2	32

Nutrients

Five nutrient parameters were sampled through the Baseflow Water Quality Monitoring program and concentration ranges are found in Table 3.34.

- Nitrate–N exceeded the CWQG of 2.9 mg/L at one site, or 5% of the time.
- Nitrite–N never exceeded the CWQG of 0.197 mg/L.
- Unionized ammonia concentrations at sample sites were always below the PWQO.
- Total phosphorus exceeded the PWQO of 0.03 mg/L at six sites, or 32% of the time at sampled baseflow water quality monitoring stations.
- Nitrite-N, nitrate-N and total phosphorus median values were below the respective water quality guidelines (Table 3.34).

Table 3.34: Nutrient concentrations sampled through the baseflow water quality monitoring program

	n	Median	Minimum	Maximum	10th Percentile	90th Percentile
Nitrite-N (mg/L)	18	0.06	0.06	0.06	0.06	0.06
Nitrate-N (mg/L)	18	0.96	0.05	4.7	0.06	2.54
Total Ammonia (mg/L)	18	0.10	0.1	0.4	0.1	0.3
Unionized Ammonia (mg/L)	18	0.005	0.005	0.005	0.005	0.005
Total Phosphorus (mg/L)	18	0.02	0.01	0.08	0.01	0.06

Bacteria
Ranges of *Escherichia coli* frequently exceed the PWQO as sampled through the Baseflow Water Quality Monitoring Program. Sample concentrations give an idea of bacteria concentrations in Graham Creek, however samples were only taken once per site and are not based on five samples per site. Therefore, results must be generally interpreted. *Escherichia coli* exceed the PWQO at 8 sites, or 42% of the time. Total coliform concentrations ranged between 168 and 3000 counts/100 ml.

Effects of Land Use on Baseflow Water Quality Monitoring Water Quality
Catchment areas were delineated for each sample point using Arc Hydro to determine land uses within the drainage areas above the sample sites. Of the 19 sample sites, eight sites were dominated by natural areas (forests, meadows, thickets, wetlands and open water), one site was dominated by development (roads, rail, urban areas, rural development or aggregates), and 10 sites were dominated by agricultural land use (intensive and non intensive agriculture). Catchments that were dominated by agriculture had concentrations of *Escherichia coli* (six sites) and total phosphorus (five sites) above the PWQO. One natural area-dominated catchment had concentrations of *Escherichia coli*, total phosphorus, and nitrate-N above the PWQO or CEQG. The one catchment dominated by development never exceeded *Escherichia coli*, total phosphorus, and nitrate-N concentration guidelines.

Although this coarse analysis of land use relationships to water quality provides an indication that land uses associated with human disturbances (e.g., agriculture) can cause increases in bacteria and nutrients, the same is seen with land uses associated with natural areas. It must be noted that at two sites where catchments were dominated by agricultural land use, no exceedances in water quality parameters such as bacteria and nutrients occurred. It appears there is a possible relationship between water quality and local land use activities, however further investigation into causes of higher concentrations of bacteria and nutrients needs to occur.

3.7.3 Provincial Water Quality Monitoring Network (PWQMN) Results

Physical Parameters

Table 3.35 describes the physical parameters as sampled at the Mill Street Provincial Water Quality Monitoring Network (PWQMN) site in Graham Creek. All physical parameters are within acceptable ranges (ranging between the 10th and 90th percentiles) and the extreme ranges as indicated by the minimum and maximum values are attributed to sampling anomalies, extreme flow or temperature conditions.

Table 3.35: Physical parameters as sampled at the PWQMN station

Parameter	n	Median	Minimum	Maximum	10th Percentile	90th Percentile
Turbidity (FTU)	279	4	0.89	200	1.93	15.3
Particulate Residue (mg/L)	374	6.31	0	2616	2.6	39.5
pH (infield and laboratory)	443	8.35	6.38	8.90	7.78	8.52
Dissolved Oxygen (mg/L)	378	10.8	1.2	18.77	8.0	13.7
Alkalinity (mg/L) as CaCO3	232	198	123	340	166	228
Conductivity (µs/cm)	47	494	349	597	439	533

Other Parameters

As previously mentioned, 52 water quality parameters have been sampled since 1965 through the PWQMN, however some parameters have been removed from this analysis of surface water quality. By relating water quality parameters to the *Provincial Water Quality Objectives* or the *Canadian Water Quality Guidelines* these parameters can be listed as those that have exceeded the guidelines, those that have not, and those where no objective or guidelines exist (Table 3.36). For the purpose of this document, surface water quality parameters that exceed a PWQO or CWQG as well as chloride will be analyzed.

Table 3.36: PWQMN sampled parameters between 2002 and 2007 in relation to PWQO and CWQG

Sampled Concentrations Greater Than PWQO	Sampled Concentrations Less Than PWQO	Sampled Concentrations Greater Than CWQG	Sampled Concentrations Less Than CWQG	No PWQO or CWQG
Aluminum	Beryllium	**Total Chromium**	**Chloride**	Total Ammonium
Cadmium	Copper		**Nitrite-N**	Barium
Iron	Molybdenum		**Nitrate-N**	Calcium
Lead	Nickle			Carbon
Total Phosphorus	Vandium			Hardness
	Zinc			Magnesium
	Cobalt			Manganese
				Phosphate
				Potassium
				Sodium
				Strontium
				Titanium
				Total Kjeldahl N

Bold signifies parameters to be further analyzed

Metal Concentrations

Five metal parameters in Graham Creek at Mill Street exceeded PWQO or CWQG between 2002 and 2007. Table 3.37 describes the range of metal concentrations and the percentage of samples that exceeded the PWQO or CWQG. Median concentrations of metals did not exceed PWQO or CWQG at the station.

Metal Trends

Of the metals that exceeded PWQO or CWQG, trends in time between 2002 and 2007 were analyzed. There is no linear relationship between time and aluminum, cadmium, total chromium, lead or iron concentrations at the Mill Street station.

Table 3.37: Metal concentrations from 2002 to 2007

Parameter	n	Median	Min*	Max	10^{th} Percentile*	90^{th} Percentile	% of Samples Exceeding Objective
Aluminum µg/L (PWQO = 75 µg/L)	38	49.1	22.0	1070	27.4	208	24
Cadmium µg/L (PWQO = 0.2µg/L)	39	0.02	-1.27	0.93	-0.41	0.42	31
Total Chromium µg/L (adapted CWQG = 2 µg/L (Pawlisz et al. 1997))	39	0.22	-1.50	12.3	-0.24	1.71	8
Iron µg/L (PWQO = 300 µg /L)	39	99.1	70.5	1380	80.4	264	8
Lead µg/L (PWQO = 5 µg/L)	39	-0.17	-23.8	5.37	-6.64	4.12	3

*Concentrations less than 0 means that the concentrations are below analytical detection limits

Chloride Concentration and Trend

Chloride concentrations sampled through the PWQMN ranged from 0.8 to 162 mg/L at Mill Street. However irregularities may exist in the data (e.g., weather conditions) given that the 10^{th} and 90^{th} percentiles range from 8.5 to 2.5 mg/L.

Chloride concentrations at the Mill Street station has increased considerably since 1965 (n= 380, r^2= 0.50, p= 0.00) (Figure 3.42). However concentrations have never exceeded the Canadian Environmental Quality Guideline of 250 mg/L. The r^2 value calculated for the station indicates that time (in years) explains 50% of the variation at the Mill Street station. Other factors (e.g., stream flow, precipitation, loading, water temperature) may also contribute to the concentration of chloride at this station.

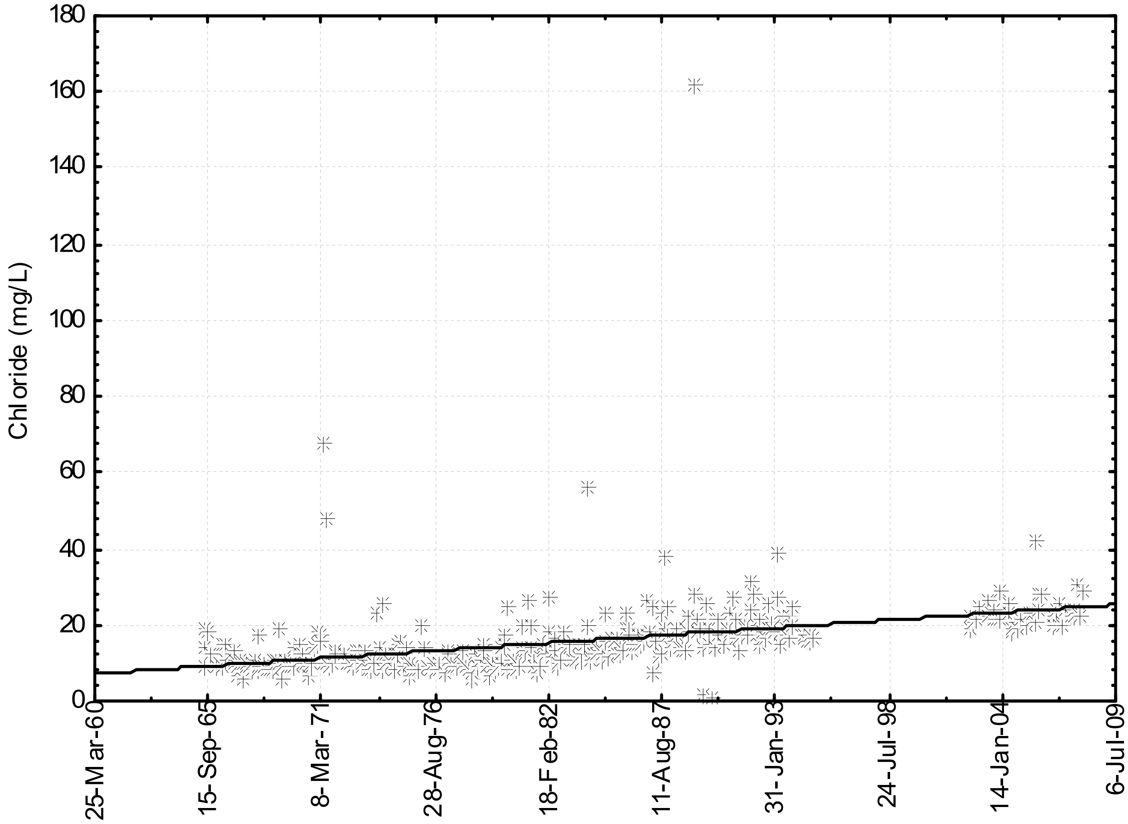


Figure 3.42: Chloride trends at the PWQMN station, 1965 to 2007

Nutrient Concentrations

Since 2002, sampled total phosphorus has exceeded PWQO 19% of the time at the Mill Street station (Table 3.38), however median concentrations are below the PWQO. Since 2002, unfiltered nitrate-N and nitrite-N has not exceeded the CWQG at the Mill Street station.

Table 3.38: Nutrient concentrations at PWQMN stations from 2002 to 2007

Parameter	n	Median	Min	Max	10th Percentile	90th Percentile	% of samples exceeding
Total Phosphorus mg/L (PWQO = 0.03 mg/L)	47	0.015	0.004	0.456	0.01	0.057	19
Nitrate-N Unfiltered mg/L (CWQG = 2.9 mg/L)	47	0.911	0.431	2.31	0.581	1.54	0
Nitrite-N Unfiltered mg/L (CWQG = 0.197 mg/L)	47	0.006	0.002	0.021	0.004	0.013	0

Nutrient Trends

- Although total phosphorus concentrations have exceeded the PWQO at the Mill Street station, there has been a decline in total phosphorus concentrations at Mill Street since 1965 (Table 3.39).
- Nitrate-N has been increasing since 1981 at the Squire Road and Regional Road 2 station (Table 3.39).
- There is no linear trend in nitrite-N concentrations at the Mill Street station between 1966 and 2007.

Table 3.39: Nutrient trends at PWQMN stations

Parameters	r^2	r	P	n	years
Total Phosphorus	0.059	-0.243	0.000*	381	1965-2007
Nitrate-N unfiltered	0.154	0.394	0.000*	200	1981-2007
Nitrite-N	0.004	0.062	0.235	368	1966-2007

* indicates a significance of $p < 0.05$

3.7.4 Discussion of Graham Creek Surface Water Quality

Physical Parameters

The background conditions of surface water quality in Graham Creek are within acceptable ranges as described by *Provincial Water Quality Objectives*. The pH values at sample sites is within acceptable ranges indicating that there are no acidity or neutralizing problems in Graham Creek. Alkalinity concentrations indicate that Graham Creek has the ability to buffer acidic changes that might occur. Alkalinity ranges from 24 to 500 mg/L as $CaCO_3$ throughout Canada (Canadian Council of Resource and Environment Ministers 1987), a range in which Graham Creek water quality falls.

Quantifying dissolved and suspended solids in Graham Creek can be done using conductivity, salinity, total dissolved solids, total suspended solids, turbidity and particulate residue. In all cases, these parameters at sample sites were within acceptable ranges, and higher concentrations of particulates and suspended solids can be attributed to higher flows.

Dissolved oxygen concentrations at sample sites are also within acceptable ranges as related to *Provincial Water Quality Objectives*. Indicating that in-stream nutrient cycling is not causing declines in oxygen levels. Dissolved oxygen as sampled through the GRWQMN has been shown to decline as stream temperatures increase however, rarely does it decline below acceptable concentrations.

The physical parameters of Graham Creek indicate that surface water quality can be resilient to anthropogenic actions related to acidification, eutrophication and chemical additions. Certain metal parameters have reduced toxicity effects in higher pH, in harder water, or in water that has a high buffering capacity such as

Graham Creek. Therefore, Graham Creek surface water has the appropriate physical background to mitigate some negative effects caused by human actions.

Chloride

Chloride is the principal component of road salts, and is the main contributing anion to salinity in surface water (Mayer et al. 1999). Road salts such as sodium chloride can affect the environment in different ways. Salts can affect the taste of drinking water, damage salt-sensitive vegetation, increase hardness and pH in soils, and increase wildlife death from vehicle collisions since they are attracted to the salts near the roads (Transportation Association of Canada 1999). Once in water, chloride can be toxic (acute and chronic) to aquatic organisms depending on the concentration the organism is subjected to and the stage of an organism's life.

Chloride concentrations in Graham Creek have increased since 1965 as seen through the Provincial Water Quality Monitoring Network (PWQMN). Chloride concentrations may also be higher in the winter in Graham Creek since salts tend to remain in water and do not have any removal mechanisms such as volatilization, degradation, sorption or oxidation (Mayer et al. 1999). As a result, only evaporation of water and addition or dilution of chloride will change the chloride concentrations in surface waters (Mayer et al. 1999). Wintertime stream conditions have increased flow over summertime baseflow conditions. This increase in flow can cause chloride to be diluted, yet winter chloride concentrations are higher than summer chloride concentrations, leading to the belief that chloride loadings outweigh the effects of dilution in the stream. The only way chloride can leave a river in winter is as water leaving the system.

One option to lower concentrations of chloride in surface water is the proper management and application of chloride, and the consideration of reduced salt use in sensitive and vulnerable areas. Lake Ontario has been noted as having higher chloride levels than the other Great Lakes, but as early as 1993, Lake Ontario experienced a decline in chloride (Mayer et al. 1999). This decline in chloride can be attributed to lower loadings from industrial and domestic sources due to improved treatment of industrial and domestic effluents (Mayer et al. 1999). Therefore with proper chloride and road salt management plans, declines of chloride in Graham Creek may be achieved.

Metals

Five metal parameters at the Mill Street PWQMN station have exceeded PWQO or CWQG between 2002 and 2007, however median concentrations of the five metals are below the respective PWQO or CWQG. Metals sampled in Graham Creek are not an immediate concern but should be continually monitored to ensure concentrations do not become elevated and to understand concentrations of cadmium in Graham Creek. Investigations and research into the contribution of metals and other constituents to Graham Creek from the Laidlaw Waste Systems landfill should take place. According to Marshall Macklin Monaghan Limited

(1989), leachate was determined to be present in the water from 3 shallow piezometers and 2 deeper piezometers. The discovery of leachate means that contaminated groundwater from the site could be influencing Graham Creek surface water via groundwater recharge into the creek. However, concentration of metals within the leachate is unknown. Proper urban landscape management (i.e., storm water management and industrial discharge) should occur to reduce the potential risk of metals in Graham Creek.

Aluminum concentrations have exceeded the PWQO 24% of the time at the Mill Street station however aluminum concentrations are somewhat misleading. The PWQO for aluminum is based on clay-free water quality samples. Samples collected as part of the PWQMN are not filtered and therefore are not considered clay free (A. Todd, MOE, Personal Communications). Elevated levels of aluminum in unfiltered samples are associated with sediments and therefore have low toxicity since they are biologically unavailable.

In addition, analysis of metal concentrations in laboratories is not always accurate given changes in analysis over time and low concentrations in samples. Although the five metals have exceeded provincial or federal guidelines these exceedances could be attributed to laboratory error, road or urban runoff during peak flows, or sampling anomalies.

Nutrients

Total phosphorus exceeds the PWQO more often than any other nutrient, but never more than 20% of the time. Since 1965 total phosphorus has declined at the Mill Street station. Unionized ammonia has been greater than the PWQO of 0.02 mg/L 30% of the time as sampled through the GRWQMN.

Nitrate-N and nitrite-N have never exceeded the CWQG through the GRWQMN or PWQMN. At the Mill Street PWQMN station nitrate-N has been increasing since 1981. Nutrients therefore can be considered the water quality parameter most capable of fluctuating beyond recommended guidelines; however exceedances may be related to high runoff due to storm events, or land use.

Phosphorus entering surface water is also a reflection of land management practices. The concentration of phosphorus in runoff is related to the amount of phosphorus in the surface layer of soil (0 to 5 cm), which reacts with rainfall runoff (Sharpley et al. 1996). Phosphorus runoff is also dependent on soil types, the amount of vegetative cover (Section 4.0.5), and whether or not manure or fertilizer was incorporated or how soon before a rainfall event that manure or fertilizer was applied (Sharpley et al. 1996).

Aquatic systems can benefit from phosphorus, which makes a system productive. Addition of phosphorus can also cause changes in a system by increasing plant and algal growth, which in turn alters the number, types and size of plants and animals, increases turbidity, and creates more organic matter, which results in losses of oxygen. Phosphorus can be directly toxic to aquatic organisms, but this is very rare (Environment Canada 2005; Carpenter et al. 1998). Indirect effects are a greater concern and occur when increases in the amount of decaying organic material cause declines in oxygen due to an increase in oxygen use by decomposers.

Nitrogen is converted to many forms in the environment. Ammonia changes to nitrite, which changes to nitrate (Csuros 1994). Nitrate is the most stable form of nitrogen in an aquatic system and therefore is a good indicator of nitrogen and its forms in surface water. Nitrate affects aquatic organisms both indirectly and directly. Similar to phosphorus, nitrates in excess can increase growth of plants and algae, which may result in indirect toxic effects such as reduced oxygen levels. Aquatic invertebrates and fish exposed to high levels of nitrate may be smaller, slower to mature, or have lower reproductive success. Under very extreme concentrations, aquatic invertebrates and fish may die (Environment Canada 2005b).

Proper management of nutrients will help to reduce high concentrations entering Graham Creek during high flows or storm events, and through direct methods such as storm drains and field tile drains. Carpenter et al. (1998) reported that more than 90% of phosphorus entering a water body comes from less than 10% of the land area during a few large storms. Methods to reduce the amount of nutrients entering Graham Creek are to increase riparian vegetation to reduce surface runoff (Section 4.0.5), and to mitigate stormwater directly entering surface water through drains in both urban and rural areas.

Bacteria

Escherichia coli exceed the recreational PWQO 37% of the time throughout the entire Graham Creek watershed and total coliforms ranged between 112 and 7,600 cfu/100 ml. The presence of *Escherichia coli* in surface water indicates that fecal material of humans or other warm-blooded animals is present in the water. Common sources of *Escherichia coli* include municipal wastewater spills, septic leachate, agricultural or storm runoff, wildlife populations, or non-point sources of human or animal waste (An et al. 2002). Total coliform includes all coliform species (*Escherichia coli* and its variants). Sources of total coliform are the same sources as *Escherichia coli*, however they are not necessarily from fecal matter, but also from plant and organic material.

Fecal coliforms are bacteria, which are single-celled living organisms. These bacteria can decay under certain environmental conditions. The rate of die-off increases with different factors such as increasing temperature, elevated pH, high dissolved oxygen levels, solar radiation, and predaceous microorganisms such as protozoa (An et al. 2002). Fecal coliforms such as *Escherichia coli* are known to cause negative health effects in humans, and therefore an associated Drinking Water Quality Objective of 0 cfu/100 ml is in place in the Province of

Ontario (Ontario Ministry of the Environment 2003) and a recreational guide line of 100 cfu/100 ml.

Direct effects of coliforms and *Escherichia coli* on aquatic species are poorly understood and researched. The United States Environmental Protection Agency sets fecal coliform concentration criteria for shellfish harvesting. Although shellfish are not affected by fecal coliform, humans consuming shellfish exposed to fecal coliform can become ill (United States Environmental Protection Agency 1976). Although the direct effect of fecal coliform on aquatic organisms is uncertain, the proper management of sources of fecal coliforms needs to be addressed in the Graham Creek watershed. In addition, surface water that serves as sources of drinking water for human or livestock consumption needs to be protected from coliform contamination.

Chapter 4 - Biotic Features

4.0 AQUATIC RESOURCES

Aquatic resources in Graham Creek include instream habitat and the aquatic organisms that rely on aquatic habitats, and riparian areas. The forms and functions of these resources are influenced by the quality and quantity of water systems and the contributing watershed areas.

4.0.1 Fisheries

This section has been summarized from (Ganaraska Region Conservation Authority 2009). Please refer to the referenced document for additional information.

Fishes are one of Ontario's most valued natural resources from an ecological, biological, economic, social and cultural perspective. Protecting and restoring the aquatic ecosystem results in a healthy fishery and environment. The Graham Creek watershed has a limited fishery given its proximity to the larger fishery of Wilmot Creek and the Ganaraska River; however it does host a salmonid spawning run from Lake Ontario. Angling is limited on Graham Creek given the lack of public lands for easy access. A Fisheries Management Plan for Graham Creek is being created in partnership with the Ganaraska Region Conservation Authority and the Ontario Ministry of Natural Resources.

Fisheries Analysis

An Index of Biotic Integrity (IBI) is a tool that measures fish community associations and is used to identify the general health of the broader stream ecosystem (Steedman 1986). IBI is determined through 10 measures of fish community composition, grouped into four general categories: species richness, local indicator species, trophic composition and fish abundance. Scoring is based on a scale from ten (poor) to 50 (very good). Further detail on IBI is found in Ganaraska Region Conservation Authority (2009).

Fisheries data sets consist of sites from multiple projects in Graham Creek from 1984 to 2003. Project methods varied within this time period and therefore only 2002 and 2003 data was utilized for IBI calculations. The 1984 to 2003 data set was used to determine fish density and biomass. All other data in conjunction with the above data was utilized to gain an understanding of species distributions, or presence/absence in the Graham Creek watershed (e.g., Sea Lamprey control Graham Creek weir information).

Density (fish/m^2) and biomass (grams/m^2) were calculated for all species sampled using electrofishing. Site area was calculated by multiplying the site length (m) by the average site width (m). Species density and biomass were ranked by percentiles (0-25; 26-50; 51-75; >75) at each site to determine relative distribution within the watershed.

Graham Creek Fisheries

43 species of fish have been sampled in the Graham Creek watershed (Table 4.0), of which five (12%) of the species are not native. Stream quality based on Steedman's IBI calculated one site being excellent (6%), 11 sites good (69%), four sites fair (25%), and zero (0%) poor sites (Figure 4.0).

Table 4.0: Fish species sampled

Species	Scientific Name
Alewife	*Alosa pseudoharengus*
Banded Killifish	*Fundulus diaphanus*
Black Bullhead	*Ameiurus melas*
Bluntnose Minnow	*Pimephales notatus*
Brassy Minnow	*Hybognathus hankinsoni*
Brook Stickleback	*Culaea inconstans*
Brook Trout	*Salvelinus fontinalis*
Brown Bullhead	*Ameiurus nebulosus*
Brown Trout*	*Salmo trutta*
Burbot**	*Lota lota*
Chinook Salmon*	*Oncorhynchus tshawytscha*
Common Carp*	*Cyprinus carpio*
Common Shiner	*Luxilus cornutus*
Creek Chub	*Semotilus atromaculatus*
Eastern Blacknose Dace	*Rhinichthys atratulus*
Emerald Shiner	*Notropis atherinoides*
Fathead Minnow	*Pimephales promelas*
Gizzard Shad	*Dorosoma cepedianum*
Golden Shiner	*Notemigonus crysoleucas*
Hornyhead Chub**	*Nocomis biguttatus*
Iowa Darter	*Etheostoma exile*
Johnny Darter	*Etheostoma nigrum*
Largemouth Bass	*Micropterus salmoides*
Logperch	*Percina caprodes*
Longnose Dace	*Rhinichthys cataractae*
Longnose Sucker	*Catostomus catostomus*
Mottled Sculpin	*Cottus bairdii*
Northern Redbelly Dace	*Phoenix eos*
Pumpkinseed	*Lepomis gibbosus*
Rainbow Darter	*Etheostoma caeruleum*
Rainbow Smelt	*Osmerus mordax*
Rainbow Trout*	*Oncorhynchus mykiss*
Rock Bass	*Ambloplites rupestris*
Round Goby*	*Neogobius melanostomus*
Sea Lamprey	*Petromyzon marinus*
Smallmouth Bass	*Micropterus dolomieu*
Spottail Shiner	*Notropis hudsonius*
Stonecat	*Noturus flavus*
Threespine Stickleback	*Gasterosteus aculeatus*
Trout-perch	*Percopsis omiscomaycus*
Walleye	*Sander vitreum*
White Sucker	*Catostomus commersonii*
Yellow Perch	*Perca flavescens*

* non-native fish ** fish only sampled in 1989

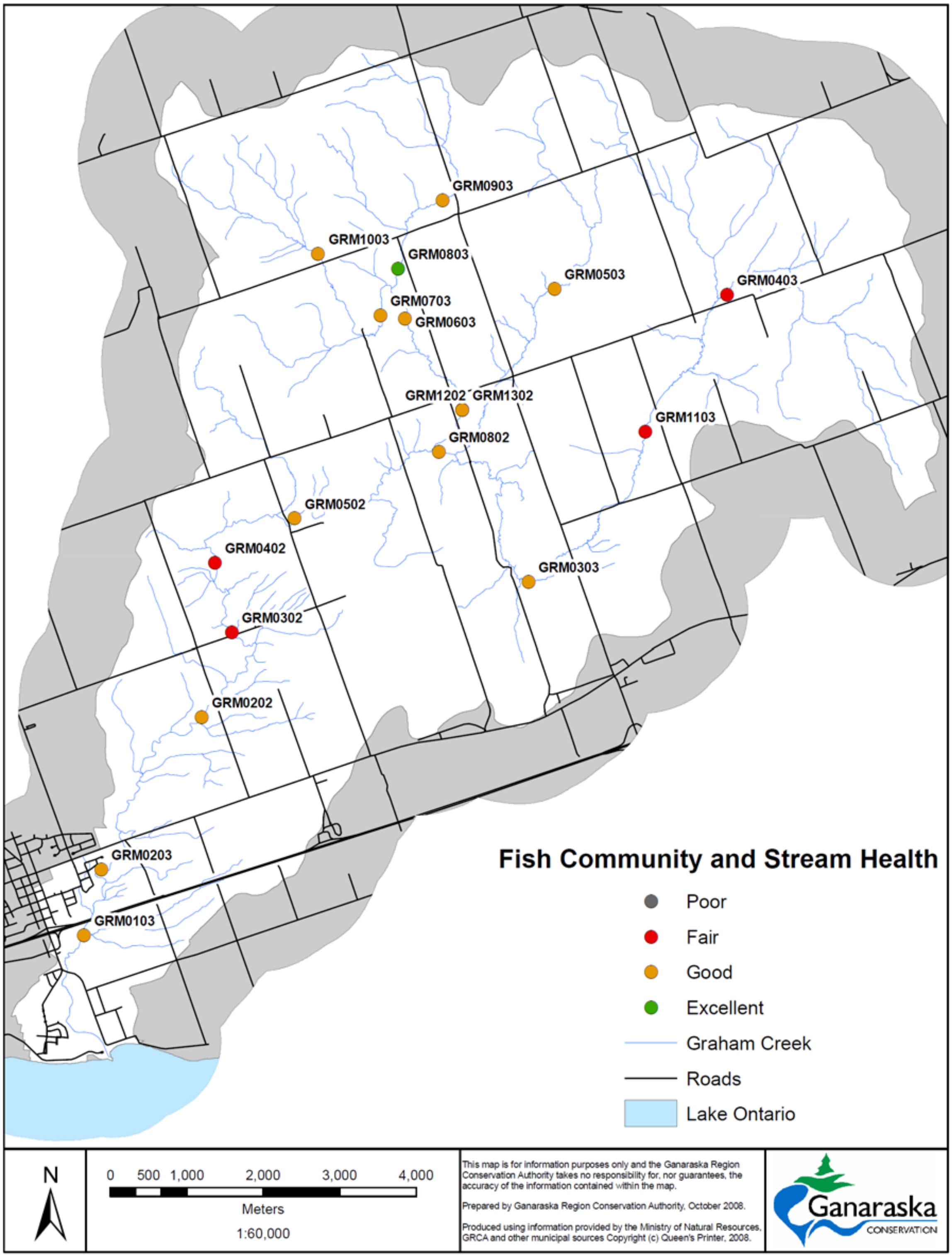


Figure 4.0: Stream quality based on Steedman's Index of Biotic Integrity

Rainbow Trout (Oncorhynchus mykiss)
Rainbow Trout are native to the Pacific Ocean, the west coast of North America, and East Asia. Rainbow Trout were first introduced into Lake Ontario in the late 1800s and now populate the Great Lakes. The adfluvial Lake Ontario populations spawn in late winter and spring, moving into streams from mid-September to June.

Rainbow Trout were sampled at 16 electrofishing stations (57% of sites). Density ranged from 0.001 to 0.15 fish/m^2 (Figure 4.1) and biomass ranged from 0.04 to 2.96 g/m^2. The number of Rainbow Trout captured at the DFO Sea Lamprey Weir range from 0 to 102 individuals between 1898 and 2007, with a mean of 57 individuals captured per year.

Brook Trout (Salvelinus fontinalis)
Brook Trout are a valued native sport fish and they have been stocked intensively because of their visual appeal and economical value. Requiring cold water, Brook Trout are sensitive to habitat alteration and their presence is indicative of a coldwater stream.

Brook Trout were only sampled at two electrofishing stations (7% of sites) in Graham Creek and historically found at two additional sites (Figure 4.2). Density ranged from 0.05 to 0.16 fish/m^2 and biomass ranged from 2.12 to 2.76 g/m^2. Brook Trout have also been captured at the DFO Sea Lamprey Weir. The number of Brook Trout captured is variable across years, ranging from 0 to 17 individuals between 1898 and 2007.

Smallmouth Bass (Micropterus dolomieu)
Smallmouth Bass were sampled at two electrofishing stations (7% of sites) and historically at four additional sites (Figure 4.2). Density ranged from 0.002 to 0.004 fish/m^2 and biomass ranged from 0.006 to 0.04 g/m^2. Smallmouth have not been captured upstream of the DFO Lamprey Weir since 1998. The number of smallmouth bass captured at the DFO Sea Lamprey Weir range from 0 to 7 individuals between 1898 and 2007. Large numbers of adults have been observed spawning below the DFO Sea Lamprey Weir during the spring.

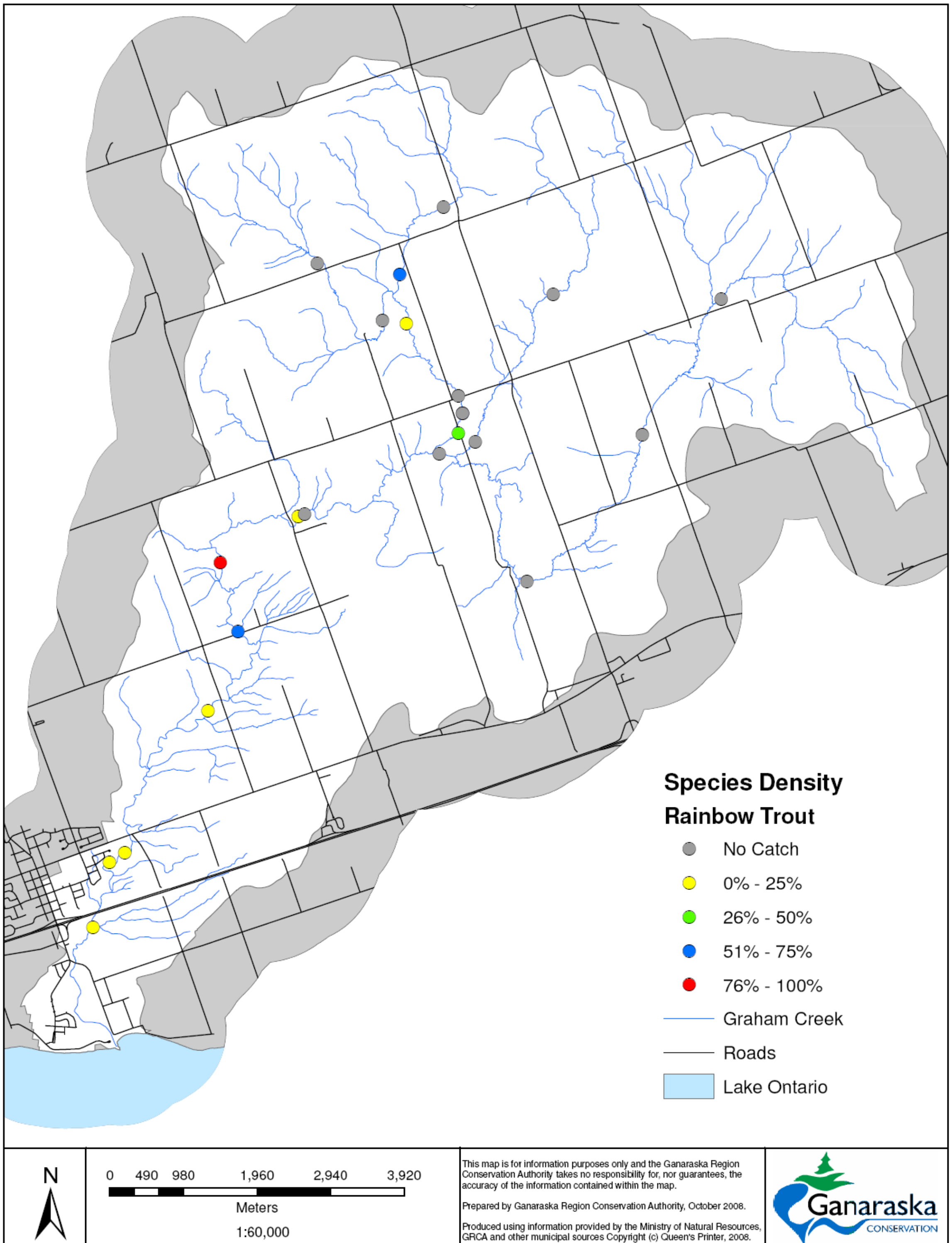


Figure 4.1: Juvenile Rainbow Trout summer density (fish/m^2)

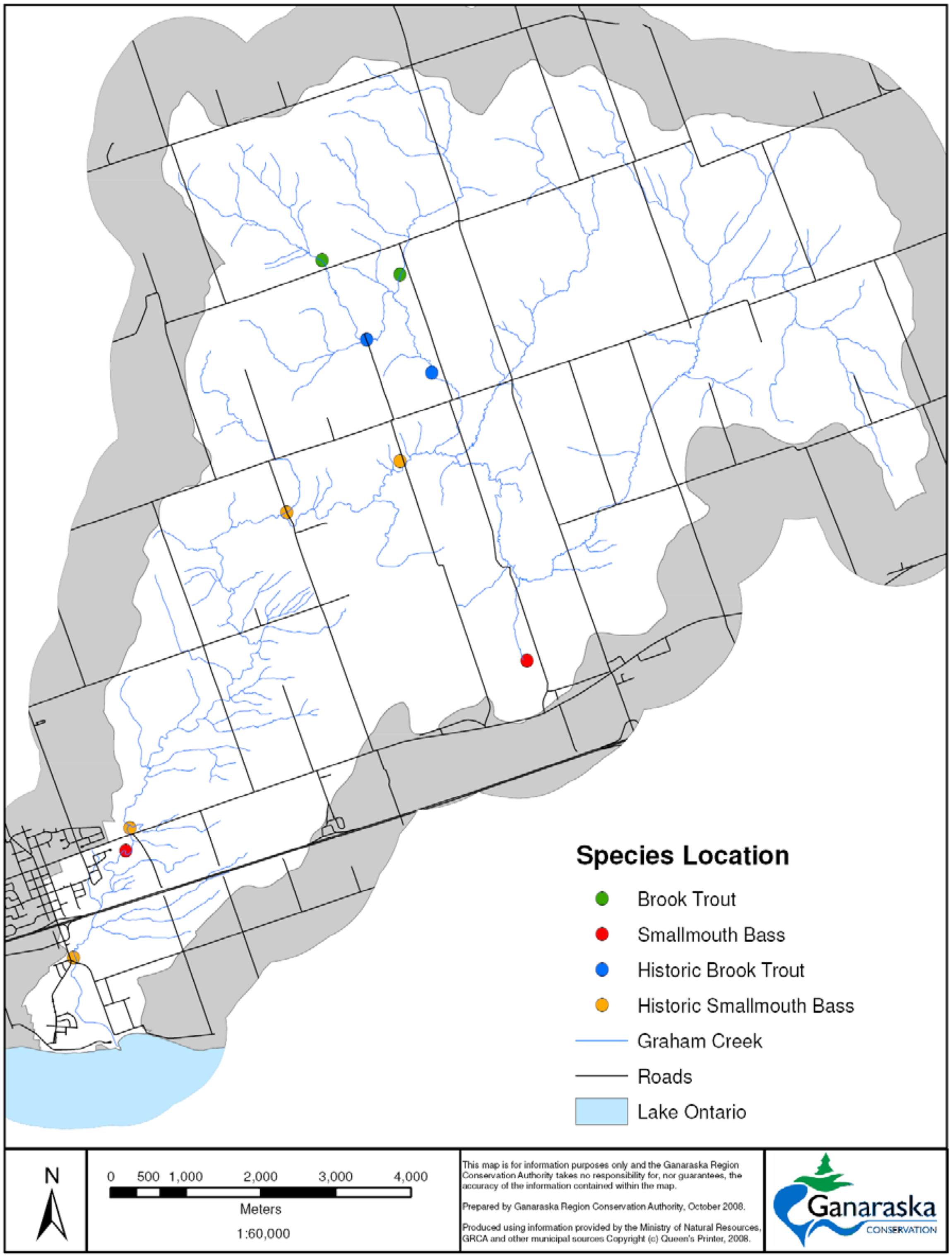


Figure 4.2: Current and historical Brook Trout and Smallmouth Bass distribution

Eastern Blacknose Dace (Rhinichthys atratulus)
Eastern Blacknose Dace is native and inhabits cool and clear streams, but is also abundant in degraded tributaries (Scott and Crossman 1998). This colourful dace is used as a baitfish in the eastern Great Lakes. Eastern Blacknose Dace spawn during the spring in fast, shallow riffles consisting of gravel substrate when water temperatures are approximately 21^{o}C. Males establish and defend territories, but do not build nests (Scott and Crossman 1998).

Eastern Blacknose Dace were sampled at 25 electrofishing stations (89% of sites). Density ranged from 0.005 to 0.81 fish/m^2 (Figure 4.3) and biomass ranged from 0.000 to 2.60 g/m^2. The number of eastern Blacknose Dace captured at the DFO Sea Lamprey Weir range from 0 to 5 individuals between 1898 and 2007.

Longnose Dace (Rhinichthys cataractae)
Longnose Dace is native to North America and occurs across Canada. Longnose Dace is a benthic species inhabiting clear, fast flowing streams and rivers, as well as inshore lake habitats (Scott and Crossman 1998). In Canada Longnose Dace is not commonly used as a baitfish, but is a valuable prey item for salmonids. Longnose Dace spawn in early spring on riffle bars over gravel substrate (Scott and Crossman 1998).

Longnose Dace were sampled at 17 electrofishing stations (61% of sites). Density ranged from 0.03 to 0.87 fish/m^2 (Figure 4.4) and biomass ranged from 0.07 to 3.03 g/m^2. The number of Longnose Dace captured at the DFO Sea Lamprey Weir range from 0 to 437 between 1898 and 2007, with a mean of 35 individuals captured.

Mottled Sculpin (Cottus bairdii)
Mottled Sculpin are native and inhabit cool-water streams in eastern Ontario. Sculpins spawn in the spring, nesting under a rock or ledge, where females deposit a mass of eggs on the cover ceiling (Scott and Crossman 1998). Mottled Sculpin were sampled at 20 electrofishing stations (71% of sites). Density ranged from 0.002 to 0.91 fish/m^2 (Figure 4.5) and biomass ranged from 0.01 to 2.34 g/m^2. The number of Mottled Sculpin captured at the DFO Sea Lamprey Weir ranges from 0 to 3 individuals between 1898 and 2007.

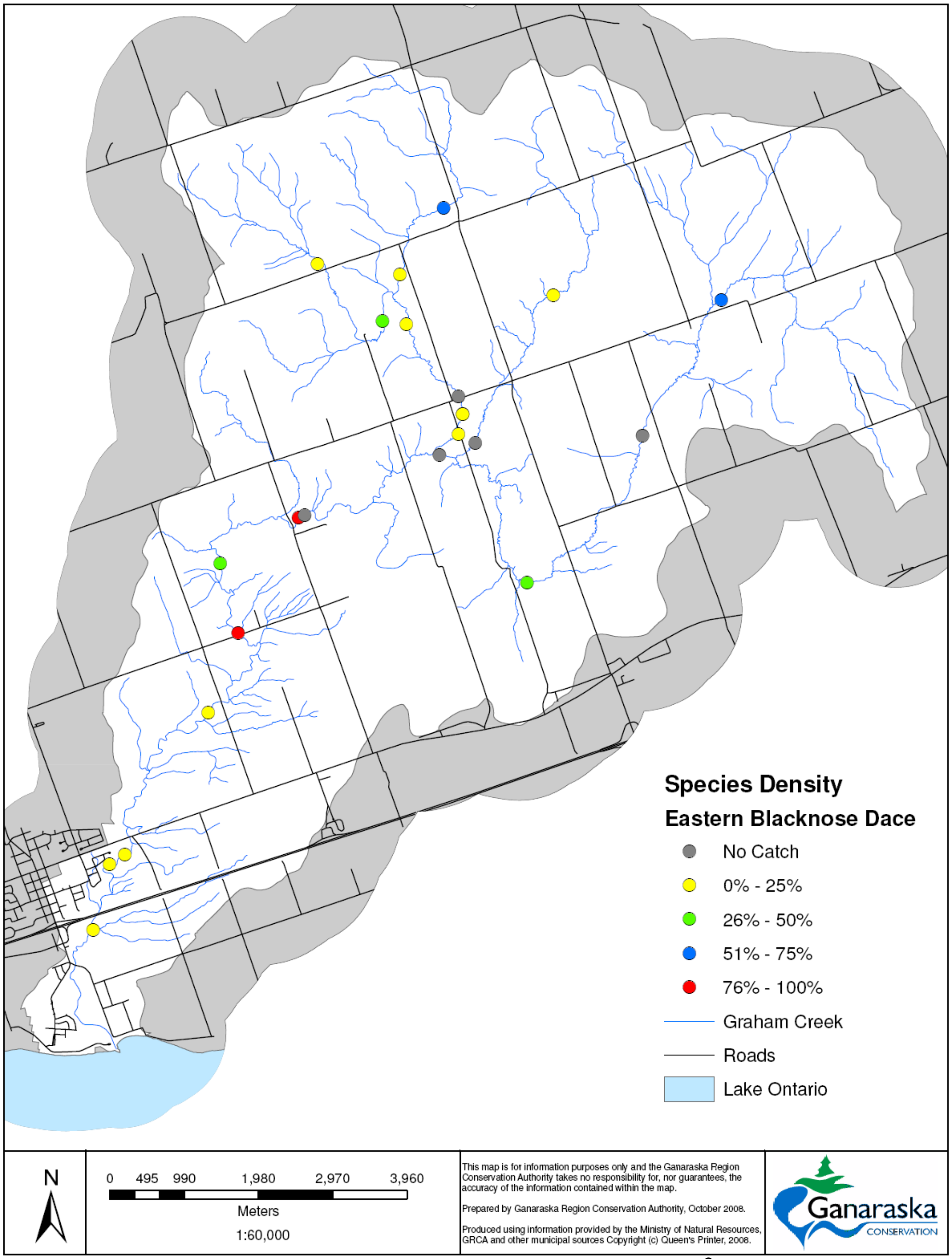


Figure 4.3: Eastern Blacknose Dace summer density (fish/m^2)

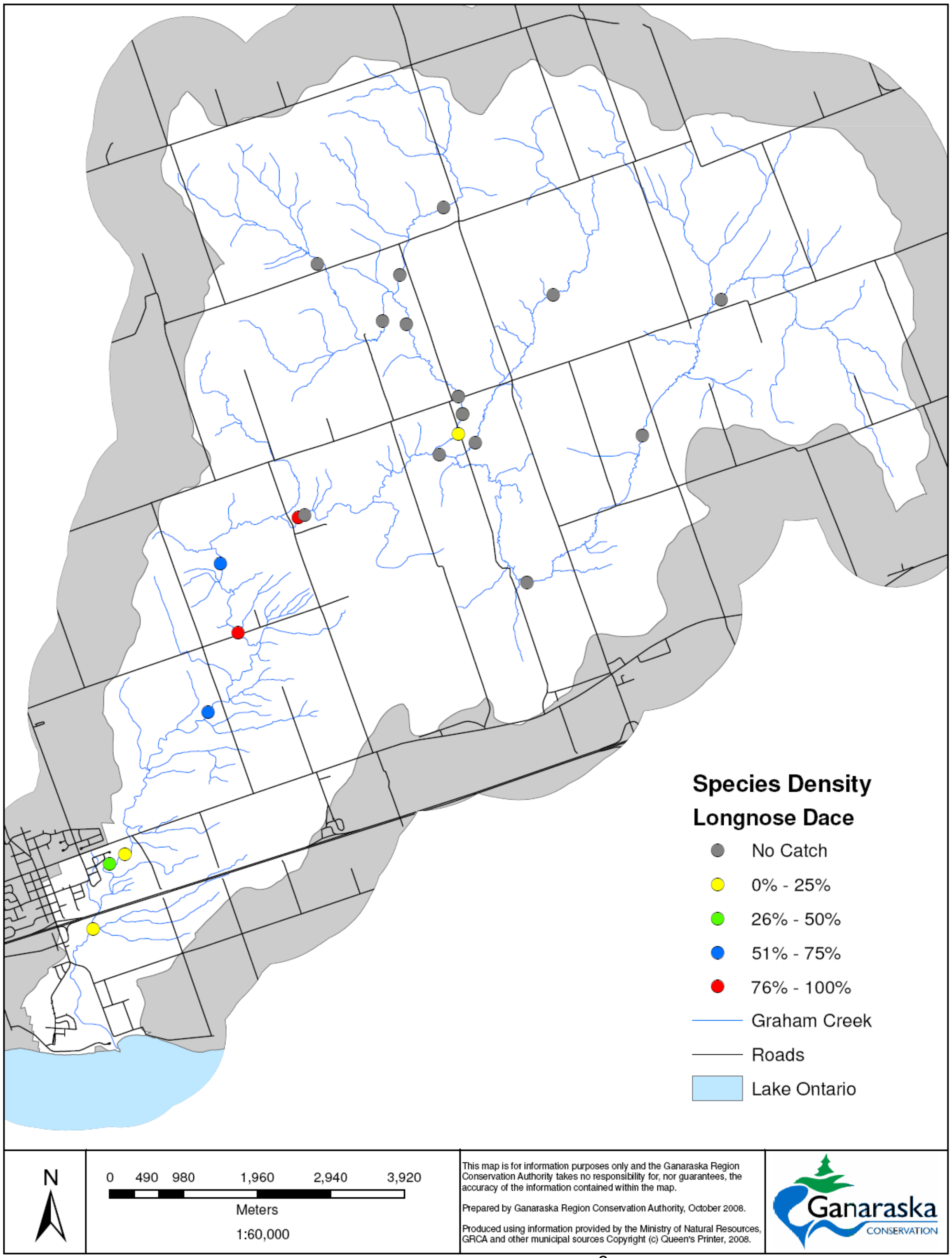


Figure 4.4: Longnose Dace summer density (fish/m^2)

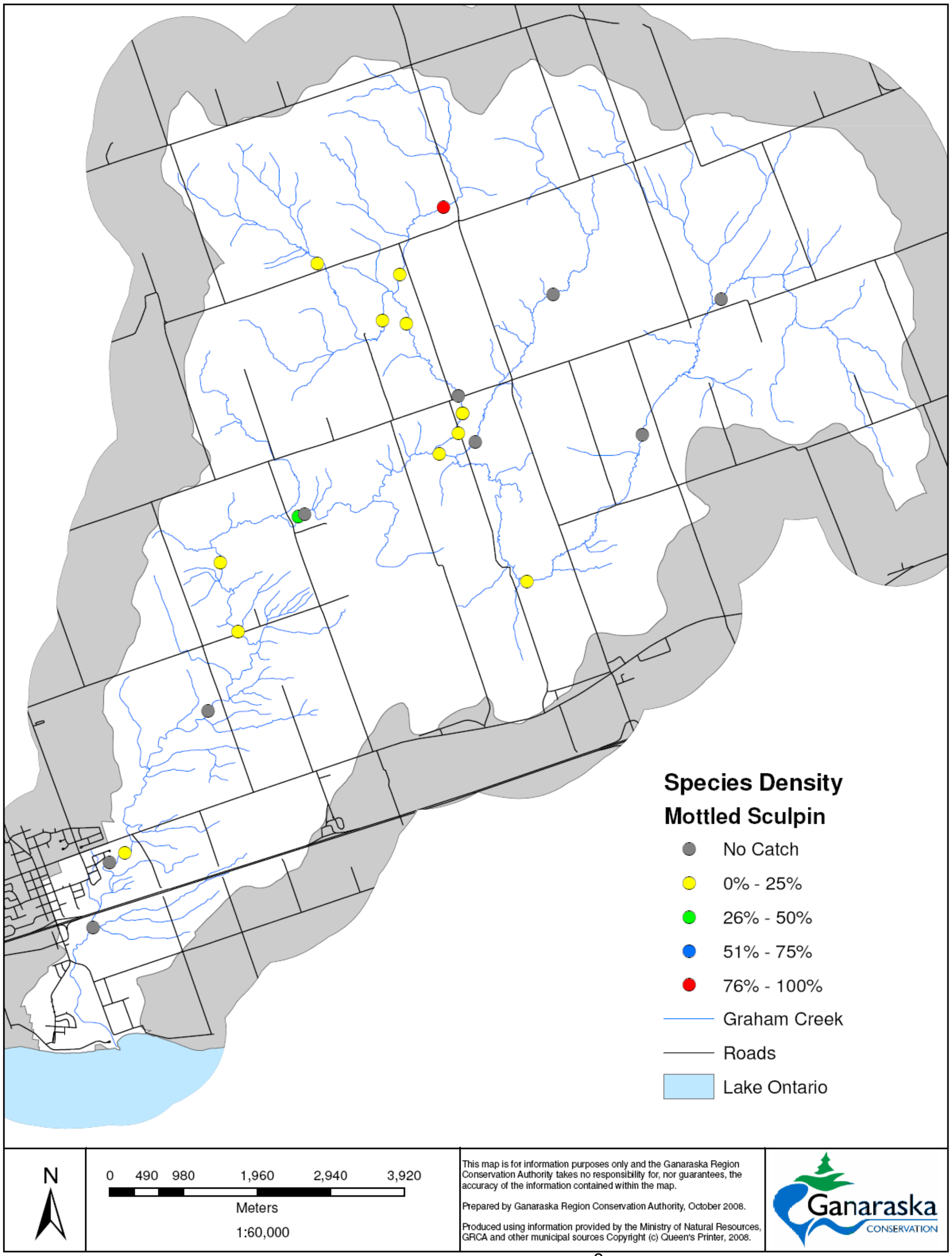


Figure 4.5: Mottled Sculpin summer density (fish/m^2)

White Sucker (Catostomus commersonii)
Native to North America, this widely distributed species spawn in early spring, utilizing streams, shoals and beaches. Spawning in streams occurs in low velocity reaches or fast moving riffle runs (Scott and Crossman 1998). White Sucker eggs adhere to stream substrate. Brook Trout are known to consume juvenile White Suckers. Adults return to their native stream in two to four years to spawn (Scott and Crossman 1998). White Suckers are tolerant of warmer water, however they are commonly found in coldwater systems

White Sucker was sampled at 23 electrofishing stations (82% of sites). Density ranged from 0.001 to 0.18 fish/m^2 (Figure 4.6) and biomass ranged from 0.01 to 4.09 g/m^2. The number of White Sucker captured at the DFO Sea Lamprey Weir ranges from 4 to 455 between 1898 and 2007, with a mean of 127 individuals captured per year.

Rainbow Darter (Etheostoma caeruleum)
Rainbow Darters are a native species, and in Canada are only found in streams entering Lakes Ontario, Erie, St. Clair and Huron. This colourful fish spawns in the spring in coarse gravel, fine grave or rubble riffles. Eggs are buried in the gravel in the spawning area and hatch 10 to 12 days after in water temperatures of 17 to 18.5 ^{o}C (Scott and Crossman 1998).

Rainbow Darter was sampled at 18 electrofishing stations (64% of sites). Density ranged from 0.002 to 0.20 fish/m^2 (Figure 4.7) and biomass ranged from 0.006 to 0.41 g/m^2. The number of Rainbow Darter captured at the DFO Sea Lamprey Weir ranges from 1 to 7 individuals between 1898 and 2007.

Johnny Darter (Etheostoma nigrum)
Darters are native and are only found in North America and in southern Canada spawn around April and May under rocks where the male provides parental care. Johnny Darter were sampled at 25 electrofishing stations (89% of sites). Density ranged from 0.013 to 1.87 fish/m^2 (Figure 4.8) and biomass ranged from 0.006 to 1.45 g/m^2. The number of Johnny Darter captured at the DFO Sea Lamprey Weir ranges from 0 to 38 individuals between 1898 and 2007.

Creek Chub (Semotilus atromaculatus)
Abundant in small streams and clear creeks and brooks, Creek Chub are found throughout North America. Nesting in rock and gravel, Creek Chub do not guard their nests. Creek Chub were sampled at 23 electrofishing stations (82% of sites). Density ranged from 0.02 to 5.23 fish/m^2 (Figure 4.9) and biomass ranged from 0.09 to 8.13 g/m^2. The number of Creek Chub captured at the DFO Sea Lamprey Weir ranges from 1 to 120 individuals between 1898 and 2007, with a mean of 49 individuals captured per year.

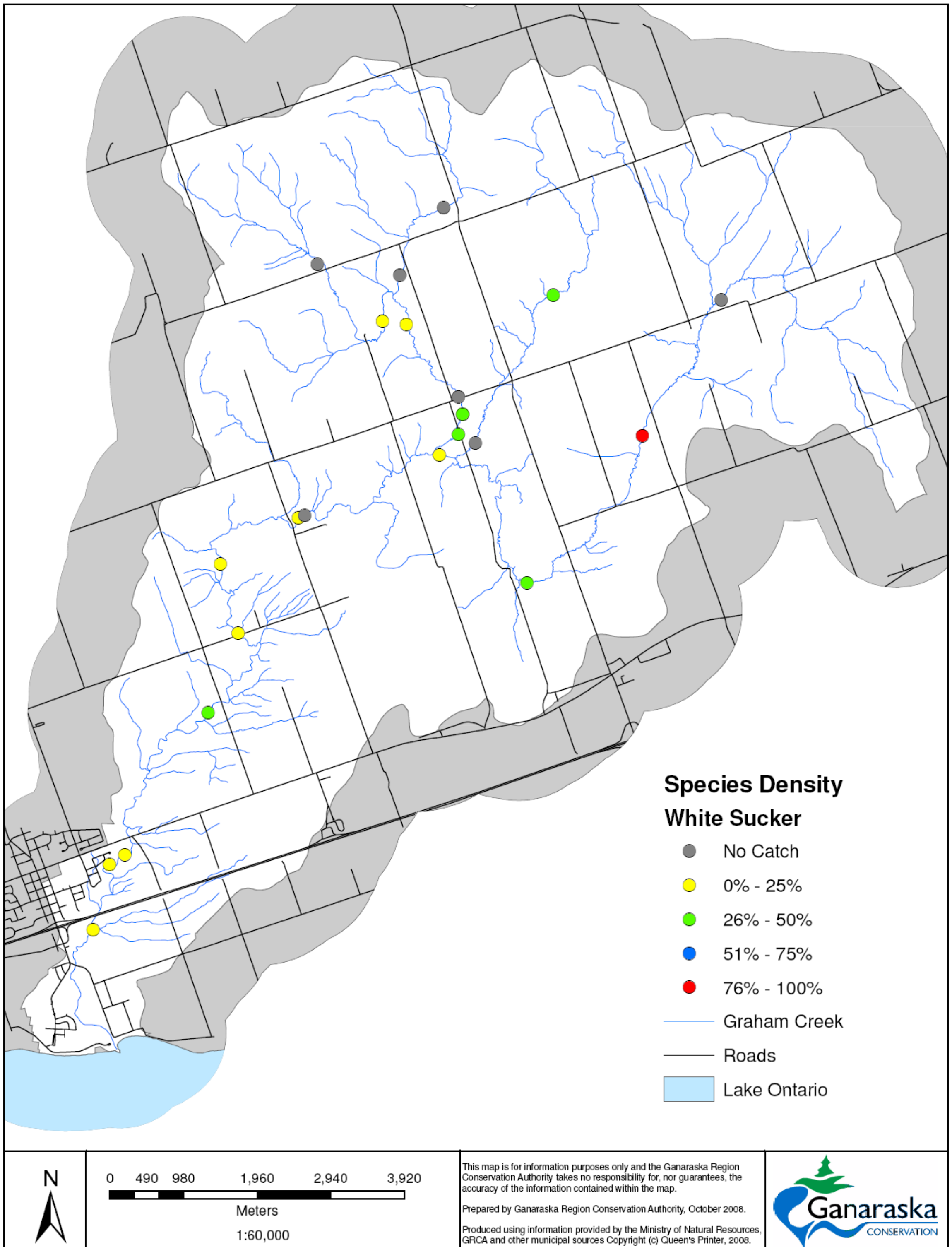


Figure 4.6: White Sucker summer density (fish/m^2)

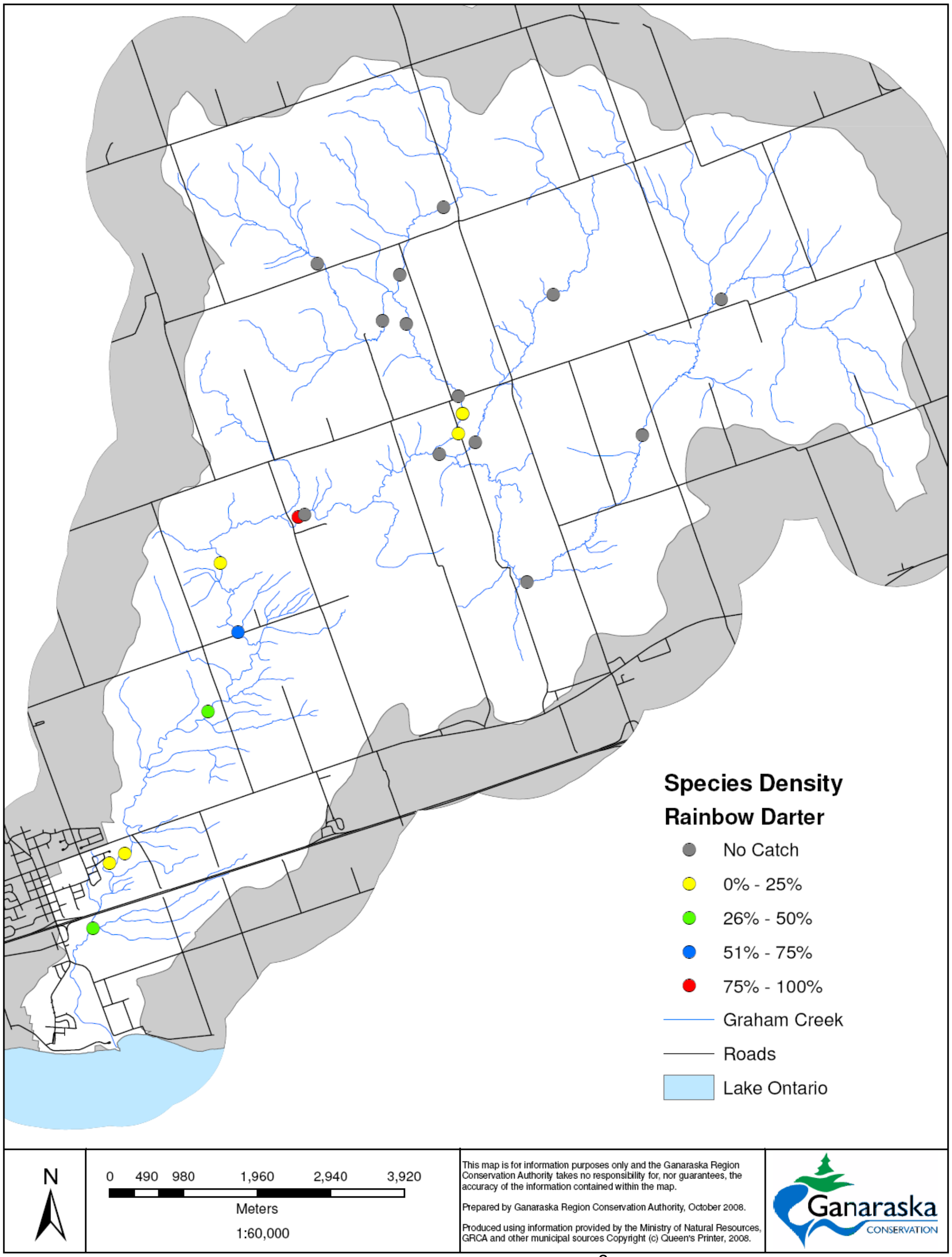


Figure 4.7: Rainbow Darter summer density (fish/m^2)

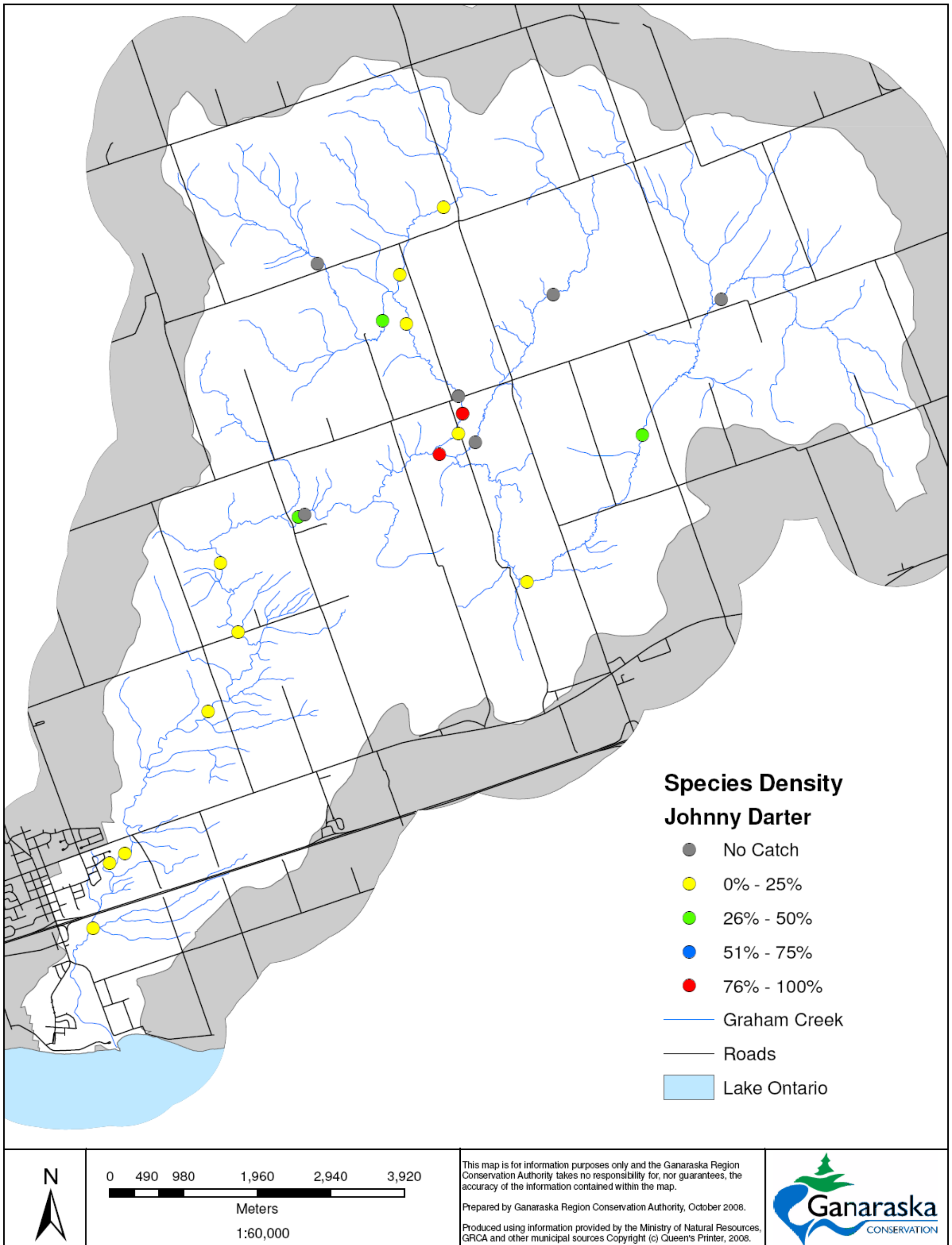


Figure 4.8: Johnny Darter summer density (fish/m^2)

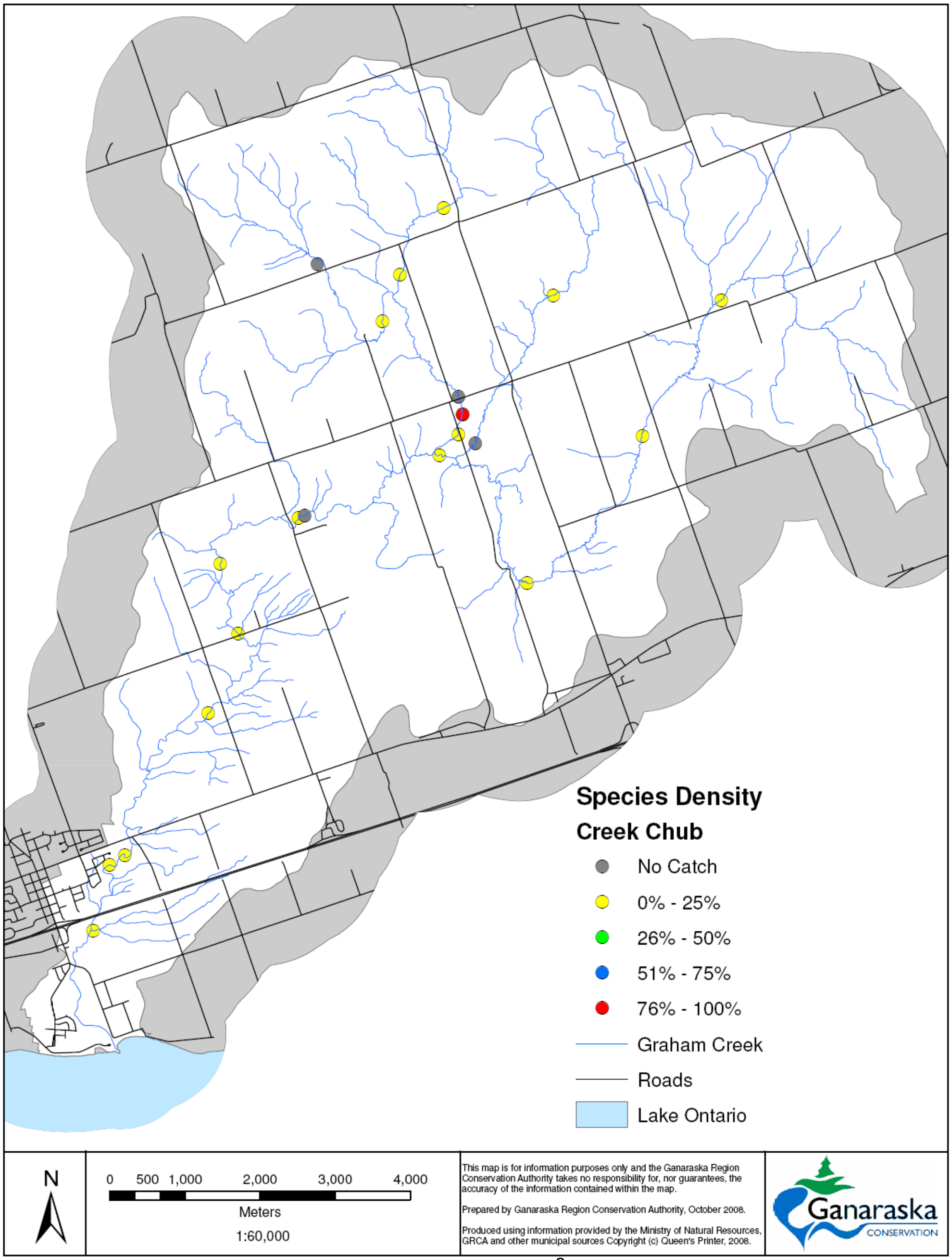


Figure 4.9: Creek Chub summer density (fish/m^2)

4.0.2 Instream Habitat

A stream's ability to support a diverse and sustainable aquatic community depends on the instream habitat characteristics that include stream temperature, dissolved oxygen, food types, cover, stream bottom type and spawning areas (Cushing and Allan 2001). Stream temperature needs to be stable and within a range necessary for specific species' health and survival. Dissolved oxygen within streams is usually abundant, however concentrations vary in relation to temperature, water aeration (e.g., water flowing over rocks), primary production and water quality (Cushing and Allan 2001). Food sources of aquatic species include vegetation (e.g., periphyton), particulate organic matter, aquatic macroinvertebrates, fish and terrestrial organisms. A range of food types needs to be present in a stream to support a dynamic food web. These instream habitat requirements are discussed in further detail in Section 4.0.3 (stream temperature), 3.7 (dissolved oxygen) and 4.0.4 (benthic macroinvertebrates) of this document.

Cover in a stream is vital to aquatic organism survival, and consists of riparian vegetation, boulders, overhanging banks, logs, root wads and shade from overhanging objects (Cushing and Allan 2001). Instream cover primarily provides shelter from predators and strong currents. Streams that support trout and salmon have a range of stream morphologies ranging from cascade (8 to 30% slope) to dune-ripple regime (<0.1% slope). Typically, local streams with a step-pool (4 to 8% slope) or pool-riffle (0.1 to 2% slope) are the most productive. Stream reaches of > 4% slope are generally not utilized by salmon for spawning because of the reaches' high bed load transport rate, deep scour, and course substrate (Roni et al. 1999). Desired stream bottom composition for trout and salmon life cycles includes a combination of large rocks, rubble, gravel and smaller amounts of sand. Other cover and substrate compositions are required for many different aquatic organisms.

The Ontario Stream Assessment Protocol was utilized to collect substrate particle sizes using the Channel Morphology method. The variable "particle size" was grouped into three categories; fines (<2 mm), gravel (2 mm to 100 mm), and cobble (<100 mm). A total of 19 sites were analyzed (Figure 4.10) to determine the dominant substrate type and use this as a proxy for other stream habitat variables such as amount of cover as pools, riffles and glides.

The highest site percentages of fines were located within the main branch and Mulligan Creek portions of Graham Creek, while the mainstem of Graham Creek below the confluence of Mulligan Creek was dominated by gravel and cobble substrates (Figures 4.11 and 4.12). The main branch of Graham Creek has an overall low gradient (fine substrates) (Figure 4.12), without defined riffle/pool sequences and has extensive adjacent wetland complexes. Mulligan Creek has a mix of fine and gravel/cobble substrates, with a higher average gradient.

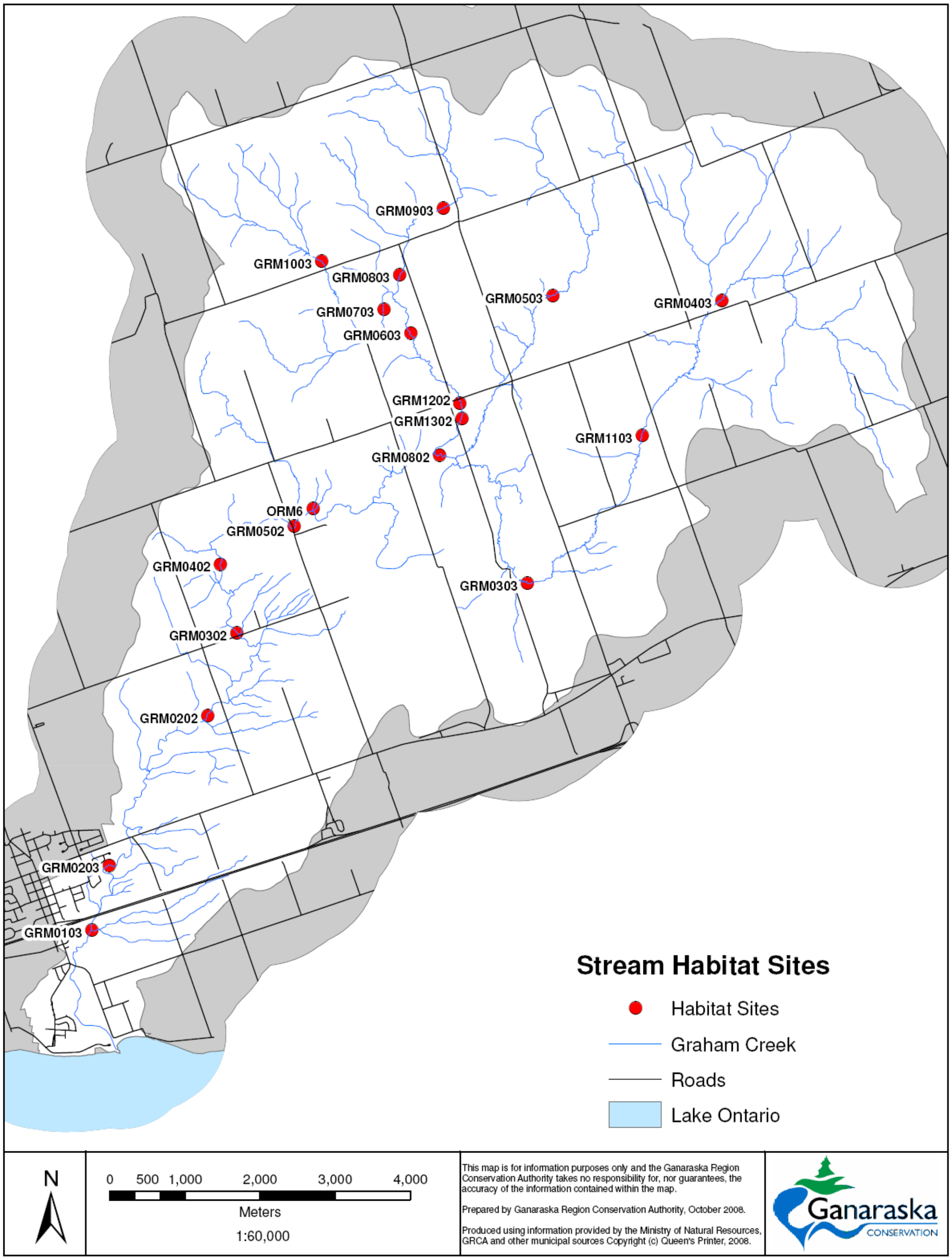


Figure 4.10: Stream habitat sampling sites

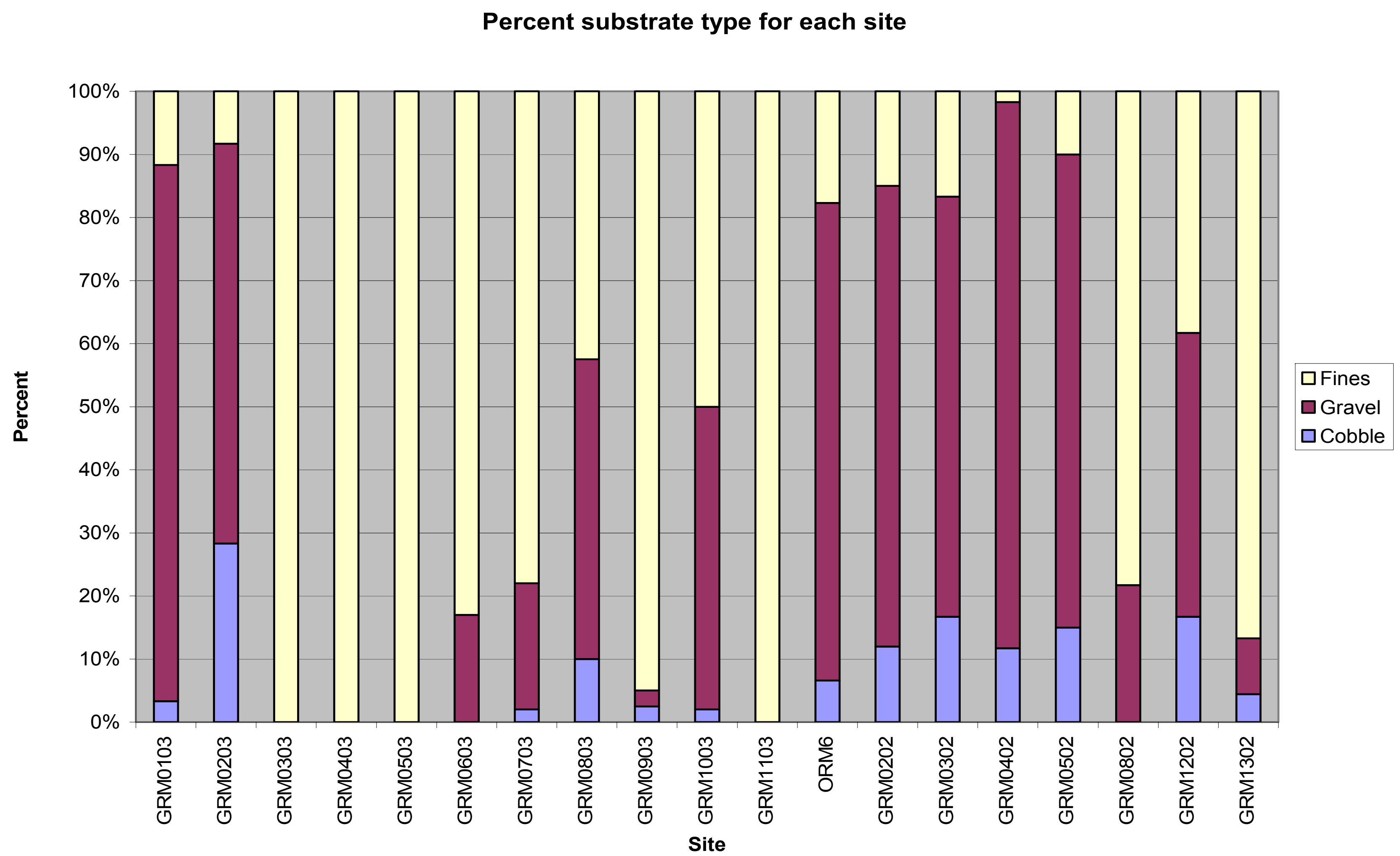


Figure 4.11: Substrate composition

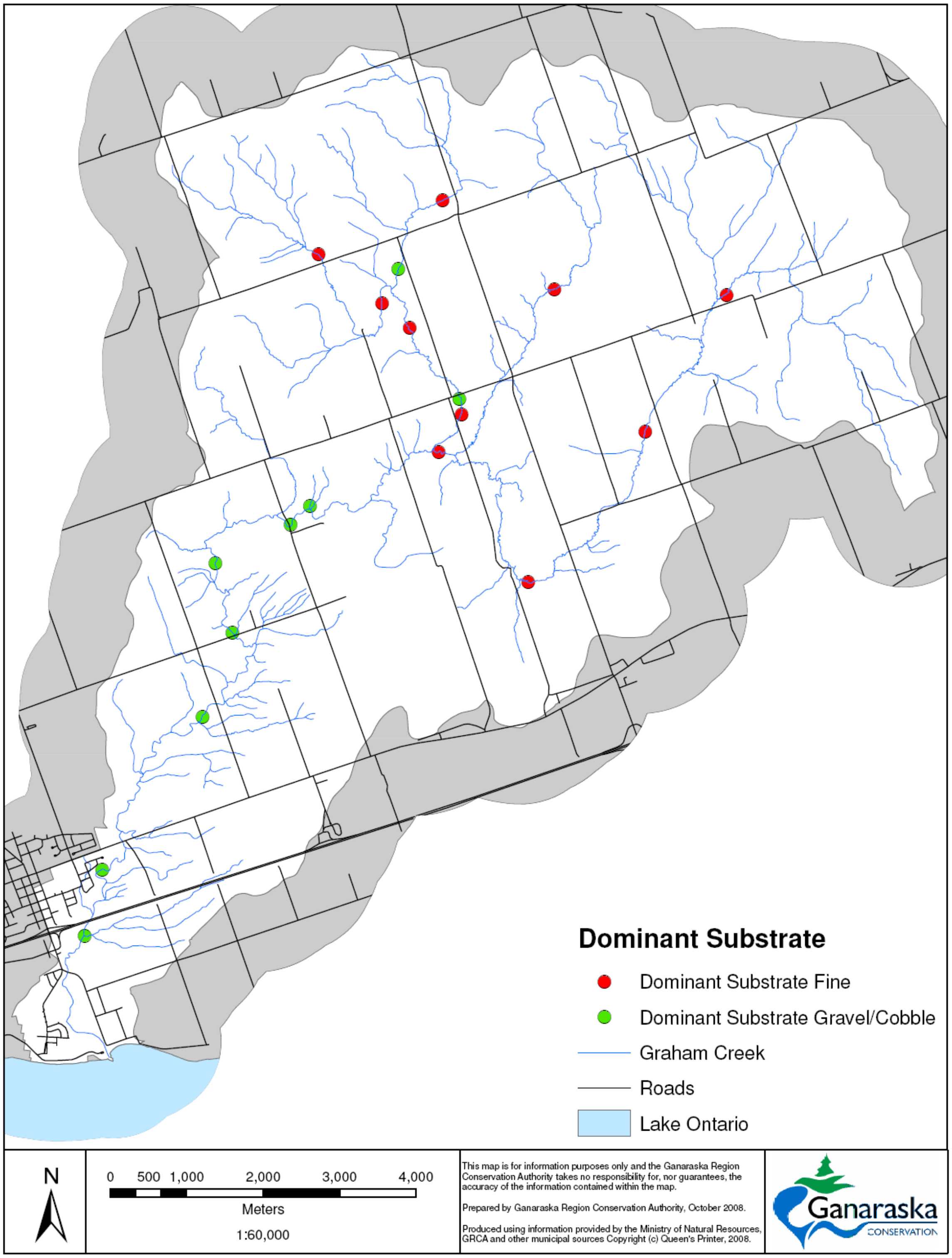


Figure 4.12: Dominate substrates (D_{50})

4.0.3 Surface Water Temperature

Surface water temperature is spatially and temporally variable and is influenced by air temperature, precipitation, stream flow, geology, topography, land use, watershed vegetation, channel and floodplain morphology, and riparian vegetation (Poole and Berman 2001). Out of all these controlling factors a strong linear relationship often exists between air temperature and river water temperature (Wetzel 2001), with a time lag by the water temperature to reflect air temperature (Stoneman and Jones 1996). As a result, air temperature is commonly used to help characterize stream temperature.

In addition to air temperature, groundwater inputs into surface water are also a dominant controlling factor of stream temperature (Power et al. 1999). Areas of groundwater discharge to a stream cause stream temperatures to be cooler than areas that do not experience discharge. Groundwater discharge areas provide places of refuge from warm temperatures, and coldwater fish tend to take advantage of these locations (Power et al. 1999). Water temperature and the presence or absence of groundwater discharge into a stream are an important factors in determining the presence or absence of fish species in a particular area of the stream (Power et al. 1999). For example, Brook Trout are generally found in the coldest reaches of a stream and utilize groundwater inputs for spawning.

As described above, stream temperature dictates the types of biota that are found in a particular reach or area of the stream. Coldwater fish species require a stream temperature below 19^{o}C, cool water fish species between 19^{o}C and 25^{o}C and warm water species above 25^{o}C. However, different life stages often require different temperatures. Although fish species can tolerate stream temperatures outside of their required range, the longer the stream temperature remains in an extreme stage, the more stress is applied to the individual fish or a particular fish species (Cushing and Allan 2001).

Water temperature data was collected in Graham Creek through two methods using digital temperature loggers to find the maximum summer surface water temperature. The Ganaraska Region Conservation Authority deployed temperature probes in 2002 and 2003 as part of their annual watershed monitoring program.

Water temperatures were digitally recorded in 30-minute intervals throughout various months in 2002 and 2003 with Hobo Temp Pro loggers, Version Hobo Tidbits. Temperature probes were anchored to a cement block, secured to the bank or stream substrate in a shaded flowing reach of the stream. The average temperature during this period was utilized to determine the thermal classification of Graham Creek. Fourteen sites (82%) were classified as coldwater, while three (18%) were classified as coolwater, based on Bowlby (2003 - unpublished) Figure 4.13 shows the sample locations and thermal regimes in Graham Creek.

Another explanation for sites experiencing differing water temperatures is the effect of shading from the riparian area. Solar radiation accessing a stream is a major variable associated with summertime stream heating (Teti 1998). Where solar radiation has access to surface water, stream temperatures will rise accordingly. If groundwater discharge is not present in those same reaches that experience solar radiation, stream water will rise as a result of heat input and no cooler water inputs from groundwater contributions. This is why riparian vegetation is an important component to reducing the variability in stream temperature changes.

Channel structure and riparian areas can play a role in providing shade to stream. Narrow channels can be shaded more easily by stream banks (Moore et al. 2005) and tree shading can help minimize temperature variability in streams. Conversely, wide channels tend to be less shaded because they have a canopy gap over the stream (Moore et al. 2005). Stream channel morphology also contributes to the temperature regime of a stream. The channel morphology may promote hyporheic (surface and groundwater interface) water flow. As warm water moves through the hyporheic zone, it dissipates heat, mixes with colder groundwater, and may return to the stream cooler than the current stream temperature.

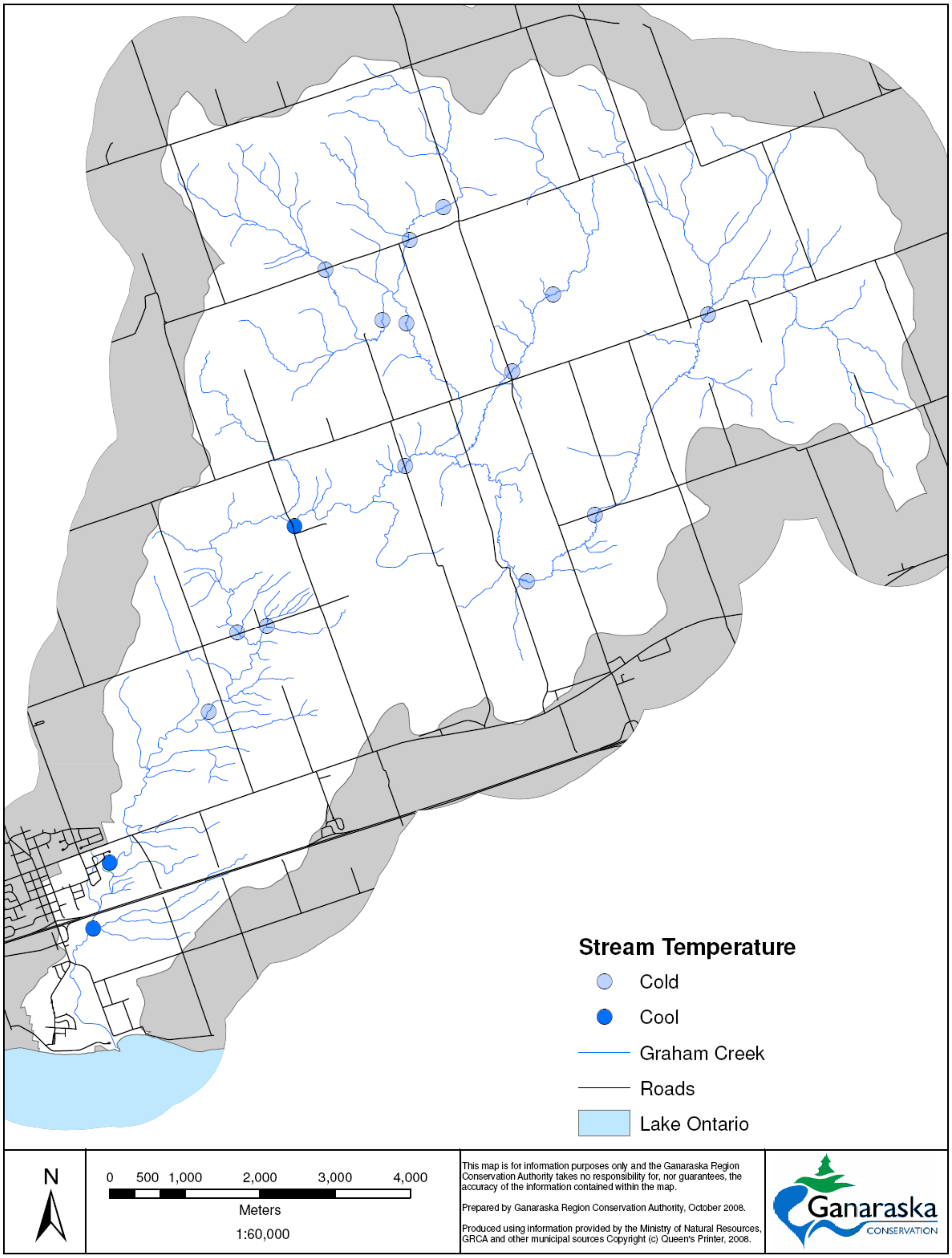


Figure 4.13: Summer stream thermal classification

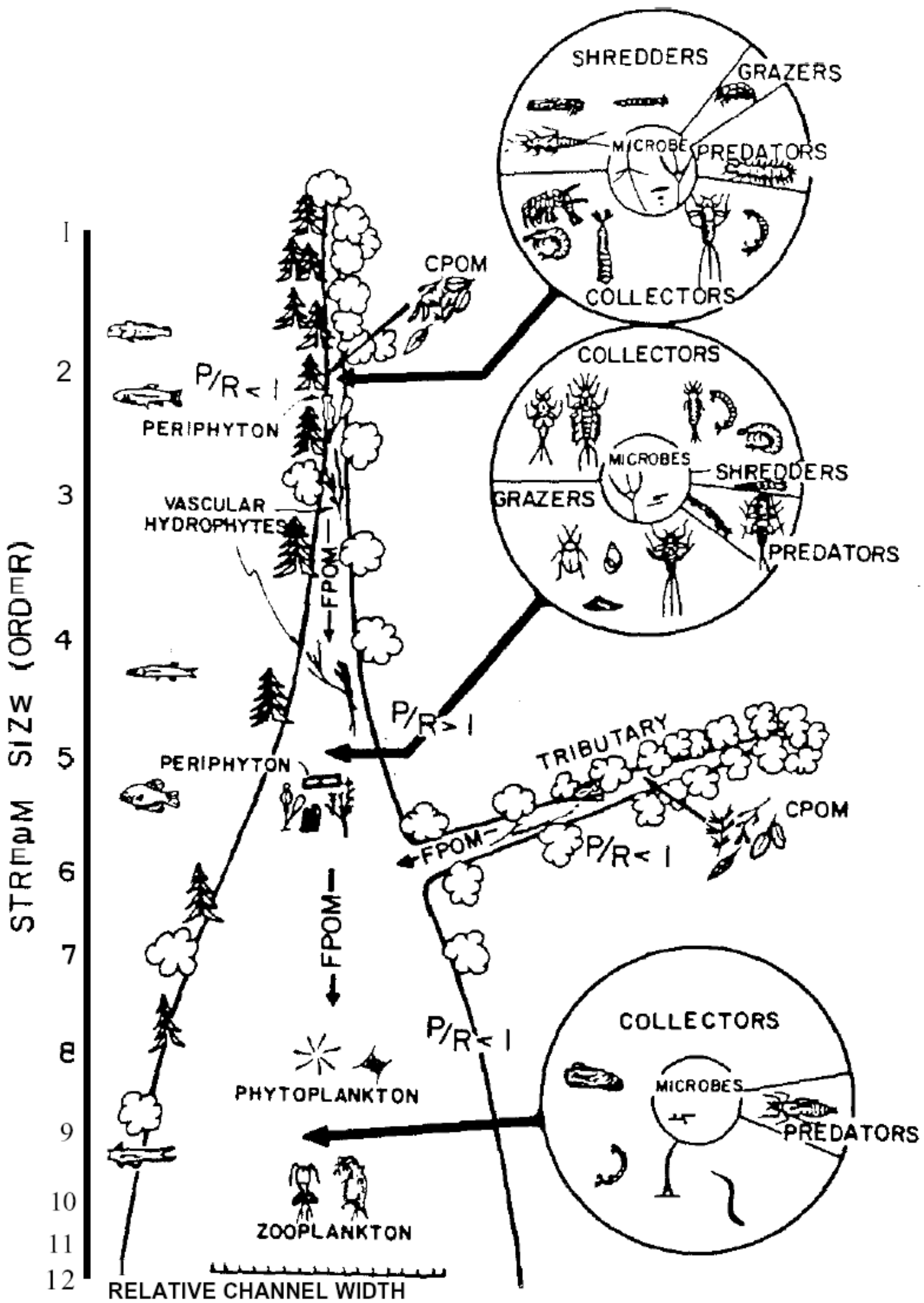
4.0.4 Benthic Macroinvertebrates

Benthic macroinvertebrates represent aquatic organisms that are visible to the naked eye and live on the bottom of a water body or in the subsurface (hyporheic zone) of a stream. The families of benthic macroinvertebrates include alderflies and fishflies, beetles, bugs, caddisflies, dragonflies and damselflies, mayflies, moths, true flies, stoneflies, crustaceans, molluscs, segmented worms, horsehair works, flatworks and mites (Jones et al. 2005). All of these organisms require water for their entire life stage or for a portion of it (e.g., reproduction and early life stages).

Benthic invertebrates carry out necessary functions in a river or stream. Grouped into functional feeding groups, benthos can be shredders, grazers, collectors or predators (Cushing and Allan 2001). As such, each functional feeding group has specialized morphologic adaptations needed to carry out necessary functions. As a result, each functional feeding group plays a role in breaking down and assimilating organic matter in a stream, and this is required in a healthy stream.

The role of benthos in a stream is recognized in the River Continuum Concept. This concept views the entire river ecosystem as longitudinally changing physical templates overlain by biologic adaptations along these gradients (Vannote et al. 1980). Seasonal variations of organic matter supply along with structure and feeding types of the invertebrate community play a large role in all biological communities found within the stream (Wetzel 2001) and their ability to adapt to current conditions and future changes. Figure 4.14 depicts the generalized model of the River Continuum Concept.

Benthic macroinvertebrates are also indicators of stream health. Certain taxonomic groupings (families, genus and species) are tolerant of organic pollution, while others are very intolerant. One index used in assessing stream health is the Hilsenoff Biotic Index, which categorizes taxa based on their tolerance to organic pollution. Indices of stream health based on benthos are useful in assessing water quality, since benthos can represent changes over a long period of time, as their presence or absence is related to current and past land use as well as local adaptation.



(Vannote et al. 1980)

Figure 4.14: River continuum concept

Benthic Macroinvertebrates Sampling Methods

Benthic macroinvertebrates are sampled using a kick and sweep method as defined in the Ontario Stream Assessment Protocol (Stanfield 2005). Benthic macroinvertebrates were sampled at 12 sites from 2002 to 2003. Identification of 27 taxa groups was performed on a mixture of classes, orders, sub-orders, and families. Sampling occurred primarily during the summer months (July and

August); pros and cons exist for this sampling time. A benefit of this sampling time is that invertebrates are most likely to show a response to habitat and stream impacts, since this is the most stressful season for biotic organisms given the high water temperature and low oxygen levels. However there is a low richness of species in relation to life history patterns (e.g., many aquatic insects have emerged to winged adults) (Jones et al. 2005).

Benthos diversity information was calculated with the Simpson's Diversity Index, where zero represents low diversity and one represents high diversity. Percent EPT (Ephemeroptera, Trichoptera and Plecoptera) was calculated as well as percent Chironomidae. These two metrics describe the proportion of intolerant and tolerant taxa respectively. Benthos was also used to rank water quality using the Hilsenhoff Biotic Index.

Benthic Macroinvertebrates as Indicators

Benthos diversity ranges from a low Simpson's diversity of 0.15 to a high diversity of 0.39 in the Graham Creek watershed (Figure 4.15). However, this reflects the diversity at coarser taxonomic levels, rather than species. In addition, the Ganaraska Region Conservation Authority does not sample during the spring and fall when benthic diversity is at its greatest in relation to the life stages of the macroinvertebrates. By sampling in the summer, diversity may be low due to the absence of macroinvertebrates that have left the aquatic environment for the terrestrial environment (Jones et al. 2005) or are within the aquatic environment as eggs. Percent EPT ranged from 17 to 74% and percent Chironomidae ranged from 1 to 37%.

Benthic macroinvertebrates can describe water quality based on the Hilsenhoff index, which gauges the degree of water quality impairment as it relates to nutrients. Using this index, most of the sample sites rank as "fair" and "good" water quality (Table 4.1; Figure 4.16). It should be noted however, that habitat conditions unrelated to the amount of nutrients could affect the presence or absence of certain benthic species. Low gradient, soft bottom stream segments will contain higher numbers of tolerant species. Their presence likely reflects the substrate as opposed to the quality of the water. Similarly, certain species may not be present during summertime sampling due to life stage cycles. The influence of past land use, particularly agriculture, on present day diversity of stream invertebrates may result in long-term modifications to and reductions in aquatic diversity, regardless of reforestation of riparian zones (Harding et al. 1998). A lag of greater than 40 years may be needed before historic invertebrate diversity and composition are present. Also, benthic particulate organic matter, diatom density, percent of diatoms in *Eunotia* species, fish density in runs, and whole-stream gross primary productivity correlated with the amount of disturbed land in catchments in 1944 (Maloney et al. 2008). A more representative nutrient level analysis in watersheds should be presented through water chemistry analysis, described in Section 3.7 of this document.

Table 4.1: Hilsenhoff index of benthic macroinvertebrates

Hilsenhoff Index	Water Quality	Degree of Organic Pollution	Number of Sample Sites
0.00-3.75	Excellent	Organic pollution unlikely	1
3.76-4.25	Very Good	Possible slight organic pollution	1
4.26-5.00	Good	Some organic pollution probable	5
5.01-5.75	Fair	Fairly substantial organic pollution likely	4
5.76-6.50	Fairly Poor	Substantial organic pollution likely	1
6.51-7.25	Poor	Very substantial organic pollution likely	0
7.26 - 10.00	Very Poor	Severe organic pollution likely	0

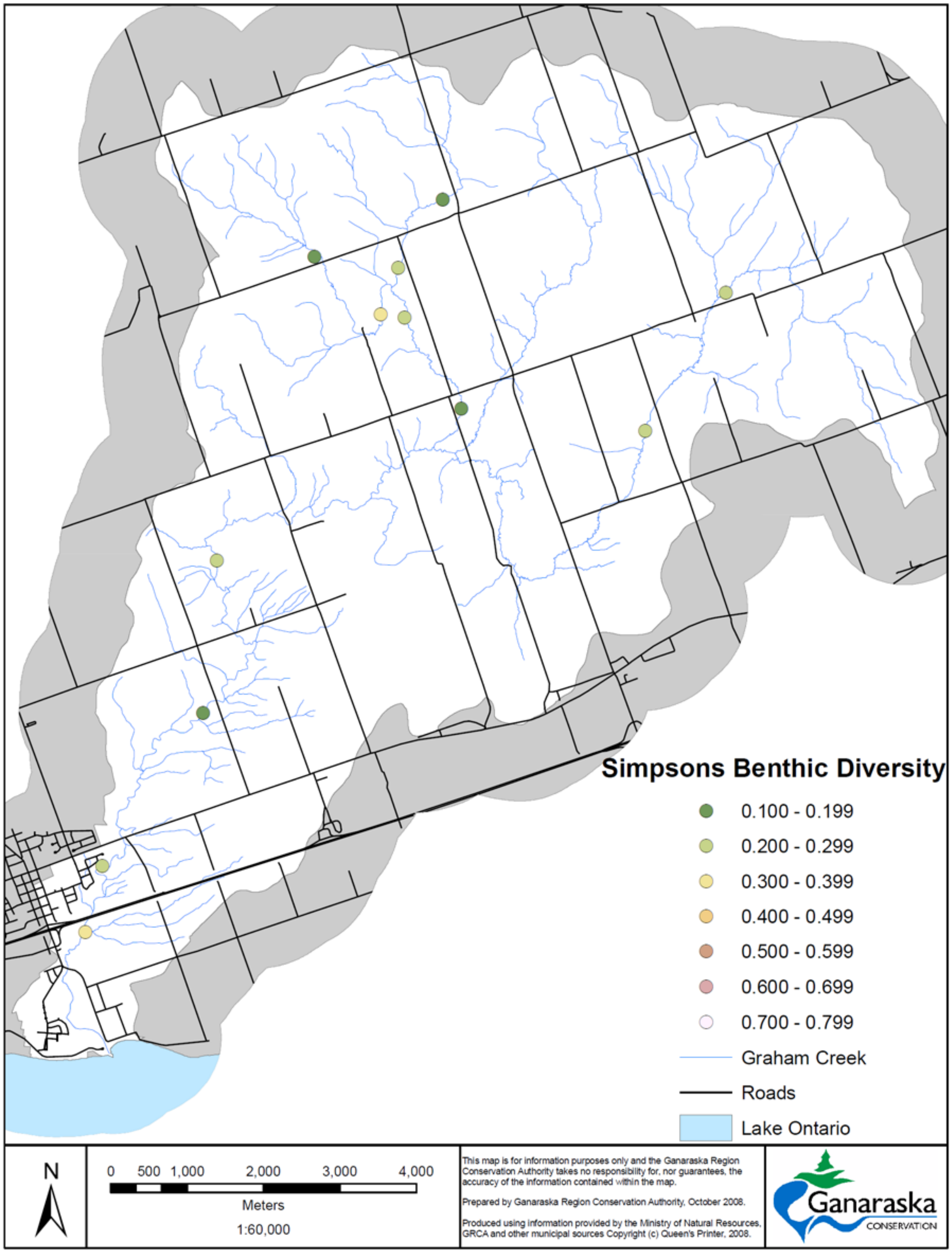


Figure 4.15: Benthic macroinvertebrate diversity

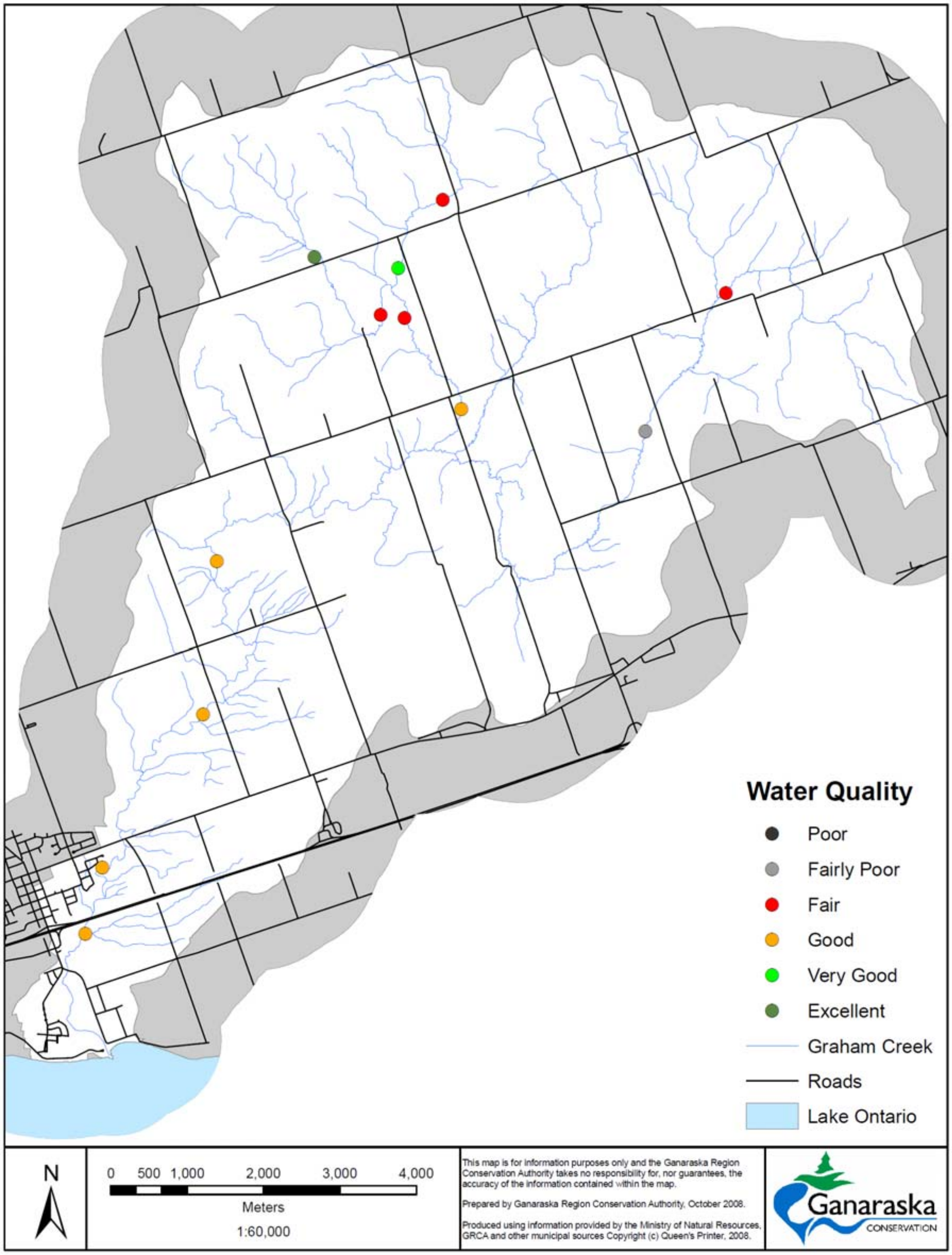
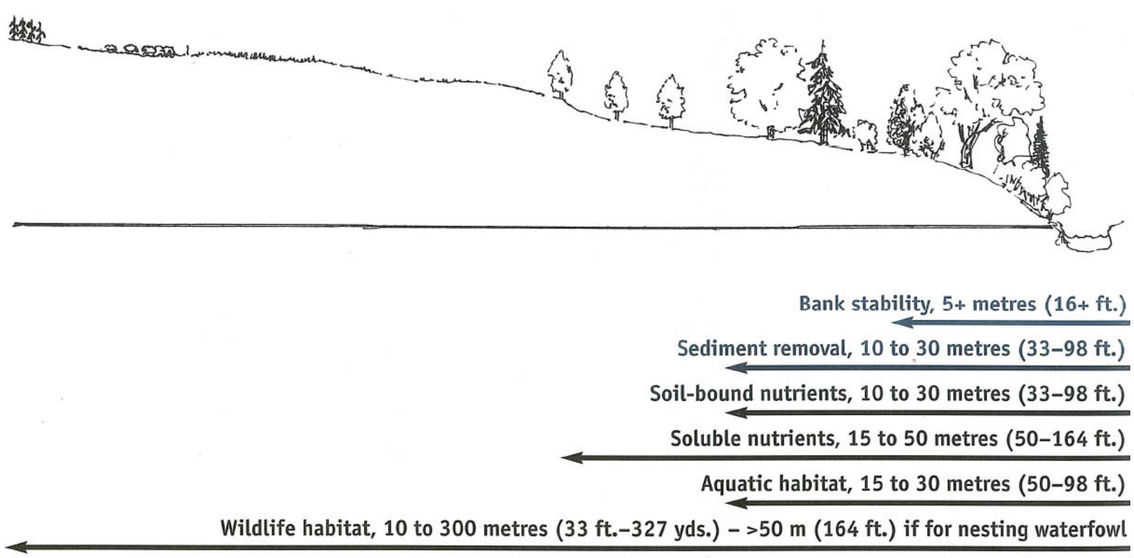


Figure 4.16: Hilsenhoff index

4.0.5 Riparian Areas

Riparian areas occur as transitional areas between aquatic and terrestrial habitats. Although not always well defined, they generally can be described as long, linear strips of vegetation adjacent to streams, rivers, lakes, reservoirs and other inland aquatic systems that affect or are affected by the presence of water (Fischer and Fischenich 2000). Riparian buffer, riparian zone, buffer strip and filter strip are terms often used and interchanged to define the extent and the functions of riparian areas. The role of riparian areas varies greatly and includes sediment retention, nutrient removal before entry into the waterbody, streambank stabilization, contribution to aquatic and riparian area biodiversity and habitats, and the regulation of stream temperature (Fischer and Fischenich 2000).

From a stewardship and management perspective riparian areas are defined as the benefit provided in relation to the width and functional contribution of the riparian area (Figure 4.17). The following describes the role and composition of a 50-metre riparian area along Graham Creek. A 50-metre buffer provides bank stability, sediment removal, soil-bound and soluble nutrient retention, protection and contribution to aquatic habitat, and provision of certain wildlife habitat (Figure 4.17). The role of riparian areas and their effectiveness on benefiting the adjacent waterbody depends on soil type, slope and watershed size, function and cover type (Fischer and Fischenich 2000).



(Agriculture and Agri-Food Canada and Ontario Ministry of Agriculture and Food Unknown Date)

Figure 4.17: Riparian area functions

Classifying riparian area cover types using Ecological Land Classification data from 2002 shows that natural cover (forest, meadows and wetlands) dominates the amount of land cover within 50 metres of the stream banks of Graham Creek

(Figure 4.18). Agricultural land use occurs within 13% of the 50-metre riparian area and developed land cover 11% (Table 4.2).

Table 4.2: Land cover within 50-metre buffers of Graham Creek

Land Cover	Percentage within 50-metre buffer
Forest	26
Agriculture	13
Meadows, savanna and thickets	19
Developed	11
Wetlands	31

Riparian Area Contributions and Benefits

Riparian areas of Graham Creek mitigate surface water quality by reducing surface runoff into Graham Creek, thereby reducing sedimentation and nutrient inputs. Where nutrients are a concern, riparian areas may not be adequate enough to hold back surface runoff, especially during heavy rainfall events (Carpenter et al. 1998). Retention of surface runoff is also dependent on the vegetative composition of the riparian area, and varies greatly between wetland, forested and grassed land cover (Mayer et al. 2006). Subsurface removal of nitrogen through plant uptake and conversion occurs in a riparian area, but efficiency is not related to buffer width, rather to microbial denitrification and plant types that are conducive to the uptake of nutrients (Mayer et al. 2006). As a result the composition and structure of a riparian area are necessary in maintaining or improving water quality.

Riparian areas contribute to instream habitat through bank stabilization, cover creation from undercut banks, root wads and wood cover. The location of wood cover seen through instream habitat sampling relates to the amount and location of forested riparian areas in the Graham Creek watershed. Stream temperature is maintained at a cold to cool water regime as a result of riparian areas providing shade to Graham Creek. Along with groundwater, riparian vegetation can regulate stream temperature (Moore et al. 2005). Stream temperatures presented in section 4.0.3 can also be seen in relation to riparian area composition, with cold and cool water temperatures occurring in areas with forested riparian cover, and warm water temperatures occurring in urban areas where the channel is wider and where limited forests or shading are present.

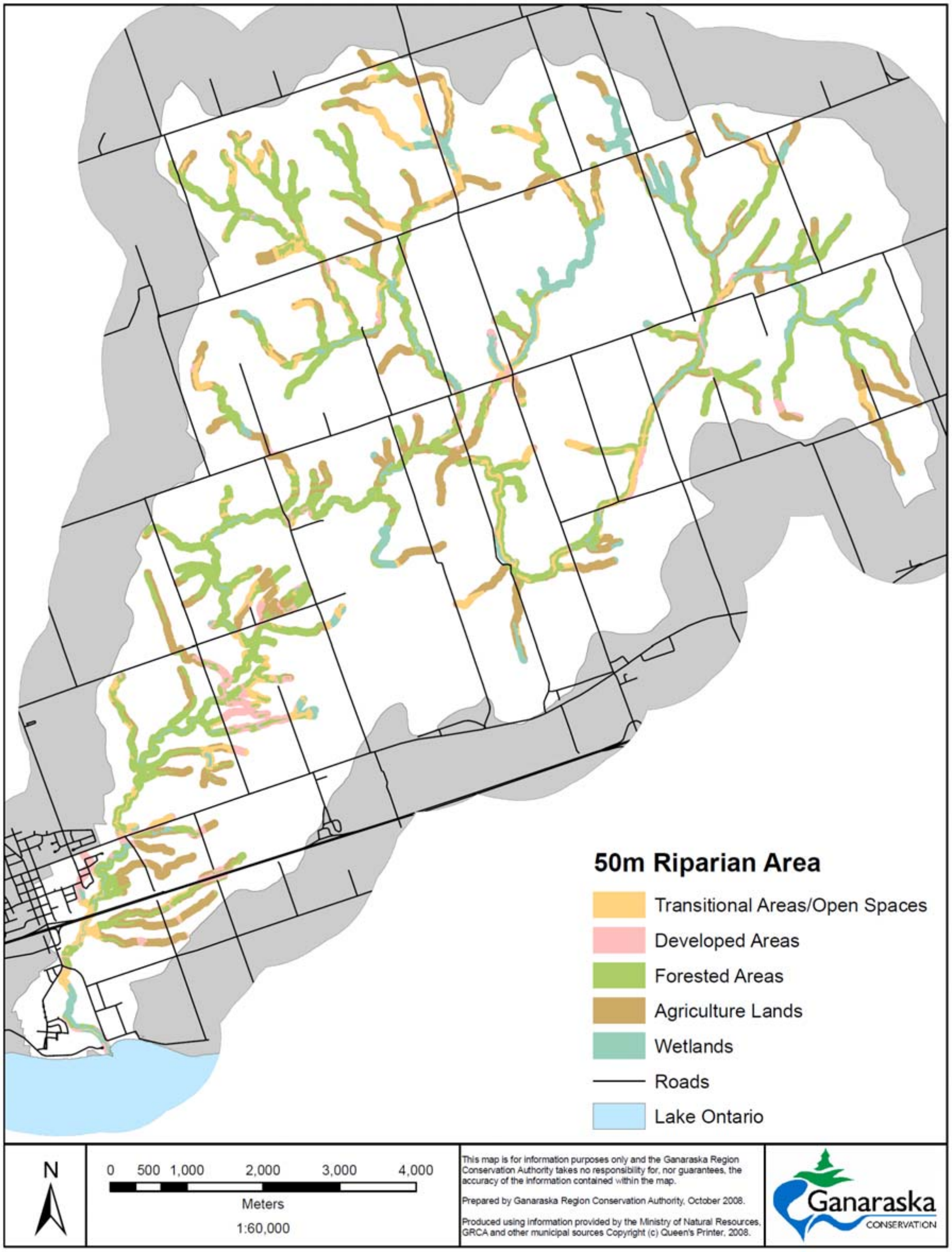


Figure 4.18: Fifty metre riparian area

4.1 Terrestrial Natural Heritage

Terrestrial natural heritage includes natural areas such as forests, wetlands and meadows, as well as their associated species. These natural features are integral components of a watershed, and are entwined with human land uses. Natural heritage features contribute to healthy watersheds in part by providing habitat for diverse aquatic and terrestrial species and communities. These areas provide food, shelter and life stage requirements, including breeding areas and migratory corridors. Natural areas also provide erosion control, flood attenuation and clean water. Land cover composition in the Graham Creek watershed is presented in Figure 4.19, and natural areas found in the Graham Creek watershed are presented in Table 4.3.

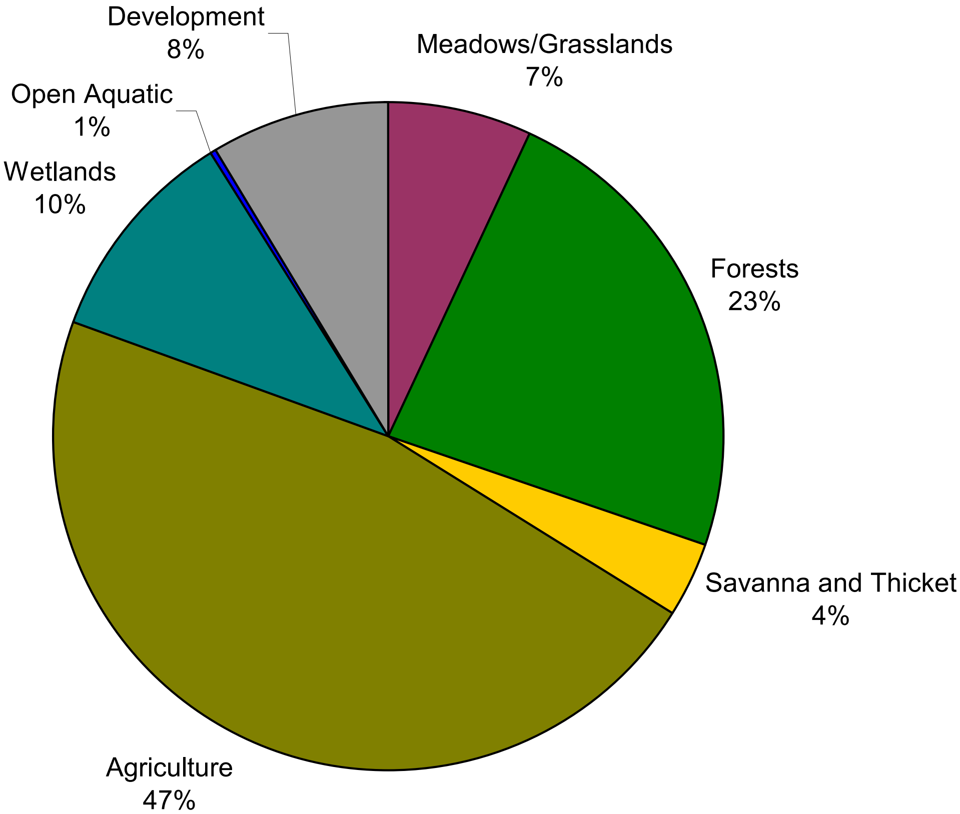


Figure 4.19: Land cover based on ecological land classification

Table 4.3: Natural areas

Natural Feature	Percentage*
Forests	23**
Meadows/grasslands	7
Savanna and thickets	4
Wetlands	10

* based on 2002 ELC Data.

** actual tree cover within the watershed is 35% given that most of the wetlands are tree covered.

4.1.1 Terrestrial Natural Heritage Study Methods

Terrestrial natural heritage can be assessed at three main scales: landscape, vegetation community or land use type, and species. The landscape level essentially follows principles of landscape ecology in which the entire landscape can be divided into three components: patches, corridors and the matrix (Forman 1996). In the heavily settled landscape of southern Ontario, including the Graham Creek watershed, the original dominant landscape cover was forest. These and other associated natural areas have since become fragmented and are represented by patches. In the surrounding landscape the matrix - the dominant land use - is agricultural and urban. Corridors in this landscape are made up of both natural and man-made features such as riparian areas or roads. For the purpose of this background study, the landscape level is evaluated primarily for forest cover by looking at total cover, distribution and habitat patch characteristics.

Vegetation communities are mapped and evaluated using the Ecological Land Classification System for Southern Ontario (Lee et al. 1998), commonly referred to as ELC. This system categorizes community types at several levels of detail. The Ganaraska Region Conservation Authority has remotely mapped vegetation communities at the Community Series level of the ELC using colour ortho-corrected aerial photography. The more detailed ecosite and vegetation type levels of the ELC require field assessment, which is expensive and impractical over large areas where most land is in private ownership. The Natural Heritage Information Centre housed at the Ontario Ministry of Natural Resources has identified rare vegetation community types for Ontario at the vegetation type level. Without this level of mapping this report combines the vegetation community reporting with the landscape level reporting, and an overall summary of conditions for major vegetation communities, specifically forest, grassland and wetland. Within these categories, rare communities, such as tallgrass prairie, are recognized.

There are many ways of evaluating terrestrial species, but it is a challenge to do so in a way that is relevant to the watershed context since individuals of many species can freely move between watersheds. What is needed is a way to use species as indicators of ecological health. As such, the Ganaraska Region Conservation Authority uses birds as indicators of forest health and frogs as indicators of wetland health. Theoretically, the more sensitive the species present and the more individuals, the healthier the ecosystem is likely to be. Roadside bird and frog surveys were undertaken as a rapid assessment approach to learning what can be found where. In this case ELC mapping was used to select a representative variety of forest patch sizes and landscape matrices for bird surveys and areas where a variety of wetland types could be found adjacent to roads.

Marsh Monitoring protocols were adapted for the roadside surveys, with 10-minute point counts used to record all birds seen and heard, and 3-minute point counts used to record singing frogs. Surveys were conducted to coincide with peak breeding for all species. In addition to indicator species, species of conservation concern are relevant to watershed management. In the future the Ganaraska Region Conservation Authority would like to develop an evaluation approach to identify species of local concern. In the meantime, reporting on this topic will be limited to an overview of species at risk known to occur in the watershed.

4.1.2 Forests

A forest ecosystem is a community of plants, animals, microorganisms, and the physical environment they inhabit, in which trees are the dominant life form (Hunter 1990). Prior to European settlement, forests covered more than 90% of southern Ontario (Larson et al. 1999). Widespread clearing for agriculture has resulted in a landscape of different successional stages and fragmented forest patches of varying sizes. The size, shape and connectivity of patches, as well as the types of land use in the surrounding landscape matrix have much to do with the species composition, and therefore the ecological integrity of the forest. The process of evolution and changes that occur to a forest ecosystem, either naturally or as a result of disturbance, is called forest succession. Succession can be defined as the process of change by which biotic communities replace each other and in which the physical environment becomes altered over a period of time (Kimmins 1996).

For the purpose of this report, forests are defined through ELC (Lee et al. 1998) and include coniferous, deciduous and mixed forests, and cultural plantations and woodlots. Treed swamps must be counted twice when calculating the area covered by forest and wetland separately, because a swamp is often only seasonally flooded and the ecosystem therefore functions as both wetland and forest. Swamp area must then be subtracted when the combined area forest and wetlands are calculated.

Coniferous and deciduous forests are classified as areas of land that contain more that 60% tree cover with a canopy cover of more than 75% coniferous or deciduous trees respectively. Mixed forests are also made up of more than 60% tree cover, but contain a canopy cover of at least 25% each of both conifer and deciduous tree species (Lee et al. 1998). Cultural plantations and woodlands are defined as an ecological community resulting from or maintained by cultural or anthropogenic activity. A cultural plantation has more than 60% tree cover, while cultural woodlands contain between 35% and 60% tree cover (Lee et al. 1998). Swamps contain more than 25% tree or shrub cover and are dominated by hydrophytic shrub or tree species. Table 4.4 describes the proportion of forest types in the Graham Creek watershed and Figure 4.20 shows the locations.

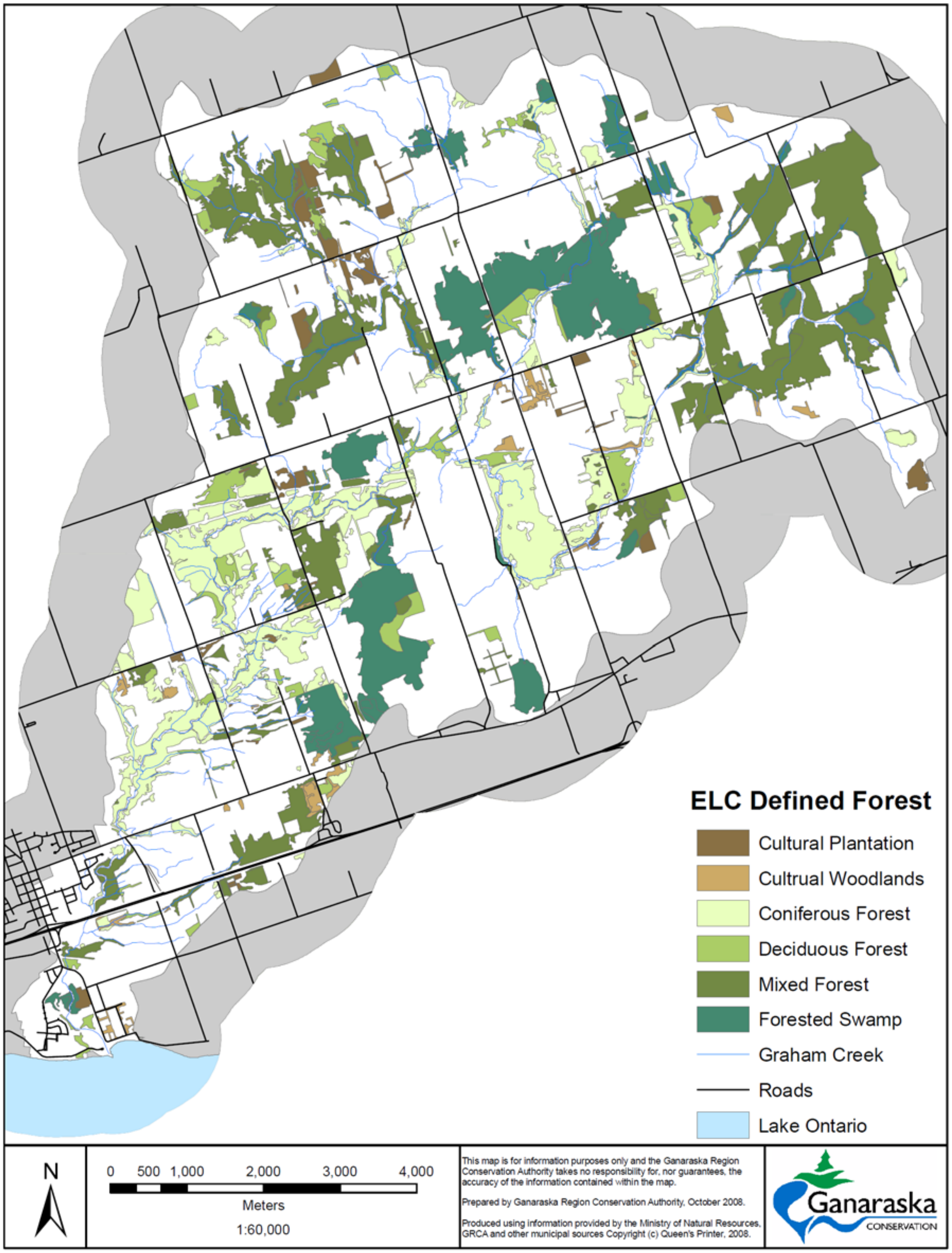


Figure 4.20: Forests

Table 4.4: Forest types

ELC Defined Forest Type	Percentage
Coniferous Forest	8
Deciduous Forest	2
Mixed Forest	12
Cultural Plantation	1
Cultural Woodlands	0.8
Thicket Swamp	0.4
Coniferous Swamp	6
Deciduous Swamp	0.3
Mixed Swamp	3

Different successional stages support different communities of plant and animal species. Although succession is often portrayed as progress terminated by disturbance, it can also be viewed as a cycle in which a series of plants and animals come and go (Hunter 1990). In order to maintain all plant and animals species in a landscape, it is necessary to maintain representation of all stages of ecological succession, however not necessarily in equal amounts. Ideally natural disturbances such as fire would dictate the relative abundance of different successional stages. During pre-settlement times old growth forest was likely dominant. Now this community type is rare and vastly under-represented. It has therefore become a conservation concern, and some mature woodlands should be managed to replace what was lost.

Patch (woodlot) size is an important consideration for forest management. Small isolated patches have limited capacity to sustain populations of many animal species. In contrast, large connected patches can support more species and more individuals of each species. They are also more likely to cover a variety of topography supporting more forest vegetation types, as well as natural disturbance regimes. A basic principle of conservation biology is that bigger patches are generally better for supporting biodiversity. Tables 4.5 and 4.6 depict the relationship between forest patch size and the types of species of wildlife that utilize particular patch sizes.

Forest patches that are compact in shape rather than convoluted are also generally better for many species, particularly those that require damp, dark, forest interior habitat. A number of birds experiencing population declines that require forest interior have been noted in the *Atlas of the Breeding Birds of Ontario, 2001-2005* (Cadman et al. 2007). Interior is generally considered to be forest area that is beyond 100 m from the outside edge of the patch. The first 100 metres is considered to be prone to negative edge effects originating in the surrounding landscape, including higher temperatures, exposure to wind resulting in desiccation or storm damage, increases in predation and parasitism, and invasions by exotic plants. Currently only 23% of the total forest cover in the Graham Creek watershed is forest interior (Figure 4.21). Of this, 4% is deep interior forest, considered to be the area beyond 200 m from the inner forest edge. Much of the interior forest is associated with treed swamps.

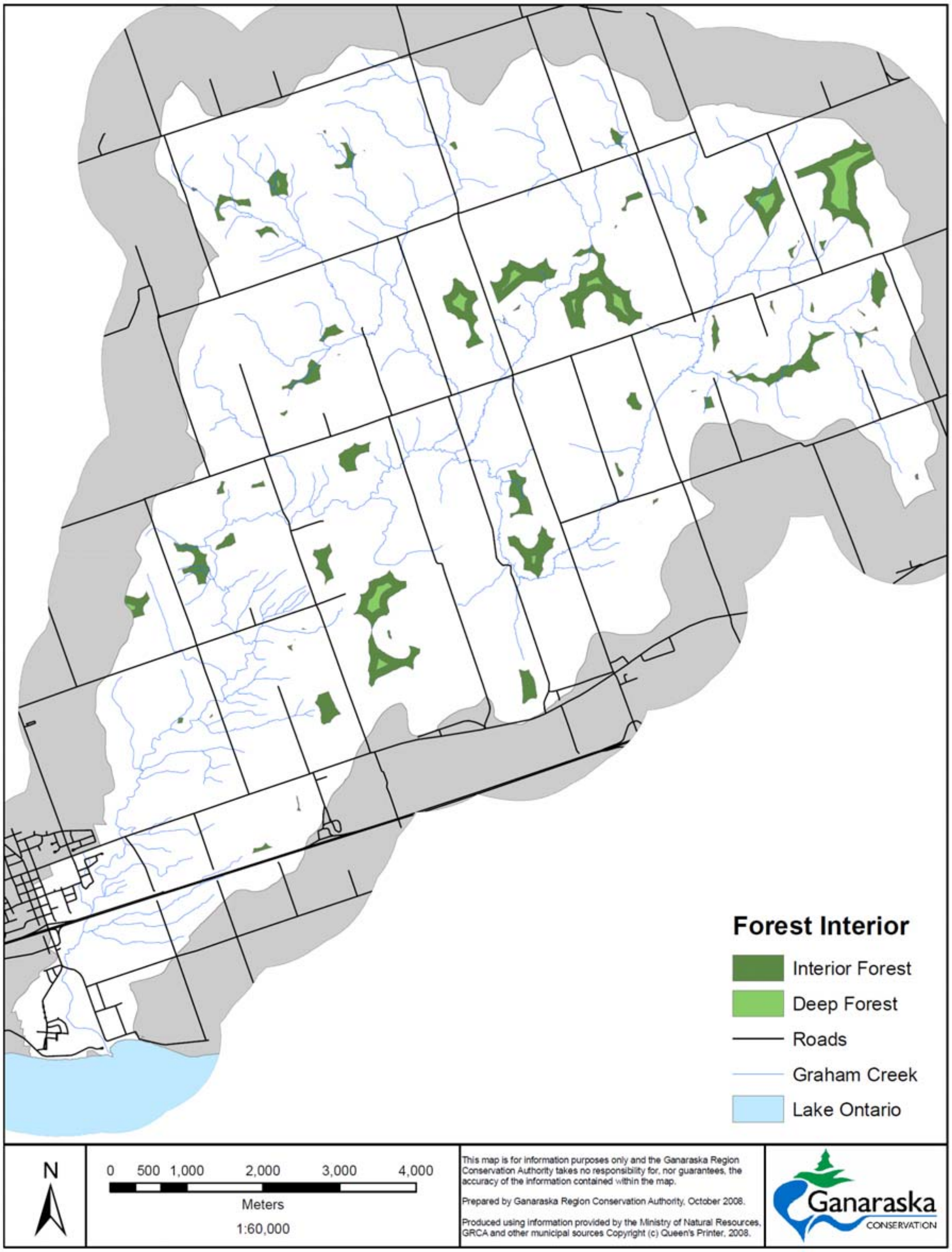


Figure 4.21: Interior forest

Given that much of the remaining forest cover in the watershed occurs in valleylands, there are a large number of convoluted patches relative to compact ones that tend to be on tablelands. This means an overall high edge-to-area ratio and therefore more exposure to negative edge effects. Natural heritage system modeling can identify opportunities to improve patch shape, and these can help set priorities for private land stewardship.

Table 4.5: Wildlife use of various forest patch sizes

Area	Forest/Treed Swamp
1 ha	■ Edge tolerant mammals (Gray Squirrel) ■ Common edge-tolerant birds (Blue Jay, American Crow) ■ A few birds may be associated with mature trees (Black-capped Chickadee, Eastern Wood-Pewee)
4 ha	■ A very few common edge-tolerant birds (Downy Woodpecker, Great Crested Flycatcher) ■ Eastern Chipmunk may be present
10 ha	■ Still dominated by edge-tolerant species may have very small areas of interior habitat supporting low numbers of modestly area-sensitive species (Hairy Woodpecker, White-breasted Nuthatch)
30 ha	■ May be large enough to support some species of salamander ■ Small populations of edge-intolerant species (Winter Wren, Brown Creeper, Black-and-White Warbler)
50 to 75 ha	■ A variety of area-sensitive species may be present; some will be absent if there is no nearby suitable habitat ■ Still predominantly edge influenced, but will support small populations of most forest bird species ■ Some will be absent if there is no nearby suitable habitat
100 to 400 ha	■ All forest-dependent bird species ■ Many will still be in low numbers and may be absent if there is no nearby suitable habitat ■ Woodland Jumping Mouse may be present
1,000 ha	■ Suitable for almost all forest birds ■ Some forest-dependent mammals present, but most still absent
10 000 ha	■ Almost fully functional ecosystem, but may be inadequate for a few mammals such as Gray Wolf and Bobcat (100 000 ha has been suggested as a minimum)

(Environment Canada 2005c)

Table 4.6: Anticipated response by forest birds to size of largest forest patch

Size of Largest Forest Patch	Response by Forest Associated
200 ha	Will support 80 percent of edge-intolerant species including most area-sensitive species.
100 ha	Will support approximately 60 percent of edge-intolerant species including most area-sensitive species.
50 - 75 ha	Will support some edge-intolerant species, but several will be absent and edge-tolerant species will dominate.
20 - 50 ha	May support a few area-sensitive species but few that are intolerant of edge habitat.
<20 ha	Dominated by edge-tolerant species only.

(Environment Canada 2005c)

In a fragmented landscape, connectivity is a key issue for all habitat types, including forest. In landscape ecology there are two types of connectivity. Structural connectivity refers to the physical layout of habitat patches on the landscape. Functional connectivity refers to the degree to which certain species are capable of moving through this structure. As an example, the American Crow (*Corvus brachyrhynchos*), a habitat generalist, has unlimited mobility through any habitat or land use type. In contrast, habitat specialists with limited mobility require contiguous specific habitats for food and cover. It is the latter that tend to be a conservation concern. Without connectivity, isolated populations of these species are at risk of inbreeding and loss of fitness. This can lead to small populations disappearing incrementally across the landscape, contributing to the regional loss of the species.

There are metrics for measuring connectivity with Geographic Information Services (GIS), however many of these merely measure the proximity of forest or other habitat patches (using GIS polygons or pixels). A more accurate method would be to model the potential movements of species or groups of species of conservation concern, although this would be time consuming. This could be done before and after GIS modeling to identify improved natural heritage systems. It could further be combined with a measure of road density, as roads are barriers to wildlife movement through the natural heritage system.

Related to both connectivity and patch size is the total amount and distribution of forest cover in the landscape or watershed. The question “how much habitat is enough?” is frequently asked when attempting to protect natural heritage features or systems. In fact, this is a very difficult question to answer because of complex issues related to species population dynamics and interacting components of ecosystems, not to mention our limited understanding of these. Nevertheless, the amount of 30% forest cover has been widely advocated (Environment Canada 2005c). This is based largely on studies in northeastern North America (including Ontario), demonstrating that landscapes with 20 to 30% forest cover tend to support the majority of bird species known in a given area. However, caution must be exercised when applying such generic cover recommendations. First, because they can fly, birds may not be good surrogates for other species that have limited mobility. Secondly, supporting the majority of species means that some species may not be supported. Finally, if a landscape supports more than 30% forest cover, does this mean we can afford to *lose* cover? At 35% forest cover in the Graham Creek watershed, is a case in point.

In short, conservation goals that set targets of 30 to 40% cover will not be adequate to conserve all species (Groves 2003), and there is no single threshold of habitat cover for species persistence (Fahrig 2001). When one factors in other concerns such as water quality and quantity and ecological functions that work at landscape scales, the amount of cover required for integrity is likely to be higher, not lower. Therefore, use of the precautionary principle is recommended.

There are other considerations. If all of the 30% forest cover is concentrated in one part of a watershed, does this mean the amount is adequate? In Graham Creek, the forest cover is fairly even in its distribution, although there is less in the vicinity of Newcastle. However, even distribution of patches can mean smaller and less connected patches overall. In fragmented landscapes there is always room for improvement in habitat cover, even if there is already more than the minimum standard. In short, although Graham Creek watershed has a good amount of forest relative to the 30% guideline and this cover is well distributed, there is still need for improvement in patch size, shape, connectivity. The use of GIS to undertake natural heritage system modeling is recommended to identify priority areas for natural cover improvement.

4.1.3 Grasslands and Thickets

Grasslands include cultural meadows, cultural savannas and cultural thickets as well as natural tallgrass prairie and savanna. The “cultural” communities are essentially stages of ecological succession as a disturbed landscape gradually reverts to forest. In many cases this amounts to abandoned agricultural fields, although cultural meadows may be fields that have simply been left fallow. These habitats play a role in overall watershed functions. They allow for reduced runoff, by slowing surface water runoff, filtering out sediments and reducing erosion.

Many species rely specifically on grassland habitats and some are of conservation concern. A decline in bird species associated with grassland and shrubland habitats across Ontario has been noted in the *Atlas of the Breeding Birds of Ontario, 2001-2005*. There are also declines in the Lake Simcoe-Rideau atlas study region, which includes the Graham Creek watershed (Cadman et al. 2007). This is part of a disturbing trend across eastern North America. These birds include Bobolink (*Dolichonyx oryzivorus*), Eastern Meadowlark (*Sturnella magna*), Upland Sandpiper (*Bartramia longicauda*), and a number of sparrow species. This change in grassland bird species abundance has been related to temporal landscape changes. Grassland bird species expanded with the clearing of forests in the 19th and early 20th centuries, however today, bird species associated with grassland habitat in Ontario appear to be declining (Cadman et al. 2007). This decline could be related to grassland and shrubland habitats becoming reforested, intensification of agricultural practices (e.g., improved pastures and increased cropping), and urban development (McCracken 2005).

Cultural meadows/grasslands make up 7% of the landscape in the Graham Creek watershed. As defined by ELC, cultural meadows contain less than 25% tree cover and less than 25% shrub cover, have a large portion of non-native plant species, and result from or are maintained through anthropogenic actions (Lee et al. 1998). Most of these are old fields that occurred from retired agricultural lands and other land that has been left fallow.

Cultural savanna and thickets make up 4% (1% and 3% respectively) of the watershed. Cultural savannas contain between 25% and 35% tree cover, have a large portion of non-native plant species, and result from or are maintained through human actions (Lee et al. 1998). Cultural thickets contain less than 25% tree cover and more than 25% shrub cover (Lee et al. 1998).

It is difficult to set cover targets for grasslands and shrublands. First, despite the conservation concerns associated with them, grasslands, in particular the cultural varieties, may actually be over-represented in southern Ontario relative to pre-settlement conditions when forest dominated the landscape. Second, because they are stages in ecological succession, maintaining an area as grassland would require active management, and to do this on a large scale would be impractical. It can be argued that if the goal is to improve forest cover relative to historical conditions, it may be a good thing that grassland and shrublands are undergoing succession. Indeed, cultural meadows may be prime areas for tree planting. Perhaps the best bet is to track habitat and land use changes, with the ultimate goal being to ensure that some form of each successional stage is well represented in the watershed or regional landscape. Furthermore, it may be advantageous to invest more in prairie restoration than in maintaining unnatural old field habitats.

4.1.4 Wetlands

Wetlands make up 10% of the Graham Creek watershed. Based on the ELC wetlands include meadow marsh, shallow marsh, deciduous swamps, coniferous swamps, mixed swamps, thicket swamps and bogs. Treed swamps must be counted twice when calculating the area covered by forest and wetland separately, because a swamp is often only seasonally flooded and the ecosystem therefore functions as both wetland and forest. Swamp area must then be subtracted when the combined area forest and wetlands is calculated. Three large wetland complexes exist in the Graham Creek watershed and are recognized by the province as significant (see Sections 4.1.7 and 4.1.8 for more detail).

Marshes are classified as having water depth less than 2 m, containing less than 25% tree and shrub cover, and dominated by emergent hydrophytic macrophytes (Lee et al. 1998). A meadow marsh contains plant species that are less tolerant to prolonged flooding, since soils become moist to dry in the summer. Meadow marshes are typically found in riparian zones and may form the transition point between shallow marsh and upland habitat. In shallow marshes standing or flowing water tends to remain all year. Dominant vegetation is typically cattail, although the invasive Common Reed (*Phragmites australis*) may take its place, especially in roadside marshes.

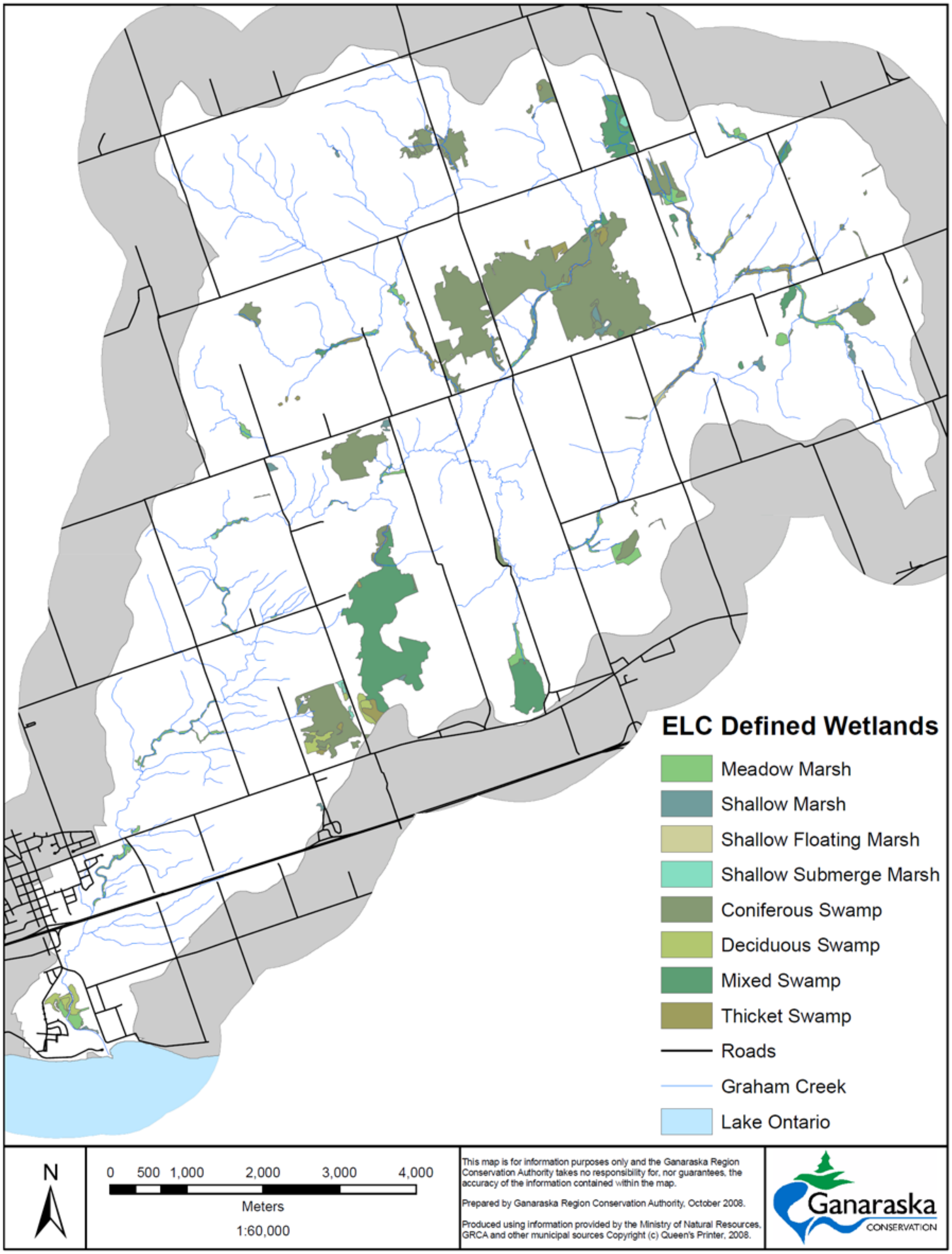


Figure 4.22: Wetlands

Swamps contain more than 25% tree or shrub cover and are dominated by hydrophytic shrub and tree species. Water depths are less than 2 m, with standing water or vernal pooling on more than 20% of the land base (Lee et al. 1998). Differences between swamp communities are based on tree canopy cover, tree species and the amount of tree cover. Table 4.7 describes wetland types in the Graham Creek watershed, and locations are shown in Figure 4.22.

Table 4.7: Wetland types

ELC Defined Wetland Type	Percentage
Meadow Marsh	0.7
Shallow Marsh	0.2
Coniferous Swamp	6
Deciduous Swamp	0.3
Mixed Swamp	3
Thicket Swamp	0.4

Swamps are the most abundant wetland type in southern Ontario, and in the Graham Creek watershed. Like other wetlands, many species rely on swamps for habitat. For example, they provide critical breeding areas for salamanders and frogs, and the cool, moist conditions required by birds such as the Northern Waterthrush (*Seiurus noveboracensis*) and Winter Wren (*Troglodytes troglodytes*). Some swamp species, such as Mallard (*Anas platyrhynchos*) and Wood Duck (*Aix sponsa*), are economically important (i.e. hunting opportunities). The diversity, species and abundance of flora and fauna that swamps as well as marshes provide is dependant on the size of the ecosystem (Table 4.8). As with other habitats, larger areas are likely to support a greater diversity of micro-habitats and larger populations, thus more species.

Depending on the terrain and geology, swamps contribute to aquatic habitats as well. Swamps provide groundwater discharge areas, providing an instream temperature regime required by native Brook Trout and other cold water fish species. Swamps also contribute nutrients, food and habitat to aquatic organisms in nearby streams. Similar to marshes, swamps also mitigate floodwaters and improve water quality.

Thicket swamps are low wet areas dominated by shrubs such as Red Osier Dogwood (*Cornus strolonifera*) and Speckled Alder (*Alnus rugosa*). These wetlands deserve special mention because they are the principle habitat of the Western Chorus Frog (*Pseudacris triseriata*) a tiny species that has been experiencing population declines throughout its range. In many cases thicket swamps are too small to pick up when interpreting aerial photographs, therefore the total cover for this wetland type may be deceiving. Even tiny thicket swamps can support an entire local breeding population of Chorus Frogs, therefore the value of these areas should be recognized.

Vernal pools can have a similar function to swamps, but on a smaller scale. These are ponds that are formed in depressions as a result of snowmelt and rain. Typically they dry up by mid to late summer. This means they are unsuitable for fish, which in turn makes them ideal breeding habitats for many species that would otherwise be subject to fish predation. Salamanders in particular rely on these habitats, and entire populations from surrounding woodlands may go to a single pond to breed in early spring.

Frogs such as Spring Peeper (*Pseudacris crucifer*) and Wood Frog (*Rana sylvatica*) rely on vernal pools and forest swamps for breeding. These amphibians are important elements of the food chain. Maintaining vernal pools and connectivity between these and upland forests is vital for the survival of populations. Vernal pools are increasingly being recognized as a conservation concern (Colburn 2005). However, because of their small size and the fact that they frequently occur in forests, they are difficult to map accurately. More work is needed to inventory and map these critical habitats.

Wetlands play an important function in any temperate watershed, and each wetland type contributes differently to the processes that are carried out. Marshes are very efficient in improving water quality, however efficiency depends on the location of marshes relative to overland flow, the substrate type within the marshes, dominant plant species, climate, and the retention time of the water within the marsh (Environment Canada 2005c). Marshes are also important in mitigating floods by storing flood waters and reducing flow velocity and ultimately peak flows in a water system (Environment Canada 2005c).

Environment Canada’s framework for guiding habitat rehabilitation (Environment Canada 2005c) recommends that watersheds should contain more than 10% wetland cover, which would suggest that the Graham Creek watershed in good shape. However, historically watersheds may have had more or less than 10%. The capacity for natural wetlands is based largely on topography and soils. In short, rather than see an increase in wetland cover of a certain percent, it may be possible to undertake a soil and slope analysis and combine this with what we know about hydrology to determine the capacity for an increase in wetland cover in the Graham Creek watershed.

Table 4.8: Wildlife use of various swamp and marsh sizes

Area	Forest/Treed Swamp	Marsh
1 ha	■ Edge tolerant mammals (Gray Squirrel) ■ Common edge-tolerant birds (Blue Jay, American Crow) ■ A few birds may be associated with mature trees (Black-capped Chickadee, Eastern Wood-Pewee)	■ Small populations of Muskrat ■ Edge-tolerant birds (Red-winged Blackbird, Canada Goose, Mallard) ■ Persistent and common herpetofauna (such as Green Frog and Midland Painted Turtle)
4 ha	■ A very few common edge-tolerant birds (Downy Woodpecker, Great Crested Flycatcher) ■ Eastern Chipmunk may be present	■ Similar species as above, but may also support Bullfrog
10 ha	■ Still dominated by edge-tolerant species may have very small areas of interior habitat supporting low numbers of modestly area-sensitive species (Hairy Woodpecker, White-breasted Nuthatch)	■ May support Marsh Wren, other waterfowl species
30 ha	■ May be large enough to support some species of salamander ■ Small populations of edge-intolerant species (Winter Wren, Brown Creeper, Black-and-White Warbler)	■ Similar marsh bird species as above, plus possibly Black Tern
50 to 75 ha	■ A variety of area-sensitive species may be present; some will be absent if there is no nearby suitable habitat ■ Still predominantly edge influenced, but will support small populations of most forest bird species ■ Some will be absent if there is no nearby suitable habitat	■ Least Bittern may be present in marshes of this size
100 to 400 ha	■ All forest-dependent bird species ■ Many will still be in low numbers and may be absent if there is no nearby suitable habitat ■ Woodland Jumping Mouse may be present	■ Small numbers of diving ducks possible (e.g., Redhead, Canvasback, Ruddy Duck)
1,000 ha	■ Suitable for almost all forest birds ■ Some forest-dependent mammals present, but most still absent	■ All marsh species, although some may still have small populations
10 000 ha	■ Almost fully functional ecosystem, but may be inadequate for a few mammals such as Gray Wolf and Bobcat (100 000 ha has been suggested as a minimum)	■ Fully-functional ecosystem

(Environment Canada 2005c)

4.1.5 Species at Risk and Species of Concern

Provincial legislation has provided for the identification and protection of Species at Risk in Ontario. The legislated purposes of the *Endangered Species Act, 2007* are:

- To identify Species at Risk based on the best available scientific information, including information obtained from community knowledge and aboriginal traditional knowledge
- To protect species that are at risk and their habitats, and to promote the recovery of species that are at risk
- To promote stewardship activities to assist in the protection and recovery of species that are at risk.

A number of Species at Risk have been identified in the Ganaraska Region Conservation Authority jurisdiction. The status of these species has been designated by the Committee on the Status of Species at Risk in Ontario (COSSARO), an independent body that assesses and classifies species at risk, and/or by the federal Committee on the Status of Endangered Wildlife in Canada (COSEWIC). A list of these species is found in Table 4.9.

Table 4.9: Provincially listed Species at Risk within the Ganaraska Region Conservation Authority

Scientific Name	Common Name	COSSARO Status	COSEWIC Status
Colinus virginianus	Northern Bobwhite	END	END
Rallus elegans	King Rail	END	END
Coturnicops noveboracensis	Yellow Rail	SC	SC
Lanius ludovicianus	Loggerhead Shrike	END	END
Ammodramus henslowii	Henslow’s Sparrow	END	END
Ixobrychus exilis	Least Bittern	THR	THR
Chlidonias niger	Black Tern	SC	
Haliaeetus leucocephalus	Bald Eagle	SC	
Melanerpes erythrocephalus	Red-headed Woodpecker	SC	THR
Dendroica cerulean	Cerulean Warbler	SC	SC
Vermivora chrysoptera	Golden-winged Warbler	SC	THR
Icteria virens	Yellow-breasted Chat	SC	SC
Wilsonia citrina	Hooded Warbler	THR	THR
Emydoidea blandingii	Blanding’s Turtle	THR	THR
St\ernotherus odoratus	Stinkpot Turtle	THR	THR
Graptemys geographica	Northern Map Turtle	SC	SC
Heterodon platyrhinos	Eastern Hog-nosed Snake	THR	THR
Tamnophis sauritus	Eastern Ribbonsnake	SC	SC
Lampropeltis triangulum	Eastern Milksnake	SC	SC
Danaus plexippus	Monarch Butterfly	SC	SC
Panax quinquefolius	American Ginseng	END	END
Juglans cinerea	Butternut	END	END
Platanthera leucophaea	Eastern Prairie Fringed Orchid	END	END

SC = Special Concern, THR = Threatened, END = Endangered

Many of the records for these species are historical, and there is a need to revisit some areas to determine if any individuals are still present. Should this be the case, the responsibility falls into the hands of the provincial or federal government, although local organizations including the Ganaraska Region Conservation Authority, can work with government authorities and landowners on stewardship measures to enhance protection for these species.

It is important to keep in mind that although Species at Risk are designated based on their national or provincial status, population declines frequently begin at the local level. There is a real need to gain a better understanding of the local status of sensitive species, and to develop a list of locally rare species. Such a list can help inform planning decisions such that populations of species are retained as components of healthy ecosystems. The habitats that support these should also be identified, along with any opportunities to protect them.

Finally, given the proximity to such a large body of water as Lake Ontario, all natural habitats in the Graham Creek watershed – particularly those in the southern portion - can have an elevated value as seasonal stopover habitats for migratory birds and Monarch Butterflies. For example, large numbers of individuals may wait for days at a time for optimum conditions to cross the lake, or require opportunities to feed and rest having crossed the lake on the journey north.

4.1.6 Invasive Species

In terrestrial habitats in the Graham Creek watershed the invasive species that are currently of greatest concern are plants, in particular Dog-strangling Vine (*Cynanchum rossicum)*, European Buckthorn (*Rhamnus cathartica)*, and Garlic Mustard (*Alliaria petiolata)*. All of these have a negative impact on biodiversity by colonizing natural areas and gaining a competitive edge over native species.

Dog-strangling Vine is spreading rapidly in the Ganaraska Region Conservation Authority. It can be found in habitats ranging from old fields to mixed and riparian forests. As is demonstrated at the Orono Crown Forest, it does particularly well in pine plantations where it can prevent understory growth and tree regeneration as well as hamper harvesting efforts. Garlic Mustard prefers moister, less acidic conditions and is a threat to riparian and hardwood forests. European Buckthorn is ubiquitous in much of southern Ontario because it was widely used in hedgerows and is spread as fruits eaten by birds. Control of all three of these and other invasive plants is difficult once they become well-established. Early detection and rapid response is the key. Infestations should be mapped, rate of spread monitored and response prioritized. Control efforts should be coordinated between organizations with an interest in invasive plant control.

Another invasive plant species that is relevant to the Graham Creek watershed is Himalayan Balsam (*Impatiens glandulifera*). This plant is found in ditches in the Port of Newcastle and is moving in to the eastern edge of the Port of Newcastle marsh. This plant can form dense thickets, displacing native wetland species.

Recent exotic insects of concern in Ontario include the Asian Long-horned Beetle (*Anoplophora glabripennis*) and the Emerald Ash Borer (*Agrilus planipennis)*. So far neither of these has been found in this part of the province, but either can have devastating impacts on forests. Sightings of insects thought to be these species should be reported immediately to the Canadian Food Inspection Agency.

4.1.7 Areas of Natural and Scientific Interest and Provincially Significant Wetlands

The Ministry of Natural Resources is responsible for determining Areas of Natural and Scientific Interest (ANSI) and provincially significant wetlands (PSW) (Figure 4.22). At present, the Ontario Wetland Evaluation System is used in conjunction with provincial scoring criteria to identify provincially significant wetlands and wetland complexes.

Environmentally Sensitive Areas (ESA) in the Graham Creek watershed was identified by the Ganaraska Region Conservation Authority during preparation of the 1983 Watershed Plan Resource Inventory. Lands were determined to be sensitive to disturbances from intensive land use such as urban development. A classification scheme was developed to determine the sensitivity based on soil erosion potential, presence of wetlands or recharge areas and wildlife production capability (Ganaraska Region Conservation Authority 1983). The ESAs identified in Figure 4.23 were classified as a medium environmental sensitive area based on the defined classification.

Clarke Summit Wetland Complex (PSW) and Clare Summit Swamp (ANSI)
The Clarke Summit Wetland Complex is a provincially significant wetland complex, made up of 11 individual wetlands. These wetlands are composed of swamps (99%) and marsh (1%). Totalling 146 hectares, the dominant vegetation is deciduous trees, tall shrubs and coniferous trees (Natural Heritage Information Centre 2008).

In the Clarke Summit Wetland Complex, 118 hectares is designated as the Clarke Summit Swamp ANSI. The physical setting of the Clarke Swamp ANSI is a shallow basin of poorly drained clay and silt which is seasonally flooded. On the east side of the basin is a small drumlin and a portion of its west flank forms a part of the ANSI. Other adjacent terrain is flat to rolling. A low ridge defines the western edge of the basin and the ANSI, and west of that ridge, several sand and gravel pits are present (Natural Heritage Information Centre 2008).

Port Newcastle Coastal Wetland
The Port Newcastle coastal wetland is a provincially significant wetland complex comprised of seven individual wetlands. These wetlands consist of two types, 42.5% marsh and 57.5% swamp (Natural Heritage Information Centre 2008). The dominant vegetation types are deciduous tress and narrow-leaved emergent plants. See Section 4.1.8 for more information.

Graham Creek Headwater Wetland Complex (PSW and ANSI)
The Graham Creek Headwater Wetland is a provincially significant complex made up of 42 individual wetlands and two wetland types, 85% swamp and 15% marsh (Natural Heritage Information Centre 2008). The dominant vegetation type is deciduous trees and tall shrubs. The total area of the wetland complex is 295 hectares. Of this, 200 hectares is designated an Area of Natural and Scientific Interest.

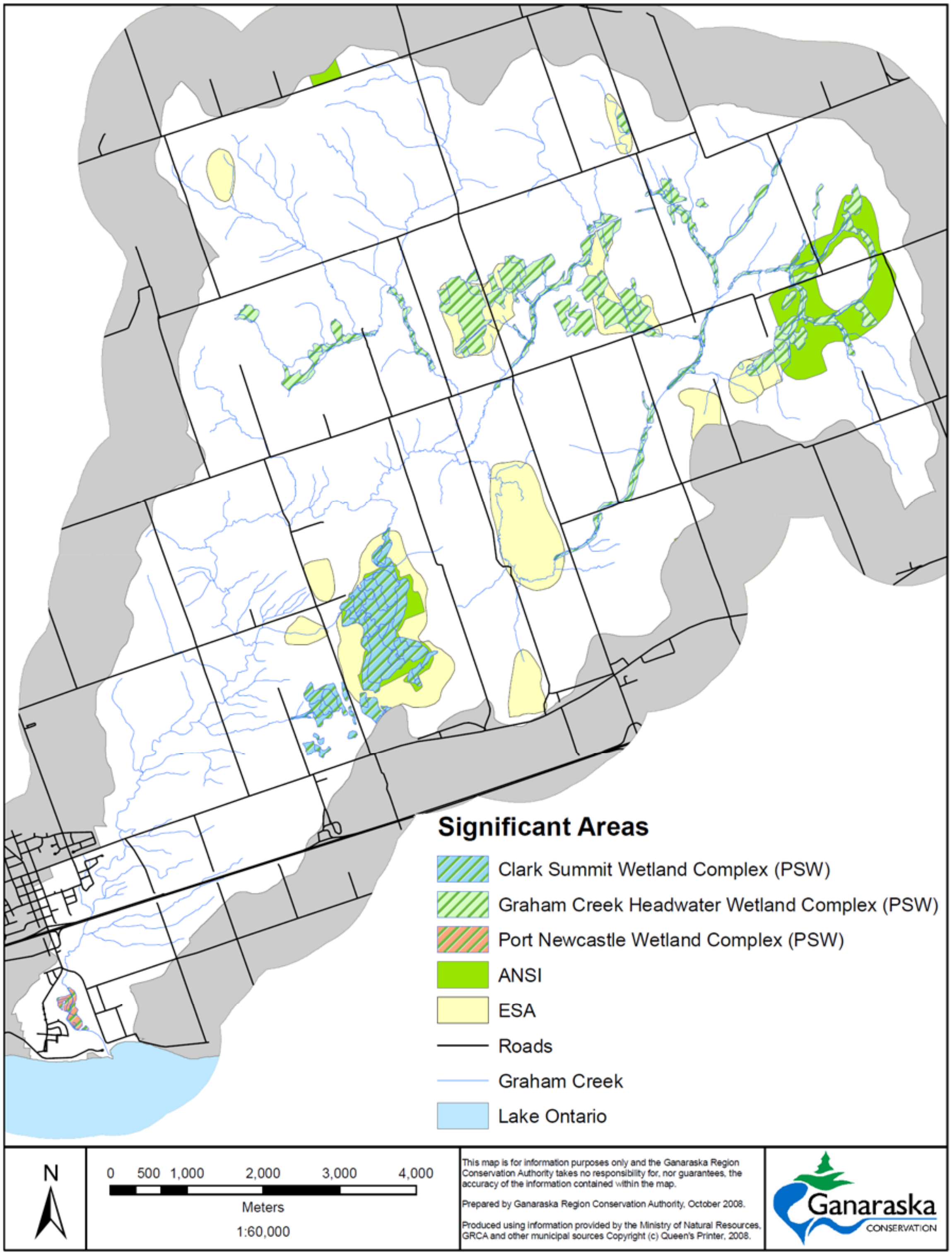


Figure 4.23: Provincially Significant Wetlands, ANSI and ESA

4.1.8 Coastal Wetlands

This section, including the Figure, has been taken with some adaptations from Environment Canada – Ontario Region (Canadian Wildlife Service) and Central Lake Ontario Conservation Authority 2004.

Port Newcastle Marsh is characterized as a drowned river mouth and is approximately 8 hectares in size. Drowned river mouth wetlands form where a river enters a lake, representing a zone of transition from stream to lake. These wetlands are characterized by meandering stream channels that are back-flooded during high lake levels (Environment Canada – Ontario Region (Canadian Wildlife Service) and Central Lake Ontario Conservation Authority 2004b). The wetland is flanked by residential development and a marina has replaced its southern portion (Figure 4.24). Graham Creek feeds into the wetland, supplying water that carries some excess nutrients but is quite clear and able to support a highly diverse community of aquatic macroinvertebrates. Many crustaceans and molluscs are common. Of particular interest were the high numbers of sensitive insect larvae, including caddisflies, mayflies, and dragonflies. Sediments are generally of good quality overall, despite slightly elevated pesticide residue.

The disturbance-sensitive Northern Leopard Frog occurs here. Other amphibian species that use the wetland in good numbers included American Toad and Green Frog. Port Newcastle Marsh has a limited capacity to support breeding bird species because of its small size. Nonetheless the area-sensitive Swamp Sparrow was present. In addition, the wetland appeared to support common marsh users such as Red-winged Blackbird and the not-so-common Great Egret.

With macroinvertebrate, bird, and amphibian communities in good condition, one would expect the fish community to be in good condition. Unfortunately, this does not appear to be the case. The fish community at the Port Newcastle Marsh resembled other impacted fish communities in the Regional Municipality of Durham coastal wetlands, illustrated by the deficiency of piscivores. In addition, the wetland appeared to support only a few native fish species and low numbers of important species such as Yellow Perch.


Figure 4.24: Port of Newcastle Marsh

Chapter 5 – CULTURAL CHARACTERISTICS OF GRAHAM CREEK

5.1 PRESENT CULTURAL CHARACTERISTICS

Present settlement patterns, communities and natural resource distribution play an important role shaping surrounding landscapes. This understanding will guide management decisions in the watershed in a localized manner.

5.1.1 Municipal Populations and Growth

Graham Creek flows through Ward 2 of the Municipality of Port Hope (formally Hope Township) in Northumberland County, and the Municipality of Clarington (formally Clarke Township) in the Regional Municipality of Durham, (Figure 5.0). In the Graham Creek watershed, 7 km^2 or 8.5% of the watershed area has a land use associated with settlement and growth areas (e.g., roads, railways, and urban and rural development), as defined by 2002 Ecological Land Classification mapping. The settlement area in Graham Creek includes Starkville, Crooked Creek, Brownsville and Newcastle. According to the 2006 Statistics Canada Census, there are 3,538 people living in the Graham Creek watershed, at a density of 46 people/km^2.

Both provincial legislation and municipal official plans have defined areas in the Ganaraska Region Conservation Authority that are expected to experience significant growth. The *Greenbelt Act, 2005* has designated Greenbelt planning areas in the Graham Creek watershed (Figure 5.0). The provincial *Places to Grow Act, 2005* has identified no urban growth centres in the Ganaraska Region Conservation Authority or in the Graham Creek watershed. In addition the *Oak Ridges Moraine Conservation Act, 2001* has provided further development directions in the Oak Ridges Moraine in the Graham Creek watershed (Figure 5.1).

Nevertheless, given its proximity to the Greater Toronto Area, the Ganaraska Region Conservation Authority watersheds, including Graham Creek watershed are expected to experience an increase in population. As a result, population projections are necessary to ensure that development and infrastructure occur at a sustainable rate for municipalities and the environment. Planning documents such as growth management strategies consider how much population and employment growth is expected to occur over a specific period of time, and then develop specific strategies for where and how this projected growth is to be accommodated. Municipal official plans also direct growth in the particular municipality.

Northumberland County

Northumberland County is the upper tier government that encompasses the Town of Cobourg, the Municipality of Port Hope, the Township of Hamilton and the Township of Alnwick/Haldimand, in the Ganaraska Region Conservation Authority. The Township of Alnwick/Haldimand is partially in the Ganaraska Region Conservation Authority. The population of Northumberland County in 2006 was 80,963 people (Statistics Canada 2007). By 2021 the population in

Northumberland County is expected to be 108,188 people (Northumberland County 2005).

Municipality of Port Hope

The Municipality of Port Hope was formed from the amalgamation of the Town of Port Hope and Hope Township in 2001. Today, the urbanized, former Town of Port Hope (Ward 1), and the rural Township of Hope (Ward 2), encompass an area of 279 km^2 (Statistics Canada 2007; Figure 5.2). The Municipality of Port Hope is contained within 12% of the Graham Creek watershed. The population has increased from 15,605 in 2001 to 16,390 in 2006, with a current population density of 58.8 people/km^2 (Statistics Canada 2007). It is estimated that 77% of the population of the Municipality of Port Hope resides in Ward 1 (Strategic Projections Incorporated 2002). The projected population growth in Ward 1 is found in Table 5.0.

Regional Municipality of Durham

The Regional Municipality of Durham is the upper tier region that encompasses the Municipality of Clarington. The Planning Department estimates that the population of the Region of Durham was 531,000 in May 2001. A target of 760,000 people has been estimated for the number of people living in the Region by the year 2011 and a target of 970,000 people by the year 2021 (Regional Municipality of Durham 2005).

Municipality of Clarington

The Municipality of Clarington represents one of the fastest growing communities in Ontario. Ward 4, of the Municipality of Clarington, located in the Ganaraska Region Conservation Authority, includes urban areas (Newcastle and Orono) and surrounding rural areas (Figure 5.3 and 5.4). The Municipality of Clarington is contained within 88% of the Graham Creek watershed. Clarington's population as a whole grew by 15.2% from 69,834 in 2001 to 77,820 in 2006. This reflects an annual growth rate of approximately 2.3% and a current density of 127.3 people/km^2 (Statistics Canada 2007). The 2006 population of Ward 4, of the Municipality of Clarington, was 13,773 people. The population is expected to grow within Ward 4 to approximately 19,700 in 2016, an increase of 43% from 2006 (Table 5.0). Most of this growth will occur in Newcastle Village (Municipality of Clarington, Personal Communications 2007).

Table 5.0: Municipal population projection

Region	Census Population	Population Projections	
	2006	2011	2016
Ward 4, Municipality of Clarington [A]	13,773	15,380	19,720
Municipality of Port Hope [B]	17,039	16,926	16,476

[A] Municipality of Clarington 2006
[B] Strategic Projections Inc 2002

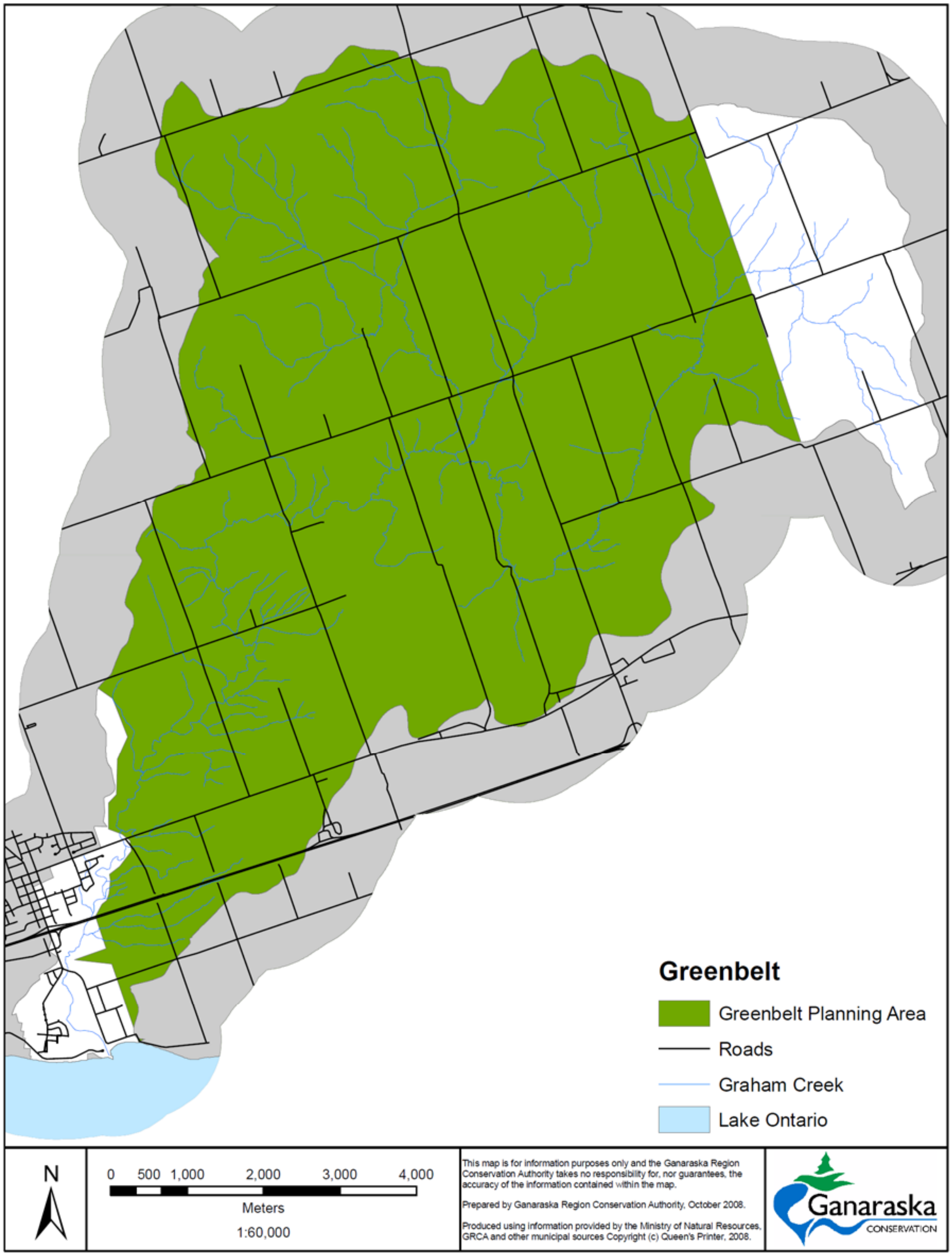


Figure 5.0: Greenbelt planning area

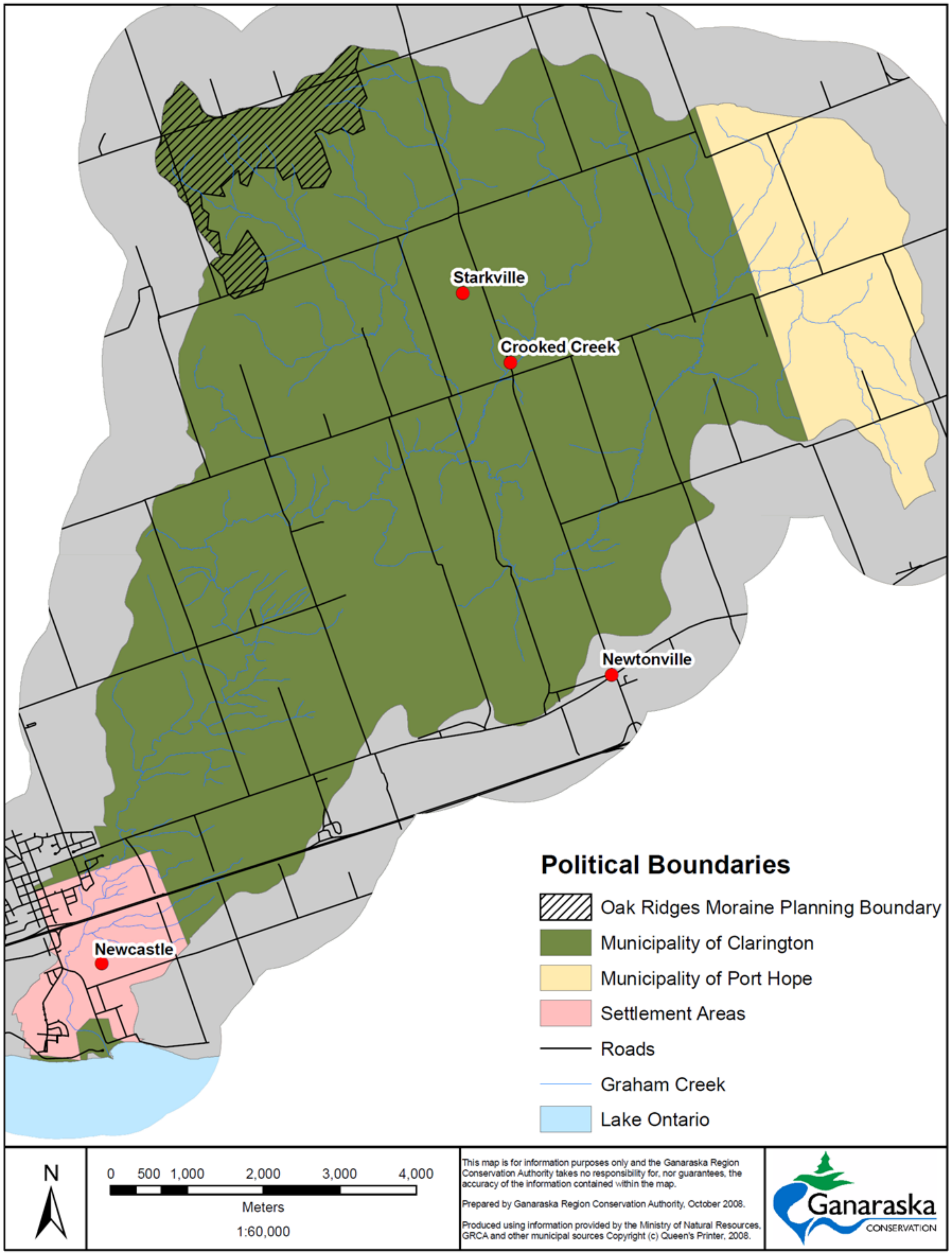


Figure 5.1: Graham Creek

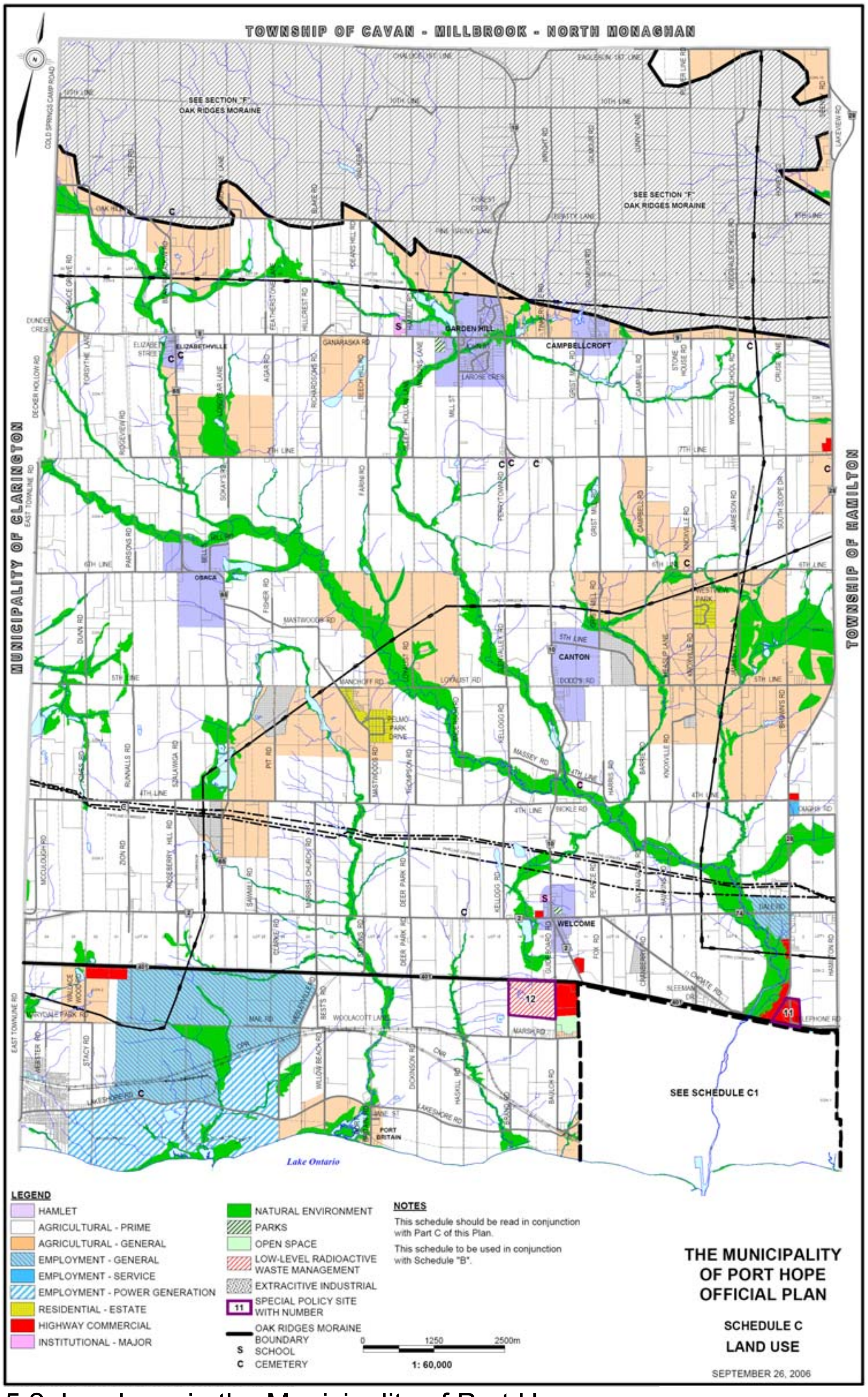


Figure 5.2: Land use in the Municipality of Port Hope (Municipality of Port Hope 2008)

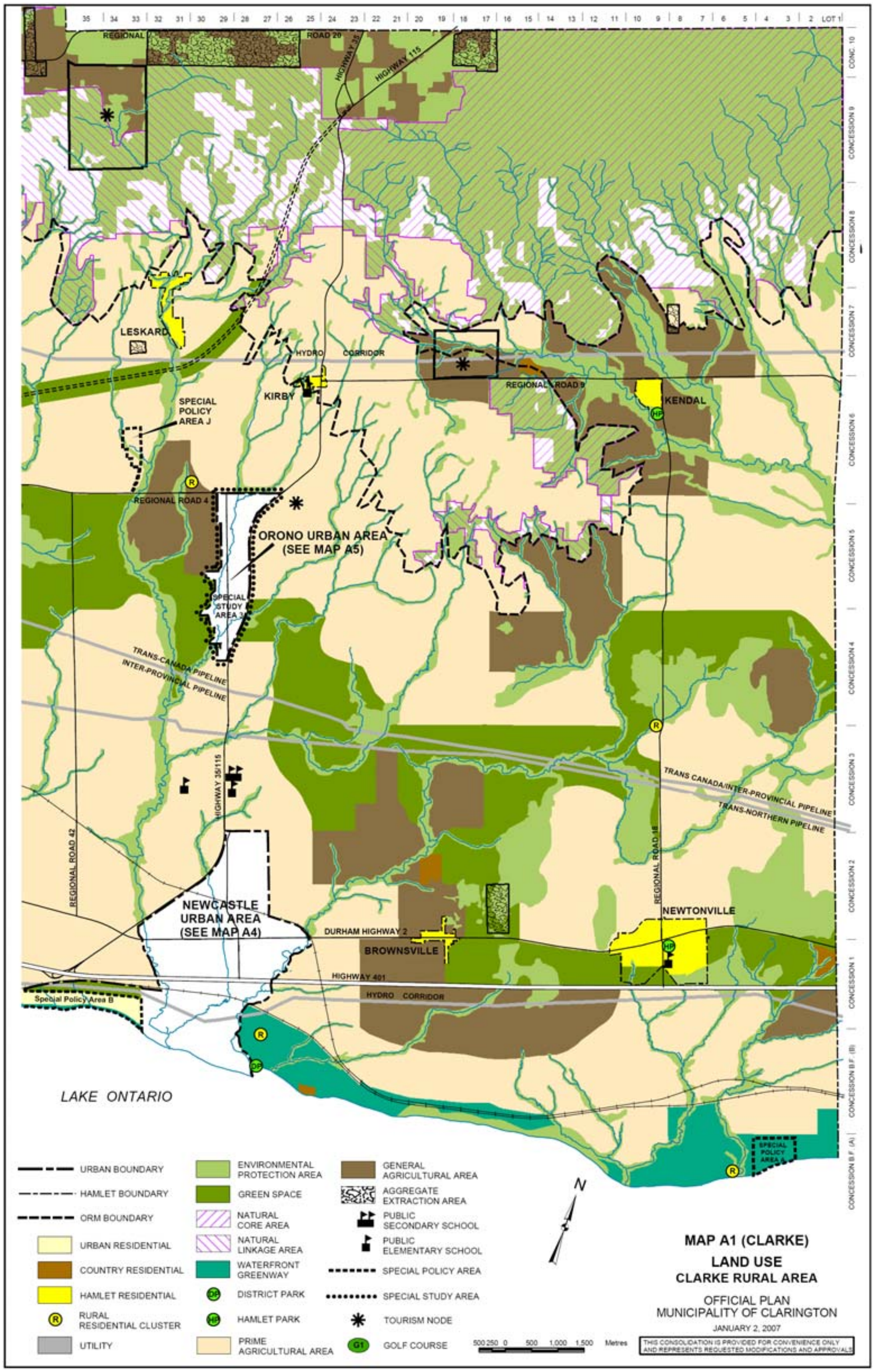


Figure 5.3: Land use in the Municipality of Clarington (Municipality of Clarington 2007)

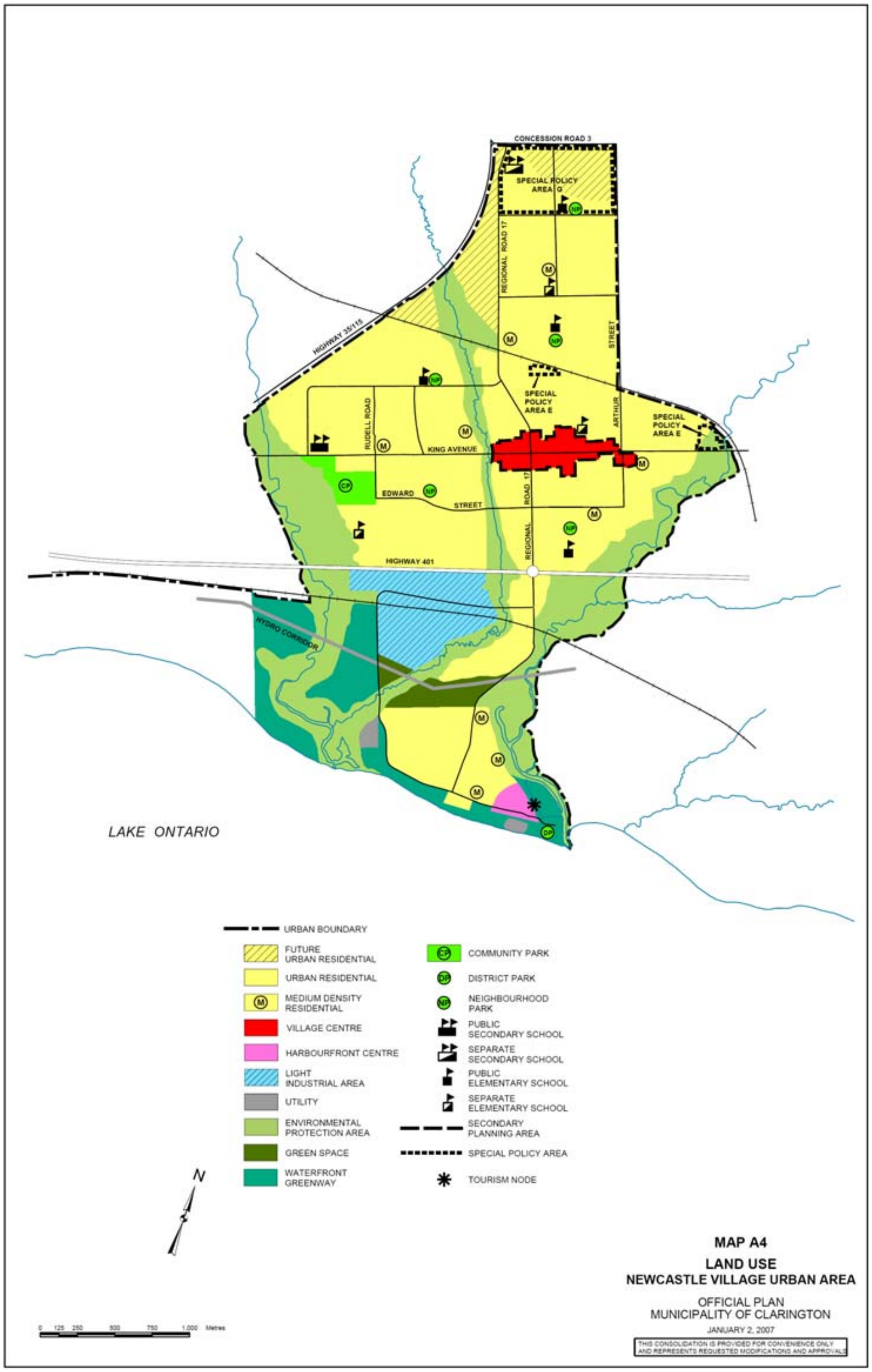


Figure 5.4: Land use in Newcastle (Municipality of Clarington 2007)

5.1.2 Industrial and Commercial Sector Distribution

Municipal official plans provide information about commercial and industrial developments that are subject to servicing studies and other necessary background information. In rural areas, tourism and agriculture remain the main industries, along with aggregate extraction. Figure 5.1 and 5.2 portray the locations of employment, commercial and institutional designated areas, identified tourism sites (e.g., parks), agricultural lands and aggregate-licensed areas.

The Municipality of Clarington, in its entirety, has five distinct industrial and business areas. Of these areas, the Newcastle Industrial Area is located in the Ganaraska Region Conservation Authority (Figure 5.3). The Municipality of Port Hope contains 2,500 acres of industrial land exists and currently 47 manufactures are located in the municipality (Municipality of Port Hope 2006). In Graham Creek these large industrial areas do not exist, however private businesses and industries are in operation. These include auto wreckers, recycling facilities, concrete and landscaping businesses, tourism, agriculture and recreation facilities.

Commercial use of groundwater and surface water exists in the Graham Creek watershed. Water use greater than 50,000 litres per day requires a permit from the Ministry of the Environment. Information on the use of water for commercial purposes is found in the Section 3.5.4 of this document.

5.1.3 Agriculture

Agricultural practices are the dominant land use in the Graham Creek watershed. Based on 2002 ELC mapping, agricultural land use covers 47% of the Graham Creek watershed (Figure 5.5). As indicated by Statistics Canada's 2006 census, agricultural production types and intensities varies throughout the Municipality of Clarington, however crop production prevails over livestock production (Statistics Canada 2008). Table 5.1 contains a breakdown of agricultural land use in the Municipality of Clarington in the Graham Creek watershed[2].

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[2] Statistics are not reported for the Municipality of Port Hope or Northumberland County, given the smaller land base within these municipalities, and the similar local agricultural practices between the Regional Municipality of Durham and Northumberland County.

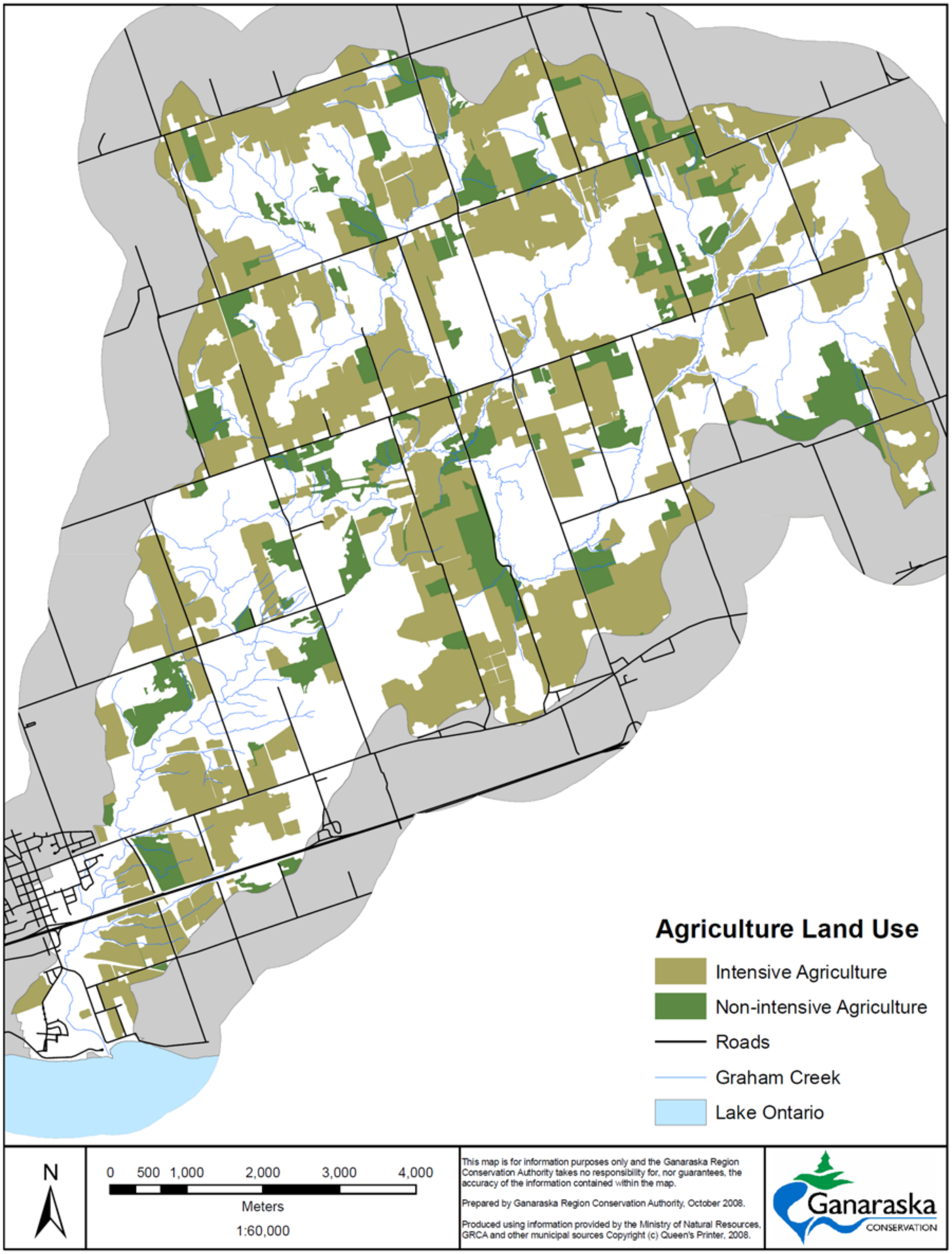


Figure 5.5: Agricultural land use

Please note that only portions of the Municipality of Clarington and Regional Municipality of Durham are in the Ganaraska Region Conservation Authority. Statistics related to agriculture will be reported at the regional level as many statistical reports are unavailable on a smaller scale. Similarly statistics are not available on a scale smaller that an entire municipality. However, activities are assumed to be constant across the municipality.

Table 5.1: Agricultural land use in 2006

Region	**Number of Farms**	**Land Farmed (Hectare)**
Regional Municipality of Durham [A]	1,686	132,212
Municipality of Clarington [A]	437	33.074

A – Only a portion of these areas are found in the Ganaraska Region Conservation Authority and the Graham Creek watershed.
(Statistics Canada 2008)

Agricultural Land
In the Regional Municipality of Durham most farm sizes are less than 53 hectares (1,080 farms), 417 farms are between 53 and 161 hectares, and 189 farms are greater than 162 hectares (Statistics Canada 2008). Of the total land farmed (132,212 hectares), 47,479 hectares of farmland are rented or leased in the Regional Municipality of Durham.

Crops and Livestock
Crops, including produce, are grown on 92,454 hectares of land in the Regional Municipality of Durham. The five most predominant field crops grown in the Regional Municipality of Durham include alfalfa and alfalfa mixtures, grain corn, soybeans, hay and fodder crops (oats, barley, mixed grains and corn silage) and winter wheat (Statistics Canada 2008). Yet, many other field crops are grown throughout the Graham Creek watershed.

Produce is also grown in both the Regional Municipality of Durham. A total of 683 hectares of fruit is produced, consisting predominantly of apples, raspberries, strawberries and grapes (Statistics Canada 2008). In 2006, major field vegetable crops grown in the Regional Municipality of Durham included sweet corn, tomatoes, pumpkins, and green or waxed beans. These crops were grown on 848 hectares of land (Statistics Canada 2008). Many other vegetable and fruit varieties are grown throughout the Graham Creek watershed; there are also floriculture (flowering plants), nursery, and sod production operations.

The Regional Municipality of Durham, in 2006, reported livestock production as dairy and beef cattle, pigs, sheep and poultry (chickens and turkeys) (Statistics Canada 2008); however, other livestock are raised and owned in the Graham Creek watershed including goats, horses, and bees (Statistics Canada 2008).

Dairy and beef cattle production are the predominant livestock raised in the Graham Creek watershed.

Agricultural Conservation Measures
In 2006, 13 farms in the Regional Municipality of Durham were reported as certified organic producers (Statistics Canada 2008) and additional 128 were reported as uncertified organic producers. Soil conservation is widely practised throughout the area, helping to mitigate soil erosion and surface runoff and to increase soil and crop productivity (Table 5.2). Many farmers in the Graham Creek watershed also participate in the Environmental Farm Plan and the corresponding funding programs to learn new best management practices and carry out stewardship projects on their lands.

Table 5.2: Farms in 2006 participating in soil conservation practices

Activity	Number of Farms Reporting
Total number of farms reporting	1,686
Crop rotation	917
Winter cover crops	206
Rotational grazing	554
Buffer zones around riparian areas	385
Windbreaks or shelter belts	511
Green manure crops for plough-down	316

* In the Regional Municipality of Durham

Agricultural production in the Ganaraska Region Conservation Authority and the Graham Creek watershed is ever evolving and shifting. The promise of increased crop prices in relation to ethanol and biodiesel production has seen marginal land being put back to crop production. The recent BSE crisis has seen many cattle producers leave the cattle industry or shift their efforts to cash cropping. Many dairy farmers have sold quota and ceased their dairy operations in the area. Continual shifts in crop markets are causing producers to bring more land into production, and trade concerns are causing farmers to question the stability of grain and oil seed productions across Canada. As a result, a trend to larger and fewer operations is evident in all sectors of the agriculture industry both in Ontario and in the Ganaraska Region Conservation Authority.

5.1.4 Infrastructure

Municipal infrastructure such as roads and bridges, utilities, landfills, water and wastewater services, and stormwater management facilities is all necessary in communities. Each utilizes natural resources or effects the natural environment in a different way. Infrastructure requires proper planning, management and development in order to sustain the local community and natural environment.

Transportation and Transmission Line Corridors
Provincial highways, Regional Roads, as well as local roads in the Graham Creek watershed are shown in Figure 5.5. Highway 401 and Regional Road 2 are the east-west transportation roads. Major north-south transportation corridors include Regional Road 18. The CPR and CNR railroads run west to east along the south half of the Graham Creek watershed (Figure 5.6). Many hydro corridors and stations exist in the Graham Creek watershed mainly running in a west to east direction and along transportation routes (Figure 5.6). The Enbridge Gas Line runs east-west through the Concession 3 of the Graham Creek watershed (Figure 5.3).

Roads are managed for the safe passage of people and goods. Provincial and municipal road standards direct the construction of roads, maintenance of existing roads and access to roads by private driveways. Roads can cause negative impacts on local streams in regards to stream crossings. Culverts are used to allow for surface water to drain under a road in such a way that running water does not causing road flooding or damage. Many culverts however are aging, and as a result of improper construction, or erosion have become perched. Perched culverts create a barrier to fish movement, since there is a vertical distance between the stream bottom and the bottom of the culvert at its downstream end. Roads also restrict the movement of stream channels. Naturally, a stream channel meanders through the creek valley and over time changes its position. With the placement of a culvert, the stream can not move naturally.

In the Graham Creek watershed, 20 perched culverts have so far been identified. Some culverts, due to their size, do not allow for the passage of woody debris, a necessary component of a healthy aquatic ecosystem. In addition, stream road crossings, and side roads are easy access point for illegal garbage dumping. This negative social action contaminates the local watershed with household garbage and hazardous waste such as electronics, tires, and appliances.

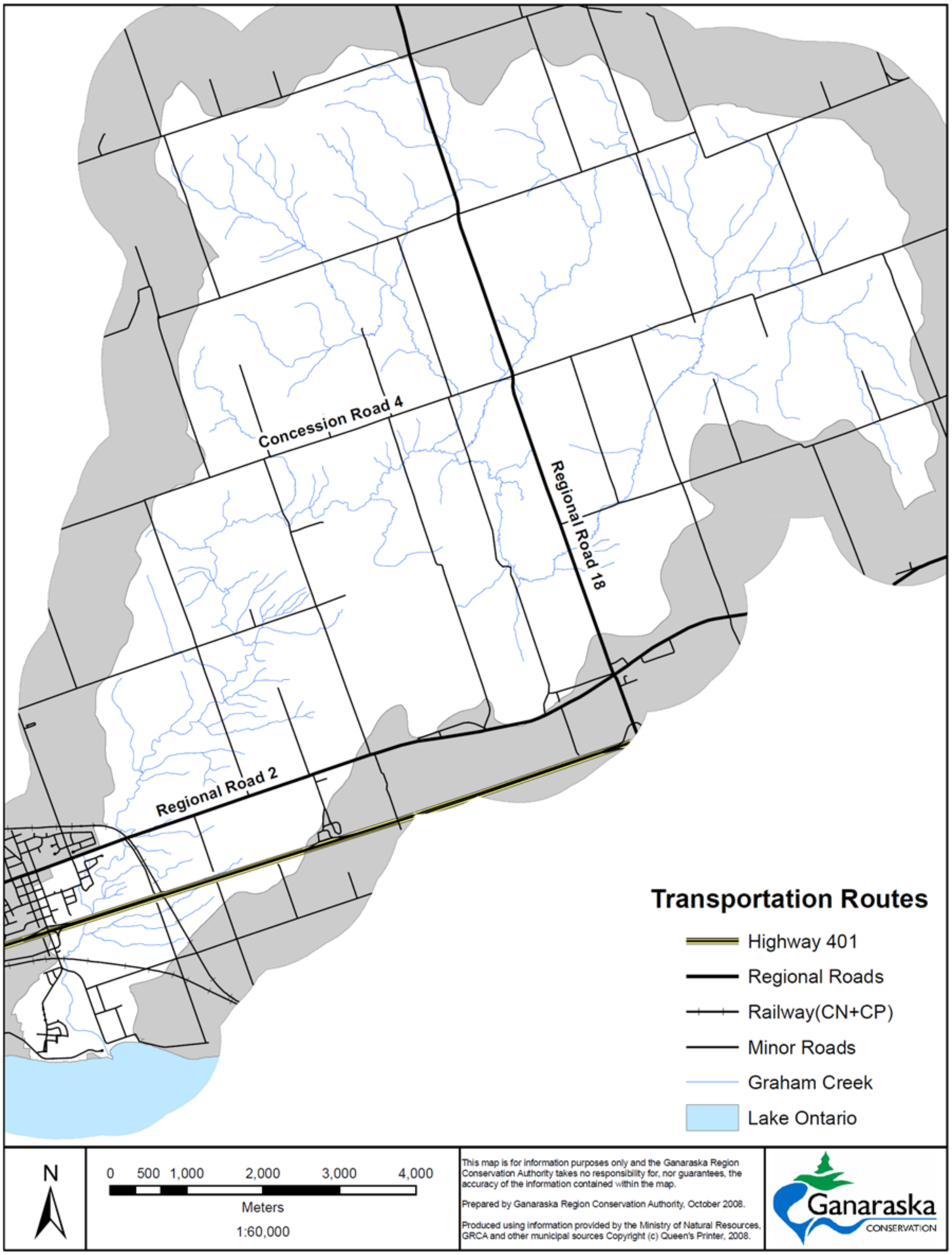


Figure 5.6: Transportation corridors

Winter Road Maintenance

Winter maintenance can have negative impacts on surface water and groundwater due to runoff from road salting and material storage locations. The Province of Ontario is responsible for the provincial highways (Highway 401 and Highway 115) in the Graham Creek watershed. The Regional Municipality of Durham are responsible for regional roads, and the Municipality of Clarington is responsible for all other roads.

The Province of Ontario manages its highways in the winter using best practices consistent with those used across North America, and employs the latest winter maintenance technologies (Ontario Ministry of Transportation 2005). Current information is not available to determine salting rates or other application methods of de-icing agents on Highway 401.

The Regional Municipality of Durham is responsible for Regional Roads 2 and 18, and follows a salt management plan to ensure that environmental regulations are followed when applying winter material and disposing of snow. No snow and sand dome are located in the Graham Creek watershed.

The Municipality of Clarington conducts winter road maintenance using a salt management plan (Municipality of Clarington 2005). The Municipality maintains a sand/salt mixture to between 10 and 15% ratios. One snow dump exists in Newcastle, with a capacity of 10,000 metric tonnes, which is located in the Graham Creek watershed (Municipality of Clarington 2005).

Landfills

Waste management in the Ganaraska Region Conservation Authority is primarily under the jurisdiction of the upper tier municipalities. There are no active landfills in the Graham Creek watershed. Three known historic landfills are located in Graham Creek. The Laidlaw Waste System landfill is located on 27.13 hectares of land with a filled area of 8.1 hectares (Marshall Macklin Monaghan Limited 1989). This landfill is located between Stapleton Road and Reid Road, south of Concession Road 4. During the mid 1950s landfilling started on the site which was previously used for gravel extractions, and filling continued until the early 1990s (Marshall Macklin Monaghan Limited 1989). The landfill accepted residential, commercial and non-hazardous solid waste. The other two landfills are detailed in Table 5.3.

Table 5.3: Historic landfills in the Graham Creek watershed

Landfill Name	Date of Operation	Size of Landfill	Size of Filling Area
Harold W. Couch Landfill Site	C of A issued in 1974, site closed in 1976	1.21 ha	0.81ha
Clarke Township Landfill	C of A expired in 1971	4.04 ha	2.02ha

(Municipality of Clarington, Personal Communications, 2007 – Data from 1991)

Water Treatment Plants and Private Wells
Figure 5.7 shows the municipal water serviced areas in the Graham Creek watershed. The Newcastle Water Supply System, operated by the Regional Municipality of Durham draws water from Lake Ontario to be treated for drinking water. The maximum daily permitted water taking from Lake Ontario is 8,180 m^3/d. The communities of Newcastle and Newtonville are serviced by the Newcastle Water Supply System. This area represents a serviced population of 7,846 people. The rest of the population in the Graham Creek watershed, not serviced by municipal water systems, relies on private water supply wells for drinking water (Figure 5.8. These wells draw water from either overburden or bedrock aquifers.

Wastewater Treatment
There is one wastewater treatment plant in the Graham Creek watershed, the Newcastle Wastewater Treatment Plant, which outlets into Lake Ontario (Figure 5.9. The rest of the population in the Graham Creek watershed rely on private septic systems. Currently, there is no specific data available about the number, concentrations, and other information of septic systems in the Graham Creek watershed.

Stormwater Management
Stormwater management facilities are normally associated with urban areas of the Graham Creek watershed where runoff is directed toward ponds, creeks and infiltration trenches. In rural areas, most of the runoff from roads and residential areas is directed toward ditches and other closed depression areas where higher infiltration rates are anticipated due to high permeability of surficial soils and topography.

Staff at the Ganaraska Region Conservation Authority review all development proposals to ensure they comply with requirements defined locally (through developed plans) and in provincial guidance documents. Both water quantity and quality, which affect aquatic habitats, are considered in any technical review. The general requirements for stormwater management are prescribed by the Ministry of Environment and are defined as follows:

> *"Stormwater Management is required to mitigate the effects of urbanization on the hydrologic cycle including increased runoff, and decreased infiltration of rain and snowmelt. Without proper stormwater management, reduced baseflow, degradation of water quality, and increased flooding can lead to reduced diversity of aquatic life, fewer opportunities for human use of water resources, and loss of property and human life."* (Ontario Ministry of the Environment 2003b)

Four Storm Water Management Plans exist in the Graham Creek watershed. One pond exists in the Port of Newcastle, two in the Dunbury Subdivision and one in the Estate subdivision. These ponds are used for water quality control, not all ponds are used for quantity control since the water is discharged into Lake Ontario, where quantity is not an issue. Limited long term management strategies have been developed for these ponds.

To meet urban development requirements, several Master Drainage Plans and hydrologic models have been developed for the watershed and for pond design. Infiltration targets, discharge targets and proposed facilities are defined. Please refer to the Surface Water Analysis section for more detail.

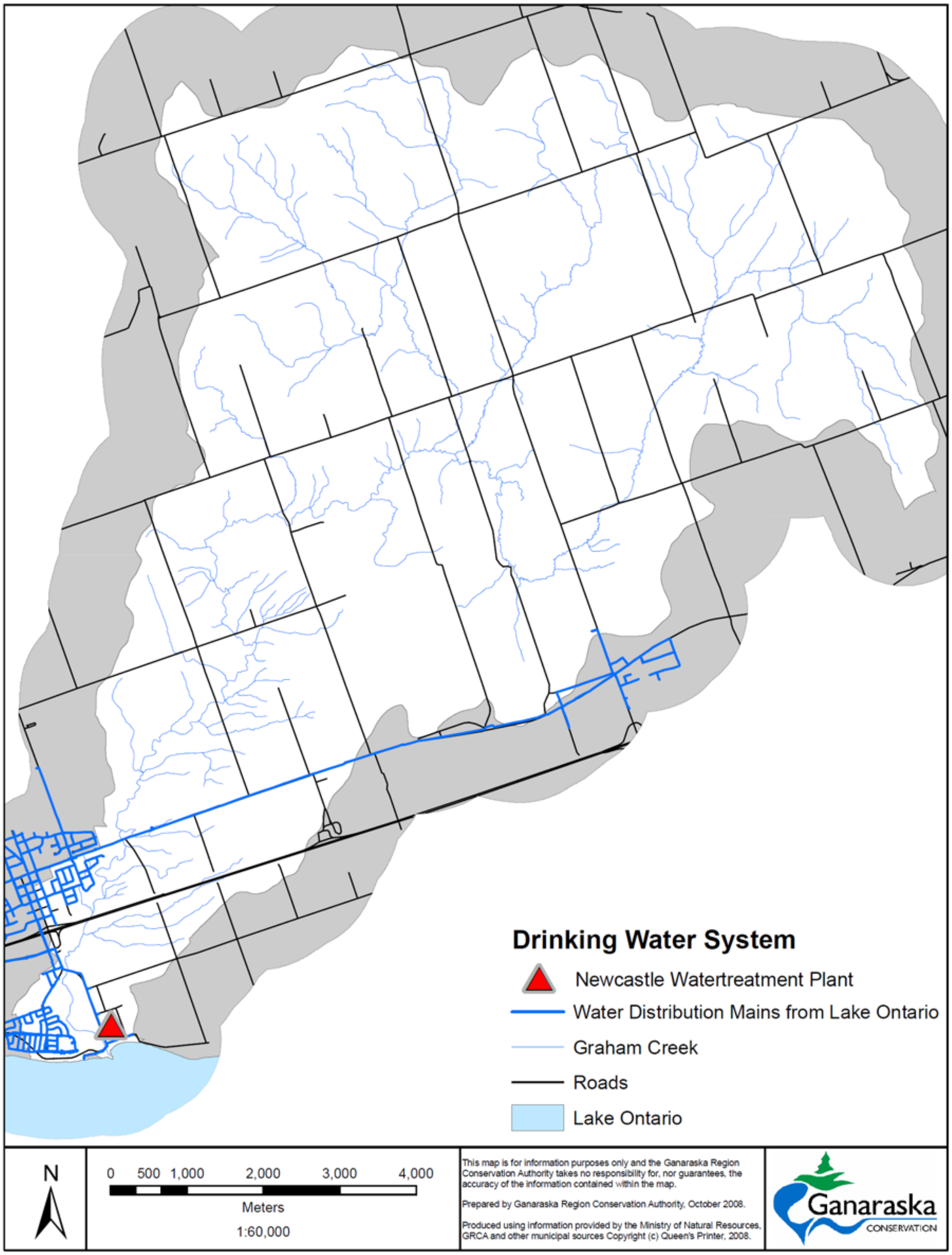


Figure 5.7: Water treatment plant

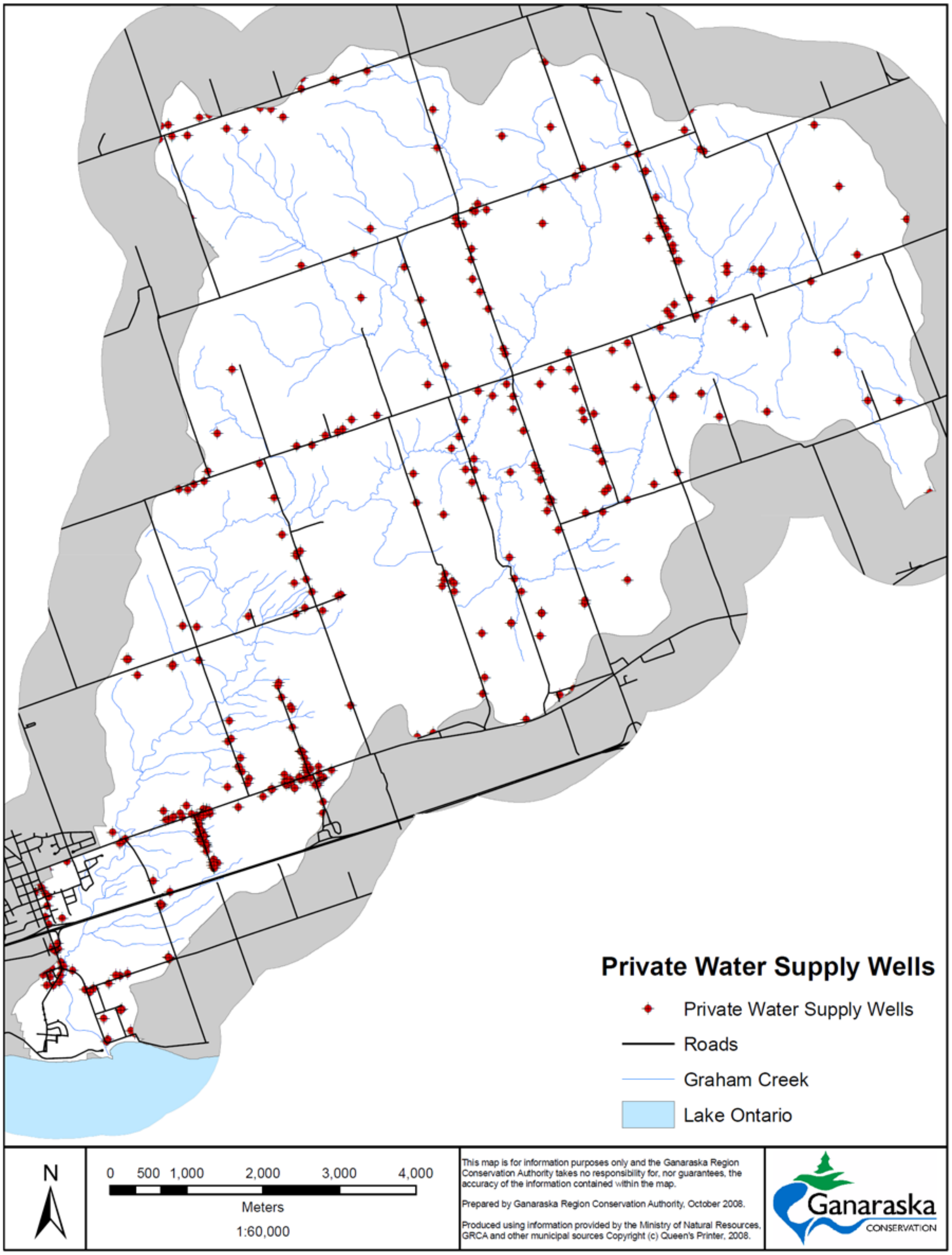


Figure 5.8: Private water supply wells

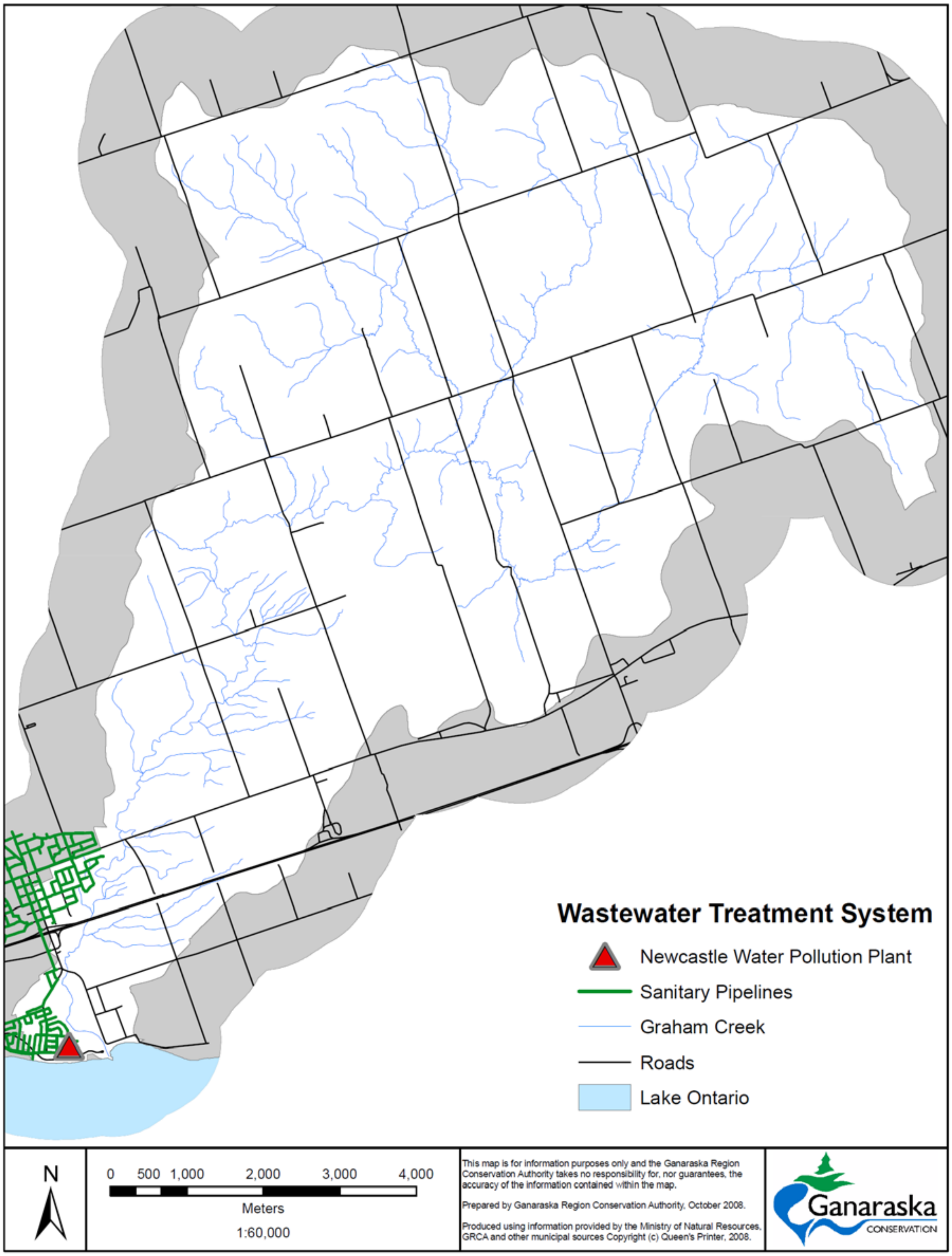


Figure 5.9: Wastewater treatment system

5.1.5 Natural Resources and Uses

The local environment is used by humans for many uses. Economies and communities are built around the extraction and conversion of natural resources for human use. Natural resources can be renewable (e.g., timber or water) or non-renewable (e.g., aggregates, oil and gas).

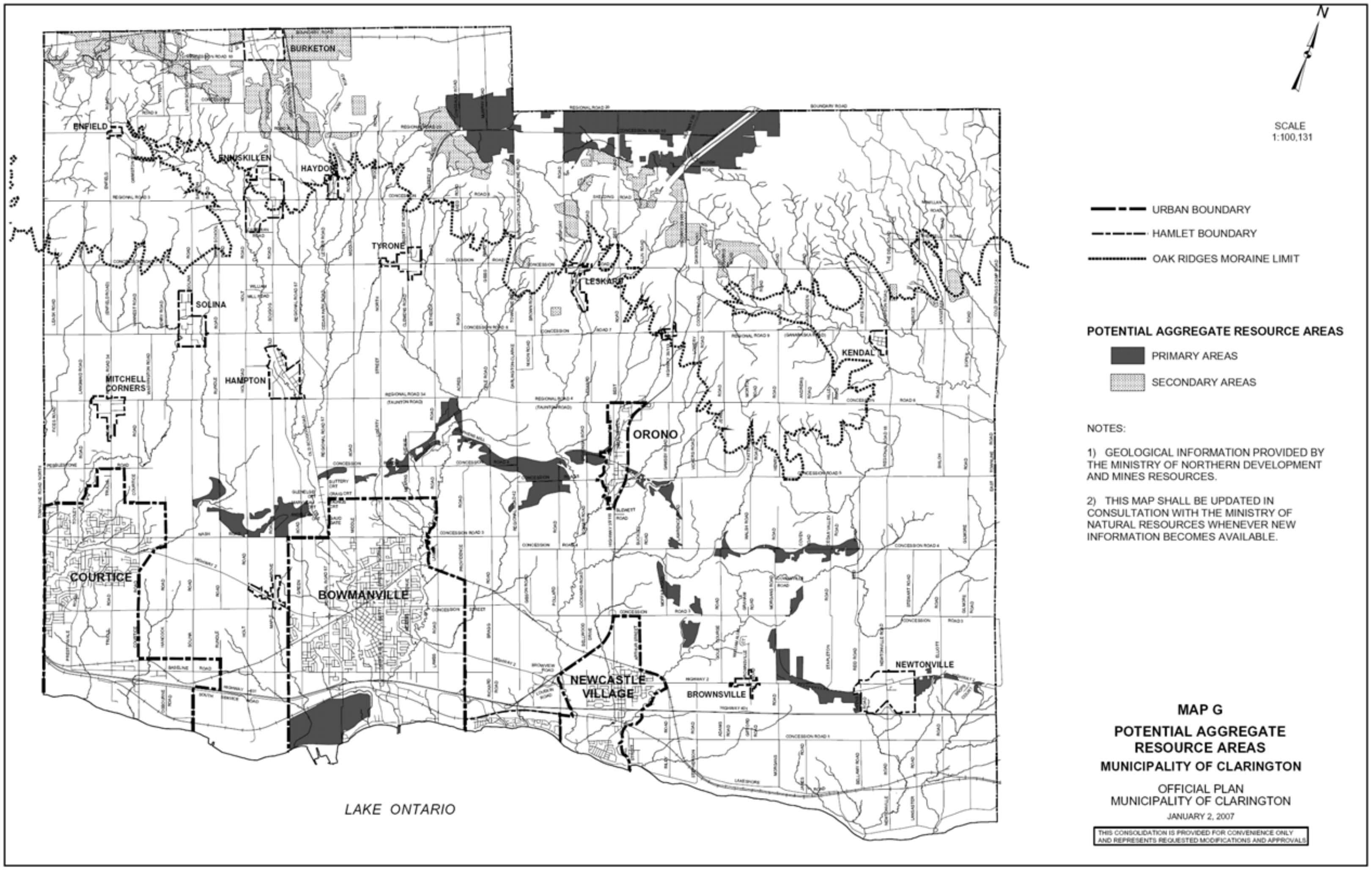
Aggregate Extraction, Oil and Gas

In the Graham Creek watershed the Iroquois Plain provide many aggregate resource opportunities (Figure 5.10). A total of 0.1 km^2 or 0.1% of the Graham Creek watershed is defined as an aggregate land use by 2002 Ecological Land Classification Mapping. The granular material contained in the Iroquois Plain region grades from fine sand to crushable, oversized gravels. The lateral extent and depths of beach deposits are variable. There are no bedrock quarries in the Graham Creek watershed due to the thickness of the overburden. Due to the nature and the depositional history of the area's geological formations, there is no oil and gas production in the Graham Creek watershed.

All municipalities have requirements on how new aggregate resource sites are developed. Many conditions are geared toward the protection of the natural environment, agricultural lands and public health and safety. The Oak Ridges Moraine Plan contains additional requirements as to which Oak Ridges Moraine land use designation aggregate resources can be developed in (e.g., natural linkage area and countryside area). Municipalities also have requirements on how a licensed aggregate is to close. The Ministry of Natural Resources regulates how an aggregate area is to be rehabilitated.

Forestry

Forestry resources in the Graham Creek watershed consist of private forestry operations and the harvest operations for personal use (e.g., firewood and lumber). Forest resource is also used for aesthetic purposes and food (e.g., fruit, maple syrup and nuts). There are no large scale harvest operations in the Graham Creek watershed.



(Municipality of Clarington 2007)

Figure 5.10: Potential aggregate resource areas

5.1.6 Conservation Areas

Certain lands in the Ganaraska Region Conservation Authority are designated as conservation areas. These properties are owned by the Ganaraska Region Conservation Authority and managed in cooperation with local municipalities. These lands are open to the public and have been created to satisfy many objectives. Objectives may include flood protection, mitigation, habitat creation, public education, and recreation. Currently, there are no Conservation Areas in the Graham Creek watershed.

5.1.7 Green Spaces

The amount and quality of green space in a watershed directly affect the health of a watershed. Green spaces contain permeable surfaces which can influence the hydrology of the area, especially in urban areas, and can provide habitat suitable to native flora and fauna. However, due to the potential of disturbance in these areas and the continuous use of these areas, invasive and exotic species have a higher potential of becoming established.

The amount and quality of green space available also have a positive relationship with human health and active lifestyles. Having opportunities to enjoy the outdoors is an important component of many people's lives, and can also have an indirect benefit of nature appreciation and increased education in local watersheds and environments. Activities such as hiking, fishing, skiing, cycling, horseback riding, nature appreciation, field sports, golf course, and more active activities such as ATVing and snowmobiling rely on green space.

For the purposes of this study, green space is defined as parkland and natural areas. Parkland represents areas that have been created for the purpose of providing recreational activities, and include active and passive recreational areas as well as existing and planned/proposed areas. Examples of parkland include municipal parks and playing fields. Natural areas are areas such as forests, wetlands, valleys and stream corridors, which exist or are planned and include naturalized areas. Infrastructure corridors such as hydro, utility and abandoned rail corridors are included in the green space system as these provide passageways (formal or informal) through otherwise impassable areas. A green space system can be created by linking these various areas, providing a continuous green space system that provides opportunities for wildlife movement, increased biodiversity and a connected green space system for the use and enjoyment of citizens.

In Graham Creek watershed there are three parks that are operated and owned by the Municipality of Clarington. These include the Bond Head Boat Launch, Walbridge Park, Brownsdale Community Hall.

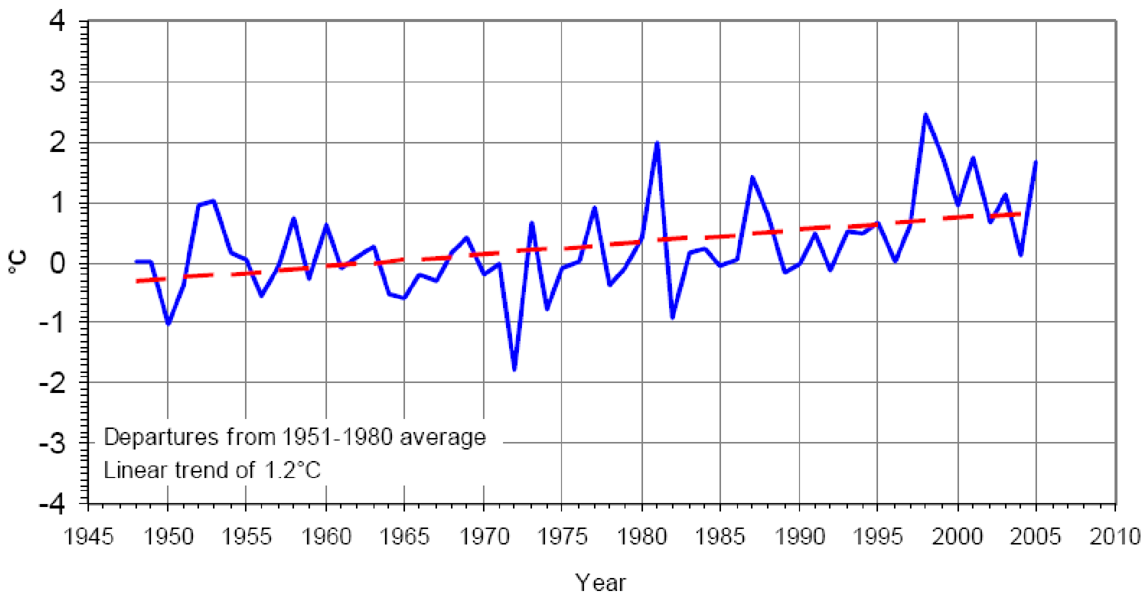
Chapter 6 - Graham Creek in a Provincial Context

6.0 Potential Climate Change Effects

Climate change is defined as a change of climate, which can be attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is, in addition to natural climate variability, observed over comparable time periods (Environment Canada 2006). Climate change is not a localized phenomenon. Occurring across the globe, effects have been felt by many different ecosystems and in many different countries. The *United Nations Framework Convention on Climate Change* (2008) summarizes global events that result from climate change.

- The average temperature of the earth's surface has risen by 0.74°C since the late 1800s. It is expected to increase by another 1.8 to 4°C by the year 2100. Even if the minimum predicted increase takes place, it will be larger than any century-long trend in the last 10,000 years.
- The principal reason for the increase in temperature is a century and a half of activities that have increased the amount of greenhouse gases in the atmosphere, especially carbon dioxide, methane, and nitrous oxide. Such gases occur naturally, keeping some of the sun's warmth from reflecting back into space, and without them the world would be a cold and barren place. But in augmented and increasing quantities they are pushing the global temperature to artificially high levels and altering the climate. Eleven of the last 12 years are the warmest on record, and 1998 was the warmest year.
- The current warming trend is expected to cause extinctions. Numerous plant and animal species, already weakened by pollution and loss of habitat, are not expected to survive the next 100 years. Human beings, while not threatened in this way, are likely to face increased difficulties. Recent severe storms, floods, and droughts, for example, appear to show that computer models predicting more frequent "extreme weather events" are on target.
- The average sea level rose by 10 to 20 cm during the 20th century, and an additional increase of 18 to 59 cm is expected by the year 2100. (Higher temperatures cause ocean volume to expand, and melting glaciers and ice caps add more water). If the higher end of that scale is reached, large populations will be displaced, coastal cities will disappear, and freshwater supplies will be destroyed for billions of people.
- Agricultural yields are expected to drop in most tropical and sub-tropical regions and in temperate regions too. This will cause drying of continental interiors, such as central Asia, the African Sahel, and the Great Plains of the United States. These changes could cause, at a minimum, disruptions in land use and food supply. And the range of diseases such as malaria may expand.

Similar climate change effects are seen in Canada. According to Environment Canada (2006), a warming trend of +1.2°C has been identified over the last 58 years in Canada (Figure 6.0). The year 2005 had the fifth highest national temperature departure since 1948, and 1998 was the warmest year (+2.5°C) during that period.



(Environment Canada 2006)

Figure 6.0: Annual Canadian temperature departures and long-term trend, 1948 to 2005

Since 1948, average annual temperatures in Ontario have increased as much as 1.4°C (Chiotti and Lavender 2008). This trend is projected to continue, with the most pronounced temperature increases occurring in winter. Projections also indicate that intense rainfall events, heat waves and smog episodes are likely to become more frequent (Chiotti and Lavender 2008).

Climate change can also be seen locally through the local Cobourg STP Environment Canada climate station. Figure 6.1 shows the maximum and minimum daily temperature average of a year, and an annual mean air temperature from 1973 to 2005. There is a significant increase in mean annual temperature since 1973 ($n=31$, $r=0.53$, $p = 0.002$). Although no study on climate change effects to aquatic and terrestrial ecosystems and habitats has occurred in the Graham Creek watershed, predicted changes in Ontario can be used to understand possible changes, outcomes and stressors. A glimpse at effects on water quantity has been gained through the water budget process (Section 3.5.4) by analyzing current water quantity data with Global Climate Change Models.

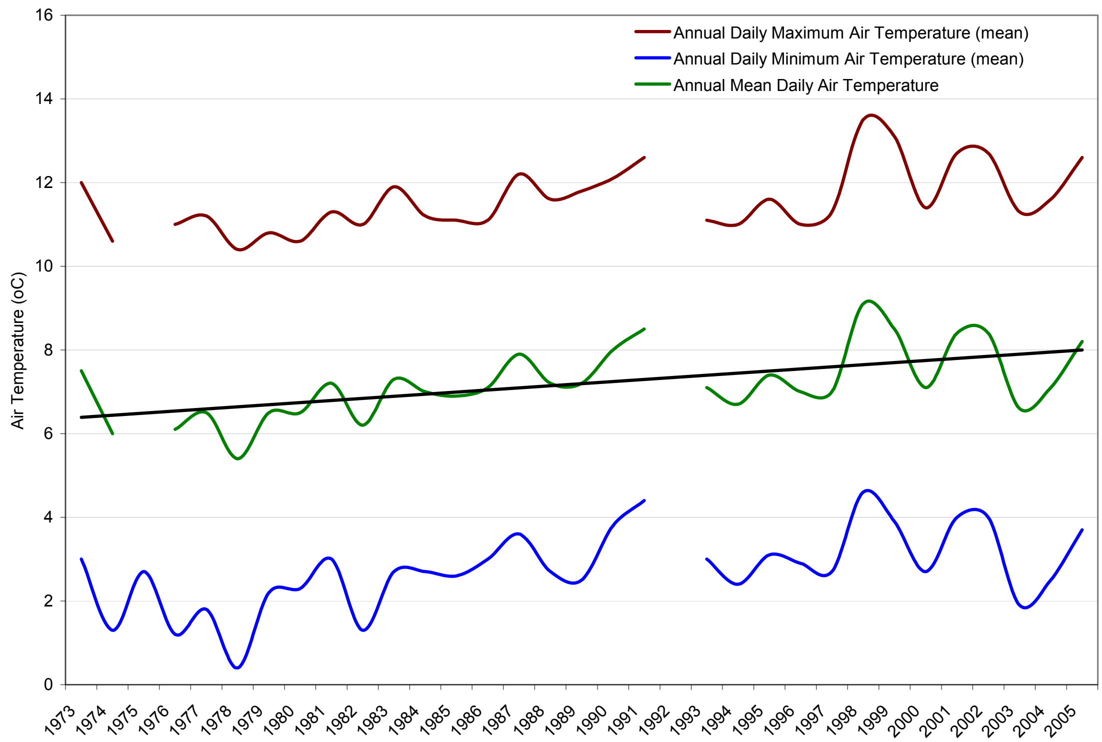


Figure 6.1: Annual average air temperature at the Cobourg STP Environment Canada Station, 1973 to 2005

Within the Great Lakes basin ecosystems change due to climate change has been noted, and is outlined by Chiotti and Lavender (2008).

- The ice cover season on the Great Lakes has been shortened by about 1 to 2 months during the last 100 to 150 years.
- Nearshore lake temperatures have increased at several locations since the 1920s. These increases are likely associated with extensive algae blooms and invasion of non-native species.
- Shifts in fish communities are expected to occur with declines in coldwater species in the Great Lakes. Warm water species such as bigmouth buffalo and flathead catfish are already being seen more frequently in the Great Lakes basin.
- Additional stressors on already fragile habitats such as coastal wetlands and terrestrial ecosystems may be unable to maintain their functions under increased climate change.

Changes are also expected for water resources in the Great Lakes basin, and will affect both groundwater and all surface water sources (Great Lakes, inland lakes, rivers, streams, and ponds). Table 6.0 outlines possible changes to water resources in the Great Lakes basin. Spring freshets and extreme rainfall events will also change the way streams respond under a flood. Increasing winter temperatures will possibly cause the spring freshet to occur earlier and because of more frequent winter thaws the freshet will likely be lower, reducing the risk of spring flooding (Chiotti and Lavender 2008). In addition, projected increases in the frequency and intensity of extreme rainfall events will result in increased summer flood risks.

Table 6.0: Expected changes to water resources in the Great Lakes Basin

Hydrological parameter	Expected changes in the 21st century, Great Lakes basin
Runoff	• Decreased annual runoff, but increased winter runoff • Earlier and lower spring freshet (the flow resulting from melting snow and ice) • Lower summer and fall low flows • Longer duration low flow periods • Increased frequency of high flows due to extreme precipitation events
Lake levels	• Lower net basin supplies and declining levels due to increased evaporation and timing of precipitation • Increased frequency of low water levels
Groundwater recharge	• Decreased groundwater recharge, with shallow aquifers being especially sensitive
Groundwater discharge	• Changes in amount and timing of baseflow to streams, lakes and wetlands
Ice cover	• Ice cover season reduced, or eliminated completely
Snow cover	• Reduced snow cover (depth, areas, and duration)
Water temperature	• Increased water temperatures in surface water bodies
Soil moisture	• Soil moisture may increase by as much as 80 percent during winter in the basin, but decrease by as much as 30 percent in the summer and fall

(Chiotti and Lavender 2008)

Many other negative impacts from climate change are predicted to occur (Chiotti and Lavender 2008). Risks to human health will come from temperature stress, air pollution, extreme weather events, vector and rodent borne disease, water borne diseases and Ultraviolet Radiation. Agriculture may see increases in pests and diseases, lower livestock productivity and changes in crop production in relation to growing seasons. Changes to energy consumption and production will occur, as will a decline in shipping and negative impacts on transportation corridors through increased temperature and extreme weather events. Finally, tourism in the southern Ontario is predicted to be effected by milder winters and shifts in warm-weather tourism industries.

Climate change presents challenges to Ontario ecosystems, communities and economic structure. Although these changes and their magnitude will be variable across the province, change will occur. As a result, ecosystems will need to adapt in order to survive increases in temperature, extreme weather and stresses to habitats (i.e., increases in invasive species and disease). The key to local ecosystems, flora and fauna, as well as humans handling changes in climate, is resilience and the ability to adapt. By preserving, enhancing and properly managing the Graham Creek watershed, resilient and healthy ecosystems will be able to better adapt to changes presented from a changing climate and many other current and future stressors.

6.1 Drinking Water Source Protection

The Ontario government has given Royal Assent to the *Clean Water Act, 2006,* which is aimed at protecting sources of municipal drinking water as part of the government's overall commitment to human health and the environment. A key focus of the legislation is the production of locally developed, science based assessment reports and protection plans (Ontario Ministry of the Environment 2007b). The need for legislation such as the *Clean Water Act* was spurred by the tragic events that occurred in Walkerton, Ontario in May 2000 when seven people died and thousands became sick from drinking municipal water that was contaminated with *E. coli*.

Assessment reports and protection plans will be written for specific planning regions, known as source protection regions or areas. The local source protection region, which includes the Ganaraska Region Conservation Authority is the Trent Conservation Coalition Source Protection Region (TCC SPR). Under the *Clean Water Act*, the Ganaraska Region Conservation Authority becomes a source protection area in the TCC SPR.

The Trent Conservation Coalition Source Protection Region is a grouping of five Conservation Authorities that comprise the Trent River watershed. The TCC SPR stretches from Algonquin Provincial Park in the north to Lake Ontario and the Bay of Quinte in the south, and includes the Trent River watershed, the Ganaraska River watershed, Wilmot Creek watershed, Cobourg Creek watershed, and several smaller watersheds that empty into Lake Ontario and the Bay of Quinte. The Source Protection Region is approximately 15,000 km^2.

Five Conservation Authorities comprise the TCC SPR (beginning from the northwest and moving in a general clockwise direction).

- Kawartha Conservation
- Otonabee Conservation
- Crowe Valley Conservation Authority
- Lower Trent Conservation
- Ganaraska Region Conservation Authority.

For the purpose of drinking water source protection planning, the TCC Source Protection Region has been enlarged beyond conservation authority jurisdiction to include the entire Trent River watershed. This includes the Gull and Burnt River watersheds, lying mainly in Haliburton County, as well as additional watershed areas draining southward to the Kawartha Lakes in the northern half of Peterborough County. Approximately 4,171 km^2 outside of conservation authority jurisdiction is included in the Trent Conservation Coalition Source Protection Region.

Although source protection plans will be created for a source protection region, the planning area of interest is municipal surface water intake zones, wellhead protection areas, significant groundwater recharge areas and highly vulnerable aquifers. These areas have been defined using defensible science based methods. The Newcastle Water Supply System have been studied as part of drinking water source protection and the Orono Water Supply System has had wellhead protection zones delineated for the purpose of protecting the sources of the municipal water supply. See section 3.3.2 for more detail on this study.

While the Graham Creek watershed plan process is taking place, work under the *Clean Water Act* framework will be occurring. A 24-member source protection committee will prepare terms of reference, an assessment report and a source protection plan for the Ganaraska Region Source Protection Area. The committee membership represents municipalities, farmers, small business representatives and a range of other stakeholders in the TCC SPR. Through the source protection committee, work will be completed to identify, assess and address risks to drinking water in municipal sources (i.e., wellhead and intake protection areas). Stakeholders such as local property owners can also participate through a number of different mechanisms.

Specifically, the terms of reference set out who is responsible for carrying out different activities. The terms of reference include strategies to consult with potentially affected property owners involve the public and resolve disputes. While the committee creates an assessment report, the committee will identify threats, issues and concerns in the planning region. This knowledge will be represented as implementation actions within the source protection plan.

As described by the Ontario Ministry of the Environment (2007b), source protection plans will generally be implemented through existing regulatory requirements or approvals, zoning by-laws, official plan amendments, education or voluntary initiatives. Source protection committees may decide that existing programs and activities, voluntary or otherwise, may not be enough to address some significant threats to municipal drinking water supplies.

If a scientific assessment shows that an activity poses a significant risk to a drinking water source, an approved source protection plan may restrict or limit certain activities on properties located in designated wellhead protection areas and intake protection zones. Activities that pose a significant risk to drinking water sources may be prohibited or may require a risk management plan before they can be carried out.

The source protection plan may be very similar to the Graham Creek Watershed Plan, but will differ in the fact that the source protection plan addresses issues surrounding municipal water sources, whereas the watershed plan will address watershed-wide ecosystem based concerns and issues. Plan implementation may occur simultaneously in some instances, when the action will protect similar resources or environmental features and achieve similar outcomes. While working with municipalities, the Ganaraska Region Conservation Authority will strive to reduce duplication between the plans and the resultant implementation tools and resources.

6.2 Lake Ontario

Lake Ontario is the final receiving lake in the Great Lake drainage basin, before water flows through the St. Lawrence River to the Atlantic Ocean (Figure 6.2). Lake Ontario is bounded by the Province of Ontario in Canada, and New York State and Pennsylvania State in the United States of America (Figure 6.3). With a total drainage area to Lake Ontario of 64,030 km^2, New York State has the largest drainage area to Lake Ontario (35,000 km^2), followed by Ontario (29,100 km^2) and Pennsylvania State (300 km^2 – upper Genesee River).

Lake Ontario is the smallest of the Great Lakes, with a surface area of 18,960 km^2 (7,340 square miles), but it has the highest ratio of watershed area to lake surface area. It is relatively deep, with an average depth of 86 metres and a maximum depth of 244 metres second only to Lake Superior (Environment Canada et al. 1998). Approximately 80 percent of the water flowing into Lake Ontario comes from Lake Erie through the Niagara River. The remaining flow comes from Lake Ontario basin tributaries (14%) and precipitation (7%). About 93 percent of the water in Lake Ontario flows out to the St. Lawrence River; the remaining 7 percent leaves through evaporation (Environment Canada et al. 1998).

In 1987, the governments of Canada and the United States made a commitment, as part of the *Great Lakes Water Quality Agreement*, to develop a Lakewide Management Plan for each of the five Great Lakes. The *Lake Ontario Lakewide Management Plan* is a binational, cooperative effort to restore and protect the health of Lake Ontario by reducing chemical pollutants entering the lake and addressing the biological and physical factors impacting the lake (Environment Canada et al. 2008).

(Great Lakes Information Network 2008)

Figure 6.2: Great Lakes drainage basin

(Environment Canada et al. 2008)

Figure 6.3: Lake Ontario drainage basin

Environment Canada et al. (2008) acknowledges the importance of watershed management to the health of Lake Ontario. A binational work plan for 2007 to 2011 recommends working with Conservation Authorities in the Lake Ontario basin to identify and promote watershed management strategies (Environment Canada et al. 2008) that will benefit and enhance Lake Ontario. In addition, many projects are currently being carried out in Graham Creek that will benefit the health and sustainability of Lake Ontario.

The Lake Ontario fishery is dependent on its tributaries for spawning and rearing habitat. Despite the trend of resource exploitation in the 1800s, there was a shift in resource management in the mid-1900’s when the *Great Lakes Water Quality Agreement* (between the United States and Canada) was signed in 1972. This agreement sparked a renewed interest in restoring the Lake Ontario ecosystem (Smith 1995). By the mid-1900’s few sport fishing opportunities existed and non-native salmonids were introduced in an attempt to restore biological balance and promote the creation of a fishery in Lake Ontario. Fish stocking and sea lamprey control conducted since the 1970s resulted in an increased abundance and diversity of fish (Smith 1995). To aid in the reduction of sea lamprey, a lamprey weir was installed and is operated near the outlet of Graham Creek.

It is envisioned that the Graham Creek watershed background document and management plan, as well as the Graham Creek Fisheries Management Background Document and Management Plan will provide needed information into the *Lake Ontario Lakewide Management Plan*, and management initiatives carried out on a watershed scale will benefit the health and sustainability of Lake Ontario.

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ACRONYMS AND GLOSSARY

AES	Atmospheric Environment's
ANSI	Area of Natural or Scientific Interest
AVI	Aquifer Vulnerability Index
CGCM	Canadian Global Climate Model
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
COSSARO	Committee on the Status of Species at Risk in Ontario
CWQG	Canadian Water Quality Guidelines
DA	Dissemination Area
DEM	Digital Elevation Model
ELC	Ecological Land Classification
EPT	Ephemeroptera, Trichoptera and Plecoptera
GCM	Global Climate Models
GIS	Global Information System
GRCA	Ganaraska Region Conservation Authority
GRWQMN	Ganaraska Water Quality Monitoring Network
LiDAR	Light detecting and Ranging
NHIC	Natural Heritage Information Center
OFAT	Ontario Flow Assessment Technique
ODWS	Ontario Drinking Water Standard
OMAFRA	Ontario Ministry of Agriculture, Food and Rural Affairs
(O)MNR	Ontario Ministry of Natural Resources
(O)MOE	Ontario Ministry of the Environment
OSAP	Ontario Stream Assessment Protocol
PGMN	Provincial Groundwater Monitoring Network
PPS	Provincial Policy Statement
PTTW	Permit to Take Water
PWQMN	Provincial Water Quality Monitoring Network
PWQO	Provincial Water Quality Objective
SWM	Storm Water Management
TCC SPR	Trent Conservation Coalition Source Protection Region
TSS	Total Suspended Solids
YPDT-CAMC	York, Peel, Durham, Toronto, Conservation Authorities Moraine Coalition

Units

cfu/100 ml	colony forming units per 100 milliliters
cms	cubicmetres per second
g/L	grams per litre
L/D	litres per day
masl	meters above sea level
mg/L	milligrams/litre
µs/cm	micro siemens per centimetre
µg/L	micrograms per litre

Glossary

Anthropogenic: human induced or caused.[7]
Aquifer: A water bearing formation that is capable of transmitting water in sufficient quantities to serve as a source of water supply.[4]
Aquitard: A low-permeability unit that contains water but does not readily yield water to pumping wells. Aquitards can restrict contaminant movement.[4]
Artesian aquifer: An aquifer that contains water under pressure resulting in a hydrostatic head above ground level.[4]
Baseflow: Streamflow that results from groundwater seeping into a stream.[4] Baseflow represents the discharge of groundwater to streams, supports flow in dry weather. The flow of streams composed solely of groundwater discharge.[5]
Bedrock: A general term for any consolidated rock.[4]
Cold Water Species/Habitat: Species with narrow thermal tolerance levels that are usually restricted to cold, highly oxygenated water. The temperature range for these species is from 10ºC to 19ºC.[9]
Community: An assemblage of interacting populations living in a particular locale.[5]
Confined aquifer: An aquifer that is bound above and below by deposits with significantly lower hydraulic conductivity.[4]
Confluence: The location where one stream flows into another.[5]
Contaminant: An undesirable chemical or biological substance that is not normally present in groundwater, or a naturally occurring substance present in unusually high concentrations. Common contaminants include bacteria and viruses, petroleum products, chlorinated substances, pesticides, nitrates and salt.[2]
Discharge: The volume of water that passes a given location within a given period of time.[1]
Drainage basin: The land area which contributes runoff to streams, rivers and lakes. Also called a watershed or catchment area.[4]
Drumlin: Oval hills of glacial till with smooth convex contours. In any areas the drumlins all point in the same direction, which is considered to be the direction of movement of the glacier, which formed them.[3]
Evapo-transpiration: The combined loss of water to the atmosphere from land and water surfaces by evaporation and from plants by transpiration.[4]
Floodlines: Lines on a watershed map depicting regional flow conditions based on a specific historical event (i.e., Hurricane Hazel).[12]
Floodplain: The area, usually low lands adjoining a watercourse, which has been or may be subject to flooding hazards.[12]
Fluvial: Of or belonging to rivers.[12]
Gauging station: The site on a stream, lake or canal where surface water data is collected.[4]
GIS (Geographic Information System): A map based database management system, which uses spatial reference system for analysis and mapping purposes.[4]

Glaciofluvial: Pertaining to glacial meltwater streams and their sedimentary deposits.[4]
Glaciolacustrine: Pertaining to lakes adjacent to glaciers and fed by glacial meltwater.[4]
Gravel: Rock particles between 4 mm and 76 mm in diameter.[4]
Groundwater flow: The movement of water through the pore spaces of overburden material or through faults and fractures in bedrock.[4]
Groundwater model: A computer model in which groundwater flow is characterized by numerical equations.
Groundwater recharge: The inflow to a groundwater reservoir.[4]
Groundwater reservoir: An aquifer or aquifer system in which groundwater is stored.[4]
Groundwater storage: Groundwater stored in aquifers.[4]
Groundwater: Water occurring in the zone of saturation in an aquifer or soil.[4]
Hardness: A measure of the concentration of divalent cations in water, (mainly calcium and magnesium).[4]
Headwaters: The origins of streams and rivers.[12]
Hydrogeology: The study of water below the ground surface.[12]
Hydrology: The study of surface water flow systems.[12]
Hydrograph: A graph that shows water level as a function of time.[4]
Hydrologic cycle: The circulation of water in and on the earth and through the atmosphere through evaporation, condensation, precipitation, runoff, groundwater storage and seepage, and re-evaporation into the atmosphere.[4]
Hydrostrati-graphic unit: A formation, part of a formation, or group of formations with similar hydrologic characteristics that allow for grouping into aquifers and confining layers.[4]
Infiltration: The flow of water from the land surface into the subsurface.[4]
Irrigation: The controlled application of water through man-made systems to supply water requirements not satisfied by rainfall.[4]
Macroinvertebrates: organisms with no backbone that are greater than 2 mm in size. Generally refers to Benthic organisms such as insects and mollusks.[6]
Nitrate (NO_3): An important plant nutrient and inorganic fertilizer. In water, the major sources of nitrates are septic tanks, feed lots and fertilizers.[4]
Non-point source contaminant: Contamination, which originates over large areas.[4]
Oak Ridges Moraine: A knobby ridge of sand deposited at the edge of a glacier by escaping meltwater; the Oak Ridges Moraine was formed by the Simcoe and Lake Ontario Ice Lobes meeting.[3]
Ontario Drinking Water Objectives: (ODWO): A set of regulations and guidelines developed by the Ontario government to help protect drinking water sources.[5]
Piezometer: A pipe installed in the ground and used to measure water levels and collect water.[4]
Pool: A section of a stream where the water has a reduced velocity, often with water deeper than the surrounding areas.[6]

Provincial Groundwater Monitoring Network (PGMN): A groundwater monitoring program operated with the Ontario Ministry of the Environment to record groundwater level changes over time, record groundwater quality and quantifies groundwater-surface water interactions.[5]
Provincial Water Quality Monitoring Program (PWQMN): A water chemistry monitoring program operated by the Ontario Ministry of the Environment in cooperation with municipal governments and agencies.[5]
Provincial Water Quality Objectives (PWQO): numerical criteria that act as chemical and physical indicators for a satisfactory level of surface water quality to protect all forms of aquatic life.[8]
Potable water: Water that is fit to drink.[4]
Precambrian: The period of geologic time that precedes the Cambrian Period (2,500 to 4,500 million years ago).[4]
Quaternary: Geologic period spanning the last 1.8 million years and characterized by alternating glacial and interglacial climates. It is divided into the Pleistocene and Holocene epochs.[11]
Recharge area: Areas where the water is absorbed into the ground and added to the zone of saturation.[4]
Riffle: A section of the stream with turbulent flow, usually with gravel, cobble or boulder bed material. Riffle sections are between pools and have faster moving water.[6]
Riparian Area: the land adjacent to a watercourse that is not normally submerged, which provides an area for vegetation to grown as a buffer to the land use alongside to the stream. It acts as a transitional area between aquatic and terrestrial environments, and is directly affected is affected by that body of water.[6]
Sand: Sedimentary particles ranging from 0.074 mm to 4 mm in diameter.[4]
Saturated zone: A subsurface zone in which openings in a soil or rock formation are filled with water.[4]
Settlement Areas: Urban areas and rural settlement areas in municipalities (such as cities, towns villages and hamlets) where development is concentrated and a mix of land uses are present and have been designated in an official plan for development. Where there are no lands that have been designated, the settlement areas may be no larger than the area where the development is concentrated.[10]
Silt: Sedimentary particles ranging from 0.054 mm to 0.002 mm in diameter.[4]
Streamflow: The surface water discharge that occurs in a natural channel.[4]
Subwatershed: A geographical area defining a single drainage zone in the watershed.[5]
Surface runoff: Water flowing over the land surface in streams, ponds or marshes.[4]
Surface Water: Includes water bodies (lakes, wetlands, ponds, etc.), watercourses (rivers and streams), infiltration trenches and temporary ponds.[2]

Till: unsorted or very poorly sorted sediment deposited directly from glacier ice. Tills usually have a fine fraction - known as the matrix - with particles ranging from sand to clay size, and a coarse or clast fraction with pebble- to boulder-sized material.[4]
Topography: The physical features, especially the relief and contours of the land surface.[4, 2]
Transpiration: The process by which water vapour escapes from living plants, principally the leaves, and enters the atmosphere.[4]
Turbidity: The amount of solid particles that are suspended in water and produce a cloudy appearance.[4]
Unconfined aquifer: An aquifer whose upper boundary is the watertable.[4]
Unsaturated zone: A soil or rock zone above the watertable, extending to the ground surface, in which the pore spaces are only partially filled with water.[4]
Warm Water Species/Habitat: Warm water habitat is classified as waters with temperatures above 25^{o}C.Warm water species are tolerant to these water conditions.[9]
Water balance: The accounting of water input and output and changes in storage of the various components of the hydrologic cycle.[4]
Water budget: A summation of input, output, and net changes to a particular water resources system over a fixed period of time.[4]
Watertable: The top of the saturated zone in an unconfined aquifer.[4]
Watershed: The land in the confines of drainage divides.[4]

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