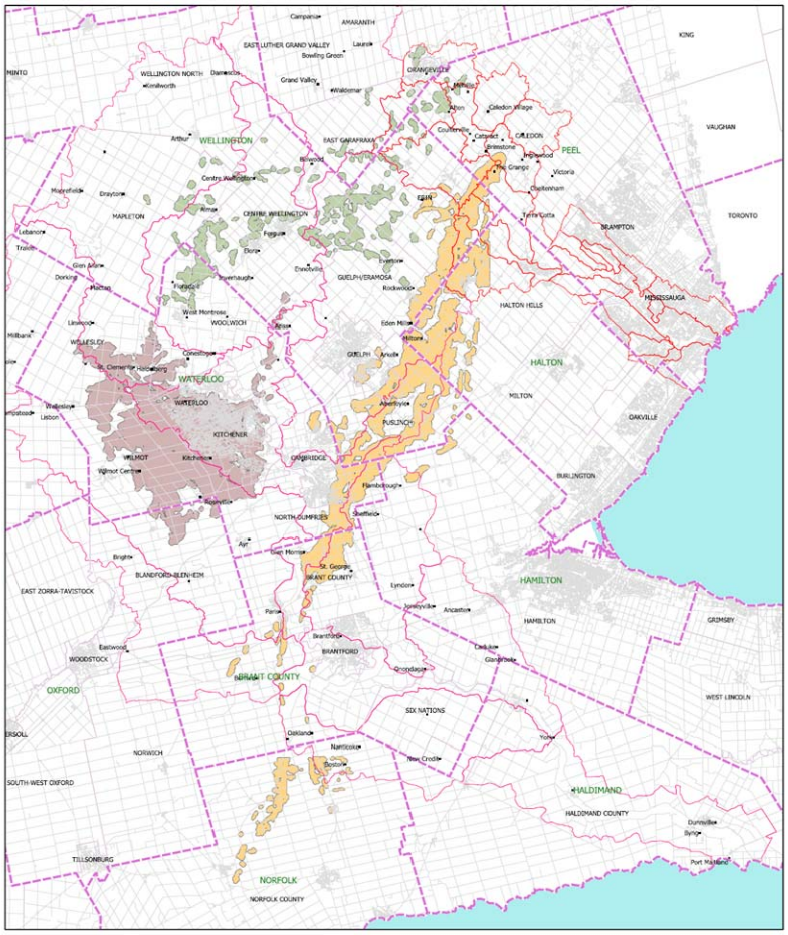
Review of the State of Knowledge for the Waterloo and Paris/Galt Moraines



February 2009

Prepared for:
Land and Water Policy Branch
Ministry of the Environment

Prepared by:
Blackport Hydrogeology Inc.
Blackport and Associates Ltd.
AquaResource Inc.

Ms. Barbara Anderson
Land and Water Policy Branch
6th Floor, 135 St Clair Ave West,
Toronto, ON
M4V1P5

February 27, 2009

Re: Review of the State of Knowledge for the Waterloo and Paris/ Galt Moraines Report

Dear Ms. Anderson,

The Team of Blackport Hydrogeology Inc., Blackport and Associates Ltd., and AquaResource Inc. are pleased to submit a final version of the ***Review of the State of Knowledge for the Waterloo and Paris/ Galt Moraines*** report.

On behalf of the project team, we appreciate the opportunity to work with you on this challenging and interesting project. Should you have any questions or comments on the content of this report, please feel free to contact me at your convenience.

Sincerely,

BLACKPORT HYDROGEOLOGY INC.

Ray Blackport, P. Geo.
President

PROFESSIONAL GEOSCIENTIST
RAY J. BLACKPORT
PRACTISING MEMBER
0915
ONTARIO

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1.0 Introduction

1.1 BACKGROUND

The Ministry of the Environment (MOE) received two Environmental Bill of Rights applications regarding the Waterloo Moraine and a similar application for a review of the Paris/ Galt Moraines. It is our understanding that as part of the MOE's continuing process to improve upon water-related best practices and policies, the MOE agreed to conduct a review of each "moraine" to determine if there is a need to develop additional provisions to protect groundwater and source water of the Waterloo Moraine and Paris/ Galt Moraines, beyond the current provisions in existing policies and legislation.

In response to the EBR applications, the MOE agreed to undertake a review of the need to develop new provincial policy or legislation to protect the Waterloo and Paris/ Galt Moraines, in order to protect groundwater functions in the Grand River watershed and, where applicable, other watersheds located along the Paris/ Galt Moraines. Several applicants also asked for a review of the Clean Water Act, 2006 and a review of the Provincial Policy Statement (PPS), 2005 developed by the Ministry of Municipal Affairs and Housing (MMAH). These requests were denied, as any legislation or policies made during the five years preceding the date of the EBR application for review are out of the scope of the review.

As part of the review, the MOE issued a Request for Resources for a "Review of the State of Knowledge of the Waterloo and Paris/ Galt Moraines" in support of the EBR Reviews. As outlined in the Request for Resources (RFR), the primary objectives of the EBR review are to:

1) Review existing policies related to protection of groundwater recharge; and,
2) Determine if there is a need for new provincial policy to protect the Waterloo and Paris/ Galt Moraines, in particular to protect groundwater and source waters from the potential impacts of development, including contamination, reductions in recharge, and the loss of existing groundwater volumes.

The focus of this RFR study is to conduct a review of the current state of hydrogeological information, for both the Waterloo Moraine and the Paris/ Galt Moraines, and determine if there are information/data gaps that could impede the implementation of existing policies or the development of new policies with respect to protection the Waterloo and Paris/ Galt Moraines.

1.2 STUDY OBJECTIVES

The primary objective of the overall review, as outlined in the RFR, is to provide background information on the state of knowledge of the general physical conditions and hydrologic functions of the Waterloo and Paris/ Galt Moraines. The objectives of the RFR review are to:

- summarize the state of hydrogeologic knowledge and determine gaps, if any, which would be required to be filled to enable policy to protect the Waterloo and Paris/ Galt Moraines;
- provide an overview of current and potential threats and impacts on the hydrologic functions of the moraines; and,
- review the best management practices and mitigative measures to protect moraine functions.

A report is to be prepared that will identify if there are information gaps in the current understanding of:

- the groundwater recharge, discharge and storage functions of each moraine;
- the linkage of moraine functions to surface water quality and quantity functions; and,

- current and potential threats to the moraine functions from urban and industrial development, aggregate operations, transportation, agriculture, and climate change (evaluation of site-specific developments are out of scope).

This background report will be used by the MOE to determine whether these information gaps are sufficient to impede adequate policy protection of the moraines.

As part of the RFR the MOE developed a terms of reference for each of the Waterloo and Paris/ Galt Moraines. The terms of reference outlined the following information as being within the scope of the requested study:

IN SCOPE
• Determining and summarizing the **current state of knowledge** with respect to: o identification and extent and boundaries of moraine (techniques for determining and status) o geology, hydrogeology (including ground water links to surface water), recharge and discharge o the degree to which features, functioning and water relationships of the moraine are understood (e.g. models, significance of hummocky terrain/kettle topography, interactions between groundwater and surface water, drinking water supplies, flood mitigation, maintenance of flows, ground water dependent ecosystems and ecological processes including, for example, cold-water fish habitat, significant recharge/discharge/storage areas (techniques and status), drinking water supplies, ecological functions, and trends in water quality and quantity)
• Documenting water quality and quantity conditions associated with the moraine: o Current conditions – e.g. existing programs for monitoring water quality and water quantity, trends in time and space o Evidence of stress or degradation – e.g. water shortages; declining water levels; contamination from de-icing salt, nitrates, pesticides o Significance of identified impacts, likely causes
NOTE: Scope could vary for existing urban areas vs. potential future urban/undeveloped areas

The MOE identified the following areas as out of scope for this study:

OUT OF SCOPE
• Direct discharges to surface water and water takings in Grand River watershed
• Natural heritage: protection of natural heritage features is part of the mandate of the Ministry of Natural Resources
• Terrestrial ecology
• Mapping the moraine and definition of boundaries
• New geological study of the moraine
• Sustainability of drinking water supplies
• Review of site specific development proposals on the moraine

1.3 STUDY AREAS

Figure 1.3.1 shows the approximate boundaries of the Waterloo and Paris/ Galt Moraines as presented in mapping produced by the MOE for this study. The general boundaries of the moraines were produced based on a combination of several criteria including, glacial depositional environments, topographic descriptions and material types described by the OGS in the Surficial Geology of Southern Ontario

(2003). One of these criteria is areas mapped as being “hummocky” on surficial geology maps. As a result, there may be specific areas included in the general mapping that are hummocky but may not be part of the Waterloo or Paris/ Galt Moraines. A graphical refinement of the moraine mapping provided by the MOE is not within the scope of this review. As indicated in Section 1.2, a component of this review is to assess the state of knowledge of the interpretation of the boundaries of each of the moraines. For the purpose of this study, the study area is generally defined by the aerial extent of the broadest interpretation of the each of the moraines and could include areas beyond the “footprint” of the moraine boundary, which may be interconnected through the aquifer system or through groundwater/surface water connections with local streams or the Grand River.

1.3.1 Waterloo Moraine

The study area is approximately 400 km^2 in size and is located almost entirely within the Region of Waterloo. The Region of Waterloo is made up of three major municipalities and four Townships as shown in **Figure 1.3.2**. The cities of Kitchener and Waterloo overlie much of the eastern portion of the Waterloo Moraine while the western central and western portions of the Waterloo Moraine are primarily in rural agricultural areas within Wilmot Township. The Waterloo Moraine is located in the central portion of the Grand River watershed.

The study area encompasses the general “footprint” of the Waterloo Moraine, including geologic units which may be above and below the depositional sediments associated with the formation of the Waterloo Moraine. The area also encompasses geologic units and areas that may be hydrologically connected to the Waterloo Moraine, including surface water features extending beyond the Waterloo Moraine to the Grand River. This is discussed in detail in Section 5.3. A discussion of the boundary aspects of the Waterloo Moraine is presented in Section 5.2.

1.3.2 Paris and Galt Moraines

The Paris/ Galt Moraine system has been interpreted to extend from the northeast, in the Caledon area of the Region of Peel, to an area southwest of Port Rowan, on the Lake Erie shoreline a distance of approximately 150 kilometres. **Figure 1.3.1** shows the distribution of the Paris and Galt Moraines as provided by the MOE for this review. Details of the criteria used for this mapping are presented in Section 6.2.1. The study area encompasses the general “footprint” of the Paris/ Galt Moraines as it relates to those criteria. The Wentworth Till of Paris/ Galt Moraine system extends south of the map area to the southwest of Port Rowan as a surficial unit but without any significant topographic structure. It is also recognized that certain moraine footprints north of Burford and in central Guelph are not considered part of the Paris/ Galt Moraines (Bajc, 2008a).

The Paris/ Galt Moraine system extends across the upper tier municipalities of Peel, Halton, Wellington, Waterloo, Brant and Norfolk and the Cities of Guelph and Cambridge. It is found within parts of four subwatersheds in the Credit River watershed (CVC), six subwatersheds in the Grand River Watershed (GRCA) and several smaller subwatersheds within the jurisdiction of the Hamilton, Halton and Long Point Conservation Authorities.

1.4 SCOPE OF WORK & METHODOLOGY

The following agencies or government organizations were interviewed and/or provided data and reports to be reviewed:

- Ministry of the Environment

- Ministry of Natural Resources
- Grand River Conservation Authority
- Credit Valley Conservation Authority
- Regional Municipality of Waterloo
- County of Wellington
- City of Guelph
- Region of Waterloo
- Region of Peel
- Hamilton/Halton Source Protection
- Ontario Geological Survey

The reports and data were reviewed primarily within the context of the understanding the moraines related to the following:

1. Hydrogeological characterization including geological history, hydrostratigraphy and groundwater flow.
2. Aquifer delineation including groundwater availability and water quality within the moraines and connections to underlying or adjacent aquifers.
3. Recharge potential within the general moraine footprint and the general water budget associated with the moraines.
4. General groundwater connection of the moraines to surface water sources including streams, lakes and wetlands.
5. Existing impacts on the moraine function due anthropogenic activities including urban development, industrial development, aggregate operation and agriculture. The general performance of existing management practices incorporated to mitigate or prevent impacts was also reviewed.
6. The potential impact of climate change.

The availability of data, pertinent reports and knowledge associated with the moraines, general functions, and potential impacts is critical in this hydrogeologic study, as it is in any hydrogeologic assessment. It is inevitable that significant pertinent data and knowledge exists related to this study that was not practically available during the time frame of this assessment. This is an inherent limitation of the groundwater knowledge/database within the province and to an unfortunate extent both nationally and internationally. The discussion of this limitation is based on the authors numerous extensive literature reviews for various studies over the past decades. This issue has also been highlighted during various reviews of the state of groundwater knowledge (e.g. Rivera, 2005; International Association for Great lakes Research, 2002; Crow et al, 2003).

As part of this review, a general presentation of hydrogeological concepts and an overview of groundwater issues related to potential impacts from land use activities is provided. This discussion is not meant to be an exhaustive presentation, given the volumes of material available in the literature, but is meant to provide a basic technical understanding for a more general audience.

2.0 Hydrogeologic Concepts

2.1 HYDROLOGIC CYCLE

The water on, above, and below the surface of the Earth is always moving, and the cycle of water movement is known as the hydrologic cycle. **Figure 2.1.1** shows a generalized example of the hydrologic cycle.

One of the processes in the hydrologic cycle is the process of **evaporation**, where water moves from a liquid on the surface of the Earth, to a vapour into the atmosphere. As the moist air is lifted into the atmosphere, it cools and the water vapour condenses forming clouds, and the moisture is then returned to the surface of the Earth as **precipitation**. Once the water reaches the surface of the Earth it can either: evaporate back into the atmosphere; travel along the ground surface and **runoff** into lakes, river and streams; or, it can move down through the soil and to the groundwater system. Groundwater flows through the subsurface in pores and fractures and eventually discharges into streams, rivers or lakes. It can be released back into the atmosphere through **transpiration** (the release of water back to the atmosphere by plants) where the groundwater is close to the ground surface.

2.2 GROUNDWATER FLOW

Hydrogeology is the science that studies the movement of water beneath the ground (groundwater) and its interaction or connection with water on the ground surface (i.e. rivers, streams, lakes and wetlands). Groundwater is water that saturates or fills the pores and fractures of underlying soil or rock. The top surface of this saturated ground is called the **water table.** The area between the ground surface and the water table is referred to as the **unsaturated zone**. Water infiltrates from the ground surface and moves downward through the unsaturated zone to the water table. As the water table builds or mounds up groundwater begins to move or flow within the **groundwater system**. How fast this water moves depends partly on the geologic material through which the water is migrating.

The process of water moving from the ground surface into the groundwater system is referred to as **recharge**. The amount of water that infiltrates (recharges) into the ground is controlled by a number of factors including: ground surface slope; vegetative type; and, the type of soil/geologic material present on the ground surface.

Figure 2.2.1 shows a generalized groundwater flow system. The water table can be very close to ground surface, or very deeply buried (several hundred meters in arid desert regions). Where groundwater flows into surface water features such as rivers, streams and lakes, is referred to as groundwater **discharge** (**Figure 2.2.1**). The component of surface water stream flow that is supplied to rivers and streams exclusively from groundwater discharge is referred to as **baseflow** (see Section 2.2.1).

Rock or soil layers below the water table that can readily store and transmit useable amounts of water are called **aquifers**. These units usually have a high permeability or hydraulic conductivity, which allows the water to easily move through them. In some cases aquifers are separated from one another by geologic units that impede the movement of groundwater. These formations have a low permeability or hydraulic conductivity and are typically referred to as **aquitards**. **Figure 2.2.1** shows an example of an aquitard separating two aquifers.

Groundwater generally flows from areas of higher elevations such as hilltops or ridges, to areas of lower elevations like rivers, streams and lakes. Groundwater also flows from areas of higher pressure, to areas of lower pressure. Groundwater flows very slowly through the ground. In some well-fractured rocks or very coarse gravels water may move 100 m or more in one day. Water will flow much more slowly through clay or similar fine-grained materials, and may move less than a centimetre a day.

2.2.1 Groundwater Recharge/ Discharge

As noted above, recharge occurs where precipitation infiltrates down through the ground and replenishes the groundwater system. Recharge takes place intermittently, during and following periods of rain and snowmelt, and in areas where the land is irrigated. Recharge areas are defined as the areas where water is transmitted downward to the groundwater flow system. **Figures 2.2.1** and **2.2.2** show examples of recharge areas. The amount of water that infiltrates and recharges the groundwater system depends on: vegetation; slope of the ground surface; surficial geology and soils; and, the presence/absence of low hydraulic conductivity layers, such as clay, below the ground surface. Recharge is greatest in areas where there are: permeable soils, such as sands and gravels, at ground surface; local depressions or natural vegetative cover to capture water and prevent surface run off; and, no low hydraulic conductivity layers above the water table to impede the downward movement of the water to the water table. These factors control the **hydrologic function** of a particular area. The hydrologic function, in the context of this review, is related to the physical factors that control the quantity of precipitation that can recharge the groundwater system. The three main physical features that control the hydrologic function of an area are:

- topographic relief;
- permeability of the geologic material; and,
- drainage system connections (open or closed depressions).

The hydrologic function, as it relates to moraine features, is discussed in Section 3.2.

Groundwater discharge is the process whereby groundwater flows into surface water features such as rivers, streams and lakes. Areas where this occurs are referred to as **discharge areas**. Groundwater discharge most often occurs where the water table intersects the land surface, as shown in **Figures 2.2.2** and **2.2.3,** typically in lowland or valley areas such where wetlands, lakes or rivers are present. In some areas of steep topography such as the sides of moraines or escarpments, seeps or springs may appear where the water table intercepts the land surface or where a local clay layer is outcrops on a hill (see **Figure 2.2.1**).

2.2.2 Groundwater Flow and Scale

Groundwater flow systems are scalar and may be very local (i.e. groundwater discharges near where the water was recharged) or regional (i.e. groundwater discharges tens or hundreds of km away from the recharge area. **Figure 2.2.2** shows an example of the scales of groundwater flow. In local groundwater flow systems, groundwater flow paths are relatively short (<5 km for example) and water may take only months or a few years to discharge to the ground surface. Deeper regional flow systems have much longer groundwater flow paths and the distance between the recharge and discharge zones can be tens or hundreds of kilometres (**Figure 2.2.2**). The variation between the two flow paths and the scale of the groundwater flow system is a function of the type and nature of the geologic units (i.e. permeable and well-connected or low permeability, impeding movement) as well as scale of topographic relief (i.e. a locally flat area or a regional high relief area). Local flow systems are the shallowest and the most dynamic, and as such, they tend to have the greatest interaction with local surface water features such as rivers, lakes and wetlands.

2.2.3 Water-Related Ecological Functions

As noted above, the regular and continuous discharge of groundwater into streams is referred to as baseflow, and it is this baseflow is critical for the maintenance of aquatic life and various plant and vegetation species. Species of fish such as brook trout and brown trout require a stable and continuous flow of water into the rivers and streams to survive, especially in the summer and winter months when there is decreased stream flow in the rivers and creeks due to lower precipitation levels.

The temperature of groundwater is often warmer than the air in winter, but cooler than the air in the summer time. Maintenance of baseflow (or groundwater discharge) through the summer months is critical to moderate the surface water temperatures, and also to sustain stream flow so aquatic species are not confined to smaller habitat areas of the river or stream. Baseflow is of critical importance in the winter months as the relatively warm groundwater discharges into the surface water features and prevents the water from freezing, allowing various aquatic species to survive the winter months.

Decreasing the contribution of groundwater to surface water features may impact the spawning, rearing and overwintering of various fish species, and as such, protecting the baseflow into rivers and creeks that contain these coldwater fish species is considered critical.

Similarly, wetlands whose ecosystems are supported by groundwater discharge also need to be protected to ensure long-term health of the ecosystem. The quantity of water, depth of water, depth to the water table and timing of wetting and drying of a wetland (hydroperiod) are all factors that affect the type of wetland and the maintenance of a wetland ecosystem.

2.3 WATER BUDGETS AND GROUNDWATER STORAGE

Water budgets in their simplest terms can be looked at for given area as water input, water output and the change in water stored within that area:

Inputs = Outputs + change in storage

If there is no change in the storage of water (e.g. change in lake level or elevation of the water table) then water input will be equal to water output. While the concept is simple, there are various components to the water input and the water output.

Examples of water inputs to a groundwater system include:

- precipitation;
- surface water inflow;
- groundwater inflow from outside the area being assessed; and,
- anthropogenic (man-made) input such as leaky infrastructure (wastewater and water).

Examples of water outputs to a groundwater system include:

- evaporation and transpiration;
- surface water outflow;

- groundwater outflow from the area being assessed; and
- groundwater withdrawals from water supply wells.

The change in storage in a given area can include:

- surface water reservoirs (e.g. lake levels);
- groundwater (i.e. fluctuation in the water table); and,
- soil moisture.

Figure 2.3.1 shows a schematic representation of water budget components, as presented in the "ORMCP Technical Paper 10 – Water Budgets". All of these components will not be described in detail here. It is shown to illustrate the three different "compartments" of the water budget for a groundwater system and inputs and outputs to each compartment.

A water budget is often conducted to examine the relationship between the input and output of water within a specified region, and it is often used to examine the relationship between water supply (how much do we have?) and water demand (how much are we using?). In other words it is used to determine the sustainability of a water supply for a specific area. Water budgets are used to manage water resources and help predict areas where there may be water shortages in the future.

The water budget calculation however does not address the issue of sustainability from an ecosystem aspect (Bredehoeft et al, 1982; Bredehoeft, 2002; Devlin and Sophocleous, 2005). Sustainability from a water supply perspective can be equated to capturing discharge (i.e. output) and using it for water supply as the water is "lost" outside the system being assessed. Some or all of this water may be required to sustain an ecosystem (i.e. wetlands, baseflow) and the sustainability of the ecosystem needs to be factored into the water budget. Water needed to sustain the ecosystem has been identified in the Source Protection Guidance Module 7, "Water Budget and Water Quantity Risk Assessment", (MOE 2007). It is recognized though, that actual quantification is a challenge.

One other component of the water budget assessment is the scale of the assessment and the interconnection of the groundwater system within the area being assessed. **Figure 2.3.2** shows a "cartoon" example of different types of storage in an aquifer system to illustrate the variation in storage when trying to develop a water budget. The aquifer system could be one large system such as a 'bath tub" in the illustration and water storage (and conversely water taking) water budget calculation can be conducted for one large closed basin. In the case of the "egg carton", there are a number of smaller storage areas (e.g. smaller closed basins or aquifer systems) which may not be connected and a water budget assessment must be done at a smaller case, rather than the entire "egg carton" (i.e. group of unconnected aquifers). An understanding of the scale of the aquifer system and the hydraulic connection(s) of the aquifer system is important when developing a water budget.

3.0 OVERVIEW OF WATERLOO AND PARIS/ GALT MORAINES

Prior to providing an overview of the Waterloo and Paris/ Galt Moraines the following sections are presented to provide a general overview of moraines and the potential significance and functions of moraines.

3.1 GEOLOGY OF MORAINES

The term "moraine" and the need to protect "moraines" have gained prominence in the Province of Ontario since the Oak Ridges Moraine Conservation Plan was implemented in 2001. This is evident by the current EBR applications and the concern to "protect" the Waterloo Moraine and the Paris/ Galt Moraines. It was felt as part of this review that an overview of the geology of moraines should be presented to gain a general understanding of geologic features known as moraines. This overview is not meant to be all-encompassing or deal with various geological interpretations or issues related to understanding the geological deposition of various types of moraines. There is a large volume of information in the literature dealing with glaciers, glaciation and glacial landforms and many interpretations and definitions of the glacial landforms which can not be captured in a higher level overview such as presented below.

Glaciers carry and deposit a variety of geologic debris that is eroded from the landscape that the glaciers move over. Some of this debris can be deposited along the edges (front and side) of the ice and some can be deposited on top of or under the ice, as the ice melts. Some of these glacial deposits are called moraines. A moraine can vary considerably in size, shape and geologic composition. There have been extensive studies related to understanding the glacial history of southern Ontario and the depositional history/environment of specific geological features or areas in southern Ontario. A complete overview of the glacial periods in southern Ontario is presented by the Barnett in the OGS Special Volume on the Geology of Ontario, 1992.

Ontario has been covered by ice sheets on several occasions over the last 70,000 years during the Quaternary geology period. Glaciations during this period resulted in both the erosion and deposition of a variety of unconsolidated geologic material (often referred to as overburden material). Deposition of the material the glacier carries is in two primary forms: 1), direct deposition of glacial debris beneath the ice or in front of the ice as the glacier retreats; and 2), fluvial deposition by streams flowing within the glacier or meltwater flowing off the glacier.

Various types of deposits occurred during advance and retreat of different ice sheets. Unsorted unstratified material laid down beneath the ice or dropped from the ice as the ice melts is known as till. Tills are usually widespread deposits originating from the movement and retreat of large ice sheets or lobes of ice. Numerous types of deposits also occur from the melting ice ranging from coarse sand and gravel in glacial meltwater streams to silt and clay in glacial lakes.

The term moraine as defined in "Moraines", Canadian Landscape Fact Sheets by Natural Resources Canada (NRC) is:

"a mound, ridge, or other distinct accumulation of generally unsorted, unstratified glacial debris (called till), deposited by the direct action of glacier ice. A moraine can take a variety of forms that are independent of control by the surface on which it lies."

A moraine is formed, as described in "Moraines" by NRC:

"Through the processes of plucking, abrasion, rocks falling from valley side walls, and a bull-dozing-like action, a glacier collects unconsolidated (loose) debris and includes it in a mass of ice. This sediment, made of rock particles of all different sizes, builds up at the front, sides, and base of the ice. The sediment is brought towards the ice margin and is deposited as the ice melts"

Figure 3.1.1 shows a schematic series of figures depicting an example of moraine formation. There a several types of moraines, identified on the basis of their shape and location in relation to the glacier. The following types and descriptions, as taken directly from the NRC Fact Sheet, are relevant to the current review:

End moraines are defined as; *"a ridge-like accumulation of glacial debris that has been produced at the lower or outer end of an actively flowing glacier."* (Note: the Paris and Galt Moraines are classified as end moraines).

Kame moraines are defined as; *"… an end moraine that contains numerous hummocky mounds of irregularly bedded sand and gravel with subordinated till, deposited in patches from meltwater flowing in contact with a moving or decaying glacier"*.

Interlobate moraines were not listed in the NRC Fact Sheet, but can be described in the following way. If large ice sheets advance irregularly so that their margins are "lobate", the retreating margins of ice deposit "terminal" moraines of boulders, clay and sand leaving the original interlobate shape of the glacier(s), hence the term interlobate moraine. Ice sheets or ice lobes that have come in contact with each other and then retreat will leave combined debris at the front of each lobe. As the ice melts there may be a substantial deposition of debris from meltwater between the two ice lobes. (Note: The Waterloo Moraine is interpreted as an interlobate moraine (Karrow, 1993).

Hummocky moraines are *"areas of knob-and-kettle topography that may have been formed either along an active ice front or around a mass of stagnant ice."* Knob-and-kettle topography is an undulating landscape in which a disordered assemblage of knolls, mounds, or ridges of glacial debris is interspersed with irregular depressions and pits (kettles) that are commonly undrained and may contain swamps or ponds.

It is obvious from the above noted descriptions that moraines contain a wide variety of geologic material ranging from coarse sand and gravel with boulders to silt and clay and can be unsorted or well sorted material. Moraines can also be composed of flow or "meltout" tills that contain lesser amounts of stratified sand and gravel.

The structure and composition of moraines are a function of their depositional environment and the underlying geological material that the glacier is moving over. Moraines can vary widely in areal extent, height and thickness. They can be prominent topographic features or be low-lying or buried by younger sediments. The various glacial advances and retreats in southern Ontario, especially from the different ice lobes originating from Lake Huron-Georgian Bay and Lake Ontario-Lake Erie, has resulted in a series of moraine deposits throughout southwestern Ontario. **Figure 3.1.1** shows the distribution of moraines throughout southwestern Ontario (Barnett, 1992).

3.2 FUNCTION AND SIGNIFICANCE OF MORAINES

Moraines are often cited for their significance in providing many functions to the environment (e.g. Sharpe and Russell, 2005; ROW, 2005). Each moraine will have its own unique functions depending on the size, structure and location of it. There are a number of characteristics or functions that are often associated with larger more extensive moraines throughout southern Ontario and other parts of the Great Lakes basin. Characteristics or functions could include the following:

- They are often high relief areas, therefore they are often at the top end of a groundwater flow system.
- In areas where permeable geologic material is present at ground surface a greater volume of recharge is often provided to the groundwater system, compared to other geologic landforms.
- They often provide substantial quantities of water to municipalities and private users.
- As a result of the high relief and recharge, larger moraines often contain the headwaters of streams, which in turn provide substantial baseflow to maintain flows streams and rivers during drier times.
- The nature of the deposition of the geologic material (e.g. melting ice trapped in the glacial debris) often results in small closed depressions (i.e. no external runoff), potentially creating areas of locally increased infiltration and/or local wetland areas.
- The high relief areas of larger moraines are often more vegetated and less conducive to agricultural practices. This potentially creates an area with a greater and more diverse natural habitat.
- They can be a major source of aggregate.

Some moraines have been cited by the OGS, GSC and Conservation Authorities (e.g. Bajc and Shirota, 2007; and GRCA, 2008) as providing considerable recharge to the groundwater system in local areas. Recharge is an important component of the hydrologic function of a specific area. As indicated in Section 2.2.1, the three most important physical features that control the hydrologic function of a specific area or landform are:

- topographic relief;
- composition of the geologic material (i.e. highly permeability or low permeability material); and,
- drainage system connections (open or closed depressions).

It is important to note that many geologic features (e.g. outwash deposits or sand plains) can have a significant hydrologic function (e.g. high rate of recharge), however moraines are more likely to have a higher topographic relief and/or closed depressions, due to the nature of their formation and deposition as discussed in Section 2.1. Both of these features, where present, can increase the significance of the hydrologic function of a moraine.

Examples of the significance of each of these physical features and the impact on the hydrologic function are presented below.

<u>Topographic Relief</u>

The topographic relief of a moraine potentially influences three main factors related to the hydrologic function:

- the volume of water that can be stored within the moraine;
- the height of water in the geologic landform that “drives” the vertical and lateral movement of groundwater; and,
- the location of potential headwaters of surface water systems.

Figure 3.2.1 shows several examples to illustrate the influence of topographic relief on the water regime. **Figure 3.2.1a** shows an example of a moraine with a low topographic relief. In this setting, there is a minor volume of water "stored" within the core of the moraine. The water level is not much higher than the surrounding area, so groundwater flow may be local, travelling only a short distance before discharging to local headwater streams. **Figure 3.2.1b** shows an example of a moraine with high topographic relief. In this case the water infiltrating into the ground has mounded up within the core of the moraine. There is a considerably greater volume of water stored in within the core of the moraine, compared to a moraine with low relief. The height of the water table also creates a greater pressure, "pushing" the water deeper, with some water moving to a more regional groundwater flow system (as discussed in Section 2). Springs and headwater streams will also occur at a higher topographic relief.

Composition of the Geologic Material

The composition of geologic units underlying the moraine, or present within the moraine structure, will influence:

- the rate at which water will infiltrate into the groundwater system;
- the depth to which water may recharge the groundwater system; and,
- the location of areas where groundwater may discharge.

Figure 3.2.2 shows some examples of the influence of geologic materials on the water regime. The figure shows three examples of water movement influenced by the composition of geologic material present. In Area 1 where there is impervious material, much of the precipitation does not recharge the groundwater system and becomes surface runoff. In Area 2, where the geologic material is generally highly permeable to depth, precipitation recharges the groundwater system and could migrate deeper in the groundwater flow system, until a low permeability geologic unit is encountered. In Area 3, the upper geologic material is permeable and most precipitation recharges the groundwater system. However, there is a low permeability geologic unit at a shallow depth that impedes much of the recharge water from moving downward. This water discharges to the surface water system at springs or headwater streams at a higher elevation than in Area 1.

Drainage Systems Connections

Drainage system connections at ground surface are a function of the local topographic relief. In areas where they are connected along the ground surface (e.g. connected swales) water will flow through them, eventually reaching a surface water course. If the surficial soils are permeable some water may recharge the underlying groundwater system through infiltration. If there are local closed depressions where there is no topographic outlet, then water precipitation will be stored in these areas (both rainfall and snowmelt) and this water will either infiltrate, be used by local plants or will evaporate. Drainage system connections influence:

- the volume and timing of surface water runoff;
- the volume and rate of recharge to the groundwater system; and,
- the development of wetlands and maintenance of local soil moisture conditions.

Figure 3.2.3 shows an example of the influence of drainage system connections. In areas where closed depressions exist, there is a greater recharge potential to the groundwater system. In areas where the drainage is open there is a predominant surface run off component.

3.3 OVERVIEW OF THE WATERLOO MORAINE

This section provides a general overview of the Waterloo Moraine and a relatively detailed description of the history of investigations of the Waterloo Moraine. It is not meant to be an exhaustive review, with a detailed discussion of each investigation, but it is meant to provide a “sense” of the level of investigations and research that has been carried out within the area of the Waterloo Moraine since a water supply well was first established within the Waterloo Moraine more than 100 years ago. Notwithstanding the study team’s collective experience in investigations of the Waterloo Moraine, the volume of technical material available from various sources was still found to be overwhelming and it is hoped that this section captures the extent of investigations that have been conducted to date or are currently being carried out. It is noted here that for simplicity of presentation and general discussion within this report, well fields or water supply wells within the geographic area of the Waterloo Moraine will be referenced as being in the Waterloo Moraine. Technically, some water supply wells are found within the Waterloo Moraine sediments while other water supply wells are found within aquifers below the Waterloo Moraine sediments, but within the geographic area of the Waterloo Moraine.

3.3.1 General Physical Setting

The Waterloo Moraine is located within the central area of the Grand River watershed as show in **Figure 3.3.1**. The Waterloo Moraine is approximately 400 km^2 in size. The central area of the Grand River basin has numerous moraine features, with 14 individual moraines identified (GRCA Watershed Characterization Report, January, 2008) as shown in **Figure 3.3.1**.

The topographic elevation of the Waterloo Moraine varies from a high of 430 mAMSL in the northern portion of the moraine to a low of about 325 mAMSL in the southeast portion, near New Dundee (**Figure 3.3.2**). The Waterloo Moraine is the dominant topographic feature in the area, trending in a general northwest-southeast direction. The topography of the Waterloo Moraine consists of gently rolling to undulating hills, with local areas of pronounced relief in the central area of the moraine and flatter less pronounced relief along the flanks of the moraine. The “crest” of the Waterloo Moraine generally follows the municipal boundary between the urban area of Kitchener-Waterloo and the Township of Wilmot.

The entire area of the Waterloo Moraine is within the Grand River watershed. Drainage is primarily from local tributaries, with drainage to the Grand River in the east and to the Nith River in the west, as shown in **Figure 3.3.3**. Local tributaries originating within the Waterloo Moraine and draining directly to the Grand River include Laurel Creek in the northeast portion of the Waterloo Moraine and Schneider and Strasburg creek in the southeast. Much of the central core area of the moraine is drained by Alder Creek, southward to the Nith River. The western portion of the Waterloo Moraine is drained by several other tributaries of the Nith River, including Bamberg Creek in the northwest, and Baden Creek and Hunsburger Creek in the southwest.

Local drainage is highly variable ranging from good to poor, depending on the surficial soils and local topography (Clarkson, 1991). In some areas tile drainage is required due to low relief and low permeability surficial soils. In many areas, in particular in the central or core area of the Waterloo Moraine, the soils are coarse and very well-drained.

Figure 3.3.4 shows the thickness of the overburden in the area of the Waterloo Moraine. The overburden sediments range in thickness from 120 m in the central area of the Waterloo Moraine to 30 m in the river/creek valleys along the flanks of the moraine, with a typical thickness of 60 to 80 m in the core area, and a thickness of 40-60 m along the flanks of the Waterloo Moraine.

3.3.2 Investigations of the Waterloo Moraine

The first geological investigation of the Waterloo Moraine was almost 100 years ago with the installation of the first municipal water supply for the City of Kitchener. The following sections provide a summary of the history of investigations since that time. The summary has been divided into three sections: historical geological investigations up to the mid-1980's; historical water supply investigations up to the 1980's; and, combined broader based hydrogeological and geologic investigations of the Waterloo Moraine since the late 1980's.

3.3.2.1 Historical Geological Investigations

The Waterloo Moraine was named by Taylor (1913), as part of his studies of moraines of southwestern Ontario. According to Bajc and Karrow (2004), Taylor was the first to recognize the Waterloo Moraine as an interlobate feature "deposited along the retreating margin of the Lake Erie ice lobe" in an area referred to as the Ontario Island. **Figure 3.3.5**, adapted from Chapman and Putman (1984), shows the recession of the Wisconsinan glacier. **Figure 3.3.5a** shows the position of the Waterloo Moraine during the early retreat of the ice lobes and **Figure 3.3.5b** shows the opening of the "Ontario Island" with a further retreat of the ice. A simplified version of the location of the ice lobes that resulted in the formation of the Waterloo Moraine is shown in **Figure 3.3.6** (from Morgan 2005).

Taylor (1913) described the Waterloo Moraine as a "finely formed moraine running south from Waterloo to Ayr and west to Bamberg" and also described it as "higher and more bulky than average". Little additional work was done until Chapman and Putman (1943), conducted further work on moraines of Southern Ontario. In 1951 Chapman and Putman refined the geographic extent and character of the Waterloo Moraine (Bajc and Karrow, 2004) as they described the moraine as an oblong tract of hills composed of sandy till with lesser amounts of kame sand and gravel. They noted a considerable amount of fine sand within the central area of the moraine, becoming finer-textured towards the south.

The Waterloo Moraine was originally interpreted to be deposited during the last glaciation, however work by Karrow in the late 1960's and early 1970's (e.g. Karrow 1974) interpreted the Waterloo Moraine to be a palimpsest feature. A palimpsest feature is a feature that reflects earlier periods of glaciation, older than the most recent ice advances. As a result, many of the depositional features are obscured by younger sediments deposited on top of the feature.

Many of the earliest detailed investigations of the Waterloo Moraine were conducted by Karrow as part of the Quaternary mapping of southwestern Ontario (Karrow, 1963 and 1968). Most of the work involved mapping of the exposed stratigraphy in road cuts, river valleys and gravel pits. This work was supported by a single partially cored borehole, drilled in the Waterloo Moraine in the late 1960's by Canada Public Works (Isherwood, 1976). Karrow noted at the time that the Waterloo Moraine had a fine sand and gravel core and was only locally capped by deposits of fine-grained till. There were several interpretations of the formation and the deposition of Waterloo Moraine during this period, including Karrow's work and work by Harris, 1970. At that time Karrow concluded that the history of the Waterloo Moraine could not be understood until an extensive deep drilling program was undertaken (Gautrey, 1996).

Figure 3.3.7 shows the surficial geology in the area of the Waterloo Moraine as interpreted by Karrow, 1993. The central area of the Waterloo Moraine was interpreted as ice-contact sand and gravel, while the flanks of the moraine were interpreted to be primarily silty clay till units at ground surface. The understanding of the Quaternary geology in the area of the Waterloo Moraine up to the 1980's can be summarized from work by Karrow (Karrow, 1987 and Karrow, 1993) as follows.

Ontario has been covered by ice sheets on several occasions over the last two million years. However, much of the glaciation that shaped the geology of southern Ontario occurred during the late-Wisconsinan period of glaciation, in the last 23,000 years. Although some pre-late-Wisconsinan Quaternary deposits exist the majority of glacial deposits are from the late-Wisconsinan period. The late-Wisconsinan period of glaciation featured three main periods: the Nissouri, Port Bruce and Port Huron stadials (colder periods of glaciation with ice advancing) separated by the Erie and Mackinaw interstadials (warmer periods of glaciation with ice retreating).

Ice lobes originating from the lake basins of Lake Huron and Georgian Bay, Lake Ontario and Lake Erie (**Figure 3.3.6**) came together in the general area of the Region of Waterloo. Advance and retreat of these ice lobes over the Region resulted in a complex deposition of various types of glacial features. The general understanding of the stratigraphy of the area of the Waterloo Moraine is shown in **Figure 3.3.8** (from Gautrey, 1996). As shown in **Figure 3.3.8**, a number of the tills were deposited from the advance and retreat of the Huron-Georgian Bay ice lobe and a number deposited from the advance and retreat of the Ontario Erie ice lobe.

One of the most prominent till units in area of the Waterloo Moraine is the Catfish Creek Till, which is widespread throughout southern Ontario. It is a stony sandy silt till to silt till and is extremely dense. Some glaciolacustrine and glaciofluvial sand and gravel units (potential aquifers) are associated with the Catfish Creek Till sequence of geologic units. Several till units were deposited over a large portion of the Waterloo Moraine area as ice sheets fluctuated in size and areal extent from both the Ontario-Erie lobe and Huron-Georgian Bay lobe. The three most prominent tills deposited were the Maryhill Till and the younger Tavistock and Port Stanley Tills. The Maryhill Till and Port Stanley Till were deposited by the Ontario-Erie ice lobe. The Tavistock Till was deposited by the Huron-Georgian Bay Ice lobe. The Maryhill Till is characterized as a clay till, and plays an important role in the water resources of the Waterloo Moraine. Where present, the Maryhill Till protects the lower aquifers from surface contamination, however it also limits recharge to the lower aquifers. The Tavistock and Port Stanley Tills are characterized as silty clay to clayey silt tills. Where present at or near ground surface, these tills will also provide some protection to underlying aquifers and limit recharge.

During various retreats of the ice lobes, sand and gravel was deposited between some of the till units. Some of these deposits were interpreted to be continuous over a large area while other deposits were more localized. These deposits form the major aquifers of the Waterloo Moraine area. The depositional sequence of these units and the relationship with the till units was historically not well understood due to limited good geological information at depth.

During the 1980s additional groundwater research was being conducted (see next section) and Quaternary geology investigations were also being conducted to obtain additional information on the subsurface geology. This additional work was spearheaded, in part, by Dr. Robert Farvolden, at the University of Waterloo. Dr. Farvolden was instrumental in developing the hydrogeology program at the University of Waterloo in the 1970s. During the 1970s the Region of Waterloo was looking at the long-term potential of building a pipeline to one of the Great Lakes, based on 25-year forecasts of water demand due to predicted population growth forecasts for the Region of Waterloo. Dr. Farvolden felt that given the high cost of the pipeline, more effort should be taken in understanding the water resources of the Region of Waterloo (Farvolden, 1981). He felt that there were significant additional water resources available; however politicians did not want to spend money to "study" the geology of the area. He stated:

"Many informed geologists and engineers believe that additional groundwater supplies are available, and perhaps sufficient to meet the forecast demands. The key factor in a technical solution is better data on the Quaternary stratigraphy. Funds have not been made available for basic stratigraphic studies using

modern techniques and as a consequence hydrogeology cannot be used effectively in dealing with the problem."

Based partly on Dr. Farvolden's comments, new research programs were initiated. The Quaternary geology research during that time focused on the subsurface geology beneath the urban areas of Waterloo and Kitchener and included the following studies:

- Pehme, P. 1984. Identification of Quaternary Deposits with Borehole Geophysics in Waterloo Region. M. Sc. Thesis University of Waterloo.
- Ross, L. C. 1986. A Quaternary Stratigraphic Cross-section through Kitchener-Waterloo, M.Sc. Project Report, University of Waterloo.
- Rowland, R. C. 1991. A Quaternary Stratigraphic Cross-section through Kitchener-Waterloo, M.Sc. Project Report, University of Waterloo.
- Farvolden et al. 1987. Subsurface Quaternary Stratigraphy of Kitchener-Waterloo, using borehole Geophysics, Final Report, O.G.R.F., Project 128.

This work provided some additional understanding of the complex glacial history in the Region of Waterloo. The understanding of the depositional environment and sedimentary structure of the Waterloo Moraine area was not further advanced until an extensive drilling program and other field investigations commenced in the 1990s. The increased investigation was primarily the result of a groundwater contamination issue in the Region in 1989/1990, which created an increased the need to understand the water resources from a geologic perspective. Those investigations are discussed in Section 3.3.2.3.

3.3.2.2 Historical Water Supply Investigations

Figure 3.3.9 shows the location of existing municipal wells or well fields located within the geographic area of the Waterloo Moraine. The first wells were constructed in 1899 at the Greenbrook well field. The majority of exploration was conducted between the late 1940s and early 1970s. Investigations were conducted independently for the Kitchener Water Commission and the Waterloo Public Utilities Commission. The Region of Waterloo was incorporated in 1973 and assumed responsibility for the municipal water supply systems throughout the Region, including Kitchener, Waterloo, Cambridge and the four surrounding townships.

Historically, water supply investigations generally consisted of a test drilling program to determine the extent of water bearing sand and gravel units. Typically, a test hole was drilled and a well installed if suitable "aquifer" material was encountered. A pumping test was conducted to determine the potential water yield of the local aquifer unit. In areas where there appeared to be considerable water, or the sand and gravel appeared to be extensive, additional testing was conducted and additional production wells were installed if warranted. Early drilling was primarily in the urban areas of Kitchener and Waterloo, and expanded outward, typically westward, as each municipality expanded.

Rapid industrial expansion in the area in the 1960s resulted in an increase in exploration for new water sources. The first interpretative study, combining historical information from previous exploration programs and data from water supply wells, was undertaken in 1963 by the Ontario Water Resources Commission (prior to the formation of the Ontario Ministry of the Environment). During this study three aquifers were identified throughout the area, with aquitard units separating these aquifers.

In the early 1970s this study was expanded by International Water Supply (Dixon, 1973). Dixon conducted the first major regional study of the water supply for the Kitchener-Waterloo area. Dixon assessed the multi-aquifer system throughout Kitchener and Waterloo and interpreted the aquifers to be relatively continuous over most of the Region. There appeared to be an area of thick sands and gravels to the west of the urban centres (what has been previously described in this report as the central or core area of the Waterloo Moraine) and deeper sands and gravels under the urban centres, below several till units. As part of the Dixon study, one of the earliest groundwater flow models in the province was developed by Dr. Emil Frind at the University of Waterloo. This led to a greater involvement of the University of Waterloo in groundwater resource studies throughout the Region of Waterloo.

As the hydrogeology program at the University of Waterloo expanded in the late 1970s and early 1980s the focus of local investigations shifted to understanding the hydrogeology of the well fields across broader areas of the Waterloo Moraine through the development of "hydrostratigraphic" models. Hydrostratigraphy is simply the defining of laterally extensive geologic units on the basis of their hydraulic properties, typically dividing geologic units into aquifers (water bearing formations) and aquitards (formations that impede the movement of water).

The following highlights the various research studies and water resources investigations that were conducted prior to 1989/1990, when a groundwater contamination issue triggered a substantially different approach to understanding and protecting groundwater resources with the Region of Waterloo (discussed in Section 3.3.2.3). Research studies included the following:

- Nowicki, V. 1976. An Investigation of the Kitchener Aquifer System Using Stable Isotopes ^{34}S and ^{18}O. M.Sc. Thesis, University of Waterloo. This study looked at the sources and source areas of water being pumped from the Greenbrook well field
- Beland, A. 1977. Management of the Greenbrook Well Field. M.Sc. Thesis, University of Waterloo. This study examined the hydraulic connection between the aquifers in the Greenbrook Well Field, based on response to pumping of wells in different aquifer units.
- Foulkes, H. 1979. Stable Isotope Analysis of Two Postglacial Sites near Waterloo, B.Sc. Thesis, University of Waterloo.
- Weitzman, M. 1980. A Probabilistic Model for Predicting Groundwater Levels in the Greenbrook Well Field. M.Sc. Thesis, University of Waterloo.
- Woeller, R. 1982. Greenbrook Well Field Management Study, 1981-1982. M.Sc. Thesis, University of Waterloo.
- Lotimer, A. 1984. Groundwater Flow in a Multi-Aquifer System – Kitchener. M.Sc. Thesis, University of Waterloo.
- Petrie, J. 1985. Field Response of a Clay Till In a Layered Aquifer system as Waterloo, Ontario. M.Sc. Thesis, University of Waterloo.
- Rudolph, D. 1985. A Quasi 3-Dimensional Finite Element Model for Steady-State Analysis of Multi-Aquifer Systems. M. Sc. Thesis, University of Waterloo.
- Clarkson, R. 1991. The Hydrogeology of a Multi-Aquifer System in Wilmot Township. M.Sc. Thesis, University of Waterloo.

In addition, the Region of Waterloo was updating their master water supply plan, which included the following studies:

- M.M. Dillon, 1984. Master Water Supply Study - Existing Groundwater Supplies and New Short-Term Supplies for Kitchener-Waterloo.

- Dames and Moore, 1990. Master water Supply Project. Updated Prototype Testing Artificial Recharge Facilities.
- Hydrology Consultants Limited, 1985. The Regional Municipality of Waterloo Master Water Supply Study- Activity G – Stage 3, New Natural Groundwater Supplies for Kitchener-Waterloo.

3.3.2.3 Recent Investigations of the Waterloo Moraine

Water Resource Investigations and Protection Strategies

In 1989 groundwater contamination was discovered in a municipal well field in the Town of Elmira (north of Waterloo). Due to general concerns regarding water quality and the impacts of groundwater contamination, the Region of Waterloo initiated the development of a comprehensive water resources protection strategy. In 1992, a Comprehensive Water Resources Protection Strategy was developed to manage and protect groundwater resources within the Region from both existing and new potential sources of contamination. In 1994, Regional Council approved a "**Water Resources Protection Strategy Implementation Plan**" that established a ten-year program for groundwater and surface water management activities. Eight separate elements of the implementation plan were recognized. The first element of the strategy was "Water Resources Definition".

Several Water Resources Definition studies were prioritized, including the following:

- Waterloo North Aquifer System Study, 1992 by Terraqua Investigations Limited. This was the first groundwater resource definition study initiated by the Region. The area encompassed portion of the Waterloo Moraine within the City of Waterloo and the Laurel Creek Watershed. The City of Waterloo, the Grand River Conservation Authority and other stakeholders had just initiated a comprehensive study to integrate environmentally responsible land use planning into urban expansion of the City of Waterloo in the western portion of the City, within the Laurel Creek watershed (see the Laurel Creek Watershed Study below). The study introduced an ecosystem approach to long-term land use planning. An extensive geologic and hydrogeologic investigation was conducted looking at: the extent of hydraulic connection of the various aquifer units; the determination of recharge areas for the Waterloo North well field; and, groundwater/surface water interaction throughout the watershed.
- The Study of the Hydrogeology of the Waterloo Moraine, completed in 1995, by Terraqua Investigations Ltd. The objective of the study was to "define the hydrogeology of the Waterloo Moraine in accordance with the Regional Municipality of Waterloo Water Resources Protection Strategy goals". There were five main study objectives as listed in Terraqua, 1995:
    - delineation of major aquifer and aquitard units;
    - definition of regional recharge areas;
    - estimation of well field capture zones and existing risks to potential contamination sources;
    - estimation of impacts from municipal pumping on water levels; and,
    - recommendations.

Investigations included drilling 25 continuously sampled boreholes, installing monitoring wells in the three main aquifer units, conducting well field shut downs and pumping tests, obtaining water quality data and isotopic data from throughout the Waterloo Moraine aquifer system, and installing stream bed piezometers through the creeks system to assess groundwater/surface water interaction.

Figure 3.3.10 shows the locations of a series of geologic cross-sections developed through the Waterloo Moraine as part of the Terraqua study (Terraqua, 1995). The hydrostratigraphic interpretation was developed using geological data, pumping test data and water quality/isotope data (Terraqua, 1995).

Figure 3.3.11 shows the conceptual hydrogeological cross-section through the Waterloo Moraine as developed from the Terraqua, 1995 study. The three aquifer system was further interpreted by trying to relate the hydrostratigraphy to the Quaternary geology.

The study also presented an initial interpretation of the major recharge area within the Waterloo Moraine, as shown in **Figure 3.3.12**. The recharge area was generally interpreted to be in the core area of the Waterloo Moraine, in areas of higher topographic relief where ice-contact sand and gravel was mapped at the ground surface. The recharge area generally corresponded to the areas of highest water table, as show in **Figure 3.3.13**. Groundwater is shown to flow generally radially out from the recharge area in a west, south and east direction.

<u>Quaternary Geology Initiatives</u>

During this time, the water resources definition studies were being conducted in co-operation with Quaternary geology research. Many high quality boreholes were being drilled as part of these investigations. Most boreholes were continuously cored and geophysical logged and in many cases drilled to bedrock to obtain a complete geologic profile to aid in the geologic interpretation of the Waterloo Moraine and the underlying geologic units. The following Quaternary geology research projects were conducted during this time:

- Paloschi, G. 1993. Subsurface Stratigraphy of the Waterloo Moraine. M.Sc. Project, University of Waterloo.
- Rajakaruna, N. 1994. The Waterloo Moraine Project Phase 1: Subsurface Stratigraphy of western Kitchener-Waterloo. M.Sc. Project Report, University of Waterloo.
- Gautrey, S. 1996. The Hydrostratigraphy of the Waterloo Moraine. M.Sc. Thesis, University of Waterloo

These studies resulted in the development of a more detailed correlation of the aquifer and aquitard units with the Quaternary stratigraphy and the chronology of deposition of various geologic units. Four major till units were recognized within the Waterloo Moraine, correlating with the four aquitard units used in the Region's stratigraphic interpretation. **Figure 3.3.14** shows the location of a series of hydrostratigraphic cross-sections developed by Gautrey (1996) as part of his research. **Figure 3.3.15** shows one of these cross-sections (Section 3) through the Waterloo Moraine. Gautrey (1996) correlated the upper two aquitard units with the upper and lower Maryhill Till, Aquitard 3 with the Catfish Creek Till and Aquitard 4, where present, with the Canning Till and other associated sediments.

The following is noted with respect to the interpreted cross-section in **Figure 3.3.15**:

- an extensive thickness of sand and gravel in the core area of the moraine;
- an increased thickness of surficial till, moving eastward from the core of the moraine;
- few continuous lower aquifer units in the core area of the Waterloo Moraine;

- a generally continuous unit of lower Maryhill Till, however where thin or absent could create a potential connection from the upper aquifer to the lower aquifers;
- a thinning of the upper sand unit (Aquifer 1), moving eastward away from the core of the Waterloo Moraine (toward the urban area); and,
- an increasing presence of lower aquifer material moving eastward from the core of the moraine, resulting in a more complex local stratigraphy at depth.

Recent Investigations

Numerous other research projects were conducted during the 1990's and early 2000's to refine the understanding of the hydrogeology of the Waterloo Moraine, or specific portions of it, as well as conducting more detailed work to manage and protect the aquifer systems as part of the Region's Water Resources Protection Strategy. These investigations included but were not limited to the following:

- Fitzpatrick, P. 1993. Groundwater Flow and Contamination at Kitchener-Waterloo, Ontario. M.Sc. Thesis, University of Waterloo.
- Martin, P. 1994. Modeling of the North Waterloo Multi-Aquifer System. M.Sc. Thesis, University of Waterloo.
- Johnston, C. 1994. Geochemistry, Isotopic Composition and Age of Groundwater from the Waterloo Moraine: Implications for Groundwater Protection and Management. M.Sc. Thesis, University of Waterloo.
- Callow, I. 1996. Optimizing Aquifer Production for Multiple Well Field Conditions in Kitchener Ontario. M.Sc. Thesis, University of Waterloo.
- Martin, P. J. and E. O. Frind, 1998. Modelling Methodology for a Complex Multi-Aquifer System: The Waterloo Moraine, Groundwater 36(4), 679-690.
- Muhammand. D. 2000. Methodologies for Capture Zone Delineation for the Waterloo Moraine Well Fields. M.Sc. Thesis, University of Waterloo.
- Waterloo Hydrogeologic Inc., 2000. Delineation of Well Field Capture Zones Within the Waterloo Moraine. Prepared for the Region of Waterloo.

The primary advancement of the understanding of the Waterloo Moraine during this time was the development of a groundwater flow model and the delineation of capture zones for well fields within the Waterloo Moraine. The Region developed a groundwater flow model for the Waterloo Moraine (WHI, 2000) to more completely understand, manage and protect the aquifer system within the Waterloo Moraine. The Waterloo Moraine Model developed by Martin and Frind (1998) was updated to develop three-dimensional capture zones for well fields within the Waterloo Moraine. The groundwater flow system was modelled using the previously interpreted multi-aquifer system of three aquifers and four aquitards. The model was calibrated to water levels in each of the aquifers and baseflow in the surface water system at locations within the area of the model boundary. **Figure 3.3.16** to **Figure 3.3.19** show the calibrated water levels for the water table and each of three aquifer units. The general groundwater flow system is similar for all aquifers with flow in a northwest to southeast direction, following the general topography, with major flow components diverging toward the Nith River in the west and Grand River in the east. Locally, there is groundwater flow from Aquifer 1 discharging to a number of the creeks, as evident for example to Alder Creek, which flows through New Dundee (**Figure 3.3.17**). Locally, groundwater flow is impacted by pumping of the well fields as shown by the water level contours wrapping around the Greenbrook, Parkway and Strasburg well fields for Aquifer 3 (**Figure 3.3.19**).

Figure 3.3.20 shows the location of wells and well fields in the Waterloo Moraine, for which capture zones were developed. **Figure 3.3.21** shows the 2-year and 10-year Time-of-Travel (ToT) capture zones for the Waterloo Moraine wells (from WHI, 2000). **Figure 3.3.22** shows a larger scale example of the 2-year and 10-year ToT capture zones for the Greenbrook well field. Larger scale mapping was prepared for the 2-year and 10-year ToT capture zones for all well fields.

Environmental Studies and Initiatives

In addition to studies related to water resources protection the Region of Waterloo was undergoing a number of environmental studies and initiatives related to ecosystem-based planning (ROW, 2005b). The Region of Waterloo developed their first Regional Official Policies Plan (ROPP) in 1976, which sought to balance land use, environment, infrastructure and social factors in decision making. The 1976 ROPP was, according to the Region (ROW, 2005b): “the first plan in Ontario to designate environmentally sensitive areas and enact policies intended to evaluate and minimize impacts of proposed new developments on ESPAs). The ROPP was updated in 1985 and again in 1995 (Note: it is currently being updated and is in Draft form for review as discussed later in Section 5.4.3.). The 1995 ROPP promoted an ecosystem-based planning approach to development and growth. The 1995 ROPP established a Natural Habitat Network (RMOW, 2005b) consisting of:

- Environmental Preservation Areas (EPAs);
- Environmentally Sensitive Policy Areas (ESPAs);
- Provincially Significant Wetlands (PSWs);
- significant valley lands;
- sensitive groundwater recharge areas and discharge areas;
- headwaters;
- aquifers;
- significant woodlands;
- locally significant natural areas;
- significant wildlife habitat; and,
- significant fish habitat.

In order to establish or map these features a number of environmentally-related studies have been conducted over the years, ranging from Region-wide ESPA studies and wetland evaluations to area-specific subwatershed studies. The Region, GRCA and local municipalities require subwatershed studies to be conducted in areas of new development or growth. These studies have been on-going since 1989. Subwatershed studies provide an ecosystem-based approach to land use planning on a subwatershed scale. They integrate groundwater and surface water, aquatic and terrestrial habitat and fisheries creating a broader understanding of the function and linkage of the natural systems. Subwatershed studies require more detailed assessments of these features to identify and protect them from adverse impacts of potential land use changes or land use activities. One of the first detailed subwatershed studies in Ontario was the Laurel Creek Watershed Study.

The Laurel Creek Watershed Study was initiated in 1991 due to concerns about development on the west side of the City of Waterloo, which is located within the central area of the Laurel Creek subwatershed (**Figure 3.3.3**). Studies were conducted to: identify existing environmental and water resources conditions; identify impacts due to existing land use activities; assess the potential for impacts related to possible future land use change scenarios; and, develop a management strategy for the subwatershed. A hydrogeological study was conducted (Terraqua, 1993) to assess groundwater flow and aquifer systems, groundwater/surface water interaction, baseflow and recharge areas as well as the groundwater contribution to ecological features such as wetlands and fisheries. The watershed encompasses much of the north central portion of the Waterloo Moraine as it includes the Clair Creek, Beaver Creek and Monastery Creek tributaries of Laurel Creek (see **Figure 3.3.3** for locations).

Since the completion of the Laurel Creek Watershed Study, there have been a number of other subwatershed studies within the area of the Waterloo Moraine including the following (see **Figure 3.3.3** for the locations of the creek systems):

- Strasburg Creek, 1989 and 1996 (southeast portion of the Waterloo Moraine);
- Doon South, 1994 (southeast portion of the Waterloo Moraine);
- Blair Bechtel Bauman Creeks, 1997 (South portion of the Waterloo Moraine);
- Alder Creek, 2008 (central portion of the Waterloo Moraine); and,
- Cedar Creek, on-going (south portion of the Waterloo Moraine)

As well, additional studies have been conducted on Baden Creek and Hunsberger Creek (southwest portion of the Waterloo Moraine) as part of an assessment looking at the impacts of water taking from the Wilmot Well Field located within the Hunsberger Creek subwatershed. Water level data and surface flows have been collected in this area since 1969, when the Wilmot Well Field was first developed.

Post Walkerton - Recent Source Protection Initiatives

As part of the recommendations of the O'Connor Report, (O'Connor, 2002), from the Walkerton Inquiry, the provincial government legislated watershed-based source protection plans. The O'Connor Report contained 121 recommendations for protection of drinking water in Ontario. Since the release of the report and recommendations the Government of Ontario has introduced legislation to safeguard drinking water from the source to the tap. The Clean Water Act (CWA) was passed in 2006 and provides a framework to develop local source protection plans. The CWA focuses on the protection of municipal drinking water supplies. Multi-stakeholders (e.g. MOE, MNR, Conservation Authorities, municipalities) are working in partnership to develop local science-based source protection plans.

The ability to develop and implement a source protection plan requires a sound understanding of the local geological and hydrogeological conditions. As part of the development of source protection plans new geological investigation initiatives were developed. Based on the need to provide a better understanding of three-dimensional interpretation of Quaternary deposits, the Ontario Geological Survey (OGS) embarked on a new program designed to provide basic geoscience information for the protection and preservation of provincial groundwater resources (Bajc and Newton, 2005). A pilot project of three-dimensional mapping of Quaternary deposits within Waterloo Region was initiated in 2002 as part of this geoscience initiative. The initiative was done in co-operation with the Geological Survey of Canada (GSC), the Region of Waterloo, University of Waterloo and the Grand River Conservation Authority. The primary objectives of the study were: 1), to develop protocols for 3-dimensional mapping of Quaternary deposits in Ontario; and 2), characterize in 3-dimensions the geometry of the subsurface Quaternary deposits in the Region of Waterloo.

The project is one of several studies currently being undertaken within southern Ontario as part of the OGS's groundwater mapping program, a provincially-mandated directive to study groundwater resources within the province (Bajc and Karrow, 2004). The OGS project has been ongoing for about 5 years and has supplemented previous work with the following (from Bajc, 2005; and, Bajc and Shirota, 2007):

- over a 1000 new surface and borehole log sections;
- 16 km of ground penetrating radar;
- 17km of seismic reflection profiling;
- continuous coring to bedrock at 13 sites;
- borehole geophysics;
- update and interpretation of the existing borehole and geophysical database with 22,952 data sets;
- use of 3-dimensional data mapping software to interpret the sub-surface geology;
- interpretation and creation of a fully attributed three-dimensional block model showing major aquifer and aquitards within Quaternary deposits in the Region of Waterloo; and,
- Interpretation and generation of aquifer recharge and susceptibility mapping based on the current OGS-constructed geologic model.

Since the release of the O'Connor report the Region of Waterloo has been actively updating their water resources protection plan, to comply with the MOE Guidance Documents developed for source protection. This source protection work is summarized in Section 5.8.

3.4 OVERVEW OF THE PARIS/ GALT MORAINES

In terms of assessing the geological and hydrogeological information available for the Paris/ Galt Moraine system a number of relevant and inherent circumstances exist. Where the Paris/ Galt Moraines stretch through the Credit River and Grand River watersheds they basically form headwater divides of the majority of subwatersheds within the two watersheds. The exceptions are the Mill Creek and Eramosa River-Blue Springs Creek subwatersheds, where the Paris/ Galt Moraines are present throughout the subwatersheds. There are few municipal wells and very little urban development within these moraines. As a result there have not been any moraine-focused hydrogeological studies, with the exception of studies within the Mill Creek and Eramosa River-Blue Springs Creek subwatersheds. The Ontario Geological Survey (OGS) has carried out a drilling program to map Quaternary deposits and potential aquifers in the Brantford-Woodstock area, which includes a portion of the Paris/ Galt Moraine (Bajc, 2006, 2007, 2008b), but again this is a very limited area.

3.4.1 General Physical Setting

The recognition of the Paris/ Galt Moraine system in various literature has it extending from an area in the vicinity of Caledon, in the northeast, to an area southwest of Port Rowan on the Lake Erie shoreline, a distance of approximately 150 kilometres (**Figure 3.4.1.1**). The Paris/ Galt Moraines are usually found close together, with the Galt Moraine found on the southeasterly side of the Paris Moraine.

The Paris/ Galt Moraines are generally found as hummocky belts or ridges (Chapman and Putnam, 1984). Their combined width can be up to 8 km (southeast of Guelph) or they can be present as faint surficial ridges that eventually disappear (e.g. the Paris area and south towards Lake Erie). The topographic relief of these moraines, above the adjacent till or outwash plains, can be as great as 30-40m in Guelph and Caledon areas.

In some areas, the moraines are not separated (Guelph area) and in other areas they may be separated by up to 10 km (northwest of Waterford). The moraines are not always coincident or continuous throughout their 150 km length. Notably the Galt Moraine is absent in the Caledon area (White, 1975) and the Paris Moraine is not continuous or is buried in the Cambridge area (Karrow, 1987). Throughout the moraine belt, from Paris southward, the surficial expression of both moraines are quite discontinuous (Cowan 1972; Barnett 1978, 1982, 1998) and are interpreted to be buried by glaciolacustrine deposits within this area (Bajc, 2008a). This lack of continuity can be seen in **Figure 3.4.1.1.**

A substantial amount of outwash sand and gravel is associated with the Paris/ Galt Moraine system in the form of both outwash plains and spillways. These outwash features may exist adjacent to the flanks of the moraines (e.g. southeast of Erin and Cambridge) or can be found in between the moraines (e.g. Puslinch) and can be readily seen on the surficial geology map (**Figure 3.4.1.2).**

The topography of the moraines provides the relief for the headwaters of a large number of streams (**Figure 3.4.1.3**). Coldwater streams are quite common, given the related permeable outwash deposits and, as will be discussed later, given the potential for more permeable material within the moraines.

The ice contact nature of the moraines provided opportunities for kettles and kettle lakes to form (e.g. Puslinch Lake). These kettle features, along with the general hummocky nature of the moraines, give rise to many local wetland features. Wetland features are quite common adjacent to moraines where runoff from the slopes may collect (**Figure 3.4.1.4**).

The Paris/ Galt Moraines overlie a number of bedrock units throughout the study area (**Figure 3.4.1.5**) and will be discussed later as they relate aquifer potential.

Agriculture is the general land use throughout most of the Paris/ Galt Moraine. Urbanized portions of the Paris/ Galt Moraine lie within the southern borders of Guelph, Cambridge and Paris.

The Paris/ Galt Moraine system crosses the upper tier municipalities of Peel, Halton, Wellington, Hamilton, Waterloo, Brant and Norfolk and the Cities of Guelph and Cambridge, 4 subwatersheds in the CVC, 6 subwatersheds in the GRCA and various within the Hamilton, Halton and Long Point Conservation Authorities (**Figure 3.4.1.1**).

3.4.2 Investigations of the Paris/ Galt Moraines

The moraines of southwestern Ontario were originally described in detail by Taylor (1913). Chapman and Putnam's various editions of the Physiography of Southern Ontario, starting in 1951, further documented the moraine features of southern Ontario, including those of the Paris/ Galt Moraines. The majority of the geological information and interpretation for the Paris/ Galt Moraines is presented in various Quaternary and Pleistocene geology reports (Barnett, 1978, 1982, 1998; Cowan, 1972, 1976; Karrow, 1968, 1987; and, White, 1975). Additional geologic information is presented in various subwatershed studies in the form of general hydrostratigraphic cross sections (Lotowater, 1997; CG&S 1996; Stantec, 1999). The OGS has conducted recent drilling and geological/hydrogeological interpretation of the Paris/ Galt Moraines in the Brantford area (Bajc, 2006, 2007, 2008b).

A substantial amount of interpretation of the Paris/ Galt Moraines has been derived from the MOE water well database. The water well data base also tends to be the major source of information for the larger-scale watershed and subwatershed studies. The watershed based groundwater characterization studies and integrated water budget studies present information on a regional scale, with limited local scale hydrogeologic data, such as recharge. The subwatershed and county wide groundwater characterization studies generally provide smaller scale characterization relating to major aquifers, water table and potentiometric surfaces, basic groundwater availability, basic groundwater quality, recharge and discharge areas, and contaminant susceptibility. Although these studies are carried out on a smaller scale they are still generally too broad to present detailed small scale analysis relating specifically to the Paris/ Galt Moraines. General groundwater characteristics are presented in a limited number of groundwater studies. Watershed and subwatershed studies and other related groundwater studies that encompass the broader geographic area where the Paris/ Galt Moraines are present include:

- AquaResource Inc., 2008a. Integrated Water Budget Report, Grand River Watershed. Submitted to the Grand River Conservation Authority. Draft report, January, 2008.
- AquaResource Inc., 2008b. Long Point Region, Kettle Creek and Catfish Creek Water Budget and Subwatershed Stress Assessment. Submitted to the Lake Erie Source Protection Region.
- CH2M Hill, 1996. Mill Creek Subwatershed Study. Report to the Grand River Conservation Authority.
- Credit Valley Conservation, 1998. West Credit Subwatershed Study – Characterization Report.
- Credit Valley Conservation, 2002. Silver Creek Subwatershed Study – Phase 1 Characterization Report.
- Credit Valley Conservation Authority, 2008. Integrated Water Budget Report-Tier 2 Credit Valley Source Protection Area (Draft Accepted).
- Golder Associates, 1991. Cambridge Groundwater Study. Report to the Regional Municipality of Waterloo.
- Golder Associates, 2006. Guelph-Puslinch Groundwater Protection Study. Report to the Grand River Conservation Authority, City of Guelph, and Township of Puslinch.
- Golder Associates, 2006. Wellington County Groundwater Study. Report to Wellington County.
- Holysh, S., Pitcher, J. and Boyd, D. 2001. Grand River Regional Groundwater Study; Grand River Conservation Authority, Cambridge, Ontario, Technical Report, 271p.
- LESPR (Lake Erie Source Protection Region), January 2008. Grand River Characterization Report (Draft).
- Lotowater, 1997. Study of the Hydrogeology of the Cambridge Area. Report to the Regional Municipality of Waterloo.
- Stantec Consulting Ltd., 1999. Eramosa River-Blue Springs Creek Watershed Study Hydrogeology Component.
- Marshall, Macklin, Monaghan Ltd. 1992. Hanlon Creek Watershed Study.
- Totten, Sims, Hubicki., 1997. Torrance Creek Subwatershed Study-Phase 1 Characterization Report.

The geological and hydrogeological details presented in the above noted reports relating to the Paris/ Galt Moraines are discussed in Section 6.0, summarizing the current understanding of the Paris/ Galt Moraines.

4.0 Overview of Potential Water-Related Issues Associated with Land Use Activities

The following discussion is presented to provide a general overview of potential water-related issues associated with various land uses and land use activities. It is not meant to be an exhaustive list or a detailed discussion, but rather provide a "sense" of the types of potential water-related issues associated with land use activities and possible measures to minimize or mitigate impacts.

Although various Best Management Practices (BMP) are referred to in the following discussion a number of activities relating to potential impacts on groundwater are controlled to a great extent through existing policies (e.g. the Provincial Policy Statement) or legislation (e.g. the Clean Water Act), including provincially mandated Certificates of Approval and the Permit to Take Water program. Where approvals are required, it is common to assess and quantify the potential impacts, related to a potential land use change, and develop and implement appropriate design, mitigation and monitoring programs.

The following sections provide a brief, high-level discussion of potential water-related impacts of various land uses, or land use activities of concern, as related to this study, in particular: urban development; industrial development; agriculture; and, aggregate extraction. As well, a brief discussion is presented related to the potential impact of climate change on water resources and water-related ecological features.

4.1 URBAN DEVELOPMENT

Urban development interferes with water resources in two ways: by altering the hydrological cycle; and, by increasing the demand for water supply. There are a number of hydrologically-related issues that need to be considered when dealing with groundwater in urban areas. Large-scale urbanization will impact the natural water cycle, both in terms of water quantity and water quality (e.g. Environment Canada, 2001, Threats to Sources of Drinking Water and Aquatic Ecosystem Health in Canada; USGS WRIR Report 97-4195, Hydrogeology and Water Quality of an Aquifer Underlying an Urban Area, Manchester, Connecticut; UNESCO, 2005, Urban Water Management; and, Vazquez-Sune, 2003, PhD. Thesis: Urban Groundwater, Barcelona Case Study). Concerns related to urban groundwater include:

- fluctuations in groundwater levels caused by changes in land and water uses through alterations to the hydrologic cycle;
- pollution from both point and non-point sources of contamination;
- characterization and quantification of various components of the water budget;
- characterizing the groundwater flow system; and,
- collection and integration of appropriate data for sustainable urban water management.

4.1.1 Water Quantity

The most significant water quantity issue, typically attributed to urban development, is the potential for a reduction in recharge due to an increase in impervious surface area. Urbanization however, will alter all parts of the hydrologic cycle (Lerner, 1990). A cursory review of existing literature (e.g. Lerner, 1990, 2002; Howard, 1997; Vazquez-Sune, 2003) indicates that there are many factors that can either decrease or increase the amount of recharge within an urban area, as a result of land use activities related to urbanization. Factors that could decrease recharge include, but are not limited to:

- an increase in impervious surface area, increasing runoff;
- infrastructure intercepting shallow groundwater flow; and,
- increased evapotranspiration, depending on the climatic conditions and urban intensification.

Factors that could increase recharge include, but are not limited to:

- importation of water from lake-based systems or a distant groundwater source;
- leaky infrastructure;
- septic systems;
- irrigation or lawn watering;
- removal of agricultural tile drains;
- increased stormwater infiltration in pervious areas; and,
- decreased evapotranspiration, depending on the climatic conditions and urban intensification.

The physical impacts of land use activities due to urbanization could include the following (from Environment Canada, 2001):

- increased flows, causing flooding, erosion and habitat wash out;
- changes in sediment regime, causing habitat destruction, interference with water quality processes, transport of contaminants and impacts on aquatic life;
- thermal energy inputs, causing thermal pollution or loss of cold water fisheries; and,
- impairment of vertical mixing and oxygenation of bottom water in surface water systems.

An inherent impact of increased urban development is increased demand on water services. This will lead to increased water withdrawal from source waters used for water supply. This additional water withdrawal could impact groundwater levels and discharge of groundwater to surface water and wetlands, potentially impacting baseflow and maintenance of aquatic and terrestrial features.

4.1.2 Water Quality

The water quality of both surface water and groundwater can be impacted in an urban setting. Rainfall and snowmelt in urban areas are converted to urban runoff and the water is either transported to storm sewers or drainage channels, ultimately discharging to streams; or infiltrates into the ground and recharges the groundwater system. During this transport, the runoff quality is degraded by various pollutants, sediment materials and thermal energy from the urban environment (Environment Canada, 2001; Crowe et al, 2003). The water quality of urban runoff can be impacted by a number of factors including, but not limited to:

- intensity and duration of precipitation events;
- local air quality (a function of air pollution from local industries, wind direction etc);
- roofing materials in contact with roof runoff;
- runoff pathways/sources (i.e. parking lots, lawns, industrial sites, roadways); and,

- stormwater management controls.

Groundwater can also be impacted by the same factors as surface runoff, where infiltration of stormwater occurs. There are many potential contaminant sources, including but not limited to:

- road salt and other de-icing chemicals used on roads, sidewalks and parking lots;
- petroleum product loss or leakage from motorized vehicle usage:
- lawn maintenance and weed control;
- septic systems or leaky sanitary sewer infrastructure;
- leaky underground storage tanks;
- landfills;
- snow dumps; and,
- industrial/transportation corridor spills.

Changes to water quality, as a result of urbanization, could include the following impacts:

- an increase in chemicals discharging with stormwater (e.g. biodegradable organics, nutrients, trace metals, chloride from road salt, persistent organic pollutants (POPs) and hydrocarbons), resulting in degradation of aquatic and ecosystem health;
- an increase in microorganisms and "new" chemicals of concern (e.g. endocrine disrupters, pharmaceutical products and antibiotics) in wastewater discharging to receiving streams or rivers (i.e. the Grand River), potentially degrading the health of aquatic and terrestrial systems;
- a decrease in the assimilative capacity of the receiving streams or rivers; and,
- an increase in chemicals infiltrating to the groundwater system (e.g. chloride from road salt, hydrocarbons, chemicals from industrial spills, and nutrients and microorganisms from leaky sanitary sewer infrastructure) potentially impacting the quality of drinking water or water discharging to surface water systems.

4.1.3 Existing Best Management Practices

The following section provides a general discussion of examples of best management practices (BMPs) that address potential urban development impacts as they relate to the quantity and quality of groundwater and surface water sources. Low impact development techniques are being applied in areas around the world to address the decrease in groundwater recharge in urban areas, as well as the degradation in urban water quality.

A large focus of BMPs for urban development relate to stormwater quantity and quality for both the receiving surface water body (i.e. decrease high flows and minimize degrading the water quality) and infiltration into the ground (maintain historical groundwater levels and minimize degrading the water quality).

Various standard stormwater management techniques are used to protect groundwater levels and quality including, but not limited to:

- minimize lot grading to promote infiltration;

- discharge of roof leaders to pervious surface or infiltration pits;
- direct drainage through natural and manmade swales (allows for some attenuation of metals and petroleum products), to ponded areas and infiltration basins;
- direct water (from parking lots or areas of potential spills) through oil/grit separators prior to discharge to infiltration pits or ponded areas;
- use of pervious stormwater pipes and catch basins;
- development of road salt management programs;
- regulating the use of lawn care products;
- education on storage and handling of typical household contaminants (i.e. gasoline, oil, paint etc).

Various manuals and guidelines dealing with stormwater management, provided by provincial and municipal agencies, are utilized for development. The adequacy for the techniques to achieve quantity and quality objectives is an ongoing point of discussion among regulators and consultants.

More recently Low Impact Development has been widely promoted. Low impact development is a comprehensive land planning and engineering design approach that aims to maintain and enhance the pre-development hydrological and hydraulic regime of an urban area, and the watershed that hosts the development. There are several measures that municipalities and/ or landowners can carry out to reduce runoff, enhance groundwater infiltration and help maintain pre-development groundwater recharge rates, and surface water hydraulic regimes.

The principals of low impact development include the clustering of houses and/or buildings to protect natural areas, which also serve as open space for recreation. Roads located in low impact developments are narrow, and parking lots, driveways and other pervious surfaces use various types of permeable pavements. Sidewalks and other impervious hard surfaces are limited, and the runoff from such surfaces, as well as roof tops are directed onto vegetated areas with porous soils. In some areas, rooftop runoff is collected and used to irrigate lawns or gardens, or in some areas to flush toilets in the homes. All of these are examples that municipalities can employ to limit urban runoff, maintain recharge to groundwater aquifers, and also to maintain a pre-development surface water regime.

In areas where development has already occurred, there are retrofitting measures that can be implemented to enhance recharge and reduce runoff to surface water features. A common retrofitting measure is disconnecting residential downspouts that drain directly into the municipal storm sewers, and drain the water into a rain barrel to be used for lawn and garden watering, or onto the lawn or an infiltration gallery.

Pervious pavement can also be laid down when repaving or installing new roads, sidewalks, parking lots, or driveways. Pervious pavements allow water to infiltrate into the ground rather than traveling over the hardened surfaces to storm sewers. Restoring the soil quality in public parks by tilling and aerating the lands can also be effective in enhancing recharge to the groundwater system and to reduce peak flows in the nearby creeks and rivers.

A basic education of the impacts on groundwater can be very efficient and cost effective for protecting groundwater resources. In many areas, residents, businesses, and industries often are not aware of the impact they have on their surroundings, and therefore, educating landowners living in significant recharge areas on responsible land management for both water quality and quantity can be very worthwhile. Targeted public education campaigns that explain the concepts of responsible land and water management may lead to enhancements in infiltration such as the implementation of pervious pavements in a business parking lot, or the disconnection of a downspout by a homeowner.

4.2 INDUSTRIAL DEVELOPMENT

4.2.1 Water Quantity

Industrial water users within urban areas typically do not have their own "private" water supply, and are required to use municipal water in their operations. In rural areas, industrial facilities will typically have their own private water supply. Some industries use only limited amounts of water, primarily for employee use. These industries are referred to as "dry" industries. Other industries may use substantial volumes of water in the operations. These industries are referred to as "wet" industries. The majority of water used in industrial/manufacturing processes is for heating or cooling or used as part of a cleaning process. There are some specific industries that use water within their manufacturing process (i.e. bottled water companies, beverage companies and food canning industries).

4.2.2 Water Quality

Industrial and commercial developments pose a wide variety of potential threats to water quality, through the on-site use of various chemicals. Water quality issues related to industrial development are typically the result of the release of point sources of contaminants, either through spills or leaks. Many of the releases of contaminants are related to historical practices or aging infrastructure and fuel storage tanks. There exist a large number of industrial facilities that are considered potential threats to water quality, including the following examples:

- equipment manufacturing;
- gas stations and automotive garages;
- food manufacturing and processing;
- recycling facilities;
- textile product and finishing;
- printing services;
- wood product manufacturing;
- bulk petroleum storage; and,
- chemical product manufacturing.

Categories of typical risk include synthetic and volatile organic chemicals, microbiological contaminants, inorganic chemicals, and nitrogen species (Golder, 2006).

Historical practices and historical use of chemicals were often conducted with limited understanding of the risk associated with the use of the chemicals. Industrial chemicals were often released to the environment through spills or leaks that were uncontained, both within and outside buildings. Underground storage tanks were not typically monitored for loss of product through leaks. Disposable of hazardous chemicals was often done by placing them in unlined waste lagoons or unlined landfills. As a result, there is a legacy of chemical contamination in most industrial areas within any urban setting.

4.2.3 Existing BMPs

Industrial water users may compete with municipalities for the same water supplies; however, there are a number of best management practices that can be implemented by the industries to reduce their water takings, and thereby reduce the impact on the municipal supplies. The methods used to reduce their water takings are as variable as the types of industries (manufacturing, pulp and paper, textile, etc); however, there are a number of measures that can be implemented by all types of manufacturing plants and industry to reduce their water use.

The majority of water used in manufacturing plants is for heating and cooling, and process use (cleaning of parts, vats, etc). Review of case histories in Canada, the US and overseas as part of an MOE funded study (AquaResource, 2007) found that the most effective water conservation technique in manufacturing facilities was the proper and optimized use of cooling towers. Cooling towers remove heat from air conditioning systems, and industrial processes that generate excess heat. The inner workings of cooling towers are complex and proper design and optimal use of the tower can greatly reduce water loss (evaporative) and water used in the cooling process (North Carolina DENR, 1998).

In addition, the use of water efficient landscaping methods and technologies such as low flow sprinklers, optimized watering schedules and xeriscaping techniques were also found to greatly decrease water use in industrial facilities. Water use by employees was also effectively reduced through the installation of low flow toilets, faucets and showers in washrooms, and water audits were also found to be very effective at identifying areas where water conservation methods can be implemented. Water recycling or reuse facilities, leak detection systems, and employee education programs were also implemented to reduce water use and found to be highly effective.

Water use in the primary metals sector is mainly used in cooling, material conditioning, dust suppression, cleaning (Kinkead, 2006). Water conservation measures in this sector have focused on the use of closed-loop (closed circuit) systems, and treatment and reuse of process water. The Canadian Steel Producers Association's cite that more than 95% of the water used in producing steel products today is recycled primarily in closed loop systems (CSPA, 2007).

With respect to water quality protection major industries are generally required to have spills action plans. Areas for loading and offloading potential contaminants are expected to be contained. In addition, the following common techniques are typically used at industrial locations to minimize the threat of a contaminant release to surface water or groundwater:

- Liquid storage areas must have secondary containment to hold any spills or leaks at 10% of the total volume of the containers or 110% of the largest container, whichever is larger.
- Design of in ground protection channels for transfer hoses to minimize damage from vehicles and to catch leaks or spills is required.
- Any areas used for cleaning parts, machinery, etc. must be located within a containment area with an impermeable floor. There must be no direct access to outside.
- New and waste material storage areas must be roofed, isolated from floor drains and have sealed surfaces.
- Underground storage tanks are discouraged, however where used, they must have secondary containment, a monitoring system incorporating high level and leak sensing audio/visual alarms, level indicators and overfill protection. A protective plate will be placed in the bottom of the tank if a dip stick is to be used.

- Untreated rinse waters and floor drains must not discharge to a sanitary sewer, septic system, storm drain or surface water.
- Waste collection stations, with labelled containers for each kind of waste, must be provided throughout the work area for spent chemicals, soiled rags, etc.
- Uncovered receiving areas must be designed with a spill sump to catch and store any spilled chemicals with a manual operation for emptying.
- Wastewater from any laboratory operation must be discharged to a lab drain system that is separate from the sanitary wastewater drains. Laboratory drains must lead to a neutralization system prior to discharge to the sanitary sewer.
- Uncovered scrap metal storage areas must have a separate stormwater collection system with an oil/grit separator which discharges to a sanitary sewer or a holding tank.
- Hazardous materials must not be put down drains, but rather must be properly disposed of by a licensed hazardous waste hauler.

4.3 AGRICULTURE

4.3.1 Water Quantity

Agricultural water use in Canada is primarily for irrigation (85%) and livestock watering (15%; Brandes and Ferguson, 2003). Agriculture accounts for approximately 9% of total national water withdrawals (Environment Canada); however, irrigation is a highly seasonal use, so the proportion of total water use during the summer months is likely much higher. Approximately 67% of all the water withdrawn for agricultural purposes is either consumed or not returned to the source from which it was taken (Kinkead, 2006).

The major agricultural water use in southwestern Ontario is primarily for irrigation of tobacco crops. Other irrigation uses include sod, vegetables, nursery and greenhouse crops. Water use for livestock can also create a significant local demand. Minor uses include cleaning buildings and equipment and domestic use.

Both surface water and groundwater are used in agricultural operations. The primary source used will depend on the local seasonal availability and water quality. In areas where water use is high such, as Norfolk County (i.e. on the Norfolk Sand Plain), the deeper groundwater sources have poor water quality.

From a water balance perspective the type of crop being grown, put into production, or taken out of production can significantly affect evapotranspiration (ET) and thus the potential for recharge. Tillage practices can also affect the potential runoff and again the potential for recharge. The re-conditioning of soil can affect the infiltration capacity.

Tiles drains may also affect the water available for recharge, by short circuiting it to water courses, although the delayed drainage may add to short term low flow impacts in some streams.

Sediment loading to streams, due to soil erosion, may impact groundwater discharge areas if the fine-grained sediment that has been eroded is deposited over the coarser-grained sediment within the stream.

A comprehensive study on agricultural water supply issues in Ontario, conducted in 2003 (Marshall, Macklin, Monaghan, 2003), noted that five studies were being carried out under the direction of the MOE and MNR related to water budgets, water allocation and instream flows. These studies, along with other initiatives in the Long Point Conservation Area, were not available for this review.

4.3.2 Water Quality

In the past 40 years agriculture in Canada has been substantially altered due to: greater mechanization; the use of mineral fertilizers and pesticides; new and better varieties of crops; and, innovative farming practices (Chambers et al, 2002, Effects of Agricultural Activities on Water Quality, CCME Workshop). Water quality can be potentially impacted by both point source and non-point source contaminants (Chambers et al, 2002; and, Harker, 1998, Non-Point Agricultural Effects on Water Quality). Non-point source contamination could include:

- fertilizer nutrients;
- sewage biosolids;
- pesticides;
- pathogens; and,
- endoctrine disrupting substances and pharmaceuticals.

General point source contaminants include:

- fuel storage;
- chemical storage;
- spills;
- septic systems for domestic sewage and farm wastewater; and,
- manure storage.

Table 4.3.1 shows a generalized chart of the potential agricultural effects on water quality as presented in Coote and Gregorich, 2000, an Agriculture Canada publication entitled “The Health of Our Water – Towards Sustainable Agriculture in Canada.

Coote and Gregorich, 2000 describe the difficulty in measuring, on a reasonable scale, the level of groundwater contamination from agriculture and the source area of the contamination, due to:

- the high cost of monitoring;
- the seasonal and spatial variability of contaminant movement and water flow;
- the large number and diversity of farms and farming practices; and,
- the scalar differences in topography, soil and climate.

Potential agricultural effects on water quality

Agricultural modifications involving . . .	through farming practices such as . . .	with these potential effects related to water quality . . .
Water inputs and water routing	■ Irrigation ■ Drainage ■ Rechanneling natural watercourses	■ More water to leach agrochemicals and bacteria into groundwater ■ Concentration of nutrients in drainage water
Nutrient cycling	■ Addition of - mineral fertilizer - animal manure - compost - sewage sludge and effluent - green manure ■ Export of nutrients in the harvested crop	Nutrient surplus → nutrient losses → water contamination by ■ nitrate ■ phosphorus ■ bacteria
Balance of biological species	■ Monoculture ■ Crop rotations ■ Weed control ■ Insect control ■ Disease control	■ Some crops allow higher rates of erosion → higher losses of sediments to water ■ Pesticide losses to atmosphere → atmospheric deposition on surface waters ■ Pesticide losses into water in runoff and by leaching
Soil condition	■ Tillage (conventional, conservation, no-till) ■ Wheel traffic ■ Cropping patterns	■ Soil degradation → poorer infiltration of water into soil → increased runoff and movement of contaminants into water ■ Greater erosion → increased sedimentation and movement of contaminants into water

L.J. Gregorich, Gregorich Research

Table 4.3.1: Potential Agricultural Effects on Water Quality (from Coote and Gregorich, 2000)

4.3.3 Existing BMPs

Extensive research has looked at methods to reduce overall water demand for irrigation purposes, and several measures were shown to be effective at reducing water demand for crop irrigation. Many of these studies were undertaken in cooperation with farmers and irrigators to determine the most effective measures for reducing water demand.

According to the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA), operational measures that have been particularly effective at reducing total demand include the use of irrigation management plans that outline crop water requirements, critical seasons, and irrigation infrastructure. Other measures include the use of high efficiency irrigation equipment such as trickle/drip or low pressure/low trajectory irrigating methods, and monitoring and maintenance of irrigation equipment to reduce leakage and water loss. Monitoring of soil moisture to indicate when irrigation is required is also effective at reducing water demand, as is the use of rain gauges within irrigated fields, to determine depth and uniformity of irrigation across an irrigated area.

Planting windbreaks or wind strips, which reduce or decrease the impact of winds, help to reduce water loss from crops. The use of plastic or organic mulches to retain water, and the use of conservation tillage to maintain more organic residue on the surface are also effective at reducing water demand. Avoiding compaction of soil across an area aids in the infiltration of water, and decreases loss of water to tile drains or nearby surface water features.

Land management practices which aid in minimizing impacts on infiltration and groundwater quality include:

- crop rotation;
- conservation tillage systems; and,
- cover crops.

Appropriate nutrient management dealing with the amount and timing of application significantly minimizes the potential for groundwater degradation. Integrated pest management (i.e. planting crops to lure pests away from main crops etc) reduces pesticide application.

4.4 AGGREGATE EXTRACTION

4.4.1 Water Quantity

The physical presence of an excavation can have a variety of potential impacts on the groundwater system. Some effects or changes will be minor, such as the impact of above water table extraction on the groundwater flow direction. Below the water table, with no mitigation measures, increases the potential to alter the local groundwater flow system.

Potential changes to the direction and flux of groundwater flow as a result of aggregate extraction are caused by two general mechanisms:

- a change in the water budget, more specifically the groundwater budget; and;
- a change to the characteristics of the porous media (i.e. the removal of aggregate material).

Changes in the water budget

Above the water table extraction factors include:

- changes in runoff and evapotranspiration; and,
- changes in unsaturated fractured rock and conduit flow within the rock.

Below the water table extraction factors include:

- Changes in runoff and evapotranspiration.
- Pumping of groundwater from ponds or well water for aggregate extraction (i.e. washing, processing) can create drawdown cones in the hydrostratigraphic unit being pumped. The extent of drawdown will depend on: the size of the pond or the location and depth of the well; the pumping rate; the hydrostratigraphy (particularly whether the flow is occurring in an unconfined,

semi-confined or confined geologic unit); local recharge conditions; and, the potential for interception of a surface water body by the drawdown cone.

- The physical extraction of aggregate material below the water table (i.e. dragline operation in sand and gravel pits) will also induce flow towards the excavation, at least on a temporary basis. The removal of solid material is replaced by inflowing water. The rate of extraction dictates an equivalent flow of water needed to replace the additional void space.

Changes in the characteristics of the geologic material

Above the water table extraction factors include:

- Loss of geologic material and soils above the water table and modification of runoff patterns.
- Induced fracturing from blasting in quarries or stress release from the quarry excavation and removal of load bearing material.

Below the water table extraction factors include:

- Removal of porous media and subsequent infilling with water creates a zone of “infinite” permeability. This zone would act as a local hydraulic lens pulling water in from upgradient and releasing it downgradient through the pond (i.e. the path of least resistance). There may be an increase or decrease in local groundwater recharge depending on climatic conditions for evaporation versus evapotranspiration. The total groundwater flow through the extraction area and the groundwater flow paths are altered on a local scale. The impacts of these changes on a more intermediate/regional scale will depend on the size and location (i.e. is it in a recharge area or discharge area) of the extractive activity relative to the overall groundwater flow system.
- Removal of porous media and subsequent infilling with material of lower permeability. There will be a decrease in recharge on a local scale. The total groundwater flow through the excavation and the groundwater flow paths near the excavation are altered on a local scale. Infilling with low permeability material is typically not done in Ontario, but is done in many areas of Europe where land available for development is limited.

A detailed literature review investigating potential impacts on groundwater and surface water related to source water protection was carried out for MNR in 2006 (Blackport and Golder, 2006). This review involved researching sources of information from international agencies, academic institutions, peer-reviewed journals and the internet. Results showed very little documentation of groundwater impacts due to aggregate extraction, other than as a result of umitigated quarry dewatering. The following findings were presented, related to groundwater quantity:

- *Aggregate extraction causes limited change to the overall water balance of an aquifer system, unless large scale unmitigated dewatering occurs, and will have limited potential impact on source water protection from a groundwater quantity perspective.*
- *Changes in the groundwater flow system, as a result of aggregate extraction below the water table, may locally modify capture areas of a municipal well or well field in the same aquifer, depending on proximity of the aggregate operation to the municipal well or well field.*
- *The existence of post-extraction lakes increases the overall groundwater storage within the aquifer where extraction has occurred.*
- *Various studies demonstrated that appropriate mitigation, including infiltration trenches and barrier walls, could reduce the impact of aggregate extraction on local groundwater levels.*

4.4.2 Water Quality

Groundwater quality concerns related to the aggregate extraction and land use activities associated with aggregate extraction can be divided into three components, based on activities that could generate a potential contaminant of concern (Blackport and Golder, 2006):

- operational activities such as on-site storage of fuel;
- ancillary uses on-site, such as asphalt plants; and,
- future land use, site rehabilitation or uncontrolled/illegal dumping.

The on-site sources of contaminants include but are not limited to petroleum products and dust suppressants from normal operational activities and possible release of contaminants related to ancillary uses (e.g. asphalt plant).

Backfilling of non-inert material both above and below the water table can leach contaminants and enter the groundwater flow system directly where no fine grained layer exists within the excavation. It is important to note that activities such the importation of fill and storage of fuel are highly regulated within the Province of Ontario and must meet strict standards.

An unmitigated loss of the surficial soil layer and loss of any amount of the unsaturated zone reduces the attenuative capabilities of the porous media to biodegrade, and chemically or physically interact with any potential contaminants that would be introduced through overland flow or acidic precipitation.

The exposure of a gravel pit pond to the atmosphere, precipitation and surface water run off can lead to a modification of aqueous chemistry through changes in nutrient inputs, oxygen demand, biological processes, water temperature etc. The resulting groundwater/surface water interchange can modify the groundwater quality downgradient of the gravel pit pond.

The shallower groundwater systems in Ontario typically have average groundwater temperatures within 2-3 degrees Celsius of the long-term average air temperature (10^{o}C). Temperatures at the water table can vary by more than 10^{o}C depending on the thickness of the unsaturated zone. Ponds will warm and cool groundwater seasonally, depending on their size and depth and rate of interchange with the shallow groundwater system. Removal of the unsaturated zone may alter the shallow groundwater temperature immediately underlying the excavation thus creating the potential for a thermal plume to migrate from the extraction site.

The MNR study (Blackport and Golder, 2006) also presented findings related to groundwater quality. These included:

- *A decrease in the contaminant attenuative ability when the soil layer and unsaturated zone is removed. This results in an increased potential for contaminants to enter and travel through the groundwater system from any surface source of contamination (e.g. surface runoff from future land use activities). Where the aggregate extends to ground surface the loss is minimal unless there is a water supply immediately adjacent to the extraction area.*
- *Water quality changes downgradient of a post-extraction lake, as a result of exposure of the water table to the atmosphere. These changes include changes in pH and dissolved oxygen that could impact nutrient and metal concentrations, locally down gradient of the post-extraction lake. The degree of impact is a function of the existing water quality and existing impact from surface sources of contamination.*

- *Thermal plumes from the below water extraction and post-extraction ponds were typically very localized. Depending on the hydrogeologic setting, the impact was typically less than 200 m.*
- *Post-extractive use of an aggregate site, in particular infilling with non-inert material, presents a significant potential source for groundwater contamination.*
- *Abandoned or uncontrolled access aggregate sites have the greatest potential for generating contaminants that could be introduced to the groundwater system through historical practices of illegal dumping. Not withstanding this concern, there is limited information in the literature indicating contamination of water supplies from poor landfilling practices or illegal dumping in closed or abandoned pits and quarries.*
- *The risk or impacts from the loss of attenuation is directly connected to the management of the potential operational contaminants (i.e. petroleum products) and the management of adjacent stormwater runoff or post extractive application of agricultural products*

It was noted that no documented cases were presented with respect to significant groundwater quality impacts of municipal well fields or water supply as a result of aggregate extraction in gravel pits.

4.4.3 Existing BMPs

Aggregate extraction and water taking gravel pit operations may induce changes to the groundwater flow system as described in Section 4.4.1. Some examples of mitigation strategies and best management practices are presented below.

<u>Extraction Geometry and Extraction Rate</u>

The distance between the extraction site and the potentially sensitive surface water body would generally be a factor in minimizing the impacts. This must be considered in the context of understanding the actual site specific groundwater flow system. Large extraction sites could have varied groundwater flow paths due to complex hydrostratigraphy.

In cases where extraction will be occurring below the water table, across a large area, then extraction could first occur at the furthest point away from any potentially sensitive area to minimize impact. This has a number of advantages:

- Ongoing monitoring can determine if measured water level changes are greater than the predicted changes. If there are greater than anticipated impacts to water levels, appropriate mitigation measures can be undertaken. The greater distance between the extraction area and the sensitive area will provide a buffer to minimize unacceptable impacts and allow for adaptive management during active extraction
- The initial extraction phase will provide a pond, to act as a storage reservoir, which will increase in size as extraction proceeds closer to a sensitive area. The increased buffering capacity of the reservoir of water will minimize water level impacts during later stages of extraction.

Ideally, to minimize impacts on the groundwater flow system, extraction should proceed such that a series post-extraction ponds would have water levels would generally emulate the pre-existing water table conditions. The simplest approach would be to proceed with a series of extraction phases that would not be connected and would conform to a geometry similar to the pre-existing water table contours. This in essence would be a form of “water table landscaping”. This approach has been modelled and has demonstrated that it can minimize changes to the water table and groundwater flow system.

Based on the groundwater flow dynamics, relating the size of the pit and the contact perimeter with the water table and the flux, it may be beneficial to initially have a larger shallow excavation below the water table, as opposed to a smaller deeper excavation. Site-specific water budget factors and operational considerations may dictate whether this is appropriate or not.

The seasonal and long-term rates of extraction could be considered in minimizing changes to the water table. Initially, smaller rates of extraction may provide minimal impacts until the pond size provides an appropriate buffer (i.e. overall reservoir and perimeter size) for higher extraction rates. Although operationally problematic, it may be better to increase production during the cooler, wetter periods to buffer against the natural seasonal reductions in water levels.

Water Management

On-site water can be moved around from pond to pond to stabilize hydraulic gradients in a particular direction. Water could be added to the ponds from sources outside the pre-existing groundwater flow system, including high flow stream run-off and groundwater from a lower confined aquifer. In both cases the removal of water from these systems must not interfere with the functional attributes they supply to their downstream/aquifer receptors.

Barriers and Infiltration Trenches

Barriers and infiltration trenches provide the same function, to support or maintain the pre-existing hydraulic gradient outside of the working area and can be successfully carried out depending on the site specific hydrogeologic setting and the extent of effort to construct.

Artificial barriers can be used in the pond settings to minimize seepage into the pond where the pond level is lower than the adjacent pre-existing water level. These barriers can be constructed in a number of ways either along portions of the pond bed or in excavations adjacent to the pond. A fine-grained layer on the bottom of the pond provides a lower hydraulic conductivity unit which reduces the effect of directing groundwater to the pond. This can reduce the groundwater flow system modification and reduce the thermal plume migration.

Recharge trenches can be constructed between the pond and the receptor, usually adjacent to the pond. Water is diverted into the trench to maintain the pre-existing water level. Recharge trenches are usually done in concert with barriers to minimize flow of recharge water back to the pond. The effectiveness of recharge trenches will be dependent on the site-specific hydrostratigraphy and the depth to the water table.

4.4.4 Cumulative Effects Assessment

There is the potential for “cumulative effects” on groundwater resources, due potential overlapping impacts of land use activities in close proximity to each other. In the case of aggregate extraction there may be cumulative impacts associated with modification to the local groundwater flow system, due to local changes in the water table elevations, and/or temporary modification to groundwater flow during active extraction. The overall impact of these combined changes will depend on:

- the resilience of the physical system;
- the natural trends or variations within the physical flow system;
- the proximity of the combined extraction activities and the location of these activities within the groundwater flow system (e.g. recharge area or discharge area); and,

- the design measures used to mitigate the potential impacts of each extraction operation or activity.

The literature review carried out for MNR (Blackport and Golder; 2006) also searched for studies or reports addressing cumulative impacts, associated with aggregate extraction operations in close proximity to each other, and concluded the following:

- *There are few studies in the literature that address cumulative impact of aggregate extraction. Case history studies that do assess cumulative impacts do not appear to show impacts to the groundwater system at a subwatershed scale, although local impacts were observed on a site-specific basis.*

It is noted that a guidance document for aggregate extraction is currently being prepared by various provincial stakeholders and is entitled “Cumulative Effects Assessment and Best Management Practices Paper for Below Water Aggregate Operations”. It is presently in Draft form and not available.

4.5 POTENTIAL IMPACTS OF CLIMATE CHANGE

The following section presents a high level overview of the potential impacts of climate change on water resources and ecological features that rely on water. As indicated in previous sections, this overview is no meant to be an exhaustive review as considerable literature exists on the potential impacts of climate change. Research is ongoing and constantly being updated. Much of the information presented in this section focuses on the potential impacts of climate change, related to the climatic conditions associated with the Great Lakes basin in general. The general information presented in this section is primarily from two main publications: Climate Change Impacts and Adaptation: A Canadian Perspective, by Natural Resources Canada, 2004; and, Threats to Water Availability in Canada, by Environment Canada, National Water Research Institute, 2004.

There are many potential impacts related to climate change, depending on the existing climatic conditions within a specific geographic location and the sector of the economy or environment that would be impacted. A general flow chart showing examples of the potential impact of climate change is presented in Figure 6.4.1 from Natural Resources Canada (2004) for lower lake levels in the Great Lakes-St. Lawrence basin. A variety of sectors, such as transportation, fisheries, municipalities and agriculture are impacted. Potential impacts include: decreased navigation on waterways due to lower water levels; loss of species habitat; poorer water quality; and, water contamination. The following presents a general summary of potential impacts and issues related to water resources and climate change that could be occur in southern Ontario:

<u>Surface Water - Water Quantity and Water Supply</u>

- Summer flows are expected to decline, which will impact the assimilative capacity of the receiving streams or rivers (e.g. the Grand River).
- The magnitude of spring flooding will likely decline, however increased winter flows will increase the risk of severe flooding in the winter.
- There will be increased property damage due to increased flooding during both winter/spring melt events and severe summer storms.

<u>Groundwater – Water Quantity and Water Supply</u>

- Under normal conditions, there will be an increase in groundwater recharge in areas where the shallow soils are permeable or there are closed depressions, due to a shift in timing of the spring thaw and increased recharge during winter conditions.
- Shallow aquifers may be temporarily (i.e. several years) impacted by an increasing number of prolonged droughts resulting in a reduction in water levels, storage in the aquifer, recharge to deeper aquifers and discharge to surface water.
- There may be greater stress on the deeper aquifer system as more water may be required from the deeper, more buffered aquifers, if there is less water available in shallow aquifers during prolonged droughts.

Water Quality

- Lower river levels will typically result in higher pollutant concentrations and increased concentrations of toxins and bacteria in the water.
- There will be an increased likelihood of water-borne health impacts.
- Higher flows and flooding events will increase the turbidity and the flushing of contaminants into the surface water system and increase erosion of soils and sediment loading to the surface water system.
- Increased surface water temperatures, decreased duration of ice cover and lower water levels may contribute to decreased concentrations of dissolved oxygen and increased concentrations of nutrients, such as phosphorous, in surface water.

Ecological

- Lower water levels will result in a decrease the assimilative and purification abilities of wetlands.
- Drier conditions may shift the hydroperiod, potentially changing the wetland ecosystem to “drier” vegetative species. Shorter winters and longer summers will impact water availability to terrestrial ecosystems.
- During increased periods of extended drought there will be less baseflow to maintain creeks and wetlands, impacting aquatic and terrestrial ecosystems.
- Greater evapotranspiration in the summer will decrease the water availability to terrestrial and wetland systems.

Water Demand

- Warmer temperatures and drier conditions will increase the urban water demand causing greater stress on the pumped aquifer system.
- Agricultural water demand will greatly increase, which is likely to impact the shallow groundwater system where most water taking will occur.

Water managers are increasingly considering the impact of climate change and how to adapt to climate change (Natural Resources Canada, 2004). Because of the uncertainty associated with climate change, it is difficult to deal with risk assessment. It is one additional factor that water managers add to other uncertainties, such as population growth and changing economic conditions. Typically, most existing water management plans, including water supply and water drainage systems are based on historical climatic and hydrological records (Natural Resources Canada, 2004). These records may not be applicable in the future, especially related to managing stormwater due to increased intensity of precipitation events. Water managers are looking at a number of adaptation options for water resources including the following (Natural Resources Canada, 2004):

- water conservation measures;
- improved planning and preparedness for floods and droughts;
- improved water quality protection from all land use activities;
- enhanced monitoring programs, quality and quantity; and,
- infrastructure adaptations, such as sizing of stormwater management ponds and storm sewer systems and modification of larger flood control structures.

Assessment of the potential impact of climate change on water resources has also been conducted on a more site-specific basis. A case study, assessing the hydrologic impacts of climate change at the watershed scale, was conducted as part of an M.Sc. thesis at the University of Waterloo. Brouwers (2007) performed complex numerical model simulations using the Alder Creek watershed area, in the Waterloo Moraine, to evaluate climate change scenarios. The Alder Creek watershed was chosen as it had been previously well characterized and was relatively small in size. A coupled surface-subsurface water model was used to determine a suitable approach for conducting long-term transient simulations at a watershed scale (Brouwers, 2007).

Two contrasting scenarios of climate change were evaluated. Drier and wetter future conditions were evaluated relative to a reference scenario. The reference scenario was based on existing climate records. The results of the study indicated the following:

- Climate change simulations results showed a strong impact on the timing of hydrologic processes, shifting the spring snow melt to earlier in the year. This resulted in an overall decrease in runoff for both drier and wetter conditions. There was also an increase in infiltration under both drier and wetter conditions.
- A marked increase in total evapotranspiration was found in both climate scenarios. This was most pronounced in the summer months.
- The simulations results showed a small overall rise in groundwater levels for both climate change scenarios.

5.0 Current Understanding of the Waterloo Moraine

5.1 OVERVIEW

Section 3.3 provided a detailed summary of the history of investigations associated with the Waterloo Moraine, in order to put into perspective the current understanding of the level of knowledge of the understanding of the Waterloo Moraine.

The following sections provide a summary of the current understanding and state of knowledge of the Waterloo Moraine. It is divided in general headings as outlined in the objectives (Section 1.2). It is noted that the discussion of the Waterloo Moraine differs considerably from the discussion of the Paris/ Galt Moraines, given: the inherently different geographical and geological settings; the major functions of each of the moraines; and, the level of investigation of each moraine due to the differences in the level of water supply exploration and urban development on each of the moraines.

5.2 WATERLOO MORAINE BOUNDARY

The boundary of the Waterloo Moraine has been interpreted in several different ways. In interpreting a feature such as the Waterloo Moraine, it is difficult to establish a "distinct" boundary. As discussed in Section 3.3, the Waterloo Moraine was mapped as early as 1913 by Taylor, and described as "a finely formed moraine ridge running south from Waterloo to Ayr and west to Bamberg" (Bajc and Karrow, 2004). Chapman and Putnam (1951) refined the geographic extent and character of the Waterloo Moraine in 1951, and subsequently in 1972 and 1984. Karrow noted many years ago that there was a core of fine sand and that parts of the moraine were capped by fine-grained tills. Two major ridges were noted (Bajc and Karrow, 2004), representing important ice-marginal positions. Karrow also recognized a number of spurs extending out from the Waterloo Moraine.

The mapping of the surficial geology also shows areas of hummocky topography throughout the general area of the Waterloo Moraine. The hummocky topography extends across a number of surficial geologic units, including the outwash sands associated with the core of the Waterloo Moraine and a number of the fine-grained till units surrounding the core area of the Waterloo Moraine. All of these factor into the variations in the interpretation of the boundary of the Waterloo Moraine.

Figure 5.2.1 shows the interpretation of the boundary of the Waterloo Moraine, as provided by MOE for this study. The interpretation is based on glacial depositional environments, topographic descriptions and geologic material types described by the OGS in the Surficial Geology of Ontario (OGS, 2003). The OGS compilation of moraine boundaries does not outline the moraines explicitly. The OGS created a layer of "hummocky topography" from the existing surficial geology maps. The hummocky topography provides an approximate outline of the moraines. Not all existing surficial geology mapping shows a hummocky topography layer. The mapping of the hummocky topography also does not necessarily indicate an association with a specific moraine. In the case of the Waterloo Moraine the boundary areas that would be of importance are the western areas of the moraine, west of the Kitchener and Waterloo city boundary (**Figure 5.2.1**). These areas appear to correlate with hummocky topography mapped by Karrow (1993), in the Quaternary Geology of the Stratford-Conestogo Area.

Figure 5.2.2 shows the interpretation of the Waterloo Moraine from Chapman and Putnam, 1984. Their mapping is based on interpreting the approximate boundary of the kame moraine landform, and was not specifically called the Waterloo Moraine in the physiographic interpretation. The general outline of the kame moraine is not as extensive as the general OGS interpretation, especially along the western boundary (e.g. north of Baden). It appears that the mapping generally corresponds to the extent of the ice-contact sand and gravel in the core area of the Waterloo Moraine and does not include the till units that overlie the ice contact sand and gravel unit.

Figure 5.2.3 shows a recent presentation of the Waterloo Moraine boundary by Karrow (Bajc and Karrow, 2004; Bajc and Shirota, 2007). Much of the mapping is similar to the OGS, (2003) version; however it is not as extensive in some of the western areas compared to earlier the OGS version. In particular, the following differences are noted:

- Two areas jutting out to the east and southeast of Haysville, on the OGS (2003) version (**Figure 5.2.1**), which were mapped as hummocky terrain, are not shown on Karrow's mapping (**Figure 5.2.3**). These areas are shown as fine-grained till units on the surficial geology mapping. Karrow's boundary corresponds more closely to the boundary of the ice-contact sands in the core area of the Waterloo Moraine.
- There is a more extensive southward extension of the Waterloo Moraine, on the OGS (2003) version, just east of Wellesley (**Figure 5.2.1**), compared to Karrow's mapping (**Figure 5.2.3**). As previously indicated the OGS version shows this area as hummocky topography from the surficial geology mapping. This area is also mapped as a fine-grained till (Mornington Till) and is mapped by Karrow as being part of the Macton Moraine, to the west. Karrow's boundary line again generally corresponds to the surficial boundary ice-contact sand (Karrow, 1993) in the core of the Waterloo Moraine.
- An extension of the Waterloo Moraine in the northwest, towards Crosshill, is evident in the OGS (2003) version, as it is mapped as hummocky topography. Karrow interprets this area as part of the Macton Moraine and is also mapped as the Mornington Till, with the exception of the Crosshill Spur, a local ice-contact sand unit. Karrow's boundary is again correlated to the ice-contact sand unit.

The OGS has been conducting three-dimensional mapping studies of the Quaternary deposits throughout the Region of Waterloo, since 2003. A report was produced in 2007, (Bajc and Shirota, 2007) presenting the findings of the detailed mapping and interpretation. The current interpretation by the OGS suggests that the Waterloo Moraine may extend farther southeast than has been previously interpreted. **Figure 5.2.4** presents mapping by the OGS (Bajc and Shirota, 2007) that shows areas of the "Waterloo Moraine and equivalent aquifers" with a total thickness greater than 10 m and an aquitard cover of less than 1 m. The mapping itself does not specifically indicate that the entire area shown in green on **Figure 5.2.4** is interpreted as the being part of the Waterloo Moraine. However, the OGS has indicated that the southern portion of this area may be an extension of the Waterloo Moraine with sediments having been modified by outwash processes within this area. This area generally correlates with ice-contact sands and gravels, outwash sands as mapped by Karrow (1987). The implications of this are discussed in Section 7.

As part of the Region of Waterloo's water resources protection strategy they have identified the importance of the Waterloo Moraine and have included the feature in their Draft Regional Official Plan (ROP), (Region of Waterloo 2008a). They have also designated major recharge areas of the Waterloo Moraine within their ROP (discussed in Section 5.5.1). **Figure 5.2.5** shows the boundary of the Waterloo Moraine, as designated by the Region of Waterloo. The boundary of the Waterloo Moraine generally corresponds to 2003 mapping by the OGS, with the exception of several of Karrow's exclusions in the northwest, as noted in the second and third bullet above. These are the areas that Karrow mapped as part of the Macton Moraine. In other words, the Region's Waterloo Moraine boundary is essentially the hummocky topography as outlined by the OGS, without the areas of the Macton Moraine as mapped by Karrow. It is also noted that both of the areas excluded are areas of fine-grained tills. The implications of these variations are discussed in Section 7.3.1.

5.3 GEOLOGY AND HYDROSTRATIGRAPHY

The understanding and interpretation of the geology and hydrostratigraphy of the Waterloo Moraine has evolved over the last 40- 50 years, as previously discussed in detail in Section 3.3. In summary, the present understanding of the Waterloo Moraine evolved in the following manner:

- Original investigations only focused on water supply in the Waterloo Moraine as the water resources potential was recognized early in the growth of Kitchener and Waterloo. Little emphasis was placed on understanding the geology of the area as the focus was on finding areas of sand and gravel that produced water. Initially, the exploration was within the urban boundaries of Kitchener and Waterloo, but expanded westward as the cities expanded.
- Work by Dixon (1973), developed the general concept of a three aquifer system, within the geographic area of the Waterloo Moraine. These units were interpreted to be hydraulically connected, at least in some areas. It was found that much of the water supply in the urban centres were existed at depth below one or more till units, while the water supplies to the west were often found in thick sands and gravels, with little or no till present above these sand and gravels.
- As the Region expanded in the mid-1970's so did the Earth Science Department at the University of Waterloo, with several top researchers in hydrogeology (Dr. Farvolden, Dr. Frind and Dr. Cherry) joining the department. The Earth Science department already had a Quaternary geologist (Dr. Karrow). Investigations on specific well fields were conducted to better understand the hydraulic connections between aquifers and begin to better understand and manage the groundwater resource. This understanding expanded in the late 1970's and 1980's as the geographic area of investigations expanded, trying to piece together the geology and hydrogeology of a multi-aquifer system, primarily in the core area of the Waterloo Moraine.
- In 1989, groundwater contamination of a municipal well in Elmira triggered the Region of Waterloo to develop a water resources protection strategy. An understanding of the hydrogeology of the Waterloo Moraine area was the first major initiative, given that it supplied most of the water to Kitchener and Waterloo. Major drilling programs, including collection of continuous geologic samples of deeper Quaternary sediments greatly increased the understanding of the geology and hydrostratigraphy of the Waterloo Moraine area. Well field shutdowns and pumping tests were conducted to assess the capture areas of well fields and the hydraulic connection between aquifer units. Additional water quality data was obtained away from the well fields, to aid in understanding the groundwater flow system and groundwater recharge throughout the Waterloo Moraine. Groundwater flow modelling was conducted using this information to further delineate capture zones for each of the well fields.
- Following the Walkerton water contamination incident of 2001, a recommendation of the Walkerton Inquiry was to develop a watershed-based approach to source protection. As part of new initiatives for source protection a more science-based approach to understanding the geology was developed through partnerships with the OGS and the GSC. This resulted in a major pilot project involving the development of a 3-dimensional model of Quaternary deposits in the Region of Waterloo.
- This OGS project has been ongoing for about five years and has supplemented the previous work with the following (Bajc and Shirota, 2007):
    - over a 1000 new surface and borehole log sections;
    - 16 km of ground penetrating radar;
    - 17km of seismic reflection profiling;

- o continuous coring to bedrock at 13 sites;
- o borehole geophysics;
- o update and interpretation of the existing borehole and geophysical database with 22,952 data sets;
- o use of 3-dimensional data mapping software to interpret the sub-surface geology;
- o creation of a fully attributed three-dimensional block model of major aquifers and aquitards throughout the Region of Waterloo; and,
- o an OGS interpretation of aquifer recharge maps for the Region of Waterloo.

A conceptual geological model has been refined for the Waterloo Moraine area, by the OGS, as shown in **Figure 5.3.1**. Within the Waterloo Moraine there are six sequences (excluding bedrock) in the conceptual hydrostratigraphic model, as shown in Table 5.3.1. Note that the first sequence in the OGS model, Sequence I, is not present in the area of the Waterloo Moraine.

Sequence	Aquifer/ Aquitard	Geologic Unit
Sequence I	ATA1	Whittlesey clay
	AFA1	Whittlesey sand
	ATA2	Wentworth Till (may contain abundant aquifer material)
	AFA2	Outwash deposits (mainly Grand River valley fill)
	ATA3	Silt and clay valley fill (lower Grand River valley)
Sequence II	ATB1	Upper Maryhill Till, Port Stanley Till, Tavistock Till, Mornington Till
	AFB1	Upper Waterloo Moraine aquifer and equivalents
	ATB2	Middle Maryhill Till and stratified equivalents
	AFB2	Middle Waterloo Moraine aquifer and equivalents
	ATB3	Lower Maryhill Till and stratified equivalents
	AFB3	Lower Waterloo Moraine aquifer or Catfish Creek Till outwash
Sequence III	ATC1	Upper/ Main Catfish Creek Till
	AFC1	Middle Catfish Creek aquifer
	ATC2	Lower Catfish Creek Till
Sequence IV	AFD1	Pre-Catfish Creek aquifer
Sequence V	ATE1	Canning Drift (till and associated fine-textured lake deposits)
Sequence VI	AFF1	Pre-Canning aquifers
Sequence VII	ATG1	Pre-Canning aquitards
Sequence VIII	Bedrock	Silurian and Lower Devonian carbonates and shales

Table 5.3.1: Sequence of Conceptual Hydrostratigraphic Units as Interpreted by the OGS (Bajc, 2005).

The following summarizes the current understanding of the geology and hydrostratigraphy of the Waterloo Moraine:

- Sequence II contains the aquifer and aquitard units of the Maryhill Till as well as any other surficial tills present in the area, including the Tavistock and Port Stanley Tills. The aquifer units in this sequence are the equivalent of Aquifer 1(AFB1 and AFB2) and Aquifer 2 (AFB3) in the Region's conceptual hydrogeological model. Aquifer 1 is extensive in the core area of the Waterloo Moraine; however it is of a more limited thickness in the eastern portion of the moraine. The aquitard units of the Port Stanley Till and the Upper Maryhill Till in the OGS interpretation are the equivalent of Aquitard 1in the Region's conceptual hydrogeological model. The lower Maryhill Till correlates to the Region's Aquitard 2.

- Sequence III, is comprised of the Catfish Creek Drift, with an upper and lower Catfish Creek Till and a middle aquifer unit within the Catfish Creek Drift. The aquifer unit is not considered a major aquifer unit in the OGS hydrostratigraphic model. This unit could be considered part of the Region's Aquifer 2 where the unit is present. It has been interpreted (Terraqua, 1995) that in some areas, parts of the Catfish Creek Drift can be considered an aquifer or an aquitard, depending on the thickness and whether some of the till has been reworked or is fractured. The transmissive nature of portions of the Catfish Creek Drift has been noticed in pumping test data (Terraqua, 1995) however it is generally considered to be Aquitard 3 in the Region's model.
- Sequence IV is comprised of Pre-Catfish Creek Till aquifers and is the equivalent of Aquifer 3 in the Region's hydrogeologic model. This unit is more extensive under the eastern portion of the Waterloo Moraine.
- Sequence V is comprised of the Canning Drift, a silty clay till and associated fine-texture lake deposits. This unit is typically not very thick, where present, but may be laterally extensive on a local scale. It is interpreted as Aquitard 4 in the Region's hydrostratigraphic interpretation.
- Sequence VI is comprised of pre-Canning Till aquifers. The geologic units in this sequence are not very prevalent throughout the most of the Waterloo Moraine area, and are often described as "dirty" or cemented. Where this sequence does exist, it appears that it is considered part of Aquifer 3 in the Region's interpretation.
- Sequence VII is comprised of Pre-Canning aquitards. This sequence is only found in a few locations throughout the area of the Waterloo Moraine, and where present is typically a sandy silt till with some clay. It is interpreted to also be part of Aquitard 4 in the Regional hydrostratigraphic model.

5.4 SIGNIFICANT AQUIFERS

As discussed in the previous section there are considered to be three significant water supply aquifers within in the area of the Waterloo Moraine, not including any potential aquifers in the underlying bedrock. For simplicity sake, the three aquifers are typically described as being part of the Waterloo Moraine, although technically the lower aquifers are found below the sediments of the Waterloo Moraine. These aquifers supply much of the water to the cities of Kitchener and Waterloo as well as several smaller municipalities in the surrounding Townships. The water supply is discussed in Section 5.5.2.

The aquifers are generally laterally extensive and may or may not be hydraulically connected to each other, throughout the area. Typically, Aquifer 1 (Regional interpretation) is an extensive sand and gravel in the core of the Waterloo Moraine capable of producing substantial quantities of water. This aquifer is found within the Waterloo Moraine sediments. The main recharge area of the Waterloo Moraine supplies water to this aquifer as the aquifer is typically exposed at ground surface throughout the core area of the Waterloo Moraine. This aquifer also supplies water to headwater streams originating in the core area of the Waterloo Moraine as well as supplying water to many of the coldwater fisheries and wetlands within the Waterloo Moraine (see Section 5.5.3).

Figure 3.3.15, previously discussed, shows a hydrostratigraphic cross-section through the Waterloo Moraine to illustrate the aquifer system. In the west portion of the cross-section, Aquifer 1 (Region interpretation) is very thick and laterally extensive throughout the core area of the Waterloo Moraine. Water supply wells in the core western portion of the Waterloo Moraine are located in Aquifer 1. Coldwater creeks such as Alder Creek and Hunsberger Creek originate in the core area of the Waterloo

Moraine (see Section 5.5.3). Aquifer 1 thins out moving eastward and is general of very limited water supply capability within the urban areas.

The lower aquifers, below the lower Maryhill Till, are typically only limited thickness and areal extent under the core of the Waterloo Moraine and, if present, are not very productive. This is due to the typically thick sequence of Maryhill Till limiting groundwater recharge to depth in the core area of the Waterloo Moraine. Aquifers 2 and 3 are thicker and more laterally extensive in the eastern portion of the Waterloo Moraine, under the urban areas of Kitchener and Waterloo (e.g. the eastern portion of the cross-section in **Figure 3.3.15**). In some areas the Maryhill Till is thin or non-existent creating a hydraulic connection between Aquifer 1 and the lower aquifers. Most of the municipal water supply wells in the urban areas are located in Aquifer 2 and Aquifer 3. Depending on the thickness of the Catfish Creek Till or the depositional environment (e.g. some reworking of the Catfish Creek Till) Aquifer 2 and Aquifer 3 can act as one aquifer, with the Catfish Creek Till sediments.

5.5 SIGNIFICANCE AND FUNCTIONS OF THE WATERLOO MORAINE

5.5.1 Recharge

The Waterloo Moraine plays a major role in the recharge of the local and regional groundwater system (Terraqua, 1995; Bajc and Shirota, 2007; GRCA, 2008). The rate of recharge however is highly variable ranging from <120 mm to >500 mm/yr (GRCA, 2008). Although the Waterloo Moraine landform is often described as a major recharge area not all areas of the Waterloo Moraine will provide major recharge. As previously discussed in the geology section, the core area of the Waterloo Moraine is sand while a major portion of the flanks the moraine has a low hydraulic conductivity till present at ground surface. **Figure 5.5.1** shows the Regional recharge areas in the Waterloo Moraine, as designated by the Region of Waterloo and included in their Draft Regional Official Plan (ROW, 2008a). This area generally corresponds to the core area of the Waterloo Moraine, where ice-contact sand is present at surface, as mapped by Karrow, (1987). Much of the area is also a topographic high within the core area of the moraine and as a result, provides recharge on a regional scale (i.e. it is located near the top of the groundwater flow system as shown in **Figure 3.3.13 and Figure 3.3.16**). As can be seen from the water table slope, groundwater moves away from the topographic high, where the ice contact sand and gravel is exposed at ground surface and recharges the aquifer system as well as providing water to surrounding creeks. It is noted that much of the main recharge area is located outside the urban area.

Recharge rates were estimated as part the water budget work by GRCA, as discussed further in Section 5.6. As part of this work hydrologic response units were defined using the GAWSER model (GRCA, 2008). Hydrologic response units were developed and recharge rates estimated using factors such as: surficial geology; slope; vegetation cover; and, drainage (open or closed). **Figure 5.5.2** shows predicted recharge rate from the GAWSER modelling (GRCA, 2008). The highest recharge rates are generally in the area of the ice-contact sand in the core area of the Waterloo Moraine. Recharge rates of >500 mm/yr are noted locally. Rates are predicted to be very high in closed depression areas (i.e. no surface drainage outlet) in the ice-contact sand. High recharge rates are also noted south of the generally interpreted boundary of the Waterloo Moraine, where recent investigations by the OGS suggest this area may be an extension of the Waterloo Moraine.

5.5.2 Water Supply

As discussed in detail in Section 3.3, the Waterloo Moraine provides the majority of water to the cities of Kitchener and Waterloo, through the Region's Integrated Urban System (IUS) of water supply. There are also a number of well fields providing rural municipalities with water in the western portion of the Region.

As well, numerous private wells are located within the Waterloo Moraine. **Figure 3.3.20**, previously discussed, shows the location of the municipal wells and well fields in the Waterloo Moraine. There are 10 active well fields as part of the IUS system, of which 7 of the well fields are within the urban areas. Three of the well fields (Erb Street, Wilmot Centre and Mannheim West) are located to the west of the urban areas, in the core area of the Waterloo Moraine. The urban municipal well fields represent about 70% of the source capacity of the IUS system (>900 L/sec) while the rural municipal well fields represent about 30% (400 L/sec) of the source capacity of IUS water supply originating from the Waterloo Moraine. **Table 5.5.1** shows a summary of water production from municipal wells within the Waterloo Moraine (Note that there are two currently operating well fields on the list (Woolner and Linwood) that are outside the Waterloo Moraine boundary).

There are also six smaller individual water supply systems within the Waterloo Moraine currently providing water to rural municipalities. The total water taking for these supplies is equivalent to about 2% of the water taking in the IUS system.

Well head protection areas were developed for each of the municipal well fields. **Figure 5.5.3** shows the well head protection areas, as adopted by the region of Waterloo (Draft ROP, 2008), for wells within the Waterloo Moraine. These well head protection areas cover a major portion of the main recharge area and urban areas of Kitchener and Waterloo.

5.5.3 Maintenance of Water-Related Ecological Features

The protection of water-related ecological features within the Region of Waterloo has been included in Regional planning policies for many years. This was previously discussed in Section 3.3.2. The Region has developed an ecosystem-based planning approach as part of previous Regional Official Plans. In order to map and establish these ecological features a number of environmentally-related studies have been conducted over the years, ranging from Region-wide ESPA studies and wetland evaluations to area specific subwatershed studies. The Region, GRCA and local municipalities require subwatershed studies to be conducted in areas of new development or growth. These studies have been on-going since 1989. Subwatershed studies provide an ecosystem-based approach to land use planning on a subwatershed scale. They integrate groundwater and surface water, aquatic and terrestrial habitat, and fisheries, creating a broader understanding of the function and linkage of the natural ecologic systems. One of the components of a subwatershed study is to provide a more detailed assessment of the ecologic features with the subwatershed, in order to identify and protect these features from possible adverse impacts of potential future land use changes or activities.

Figure 5.5.4 shows the Regional Environmentally Sensitive Policy Areas (ESPAs) found within the Waterloo Moraine. **Figure 5.5.5** shows the Provincially Significant Wetlands (PSWs) within the Waterloo Moraine. It is noted that the majority of the wetlands are found in one area, in and around the upper reaches of Laurel Creek. This area has been recently designated by the Region as an Environmentally Sensitive Landscape (ESL). **Figure 5.5.6** shows the fisheries resources in the Waterloo Moraine area, as designated by the GRCA.

The following is highlighted with respect to water-related ecological features:

- Many of the water-related ecological features are found in and around the main recharge area, in the core of the Waterloo Moraine.
- Over 70 Provincially Significant Wetlands (PSW's) have been mapped within the boundary of the Waterloo Moraine. Most of the wetlands are located within or adjacent to the upper reaches of the Laurel Creek subwatershed. The direct linkage between groundwater and surface water is

Table 5.5.1 Well Field Water Production Summary for the Waterloo Moraine Area

Well Field	Major or Minor Supply	Major Aquifer Name	Production Well Name	Status	Permit to Take Water Details: MOE Permit Number	Permitted Capacity (total m³/year)*	Permitted Rate (L/s)*	2003 Production Summary: Total Production Well Volume (total m³/year)	Average Daily Rate (m³/day)	Average Rate (L/s)	2004 Production Summary: Total Production Well Volume (total m³/year)	Average Daily Rate (m³/day)	Average Rate (L/s)	2005 Production Summary: Total Production Well Volume (total m³/year)	Average Daily Rate (m³/day)	Average Rate (L/s)	2006 Production Summary: Total Production Well Volume (total m³/year)	Average Daily Rate (m³/day)	Average Rate (L/s)	2007 Production Summary: Total Production Well Volume (total m³/year)	Average Daily Rate (m³/day)	Average Rate (L/s)
WELL FIELDS IN KITCHENER:																						
Greenbrook	Major	Greenbrook	K1	Standby	not required - well installed prior to Ontario Water Resources Act			483,180	NI	NI	303,965	831	9.6	6,326	17	0.2	1	0	0.0	0	0	0.0
			K2	Standby	not required - well installed prior to Ontario Water Resources Act			424,196	1,162	13.5	234,366	640	7.4	334,485	916	10.6	801,465	2,196	25.4	960,824	2,632	30.5
			K4B	Standby	0748-6KSJDW	2,389,655	75.8	1,245,884	3,413	39.5	576,997	1,576	18.2	654,084	1,792	20.7	1,100,584	3,015	34.9	752,972	2,063	23.9
			K5A	Standby	98-P-2047	5,973,444	189.4	550,658	1,509	17.5	457,510	1,250	14.5	11,322	31	0.4	206,184	565	6.5	86,657	237	2.7
			K8	Standby	5575-6WHRGK	1,195,010	37.9	739,685	2,027	23.5	488,072	1,334	15.4	14,021	38	0.4	0	0	0.0	0	0	0.0
					Well Field Total	N/A	N/A	3,443,603	9,435	109.2	2,060,910	5,631	65.2	1,020,238	2,795	32.4	2,108,234	5,776	66.9	1,800,453	4,933	57.1
Lancaster Street	Minor	-	K41	Disconnected	not required - well installed prior to Ontario Water Resources Act			0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
			K42A	Disconnected	7740-6U7PKF	835,850	26.5	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
					Well Field Total	N/A	N/A	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
Mannheim East	Major	Mannheim	K21	Supply	not required - well installed prior to Ontario Water Resources Act			680,597	1,865	21.6	888,876	2,429	28.1	848,503	2,325	26.9	883,315	2,420	28.0	805,691	2,207	25.5
			K25	Supply	71-P-0338	2,488,935	78.9	1,061,850	2,909	33.7	1,503,789	4,109	47.6	1,604,367	4,396	50.9	1,625,525	4,453	51.5	1,544,411	4,231	49.0
			K29	Supply	01-P-2237	1,923,915	61.0	1,647,404	4,513	52.2	1,218,927	3,330	38.5	982,777	2,693	31.2	885,850	2,427	28.1	1,108,671	3,037	35.2
			ASR1	Recharge	03-P-2385			NI	NI	NI	397,823	1,087	12.6	37,956	104	1.2	56,350	154	1.8	89,338	245	2.8
			ASR2	Recharge	03-P-2385	Combined rate for PTTW 03-P-2385								n/a	n/a	n/a	106,076	291	3.4	61,382	168	1.9
			ASR3	Recharge	03-P-2385									n/a	n/a	n/a	109,602	300	3.5	134,561	369	4.3
			ASR4	Recharge	03-P-2385	8,650,850	274.3							n/a	n/a	n/a	233,686	640	7.4	135,902	372	4.3
			RCW1	Recovery	03-P-2385															275,805	756	8.7
			RCW2	Recovery	03-P-2385															231,828	635	7.4
					Well Field Total	N/A	N/A	3,389,851	9,287	107.5	4,009,415	10,955	126.8	3,473,603	9,517	110.1	3,900,404	10,686	123.7	4,387,589	12,021	139.1
Peaking	Major	Mannheim	K91	Supply	0304-6P2QLS			n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	130,450	n/a	n/a	282,399	n/a	n/a
			K92	Supply	0304-6P2QLS	Combined rate for PTTW 0304-6P2QLS		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	164,291	n/a	n/a	333,707	n/a	n/a
					Sub-total (K91 & K92)			802,478	2,199	25.4	726,666	1,985	23.0	919,997	2,521	29.2	294,741	808	9.3	616,106	1,688	19.5
			K93	Supply	0304-6P2QLS			n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	19,036	n/a	n/a	320,030	n/a	n/a
			K94	Supply	0304-6P2QLS	5,991,840	190.0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	61,550	n/a	n/a	357,411	n/a	n/a
					Sub-total (K93 & K94)			505,536	1,385	16.0	763,784	2,087	24.2	700,663	1,920	22.2	80,586	221	2.6	677,441	1,856	21.5
					Well Field Total	5,991,840	190	1,308,014	3,584	41.5	1,490,450	4,072	47.1	1,620,660	4,440	51.4	375,327	1,028	11.9	1,293,547	3,544	41.0
Parkway	Major	Parkway	K31	Supply	not required - well installed prior to Ontario Water Resources Act			1,116,190	n/a	n/a	1,258,957	n/a	n/a	1,016,543	2,785	32.2	886,666	2,429	28.1	965,325	2,645	30.6
			K32	Supply	not required - well installed prior to Ontario Water Resources Act			1,266,083	n/a	n/a	1,296,297	n/a	n/a	940,389	2,576	29.8	898,681	2,462	28.5	805,802	2,208	25.6
			K33	Supply	7731-78QJ44	1,660,750	52.7	1,431,219	n/a	n/a	1,259,665	n/a	n/a	988,139	2,707	31.3	876,879	2,402	27.8	1,146,565	3,141	36.4
					Well Field Total	N/A	N/A	2,926,091	8,017	92.8	2,926,091	7,995	92.5	2,926,091	8,017	92.8	2,926,092	8,017	92.8	2,917,692	7,994	92.5
Pompeii and Forwell	Major	River	K70	Disconnected	79-P-2009	Combined rate for PTTW 79-P-2009		0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
			K71	Disconnected	79-P-2009	3,345,129	106.1	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
			K72	Disconnected	80-P-2020			0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
			K73	Disconnected	80-P-2020	Combined rate for PTTW 80-P-2020		0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
			K74	Disconnected	80-P-2020			0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
			K75	Disconnected	80-P-2020	1,655,640	52.5	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
					Well Field Total	5,000,769	158.6	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
Strange Street	Major	Manheim	K10A	Supply	0861-5YGJP2	836,282	26.5	445,856	1,222	14.1	355,934	972	11.3	257,272	705	8.2	228,768	627	7.3	214,668	588	6.8
			K11	Supply	not required - well installed prior to Ontario Water Resources Act			435,653	1,194	13.8	450,366	1,231	14.2	264,753	725	8.4	176,527	484	5.6	92,689	254	2.9
			K13	Supply	not required - well installed prior to Ontario Water Resources Act			302,520	829	9.6	399,113	1,090	12.6	191,212	524	6.1	284,926	781	9.0	383,013	1,049	12.1
			K18/K19	Supply	3233-6EVHLQ	1,797,625	57.0										621,906	1,704	19.7	699,658	1,917	22.2
					Well Field Total	N/A	N/A	1,206,932	3,307	38.3	1,681,402	4,594	53.2	1,655,358	4,535	52.5	1,312,127	3,595	42	1,390,028	3,808	44
Strasburg	Minor	Parkway	K34	Supply	7723-6K5MD4	1,672,430	53.0	0	0	0.0	746,637	2,040	23.6	1,429,373	3,916	45.3	1,460,181	4,000	46.3	1,437,222	3,938	45.6
			K36	Disconnected	571-78HLAC	835,850	26.5	234,931	644	7.4	105,089	287	3.3	58	0	0.0	0	0	0.0	0	0	0.0
					Well Field Total	2,508,280	79.5	234,931	644	7.4	851,726	2,327	26.9	1,429,431	3,916	45.3	1,460,181	4,000	46.3	1,437,222	3,938	45.6
Woolner	Major	River	K80	Supply	81-P-2017			0	0	0.0	634,017	1,732	20.0	157,800	432	5.0	68,273	187	2.2	25,242	69	0.8
			K81	Supply	81-P-2017	Combined rate for PTTW 81-P-2017		0	0	0.0	589,777	1,611	18.7	807,011	2,211	25.6	681,175	1,866	21.6	303,217	831	9.6
			K82	Supply	81-P-2017	4,051,500	128.5	0	0	0.0	943,210	2,577	29.8	1,340,958	3,674	42.5	1,105,998	3,030	35.1	628,837	1,723	19.9
					Well Field Total	4,051,500	128.5	0	0	0.0	2,167,004	5,921	68.5	2,305,769	6,317	73.1	1,855,446	5,083	58.8	957,296	2,623	30.4

Table 5.5.1 Well Field Water Production Summary for the Waterloo Moraine Area

Well Field	Major or Minor Supply	Major Aquifer Name	Production Well Name	Status	Permit to Take Water Details: MOE Permit Number	Permitted Capacity (total m³/year)*	Permitted Rate (L/s)*	2003 Production Summary: Total Production Well Volume (total m³/year)	Average Daily Rate (m³/day)	Average Rate (L/s)	2004 Production Summary: Total Production Well Volume (total m³/year)	Average Daily Rate (m³/day)	Average Rate (L/s)	2005 Production Summary: Total Production Well Volume (total m³/year)	Average Daily Rate (m³/day)	Average Rate (L/s)	2006 Production Summary: Total Production Well Volume (total m³/year)	Average Daily Rate (m³/day)	Average Rate (L/s)	2007 Production Summary: Total Production Well Volume (total m³/year)	Average Daily Rate (m³/day)	Average Rate (L/s)
WELL FIELDS IN WATERLOO:																						
Waterloo North	Major	Greenbrook	W4	Supply	not required - well installed prior to Ontario Water Resources Act			149,179	409	4.7	74,486	204	2.4	90,959	249	2.9	108,517	297	3.4	103,619	284	3.3
			W5	Disconnected	not required - well installed prior to Ontario Water Resources Act			0	Note: well is a flowing well		0	Note: well is a flowing well		0	Note: well is a flowing well		0	Note: well is a flowing well		0	Note: well is a flowing well	
			W10	Supply	7063-66JLR6	1,146,903	36.4	282,674	774	9.0	108,917	298	3.4	128,456	352	4.1	181,034	496	5.7	0	0	0.0
					Well Field Total	N/A	N/A	431,853	1,183	13.7	183,403	501	5.8	219,415	601	7.0	289,551	793	9.2	103,619	284	3.3
William Street	Major	Greenbrook	W14	Purge	00-P-2555	1,659,290	52.6	109,910	301	3.5	99,801	273	3.2	71,968	197	2.3	52,410	144	1.7	60,887	167	1.9
			W1B	Supply	79-P-2004	1,911,502	60.6	221,141	606	7.0	169,393	463	5.4	397,252	1,088	12.6	203,225	557	6.4	262,463	719	8.3
			W1C	Supply	4001-6K4MPX	1,195,010	37.9	745,895	2,044	23.7	718,625	1,963	22.7	43,990	121	1.4	472,098	1,293	15.0	493,127	1,351	15.6
			W2A	Disconnected	71-P-0199	1,914,790	60.7	755,916	2,071	24.0	694,118	1,896	22.0	917,250	2,513	29.1	1,169,031	3,203	37.1	1,083,915	2,970	34.4
			W3	Disconnected	not required - well installed prior to Ontario Water Resources Act			0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
					Well Field Total	N/A	N/A	1,832,861	5,022	58.1	1,681,937	4,595	53.2	1,430,460	3,919	45.4	1,896,764	5,197	60.1	1,900,392	5,207	60.3

Notes:
- **- = no applicable data**
- **n/a = data not available**
- *** = rates and volumes based on permitted L/day**

WELL FIELDS IN WILMOT:																						
Baden	Minor	Mannheim	B1	Disconnected	94-P-2035	Combined rate for PTTW 94-P-2035		0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
			B2	Disconnected	94-P-2035	1,659,290	52.6	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
					Well Field Total	1,659,290	52.6	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
Erb Street	Major	Mannheim	W6A	Supply	70-P-0148	2,030,860	64.4	n/a	n/a	n/a	n/a	n/a	n/a	679,670	1,862	21.6	636,093	1,743	20.2	342,537	938	10.9
			W6B	Standby	147375DHR5	1,672,430	53.0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0	n/a	n/a	0	n/a	n/a
			W7	Supply	3856-79ZSPDP	3,318,580	105.2	2,713,896	7,435	86.1	2,684,430	7,335	84.9	2,638,106	7,228	83.7	2,407,093	6,595	76.3	2,524,217	6,916	80.0
			W8	Supply	69-P-0409	3,823,004	121.2	1,432,092	3,924	45.4	1,973,431	5,392	62.4	1,940,485	5,316	61.5	1,018,020	2,789	32.3	1,099,999	3,014	34.9
					Well Field Total	10,844,874	343.9	4,145,988	11,359	131.5	4,657,861	12,726	147.3	5,258,261	14,406	166.7	4,061,206	11,127	128.8	3,966,753	10,868	125.8
Foxboro Green	Minor	-	FG1	Supply	00-P-2789	Combined rate for PTTW 00-P-2789		42,423	116	1.3	42,502	116	1.3	36,046	99	1.1	5,025	14	0.2	37,614	103	1.2
			FG2	Supply	00-P-2789	105,120	3.3	121	0	0.0	44	0	0.0	2,634	7	0.1	35,413	97	1.1	2,047	6	0.1
			FG4	Disconnected	01-P-2241	70,956	2.3	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	628	2	0.0
					Well Field Total	176,076	5.6	42,544	117	1.3	42,546	116	1.3	38,680	106	1.2	40,438	111	1.3	40,289	110	1.3
Mannheim West	Major	Mannheim	K22A	Supply	7155-6WLJFK	2,390,750	75.8	456,798	1,252	14.5	172,949	473	5.5	n/a	n/a	n/a	480,845	480,845	480,845	281,342	771	9
			K23	Supply	not required - well installed prior to Ontario Water Resources Act			966,491	2,648	30.6	989,272	2,703	31.3	785,292	2,151	24.9	864,583	2,369	27.4	816,286	2,236	25.9
			K24	Supply	not required - well installed prior to Ontario Water Resources Act			718,031	1,967	22.8	916,522	2,504	29.0	883,651	2,421	28.0	942,418	2,582	29.9	947,461	2,596	30.0
			K26	Supply	70-P-0004	3,318,580	105.2	2,391,463	6,552	75.8	2,748,975	7,511	86.9	2,613,387	7,160	82.9	2,420,426	6,631	76.8	2,532,776	6,939	80.3
					Well Field Total	N/A	N/A	4,532,783	12,419	143.7	4,827,718	13,190	152.7	4,282,330	11,732	135.8	4,708,272	12,899	149.3	4,577,865	12,542	145.2
New Dundee	Minor	Mannheim	ND2	Abandoned	89-P-2001	Combined rate for PTTW 89-P-2001		177	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
			ND4	Supply	2602-5WSJ7R	Combined rate for PTTW 2602-5WSJ7R		81,273	223	2.6	83,403	228	2.6	56,816	156	1.8	35,646	98	1.1	23,674	65	0.8
			ND5	Supply	2602-5WSJ7R	358,722	11.4							31,014	85	1.0	59,065	162	1.9	69,703	191	2.2
					Well Field Total	358,722	11.4	81,450	223	2.6	83,403	228	2.6	87,830	241	2.8	94,711	259	3.0	93,377	256	3.0
New Hamburg	Major	-	NH3	Supply	2101-6FTQM9	1,293,195	41.0	726,616	1,991	23.0	774,835	2,117	24.5	768,967	2,107	24.4	787,905	2,159	25.0	835,031	2,288	26.5
St. Agatha	Minor	Mannheim	SA3	Supply	98-P-2034	Combined rate for PTTW 98-P-2034		n/a	n/a	n/a	3,965	n/a	n/a	4,308	12	0.1	3,386	9	0.1	261	1	0.0
			SA4	Supply	98-P-2034	2,996,504	95.0	n/a	n/a	n/a	7,233	n/a	n/a	3,436	9	0.1	3,893	11	0.1	6,668	18	0.2
			SA5	Supply	3870-6WEL8G	Combined rate for PTTW 3870-6WEL8G								26,474	73	0.8	22,041	60	0.7	18,990	52	0.6
			SA6	Supply	3870-6WEL8G	199,290	6.3							17,604	48	0.6	18,612	51	0.6	17,993	49	0.6
					Well Field Total	3,195,794	101.3	6,874	19	0.2	11,198	31	0.4	51,822	142	1.6	47,932	131	1.5	43,912	120	1.4
Wilmot Centre	Major	Mannheim	K50	Supply	0287-6WHQTY	Combined rate for PTTW 0287-6WHQTY		1,543,464	4,229	48.9	1,470,088	4,017	46.5	1,559,578	4,273	49.5	1,488,847	4,079	47.2	1,507,237	4,129	47.8
			K51	Supply	0287-6WHQTY	4,977,870	157.8	1,325,221	3,631	42.0	1,363,622	3,726	43.1	1,077,389	2,952	34.2	875,598	2,399	27.8	1,044,020	2,860	33.1
					Well Field Total	4,977,870	157.8	2,868,685	7,859	91.0	2,833,710	7,742	89.6	2,636,967	7,225	83.6	2,364,445	6,478	75.0	2,551,257	6,990	80.9

Table 5.5.1 Well Field Water Production Summary for the Waterloo Moraine Area

Well Field	Major or Minor Supply	Major Aquifer Name	Production Well Name	Status	Permit to Take Water Details			2003 Production Summary			2004 Production Summary			2005 Production Summary			2006 Production Summary			2007 Production Summary		
					MOE Permit Number	Permitted Capacity (total m^3/year)*	Permitted Rate (L/s)*	Total Production Well Volume (total m^3/year)	Average Daily Rate (m^3/day)	Average Rate (L/s)	Total Production Well Volume (total m^3/year)	Average Daily Rate (m^3/day)	Average Rate (L/s)	Total Production Well Volume (total m^3/year)	Average Daily Rate (m^3/day)	Average Rate (L/s)	Total Production Well Volume (total m^3/year)	Average Daily Rate (m^3/day)	Average Rate (L/s)	Total Production Well Volume (total m^3/year)	Average Daily Rate (m^3/day)	Average Rate (L/s)
WELL FIELDS IN WELLESLEY:																						
St. Clements	Minor	Mannheim	SC2	Supply	93-P-2107	Combined rate for PTTW 93-P-2107		11,377	31	0.4	34,429	94	1.1	55,485	152	1.8	50,803	139	1.6	41,248	113	1.3
			SC3	Supply	93-P-2107	646,488	20.5	89,587	245	2.8	64,920	177	2.1	46,005	126	1.5	46,500	127	1.5	63,610	174	2.0
					Well Field Total	646,488	20.5	100,964	277	3.2	99,349	271	3.1	101,490	278	3.2	97,303	267	3.1	104,858	287	3.3
Linwood	Minor	-	L1A	Supply	85-P-2007	Combined rate for PTTW 85-P-2007		55,424	152	1.8	59,989	164	1.9	57,719	158	1.8	57,845	158	1.8	32,459	89	1.0
			L2	Supply	85-P-2007	382,300	12.1	9,938	27	0.3	1,766	5	0.1	772	2	0.0	617	2	0.0	28,012	77	0.9
					Well Field Total	382,300	12.1	65,362	179	2.1	61,755	169	2.0	58,491	160	1.9	58,462	160	1.9	60,471	166	1.9
Wellesley	Minor	-	WY1	Supply	93-P-2070	Combined rate for PTTW 93-P-2070		113,167	310	3.6	75,704	207	2.4	140,153	384	4.4	88,840	243	2.8	158,837	435	5.0
			WY5	Supply	93-P-2070	548,595	17.4	49,628	136	1.6	79,343	217	2.5	28,528	78	0.9	90,114	247	2.9	31,250	86	1.0
					Well Field Total	548,595	17.4	162,795	446	5.2	155,047	424	4.9	168,681	462	5.3	178,954	490	5.7	190,087	521	6.0

Notes:

- = no applicable data

n/a = data not available

*** = rates and volumes based on permitted L/day**

not fully defined throughout this area. The downgradient wetlands are driven primarily by discharge, but wetlands in the upper areas may be the result of depressional features (i.e. hummocky terrain) collecting surface runoff, or they may be sustained by local groundwater discharge.

- The Waterloo Moraine provides water to the many PSWs in the Strasburg Creek subwatershed, located in a downgradient area of the Waterloo Moraine.
- Cold water fisheries and spawning areas have been mapped throughout the Waterloo Moraine. The main recharge area provides baseflow to many coldwater streams whose headwaters originate in the main recharge area, in particular: Alder Creek, Hunsberger Creek, Bamberg Creek and Laurel Creek. Cold water fisheries have also been mapped along the eastern flank of the Waterloo Moraine in Schneider Creek and Strasburg Creek. All of these creeks have been investigated as part of subwatershed studies or water taking assessments, with the exception of Bamberg Creek, which is only partially in the Waterloo Moraine and is far removed from urban development pressure.
- Many of the water-related ecological features are located outside the urban area. In the few areas where development pressure exists (e.g. southwest Kitchener and northwest Waterloo), more detailed studies are ongoing.

5.6 WATER QUANTITY/ WATER BUDGET

The GRCA and the Region of Waterloo have conducted water quantity and water budget assessments in several different ways and at various scales. Much of this work has been related to Water Budget and Water Quantity Risk Assessments, conducted as part of Source Protection studies. A water budget for the Waterloo Moraine has not specifically been developed by the Region or the GRCA from these studies, as most analyses have been conducted on a watershed and subwatershed scale rather than a landform-specific scale. The Waterloo Moraine area is generally captured within these assessments.

Prior to the initiation of the Water Budget and Water Quantity Risk Assessments, the Region conducted several studies and programs to aid in understanding water quantity and sustainable capacity of the municipal water supply. As previously discussed in Sections 3.3 and 5.5.2, a groundwater flow model was developed (WHI, 2000) to delineate well field capture zones within the Waterloo Moraine. The location of the well and well fields modelled as part of that study was previously presented in **Figure 3.3.16**. The primary purpose of the groundwater flow model was to establish a defensible 2-year and 10-year time-of-travel capture zones (as discussed in Section 5.5.2). This required the development of a fully calibrated groundwater flow model. As part of the calibration process, recharge rates were calibrated to infiltration rates, based on direct recharge in high permeability areas and runoff from low permeability soils onto high permeability soils. Recharge rates were established across the Waterloo Moraine modelled area. Calibration of the model was performed by matching simulated water levels in the three aquifers with existing water level data within each of these aquifers. Calibration to stream flows was performed for major sections of the Grand River, Conestogo River and Nith River. More detailed estimates of stream flow were conducted for portions of some of the major tributaries draining the Waterloo Moraine area. The calibration was not a high level calibration due to low resolution in the digital elevation model and limited field data in the upper reaches of a number of the tributaries. The overall water balance however was considered reasonable for the scale of the study.

As part of a general assessment of a water balance in the Region of Waterloo, the Region monitors water levels throughout the Region, focusing on well field areas. Although not specifically a water budget assessment the Region uses this data to assess the impact of municipal pumping on water level changes in the aquifer system (i.e. storage depletion) and discharge to local streams. Historical data exists on a number of well fields, dating back decades. Typically though, there was often limited data collected during the early years of well field pumping. Where historical data does exist, water level records show that there was often a 5-10 m decline in water levels, near the production wells, during the early years of pumping (Burnside, 2008), but the water levels have stabilized over time. The Region established a more permanent groundwater monitoring network in the mid-1990s. These data provide a broad assessment of the impact of water taking, as well as other factors (e.g. precipitation changes), on water levels throughout the Region. Annual monitoring programs are conducted, collecting water level data and synthesizing the data with pumping rates, precipitation and selected stream flows and presented in annual monitoring reports (Burnside, 2008).

Figure 5.6.1 shows the locations of wells monitored within the Waterloo Moraine area (from Burnside 2008). Water levels are monitored in production wells, and dedicated monitoring wells within the three aquifer system of the Waterloo Moraine. Several examples of the water level data collected are shown in this report to indicate the type of data currently being collected. **Figure 5.6.2** shows an example of a water level hydrograph (from Burnside, 2008) for a production well (K50) at the Wilmot Centre Well Field, located in the core area of the Waterloo Moraine. **Figure 5.6.3** shows water level hydrographs for a monitoring well nest located near the Wilmot Centre Well Field. In this example, the monitoring wells are located in the pumped aquifer (shallow – WM14S-93 and deep – WM14I-93) and in the upper bedrock (WM14D-93). **Figure 5.6.4** shows an example of the historical water level data, dating back to 1989, collected for a monitoring well near the Wilmot Centre Well Field.

Trends in these water levels have been analyzed by the Region as part of the monitoring program. Data from the last 10 years shows there has been little change in water levels as result of current pumping of the aquifer systems, indicating a relatively stable groundwater system.

More detailed water use analyses and water budget assessments have been conducted since 2005. In 2005, the MOE completed an analysis of water use in the main tertiary watersheds of the province (AquaResource, 2005). This was done in support of revisions to the regulations for water taking permits. A report was also prepared by the GRCA, assessing water use in the Grand River watershed (GRCA, 2005). The MOE work identified the upper part of the Grand River watershed, which includes the Region of Waterloo, as a “medium-use” watershed. This means that in low-flow conditions 25-50% of the flow is allocated for use, based on permitted water taking (not actual usage).

In order to provide a more detailed water budget assessment for the Region, since the Region is the major water taker in the upper portion of the Grand River watershed, a more detailed assessment was conducted, sub-dividing the Region into five subwatershed areas as shown in **Figure 5.6.5**. The majority of the Waterloo Moraine area is encompassed by the Nith River subwatershed grouping and Laurel-Schneider subwatershed-grouping. **Table 5.6.1** shows the water balance summary for the five sub-watersheds (Note that the infiltration rate is based on the GAWSER modelling performed by the GRCA). Results of the 2005 analysis showed that there was high percentage of water use, 40.3%, in the Laurel-Schneider sub-group, relative to the estimated infiltration within the area of the subwatershed group. As indicated in the Region’s Water Resources Protection Master Plan (RMOW, 2008), the comparison of infiltration to pumping for each subwatershed does not factor in “recharge” to the aquifer system from outside the subwatershed area. A considerable volume of water recharging the Laurel-Schneider subwatershed grouping originates from the main recharge area to the west, within the Nith River subwatershed grouping. The combined water usage for the two subwatershed areas is about 24% of the combined total estimated infiltration.

It is noted in the Burnside, 2008 report, that the GAWSER model was updated as part of the Tier 2 Water Budget and Water Quantity Risk Assessment (discussed below), from modelling done in 2000. A substantial increase in the estimated recharge values is noted in the Nith River subwatershed grouping, which encompasses much of the core area of the Waterloo Moraine. Much of this increase is the result of

Table 5.6.1: Water Balance Summary for Subwatershed Grouping Areas, 2005 Groundwater Monitoring Program

Water-shed Grouping	Well Fields & Wells	Infiltration (m^3/year)	Pumping (m^3/year)	Surplus Water (m^3/year)	Percent Water Use
Mill Creek Group	Clemens Mill (P11, P17, G17, G18, G6) Shades Mill (G7, G8, G38, G39) Middleton (G2, G14, G3, G1, G1A) Branchton Meadows (BM1, BM2) Wells G6, G4, G9, G15	27,019,914	14,228,002	12,791,912	52.66%
Nith River Group	Wellesley (WY1, WY5) Foxboro Green (FG1, FG2, FG4) Wilmot Centre (K50/K51) St. Agatha (SA1, SA2) Roseville (R5, R6) New Hamburg (NH3) New Dundee (ND4, ND5) Mannheim West (K22A, K23, K24, K26) Peaking (K91, K92) Erb Street (W7, W8)	81,805,390	14,427,700	67,377,690	17.6%
Laurel/ Schneider Creek Group	Strange Street (K10A, K13, K18) Erb Street (W6, W6A) William St. (W1B, W1C, W2, W3) Waterloo N.(W5, W10) Mannheim ASR (ASR1) Lancaster (K41, K42) Mannheim East (K21, K25, K29) Peaking (K93, K94) River (K70, K71, K72, K73, K74, K75, K80, K81, K82) Greenbrook (K1, K2, K4B, K5A, K8) Parkway (K31, K32, K33) Strasburg (K34, K36)	39,396,340	15,859,678	23,536,662	40.3%
Speed River Group	Hespeler (H3, H4, H5) Pinebush (P9, P15, P10, G5, G16) Maryhill (MH1, MH2, MH3, MH4)	24,289,240	3,135,702	21,153,538	12.9%
Conestogo River Group	West Montrose (WM1, WM2, WM3, WM4) Conestoga (C3, C4, C5, C6) Linwood (L1A, L2) St. Clements (SC2, SC3) Heidelberg (H1, H2)	63,922,130	314,169	63,607,961	0.5%
All Areas of the Region		**236,433,014**	**47,965,251**	**188,467,763**	**20.3%**

a revision to recharge rates within closed depressions in these areas. The total infiltration was adjusted from 81,805,390 m^3/yr to 142,983,807 m^3/yr. As a result, the percentage of water extracted for water supply is interpreted to be substantially lower than previously estimated in the Nith River subwatershed grouping, at about 10% of the estimated infiltration. The percentage water extracted by municipal pumping for the combined subwatershed groupings is about 16% of the total estimated infiltration.

As part of the Province's watershed-based source protection water budget and water quantity risk assessments are required. The approach taken to develop a water budget is to take a tiered approached, beginning with a large scale area and quantifying or refining the accuracy as the scale is reduced. As discussed above, the GRCA performed a water use analysis at the watershed scale in 2005, to provide a general assessment of a watershed-wide water budget. As part of a Tier 2 Water Budget and Water Quantity Risk Assessment, the GRCA has refined their water budget modelling framework, which has been on-going since the mid-1990s. The current refinement of GRCA's water budget was carried out to support the implementation of the Province of Ontario's Clean Water Act, 2006 (AquaResource, 2008a). The GRCA produced an integrated water budget report (AquaResource, 2008a) using a groundwater and surface water model, and integrating these models through groundwater recharge and discharge distribution. The work also included refining the water demand estimates. The main purpose was to update the groundwater and surface modelling and develop water budgets on a subwatershed basis. The Grand River watershed was divided into 18 subwatershed basins and water budgets estimated for each area. A water budget assessment was also conducted for four "moraine assessment areas" within the Grand River basin. **Figure 3.3.1**, previously presented, shows the Waterloo Moraine and other moraine areas surrounding the Waterloo Moraine, considered part of the Central-West Moraine assessment area.

On the basis of the findings of the water budget assessment as part of the Tier 2 study, more detailed water budget and water quantity risk assessments were recommend for several area of increased stress. The Regional Municipality of Waterloo was designated in the GRCA Tier 2 Water Budget Study as having a moderate to significant potential for hydrologic stress. A Tier 3 Water Budget and Water Quantity Risk Assessment study is currently being undertaking by the Region, scheduled for completion in 2010. The area being studied includes the urban well fields within the Cities of Kitchener, Waterloo and Cambridge as well as a few of the surrounding well fields, in particular some of the well fields within the core area of the Waterloo Moraine, in areas that contribute recharge to the potentially stressed areas identified in the Tier 2 study .

The goal of the Tier 3 Water Budget and Water Quantity Risk Assessment is to evaluate the sustainability of the water supply system for the Region and identify potential threats to the long term municipal water supplies. The Tier 3 Assessment will be centered on the development and refinement of the Water Budget in the study area, using refined and updated numerical modelling tools, which include a continuous GAWSER surface water model and the finite element FEFLOW groundwater model, previously used in the Tier 2 study.

The Tier 3 Assessment is divided into 2 phases; 1), enhancement of the conceptual and numerical models of the Region's well fields; and 2), Risk Assessment, and evaluation of potential water quantity threats. Field work is currently underway for the Phase 1 portion of the study and includes spot baseflow data collection, as well as the installation and monitoring of mini-piezometers within surface water features located near the municipal well fields under investigation. This portion of the study aims to improve the overall understanding of the interaction between the municipal aquifers and the local surface water features. A water level "snapshot" of available monitoring wells is also being completed to collect representative water levels, across as much of the study area as possible for use in calibrating the FEFLOW groundwater flow model. The study area encompasses much of the Waterloo Moraine area, and almost the entire portion of the area where water quantity impacts could occur as a result of existing land use activities (i.e. urbanization and municipal water taking). It is anticipated that the work will be completed in 2010.

5.7 WATER QUALITY

The Region of Waterloo undertakes two separate water quality monitoring programs. The water supply system is routinely monitored in accordance with the requirements of the Safe Drinking Water Act. These data aid in assessing trends in water quality in the drinking water system. The Region also undertakes a water quality monitoring program as part of its source protection activities at selected water supply wells and monitoring wells throughout the aquifer system. The monitoring is used to provide additional information within capture zones of well fields, as well as provide information on background water quality and monitor water quality in areas of known groundwater contamination. **Figure 5.7.1** shows locations of monitoring wells sampled in the Waterloo Moraine area. The following highlights some of the findings of the water quality monitoring program:

- Nitrate concentrations are elevated in several of the municipal wells in the core area of the Waterloo Moraine. This is a result of decades of nitrate loadings in agricultural areas. Water for these wells is obtained from Aquifer 1 in these areas and there is limited natural protection at ground surface. Several of the local well fields, supplying rural municipalities west of Kitchener and Waterloo, also have elevated nitrate concentrations. There is a “stratification” of nitrate, with a higher nitrate concentration in the upper portion of the Aquifer 1 in some areas. Some of the local municipal wells are currently not operational, or their rate of water taking is managed, to minimize the increase in nitrate concentration from the upper portion of Aquifer 1. **Figure 5.7.2** shows an example of the distribution of nitrate concentrations above 10 mg/L, in wells sampled within the Waterloo Moraine for 2005 (from Burnside, 2006).

- There has been an increase in sodium and chloride concentrations in a number of the urban well fields since the 1960’s, as a result of decades of road salt application on roads, sidewalks and parking lots. Several of the older well fields have sodium and chloride concentrations exceeding recommended drinking water guidelines in individual wells within the well field. The sodium and chloride loading is likely a combination of both a broad-scale migration of road salt-impacted water migrating down through the aquifer-aquitard system and a downward migration of road salt-impacted water through local “windows” in some of the aquitard units. **Figure 5.7.3** shows an example of the range in concentrations of chloride, in wells sampled in the Waterloo Moraine in 2005 (from Burnside, 2006).

- Several well fields have experienced local site-specific industrial contamination, in particular the Greenbrook Well Field and to a lesser extent the William Street Well Field. Although there appears to be considerable natural protection, it is likely that there are local “windows” in the aquitard units that have resulted in the downward migration of contaminants. The contaminant sources are from old industrial sites. These well fields also have the high sodium and chloride concentrations.

As part of the Region’s Source Protection initiatives, the Region has developed Well Head Protection Areas, delineated vulnerable areas, compiled a threats inventory database and a list of threats within Well Head Protections Areas. The Region has also developed a risk management program to rank potential risks and developed a risk reduction program. The Source Protection program is summarized in the next section.

The Region has also been actively involved in a number of pro-active initiatives to minimize the risk of contaminants entering the groundwater system (ROW, 2008) including, but not limited to:

- implementation of a Rural Water Quality Program (with GRCA and OMFRA);

- conducting a "Road Salt Management and Chloride Reduction Study" and implementation of a Region-wide road salt reduction initiatives;
- development of nitrate reduction strategies at a rural well field; and,
- implementation of aggregate extraction policies to minimize aquifer vulnerability impacts within well head protection areas.

5.8 SUMMARY OF TECHNICAL SOURCE PROTECTION STUDIES

As indicated in previous sections, the Region of Waterloo has been actively involved with water resources protection for many years. The Region has been implementing a Water Resources Protection Strategy since 1993, to minimize the risk of historic, existing and future land use activities on municipal water supplies. In 2003, the Region in partnership with the GRCA was awarded funding from the MOE "Operation Clean Water Municipal Groundwater Study Initiative", (ROW, 2008). One of the main components of the work was to develop a new ten-year Water Resources Master Plan, updating the existing Master Plan and incorporating new initiatives and policies developed by the Province of Ontario, including the Clean Water Act and related regulations. The following is a summary of the various studies and initiatives that have been completed or on-going, within the Region of Waterloo:

- <u>Groundwater Mapping and Aquifer Vulnerability Assessment</u> – The Region has delineated well head protection areas for all of their groundwater supply wells using a Regional-scale groundwater flow model. Capture zones have been delineated and "Well Head Protection Areas" assigned levels of "sensitivity". These areas have been updated, or are currently being updated, to integrate with the Source Protection Groundwater Vulnerability Analysis (i.e. Guidance Module 3).
- <u>Delineation of Surface Water Intake Protection Areas</u> – The Region has completed a study to delineate Inland Protection Zones and Total Water Contributing Area for the Hidden Valley Intake on the Grand River.
- <u>Groundwater Use Inventory and Assessment</u> – These studies include an MOE water-use assessment and a Region water-use assessment. As previously indicated, a Tier 2 Water Budget and Risk Assessment Analysis has been completed and a Tier 3 Water Budget and Risk Assessment Analysis is currently being conducted for the Laurel/Schneider Creek group of subwatersheds.
- <u>Region-scale Assessment of Potential Contaminant Sources</u> – A reconnaissance level survey of sites that pose a potential threat to water supplies was conducted in 1996 and detailed studies completed in 1997 and 1998. A Threats Inventory Database (TID) was developed by the Region and ranking of each threat developed to provide a relative ranking of the threat to water resources. This information is being updated as part of the Source Protection Threats Inventory Assessment and Issues Evaluation (i.e. Guidance Module 5).
- <u>Risk Reduction Programs and Tools</u> – The Region has implemented, or is proposing to implement a number of Risk-Mitigation Measures for existing and future threats to municipal wells within the different Well Head Protection Sensitivity Areas. Threat categories such as: contaminated sites; winter maintenance; agriculture nutrient application; impervious cover increase; and, aggregate extraction are addressed with various risk reduction measures proposed for each category.

6.0 Current Understanding of the Paris/ Galt Moraines

6.1 OVERVIEW

In terms of assessing an understanding of the Paris/ Galt Moraine system the limited data availability and subsequent geological and hydrogeological interpretation was discussed in Section 3.4. The following sections present a summary of the current understanding of the Paris/ Galt Moraines.

6.2 GEOLOGY AND HYDROSTRATIGRAPHY

6.2.1 Paris/ Galt Moraine Boundary

Mapping provided by the MOE for this study, showing the location of the Paris/ Galt Moraines (**Figure 3.4.1.1**), was based on information from several existing documents, including the following:

- GRCA Watershed Report, 2005 – Page 9, Moraine areas map, under the heading “Natural Areas: Moraines are the backbone of the Grand”;
- Protecting Significant Moraines in Waterloo Region, A Supplementary Report in Support of Waterloo Region’s Growth Management Strategy, prepared by: Planning, Housing and Community Services, Grand River Conservation Authority, and Meridian Planning Consultants Inc.; and,
- Aquifer Characterization and Capture Zone Delineation for the Region of Waterloo, prepared by Waterloo Hydrogeologic Inc.

Using the above noted mapping as reference maps, the OGS Surficial Geology data from 2003 was then utilized, specifically the GIS layers called sgu_mor and sgu_poly and the selected polygon features from both data sets that corresponded to the features on the reference maps. In addition, any features with Paris Moraine or Galt Moraine within the annotation layer included with the surficial geology data were also used.

The moraine footprint for the current study was derived primarily relying on areas mapped as hummocky terrain, from surficial geology mapping. A comparison of the hummocky terrain mapping, to either the physiography or the Quaternary geology mapping, will show variations in the boundary features when compared to the mapping provided by MOE.

In the Caledon Hills area a portion of the Paris Moraine, north of Caldwell, (White 1975, Map 2275) is not shown on the current moraine footprint. This area is presented on the physiographic layer of the map as an elongated till moraine area just north of the furthest extent of the current Paris Moraine footprint.

A comment on the moraine boundary issue, from Ross Kelly (pers. Com) at the OGS, provides additional insight:

“The compilation that the OGS did in 2003 and which has been used for outlining moraines by some people does not outline moraines explicitly. We created a layer termed "hummocky topography" in the 2003 compilation that incorporated areas mapped as hummocky topography outlined on the old 1:50 000 hard copy maps. Some geologists outlined areas of hummocky topography while others didn't. That is why you will see boundary faults on the hummocky topography layer… As moraines generally consist of "hummocky topography" the layer provides an approximate outline of moraines but it should not be considered definitive. That is why there are little blobs sticking out on the Wellington County Moraines

map and others. These little "blobs" are just areas of hummocky topography and may or may not be related to specific moraines. Another alternative is to use the Chapman and Putnam physiography maps that we (OGS) made digital in 2007. The outline of the moraines portrayed on the C and P maps is different from the "hummocky topography" moraines that have been outlined."

Within a hydrogeological context the boundary should likely reflect the following:

- the hummocky topography;
- the recharge/discharge function in particular the local discharge function; and,
- the Wentworth Till cap.

6.2.2 Geology and Hydrostratigraphy

The Paris Moraine was formed during an advance and stagnation of the Ontario ice lobe approximately 12-13,000 years ago (Karrow, 1968; Cowan, 1972; White, 1975; Bajc, 2007). The formation of the Galt Moraine was generally interpreted to occur as a result of a subsequent retreat and stagnation, or a retreat and re-advance and stagnation, of the Ontario ice lobe (Karrow 1968; White 1975). Various reports differ as to whether these glacial events happened during the Port Huron Stadial or the Port Bruce Stadial. Bajc and Karrow (1994) presented the following discussion:

The Paris and Galt moraines are now believed to be correlated in age to the Oak Ridges Moraine north of Lake Ontario, and the Singhampton and Gibraltar moraines south of Georgian Bay. Barnett (1984, 1991) suggested that the Paris and Galt moraines formed in response to a period of readjustment of the Erie-Ontario ice lobe margin during the Mackinaw Phase; an observation that agrees with those proposed by Taylor in his initial investigation. Evidence for a local readvance of the ice margin occurs in isolated areas to the north but is lacking to the south where the ice margin was fronted by a large glacial lake. The extent to which ice retreat occurred prior to the readvance is not known.

Extensive glaciofluvial deposits following low tracts of land in front of and between the moraines flowed southward toward the Lake Erie basin where a large glaciolacustrine delta was constructed at the Jacksonburg level. The source of these deposits may be, in part, attributed to the release of subglacial meltwaters that carved large tunnel valleys north of the Oak Ridges Moraine. Detrital organic remains recovered from the deltaic sediments in front of the Galt Moraine were radiocarbon dated at 13.4 ka BP (Barnett, 1985) and provide one of the most reliable dates on the age of the Mackinaw Phase. Bog bottom dates from kettle depressions within the moraine range between 11.95 and 5.78 ka BP and only provide minimum deglaciation dates for the moraines.

The primary composition of the Paris/ Galt Moraines is the Wentworth Till. Within the moraines, the Wentworth Till is generally characterized as a brown to reddish brown silty sand or sandy silt till. The Wentworth Till is relatively coarse-grained and varies in composition along the moraine generally becoming finer-grained to the south (White, 1975), due to the incorporation of glaciolacustrine basinal clays (Bajc and Karrow, 2004). The Wentworth Till in the Till plains adjacent and distal to the moraines is generally finer grained (Karrow, 1968). The coarser-grained nature of the till within the moraines varies and is interpreted as being dependent on more local inclusions of permeable kame deposits or outwash, and the reworking of these more permeable deposits during minor glacial re-advances (Karrow, 1968; Karrow, 1987). Barnett (1978) referenced a description of the Paris/ Galt Moraines by Dreimanis (1961) as follows: "the Paris and Galt Moraines serve as good examples of the influence of incorporated non-consolidated glacial sediments."

Within the Credit Valley watershed the Paris Moraine provides the relief (30-40m) for the headwaters of Silver Creek, the West Credit River and the Credit River from Cheltenham to Glen Williams. The Paris/ Galt Moraines provide relief for the headwaters of Black Creek and make up the boundary between the Credit River watershed and the Grand River watershed. Outwash sand and gravel is extensive off the northern flank of the Paris Moraine towards the Village of Erin. Within Black Creek, and moving southeasterly, the Paris and Galt Moraines are inseparable and are up to 8 km wide. It is noted that the moraines in this area have pockets of glaciofluvial sediment (White, 1975) and may contain a core of stratified drift (Cowan, 1976; CVC, 2008). The area also contains numerous boggy kettles and wetlands (Cowan, 1976; CVC, 2008). The Wentworth Till cap throughout the area is noted to be 1-15 metres thick (CVC, 2008).

Continuing on to the southwest from the Credit River watershed, the Paris/ Galt Moraines remain relatively inseparable (Blue Springs Creek provides some separation) until the Aberfoyle area, where a major outwash channel separates them for about 10 km. At some locations the outwash channel is up to 4 km wide (**Figure 3.4.1.2**). Farther along, smaller spillways, including those associated with lower Mill and Moffat Creeks, separate the moraines.

Through the Guelph-Cambridge area the Galt Moraine forms a continuous ridge but the Paris Moraine is absent between the Shades Mills Conservation Area and the Pinehurst Lake Conservation Area. The moraine in this area may be buried by the significant outwash deposits or may have been eroded away (Karrow, 1997). This major outwash was deposited as the ice remained stagnant at the edge of the Paris Moraine (Karrow, 1997). The Wentworth Till is quite sandy from north of Acton down through Cambridge and the moraine structure commonly has permeable kame deposits associated with it (Karrow, 1997; Karrow, 1998). They are more common in the Paris Moraine and likely reflects greater melting at the ice front. A complex internal structure with till units, sand and silt lenses and discontinuous sand and gravel is also common (Golder, 2006a; Golder, 2006b). Kettles and kettle lakes (e.g. Puslinch Lake) are more common on the Paris Moraine and tend to indicate abundant meltwater (Karrow, 1987). Kettles are less abundant on the Galt Moraine. Swamps and bogs are also common on the Paris Moraine and within the outwash in front of the Galt Moraine (Karrow, 1987; Golder, 2006b). The moraine relief in this area is on the order of 20-30m.

Existing stratigraphic cross-sections through the Galt/Paris Moraines were found to be limited in the reports that were reviewed. Two examples are shown in **Figures 6.2.1** and **Figure 6.2.2**. **Figure 6.2.1** (CG&S, 1996) shows a hydrostratigraphic cross-section through Mill Creek from north to south, in the area of Aberfoyle. Note the extensive more permeable material within the Paris Moraine, the outwash channel and to a slightly lesser extent within the Galt Moraine. Also note a less permeable unit above the bedrock, which is likely the Port Stanley Till (CG&S, 1996). **Figure 6.2.2** (Lotowater, 1997) is a north to south stratigraphic cross-section just west of Puslinch Lake south to Highway 6. The cross-section shows the Wentworth Till and the abundance of more permeable sand and gravel below the surficial till unit. The more permeable sand and gravel does not appear to extend completely into the Galt Moraine. As well, a less permeable till (Port Stanley Till) is present at the bedrock contact. The Port Stanley Till is noted in most reports within the Guelph/Cambridge area, although it may not be a continuous unit. The overburden thickness throughout the Guelph and Cambridge area can be on the order of 30-40m. **Figure 6.2.3** presents a cross-section in the Eramosa River-Blue Springs Creek area (Stantec, 1999).

Moving southerly through to Paris, the moraines become narrower and more subdued, with relief on the order of 10-20m (Cowan, 1972). The Moraines are also discontinuous at ground surface and appear to be buried by younger sediments in some areas. Kame cores are associated with the moraines in this area (Cowan, 1972). The Galt Moraine is absent west of Brantford and reappears north of Waterford (Barnett, 1978). Major glaciolacustrine sand deposits, or outwash and deltaic sand and gravel deposits, are adjacent to, or separate the moraines (**Figure 3.4.1.2**). Drilling by the OGS north of Oakland, along the margin of the Galt Moraine, encountered 41 metres of well-bedded sand and gravel with lesser silt and clay. The preliminary interpretation of the drilling results suggests a subaquatic fan depositional environment with coalescing fan lobes (Bajc, 2008). Moving south along the Paris/ Galt Moraines, the Wentworth Till becomes more fine-grained and the relief far more subdued (Burnett, 1978). The Moffat Moraine rides in behind the Galt Moraine and is almost coincident with it southwest of Brantford. The Paris Moraine is mapped through to Delhi but is basically nonexistent through to Lake Erie. The Galt Moraine is absent from Waterford on down to Lake Erie. In both case the moraines are likely buried under the extensive glaciolacustrine and glaciofluvial sand deposits and in both cases very minor pockets of Wentworth Till may exist a ground surface (Lake Erie Source Protection Report, 2008).

In summary, within a hydrostratigraphic context, the following general opinions or interpretations have been put forward in the literature concerning the Paris/ Galt Moraines:

- The Wentworth Till cap is a relatively consistent unit although it is generally more fine-grained to the south. Locally, areas of the Wentworth Till may be coarser-grained (more permeable) or finer-grained (less permeable).
- The internal structure is a complex mixture of till, stratified drift and discontinuous layers of more permeable material. Locally, this permeable material may be continuous.
- The Galt Moraine may contain less permeable core material and is generally less hummocky, compared to the Paris Moraine.
- There may exist a less permeable till unit above the bedrock, but below the more permeable material found in the core of the moraines. The continuity of this unit is likely variable.

6.3 SIGNIFICANT AQUIFERS

The large-scale aquifer potential within the Paris/ Galt Moraine overburden area, as presented in the literature, is basically limited to the adjacent meltwater channel sand and gravel deposits (e.g. Erin, Acton, Puslinch and Cambridge areas). The one notable exception is the interpretation of an aquifer unit within the Galt Moraine in the vicinity of St. George (AquaResource, 2008a). This was noted during the current OGS drilling program (Bajc, 2008). The permeable deposits within the moraines do support private wells and a small number of communal wells (CVC, 2002; Golder, 2006a, b; CG&S 1996; AquaResource, 2008a). Major aquifers exist in the underlying bedrock, particularly in the Guelph and Amabel Formations.

As discussed previously, south of St. George the Paris/ Galt Moraines become more subdued, are less connected and eventually disappear. The moraines become finer grained to the south. The local overburden aquifer in this area is the adjacent outwash (e.g. Paris and Brantford area) or more regionally, the Norfolk Sand Plain.

Generally there are more private wells in the underlying bedrock than the overburden within the moraine footprints in the CVC and GRCA watersheds. This likely reflects the more consistent water producing capability in the upper bedrock. The limiting factor for water supply wells in the overburden is a lack of a continuous permeable overburden unit. **Figure 6.3.1** provides a comparison between the number overburden and bedrock wells within in the County of Wellington portion of the Paris/ Galt Moraines. **Figure 6.3.2** provides the well types for the CVC. Both show a predominance of bedrock wells within the area of the Paris/ Galt Moraines.

The Guelph-Puslinch Groundwater Study (Golder, 2006a) concluded that even though there were a large number wells throughout the area it was not possible to interpret individual aquifer units within the Paris/ Galt Moraines.

It is important to note that when dealing with a complex stratigraphy as described above there may be hydraulic interconnections between what appear to be discrete sand lenses and therefore, the potential for larger-scale but still more localized groundwater production zones. This reflects the possible limitations of a three-dimensional hydrostratigraphic quantification of this type of ice-contact environment, based solely on geologic stratigraphy.

The underlying bedrock dolostone aquifer and the overlying overburden local aquifers may or may not be connected. Aquitards of fine-grained material (e.g. Port Stanley Till) may hydraulically separate these aquifer units. The hydraulic connection between the bedrock and overburden of the Paris/ Galt Moraines is not well known, based on the information in the reports reviewed for this study.

6.4 SIGNIFICANCE AND FUNCTIONS OF THE PARIS/ GALT MORAINES

6.4.1 Recharge

The recharge function has been one of the major hydrogeologic characteristics discussed for the Paris/ Galt Moraines. It is generally interpreted or perceived that till, by nature, should have a low permeability therefore a relatively lower recharge potential as compared to say a medium sand. In the case of the Paris/ Galt Moraines the till is generally sandy in composition. In addition, the hummocky nature of the moraines gives rise to closed depressions which can collect runoff, which can lead to a higher recharge potential, depending on the permeability of the surficial unit within the depressions. This factor was presented in Karrow, 1968.

These two basic components have been factored into estimating recharge potential and more recently into groundwater/surface water modeling and water budget calibration. As a result, current recharge values for the Paris/ Galt Moraines vary from 100-360 mm/year but are usually interpreted to be the higher end (CVC, 2008; Davies and Holysh, 2007; AquaResource, 2008a/b; LESPR, 2008). The hummocky portions of the moraine are commonly reflected as significant recharge areas. **Figure 6.4.1.1** shows estimated recharge distribution in GRCA watershed (LESPR, 2008).

The closed depressional nature of the hummocky terrain must be considered within a scalar context when looking at depression-focused recharge. A number of the depressions may be connected on a smaller scale and eventually direct surface runoff towards an endpoint for recharge within the hummocky terrain or to the more permeable outwash on the lower slopes. Within this framework, the overland flow and hummocky terrain may create highly localized recharge areas, which may dominate recharge to the groundwater flow system.

The recharge into the Paris/ Galt Moraines provides for the hydraulic head to move water into the underlying bedrock, where hydraulically connected. Depending on the flow pathways, this water may discharge to reaches of adjacent streams or into local wetlands (CVC 2008; Golder 2006a; LESPR 2008; CG&S 1996).

6.4.2 Water Supply

Municipal water supplies found in proximity to the Paris/ Galt Moraines are almost solely confined to deeper bedrock aquifers, except for the Paris municipal water supply. On the full scale of the Paris/ Galt Moraines, only a very small portion of these moraines is subject to capture of water from municipal supply wells.

Municipal wells adjacent to the Paris/ Galt Moraines and their respective capture zones for Acton and Guelph are presented in **Figures 6.4.2.1** and **6.4.2.2**. The Acton municipal well capture zones extend under the Paris Moraine to the north. The Guelph capture zones extend under the Paris Moraine to the northeast. The capture zones of Cambridge wells, in the vicinity of the Galt Moraine, are not known to extend under the moraine. The municipal wells in Paris, adjacent to the Paris Moraine, are a combination of both overburden and bedrock wells, with capture zones extending within the permeable sediments, adjacent to or part of the Paris Moraine (Lotowater, 1997).

The Region of Halton, City of Guelph and Region of Waterloo are currently undertaking Tier 3 Water Budget and Water Quantity Risk Assessments (Section 6.7). The areas of these assessments will include consideration of the Paris/ Galt Moraines. Groundwater flow modelling specific to the capture zones, reflecting areas under the Paris/ Galt Moraine and the effect on the moraine flow system, is expected to be addressed during the Tier 3 studies for the City of Guelph and the Region of Waterloo. The terms of reference for the Acton Tier 3 study have not been finalized.

Water supply for domestic purposes was found to be sufficient, utilizing both the local overburden aquifers and the underlying bedrock. Use of groundwater for agricultural purposes (e.g. mainly tobacco irrigation) was greatest in the southern portion of the Paris/ Galt Moraine study area, but the wells appeared to be mainly within the adjacent Norfolk Sand Plain. Areas where agricultural wells may have been located within the potential buried portions Paris/ Galt Moraine were not determined within the scope of this study. There were no specific references to groundwater shortages for agricultural use, within the Paris/ Galt Moraines.

6.4.3 Maintenance of Water-Related Ecological Features

The maintenance of baseflow for coldwater streams is often a major focus in many subwatershed studies. At the subwatershed level of study it is common to obtain field baseflow measurements for groundwater balances (CVC 1998; CG&S 1996; Golder 2006a) and as input parameters for groundwater and surface water model calibration (AquaResource 2008a; CVC 2008). Determining the area of recharge contributing to groundwater discharge is generally carried out on a coarse scale in watershed models.

Groundwater flow modelling, to look at impacts on baseflow due to reductions in recharge from unmitigated urban development or changes to the groundwater flow system resulting from unmitigated aggregate extraction within the Aberfoyle outwash, was carried out for various recharge reduction and extraction scenarios (CG&S 1996; Golder 2006b). The results were summarized as follows:

"The groundwater model was also used to examine (in a conceptual manner) the sensitivity of the groundwater flow system to below water table aggregate extraction operations in the Mill Creek area. The modelling results indicate that below-water table aggregate extraction has the potential to temporarily affect groundwater flow directions and reduce baseflow to area watercourses as groundwater inflows to replace the volume of aggregate materials during extraction. At closure, following the completion of extraction operations, groundwater flow directions and water budgets may be locally affected. However, while the potential for these impacts has been demonstrated in a generic manner with the model, the actual impacts of these operations would have to be assessed on a site specific basis, and in the context of specific criteria established for surface water features that are in the vicinity of the operations.

The effects of a reduction in recharge were also considered using the 3-dimensional model (again, in a conceptual manner only). In the event that extensive development occurred across the Paris Moraine, recharge could be reduced because of paved surfaces and storm sewers. The potential impact of this was assessed in the model by reducing the amount of recharge over the moraine footprint in increments of 10%, 20%, 30% and 40%. The modelling results indicated, as expected, that a reduction in recharge into the moraine results in a reduction in groundwater discharge (baseflow) *to the surface watercourses in the area. The greatest sensitivity (given the assumed footprint of recharge reduction) was observed for Irish Creek, where a 10% reduction in the recharge resulted in a 20% reduction in the simulated baseflow at Irish Creek. In comparison, a similar reduction in recharge resulted in an 8% reduction in the simulated baseflow for Mill Creek at Side Road 10. While the reduced recharge rates did not affect regional groundwater patterns, groundwater elevations in the moraine were simulated to have dropped 1 to 4 metres for recharge reductions of 10% to 40%, respectively. As described earlier, while the model demonstrates the potential impacts associated with reduced recharge, actual impacts would have to be assessed on a site specific (or development specific) basis."*

There are a significant number of gravel pits associated with the outwash sands and gravels related to the Paris/ Galt Moraines (**Figure 6.4.3.1**). The individual reports were not reviewed for this study, however a detailed peer review was previously performed for DFO to assess the groundwater/fisheries impact from a group of localized below the water table aggregate operations in the Township of Puslinch (Blackport and Portt; 2002). The review focused on the changes to the groundwater flow system, groundwater discharge and the impacts on the local fish habitat for Mill and MacCrimmon Creeks. The study basically concluded that the were modifications to the local water table but no significant changes in overall reach baseflow or subsequent impacts on fish habitat, based on the existing data and natural trends. The potential for impacts on local baseflow may be increased with future expansion of the aggregate operations but can be minimized with appropriate design and operation practices. It was qualified in the report that these general conclusions were to be refined and confirmed with ongoing monitoring.

It is noted that hummocky topography can gives rise to local wetlands within the depressional areas. The maintenance and assessment of the groundwater function for ecological features are standard components of all current subwatershed and follow-up site specific studies, regardless of the physiographic feature(s).

Recharge into the Paris/ Galt Moraines, and the subsequent groundwater flow, is interpreted to provide significant groundwater discharge to reaches of the Eramosa River/Blue Springs Creek (Stantec, 1999), Mill Creek (CH2M-Hill, 1996) and reaches along the Grand River in Cambridge. Coldwater reaches of the streams on and adjacent to the Paris/ Galt Moraines have not been fully quantified.

Groundwater storage within the Paris/ Galt Moraines is likely significant in providing a level of resilience for associated groundwater discharge on a seasonal basis and during extended drought periods.

6.5 WATER QUANTITY/ WATER BUDGET

Within a water quantity context, Section 6.3 showed the location of water wells within the overburden and the bedrock. The specific capacities for the overburden and bedrock wells, based on the MOE water well database, were quite consistent throughout the reports. The specific capacity of both sets of wells, were, on average, between 2.0 and 5.0 IGPM/ft (CVC 2008; Golder 2006b; Golder 2006a) but, as discussed above, more wells were completed in the bedrock than the overburden.

The quantification for water budget and water use was not specifically conducted for the Paris/ Galt Moraines in the larger scale reports (See Section 6.1). The Mill Creek Subwatershed Plan (CG&S 1996) performed an impact assessment on the water budget as discussed above. Water budgets for smaller scale subcatchments are commonly carried out at the block plan stage where development is occurring.

Water quantity or water storage within the saturated units can be assessed by looking at trends in water level hydrographs. Some monitoring wells exist for the Paris/ Galt Moraine area, including PGMN wells (**Figure 6.5.1**) and a detailed monitoring program for the Township of Puslinch (**Figure 6.5.2**). **Figure**

6.5.3 shows the hydrograph for PGMN well GA-20. **Figure 6.5.4** shows two hydrographs for the Paris/ Galt Moraines, from the Township of Puslinch Monitoring Program. The hydrographs demonstrate the seasonal variations in water levels. The long term trend shows no overall increase or decrease in water levels**.**

The detailed review for DFO described above (Blackport and Portt, 2002) did not indicate any significant impacts on the groundwater flow systems, related linkages to surface water and wetlands or the water budget as a result of aggregate extraction in outwash areas adjacent to the Paris/ Galt Moraines.

6.6 WATER QUALITY

The water quality within the overburden and bedrock is presented in general terms within a majority of the reports. The water in both the overburden and bedrock (Guelph Amabel Formations) is generally hard with higher iron in the bedrock and slightly lower hardness in the outwash sand and gravel. The only reference within the Paris/ Galt Moraines related to contamination from a surface source, was elevated nitrate levels (Golder 2006a) which is likely the result local septic systems or agriculture and elevated sodium possibly from road salt or septic systems (Golder 2006a). The monitoring sites for this study are shown in **Figure 6.5.4**.

Potential contaminant sources for the Guelph-Puslinch Study are shown on **Figure 6.5.5**. The majority are related to agriculture for the Paris/ Galt Moraines but there are relatively few sources.

Both rural and urban threats inventories were carried out for the Region of Waterloo and include the Cambridge area of the moraines.

The detailed review for DFO, previously described above, did not indicate any significant impacts on the groundwater quality. Thermal plumes from below water aggregate extraction were found to be attenuated within a short travel distance in the groundwater (i.e. less than 200 metres).

6.7 SUMMARY OF TECHNICAL SOURCE PROTECTION STUDIES

6.7.1 GRCA Tier 2 Water Budget

The GRCA Tier 2 Water Budget utilized available numerical models, specifically a continuous surface water model (GAWSER) and a steady-state three-dimensional groundwater model (FEFLOW) to quantify the individual water budget components (AquaResource, 2008a). The demand estimates of the water budget were refined by building upon previous work carried out by the GRCA and AquaResource, which involved interviewing and surveying permit to take water permit holders on their actual water usage. Monthly consumptive water use rates were then estimated for each permit by applying seasonal and consumption factors; consumptive rates are estimates of the volume of water that is not returned to the original source it is extracted from, by the water taking operation. While less significant from a quantity perspective than permitted takings, non-permitted takings such as rural residential or livestock watering, were also accounted for in the water demand estimates.

A draft of the Tier 2 Water Budget report was completed in 2008 by AquaResource Inc. (2008a), and underwent a peer review by external experts, as well as technical members of the Lake Erie Source Protection Region. A draft of this report is available at the following website; http://www.sourcewater.ca/index/document.cfm?Sec=7&Sub1=6&Sub2=5. The water budget estimated approximately 60% of the water flowing through the GRCA Watershed exists as surface water runoff, while 40 per cent flows through the groundwater system. The majority of groundwater flow (~85%) re-surfaces within the watershed as baseflow discharge into rivers, creeks and wetlands, an estimated 8%

discharges to areas outside of the watershed. At the watershed scale, groundwater extraction accounts for approximately 10% of the total groundwater flow in the watershed (AquaResource, 2008a).

Aside from the quantification of the Water Budget components, the study also included a Stress Assessment that involved calculating the level of potential hydrologic stress within each of the subwatersheds within the GRCA. As outlined in the Province's Water Budget Guidance Module, those subwatersheds that are deemed to be under moderate or significant hydrologic stress are required to undertake a more detailed and refined Tier 3 Water Budget Assessment. Within the GRCA, the Region of Waterloo and the City of Guelph were identified as having water supply systems that have a moderate to significant potential for hydrologic stressed, and as such are currently undertaking Tier 3 Water Budget Pilot Projects with funding provided by the Province.

6.7.2 Long Point Region, Kettle Creek and Catfish Creek Tier 2 Water Budget

The Lake Erie Source Protection Region also conducted a Tier 2 Water Budget study within the Long Point, Kettle Creek and Catfish Creek subwatersheds. The tools used for the study included a continuous surface water model (GAWSER) and a steady-state three-dimensional groundwater model (FEFLOW) to quantify the individual water budget components (AquaResource, 2008b). The process carried out to estimate the water demands and other water budget components were estimated using the process outlined in the Province's Water Budget Guidance module (MOE, 2007), and are consistent with Tier 2 studies completed for the GRCA and CVC (latter is discussed below).

A draft of the Tier 2 Water Budget report was completed in 2008 by AquaResource Inc., and underwent a peer review by external experts, as well as technical members of the Lake Erie Source Protection Region. The Water Budget and Stress Assessment underwent internal review by the Source Protection Region and their peer reviewers and comments on the document are currently being addressed by AquaResource Inc. An updated report is anticipated to be re-submitted to the Source Protection Region in early 2009.

6.7.3 CVC Tier 2 Water Budget

Similar to the Tier 2 Water Budgets projects described above, the Credit Valley Conservation Authority (CVC) also recently completed a Tier 2 Integrated Water Budget report for the CTC (CVC- TRCA-CLOCA) Source Protection Region (AquaResource, 2008c). Individual water budget components were analyzed on a subwatershed scale across the Watershed using the CVC's continuous surface water model (HSP-F) and their three-dimensional groundwater model (FEFLOW).

Estimates of water demand were refined using the Province's Permit to Take Water database, as well as actual water use values obtained from earlier surveyed results collected by the MOE and CVC. The estimates were refined using monthly consumptive water use rates for each permit by applying seasonal and consumption factors, and non-permitted water takings such as rural residential takings were also included in the water demand estimates.

The Tier 2 Study also included a Subwatershed Stress Assessment that involved calculating the level of potential hydrologic stress within each of the subwatersheds within the Credit River Watershed. As outlined in the Province's Water Budget Guidance Module, those subwatersheds that are deemed to have a moderate or significant hydrologic stress are required to undertake a more detailed and refined Tier 3 Water Budget Assessment. Within the CVC, the Town of Orangeville (Subwatershed 19) and the Region of Halton (Subwatersheds 10 and 11) were identified as having water supply systems that have a moderate to significant potential for hydrologic stressed, and as such, these municipalities are currently undertaking Tier 3 Water Budget Pilot Projects with funding provided by the Province.

A draft of the Tier 2 Water Budget report was completed in 2007, and it subsequently underwent a peer review by external experts, as well as technical members of the CTC Source Protection Region. A draft of this report was recently made available to the Source Protection Region and the peer review team for their final review in October, 2008.

6.7.4 Conservation Halton/ City of Hamilton Tier 2 Water Budget

The Tier 2 Water Budget is at the Draft Proposal Stage and there is no further information.

6.7.5 Region of Waterloo Tier 3 Water Budget

The Regional of Waterloo is currently undertaking a Tier 3 Water Budget and Water Quantity Risk Assessment as the Region was designated in the GRCA Tier 2 Water Budget Study as having a moderate to significant potential for hydrologic stress. The area being studied includes the urban well fields within the Cities of Kitchener, Waterloo and Cambridge as well as a few of the surrounding well fields. The goal of the Tier 3 Assessment is to evaluate the sustainability of the water supply system for the Region and identify potential threats to the long term municipal water supplies. The Assessment will be centered on the development and refinement of the Water Budget in the area using refined and updated numerical modelling tools, which include a continuous GAWSER surface water model, and finite element FEFLOW groundwater model.

The Tier 3 Assessment was divided into 2 phases; 1) Enhancement of the conceptual and numerical models of the Region's well fields; and, 2) Risk Assessment, and evaluation of potential water quantity threats. The Study is currently focusing on the first task and this involves the following key deliverables;

- Updated hydrogeologic database;
- Conceptual Model Report, including a refined hydrogeologic characterization of the Region's well fields within the Study Area;
- Updated groundwater and surface water modelling tools, refined around the Region's well fields within the Study Area; and,
- Water Budget Report, incorporating the results of the refined modelling tools.

Field work being completed for the Phase 1 portion of the Study includes spot baseflow data collection within the Region, as well as the installation and monitoring of mini-piezometers within surface water features located near the municipal well fields under investigation. This work aims to improve the overall understanding of the interaction between the municipal groundwater aquifers and the local surface water features. Drilling is not being undertaken as part of the Phase 1 portion of the study; however, should additional funds become available, additional boreholes may be drilled to fill data or knowledge gaps in the conceptual understanding of the subsurface groundwater flow system. A water level snapshot is also planned to take place as part of the study, and it aims to collect representative water levels for use in calibrating the FEFLOW groundwater flow model.

It is estimated that the Phase 1 work will be completed in June 2009 and will be useful for inclusion within the Source Protection Region's Assessment Report. Phase 2 will commence following the Phase 1 study.

6.7.6 City of Guelph Tier 3 Water Budget Assessment

Similar to the Region of Waterloo, the City of Guelph is also currently undertaking a Tier 3 Water Quantity Risk Assessment as it was also designated in the GRCA Tier 2 Water Budget Study as having a moderate to significant potential for hydrologic stress. Again, the objective of the Tier 3 Assessment is to evaluate the sustainability of the water supply system for the City and identify potential threats to the long term municipal water supplies. The Assessment will be centered on the development and refinement of the Water Budget in the City of Guelph and beyond, using refined and updated numerical modelling tools, which include a continuous GAWSER surface water model, and finite element FEFLOW groundwater model.

The Assessment will aim to refine the understanding of the groundwater and surface water flow systems within the study area, and improve the estimates of the various Water Budget components. As the majority of the municipal wells are completed in the bedrock, field work was focussed on collecting information to improve the understanding of the fractured bedrock environment in the Study Area. Several boreholes will be drilled within the Study Area (**Figure 6.7.1**) as part of this Assessment, including 2 wells within or near the Paris- Galt Moraine. All of the wells will be rotary drilled through the overburden, to the top of bedrock, and then will be continuously cored through the bedrock. The bedrock portion of the wells will be geophysically logged, and flute conductivity profiling will also be conducted within the bedrock. Multi-level monitoring wells will be installed in the wells (shallow overburden, shallow bedrock and deep bedrock), and water quality samples will also be collected and analyzed.

Although the Paris and Galt Moraines lie within the study area, the moraines are not being studied in any greater detail than any other geologic or physiographic features located within the study area.

6.7.7 Region of Halton Tier 3 Water Budget Assessment

This water budget assessment is still in the draft proposal and work plan stage.

7.0 Knowledge/ Data Understanding and Issues

7.1 COMMENTS ON THE KNOWLEDGE REQUIREMENTS FOR POLICY DEVELOPMENT

The following section provides a "high level" discussion of the knowledge/data needs as they relate to the technical decision-making process. It is not meant to be a detailed discussion on specific methodologies for characterization, impact assessment or a decision making process framework. That discussion is beyond the scope of this review as it would be of a scale similar to MOE documents prepared as Draft Guidance Modules for Source Protection (e.g. Module 1: Watershed Characterization, MOE, 2006; Module 7: Water Budget and Water Quantity Risk Assessment, MOE, 2007).

Within the context of this discussion, the following defines data and knowledge, using the groundwater system as an example:

Data

These represent the basic spatial and temporal quantification of parameters that are input into:

- physical models;
- computer models; and,
- assessment and decision making models.

Examples of groundwater and related geological data include:

- groundwater levels and chemistry;
- porosity, hydraulic conductivity and groundwater velocity;
- geological logs and field observations;
- stream flow measurements; and,
- topography and overburden thickness.

Knowledge

The types of data, as described above, can be utilized to develop conceptual geologic and hydrostratigraphic models. A physical characterization or interpretation of the groundwater system can then be made. The understanding can be expanded or refined by assigning spatially and temporally variable characteristic data (e.g. recharge, hydraulic conductivity of hydrostratigraphic units) for input into analytical or numerical models. Computer models are the most commonly used tool in interpreting or characterizing groundwater flow systems. This interpretation or characterization is considered basic knowledge and when calibrated with field data provides two-dimensional and three-dimensional representations and temporal trends of:

- groundwater recharge and discharge quantities;
- groundwater flow direction and velocity; and,
- contaminant transport.

This characterization is the *basic* technical knowledge used for decision making. The level of detail of knowledge necessary for decision making can depend on a number of factors, including but not limited to:

- the complexity of the geologic and hydrogeologic system;
- the sensitivity of the hydrogeologic system to changes in:
  - recharge quantity and quality;
  - groundwater withdrawal;
  - physical change to the hydrogeologic media (excavation, deposition, infrastructure);
- the potential impacts related to specific land use activities; and,
- the sensitivity of the functional linkage of groundwater to its receptors (i.e. spawning areas, sensitive wetlands, water supply wells).

A similar approach can be used to assess the entire hydrologic system, with the coupling of groundwater and surface water data, using all the components of a water budget for the hydrologic system and characterizing the connections and the pathways of water movement through a system such as a watershed.

7.1.1 Requirements Based on Scale and Complexity

Hydrological and ecological processes function on a variety of spatial and temporal scales. As outlined in Section 2.2.2, groundwater flow systems can be assessed on a variety of scales, ranging from a regional scale (10 – 100's of km) to a local scale (10 – 100's of m). A technically sound characterization should take this into account, both in terms of the spatial (3-dimensional) area of assessment and the amount of time-dependent data (temporal scale) required to appropriately characterize these processes.

A study completed to examine the impact of a residential development on a nearby wetland is an example of a local scale assessment, while a study of the regional groundwater flow from the Oak Ridges Moraine into Lake Ontario would be classified as a regional assessment. In the case of the local study, the regional groundwater flow picture may be overlooked as it may not be needed to answer questions regarding the local groundwater-surface water interaction at the wetland. Similarly, the intricacies of the local scale groundwater flow systems would be largely disregarded in the regional scale assessments.

In many areas of southern Ontario, hydrogeological assessments have been completed on the various scales outlined above. Most often, regional scale studies have been completed using provincial or municipal level funding (i.e. MOE funded Groundwater Management Studies or multi-stakeholder watershed studies). Local scale studies primarily arise in response to questions regarding proposed land use changes, such as a new landfill, aggregate operation, etc. Compiling the available monitoring information or interpretations that are relevant to the study being conducted involves examining the bigger picture (regional scale assessments), and using information and interpretations made in the local scale studies.

In some instances, local studies may not have been undertaken or there may be limited data available, resulting in knowledge or data gaps that place limitations on the physical interpretation within a given area. Knowledge gaps primarily relate to areas where the understanding of the geology or hydrogeology of an area is insufficient to make a refined interpretation with a sufficient degree of confidence. Additional data is required. As discussed above, data gaps are commonly addressed by collecting field data such as water levels, water chemistry data, or drilling boreholes and knowledge gaps are addressed by carrying out the characterization and assessment.

A technically based process would typically incorporate a “top down” approach. Studies would be carried out on a watershed scale utilizing the most data in a resource effective fashion. This may include using representative site-specific data (i.e. one or two data points from a detailed local study) to provide a characterization at a watershed scale. The characterization and assessment at this scale would determine:

- hydrogeologically sensitive areas;
- areas with urban development pressure;
- areas already being impacted by land use activities; and,
- areas with a lack of data/knowledge;

An assessment of these factors would prioritize areas for characterization in more detail, generally at the subwatershed scale. The process continues down through the “block plan” scale to the “site-specific” scale, with general planning and assessment being carried out in correlation with these studies. *It is important to note that these studies are not solely based on hydrogeologic characterization. The interdependent functions with other hydrological, aquatic and terrestrial components need to be characterized and assessed.*

From a scalar aspect, it is generally recommended that site-specific studies (i.e. gravel pit, landfill sites, subdivision etc) utilize an investigative methodology that uses as its foundation the larger scale studies and refines them on a local scale with site-specific data collection. The hydrogeologic complexity and sensitivity will usually determine whether there is a gap between the site-specific study and the larger scale study. For example, in some cases more detail than that usually found in a watershed study may be needed to put a site-specific study in the proper larger scale context. A subwatershed scale study with more detailed data from field observations and report reviews may be the necessary foundation if the hydrogeologic setting is more sensitive and complex.

There will always be some level of data gaps, given the spatial and temporal variability of hydrogeologic and ecosystem settings. This is an inherent factor, given the resources necessary to collect data. The issue is whether the amount of data available provides an appropriate level of understanding, which is usually determined through sensitivity analysis or risk assessment. In some cases there may be what are considered “data gaps” (i.e. geological data to fill in interpreted hydrostratigraphy) but the level of knowledge (i.e. knowing that certain parts of a system are hydraulically connected through pump tests etc. without a detailed stratigraphy) of the groundwater flow system may be sufficient.

For example, if it is established that a recharge area exists, and there are no proposed changes to land use (e.g. urban or industrial development) or land use activities (e.g. changes to agricultural practices) proposed in the recharge area, then there will be no change in quantity of recharge. So without having additional information, the quantity of water in the recharge area is protected. While there may be data gaps in fully understanding the recharge area and its connection to water supply wells or wetlands it is not necessary to understand these connections. In effect, there are no knowledge gaps to provide this broad level of protection. It is noted however that this may not be the case for water quality, especially in areas where broad non-point source impacts can occur (e.g. agricultural loadings, road salting). More detailed assessment may be required even though there has been no change in land use.

If however, a broad area has been established as a recharge area and certain types of development can occur in areas where it can be shown to have no impact on local wetlands or be outside the capture zone of a nearby well field etc., then there are a number of knowledge gaps that have to be satisfied through appropriate studies that would be set through policies.

From the perspective of policy development there needs to be a sufficient characterization of a specific area, and an understanding of the hydrologic functions within this area, to assess the level of sensitivity with respect to an existing land use or proposed land use change.

Policies are required to ensure:

- There is a sufficient understanding of the science (i.e. geology, groundwater flow, recharge areas, cold water fisheries) at whatever scale (e.g. watershed) being studied, to make decisions at that scale to ensure a broad level of protection.
- As the scale is refined (e.g. subcatchment area) the appropriate level of investigation is carried out to assess any potential impacts from proposed land use changes and provide appropriate protection (i.e. address the knowledge gaps that exist, moving down from the broader scale to the smaller scale).
- Appropriate monitoring is in place and there is a feedback loop (e.g. adaptive management plan) to ensure that everything is working as predicted, and if not, appropriate mitigation measures can be implemented.
- Appropriate monitoring and assessment is done far enough in advance to provide a technically sound characterization (i.e. basic functions and natural trends) to be incorporated into the planning process.

7.1.2 Technical Requirements for Policy Development

Given the complexities of the preceding discussion we generally feel that the major components of the technical process are in place and that the various agencies have applied considerable time and resources to apply the “top down” approach. However, there appear to be some shortcomings in the timing and chronology of the technical studies within the planning process. These may be of greater importance within more complex hydrogeologic/hydrologic settings such as the Waterloo and Paris/ Galt Moraines where the topography, thickness of and nature of overburden, and hummocky surface provides for a greater potential for increased recharge, storage and ecological linkages. Examples of potential shortcomings could include the following:

- Technical studies characterizing the geologic and hydrogeologic system must be done at an appropriate scale (i.e. subwatershed minimum) and over an appropriate length of time (e.g. 2+ years) to obtain a technically sound database for assessment, prior to implementing broad-scale planning decisions within the study area.
- More detailed studies at a smaller scale should be carried out prior to block plan design.
- Follow-up monitoring and review of monitoring data is necessary to confirm performance of land use design and related BMPs. This would provide for mitigation or revised design of future land use changes, where necessary (i.e. develop an appropriate AMP through a feed back loop with appropriate monitoring).
- Long-term monitoring in developed and undeveloped areas in different hydrologic sensitivities is necessary to assess climatic trends.

A significant component of the knowledge base includes all the historic and ongoing initiatives and programs dealing with technical issues and processes. These can include:

- Technical assessments at all levels of government, related to basic research, assessment framework development, technical guidance documents.
- Academic research and review.
- Other stakeholder initiatives into technical research, assessment and guidance (i.e. industry, commercial, environmental groups).

Providing input and obtaining results from these studies is needed, to be cost and resource effective, given there is usually significant overlap in the issues and objectives of the studies. This can be extended to all the basic groundwater characterization studies which are being, or have been carried out and the data that exists within the various agencies (i.e. groundwater databases, aquatic, terrestrial and geological data). These data should be readily accessible for minimal cost and with minimal time delay to carry out relevant technical assessments needed to satisfy current policy and regulations.

7.2 GENERAL SCIENCE ISSUES

Previous discussions have raised issues which give rise to challenges in providing a confident characterization of the hydrogeologic system including; complex hydrostratigraphy, appropriate spatial and temporal scale and subsequent adequate monitoring. Another challenging aspect, regardless of the hydrogeological setting, is the inherent limitations of the science, both the physical understanding and the methodology for assessment. The following is presented in the Water Budget and Water Quantity Risk Assessment – Guidance Module 7; Appendix A - Water Budget Essentials (MOE, 2007):

"The interaction of the processes affecting the various components of the hydrologic cycle is complex and often non-linear. For example, it is difficult to measure evapotranspiration, even though it is often the largest fluctuating variable. Estimating groundwater recharge, often done as a residual, is a complicated process that has a high potential for error (Lerner et. al., 1990). Given the error inherent in these parameters, the team should compare, calibrate, and incorporate multiple estimation methods into the water budget calculations. Most importantly, the team must always keep in the forefront that the complex water budget estimates carry varying levels of uncertainty. This level of uncertainty can be reduced by having better monitoring data to support more refined levels of model calibration."

This highlights a number of aspects:

- the parameters of evapotranspiration, (ET), and recharge are difficult to measure;
- there are multiple methodologies and the methodologies themselves have inherent error; and,
- the uncertainty is minimized with more comprehensive monitoring data.

In addition to the limitations for quantifying ET and recharge other examples with the same general limitations include:

- quantifying groundwater discharge both reach-specific (spot baseflow) and basin wide;
- determining and quantifying the spatial variability of hydrostratigraphic parameters (i.e. hydraulic conductivity); and,
- quantifying flow in fractured rock.

Although these types of limitations appear to challenge obtaining a confident understanding, the use of robust numerical models with an appropriate level of monitoring data to calibrate the models provides a high level of confidence. The modelling methodology also incorporates the following for more accuracy:

- a sensitivity analysis on each of the hydraulic parameters, to determine the most sensitive parameters and refine data collection and/or monitoring programs accordingly;
- follow-up monitoring on predicted impacts, to validate or refine the model; and,
- on-going incorporation of state-of-the-art research.

Aside from the relationship of these abiotic limitations specifically related to groundwater the limitations in quantifying the aquatic and terrestrial communities comes into play when considering ecosystem impacts. The limitations are not just confined to the component specific methodologies (i.e. quantifying fish populations) but the complex interdependence of the abiotic and biotic systems. For example the hydrogeologic community may be able to quantify modifications to the groundwater discharge to a stream due to a land use change but the subsequent impact to fish populations is not an exact science. **The quantification of an ecological reserve of water is a major issue for the scientific community as well as resource managers.** Any follow-up monitoring to assess the impact would have to include all the other abiotic and biotic factors affecting fish populations. This also raises the issue of scale as the biotic scale for assessment may not coincide with the groundwater scale, both spatially and temporally.

Another issue, with respect to impact assessment, is the concept of cumulative effects. Cumulative effects, as related to groundwater and functional linkages, would encompass the overall change to a larger scale groundwater flow system due to smaller changes on a local scale. Aside from the combined impacts on groundwater quantity for anthropogenic use, the functional linkage and potential impacts on the ecosystem can also be significant. When considering ecosystem aspects, the following abstract from Sidle, 1991 provides context:

"The concept of cumulative effects encompasses a broader spectrum of resources and land uses than has typically been evaluated in research. As management pressures in large drainage basins intensify, pristine areas may be subjected to multiple human activities. These activities are distributed through time and space, and their effects can occur at the location of a particular land use or away from the location. Even though individual land uses my not significantly degrade environmental components such as soil productivity, water quality, or aquatic habitat, the combined effects of several activities may be unacceptable. Theoretically, cumulative effects of land management may also provide benefits to portions of ecosystems, such as increased stream productivity generated by nutrient inputs. Cumulative effects of land management must also be evaluated within the context of natural processes and events, such as large storms, wildfire, geochemical weathering, and vegetation succession."

This again focuses on the importance of the following, related to characterization and protection:

- the interdependence of biotic and abiotic ecosystem components (i.e. not solely groundwater specific);
- the temporal and spatial scale relating to assessment and protection (not solely moraine specific); and,
- the extent of monitoring.

7.3 SUMMARY OF THE STATE OF KNOWLEDGE OF THE WATERLOO MORAINE

Prior to providing specific comments or discussing the state of data/knowledge related to the Waterloo Moraine the following general comments are presented:

- The Waterloo Moraine has provided much of the water supply to cities of Kitchener and Waterloo for over a hundred years resulting in an accumulation of a considerable volume of information.

- The Waterloo Moraine is located in one major watershed, the Grand River watershed, and drains towards one regional lake basin.
- It is located almost entirely within a single Tier 1 municipality, the Region of Waterloo. The Region manages the entire regional municipal water supply system and has responsibility over existing municipal water supply wells, assessment of new water supplies and monitoring programs, with respect to permitted municipal water taking within the Waterloo Moraine.
- Research level studies have been conducted throughout the Waterloo Moraine for about 35 years, including water resource assessment, hydrogeology investigations, Quaternary geology studies and ecological assessments.
- Groundwater contamination problems almost 20 years ago, at a well field outside of the Waterloo Moraine, resulted in the Region of Waterloo being one of the first municipalities in the country to develop a water resources protection strategy. An increased the level of study and understanding of the hydrogeology throughout the Region and in particular in the Waterloo Moraine. This protection strategy has recently been updated (2008).
- The Region of Waterloo has the most comprehensive data set of subsurface information anywhere in the province.
- Requirements of watershed studies and subwatershed studies in areas of existing and future development has provided a refined level of understanding of local water-related ecological features.
- There has been, and continues to be, on-going collaborative research of the Waterloo Moraine with the Region of Waterloo, the University of Waterloo, the OGS, the GSC and the GRCA.
- There is currently a Tier 3 Water Budget and Water Quantity Risk Assessment, being conducted on a subwatershed grouped basis, within the general area of the Waterloo Moraine and includes most of the major municipal well fields in the Region of Waterloo.

The following sections summarize our interpretation of the current state of knowledge of the Waterloo Moraine. The discussion is divided into the general headings previously used Section 5 and described in the general objectives of this study.

7.3.1 Waterloo Moraine Boundary

One of the objectives of the current hydrogeology review was to examine boundary issues associated with the Waterloo Moraine. This review was not meant to investigate all the interpretations and provide our own interpretation, but rather examine the interpretations and the possible implications of differing interpretations, with respect to protection of water-related features within the Waterloo Moraine.

Comments on the State of Knowledge

- It is recognized that the history of deposition and the depositional environment of features such as moraines make it difficult to draw a definitive boundary, outlining such features on a map.
- Previously interpreted boundaries of the Waterloo Moraine, as discussed in Section 5.2, are not substantially different. The variations are related to the use of mapped boundaries that included hummocky terrain and ice-contact sand, and the inclusions of some of the fringe areas that have been mapped as part of the Macton Moraine, found west of the Waterloo Moraine, but were considered part of the Waterloo Moraine on some mapping.

- The Region has chosen a combination of the two approaches; mapped hummocky terrain areas, and areas classified by Karrow, 1993 as the Waterloo Moraine, within these hummocky areas. The areas of the Waterloo Moraine that are not included within the Region's boundary are primarily hummocky areas that Karrow has interpreted as the Macton Moraine, found to the west of the Waterloo Moraine.
- The areas not included in the Region's mapped boundary are primarily on the fringe of the western or north western boundary of the Waterloo Moraine, away from any development pressure. The surficial geology of these areas is mapped as silty clay till. These areas provide limited recharge capability and would be interpreted as having a low sensitivity or importance to the overall function of the moraine.
- Recent investigations by the OGS have presented the possibility that the Waterloo Moraine may extend farther south than previously interpreted. Much of the area that the OGS is interpreting as potentially being part of the Waterloo Moraine is mapped as kame and outwash sands or gravels; and is interpreted as potentially providing substantial recharge. The moraine within this area is interpreted to be partially buried by younger, high permeability Grand River outwash deposits.

Comments on Data or Knowledge Gaps

- As a general comment, defining the actual "boundary" of a moraine would be considered a knowledge gap, if specific measures were to be developed to protect an entire moraine landform. There does not appear to be a consistent methodology that can be used to determine the boundary of a moraine. This was evident in the development of the Oak Ridges Moraine Conservation Plan (ORMCP), where it took years to determine the "boundary" of the moraine that would fall under the ORMCP. Eventually a specified topographic elevation was chosen, which was not based on the geological interpretation of distribution of the Oak Ridges Moraine sediments.
- Although the exact interpretation of the Waterloo Moraine boundary could be considered a data gap, it is not interpreted as a knowledge gap given the limited significance, from a recharge perspective, of the areas potentially in dispute. Any ecological features associated with these areas, primarily along the western boundary of the Waterloo Moraine, do not appear to be directly linked to the areas of significant hydrologic functions within the Waterloo Moraine.
- The area where the OGS is potentially extending their interpretation of the Waterloo Moraine could be considered a knowledge gap. However, most if not all of this area is part of the Region's Environmentally Sensitive Landscape (ESL). It is intention of this designation to protect natural heritage, ecological features and water-related hydrologic features and functions within this area.

Conclusions

- It is not necessary to determine the "boundary" of the Waterloo Moraine, related to groundwater protection or the protection of hydrologic functions. Although there may be areas of the Waterloo Moraine that provide important hydrologic functions, any functionally significant features should already be known or will be further refined through additional studies independent of the moraine boundary.
- It is our interpretation that the boundary of the Waterloo Moraine is not considered an issue, with respect to the protection of hydrologic functions, as the areas where there are varying boundary interpretations appear to have limited water-related functions. If ecological features do exist in these areas, these features will be subject to existing Regional and Provincial policies. Where the OGS has identified the possibility that there could be a re-interpretation of the extent of the

Waterloo Moraine to the south, it is noted that this area is currently protected through the Region's ESL policy, with respect to ecological and water-related functions.

7.3.2 Geology and Hydrogeology

The geology and hydrogeology of the Waterloo Moraine has been investigated at varying scales and with various investigative techniques since the mid-1970s. There have been two approaches to attempt to refine the understanding of the Waterloo Moraine: a) from a water resources and groundwater flow perspective; and b), from a Quaternary geology perspective. Since the early 1990's, these two approaches have been combined to try to provide a more definitive interpretation of the physical features of the Waterloo Moraine. With the advent of source water protection in the Province of Ontario over the last five years more extensive investigations have been conducted through partnerships with the Ontario Geological Survey (OGS), the Geological Survey of Canada (GSC), the Region of Waterloo and the University of Waterloo and the Grand River Conservation Authority. The following summarizes our current understanding of the state of knowledge of the geology and hydrogeology of the Waterloo Moraine.

Comments on the State of Knowledge

- The Waterloo Moraine is a complex geologic structure and the general area defined as the Waterloo Moraine has been interpreted to consist of three major aquifers and a number of low hydraulic conductivity till units separating the aquifers. Conceptual hydrostratigraphic and hydrogeologic models have been developed for the Waterloo Moraine area and continue to be refined with new data, data mining techniques and analysis tools.
- The Region of Waterloo has the most comprehensive set of subsurface information in the province.
- The connection between the well fields, aquifer systems and Quaternary stratigraphy is generally understood on a broad-scale. The internal structure is not fully understood at a local or detailed scale, but research is ongoing.
- A three-dimensional model of Quaternary deposits in the Region of Waterloo has been recently developed by the OGS. There is the potential for updates and reinterpretations of the subsurface geology using new Digital Elevation Models (DEMs), recent borehole information and the latest upgrades to the Aquifer Mapping System utilized by the OGS.
- Three-dimensional groundwater flow models have been developed and continue to be refined as new data become available or as new geological interpretations are developed. Refinements to the hydrogeological interpretation are currently being conducted for much of the area of the Waterloo Moraine, as part of a Tier 3 Water Budget and Water Quantity Risk Assessment by the Region of Waterloo.
- In well fields where there have been groundwater contamination issues, extensive studies have been conducted to determine the source and pathway of contaminant migration in the groundwater system.

Comments on Data or Knowledge Gaps

- In a complex geologic setting such as the Waterloo Moraine, the understanding of the geology and hydrogeology can always be refined. There is presently a good understanding of the broad interpretation of the geology and hydrogeology of the Waterloo Moraine. Refinements to the geologic and hydrogeologic models will continue as new information becomes available and new analysis tools are developed.

Conclusions

- There is a sufficient understanding of the geology and hydrostratigraphy of the Waterloo Moraine. Although there are areas where data gaps exist and knowledge of the Waterloo Moraine can be further refined, it is concluded that the intent of the existing policies and current approach to technical studies are sufficient to refine the knowledge and understanding of the Waterloo Moraine.

7.3.3 Functions of the Waterloo Moraine

The Waterloo Moraine is an important feature within Region of Waterloo and the Grand River watershed as it provides substantial volumes of water to maintain water supplies within the Region and provides water to maintain wetlands and baseflow to numerous creeks originating on the moraine. It also provides more regional baseflow through discharge to the Grand River. The following summarizes the state of knowledge of the functions of the Waterloo Moraine.

Recharge and Storage

Comments on the State of Knowledge

- The main recharge area to the municipal well fields within the Waterloo Moraine area has been identified and designated by the Region of Waterloo as a major recharge area.
- Much of the main recharge area is outside the existing and future designated urban areas of Kitchener and Waterloo.
- The recharge rates have been generally quantified through an integrated surface water and groundwater flow model. The GRCA has conducted extensive hydrological response modelling (GAWSER) of the Grand River watershed using surficial geology, and detailed Digital Elevation Models (DEMs), to determine local closed depressions and slopes. High recharge rates were predicted for much of the western portion of the Waterloo Moraine, as high as 500 mm in some areas. The high recharge area generally correlates with the Region's designated recharge area.
- The core area of the Waterloo Moraine contains an extensive thickness of sand and gravel, both above and below the water table. The large unsaturated zone creates the ability to store large quantities of water, beyond the recharge capacity of the natural infiltration. The Region of Waterloo is currently utilizing a portion of the unsaturated zone for aquifer storage and recovery (ASR), by storing treated river water for re-use later as part of the municipal water supply.

Comments on Data or Knowledge Gaps

- The major recharge area within the Waterloo Moraine has been defined but there is the potential for local areas of significant recharge to exist, which may not be part of the major recharge area supplying water to the Regional municipal well fields. There could be local "windows" in low permeability geologic units that allow greater recharge at some locations. Recharge areas that supply water-related ecological features are not specifically defined or mapped at a Regional scale. This is typically done at a local watershed or subwatershed scale study.
- The GAWSER modelling has elements of uncertainty based on the scale and accuracy of characterization of such things as surficial soils, local topography and local stream flow estimates.

The integrated modelling does allow for a "reasonableness" check on some of the water balance parameters but this is again a function of scale. These types of errors are inherent in all recharge assessments.

Conclusions

- The main recharge area within the Waterloo Moraine, which provides water to most of well fields within the Waterloo Moraine, is reasonably well mapped.
- Additional recharge areas, providing water to water-related ecological features and baseflow to the Grand River, are not specifically protected through the Region's Water Resources Protection Strategy. However, other current policies (e.g. PPS, 2005), if implemented properly, should provide adequate protection for these recharge areas through an appropriate assessment of the understanding and protection of sensitive water-related features. Guidance on the implementation of the PPS, related to the protection of sensitive water-related ecological features, would assist in developing a consistent approach to the interpretation of the PPS. It is noted that this is beyond the scope of this work but would in any landscape. Appropriate scale investigations, conducted at an appropriate time in the planning process (e.g. the subwatershed planning stage and refinement beyond the subwatershed level), is important for the protection of sensitive water-related features.

Water Supply

The Waterloo Moraine aquifer system provides the majority of the water supply to the cities of Kitchener and Waterloo through the Region of Waterloo's integrated urban system (IUS) of water supply. Currently there are 10 well fields in operation within the area of the Waterloo Moraine. Seven of the well fields are located within the urban areas of Kitchener and Waterloo, while the other three well fields are located in the core of the Waterloo Moraine, west of the urban areas. Water supply wells within the area of the Waterloo Moraine also supply private wells and towns and villages in the western portion of the Region of Waterloo.

Comments on the State of Knowledge

- As part of the Region of Waterloo's Water Supply Strategy Update (RMOW, 2007), present and short term future water supplies have been assessed. For each of the municipal water supplies three values are assigned: maximum source capacity, maximum summer sustainable capacity and short term peaking capacity. All well fields within the area of the Waterloo Moraine have been assessed.
- New short term future water supplies (next five years) are currently being assessed within the IUS area, including three areas within the Waterloo Moraine.
- Capture zones have been developed for all wells or well fields within the area of the Waterloo Moraine.
- An extensive water monitoring program (groundwater and surface water) is conducted, both within the local area of each well field and more broadly across the Waterloo Moraine, to ensure that hydrologic-related impacts are minimized as a result of water taking.

Comments on Data or Knowledge Gaps

- The extent of additional water that could be taken from the Waterloo Moraine aquifer system is generally well defined. There is the potential for new sources or additional water taking from existing sources within the Waterloo Moraine and these are currently being explored as part of a Regional IUS optimization and expansion project.

- The majority of the Waterloo Moraine is within an area that is currently being assessed as part of a Tier 3 Water Budget and Water Quantity Risk Assessment. The study will refine the water budget and water quantity risk for the areas currently interpreted as being moderately stressed within the Region of Waterloo. This study is expected to be completed in 2010.

Conclusions

- Based on the state of knowledge of the water supply system, current legislation governing water taking and updated Regional policies (Water Resources Protection Master Plan, January, 2008) it is concluded that municipal water supply within the Waterloo Moraine is generally well-protected. However, a more complete assessment of water quantity is currently being conducted as part of a Tier 3 Water Budget Assessment.

Maintenance of Water Related Ecological Features

Comments on the State of Knowledge

- The Waterloo Moraine maintains many water-related ecological features, especially in the core area of the Moraine (i.e. the main recharge area).
- Over 70 Provincially Significant Wetlands (PSW's) have been mapped within the boundary of the Waterloo Moraine. Most of the wetlands are located within or adjacent to the upper reaches of the Laurel Creek subwatershed. The direct linkage between groundwater and surface water is not fully defined throughout some of this area; however the hydrologic functions of the area are protected through the Region's Environmentally Sensitive Landscape (ESL). Extensive studies have been carried out within the Laurel Creek subwatershed. The wetlands in the downgradient portion of the subwatershed are driven primarily by discharge but wetlands in the upper areas may be depressional features (i.e. hummocky terrain) collecting surface runoff, or they may be sustained by local groundwater discharge.
- The Strasburg Creek subwatershed also contains some PSW's. The Waterloo Moraine provides water to these PSW's. A subwatershed study has been conducted to refine the understanding of the hydrologic regime.
- Cold water fisheries and spawning areas have been mapped throughout the area of the Waterloo Moraine. The main recharge area provides baseflow to many coldwater streams whose headwaters originate in the main recharge area of the Waterloo Moraine, in particular Alder Creek, Hunsberger Creek, Bamberg Creek and Laurel Creek. Cold water fisheries have also been mapped along the eastern flank of the Moraine in Schneider Creek and Strasburg Creek. All of these creeks have been studied as part of subwatershed studies or water taking assessments, with the exception of Bamberg Creek, which is only partially in the Waterloo Moraine and is far removed from urban development pressure.
- Many of the water-related ecological features are located outside the urban area. There are several areas within the urban boundaries of Kitchener and Waterloo where water related ecological features exist. In these areas more detailed studies have been conducted or are ongoing (e.g. the lower portion of Laurel Creek, Schneider Creek and Strasburg Creek).

Comments on Data or Knowledge Gaps

- There appears to be a good understanding of the water-related ecological features in the Waterloo Moraine at a subwatershed scale. The local linkage between groundwater and the ecological features may not be well defined at a very local scale. There may be local knowledge gaps in site-specific areas, especially in southwest Kitchener, where development pressure is great and there may be data gaps due to timing of studies being conducted relative to the timing of potential land use changes. One of the key areas, the headwaters area of Laurel Creek, has many Provincially Significant Wetlands; however this area is now part of a larger area designated by the Region as an Environmentally Sensitive Landscape (ESL).

Conclusions

- There is generally sufficient information available to show where water-related ecological features exist. At a local scale the actual linkage between the groundwater and specific ecological features may not be fully defined and this is assessed through local subwatershed studies. Typically, through existing policies, additional site-specific environmental impact studies are required in these areas prior to development. There may be an issue in some areas, with respect to the timing of data collection and assessment of local site-specific features, relative to the development of conceptual land use designations and/or constraints.

7.3.4 **Water Quantity/ Water Budget**

Comments on the State of Knowledge

- Current monitoring of water levels throughout the Waterloo Moraine has not shown an overall decline due to water taking over the last 15 years. Historical impacts from the initial pumping from the older well fields (prior to 1970) are not well documented, but suggest there may have been a local decline in water levels of 5 -10 m in some areas, during the early operation of some of the well fields.
- Monitoring of water levels during pumping and well field shutdowns have provided a reasonable understanding of capture areas, sustainability of individual well fields and potential stresses due to pumping, on a local scale.
- Water budget and water quantity risk assessments have been conducted for throughout the Grand River watershed as part of Source Protection studies. Results of the Tier 1 assessment indicated a potential area of stress in the Region of Waterloo, covering a larger subwatershed grouping in which the Waterloo Moraine is located.
- A more detailed water budget assessment was conducted as part of the Tier 2 Water Budget and Water Quantity Risk Assessment. The assessment further subdivided the Region into five subwatershed groupings, with the Waterloo Moraine primarily in two main groupings. One of the subwatershed groupings, which included the eastern portion of the Waterloo Moraine, showed the potential for a moderate level of stress in the Tier 2 study. A Tier 3 water budget and water quantity risk assessment is presently being carried out for this area.

Comments on Data or Knowledge Gaps

- The water budget and water quantity risk assessments are not “moraine-specific” but have been carried out on a broader watershed/subwatershed scale. This could be interpreted as a data gap however the broader scale studies have encompassed the Waterloo Moraine. Current Tier 3 Water Budget Assessments are assessing areas with the Region that are considered stressed, from the findings of the Tier 2 study.

Conclusions

- There is a general understanding of water quantity and water budget within the Waterloo Moraine. A portion of the Waterloo Moraine has been identified as being moderately stressed. Detailed Tier 3 studies are underway to refine the water quantity assessment and water budget in areas of the Waterloo Moraine that have been identified as being under moderate stress. These studies will be completed in 2010.

7.3.5 Water Quality

Comments on the State of Knowledge

- Water quality monitoring has been conducted at most well fields within the Waterloo Moraine for decades. The Region of Waterloo implemented a formal water quality monitoring program throughout the Region in the mid-1990s. A water quality monitoring program for monitoring wells within the capture area of the well fields and general areas outside the well fields has been in place since 1999.

- There has been an increase in sodium and chloride concentrations in a number of the urban well fields since the 1960s, as a result of decades of road salt application on roads, sidewalks and parking lots. Several wells within some of the older well fields (in particular the Greenbrook and William Street well fields) have sodium and chloride concentrations exceeding recommended drinking water guidelines. The sodium and chloride loading is likely a combination of broad scale migration of road salt impacted water moving downward through the regional aquifer-aquitard system and local migration through “windows” in some of the aquitard units

- Nitrate concentrations are elevated in several of the municipal wells in the Waterloo Moraine, located in the rural area west of Kitchener. This is a result of decades of nitrate loadings in agricultural areas. Water for these wells is obtained from “Aquifer 1” in these areas and there is limited natural protection of this aquifer at ground surface. Several of the local well fields supplying rural municipalities west of Kitchener and Waterloo also have elevated nitrate concentrations and some of the wells are currently not operational. There is a “stratification” of nitrate concentrations in the upper portion of Aquifer 1 in some areas. As a result, the rate of water taking in some wells is managed in order to minimize the increase in nitrate concentration at depth in the aquifer.

- Several well fields have experienced local site-specific industrial contamination as a result of historical industrial development and practices, in particular the Greenbrook well field and to a lesser extent the William Street well field. Although there appears to be considerable natural protection, it is likely that there are local “windows” in the aquitard units that have allowed the migration of contaminants to depth. The contaminant sources are from old industrial sites. These well fields also have the high sodium and chloride concentrations.

- As part of the Region’s source water protection program, the Region has developed well head protection areas, delineated vulnerable areas, and compiled a threats inventory database and a list of threats within well head protections areas. The Region has also developed a risk management program to rank potential risks and developed a risk reduction program within the wellhead protection areas.

Comments on Data or Knowledge Gaps

- There is a general understanding of the broader water quality issues. There are data gaps in understanding the distribution of contaminants in the groundwater, for both point source and non-point source contaminants. This is expected in any large-scale water quality monitoring program, where there are many potential sources of contamination from various land use activities.

- Numerous investigations have been conducted in areas of industrial contamination at local well fields; however in some cases an understanding of the contaminant source and distribution has not been fully determined. Studies are on-going in these areas.
- Pilot studies have been undertaken by the Region, including: nitrate reduction strategies within a well head protection area where nitrates are elevated; and, conducting road salt management and chloride reduction studies.

Conclusions

- There are data gaps, as would be expected in any water quality monitoring program at this scale. The data continues to be collected and refined as part of routine monitoring programs and site-specific investigations. Without a detailed assessment of all of the water quality data available it would be difficult to determine if more should be done, however this is beyond the scope of this report. The Region has implemented a number of new initiatives such as: the Rural Water Quality Program; land management and financial incentives in the area of a rural water supply well with elevated nitrates; a salt reduction program throughout the Region; and, prioritization of high risk threats within well head protection areas to reduce risks to water quality.

7.4 SUMMARY OF THE STATE OF KNOWLEDGE OF THE PARIS/ GALT MORAINES

7.4.1 Paris/ Galt Moraine Boundary

As with the Waterloo Moraine boundary one of the objectives of the study was to consider the limits of the Paris and Galt Moraine. The Waterloo Moraine boundary has been discussed in some detail because of its history. This review was not meant to investigate the current mapping provided by the MOE or to provide our own interpretation, but rather examine the interpretations and the possible implications of differing interpretations with respect to protection of water-related features within Paris/ Galt Moraine.

Comments on the State of the Knowledge

- The Paris and Galt Moraines have been historically assessed within a simple physiographic framework (i.e. Chapman and Putnam, 1984) without any significant concern for their exact boundaries. Within a hydrogeological context its associated hummocky nature and the sandy characteristic of the Wentworth Till has been dominant. Inclusions of permeable kame deposits are common.
- There was no documentation during the current review that expressed concern related to defining the boundary of either the Paris or Galt Moraine.

Comments on Data or Knowledge Gaps

- As a general comment, defining the actual boundary of a moraine would be considered a knowledge gap, if specific measures were to be developed to protect a moraine. There does not appear to be a consistent methodology that can be used to determine the boundary of a moraine. This was evident in the development of the Oak Ridges Moraine Conservation Plan (ORMCP), where it took years to determine the "boundary" of the moraine that would fall under the ORMCP.
- Some discussion has centred on the buried nature of these moraines, in some areas along their extent. This raises the question of the significant functionality of determining the extent of the

buried moraine and whether any practical level of effort (i.e. drilling, geophysical mapping) could delineate a boundary.

Conclusions

- It is not considered necessary to determine the boundary of the Paris/ Galt Moraines, related to groundwater protection or the protection of hydrologic functions. Any functionally significant features should be known or determined independent of the moraine boundary when various studies are carried out.

7.4.2 Geology and Hydrostratigraphy

Comments on the State of the Knowledge

- The general geology and stratigraphy are presented within the Quaternary geology reports. Watershed and subwatershed studies and more recent groundwater protection and source protection studies provide hydrostratigraphic interpretation and hydrostratigraphic cross-sections in limited geographical areas.
- Recent drilling by the OGS has refined the stratigraphic structure and interpretation in the Oakland/Glen Morris area.

Comments on Data or Knowledge Gaps

- The detailed geology and hydrostratigraphy of the Paris and Galt Moraines has not been extensively investigated. Again, detailed investigations have historically been conducted where land use changes or groundwater taking has already occurred. Detailed geologic investigations over the total extent of the Paris/ Galt Moraines have also not occurred.
- The complex nature of the internal and associated deposits makes it inherently difficult to quantify the stratigraphy given the amount of investigative drilling that would have to be carried out along the length of these moraines.

Conclusions

- A more detailed characterization of the geology and hydrostratigraphy should be carried out within and adjacent to areas being considered for future development (refer to Section 7.1.2). These more local characterization studies should take into account the larger scale interpretation and incorporate the new information into refining the larger scale characterization.

7.4.3 Significant Functions of the Paris and Galt Moraines

Recharge and Storage

Comments on the State of the Knowledge

- The characterization of recharge along the length of the moraines system varies depending on the scale of the studies carried out. The watershed studies and Tier 2 source protection studies have characterized the level of recharge in some detail. The subwatershed studies in various areas, particularly northerly along the moraines from Cambridge through to the Caledon area usually provide a more detailed quantification of recharge particularly if spot baseflow measurements and surface water modelling are integrated.

- The storage aspect has been discussed within the context of private wells, specific capacities and the expected discontinuous nature of the permeable sand and gravel lenses within the core of the moraines. The storage aspect is limited for major supplies but may be significant for private water supplies and local groundwater discharge.

Comments on Data or Knowledge Gaps

- The amount of recharge which makes its way into the underlying bedrock aquifer(s) has not been quantified to any great extent.
- Recharge and storage has only been quantified to a limited extent, primarily in areas where more detailed subwatershed studies have been conducted.

Conclusions

- Recharge should be refined in areas where land use change is expected particularly where it may relate to local groundwater discharge.

Water Supply

Comments on the State of the Knowledge

- A basic understanding of private water supplies as it relates to potential aquifers is known.
- The general areas of capture for the major well fields are known and will be refined through the Tier 3 process.
- The Tier 3 process for the City of Guelph and Region of Waterloo will evaluate the sustainability of the water supply system(s) and identify potential water quantity threats to each of the municipal water supplies.

Comments on Data or Knowledge Gaps

- More significant aquifers may exist related to the Paris/ Galt Moraines. Some studies are currently being conducted by the OGS.

Conclusions

- An understanding of potential impacts from municipal water supplies and the potential impacts on municipal water supplies appears to be addressed, and where there are current stresses Tier 3 Water Budget Assessments will further refine the understanding.

Maintenance of Ecological Features

Comments on the State of the Knowledge

- The general understanding of the groundwater function to the streams and wetlands is known. The level of detail of understanding increases where there have been subwatershed studies but detailed quantification at a smaller scale should be carried out prior to development. These subwatershed studies have been carried out within three of the areas of municipal groundwater development and within the urban boundaries of Cambridge and the City of Guelph.

Comments on Data or Knowledge Gaps

- The capture zones and recharge areas which supply water for the municipal water supplies may not coincide with the overall recharge areas which may be developed within the urban boundary and as such may not be looked at in detail in the Tier 3 studies.
- The assessment and maintenance of the ecological features would generally require an understanding the recharge, groundwater flow and discharge flow paths. The maintenance would usually be necessary if there were going to be land use changes or water resource development. If these are not occurring than the issue becomes "is a detailed understanding necessary?" (refer to comments in Section 7.1.2).

Conclusions

- The most significant issue is to characterize the linkages at an appropriate scale prior to planning (refer to Section 7.1.2).
- More widespread monitoring of groundwater levels and baseflow is necessary in areas of proposed future development, regardless of whether these areas are within either moraine footprint (refer to discussions in Sections 7.1.1 and 7.1.2).

7.4.4 Water Quantity and Budget

Comments on the State of the Knowledge

- There is a lack of understanding of the localized extent of the permeable sand and gravel lenses within the Paris/ Galt Moraines as well as the distribution of potential older aquifer material that may underlie these moraines.
- The Paris/ Galt Moraines form the headwaters of the surface water divides. The moraine features are not specifically separated out during the water budget analysis except when providing estimates of recharge.
- More detailed data is limited to areas where more detailed subwatershed studies have been carried out.
- Limited groundwater monitoring along the moraine presents general water level trends which indicate seasonal variations but no significant long term changes.
- Monitoring in select areas of extensive gravel extraction does not indicate significant water level impacts.

Comments on Data or Knowledge Gaps

- Given the potentially complex and relatively discontinuous hydrostratigraphic nature of the Paris/ Galt Moraines it would require extensive monitoring and assessment to determine the overall water quantity and water budget for the entire extent of the Paris/ Galt Moraines.
- More widespread monitoring of groundwater levels and baseflow is necessary in areas connected to proposed long term development but are not necessarily moraine specific (refer to Section 7.1.2).

Conclusions

- More widespread monitoring of groundwater levels and baseflow is necessary in areas of proposed future development, regardless of whether these areas are within either moraine footprint (refer to discussion in Sections 7.1.1 and 7.1.2).

7.4.5 Water Quality

Comments on the State of the Knowledge

- The general water quality understanding described in Section 6.6 presents a more qualitative description.
- Limited water quality data shows elevated nitrate and sodium levels in localized areas. These are attributed to agriculture, septic systems and road salting.
- Potential contaminant sources were documented for the City of Guelph, Puslinch Township and the Region of Waterloo.

Comments on Data or Knowledge Gaps

- Given the discontinuous nature of permeable units within the moraines and the lack of any widespread aquifer units the issue becomes determining the most appropriate locations to monitor for groundwater quality.

Preliminary Conclusions

- In the absence of any major land use changes or water resource demand along the rest of the Paris and Galt Moraines the technical need for water quality monitoring may be limited, but can be useful in characterizing the groundwater flow system for the functions described above.

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