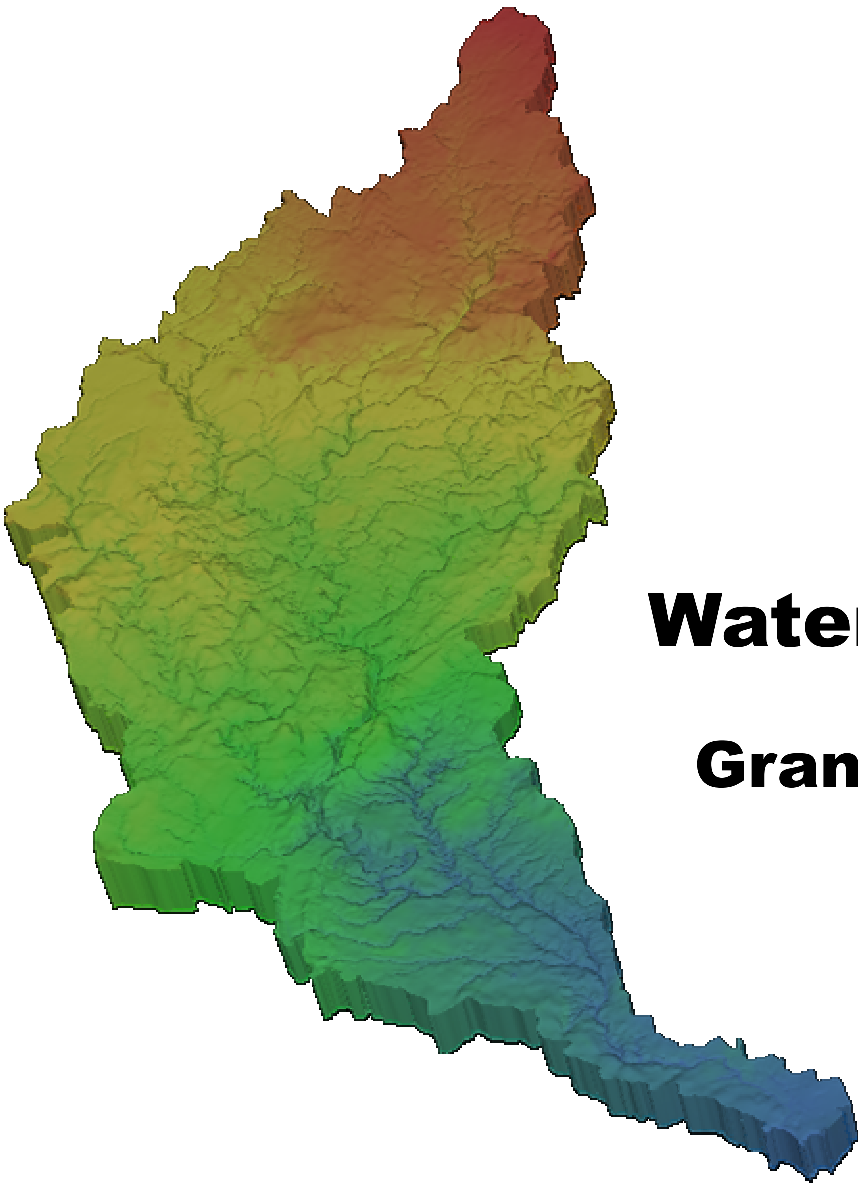
Grand River
Conservation Authority



Integrated Water Budget Report

Grand River Watershed

Final Report
June 2009

Prepared by

AquaResource Inc.
Integrity · Technology · Solutions

Executive Summary

The Grand River Watershed is approximately 6,800 km^2 in size and is home to over 900,000 residents. The population is expected to grow by 300,000 people in the next 20 years, and with this growth, there will be increased demands on the water resources of the Watershed.

Recognizing the hydrologic stresses that current and future water demands place on the Watershed, the Grand River Conservation Authority (GRCA) initiated the Water Budget Project in the mid 90's to quantify the significant components of the hydrologic cycle, including anthropogenic water takings. This document summarizes the current status and application of a water budget framework for the Grand River Watershed. This framework is based on the integration of a continuous streamflow-generation model (GAWSER) and a three-dimensional steady-state groundwater-flow model (FEFLOW) to represent the conceptual hydrology and hydrogeology conditions at a scale appropriate for subwatershed assessment. With these models in place, the GRCA is able to better characterize hydrological processes throughout the Watershed and quantify key water budget parameters.

Historically, hydrologic investigations focused on either the surface water or the groundwater perspective, with limited recognition of the inter-connectedness of the systems. In this report, modelling tools that represent both the surface water system and the groundwater system were coupled to help visualize the complete hydrologic system. Groundwater recharge values predicted by the regional continuous streamflow-generation model were used as input for the three-dimensional groundwater flow model. The groundwater flow model was then calibrated to ensure results of both models were consistent with observed conditions and consistent with one another. This resulted in a streamflow-generation model and groundwater flow model that are consistent with one another; the coupling also allowed a regional understanding of the complete hydrologic cycle to be developed.

Scope of Current Effort

The refinement of the GRCA's water budget modelling framework was carried out to support the implementation of the Province of Ontario's Clean Water Act (2006). A key focus of the legislation is the production of locally-developed, science-based source water assessment reports and protection plans. A significant component of this science-based approach is the development of a watershed-based water budget. A water budget, as described by the Province's Water Budget Guidance Document, is an understanding and accounting of the movement of surface and groundwater and the demands on that water over time.

To satisfy the full requirements of the Clean Water Act, the GRCA has also prepared a Tier 2 Subwatershed Stress Assessment Report (AquaResource, 2009b). This companion report compares existing and future water demands against surface water and groundwater supply to identify areas within the Watershed that have a potential for hydrologic stress. Municipal water systems contained within these potentially stressed areas will be subject to the requirement to complete a Tier 3 Water Quantity Risk Assessment, which evaluates the ability for the municipality to meet its planned water demands for those identified systems.

A key part of the water budget methodology is the estimation of water demand. Water demand estimates were generated by building upon previous work carried out by the GRCA (2005). The Ministry of Environment (MOE) Permits To Take Water (PTTW) database provides records of the permitted water users throughout the Watershed and is the primary source of information. This report describes the application of an irrigation model used to develop better estimates of agricultural irrigation requirements. Monthly consumptive use rates were estimated for each PTTW by applying seasonal and consumption factors to all permits; the consumptive rates are estimates of the volume of water that is not returned to the original source by each water taking operation. Wherever available, reported water taking rates were included in consumptive water demand estimates. While they are much smaller than permitted takings, non-permitted takings such as rural residential or livestock watering are also included in the water demand estimates. Water demand estimates are summarized for each subwatershed.

The integrated water budget framework for the Grand River Watershed utilizes available numerical models, specifically a continuous streamflow-generation model (GAWSER) and a three-dimensional steady-state groundwater-flow model (FEFLOW) to quantify water budget components. The two models are loosely coupled through the groundwater recharge and discharge distribution; the groundwater recharge rates predicted by GAWSER are used as input into the FEFLOW steady-state groundwater-flow model, and groundwater discharge predicted in the FEFLOW steady-state groundwater-flow model are compared against flow targets at stream gauges. This coupling helps to increase the certainty of estimated water budget parameters.

Water Demand Estimates

Water use within the Watershed was initially quantified through the Grand River Water Use Study (GRCA, 2005). This assessment built upon that knowledge by incorporating the consumptive nature of water takings into water demand estimates. Consumption considerations include spatial and scale dependence, distinguishing water takings that are simply moving water between hydrologic units and those that are removing water from the Watershed.

Actual water use information collected by GRCA for the most significant water use sectors (including municipalities) was incorporated to increase the certainty of the water use estimates wherever possible.

The estimated average annual pumping in the Watershed is 25,150 L/s. Much of this total pumping rate is not consumptive as water is returned or recycled back to the source from which it was pumped. After accounting for actual consumption, the average source specific consumptive demand is estimated to be approximately 4,900 L/s. This consumptive demand estimate refers to the water that is not returned directly to the source from which it was pumped. As an example, groundwater taken from a well that is used and discharged to a surface water feature is considered completely consumptive as the water is not returned to the groundwater aquifer from which it was taken.

The water demand assessment estimated the breakdown of consumptive water demand by sector as follows;

1. Municipal Water Supply – 53%
2. Industrial Purposes – 8%
3. Dewatering – 9%
4. Commercial Purposes – 9%
5. Agricultural Irrigation – 7%
6. Private Water Supplies – 4%
7. Livestock & Un-serviced Domestic – 5%
8. Groundwater Remediation – 3%
9. Miscellaneous – 2%

Streamflow Generation Model

The existing Grand River Watershed GAWSER continuous streamflow-generation model was used as the basis for the surface water component of this water budget study. The model reflects approximately 15 years of continuous improvement and advancement. Originally created for flood flow estimation, the investment in the model has been leveraged to provide flood forecasting capability as well as continuous water budget modelling.

The GAWSER continuous streamflow-generation model utilizes quaternary geology, land cover and topography to predict how a specific combination of the three will respond to a precipitation event. Precipitation, which is input from observed climate records, is partitioned into 3 major hydrologic components: evapotranspiration, runoff, and recharge. The model subdivides subwatersheds into smaller subcatchments and simulates streamflow hydrographs based on the hydrologic response of these subcatchments. The model is calibrated by comparing the simulated hydrographs to observed streamflow. One of the refinements in this study was to calibrate the model to monthly median and lower decile flows. This resulted in better estimates of baseflow and increased the estimated groundwater recharge rates.

While the GAWSER continuous streamflow-generation model has been developed and calibrated to represent hydrologic conditions within the Watershed, this model does not necessarily reflect all local hydrologic conditions and therefore the model may not be suitable for the assessment of site-specific hydrology.

Groundwater Flow Model

The groundwater model applied for the groundwater portion of the water budget assessment built upon earlier work completed by WHI (2005). The calibration was refined by AquaResource and Waterloo Numerical Modelling Corp (2005) and further refined through this study. The FEFLOW steady-state groundwater-flow model simulates movement of groundwater through the subsurface, and can quantify the volume of water moving between subcatchments.

The GRCA FEFLOW steady-state groundwater-flow model encompasses the entire Watershed and is comprised of 13 hydrostratigraphic units (5 overburden, 8 bedrock). The model layer structure was developed to provide a representative sub-division within the overburden, while bedrock units were more discretely delineated based on available borehole logs and known structural trends. To develop the groundwater model, estimates of hydraulic properties were based on lithologic descriptions within available borehole logs and/or conceptual understanding of the geologic/stratigraphic units. Boundary conditions applied to the model represent interaction of the subsurface with regions beyond the GRCA as well as surface water features throughout the Watershed. Additionally, the recharge input boundary for the groundwater model is directly taken from the GAWSER continuous streamflow-generation model to provide the interconnection between the two models.

Observed water levels (head) and groundwater discharge (portion of stream baseflow) were used as calibration targets in the groundwater flow model. Water level targets were selected from the MOE Water Well Information System database for the 1980-2000 period. In addition, baseflow discharge estimates at 28 locations throughout the Watershed for the 1980-2000 period were also used as calibration targets. The calibrated FEFLOW steady-state groundwater-flow model provides water budget estimates for averaged flow through the groundwater system.

Similar to the GAWSER continuous streamflow-generation model, the FEFLOW steady-state groundwater-flow model was developed and calibrated to represent regional hydrogeologic conditions within the Watershed. The model does not necessarily reflect all local conditions, and therefore the model may not be suitable for the assessment of hydrogeology at a particular site or wellfield.

Integrated Water Budget

This project represents the first time that the GAWSER continuous streamflow-generation model and FEFLOW steady-state groundwater-flow model were calibrated in an integrated fashion for the Grand River Watershed. Calibrating both models together increases the certainty relating to the magnitude and distribution of groundwater recharge. Of particular importance, the groundwater recharge conditions produced from the iterative calibration resulted in more representative simulation of median monthly surface water flows, particularly for low flow months.

The modelling tools developed for this study were calibrated to observations at the subwatershed scale and correspondingly the focus of the calibration was on large-scale features. Consequently, the models may not be equivalently valid at smaller scales where local features and processes have not been equally-well represented.

The water budget understanding that resulted from the integrated modelling has provided an enhanced understanding of flow throughout the GRCA. This understanding is documented on a subwatershed-by-subwatershed basis to support further evaluations at that scale.

Based on the regional GAWSER continuous streamflow-generation model and the FEFLOW steady-state groundwater-flow numerical models utilized within this study, a table of average watershed water budget parameters is included in Table i.

Table i - Watershed Water Budget Summary

Water Budget Parameter	Value (m^3/s)	Value (mm/y)
Precipitation	200	933
Evapotranspiration	105	491
Runoff	57	266
Recharge	38	176
Net Groundwater Discharge to Surface Water Features	33	152
Average Annual Consumptive Groundwater Demand	4	18

The Integrated Water Budget assessment presents an analysis of groundwater recharge and discharge using particle tracking techniques. The analysis demonstrates that while groundwater divides are generally consistent with surface water divides, there are some specific locations within the Watershed where they differ. As an example, groundwater flow in the vicinity of the upper and lower reaches of the Conestoga River is inconsistent with subwatershed boundaries. Three-dimensional particle tracking was also used to help visualize the paths of groundwater flow from overburden into bedrock and then as discharge into surface water. This analysis illustrated the different degrees of interaction between surface water and deeper groundwater flow in several areas of the watershed and demonstrates the effectiveness of this technique in better understanding subwatershed-scale hydrological processes.

Uncertainty Considerations

Sources of uncertainty in water budget assessments include conceptual model data and knowledge gaps, assumptions in water demand estimates, modelling assumptions and simplifications, and calibration. The water budget models presented in this report effectively represent the hydrology and hydrogeology of the Grand River at the subwatershed scale, meaning that they are shown to simulate flow out of each subwatershed consistent with observed data. The water budget models are also effective at estimating the different hydrologic and hydrogeologic responses associated with various physiographic and geologic features within the Watershed. While the models have been calibrated at the watershed-scale, the influence of uncertainty would be most significant if the models were used to evaluate local-scale conditions such as those near municipal wellfields, or the hydrologic impacts of urban development. The Watershed model may be suitable for evaluating these types of local scenarios; however, the potential implications of uncertainty should always be considered.

Table of Contents

Appendixes (Provided on CD-ROM)

List of Tables

List of Figures

1.0 Introduction

Over 900,000 residents live within the Grand River Watershed, which covers an area of approximately 6,800 km^2. The population within the Watershed is expected to grow by 300,000 over the next 20 years, and this growth is expected to increase the demands on the water resources within the Grand River Watershed.

This Integrated Water Budget report summarizes the development and application of a water budget framework for the Grand River Watershed. This framework is based on the integration of a continuous streamflow-generation model (GAWSER) and a three-dimensional steady-state groundwater-flow model (FEFLOW) to represent the conceptual hydrology and hydrogeology of the Watershed. The Grand River Conservation Authority's (GRCA) GAWSER streamflow model, initially developed in the late 1980's as a flood forecasting model, has evolved into a continuous hydrologic model calibrated to simulate the many hydrologic processes. To better represent the complex spatial distribution of groundwater flow throughout the Watershed, the Watershed's FEFLOW steady-state groundwater-flow model was developed over the past several years to integrate with the GAWSER continuous streamflow-generation model and to support the development of a complex water budget. With these models, the GRCA is able to better characterize hydrological processes above and below the ground surface throughout the Watershed, and to able to evaluate the Grand River Watershed's water budget.

This Integrated Water Budget Report has been developed to meet the requirements of the Province of Ontario's Clean Water Act (2006). The report has been revised from an earlier draft (AquaResource, 2007) as follows:

- Water Demand estimates. Agricultural irrigation water demands are modified to be consistent with the approach used in the Long Point, Catfish Creek, and Kettle Creek Tier 2 Water Budget (AquaResource, 2008). Municipal water demands have also been revised based on reported water demands;
- New content has been added to the report relating to monitoring locations in the Watershed, and in particular, Provincial Groundwater Monitoring Network (PGMN) Wells; and,
- Numerous content changes and editorial updates throughout in response to Peer Review Comments.

1.1 THE WATERSHED

The Grand River Watershed is the largest watershed in southwestern Ontario (Figure 1). Located west of the Greater Toronto Area (GTA), the Grand River begins its 310 km long journey near the village of Dundalk, in the Dundalk Highlands. The Grand River joins with its major tributaries, the Conestogo, the Speed and the Nith Rivers, as it flows by the major urban centers of Waterloo, Kitchener, Cambridge, and Brantford. The City of Guelph is another major urban centre in the Watershed, and is located at the confluence of the Speed and the Eramosa Rivers. Downstream of Brantford, the Grand River passes by the Six Nations, as well as the towns of Caledonia, Cayuga and Dunnville, before flowing into Lake Erie at Port Maitland.

The GRCA subdivided the Grand River Watershed into 7 major watershed areas and these are further subdivided into 18 subwatersheds. These watershed areas and their subwatersheds share similar geologic conditions. The subwatersheds use existing stream gauging locations as division points, and divide the Grand River Watershed at confluences of major tributaries with the main stem of the river system. Watershed areas are delineated around the larger tributaries to the Grand River and around the upper, central, and lower reaches of the Grand River itself. Table 1.1 lists the 7 watershed areas and the 18 subwatersheds, which are also all illustrated on Figure 2. This Report refers to the “Subwatershed” when one of the 18 subwatersheds is discussed, the “Watershed Area” when one of the 7 watershed areas is discussed, and the “Watershed” when the Grand River Watershed is discussed.

Much of the analysis in this water budget assessment is reported at the subwatershed scale. This scale is generally appropriate as it encompasses areas of similar hydrology and hydrogeology and areas of similar land use. As an example, the Grand Above Doon to Conestogo Subwatershed, it is largely urbanized and is underlain by till plains and the Waterloo and Galt/Paris Moraine. In contrast, the Whiteman’s Creek Subwatershed has largely agricultural land use overlying a sand plain.

Groundwater flow systems may not adhere to the surface water flow boundaries. This is particularly true of deeper, more regional groundwater flow systems that may transfer large volumes of water into or out of a subwatershed. To produce a complete characterization of groundwater resources at this subwatershed scale, numerical modelling tools were utilized to quantify groundwater movement between subwatersheds and, in some cases, between adjacent watershed areas.

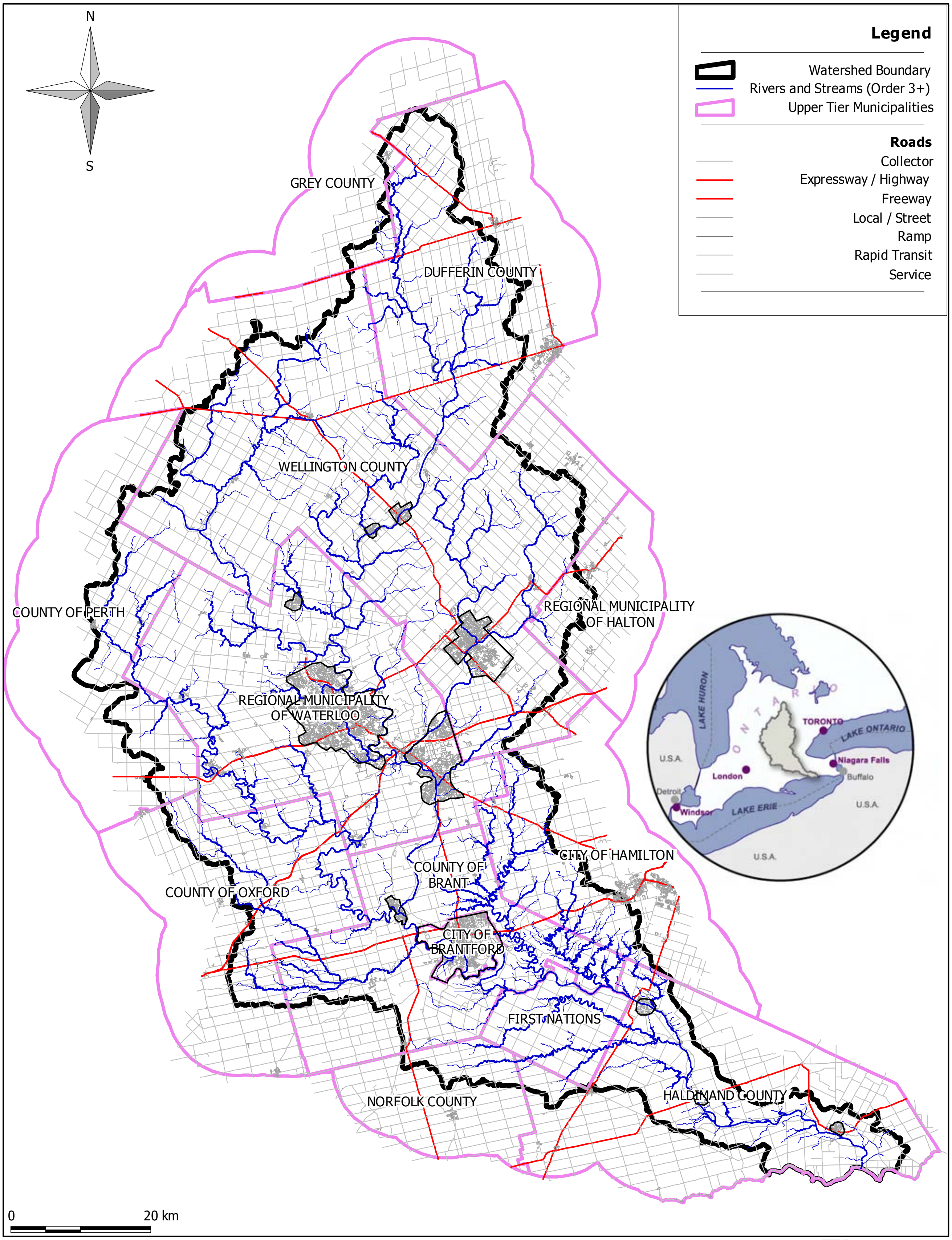


Figure 1
Watershed Base Map

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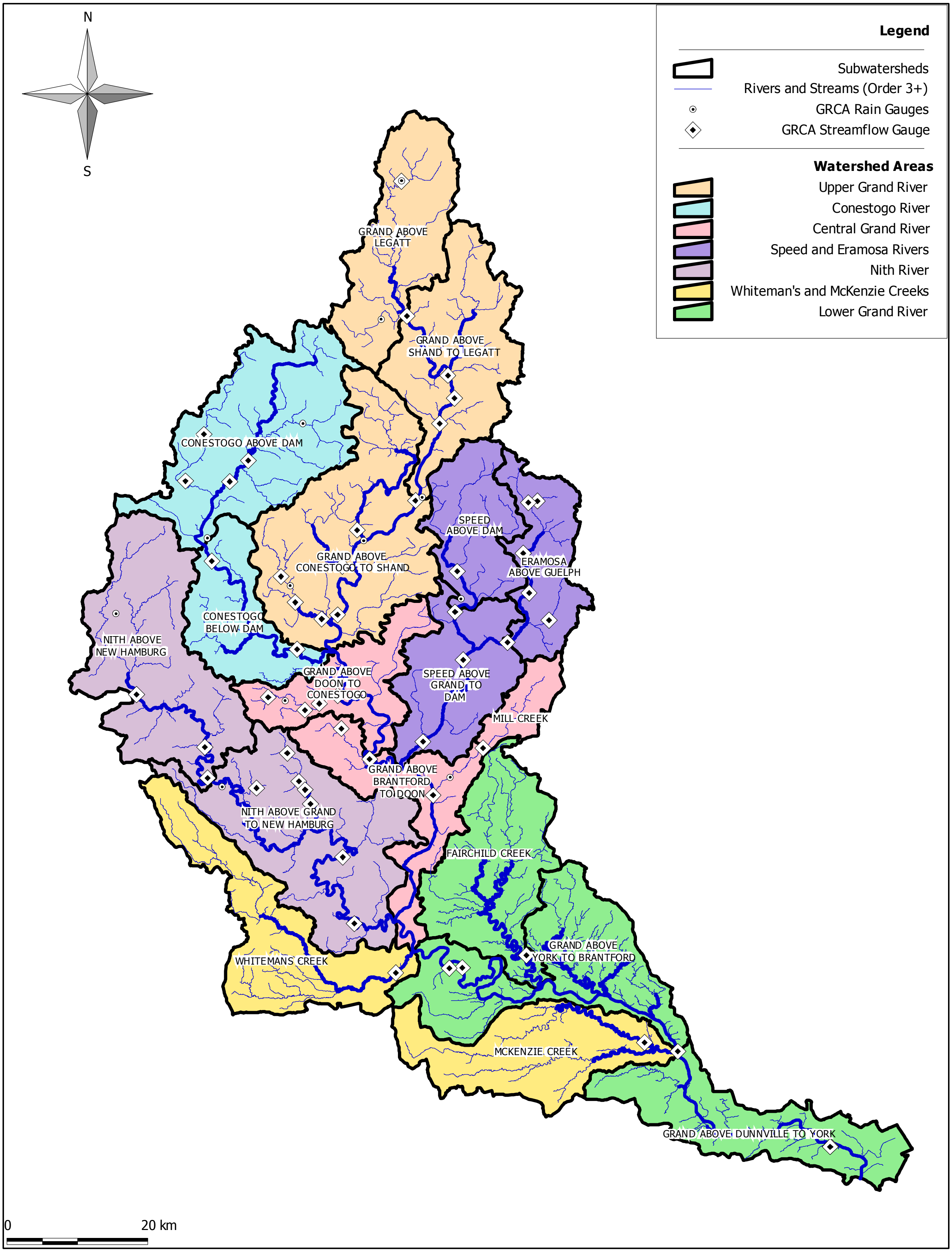

Figure 2
Subwatershed Boundaries

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Table 1.1 - Summary of the Grand River Watershed's Watersheds and Subwatersheds

Watershed Area	Subwatershed	Drainage Area (km^2)
Upper Grand River	Grand Above Legatt	365
	Grand Above Shand To Legatt	426
	Grand Above Conestogo To Shand	640
Conestogo River	Conestogo Above Dam	566
	Conestogo Below Dam	254
Central Grand River	Grand Above Doon To Conestogo	248
	Grand Above Brantford to Doon	274
	Mill Creek	82
Speed and Eramosa Rivers	Eramosa Above Guelph	230
	Speed Above Dam	242
	Speed Above Grand to Dam	308
Nith River	Nith Above New Hamburg	545
	Nith Above Grand to New Hamburg	583
Whiteman's and McKenzie Creeks	Whiteman's Creek	404
	McKenzie Creek	368
Lower Grand River	Fairchild Creek	401
	Grand Above York to Brantford	476
	Grand Above Dunnville to York	356

The predominant land cover in the Watershed is agricultural as shown in Figure 3; only 5% of the total area is considered to be urbanized.

The GRCA considers the Grand River Watershed as three general physiographic areas. These physiographic areas are summarized below and are shown on Figure 4:

1. Till Plains. The north parts of the Watershed largely consist of lower permeability till plains (Dundalk, Stratford Till Plains) with moderate to high topographic elevations;

2. Central Moraines. The central parts of the Watershed are composed of higher permeability sand and gravel kame moraines and recessional moraines (Waterloo Moraine, Paris/Galt Moraine) with moderately high topographic elevations; and

3. Clay Plains. The south part of the Watershed is characterized by low topographic elevation, low permeability lacustrine clay plains (Haldimand Clay Plain).

The above physiographic areas describe regional features and localized quaternary deposits throughout the Grand River Watershed; they may not always be consistent with local conditions. Detailed discussions relating the surficial geology to the hydrogeology in specific areas of the Watershed are provided by Holysh et al. (2001).

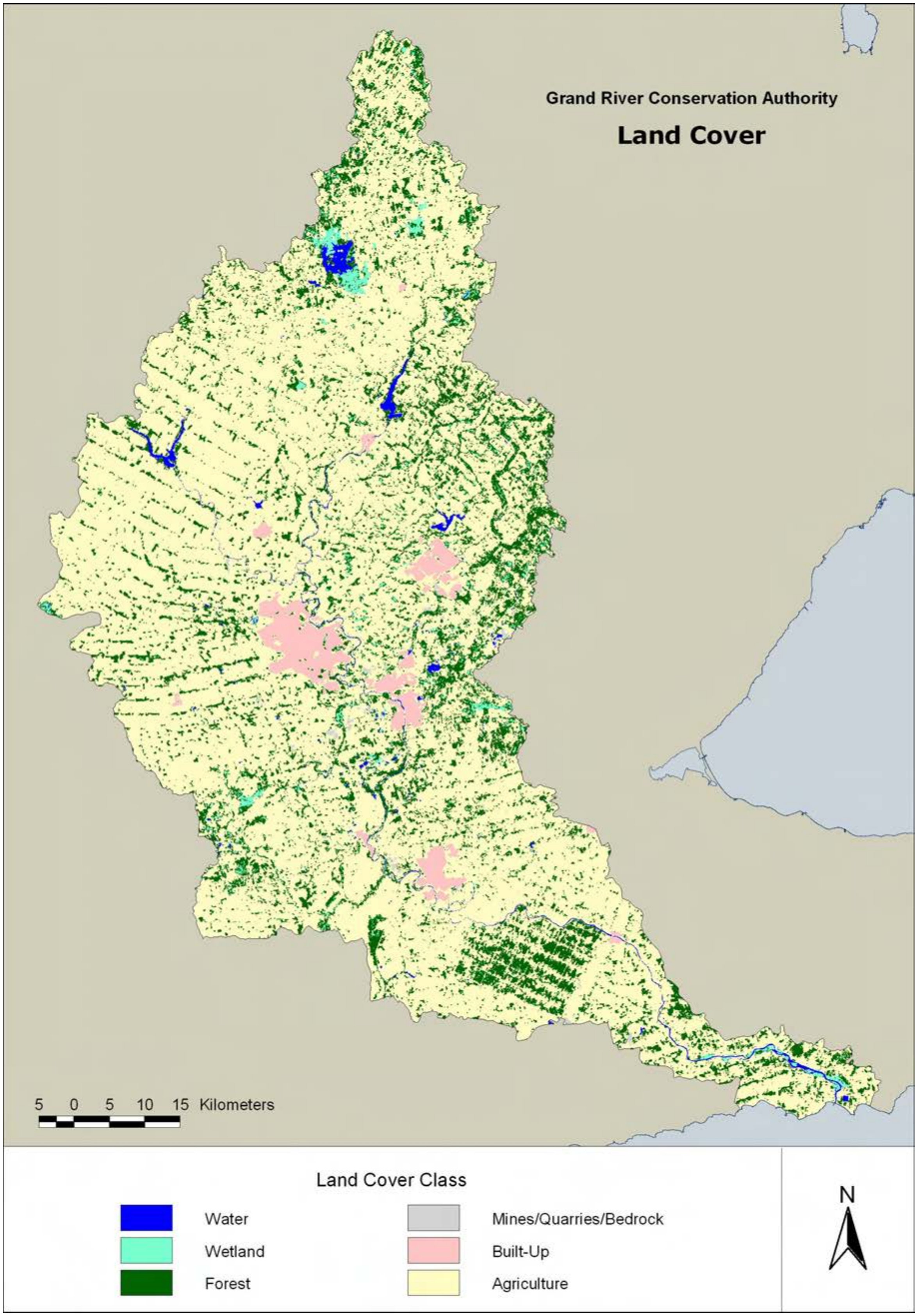

Figure 3
Land Cover

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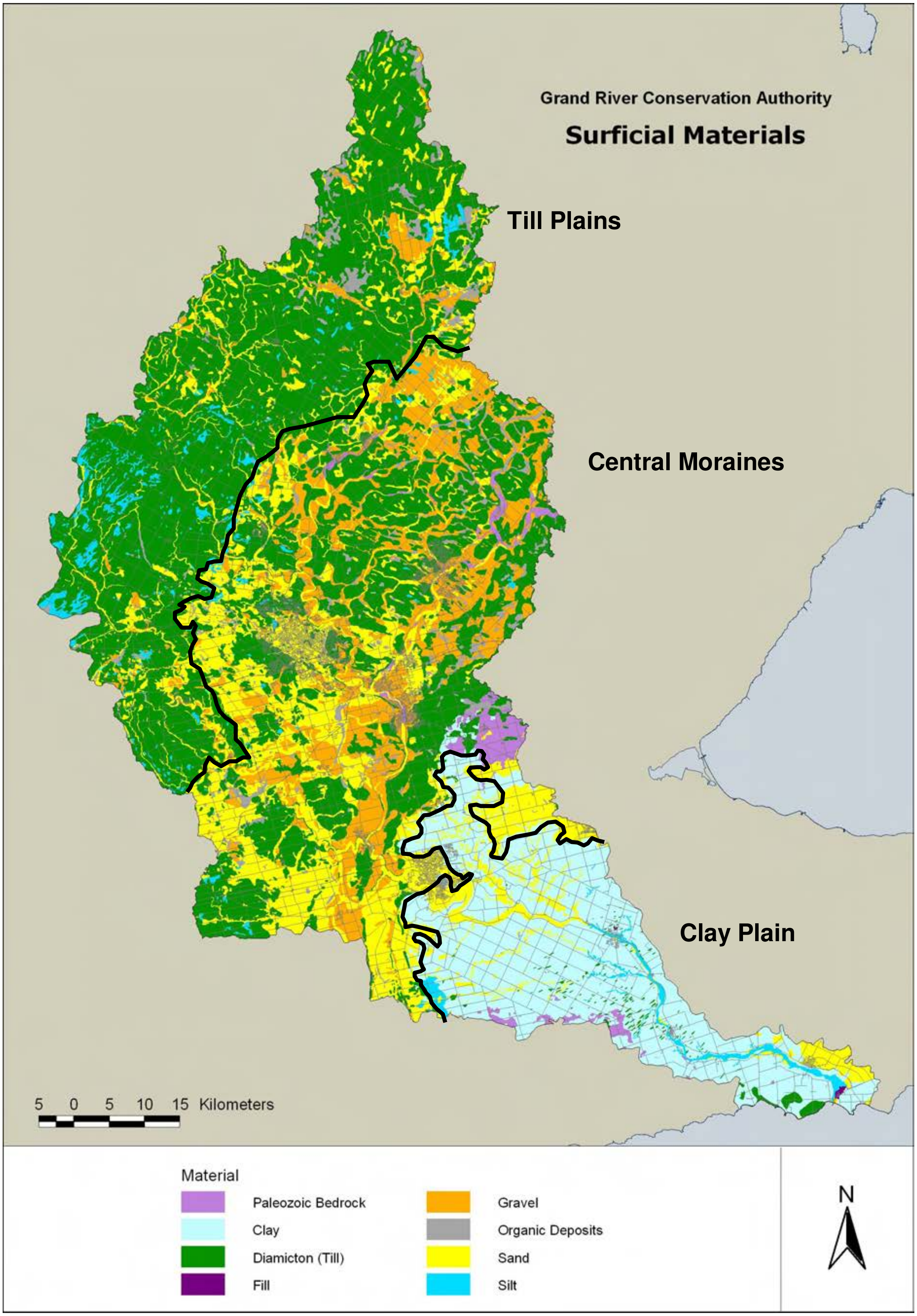

Various Authors, 1967-1993, Quaternary and Pleistocene Geology, Southern Ontario, Ontario Geological Survey. Refer to GRCA metadata.

Figure 4
Simplified Surficial Geology

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1.2 SIGNIFICANCE OF WATER USE IN THE GRAND RIVER WATERSHED

As the Grand River Watershed continues to experience both economic and population growth, there will be increased demands on the Watershed's water resources to supply sufficient water to residential, commercial, and industrial consumers. The GRCA completed an assessment of water use for the Grand River Watershed (GRCA, 2005). This assessment surveyed municipalities to obtain information on municipal water supplies, utilized Statistics Canada data to estimate rural domestic and livestock water use, and relied on PTTW data for information on private water taking operations.

The *Water Use in the Grand River Watershed* study (GRCA, 2005) estimated water use in the Watershed. This assessment included water supplied from all sources including the Great Lakes and represented the total amount of water pumped without being adjusted for consumption. The Water Use Study identified the major water use sectors in the Grand River Watershed. These sectors and their percentage of total water use are summarized in Table 1.2. These water use estimates were revised as part of this study.

Table 1.2 - Summary of Total Water Use (GRCA, 2005)

1. Municipal Water Supply – 36.9%
2. Dewatering – 16.0%
3. Aggregate Washing – 7.7%
4. Aquaculture – 5.5%
5. Remediation – 5.2%
6. Golf Courses – 3.6%
7. Livestock – 3.2%
8. Agricultural Irrigation – 3.2%
9. Other – Industrial – 3.1%
10. Miscellaneous / Other – 15.6%

Source: *Water Use in the Grand River Watershed (GRCA, 2005)*

1.3 HISTORY OF WATER BUDGET ACTIVITIES

The GRCA began their water budget modelling activities 20 years ago. The GAWSER streamflow model, initially developed to address the need for flood forecasting, was expanded to better understand the Watershed's hydrology, and to better estimate the impacts of land development.

Table 1.3 lists the major surface water modelling efforts using the GAWSER continuous streamflow-generation model within the Grand River Watershed. The table presents the contribution each of these studies made to the current water budget efforts.

Table 1.3 - Large-Scale Surface Water Modelling Studies within the Watershed

Date	Name of Study	Description
1988	Speed and Eramosa Floodplain Mapping Study	GAWSER continuous streamflow-generation model was used to supply flood flows estimates for both rain-only, snowmelt, and rain-on-snowmelt events.
1988	Grand River Hydrology Study	
1992	GRIFFS Implementation	Grand River Integrated Flood Forecasting System (GRIFFS) was constructed. It effectively 'integrated' real - time meteorological and streamflow data with the GAWSER continuous streamflow-generation model.

Date	Name of Study	Description
1992	Laurel Creek Watershed Study	Continuous simulation mode of the GAWSER continuous streamflow-generation model was created. The program was modified to produce a continuous series of flows for several years at any point of interest within a watershed. The enhancements included the addition of recharge pond modelling, flow diversions, and pipe routing for urban areas.
1996	Mill Creek Subwatershed Study	Studies involved direct land use planning options and the assignment of 'hydrologic response units'. Output from the GAWSER continuous streamflow-generation model's water balance computations were used as direct input to the groundwater flow modelling.
1996	Blair/Bechtel/Bauman Creeks Subwatershed Study	
1998	Eramosa River Watershed Hydrology Study	The study demonstrated the first use of 'recharge ponds' in a model to account for hummocky topography, a characteristic of landscapes situated on moraines.

The FEFLOW groundwater-flow model, developed in 2005 (WHI, 2005), incorporates steady-state three-dimensional groundwater flow into the water budget modelling framework. This model contributes an alternate approach to model development as part of a long history of regional groundwater modelling within the Grand River Watershed. Some of this history is presented in Table 1.4**.**

Table 1.4 - Large-Scale Groundwater Modelling Studies within the Watershed

Date	Name of Study	Description
1973	Kitchener-Waterloo Groundwater Evaluation (Dixon, 1973)	2D Groundwater Resource Assessment for Kitchener-Waterloo Area (UW Code)
1994	Middleton Street Well Field Study – (Beak Associates, Raven Beck and WHI, 1994)	Wellhead protection area model for the Region of Waterloo's wells in central Cambridge (MODFLOW)
1995 - 2000	Waterloo Moraine – (WHI, 1999)	Regional model encompassing the Waterloo Moraine and used by the Region of Waterloo for Wellhead Protection (WATFLOW)
1996	Mill Creek – (CH2M Hill, 1996a)	Subwatershed and land use modelling studies. (MODFLOW)
1996	Blair/Bechtel/Bauman Creeks Subwatershed Study (CH2M Hill, 1996b)	Subwatershed and land use modelling studies. (MODFLOW)
1998	The Study of the Hydrogeology of the Parkway Area – (Terraqua and WHI, 1998)	Wellhead protection area model for several of the Region of Waterloo's wells in Kitchener (WATFLOW)

1997	Wilmot Centre Monitoring Program (Stantec and WHI, 1999)	Nitrate plume evolution analysis in the vicinity of the Baden and Wilmot Centre wellfields (FEFLOW)
1998	Cambridge Capture Zone Modelling (Duke Engineering, 1998)	Wellhead protection area model for the Region of Waterloo's Cambridge wells (MODFLOW)
1999	Guelph / Arkell Springs Model (Gartner Lee Limited, 2003b)	Wellhead protection area model for the City of Guelph (MODFLOW)
2001	Centre Wellington Groundwater Protection Study (Terraqua and WHI, 2002)	Integrated wellhead protection area model for the Towns of Fergus and Elora (MODFLOW)
2003	Alder Creek Watershed Study (CH2M Hill and S.S. Papadopulous, 2003)	Municipal Well Capture Zone Delineation, GUDI Analysis, Groundwater / Surface water interaction along Alder Creek (MODFLOW)
2004 2005	GRCA Watershed Groundwater Model (WHI, 2005)	Watershed groundwater flow model for water budgeting (FEFLOW)
2005	Guelph-Puslinch Groundwater Study (Golder Associates, 2005)	Wellhead protection area model for the City of Guelph and Villages in Puslinch Township (FEFLOW)
On-going	Region of Waterloo IUS (WHI, In Progress)	Regional model encompassing the Waterloo Moraine and used by the Region of Waterloo for Wellhead Protection and Groundwater Management (FEFLOW) and new supply well investigations

There is a wealth of hydrogeologic knowledge in this Watershed gained from the many studies carried out by the Regional Municipality of Waterloo and the City of Guelph. Table 1.4 summarizes only a selection of these. Also contributing to this collective knowledge of the Watershed's hydrogeology is the University of Waterloo's world-leading group of groundwater researchers. The Region of Waterloo established a database of information as part of their source protection efforts beginning in the1990's. Regional groundwater investigations date back even earlier to the 1960's, when exploratory drilling was undertaken west of Kitchener-Waterloo to expand water supply capabilities. That work was built upon by the Region of Waterloo in the 1990's (Golder, 1991; CH2M Hill, 1994; Lotowater, 1997; Terraqua, 1995) and is currently being revisited (Golder, in progress).

Additional regional groundwater protection studies that have been conducted include:

- Wellington County (Terraqua and WHI, 2002; Burnside, 2001a-d; Greenland, 2001; Gartner Lee, 2003a,b; and Golder, 2006),
- Perth County (WHI, 2002)
- Dufferin County (Burnside 2001e,f)
- Brant County (Lotowater, 2001; 2005),
- Norfolk County (WHI, 2003), and
- Six Nations (Burnside, 2004).

This collective knowledge provides a solid background to build upon for water budgets. Much of the recent knowledge has been generated concurrently with the GRCA water budget model development (2002-2006).

1.4 GRCA WATER BUDGET METHODOLOGY

The GRCA developed a continuous streamflow-generation model (GAWSER) and a three-dimensional steady-state groundwater-flow model (FEFLOW). The GAWSER streamflow model, calibrated in 2002 to a long-term period of record (1961-1999) is a water budget assessment tool. The FEFLOW steady-state groundwater-flow model was developed by Waterloo Hydrogeologic, Inc (WHI, 2005) under contract to GRCA. The two models are loosely coupled; the groundwater recharge rates predicted by the GAWSER continuous streamflow-generation model are used as input into the FEFLOW steady-state groundwater-flow model, and the groundwater discharge predicted by the FEFLOW steady-state groundwater-flow model are compared against flow targets for the same stream gauges used for calibration of the GAWSER continuous streamflow-generation model. Coupling of the two models is essential to combine the predictions made by the two models into a single water budget framework.

1.4.1 Water Use Estimates

Through the Grand River Water Use Study (GRCA, 2005), the GRCA estimated water use in the Grand River Watershed. The Water Use Study incorporated data from a variety of sources, including Permits-To-Take Water (PTTW), municipal pumping information, and Statistics Canada data.

This study refines the estimated consumptive water use demand for the Grand River Watershed. While the Grand River Water Study estimated the total amount of water pumped in the Watershed, much of this water is returned to the Watershed or recycled as part of local water management practices. Using the methodology provided by the Water Budget Guidance Document (MOE, 2008), this study estimated consumptive water demand as the amount of water that is not returned to the source from which it was removed. By focusing on consumptive water demand, this study provides a better estimate of the amount of water that actually used as a proportion of the total amount of water used in the Grand River Watershed.

1.4.2 Continuous Streamflow-Generation Model (GAWSER)

The Guelph All-Weather Sequential-Events Runoff (GAWSER) streamflow-generation model is a physically based deterministic hydrologic model used to predict the total stream flow resulting from inputs of rainfall and/or snowmelt. It can operate in both continuous or event based mode. It can be used to model recharge ponds and can predict pollutant accumulation, wash off, and transport. The climate input data required for continuous modelling includes daily maximum and minimum temperatures, daily total precipitation, and hourly rainfall.

There are nine main hydrologic processes represented in the GAWSER continuous streamflow-generation model:

1. Accumulation and ablation of snow;
2. Filling and emptying of interception storage and depression storage;
3. Infiltration;

4. Filling and Depletion of Soilwater Content;
5. Evapotranspiration;
6. Runoff and Overland Flow Routing;
7. Subsurface and Baseflow Generation and Routing;
8. Channel Routing; and,
9. Reservoir Routing.

The above processes are documented in the GAWSER Training Guide and Reference Manual (see Schroeter & Associates, 2004).

Seasonal changes in model parameters (e.g. soil hydraulic conductivity) can be specified on a monthly basis or automatically shifted based on air temperature. Evapotranspiration is calculated by either specifying monthly potential evapotranspiration rates or allowing the model to generate potential evapotranspiration rates using the Linacre equation, a simplification of Penman's equation. Actual evapotranspiration is calculated as a proportion of potential with the proportion dependent on storage status and type of storage (interception, depression, soilwater).

Variability in infiltration characteristics are accounted for by conducting separate calculations within each model subcatchment for one impervious unit and up to eight pervious units with different combinations of soil and landuse. Subcatchments are smaller land areas within subwatersheds whose drainage areas contribute to smaller streams or river reaches. The Green-Ampt equation is used in the infiltration calculations allowing for the recovery of infiltration between events, and reductions in infiltration caused by high soil water conditions.

Overland runoff routing uses area/time versus time relationships, with travel time relationships based on channel rating tables developed from stream cross-section measurements. In-channel routing is completed using the Muskingum-Cunge method. Reservoir routing is handled using the Puls method with controlled releases allowed. Diversions of water flow from channels and reservoirs can be directed to other channels or to groundwater storage. The routing method is stable over a range of channel slopes, allowing the application of the GAWSER continuous streamflow-generation model in watersheds with large variations in both channel slope and geometry.

For further information on the GAWSER continuous streamflow-generation model and its application as a water management tool see GAWSER: A Versatile Tool for Water Management Planning, Schroeter et al. (2006).

1.4.3 FEFLOW Steady-State Groundwater-Flow Model

The Grand River Watershed steady-state groundwater-flow model was developed using FEFLOW and resulted in a regional scale calibrated groundwater flow model encompassing the entire Grand River Watershed. The following tasks were completed for the development of both the conceptual geological model and the hydrogeological model:

1. Acquired available datasets and the existing GRCA FEFLOW steady-state groundwater-flow model developed by WHI (2005);
2. Developed a spatially-referenced database of information on the hydrogeology of the study area and completed GIS mapping to characterize the aquifers and aquitards across the Watershed;

3. Identified regional and local boundaries for groundwater flow (e.g., groundwater / surface water divides) and developed a conceptual geological model including regional (e.g., buried valleys) and local elements (e.g., surface water features);
4. Constructed and calibrated a three-dimensional hydrogeological model based on the conceptual geological model utilizing the database information and GIS mapping. The model calibration focused on the regional scale while attempting to calibrate to existing local scale models;
5. Calibrated the model to average conditions using MOE water well records, spot baseflow measurements and baseflow estimates in area streams from a time period between 1980 and 2000.

1.4.4 Integrated Water Budget

In a watershed, such as the Grand River Watershed, where surface/groundwater interactions are significant, a combined use of surface water and groundwater flow models contribute to a greater understanding of the hydrologic system. For this reason, output from both the GAWSER continuous streamflow-generation model and the FEFLOW steady-state groundwater-flow model are used to quantify the processes that drive the hydrologic cycle. The GAWSER streamflow-generation model partitions rain and snowmelt reaching the watershed surface into overland runoff, percolation to subsurface stormflow/groundwater storage, and replenishment of soilwater storage. Infiltration is allocated to the latter three components with both infiltrability and the allocation amounts dependent on the status of soilwater storage. Evapotranspiration depletes soilwater storage. Discharge from groundwater storage (baseflow) is calculated for the subwatershed outlet location and added to routed overland runoff and subsurface stormflow to create the total streamflow at the subwatershed outlet. Groundwater storage can be augmented or depleted by transfer of groundwater from or to adjacent subwatersheds. The FEFLOW steady-state groundwater-flow model simulates how groundwater flow moves through the complex three-dimensional strata of the subsurface and interacts with the surface water system.

Output data from both models is aggregated to common subwatersheds in order to compare the results at a variety of spatial scales. A summary of the water budget parameters presented is provided below:

- **Precipitation**. Hourly climate data (precipitation, temperature) is input into the GAWSER continuous streamflow-generation model for each Zone of Uniform Meteorology (ZUM). Data for a ZUM is based on one or more climate stations. When formulating the input data for each subcatchment, the GAWSER input file refers to the climate station appropriate for that subcatchment. As a result, precipitation data is reported in the output file prepared for each subcatchment.
- **Runoff**. The GAWSER continuous streamflow-generation model reports daily runoff at a variety of scales, from the individual geology/land cover combination that produces the hydrologic response from a precipitation event, to the total runoff for an individual subcatchment, or the total runoff for a subwatershed.
- **Percolation.** The GAWSER model estimates the amount of water that percolates out of the evaporative root zone, moving towards the saturated zone (water table). Percolation can constitute the subsurface stormflow or baseflow response of the modelling element. This value is reported at the daily time step for spatial scales ranging from the geology/land cover combination to subwatershed scale.
- **Evapotranspiration**. The GAWSER continuous streamflow-generation model computes evapotranspiration for every scale that runoff and recharge are available for. When considering

the average results over the simulation period, evapotranspiration can also be calculated by subtracting runoff and recharge from precipitation.

- **Streamflow**. The GAWSER continuous streamflow-generation model computes total average streamflow, peak daily flow, and the baseflow component, and reports these results for the subcatchment. The model also exports computed streamflow, observed streamflow, and upstream area precipitation at gauge locations, or at any junction point within the model.
- **FEFLOW Groundwater Discharge / Baseflow**. The three-dimensional steady-state groundwater-flow model (FEFLOW) computes groundwater discharge rates at finite element nodes located along the Grand River and its tributaries. This will allow the distribution of groundwater discharge that is often measured at stream gauges to the estimated point locations of discharge.
- **External Groundwater Transfer**. The FEFLOW steady-state groundwater-flow model is able to estimate the volume of groundwater that enters or exits through the model boundary. With the current groundwater model domain being the topographic boundary of the Grand River Watershed, this ability will allow the GRCA to identify where groundwater is leaving or entering the Watershed.
- **Inter-Basin Groundwater Transfer**. Similar to external groundwater transfers, the FEFLOW steady-state groundwater-flow model is able to determine the quantity of groundwater that leaves one subwatershed within the Grand River, and enters an adjacent subwatershed.

1.5 SCOPE OF CURRENT ASSESSMENT

The purpose of this Integrated Water Budget Report is to characterize, understand and complete the Grand River Watershed's hydrology water budget modelling framework, and also to meet the requirements of the Province of Ontario's Clean Water Act (2006). This report was developed specifically to meet the Province of Ontario's requirements for a Tier 2 Water Budget Assessment. In addition to the water budget, a Tier 2 Subwatershed Hydrologic Stress Assessment estimating the potential hydrologic stress for each of the subwatersheds within the Grand River Watershed was prepared as a separate companion report (AquaResource, 2009b). For the purposes of meeting the GRCA's water budget requirements under the Clean Water Act, this report supersedes the earlier draft version of this report (AquaResource, 2007).

1.5.1 Source Protection Water Budgets

The Clean Water Act (2006) was introduced by the Government of Ontario to the Ontario Legislature Province of Ontario in its First Reading on December 5, 2005 and received Royal Assent on October 19, 2006. The Clean Water Act and its five regulations came into effect on July 3, 2007. The intent of the legislation is to ensure communities are able to protect their municipal drinking water supplies through the development of collaborative, locally driven, science-based source water protection plans. Communities will identify potential risks to local water sources and take action to reduce or eliminate these risks. Municipalities, conservation authorities, property owners, farmers, industry, community groups, and the public will work together to meet these common goals.

In addition to understanding threats to water quality, the Clean Water Act requires communities understand threats to the quantity of water required to sustain the current and future water supply needs. The Ministry of Natural Resources (MNR) in association with the Ministry of the Environment (MOE) has prepared the Water Budget and Water Quantity Risk Assessment Guidance Module (Guidance Module 7)

(MOE, 2007) to provide instructions for evaluating threats to water quantity. This Guidance Module outlines the steps to: 1) estimate the quantity of water flowing through a watershed; 2) understand the pertinent processes and pathways water follows; and 3) assess the sustainability of water supply sources from a quantity perspective. The goals of this water quantity risk assessment are to identify watershed communities where the sustainability of water supplies is questionable and to highlight key factors that may limit the sustainability, such that appropriate risk management activities can be completed.

The Water Budget and Water Quantity Risk Guidance Module describes a three-tiered assessment approach with each tier of the framework being more detailed, and providing greater certainty, than the previous tier.

Within the tiered assessment approach, water demand and supply scenarios are initially studied within a watershed-scale study, where surface water and groundwater systems are modelled and assessed to identify the associated water stresses. Water demand and water supply stresses are then evaluated in different areas of the Watershed and assigned a score based on a rating system developed by the MOE and detailed in the guidance documents. In areas where the availability of water far outweighs the demand, a simplified approach (Tier 1) may be sufficient for decision-making and further efforts are not required. Highly developed areas that obtain municipal water supply from local resources may require more advanced and detailed assessments. Once the stresses exceed a certain threshold value, more detailed subwatershed-scale (Tier 2) studies are recommended.

An overview of the tiered studies prescribed within the Guidance Module is provided in the following sections.

1.5.2 Conceptual Water Budget

The Water Budget and Risk Assessment Guidance Module requires that a Conceptual Water Budget be developed for each watershed. The Conceptual Water Budget should address baseline data collection, mapping, and an analysis of the information compiled. The conceptual understanding phase of the water budget is envisioned to build on the Watershed Characterization Report, which is an initial collection of all existing information of a watershed's natural characteristics, population distribution, and land use. The Conceptual Water Budget should present an initial overview of the functions of the flow systems in the study area (both groundwater and surface water). Four questions are emphasized at this stage:

1. Where is the water?
2. How does the water move between the various watershed elements (soils, aquifers, lakes, rivers)?
3. What and where are the stresses on surface water and groundwater?
4. What are the trends?

In addressing the above questions, the Conceptual Water Budget will include an initial understanding of the various watershed hydrologic elements (e.g. soils, aquifers, rivers, lakes) and fluxes in a study area (precipitation, recharge, runoff, evapotranspiration). It will also require an understanding of the geologic system and a consideration of surficial features, such as wetlands and large impervious areas that would have to be incorporated into any water budget analysis. A preliminary inventory of all water takings would also be undertaken at this stage.

The Guidance Module lists the expected deliverables for the Conceptual Water Budget.

1.5.3 Tier 1 Simple Water Budget and Water Quantity Stress Assessment

The goal of the Tier 1 Simple Water Budget and Water Quantity Stress Assessment is to estimate a subwatersheds potential for stress, caused by water takings. The study team undertaking the Tier 1 Assessment will estimate the Percent Water Demand. The Percent Water Demand is the percentage of water supply that is demanded by water users. In subwatersheds where the Percent Water Demand is above a threshold value, the subwatersheds are classified as having a 'moderate' or 'significant' potential for stress and require more detailed study. Watersheds calculated as having a low Percent Water Demand are identified as having a 'low' potential for stress and are not be subject to additional water budget requirements.

The Guidance Module lists the expected deliverables for a Tier 1 Water Budget and Subwatershed Stress Assessment.

1.5.4 Tier 2 Complex Water Budget and Water Quantity Stress Assessment

Tier 2 Stress Assessments are completed to verify the results of the Tier 1 Stress Assessment. This is completed through the use of additional data and numerical water budgeting tools. The Tier 2 Water Budgets are developed at the subwatershed scale, similar to the Tier 1 level, and they require both a continuous streamflow model and a calibrated groundwater flow model.

With the understanding that the GRCA had already completed a large amount of characterization and modelling work, the Ontario Ministry of Natural Resources approved the GRCA to proceed directly with a Tier 2 Water Budget and Subwatershed Stress Assessment. This approval was in accordance with the Technical Rule 24 (MOE, 2008) which allows a Source Protection Area to move directly to a Tier 2 water budget if preliminary water budgets already exist for subwatersheds in the area. This Integrated Water Budget Report contains the results of the Tier 2 Water Budget effort and the companion report (AquaResource, 2009b) contains the results of the Tier 2 Subwatershed Stress Assessment. The methodologies used throughout both reports are consistent with the methodologies presented in the Province's Water Quantity Guidance Modules (MOE, 2007).

The Guidance Module lists the expected deliverables for a Tier 2 Complex Water Budget and Subwatershed Stress Assessment.

1.5.5 Tier 3 Water Quantity Risk Assessment

The objective of the Tier 3 Water Quantity Risk Assessment is to estimate the likelihood that municipalities will be able to meet future water quantity requirements. Tier 3 Risk Assessments are carried out on all municipal water supplies located in subwatersheds that were classified in the Tier 2 Assessment as having a moderate or significant potential for hydrologic stress. This assessment uses refined surface and/or groundwater flow models and involves a much more detailed study of the available groundwater or surface water sources.

2.0 Watershed Characterization

This chapter characterizes the surface water hydrology and groundwater hydrogeology relating to the development of the GRCA's water budget tools.

2.1 TOPOGRAPHY AND PHYSIOGRAPHY

Topography throughout the Grand River Watershed ranges from more than 500 m above sea level near Dundalk to approximately 175 m above sea level at the Lake Erie shoreline. Significant topographic features in the Watershed include moraines, clay/till plains, drumlin fields, and incised river valleys. The topographic relief varies from relatively flat terrain within the clay plains to rolling (hummocky) topography within moraine features. The clay plains tend to have increased runoff and often contain more tributaries, municipal drains, and tiled fields than the moraines and till areas. Hummocky topography identifies areas that contain closed depressions, usually characterized by depression storage and limited connectivity of surface drainage. Detailed discussions relating the surficial geology to the hydrogeology in specific areas of the Watershed are provided by Holysh et al. (2001).

A map of surficial materials across the Watershed is shown on Figure 4. This figure also subdivides the Grand River Watershed into three physiographic areas. The physiographic features in the Grand River Watershed are shown on Figure 5 and are primarily the result of the last glaciation (ending ~10 000 years ago). The present day geologic setting consists of eroded Paleozoic sedimentary bedrock units, overlain by glacial deposits and more recent alluvial deposits. The landscape can be subdivided into three general physiographic areas:

1. The northern parts of the Watershed largely consist of lower permeability till plains (Dundalk, Elma, Stratford till Plains) showing varying relief.

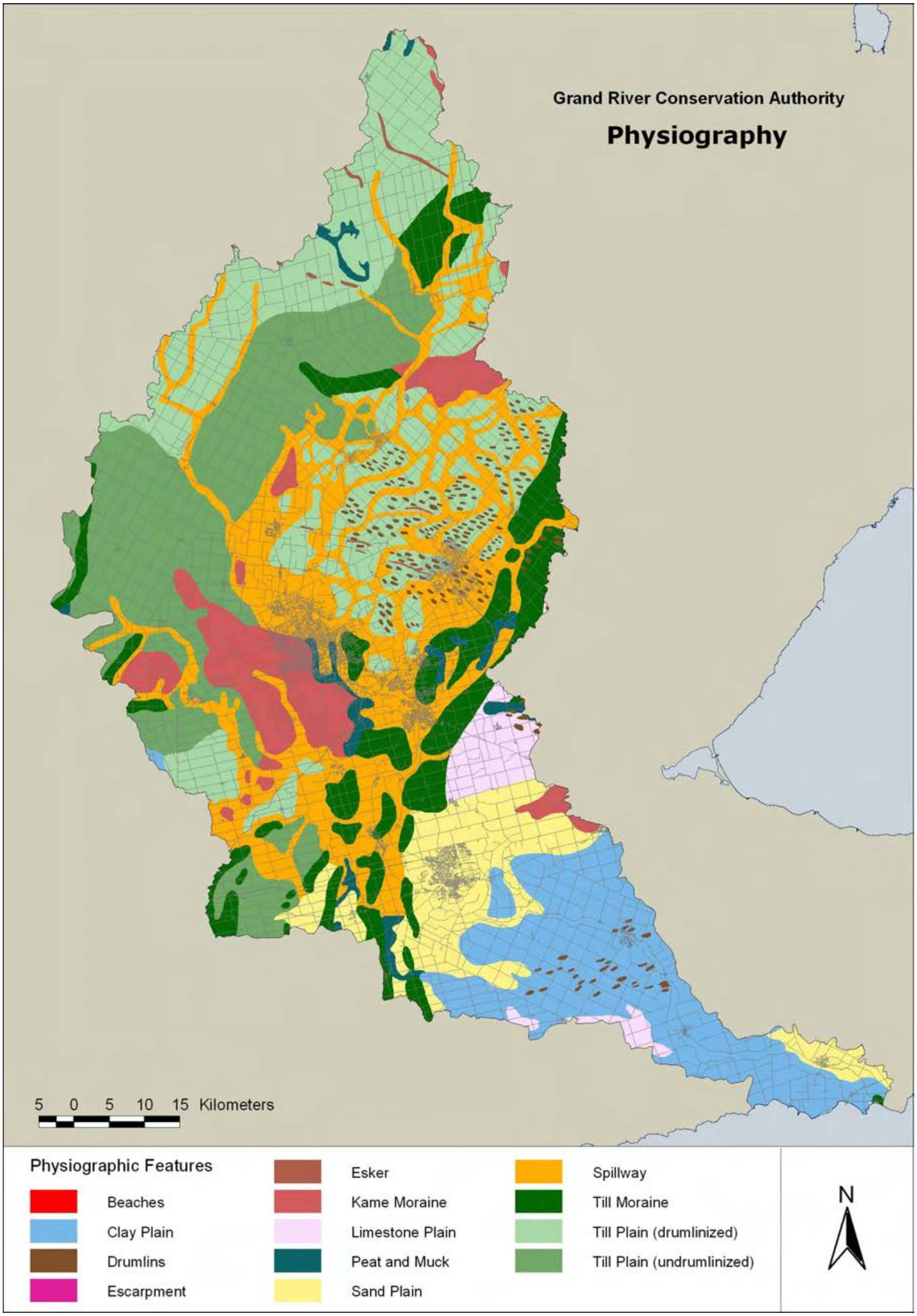
- Canning Till
- Maryhill Till
- Wartburg Till
- Tavistock Till
- Port Stanley Till
- Stratford Till Plain
- Elma Till
- Wentworth Till
- Catfish Creek Till
- Mornington Till
- Dundalk Till Plain

2. The central parts of the Watershed are composed of hummocky topography, higher permeability sand and gravel kame and kettle moraines, and recessional moraines (Waterloo Moraine, Paris/Galt Moraine) with moderately high relief.

- Macton Moraine
- Elmira Moraine
- Orangeville Moraine
- Paris Moraine
- Galt Moraine
- Chesterfield Moraine
- Ingersoll Moraine
- Moffat Moraine
- Milverton Moraine
- Breslau Moraine
- Easthope Moraine
- Waterloo Moraine
- Norwich Moraine
- Tillsonburg Moraine

3. The south part of the Watershed is characterized by low relief, low permeability lacustrine clay plains (Haldimand Clay Plain).

Higher permeability, low elevation outwash sand and gravel deposits, including modern spillways, are located throughout the three main physiographic areas.



Chapman, L.J. and Putnam D.F. 1984: Physiography of Southern Ontario; Ontario Geological Survey, Map P.2715 (coloured). Scale 1:600 000.

Figure 5
Physiography

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2.1.1 Moraines

Moraines are the predominant physiographic features in the central part of the Watershed. Fourteen unique moraines, identified within the Watershed, have been grouped into three moraine areas by the GRCA, as illustrated on Figure 6 (Orangeville, Paris/Galt, and Waterloo Moraines). By definition, a moraine is a mound or ridge of glacial drift deposited primarily by the direct action of a glacier. The fourteen glaciers within the Watershed were formed under varying depositional environments, and consequently each moraine has unique geologic and physiographic qualities. Many of the moraines, have common characteristics such as higher permeability soils, hummocky topography, and closed depressions (kettle lakes), which enhance recharge in those areas. Moraines can also support ecological functions, as the vegetated portions of moraines provide habitats for plants, animals and vegetation communities, and act as a breeding area for amphibians and waterfowl.

The moraine areas of the Watershed are summarized below.

- Waterloo Moraine Complex. This complex encompasses a large portion of the western area of the Grand River Watershed. The Waterloo Moraine is the largest moraine in the Watershed and is referred to as an Interlobate Moraine (Chapman and Putnam, 1984) formed when the Georgian Bay and Lake Ontario ice lobes came together. The Moraine plays host to several overburden aquifers that discharge to, and help maintain, baseflow in the Grand River, Nith River, and many of their tributaries. These overburden aquifers are also the source for approximately 50 percent of the groundwater used by the Region of Waterloo's water supply system. The overburden deposits of the Waterloo Moraine reach up to 120 m in thickness. This complex also includes the Macton and Milverton Moraines, located in the northern and western portion of this area respectively.

- Orangeville Moraine Complex. The Orangeville Moraine lies east of Belwood Lake and extends to the west side of Orangeville within the upper reaches of the Speed River. Similar to the Waterloo Moraine, this moraine was built between the Lake Ontario, Lake Simcoe and Georgian Bay Ice Lobes (Chapman and Putnam, 1984). The Moraine is composed of ice contact stratified drift consisting of sand and/or gravel with interbedded tills and fine-grained sediments. It is a highly permeable feature with high groundwater recharge rates. The western area of the complex includes the Elmira Moraine, which is comprised of ice contact stratified drift, with significant deposits of sand and/or gravel.

- Paris/Galt Moraine Complex. The Paris/Galt Moraines were created by the westward advance of the Lake Ontario Ice Lobe. The Paris Moraine crosses the Watershed from northeast to southwest, from the headwaters of Mill Creek (east of Aberfoyle), through Cambridge and south to Paris and Burford along the west side of the Grand River. The Galt Moraine lies southeast of the Paris Moraine and forms the southern edge of the Mill Creek subwatershed before following the east side of the Grand River through St. George and Brantford. These moraines form broad topographic ridges with irregular, hummocky topography, and numerous closed depressions and kettle lakes. The moraines are composed of Wentworth Till (Karrow, 1987) with underlying sand and gravel deposits (Russell et al., 2009). The Moffat Moraine located along the eastern extent of the Watershed in the Rockwood/Acton area is also part of the Paris/Galt Moraine Complex. Collectively these morainal features provide important recharge contributions to the local and regional aquifer systems.

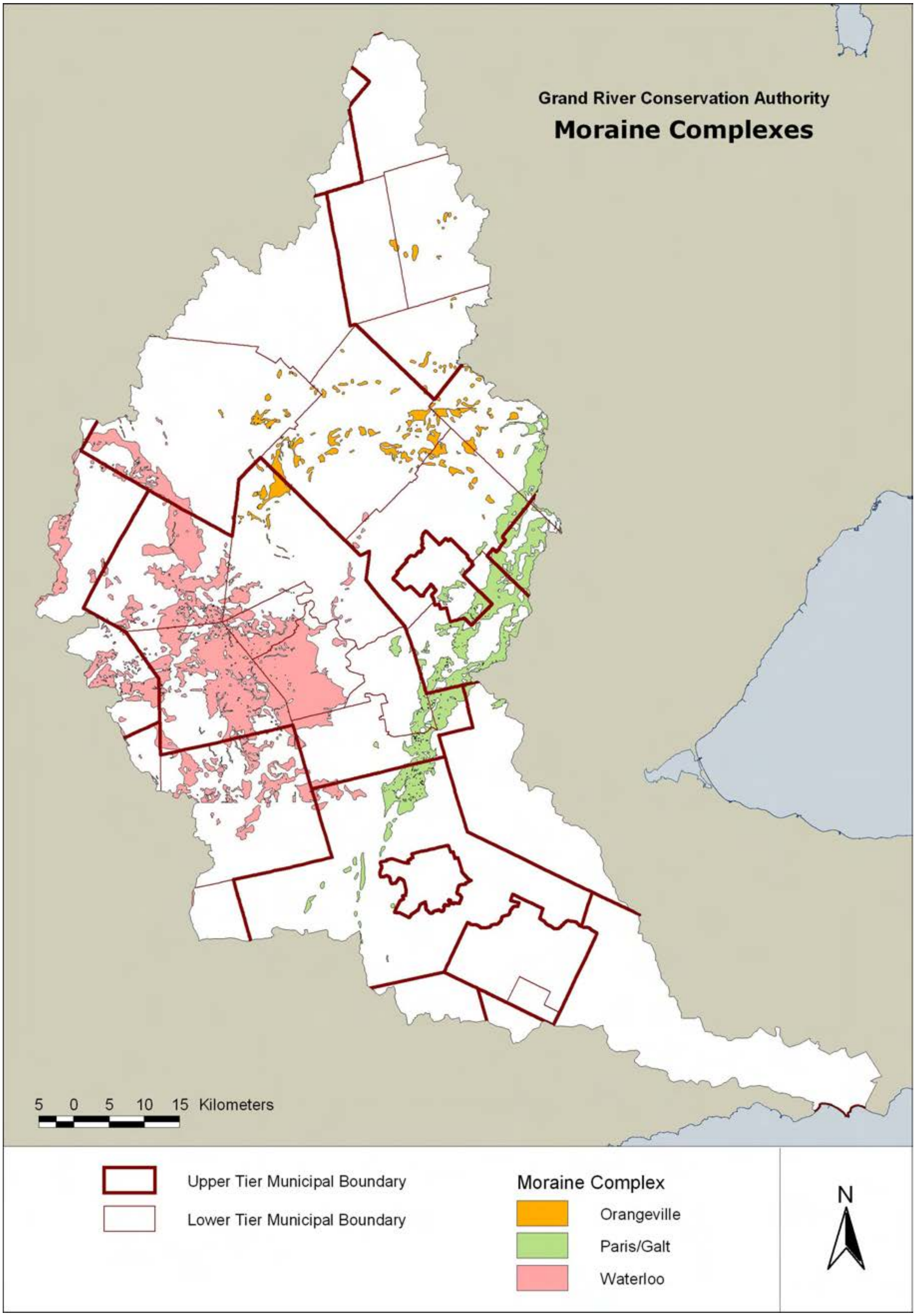

Figure 6
Moraines / Hummocky Topography

Various Authors, 1967-1993, Quaternary and Pleistocene Geology, Southern Ontario, Ontario Geological Survey. Refer to GRCA metadata.

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2.2 GEOLOGY

This section provides a summary of the bedrock and overburden geology in the Grand River Watershed.

The Ontario Geological Survey (OGS) is currently updating its conceptual bedrock geology model, particularly in the Guelph and Cambridge areas focusing on the Amabel, Eramosa, and Guelph Formations (Brunton, 2008). The revised conceptual model integrates sequence stratigraphy and sedimentology and renames local stratigraphic units to be consistent with a wider conceptual model that can be correlated as far away as New York State. This current OGS project is in progress and therefore the revised conceptual bedrock geological model is not reflected in this report. The revisions to the bedrock conceptualization will be incorporated into subsequent Water Quantity Risk Assessment investigations (Tier 3 Risk Assessments).

2.2.1 Bedrock Geology

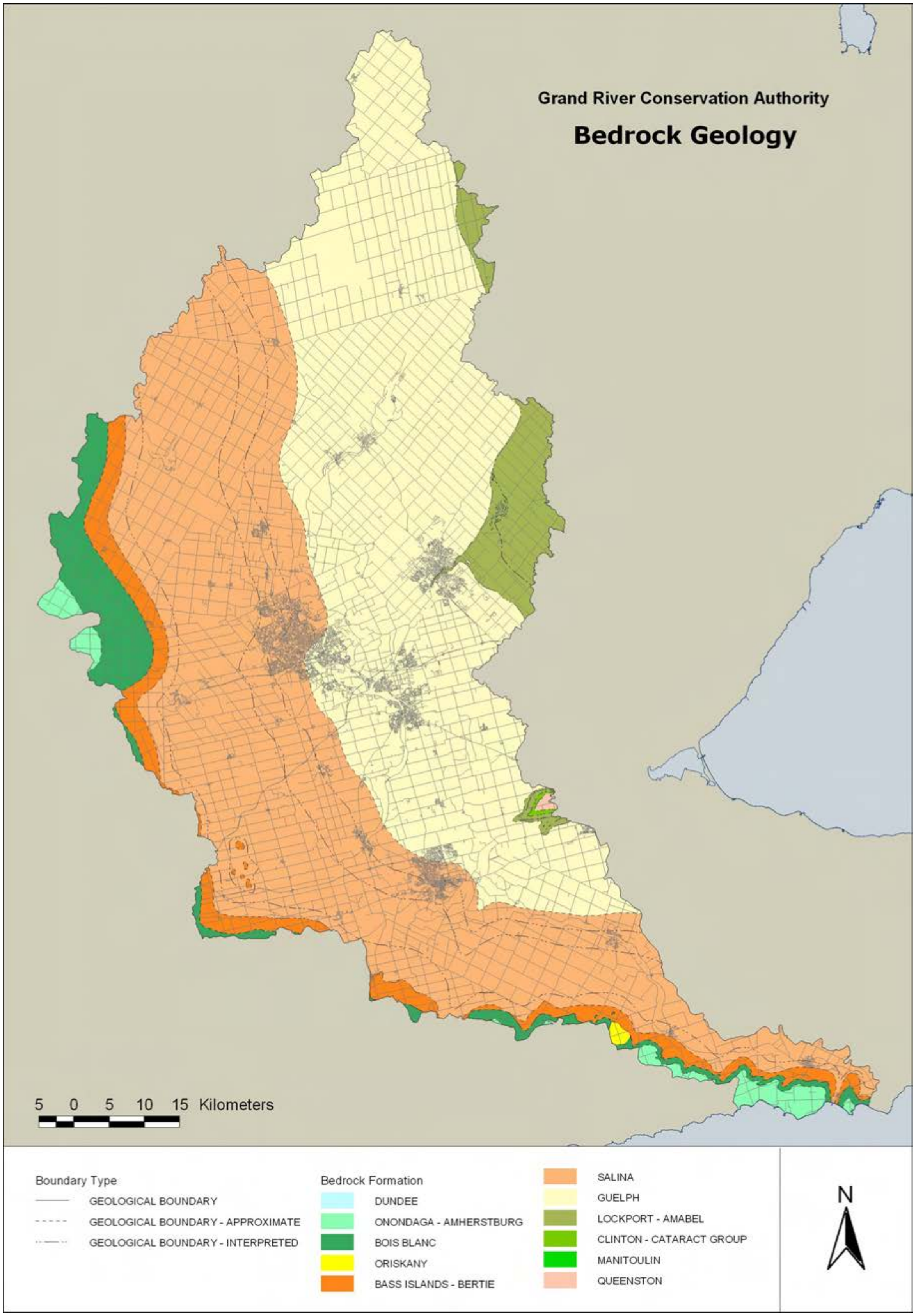
This section provides an overview of bedrock geology in the Watershed. Detailed descriptions of each of the bedrock formations are provided in other reports (e.g., Holysh et al., 2001).

Bedrock underlying the Grand River Watershed is part of the Michigan and Appalachian Basins, consisting of Devonian, Silurian, and Ordovician aged marine sediments deposited at the bottom of a sea that once inundated this area between 345 to 370 million years ago (Sibul et al., 1980 - See Figure 7). Table 2.1 summarizes each of the bedrock units with the approximate thickness range interpreted by WHI (2005) as part of the conceptual geologic model. They are listed from youngest to oldest unit; older units underlie younger units, and all units dip toward the south (Appalachian Basin) or south-west (Michigan Basin). Figure 8 shows a plan view of bedrock geology through the Watershed along with the locations of the three watershed-wide cross-sections. Figures 9, 10, and 11 present three watershed-wide cross-sections through the Grand River Watershed that illustrate the slope of the bedrock units and their relation to mapped subcrop locations.

The sedimentary bedrock mainly consists of interbedded limestone and dolostone carbonate materials, and shale of the Ordovician (oldest) to Devonian (youngest) age. The bedrock contains a slight dip to the west and southwest of less than one degree (5 m/km). The Grand River Watershed spans the Michigan Basin (dipping to the west) in the northern portion of the Watershed into the Appalachian basin (sloping south) in the south. The transition between the two basins (separated by the Appalachian Arch) occurs in the Brantford area; the consequence is that the bedrock subcrop units are seen to transition from north-south trends to east-west trends (see Figures 7 and 8).

Bedrock outcrops are most commonly found in the central-eastern and southern portions of the Grand River Watershed. Outcrops in the central-eastern area (Fergus-Elora-Guelph-Rockwood-Rockton) primarily consist of the Guelph and Amabel Formations and are commonly found along river valleys. Outcrops in the southern portion of the Watershed are associated with the Bass Island, Bertie, and Bois Blanc Formations that comprise part of the Onondaga Escarpment (Karrow, 1973).

The Queenston Formation, commonly known as the Queenston Shale, is the oldest Paleozoic bedrock formation to subcrop in the region; it consists of shale with minor interbeds of limestone and siltstone. The formation ranges in thickness from 135 m to 335 m. Overlying the Queenston Formation is the Cataract Group, primarily consisting of shale and sandstone, and the Clinton Group consisting of interbedded shale and dolostone. Subcrops of these formations (where they are directly overlain by unconsolidated materials) are present near Ancaster as part of the Dundas Buried Bedrock Valley. Younger bedrock units were eroded in this ancient valley.



Produced using information provided by the Ministry of Natural Resources,

Portions of this map are produced under license from Her Majesty the Queen in Right of Canada, with permission of Natural Resources Canada.
Sanford, B.V. 1969 Geology of the Toronto–Windsor Area, Ontario; Geological Survey of Canada, Map 1263A.
Various Authors, 1975-1980, Paleozoic Geology, Southern Ontario, Ontario Division of Mines. Refer to GRCA metadata.

Figure 7
Bedrock Geology

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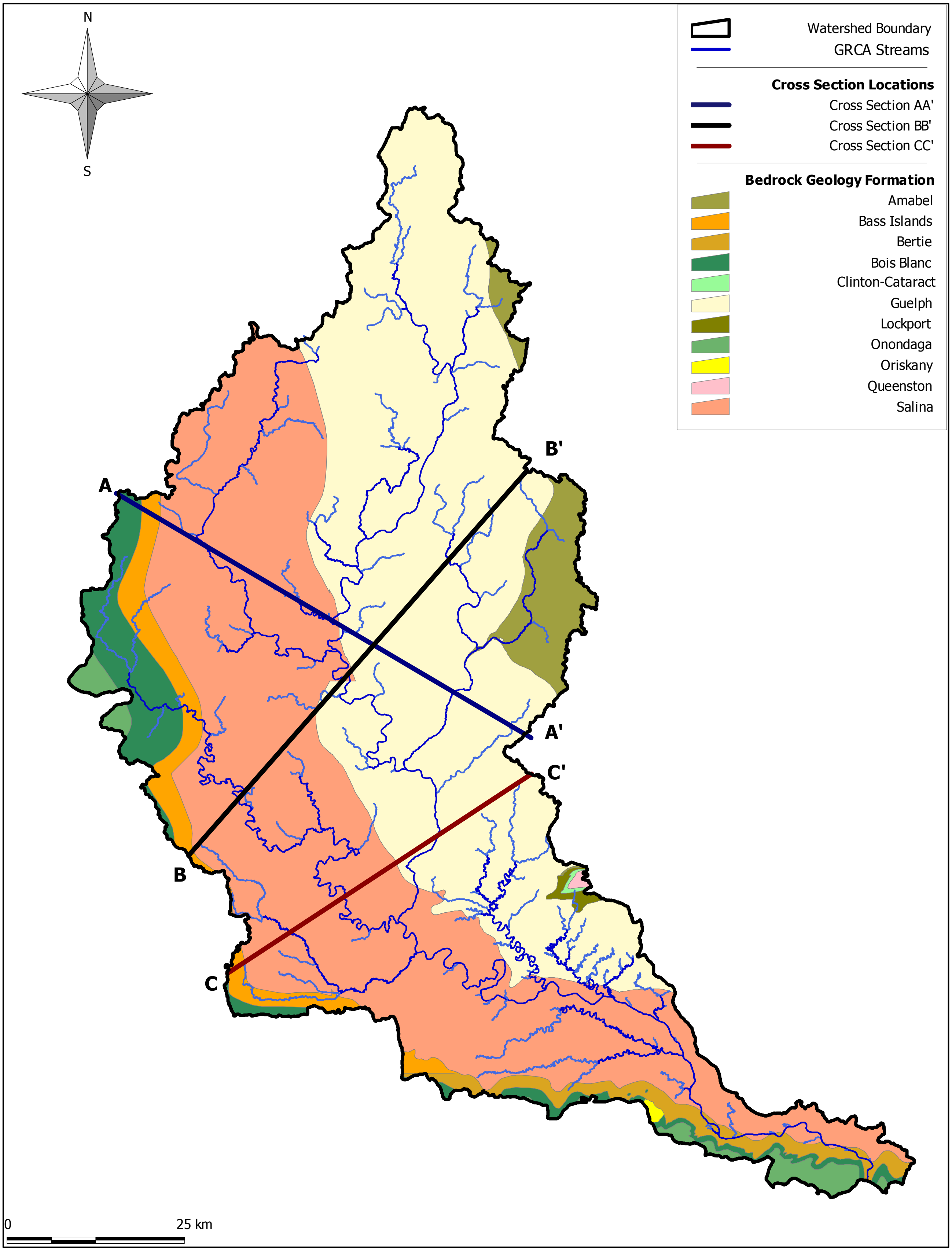

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Sanford, B.V. 1969 Geology of the Toronto–Windsor Area, Ontario; Geological Survey of Canada, Map 1263A.
Various Authors, 1975-1980, Paleozoic Geology, Southern Ontario, Ontario Division of Mines. Refer to GRCA metadata.

Figure 8
Plan View of
Cross Section Locations

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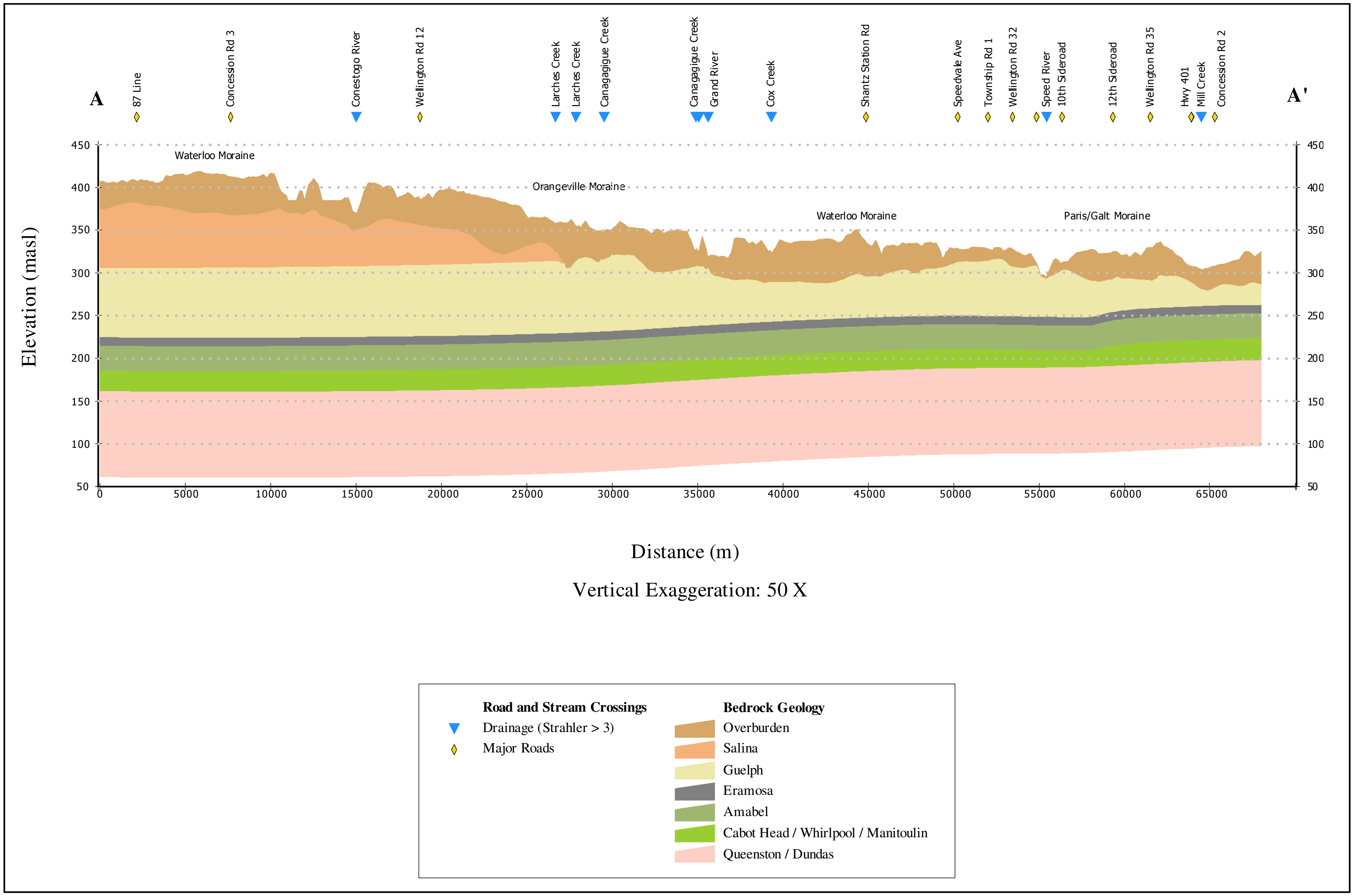

Figure 9 - Bedrock Geology Cross Section AA'

Sanford, B.V. 1969 Geology of the Toronto–Windsor Area, Ontario; Geological Survey of Canada, Map 1263A.
Various Authors, 1975-1980, Paleozoic Geology, Southern Ontario, Ontario Division of Mines. Refer to GRCA metadata.

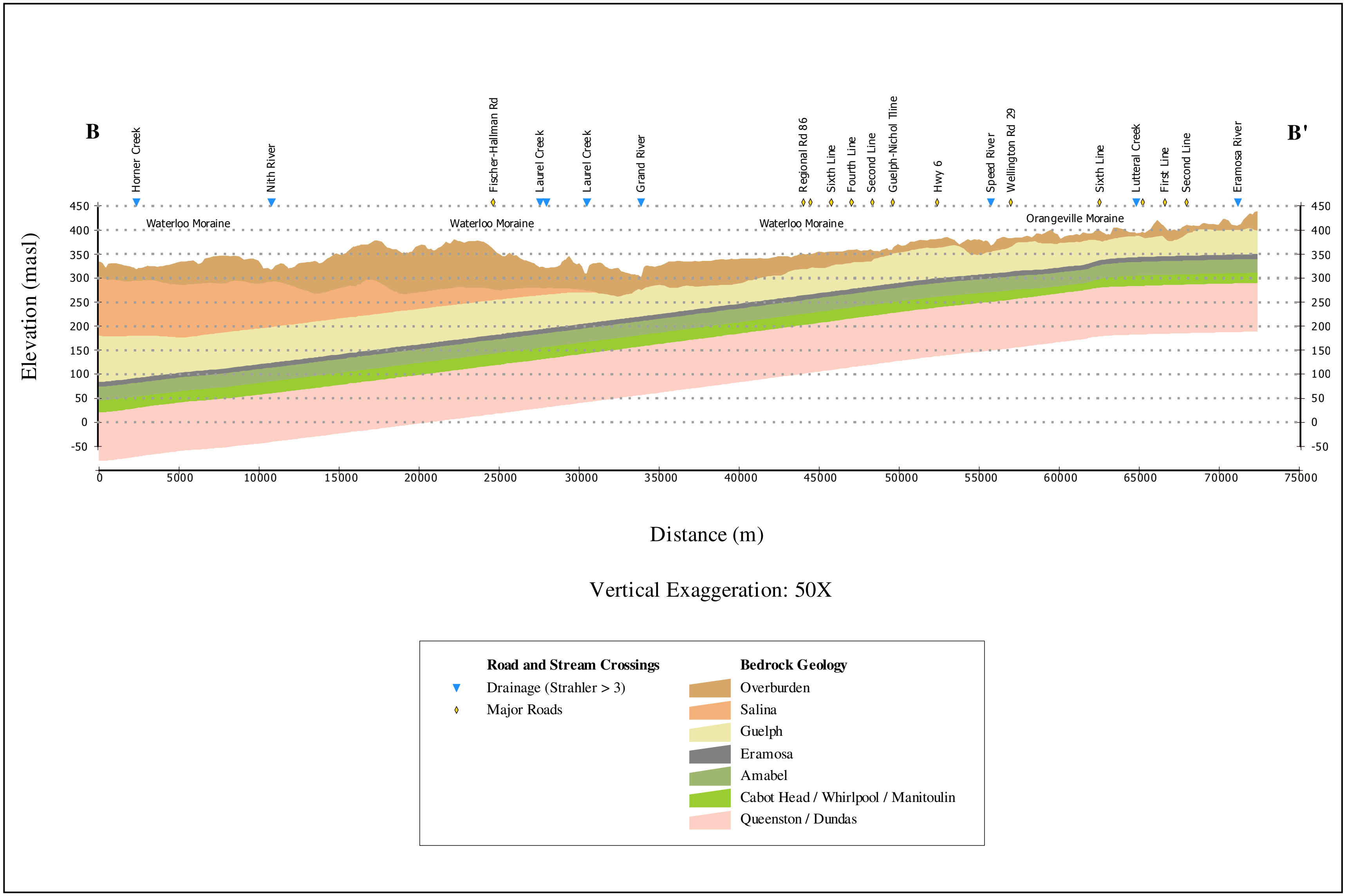

Figure 10 - Bedrock Geology Cross Section BB'

Sanford, B.V. 1969 Geology of the Toronto–Windsor Area, Ontario; Geological Survey of Canada, Map 1263A.
Various Authors, 1975-1980, Paleozoic Geology, Southern Ontario, Ontario Division of Mines. Refer to GRCA metadata.

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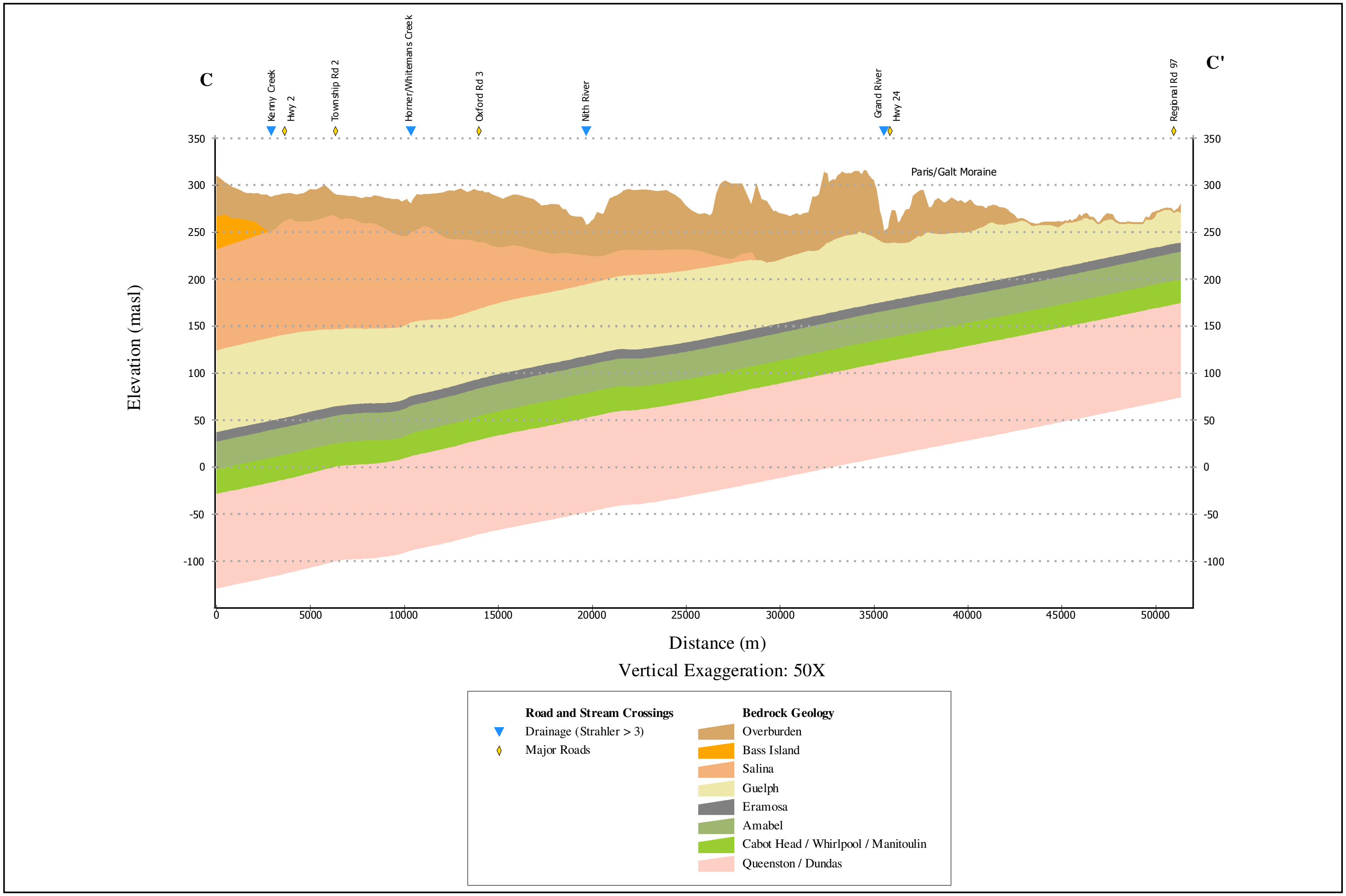

Figure 11 - Bedrock Geology Cross Section CC'

Sanford, B.V. 1969 Geology of the Toronto–Windsor Area, Ontario; Geological Survey of Canada, Map 1263A.
Various Authors, 1975-1980, Paleozoic Geology, Southern Ontario, Ontario Division of Mines. Refer to GRCA metadata.

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Table 2.1 - Bedrock Geology Underlying the Study Area (From WHI, 2005)

Formation	Sub-Members	Geology	Subcrop Location	Thickness (m)
Onondaga-Amherstburg		Fossiliferous limestone, variably cherty and shale interbeds	Western boundary near Wellesley to Dunnville	45 – 75
Oriskany		White or grey quartz sandstone	Between Bass Island-Bertie and Bois Blanc near Cayuga	6
Bois Blanc		Grey and greyish brown dolomite, limestone with nodular chert	Western boundary	40 – 60
Bass Islands-Bertie		Cream and tan to greyish-tan dolomite	Inside western boundary	22 – 28
Salina	A	Tan dolomite and grey mudstone	central to western boundary from Drayton to Dunnville	up to 330
	C	Grey and olive green shales with lenses of anhydrite and gypsum		
	E	Tan dolomite with lenses of anhydrite and gypsum		
	F	Grey and red shale containing lenses of anhydrite and gypsum		
Guelph		Brown/tan dolostone	Eastern boundary to central (30 km wide)	15-90
Lockport / Amabel	Eramosa	Dark brown / black bituminous dolostone	Northeastern Boundary, Dundas Valley	30
	Goat Island (Appalachian Basin)	Light brown dolostone		
Clinton-Cataract Group	Whirlpool	Grey to reddish sandstone	Dundas Valley	5
	Manitoulin	Grey, medium bedded dolostone with shaley interbeds		5
	Cabot Head	Greenish grey and red-silty shale		10
	Reynales – Fossil Hill	Argillaceous dolostone		2-3
Queenston		Red Shale	Dundas Valley	135-335

Overlying the Clinton Group is the Lockport / Amabel Formation, which is predominately composed of limestone and dolostone. The name "Lockport" is used to describe this formation in areas east of Burlington (Appalachian Basin), and the name Amabel Formation is used further west and north in the Michigan Basin. This formation is recognized as the cap rock formation of the Niagara Escarpment, and it is much harder than the underlying shales and sandstones of the Cataract, Clinton, and Queenston Formations. Despite its resistance to erosion, portions of the Amabel Formation are found to have a higher porosity (i.e. vugs); it is also subject to karstification. Karst features are typically formed by the dissolution of limestone bedrock (and to a lesser extent of dolostone bedrock), which creates pathways for water to move through the rock formation. This has been well documented through recent work in the City of Guelph (Golder, 2006) where the middle portion of the Amabel Formation (also known as the production zone) was found to contain a much higher porosity than the surrounding bedrock.

The Eramosa Member of the Amabel Formation is commonly found to overlie the "productive" portion of the Amabel Formation; it can be up to 20 m thick and is distinguished by its black and shale-rich nature. As a result, the Eramosa Member is commonly found to restrict the movement of water between overlying units and the "production zone" of the Amabel Formation. The Eramosa Member plays an important role in the water budget.

The Guelph Formation overlies the Lockport / Amabel Formation and is also composed of dolostone. It is the uppermost bedrock unit throughout the eastern half of the Grand River Watershed (north of Caledonia) and has a reported thickness of up to 100 m. The Guelph Formation is similar in composition to the Amabel Formation dolostone and as such they are often grouped together. The Guelph and Amabel Formation rocks are an excellent source of aggregate and are, therefore, quarried when exposures are present. These bedrock formations are well-producing aquifers and provide water supplies for the Cities of Guelph and Cambridge. Many other smaller communities also obtain their water supply from these formations.

The Salina Formation overlies the Guelph Formation, and consists of interbedded evaporates (salts, gypsum, anhydrite), shales, and carbonate rock (limestone/dolostone). The Salina Formation is the uppermost bedrock formation in much of the western half of the Watershed (Michigan Basin) as well as the southern region (Appalachian Basin). The Salina Formation, in the Appalachian Basin, is mined to extract the gypsum; Gypsum is used to make plaster, wallboard, and sheetrock products. Gypsum mining in the GRCA Watershed has existed for over 100 years and was the origin of the term "Plaster of Paris", due to the ease of extraction in the Paris area. Current mines are located near Hagersville, Cayuga and Caledonia. Further west near Goderich, the Salina Formation is mined for its salt content.

The Bass Island - Bertie, Oriskany, Bois Blanc, and Onondaga-Amherstberg Formations overlie the Salina Formation and are found along the south-west and western extent of the Grand River Watershed. The Bass Island (Michigan Basin) and Bertie (Appalachian Basin) Formations are the oldest of these three formations and consist of grey and tan dolostone. The Oriskany Formation is only found in the Appalachian Basin (near Cayuga) and consists of coarse-grained sandstone. The Bois Blanc Formation overlies the Bertie (or Oriskany) Formation, consists of mostly limestone, and forms the cap of the Onondaga Escarpment. The Onondaga Formation (Appalachian Basin) consists of thin to medium-bedded limestone and is typically found above the Onondaga Escarpment. The Amherstberg Formation (Michigan Basin), present in the far western portion of the Watershed near Wellesley, is another tan to grey limestone unit.

2.2.1.1 Bedrock Topography and Bedrock Valleys

Bedrock topography, shown on Figure 12, has a regional downward slope, from north to south, from approximately 525 m AMSL at the most northern extent of the Watershed to 135 m AMSL where the Grand River enters Lake Erie. Numerous bedrock valley features were mapped by the GRCA (Holysh et al., 2001) and are also shown on Figure 12. The hydrogeologic significance of the buried bedrock valleys within the Watershed is poorly understood due to the limited information on the depth and location of the buried valleys and the valley infill material. Depending on the material infilling the bedrock valley, the ability for groundwater to flow through the valley may be significant when infilled with coarse grained materials, or relatively insignificant when in-filled with fine-grained materials. Without the completion of detailed drilling and hydraulic testing in the bedrock valleys, the hydrogeologic significance of the valleys is not known.

Important bedrock features in the Watershed include:

Dundas Valley: The Dundas Valley (see Figure 12) is a buried bedrock valley (no surface expression) that trends east-west from Hamilton Harbour toward Brantford before trending north within the Salina Formation. The valley again trends west through Wellesley from the north Waterloo area. The valley is interpreted to be eroded by an earlier Grand River and deepened by glacial action (Singer et al., 2003). The valley has been traced all the way to Lake Huron, likely exiting near Douglas Point. Within the Salina Formation, the thalweg of the Dundas valley is not well defined.

Rockwood Valley: The Rockwood Valley (see Figure 12) is a buried bedrock valley (no surface expression) that trends northeast-southwest from the Rockwood area to the northeastern portion of Guelph, emerging in the Eramosa River Valley. The valley system consists of a few parallel trending thalwegs, some of which extend across the Watershed boundary and generate interaction with the neighbouring Credit Valley Watershed (near Erin).

Onondaga Escarpment: The Onondaga Escarpment (see Figure 12) extends from Buffalo, running along the north side of Lake Erie and trending north along the west side of the Grand River Watershed, south of Brantford. This escarpment is thought to be limited to the Appalachian Basin with the Bois Blanc Formation acting as the cap rock (follows its subcrop). It is the result of differential erosion between the harder bedrock cap (Bois Blanc – Bertie Formations), and the softer underlying bedrock (Salina Formation). This differential erosion forms a cuesta landform on the bedrock surface, which can be identified along the Salina Formation to Lake Huron (Saugeen River Valley). This feature creates a margin of exposed Paleozoic bedrock along the south-western edge of the Watershed, near Cayuga (see Figures 5, 13 - Physiography and Surficial Materials).

2.2.2 Surficial / Quaternary Geology

The surficial geology of the Grand River Watershed (see Figure 13) was influenced by the events of the last glaciation which, in this part of Ontario, came to an end about 10,000 years ago. The Quaternary record preserved within the area is characterized by repeated glacial advances of ice lobes originating from the Lake Huron-Georgian Bay and the Erie-Ontario basins (Bajc, 2004). Subsequent erosion and geomorphologic processes relating to the Grand River and its tributaries have also played a role in shaping the Watershed's landscape.

The nature of the overburden materials is important in terms of both the hydrologic and hydrogeologic understanding of the Watershed. Soils, which are generally a weathered reflection of the underlying quaternary deposits, influence the degree of runoff and the degree of groundwater recharge. Areas with low permeability tills and clayey deposits at the surface tend to have higher runoff volumes, lower recharge, and a higher density of tributaries. In contrast, areas of higher permeability soils at the ground surface result in higher recharge rates, low runoff, and fewer tributaries. The type of soils and quaternary deposits and their hydrologic and hydrogeologic characteristics play an important role in the development of aquatic and terrestrial resources, many of which have unique characteristics throughout the Grand River Watershed.

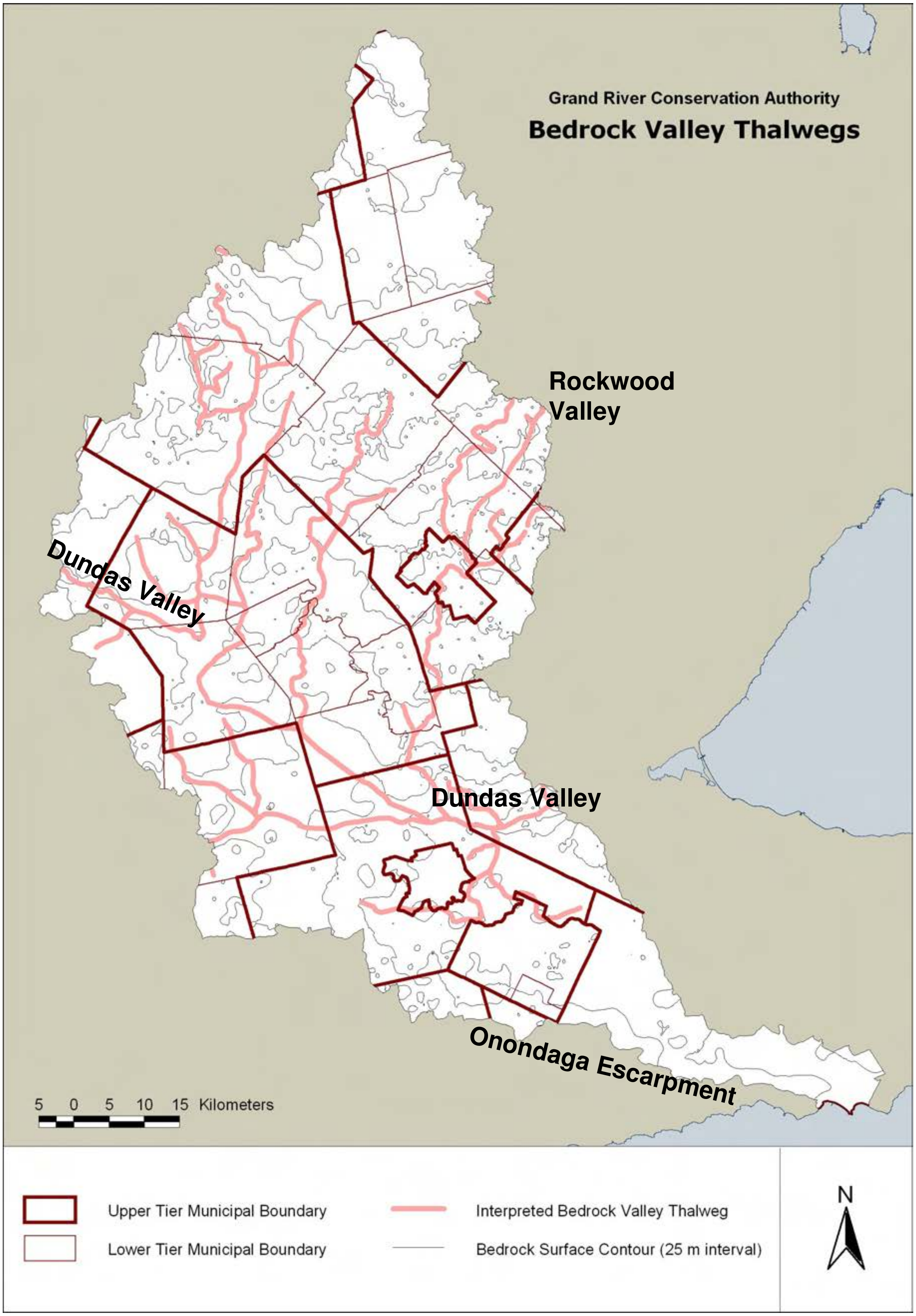
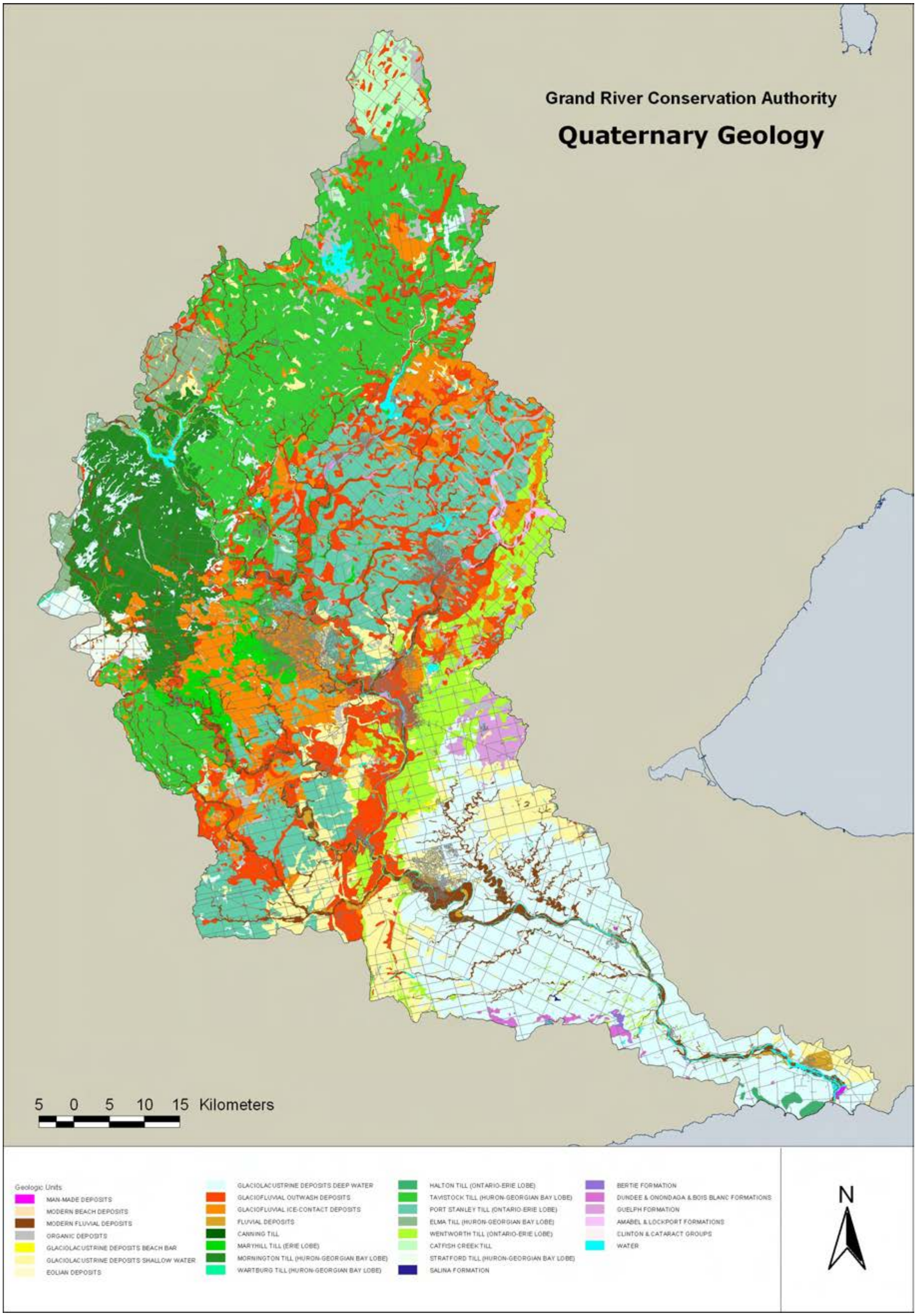


Figure 12
Bedrock Topography and Valleys



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Various Authors, 1967-1993, Quaternary and Pleistocene Geology, Southern Ontario, Ontario Geological Survey. Refer to GRCA metadata.

Figure 13
Quaternary Geology

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2.3 HYDROGEOLOGY

2.3.1 Hydrostratigraphy

When constructing the initial Watershed groundwater flow model, WHI (2005) generalized the complex hydrogeology in the Watershed into 12 hydrostratigraphic layers. The elevations of these layers were determined by an automated routine that analyzed the geology reported in 'high quality' water well records as identified by WHI. The Guelph, Eramosa, and Amabel Formations were grouped together in the WHI interpretation; this interpretation has been shown to be inappropriate throughout the Guelph and Puslinch area (Golder, 2006). As a result, in the current modelling, the Guelph and Amabel Formations were separated by a layer representing the Eramosa Member of the Amabel Formation. Table 2.2 presents a summary of the hydrostratigraphic units in the study area, including a description of the type of hydrostratigraphic unit (aquifer /aquitard), the stratigraphic position (overburden / bedrock), the spatial distribution of the unit, and the potential well yield expected from the unit. Figures 9, 10, and 11, show the bedrock formations in cross-section as they are represented in the water budget model.

Table 2.2 - Generalized Hydrostratigraphic Units in the Grand River Watershed (After WHI, 2005)

Hydro-stratigraphic Unit	Geologic Unit	Description	Zone	Spatial Distribution	Well Yield
Aquitard 1	Till units at surface as defined in the Quaternary Geology map	Silty to clay silt till / sandy silt till	Overburden	Continuous in Till Plains and on Escarpment; more variable and laterally discontinuous along moraine axes; *Unstratified*.	Low
Aquifer 1	Coarse-grained materials at surface as defined in the Quaternary Geology map	Glaciofluvial/ ice-contact sands and gravels	Overburden	Variable thickness up to ~65 m; largest deposits in kame moraines and channels; *Stratified*	High
Aquitard 2	Lower Till units/ Moraine fine-grained materials	Silty sand till / glaciolacustrine silt and clay	Overburden	Regional but discontinuous, channelized	Low to Moderate
Aquifer 2	Early to Mid-Wisconsinan Sediments	Fine to medium sand, with till remnants	Overburden	Thin to absent; greatest thickness in buried valleys	Low
Aquitard 3	Till on Bedrock	Silty sand till / glaciolacustrine silt and clay	Overburden	Regional but discontinuous, channelized	Low to Moderate
Bedrock Aquifer 1	Weathered bedrock	Upper 3-5 m of fractured bedrock	Bedrock (Contact Zone)	Continuous with variable thickness of 3-5 m.	Moderate to High
Bedrock Aquifer 2	Onondaga – Amherstburg / Bois-Blanc / Bass Islands – Bertie Formations	Limestone / Dolostone	Bedrock	Regional (west to southern portion of Watershed)	Moderate

Hydro-stratigraphic Unit	Geologic Unit	Description	Zone	Spatial Distribution	Well Yield
Bedrock Aquifer 3	Salina Formation	Dolostone to dolomitic Shale	Bedrock	Regional (west central to southern portion of Watershed)	Moderate to Low
Bedrock Aquifer 4	Guelph Formation	Dolostone	Bedrock	Regional (north eastern portion of Watershed)	Moderate to High
Bedrock Aquitard 1	Eramosa Member	Black, Shaley Dolostone	Bedrock	Regional although discontinuous (north eastern portion of Watershed)	Low to Moderate
Bedrock Aquifer 5	Amabel Formation	Dolostone	Bedrock	Regional (north eastern portion of Watershed)	Moderate to High
Bedrock Aquitard 2	Clinton-Cataract Group	Sandstone, Dolostone, shaley interbeds	Bedrock	Regional	Low to Moderate
Bedrock Aquitard 3	Queenston Formation	Red shale / blue shale	Bedrock	Continuous, fracturing varies by layer but is greatest in upper 3-5 m if at contact	Low

Mapping the distribution of these hydrostratigraphic units in the Study Area was completed by interpolating the aquitard/aquifer classification (i.e. surface elevations and isopachs) of each borehole (WHI, 2005). The distribution mapping was verified using regional cross-sections (WHI, 2005).

The division of the Guelph and Amabel Formations in the current study was completed as follows: the permeable portion of the Amabel Formation was specified as a 30 m thick unit along the base of the former layer, and the Eramosa Member was represented as an 11 m thick unit directly overlying the Amabel unit. These constant thickness values were generalized from mapped isopachs created through the Guelph-Puslinch Groundwater Study (Golder, 2006). Where the thickness of the unit was less than 1 m, the additional layers were truncated to a minimum thickness of 1 m. The interpolated layer elevations were then used to generate the structure for the three-dimensional groundwater flow model.

2.3.2 Significant Aquifers

Groundwater is the most important water supply source within the Grand River Watershed. More than 80% of the water supply in the Watershed is extracted from groundwater, including municipal water supply for the local municipalities and for rural domestic users. The municipalities of Kitchener, Waterloo, Cambridge, and Guelph represent the largest municipal groundwater users in the Province of Ontario. Many smaller communities also rely on groundwater to meet their water supply needs.

Singer et al. (2003) provides a summary of most of the key aquifers relied upon for water supply in the Grand River Watershed. These aquifers, in addition to others identified through this study, are described in Table 2.3.

Table 2.3 - Aquifers within the Grand River Watershed

Name	Description
Overburden Aquifers within the Regional Municipality of Waterloo	The **Waterloo Moraine** within the Region of Waterloo provides a source of overburden aquifers that support a number of high capacity wells. Due to the complexity of the Moraine, the lateral and vertical continuity of these deposits remains a complex issue. From a regional point of view, however, groundwater flow is characterized by having high recharge rates throughout the Waterloo Moraine with groundwater discharging to the Grand and Nith Rivers.
Bedrock Aquifers within the Regional Municipality of Waterloo	The bedrock units in Cambridge provide an excellent water supply. The **Guelph and Amabel Formations** primarily act as one unit within the Cambridge area – the Eramosa member is not found to be an aquitard throughout most of Cambridge.
Guelph Bedrock Aquifers	Most of Guelph's water comes from a permeable zone within the **Amabel Formation** which is locally referred to as the "Production Zone". The Eramosa member of the Amabel Formation acts as a low permeability aquitard for the Guelph water supply; however the extensiveness of the Eramosa member is not certain.
The Guelph and Amabel Formations	In general, the **Guelph and Amabel Formations** provide an ample water supply for rural residents and many smaller towns throughout their subcrop region (Fergus, Elora, Arthur, etc.)
The St. George Aquifer	The **Galt Moraine** yields two local aquifers to the north of St. George; a deep aquifer consisting of 3.0 to 5.0 m thick gravel deposits, and a shallow aquifer of sand and gravel.
The Norfolk Sand Plain Aquifer	The **Norfolk Sand Plain**, extending between Brantford, Boston and Cathcart, this area is covered by sand and gravel of ice-contact and outwash origins and by some Port Stanley till.
Orangeville Moraine Aquifer	While municipal wells do not directly tap the **Orangeville Moraine**, it does provide a major recharge source for the bedrock wells located within the town of Orangeville, just outside of the Watershed.

There are also many other local aquifer systems within the overburden deposits scattered throughout the Watershed, many of which support the water supply for local towns or villages (Grand Valley, Drayton, Rothsay, Arthur, Flordale, Hawksville, Damascus, New Hamburg). In addition, smaller moraine features generate local aquifer systems that supply rural residential and agricultural water supply systems (Easthope, Chesterfield, Norwich, Macton, Moffat, and Paris/Galt Moraines).

2.3.3 Groundwater Levels (Potentiometric Surfaces)

The GRCA (Holysh et al., 2001) produced two water level surfaces to understand and visualize groundwater flow directions within the Watershed; these surfaces include maps of the shallow watertable elevation, and the potentiometric elevation for deeper wells. MOE water well record data used to prepare these surfaces do not show the influence of municipal pumping; as a result, actual groundwater levels in the municipal wellfield areas would be lower than those illustrated on the maps in the Guelph and Region of Waterloo areas. Furthermore, mapping water levels at this regional scale does not follow specific aquifer units; however, the maps provide a reasonable representation of regional flow conditions. While it is understood that some uncertainty exists in the water levels reported in the MOE water well database, these water levels do provide a reasonable characterization of groundwater flow at the regional scale.

The following information can be interpreted from these maps:

- The watertable elevation map was produced using the water levels for all wells less than 35 m deep reported in the Ministry of Environment's water well database. As shown on Figure 14, the

Grand River and its tributaries are shown to have a significant influence on groundwater movement within that zone throughout the Watershed.

- The second water level surface (potentiometric surface) was produced using the deeper wells in the Watershed (greater than 35 m deep). Figure 15 indicates that the deeper groundwater generally moves in a similar direction to the shallow groundwater, with the highest potentiometric elevations found in the north part of the Watershed. The major river systems, as well as the Dundas Valley, are also observed to influence groundwater movement in the deeper subsurface units within the Watershed.

2.3.4 Groundwater Monitoring

Throughout the Grand River Watershed many groundwater monitoring wells are maintained by the Province, municipalities, and private organizations. Figure 16 shows the locations of selected monitoring wells in the Watershed provided by the City of Guelph, the Region of Waterloo, and the Provincial Groundwater Monitoring Network (PGMN). The groundwater monitoring undertaken by the City of Guelph and the Region of Waterloo are primarily focused on monitoring groundwater levels in the vicinity of their municipal wellfields within or near their urban boundaries. Appendix B provides a list of the PGMN wells and the monitoring wells maintained by the City of Guelph and the Regions of Waterloo in the Watershed.

The Provincial Groundwater Monitoring Network (PGMN) is a partnership program between the MOE, 36 Ontario Conservation Authorities and 10 municipalities (in areas not covered by a Conservation Authority). The PGMN partners collect and manage ambient (baseline) groundwater level and water quality information from key aquifers across Ontario. The locations of PGMN wells in the Grand River Watershed are shown on Figure 16. Figures 17 to 23 are the groundwater level hydrographs from eight PGMN wells in the Watershed. In addition to providing insight into the response of the groundwater system to short term climate variation, this data is also valuable for monitoring and detecting the effects of changes in longer term climate variability or climate change. The PGMN network is well suited for monitoring climate change impacts, as their primary objective is to monitor ambient groundwater levels and therefore should be less impacted by groundwater pumping and land use changes than municipal observation networks.

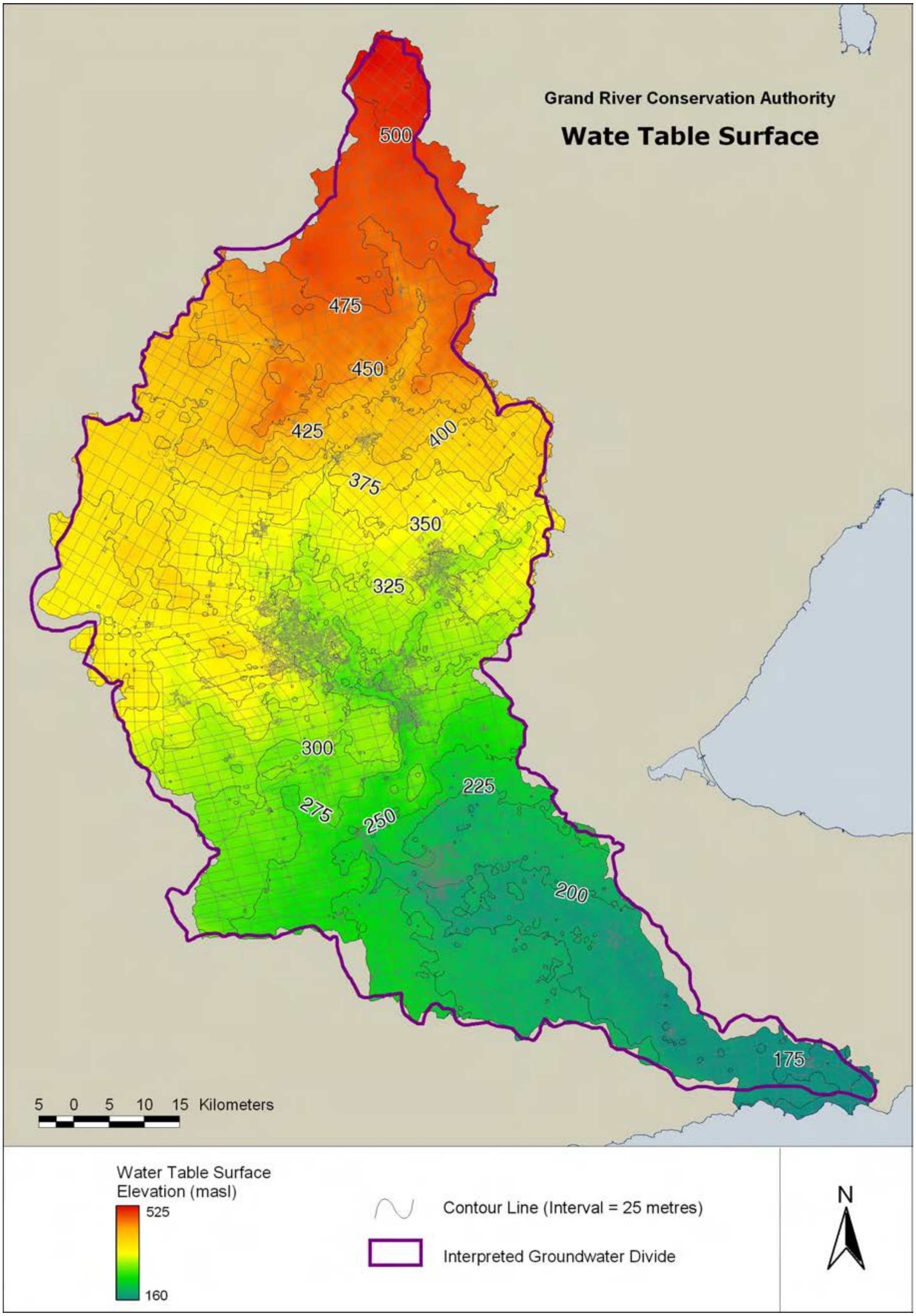

Figure 14
Water Table Surface

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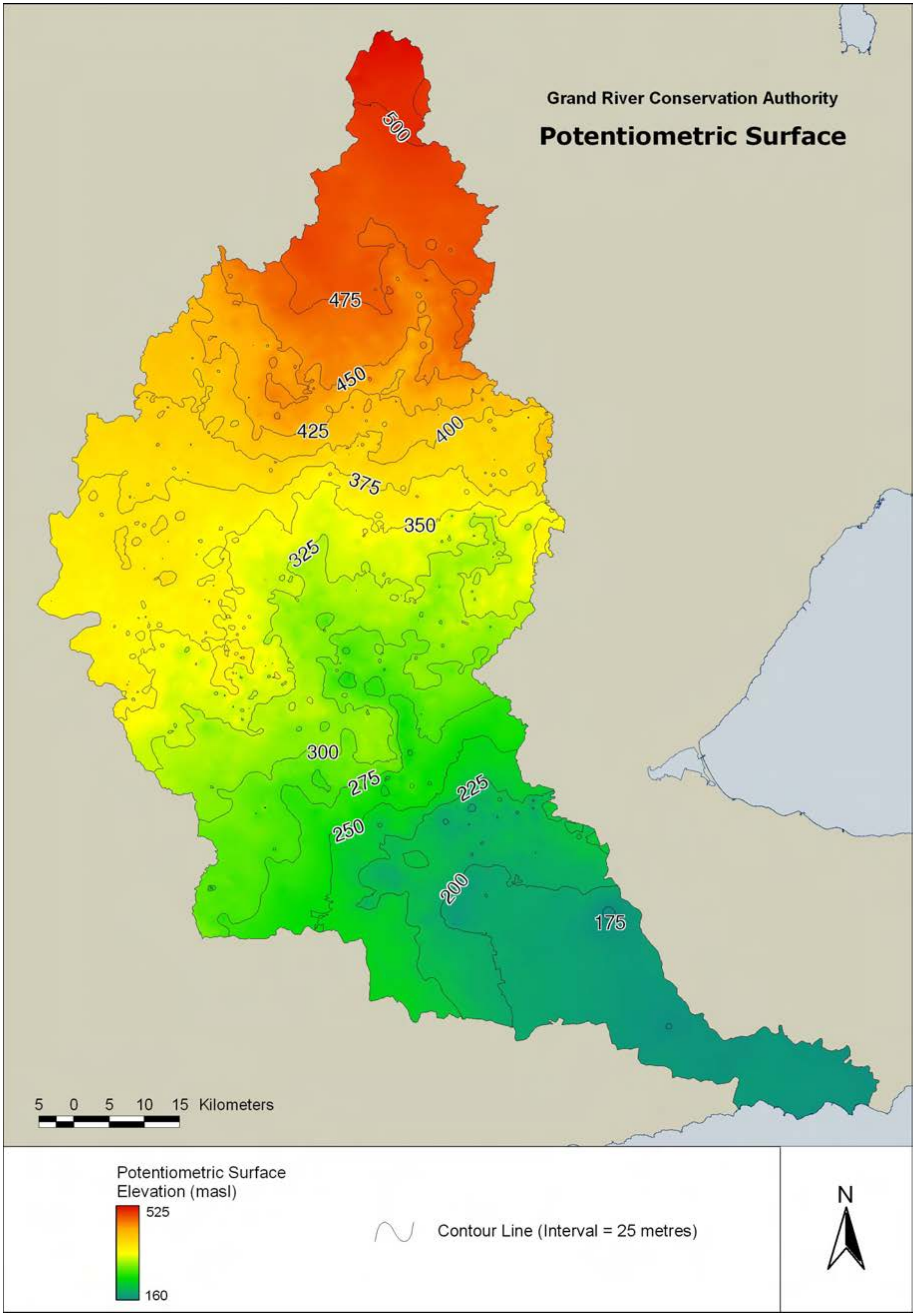

Figure 15
Potentiometric Surface

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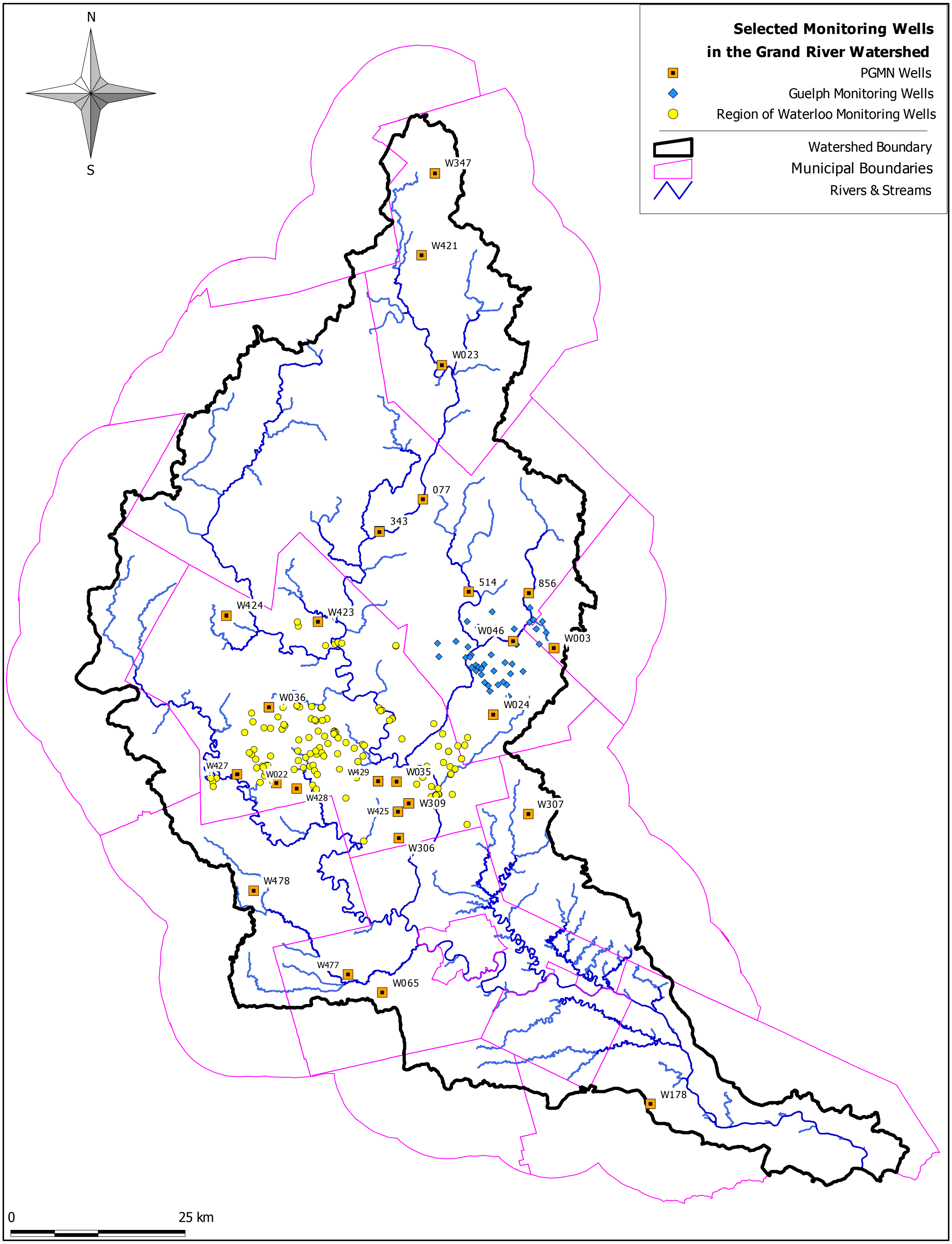

Figure 16
Selected Monitoring Wells

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Figure 17 shows the well hydrograph from Dundalk, in the headwaters of the Watershed. A bedrock well drilled in the Guelph Formation Aquifer shows the seasonal variability of groundwater levels. Winter and spring high water levels precede decreasing water levels measured over the spring and summer months.

Figure 18 illustrates shallow overburden groundwater levels in the Paris Moraine in Puslinch. The water levels shown in this hydrograph also reveal seasonal trends, but these trends are less variable than in Figure 18. The chart also shows an increasing trend in groundwater levels from 2001 until 2008.

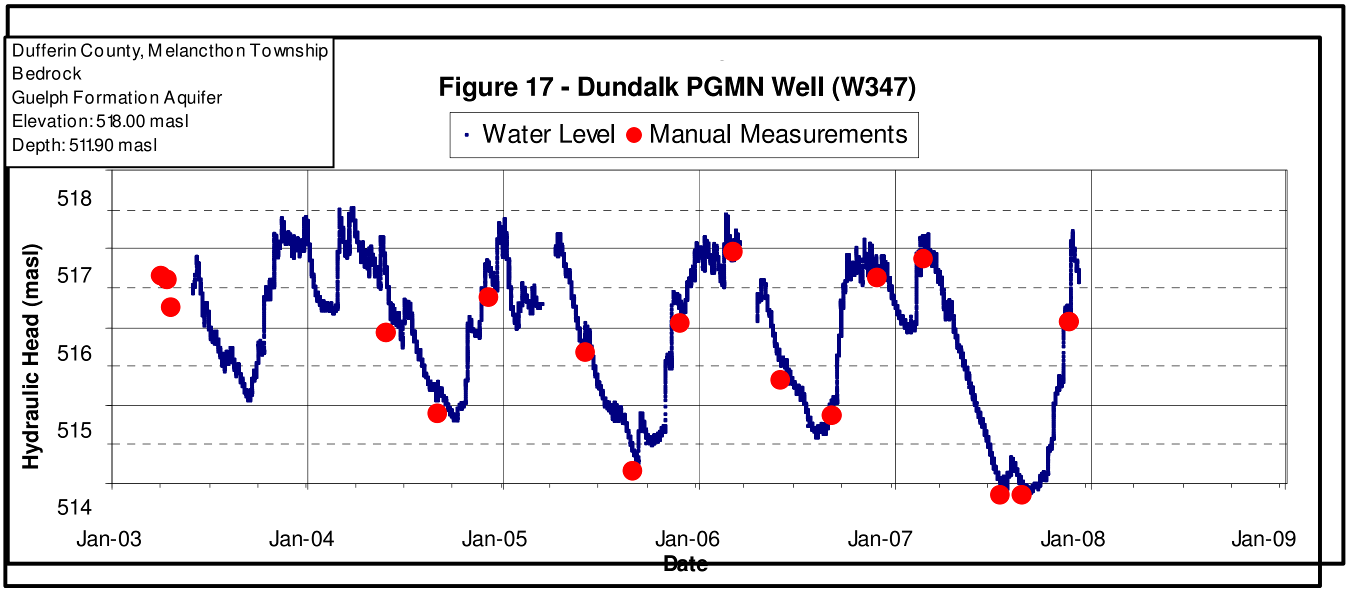
Figure 19 shows a New Hamburg PGMN shallow overburden well in the Waterloo Moraine Aquifer. The New Hamburg well is completed in shallow overburden and shows water levels that are much more responsive to hydrologic events than the Puslinch well. Several sharp peaks in groundwater levels in the winter and early spring months may be caused by high recharge events.

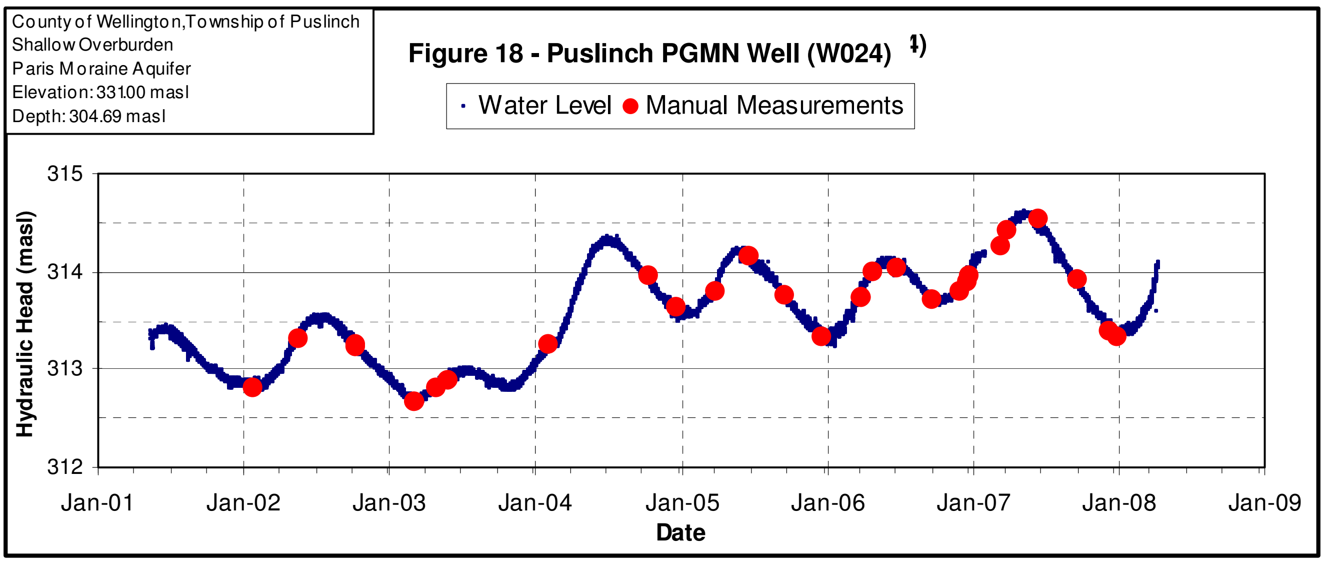
Figure 20 displays the hydrographs of two wells drilled into the deep overburden near Edworthy Road, in the Waterloo Moraine Aquifer. Well W309-3 is the deeper of the two wells and while it shows consistently lower water levels, the trend in annual variability of water levels is uniform in both hydrographs.

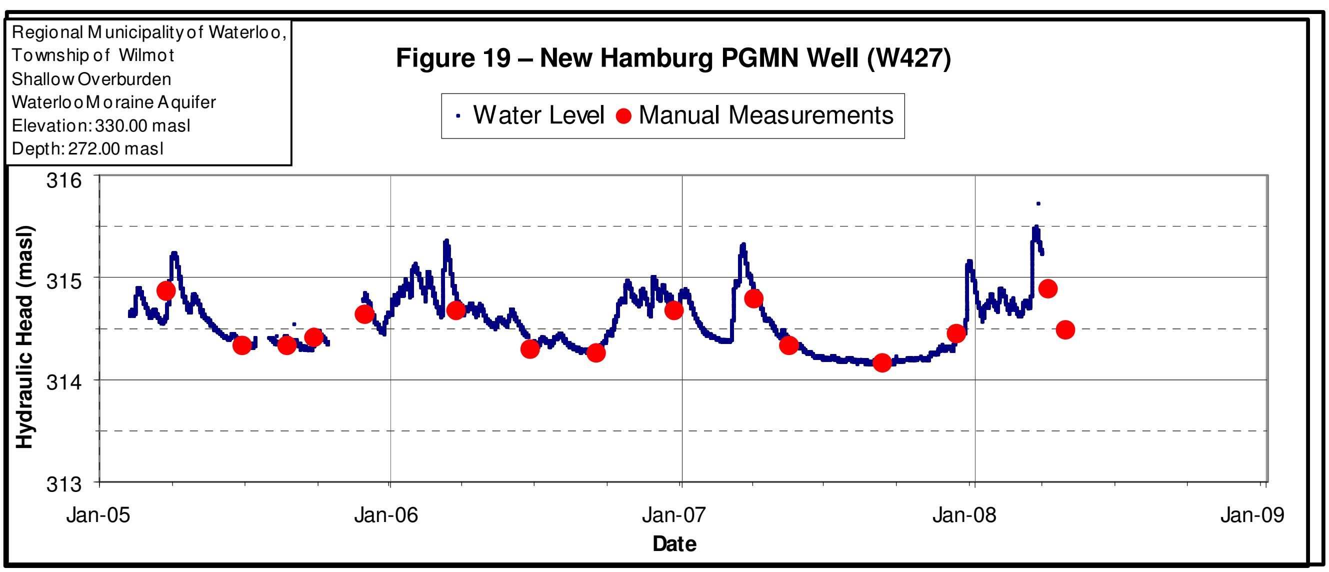
South of Waterloo and Kitchener in the center of the Watershed, the Bannister Lake PGMN bedrock well (Guelph Formation) is shown in Figure 21. This figure shows seasonal water level variability of 1 to 1.5 m and a slight upward trend from 2003 to 2008.

Figure 22 illustrates data from the Burford PGMN shallow overburden well in the Norfolk Sand Plan Aquifer. The lower water levels shown in 2001 – 2003 are offset by consistent water levels between 2004 and 2007, annually fluctuating 0.5 m between the higher water levels in the spring and the lower water levels in the winter.

The last PGMN well, shown in Figure 23, is from the lower reach of the Grand River Watershed, a bedrock well in Cayuga drilled in the Oriskany Formation Aquifer. Despite being a bedrock well, the Cayuga well is similar to the shallow overburden New Hamburg well, with water levels responsive to hydrologic events in the winter and spring each year by peaking several times. In 2005, water levels range by almost 4 m over the course of the calendar year.







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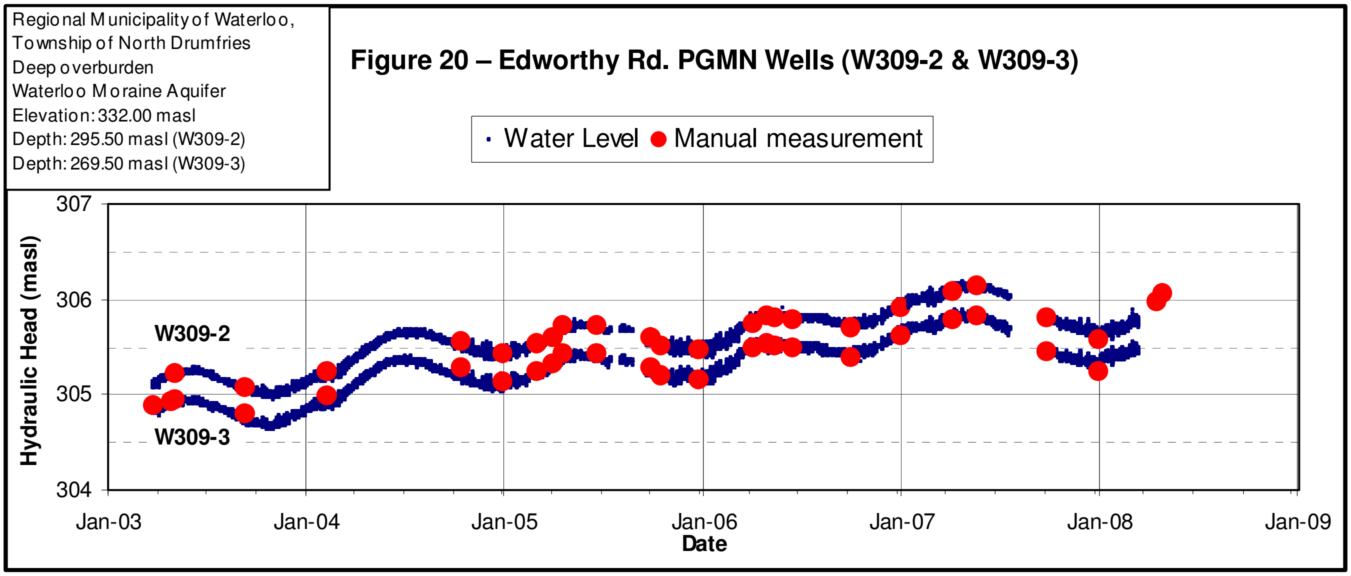


Figure 20 – Edworthy Rd. PGMN Wells (W309-2 & W309-3)

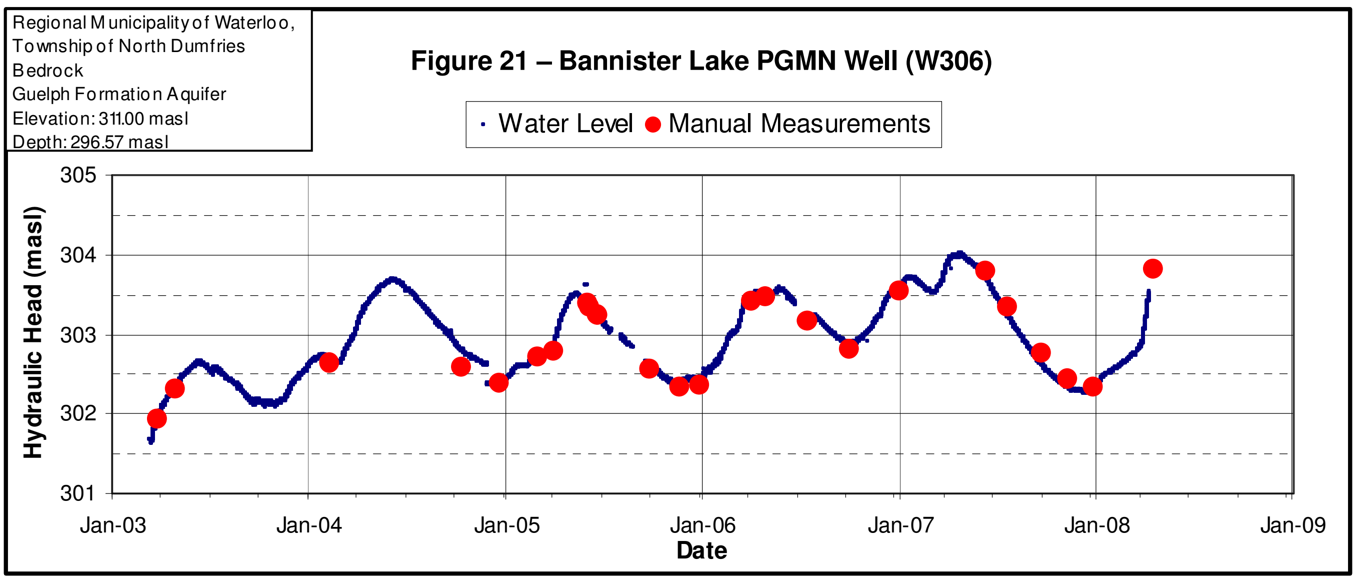


Figure 21 – Bannister Lake PGMN Well (W306)

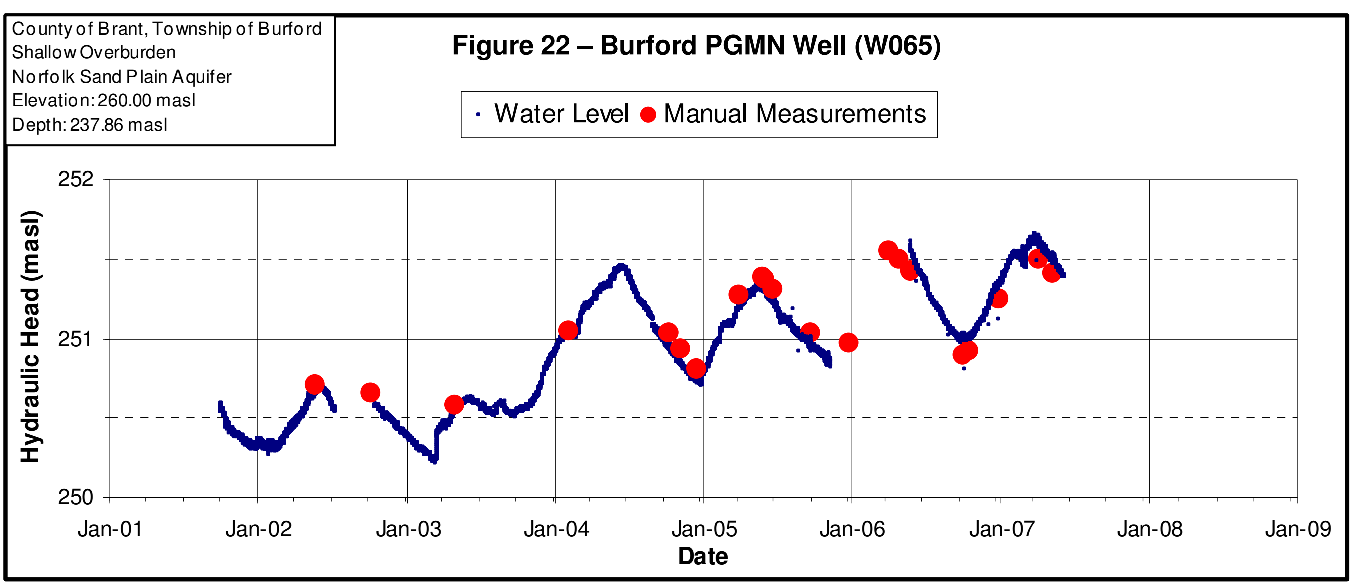
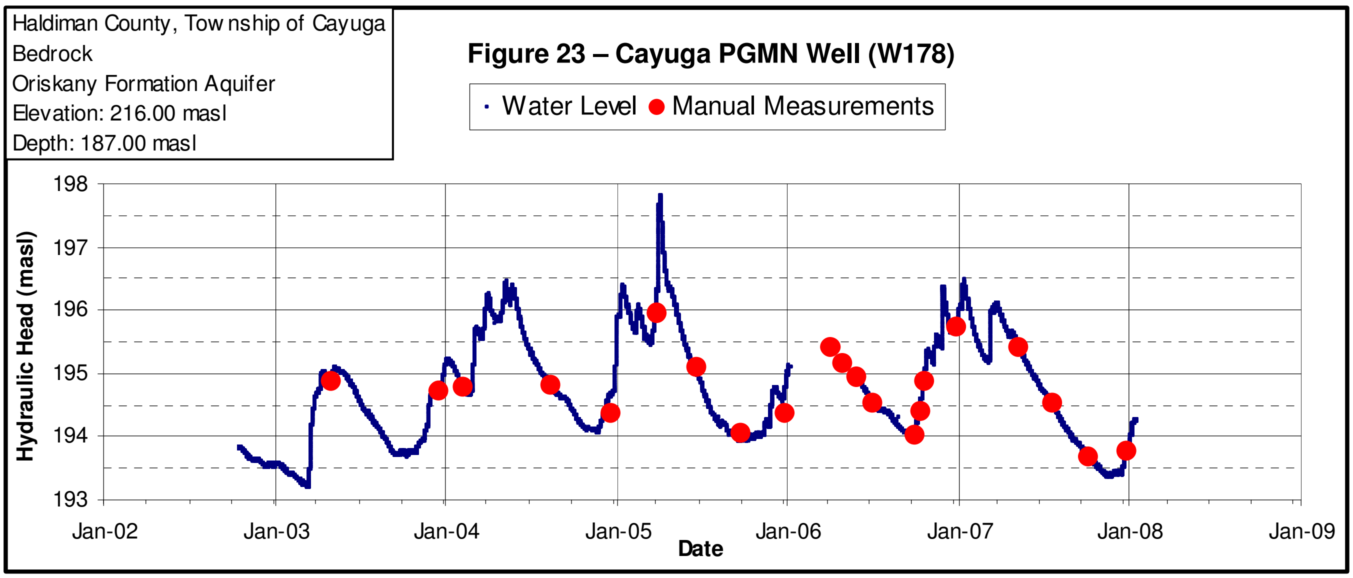


Figure 22 – Burford PGMN Well (W065)


Haldiman County, Tow nship of Cayuga
Bedrock
Oriskany Formation Aquifer
Elevation: 216.00 masl
Depth: 187.00 masl
Figure 23 – Cayuga PGMN Well (W178)
Water Level
Manual Measurements
Hydraulic Head (masl)
198
197
196
195
194
193
Jan-02
Jan-03
Jan-04
Jan-05
Jan-06
Jan-07
Jan-08
Jan-09
Date

2.4 SURFACE WATER HYDROLOGY

This section provides a summary of Grand River Watershed's surface water resources. The basic hydrologic processes including precipitation and evapotranspiration are outlined, followed by a brief discussion of each Watershed Area.

2.4.1 Precipitation

Precipitation includes rainfall, snowfall, freezing rain, sleet, and hail and is measured at various locations in the Watershed. Figure 24 shows the locations of GRCA rain gauges, GRCA snow courses, and Environment Canada climate stations.

Climate normals are published by Environment Canada to describe average climatic conditions during the 1971-2000 period. Climate stations with at least 15 years of data have climate normals published. Figure 25 shows a continuous map of average annual precipitation created by interpolating the Environment Canada climate normals. Although GRCA collects additional climate data, these data are not available consistently throughout the simulation period and therefore were not used in the analysis.

Average annual precipitation is variable across the Grand River Watershed, ranging from more than 1000 mm/y in the north down to 900 mm in the central and southern portions of the Watershed. There is also a decrease in precipitation from west to east.

2.4.1.1 Annual Variability

Climate varies naturally on timescales ranging from seasons to the tens of thousands of years between ice ages. Mid-term climate trends in the Grand River Watershed have been observed by significant droughts in the 1930's, 1960's, and 1990's, and shorter-term trends are observed by intermittent sequences of cold and warm, and wet and dry years. These observations of climate variability are typically explained by a number of factors including global climate systems (e.g., El Nino), variability in solar intensity (e.g., sunspot cycles) and short-term unpredictable "chaotic" behavior.

Figure 26 shows average annual precipitation at three locations in the Grand River Watershed and also highlights the average of these three locations. Although the chart shows definite long-term trends (i.e. droughts in the 1960's and 1990's), it also highlights annual variability and also significant variability in different areas in the Watershed within the same year. More than two-thirds of the "maximum precipitation" values in the figure occur in the Upper Grand and more than two-thirds of the "minimum precipitation" values occur in the Middle Grand. There is a dip in precipitation in the Middle Grand, with higher precipitation amounts in both the Upper and Lower Grand. Considering the precipitation variability shown by Figure 26, significant annual variability in the simulated hydrologic water budget parameters (i.e., runoff, evapotranspiration, and recharge) is also expected.

2.4.1.2 Snowfall

Figure 27 illustrates an interpolated image representing average annual snowfall created from published climate normals. The impact of lake-effect snowfall is apparent in the northern areas of the Watershed, with annual snowfall totals in excess of 250 cm in the northern portion declining to 150-200 cm in the central portion. For the southern portion of the Watershed, snowfall is more uniform, with annual averages in the 100-150 cm range.

Snow redistribution, sublimation and melt are all important processes that dramatically affect the water budget at a seasonal scale.

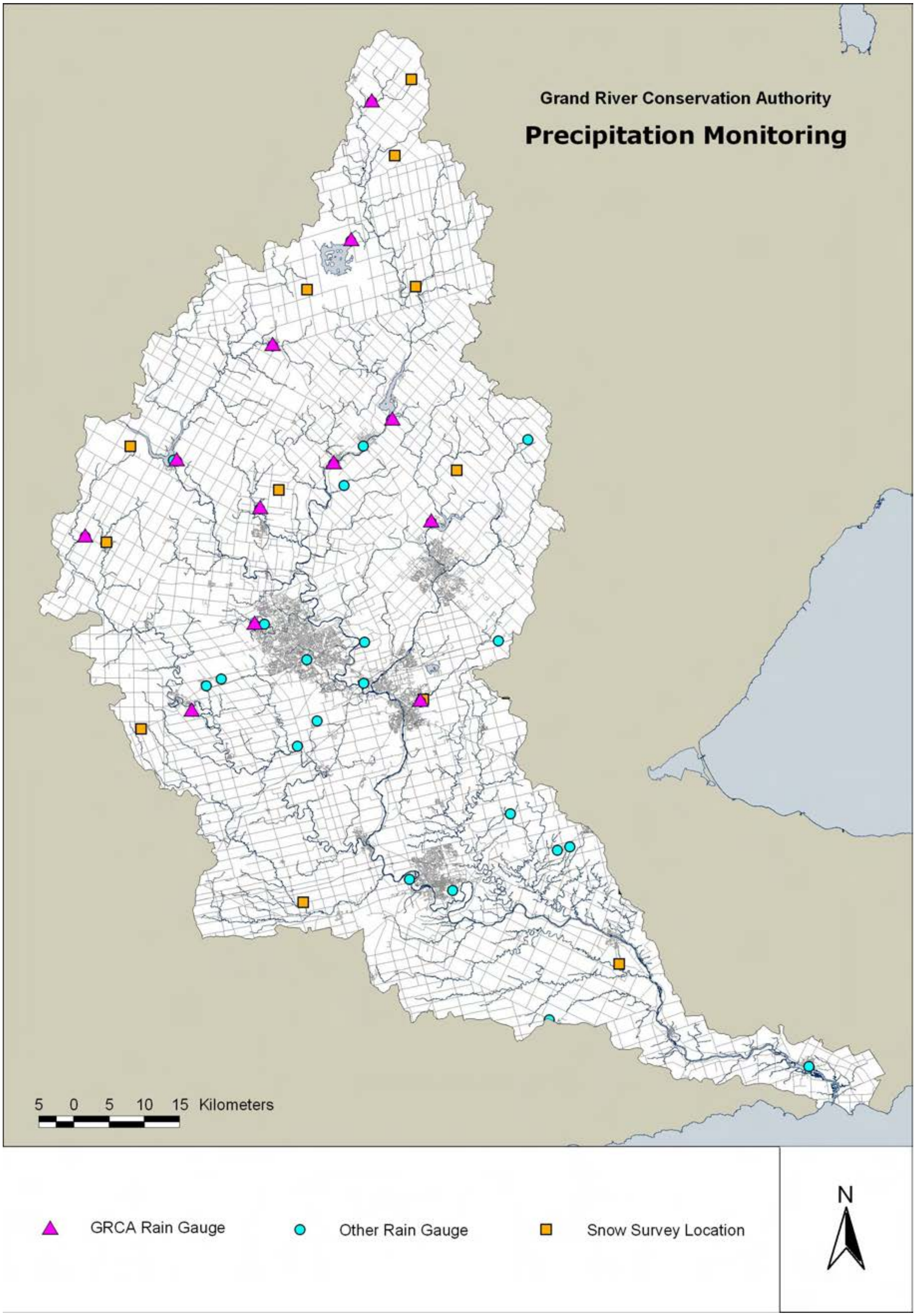


Figure 24
Climate Stations

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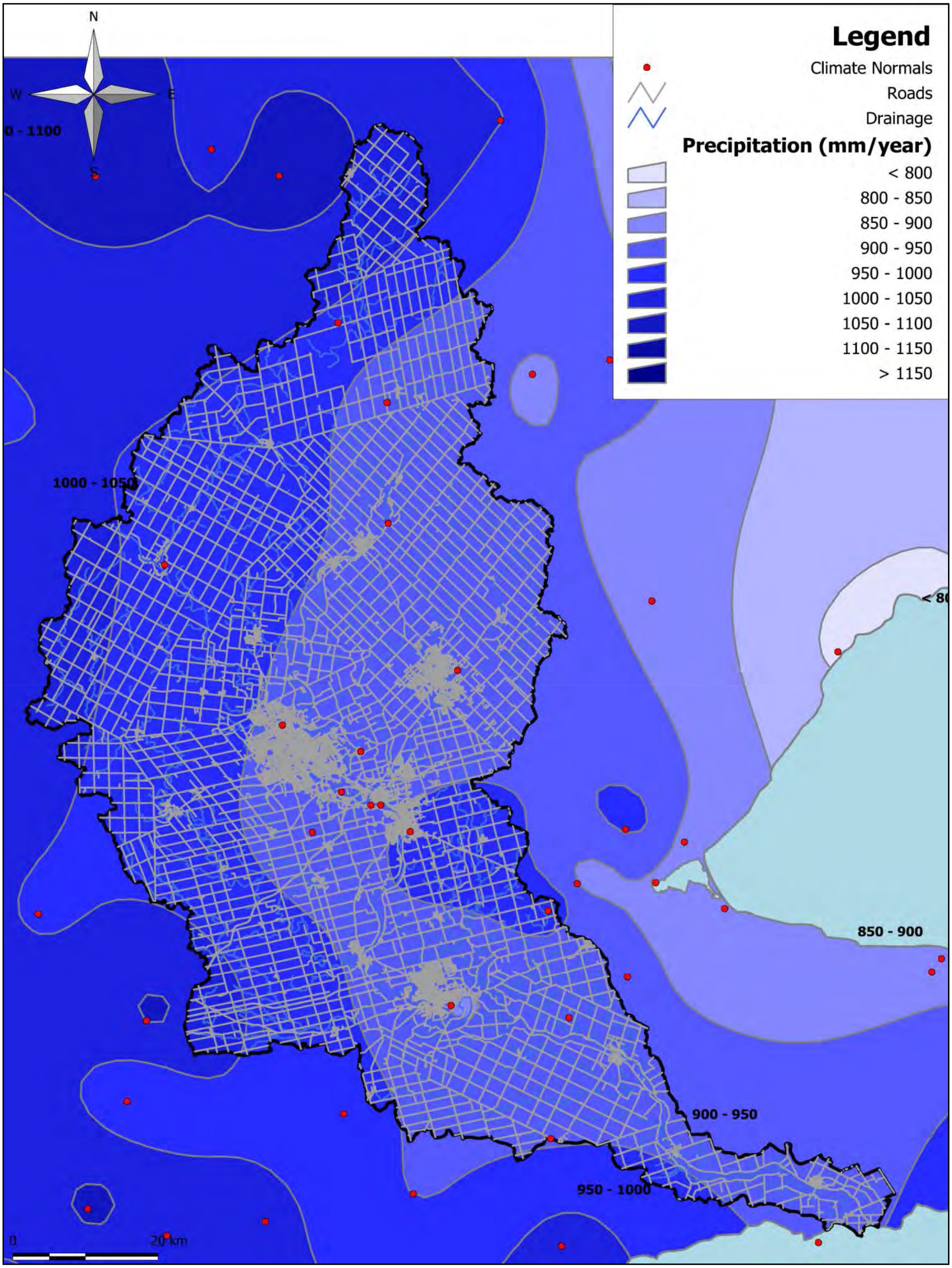

Figure 25
Annual Precipitation

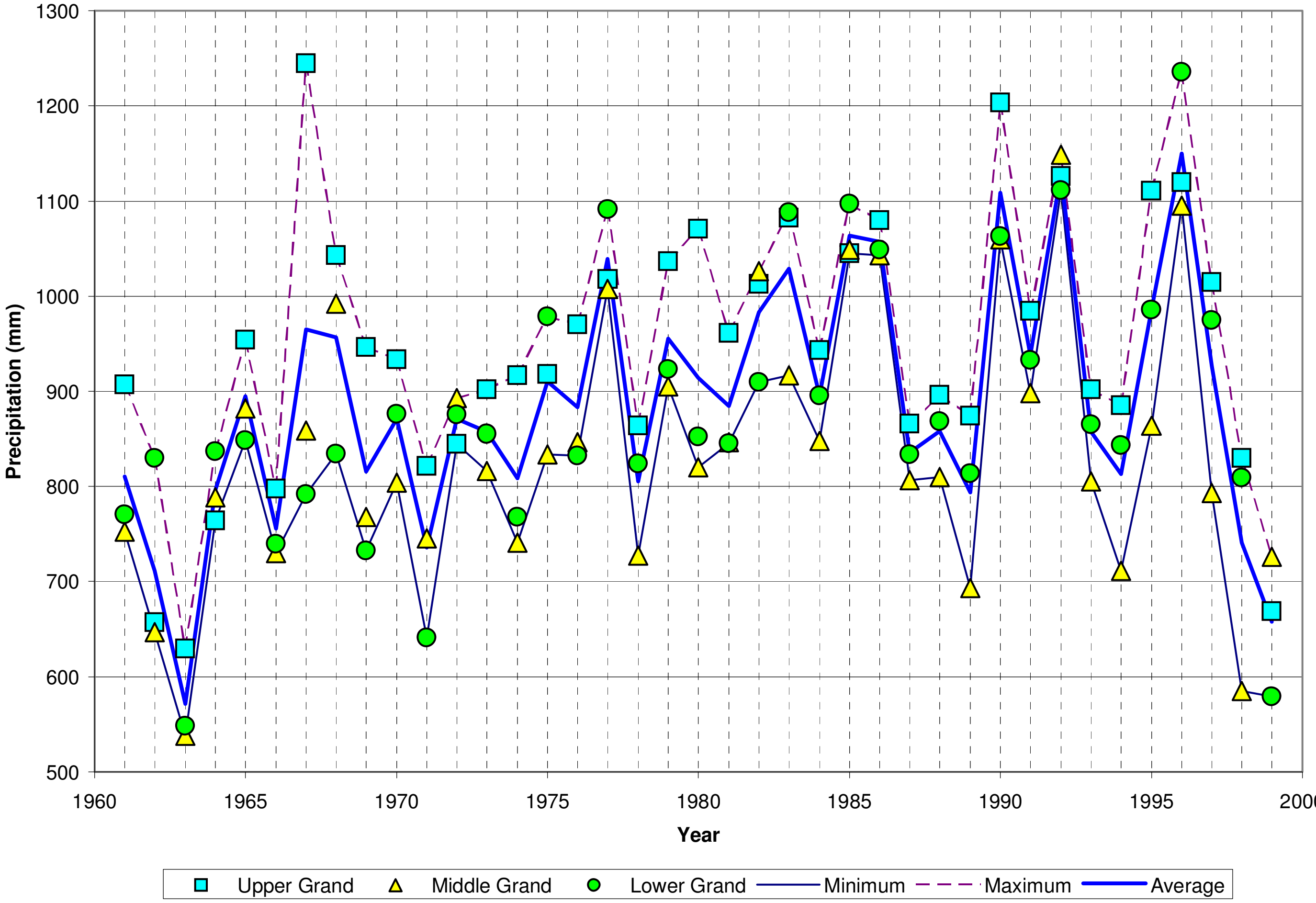

Figure 26
Annual Precipitation Variability

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2.4.2 Evapotranspiration

Evapotranspiration represents the total amount or rate of transfer of liquid or solid water into atmospheric water vapour at the Watershed surface. Evapotranspiration is the sum of sublimation of snow or ice, evaporation of liquid water in surface depressions (streams, ponds or lakes), evaporation of liquid water in leaf stomata (transpiration), evaporation of liquid water in soil water pores exposed to the atmosphere, and evaporation from groundwater in locations where the watertable is exposed to the atmosphere. In summer, and for vegetated surfaces, the main contribution to evapotranspiration is transpired water.

After precipitation, evapotranspiration is usually the largest component of the water budget. Unfortunately, it is often the least understood process since it cannot be accurately measured with conventional monitoring techniques. It is typically estimated as the residual hydrologic term after measuring precipitation and streamflow.

Provincial estimates of mean annual evapotranspiration are documented in the Water Quantity Resources of Ontario (MNR, 1984); they are calculated by subtracting mean annual streamflow from mean annual precipitation. Over the long term, the difference between annual streamflow and precipitation equals annual evapotranspiration. For the Grand River Watershed, average annual evapotranspiration is estimated to be 400-500 mm/y in the north, 600 mm/y in the extreme south, and generally 500-600 mm/y over the majority of the Watershed.

2.4.3 Wetlands

Wetlands play an important role in many of the Watershed's hydrological and ecological processes. The hydrologic functions of wetlands vary; some wetlands are groundwater discharge areas providing sustained baseflow during low flow periods, and others retain surface runoff, reduce flood flows, and also augment low flows. In addition, wetlands also provide a positive water quality benefit, effectively acting as water filters, capturing sediment, dissolved nutrients and other contaminants. Wetlands are also typically highly productive ecological habitats, with great biodiversity, and often home to threatened species.

Table 2.4 summarizes the Provincially Significant Wetlands greater than 500 ha in size in the Grand River Watershed as mapped by the MNR.

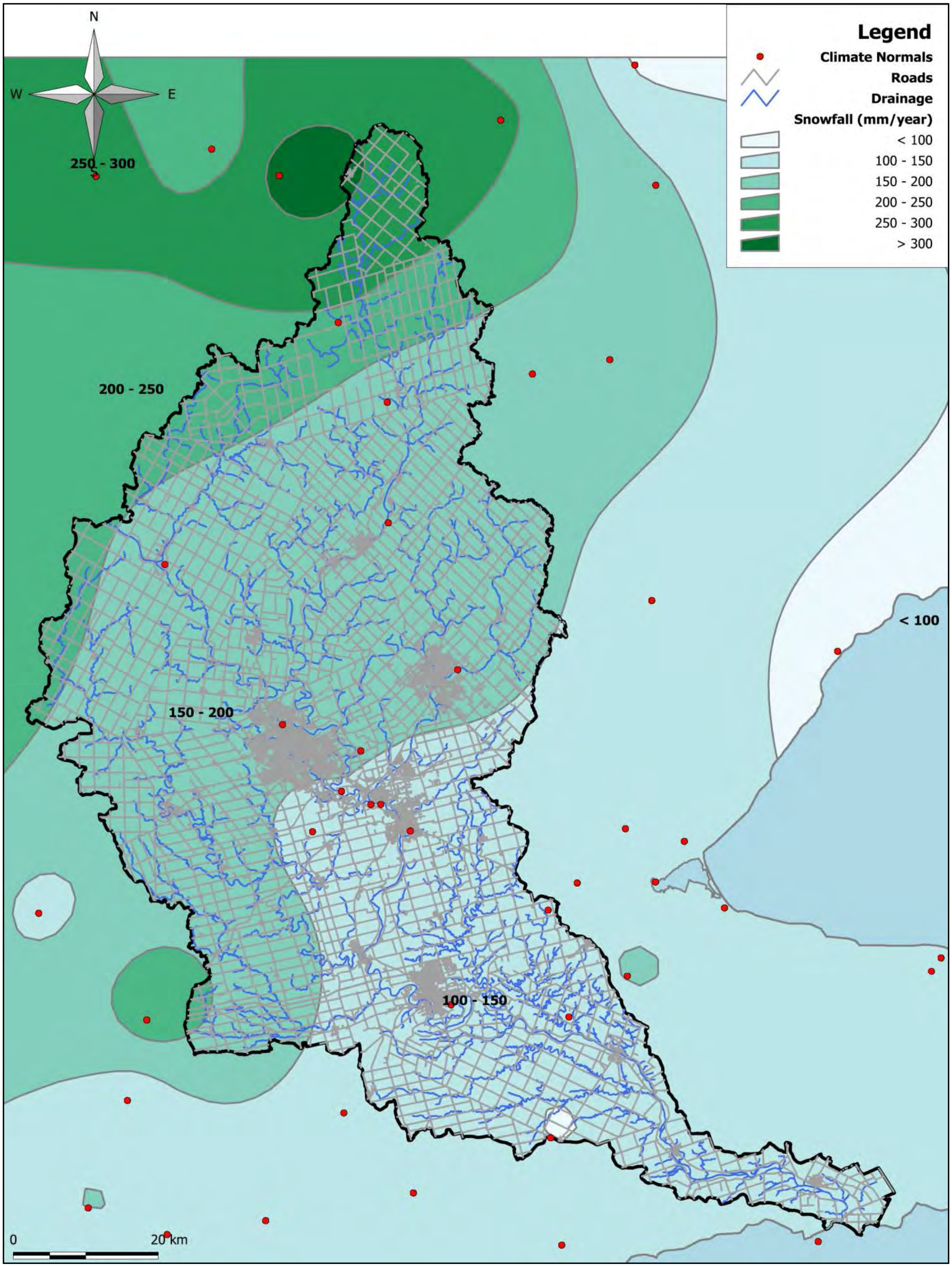

Figure 27
Annual Snowfall

Table 2.4 - Wetland Complexes (Area Greater than 500 ha)

Official Wetland Complex Name (MNR, 2005)	Primary Sub-Watershed	Other Subwatersheds	Area (ha)
Speed - Lutteral - Swan Creek Wetland Complex	Speed Above Dam	Grand Above Conestogo To Shand Eramosa Above Guelph	5,515
Central Whitemans/Horner Creek Complex	Whitemans Creek	Nith Above Grand to New Hamburg	3,902
Luther Marsh	Grand Above Legatt	Grand Above Shand to Legatt	3,869
Melancthon Wetland #1	Grand Above Legatt		2,817
Whitemans Creek - Kenny Creek Wetland Complex	Whitemans Creek		1,851
Eramosa River - Blue Springs Creek Wetland Complex	Eramosa Above Guelph		1,586
Mill Creek Wetland	Mill Creek		1,510
Sheffield - Rockton Complex	Fairchild Creek		1,286
Keldon Swamp	Grand Above Legatt		921
Grand River Marshes	Grand Above Dunnville to York		913
Ellice Swamp	Nith Above New Hamburg		870
Beverly Swamp Complex	Fairchild Creek		853
Oakland Swamp	McKenzie Creek		788
Sunfish Lake - Laurel Creek	Grand Above Doon to Conestogo	Nith Above New Hamburg	757
Speed River Wetland Complex	Speed Above Grand to Armstrong		712
Marden South Complex	Speed Above Grand to Armstrong	Speed Above Dam Grand Above Doon to Conestogo	667
Willow Brook Swamp	Grand Above Shand To Legatt		662
Roseville Swamp - Cedar Creek Wetland	Grand Above Doon to Conestogo	Nith Above Grand to New Hamburg	603
North Cayuga Slough Forest (Young Tract)	Grand Above Dunnville to York		539

2.4.4 Water Control Structures

The Grand River Watershed is a highly regulated basin; operation and maintenance of its flow control structures plays a critical role in flood control and low flow augmentation. In 1942, the Grand River Conservation Commission completed the Shand Dam, the first multi-purpose dam in Canada, built for flood control and low flow augmentation to improve water quality during the dry summer months. A series of multi-purpose reservoirs were constructed in the decades that followed to provide similar control over stream flows. The 7 major control structures managed by the GRCA are summarized in Table 2.5.

Table 2.5 - Significant Water Control Structures

Dam	River (Watershed Area)	Purpose	Year Built	Dam Type	Max Storage (Million m^3)	Height (m)	Drainage Area (km^2)
Shand	Upper Grand River	Flood Control, Low Flow Augmentation	1942	Earth Fill	63.7	25.9	800
Conestogo	Conestogo River	Flood Control, Low Flow Augmentation	1958	Earth Fill	59.5	24.4	570
Luther	Upper Grand River	Low Flow Augmentation and Conservation Area	1954	Earth Fill	23.3	7.0	64
Guelph	Speed River	Flood Control, Low Flow Augmentation	1976	Earth Fill	20.5	19.9	230
Woolwich	Canagagigue Creek (Upper Grand River)	Flood Control, Low Flow Augmentation	1974	Earth Fill	5.5	18.3	50
Shades Mills	Mill Creek (Central Grand River)	Storage and Recreation	1970	Earth Fill	2.4	7.8	105
Laurel	Laurel Creek (Central Grand River)	Flood Control and Recreation	1966	Earth Fill	1.6	6.1	30

The current reservoir network operation approach was designed in the 1982 Grand River Basin Study. The Basin Study optimized the operation of the dams to meet downstream flow targets for the dual purpose of wastewater effluent assimilation and municipal water supplies, while still providing an adequate level of flood control protection. During the spring snowmelt, the reservoirs are used to reduce flood flows for downstream communities, and are also filled in order to ensure an adequate volume of water is available for low flow augmentation purposes. Throughout the summer and fall months dam outflows are adjusted to achieve downstream flow targets, as listed in Table 2.6. During significant drought conditions, 80-90% of the flow in the Grand River at Kitchener can be sustained by releases from the reservoir network storage.

Table 2.6 - Summer Flow Targets in the Grand River Watershed

Gauge Location	Summer Flow Target (m^3/s)
Grand at Legatt	0.42
Grand at Doon	9
Speed River at Edinburgh Rd	1.7
Grand River at Brantford	17

2.4.5 Surface Water Characterization

This section summarizes the main elements of the watershed areas and subwatersheds in the Grand River Watershed. Each watershed area referenced in Table 1.1 and on Figure 2 is characterized with respect to their general surficial geology and land cover. The effects of these parameters on the surface water hydrology are discussed, with reference to summaries of stream gauge data where appropriate. This section focuses on general hydrologic features and does not include features such as storm water management controls, tile drains, fractured clays, and karstic bedrock that may play large roles in local systems.

Table 2.7 summarizes the simplified surficial geology and physiography of each of the watershed areas and subwatersheds. This summary was calculated from landcover mapping produced by the GRCA. All land area is classified into the first 7 categories shown on Table 2.7. Impervious areas do not include urban areas in the table; impervious areas relate to mapping of exposed bedrock or open water within the subwatershed. Any of the land areas can be further classified as hummocky, which may indicate closed drainage areas resulting in higher recharge rates and reduced runoff.

Table 2.7 - Subwatershed Characteristics

	Area (km^2)	Impervious (Bedrock /Open Water)	Urban	Wetland	Clayey Tills	Silty Tills	Sandy Till	Sand & Gravel	Hummocky
Upper Grand River	**1,431**	**3%**	**1%**	**7%**	**47%**	**12%**	**8%**	**22%**	**3%**
Grand Above Legatt	365	5%	0%	13%	41%	0%	32%	10%	0%
Grand Above Shand To Legatt	426	2%	0%	9%	57%	1%	1%	30%	2%
Grand Above Conestogo To Shand	640	2%	1%	3%	44%	26%	0%	24%	6%
Conestogo River	**820**	**2%**	**0%**	**1%**	**72%**	**0%**	**12%**	**13%**	**11%**
Conestogo Above Dam	566	2%	0%	2%	69%	0%	16%	11%	2%
Conestogo Below Dam	254	1%	0%	1%	78%	1%	1%	18%	31%
Central Grand River	**604**	**3%**	**19%**	**5%**	**9%**	**14%**	**15%**	**34%**	**36%**
Grand Above Doon To Conestogo	248	2%	18%	5%	13%	32%	0%	30%	24%
Mill Creek	82	2%	0%	14%	1%	0%	45%	38%	50%
Grand Above Brantford To Doon	274	4%	26%	4%	7%	2%	21%	37%	42%
Speed And Eramosa Rivers	**780**	**4%**	**5%**	**7%**	**3%**	**32%**	**10%**	**40%**	**19%**
Eramosa Above Guelph	230	7%	0%	10%	1%	27%	23%	31%	36%
Speed Above Dam	242	2%	0%	7%	3%	40%	10%	47%	14%
Speed Above Grand To Dam	308	3%	11%	5%	4%	29%	0%	40%	10%
Nith River	**1,128**	**1%**	**0%**	**3%**	**46%**	**15%**	**4%**	**30%**	**28%**
Nith Above New Hamburg	545	0%	0%	3%	72%	9%	4%	12%	27%
Nith Above Grand To New Hamburg	583	2%	0%	3%	22%	21%	4%	47%	29%
Whitemans And McKenzie Creeks	**772**	**1%**	**2%**	**2%**	**58%**	**13%**	**2%**	**34%**	**5%**
Whitemans Creek	404	0%	0%	4%	25%	26%	3%	42%	7%
McKenzie Creek	368	2%	0%	1%	79%	0%	3%	14%	0%
Lower Grand River	**1,233**	**7%**	**2%**	**1%**	**65%**	**0%**	**8%**	**14%**	**4%**
Fairchild Creek	401	13%	3%	3%	42%	0%	21%	18%	11%
Grand Above York to Brantford	476	2%	4%	0%	72%	0%	2%	20%	0%
Grand Above Dunnville To York	356	8%	0%	1%	79%	0%	2%	10%	0%

There are approximately 45 continuously recording stream gauges in the Grand River Watershed, as shown in Figure 28. These stream gauges include gauges that are part of the federal/provincial stream flow monitoring partnership, gauges that are owned and operated by the GRCA, and gauges operated in partnership between GRCA and its member municipalities. These stream gauges are operated to meet a number of objectives, including: flood forecasting, low water response, subwatershed studies, and general water management.

In order to characterize hydrology across the Watershed, 16 stream gauges were selected for further analysis in this section of the report. These specific stations were selected to be representative of the GRCA's subwatersheds and are considered to provide reliable data. The selected stream gauges are shown on Figure 29 and listed along with their respective drainage areas and average streamflows in Table 2.8.

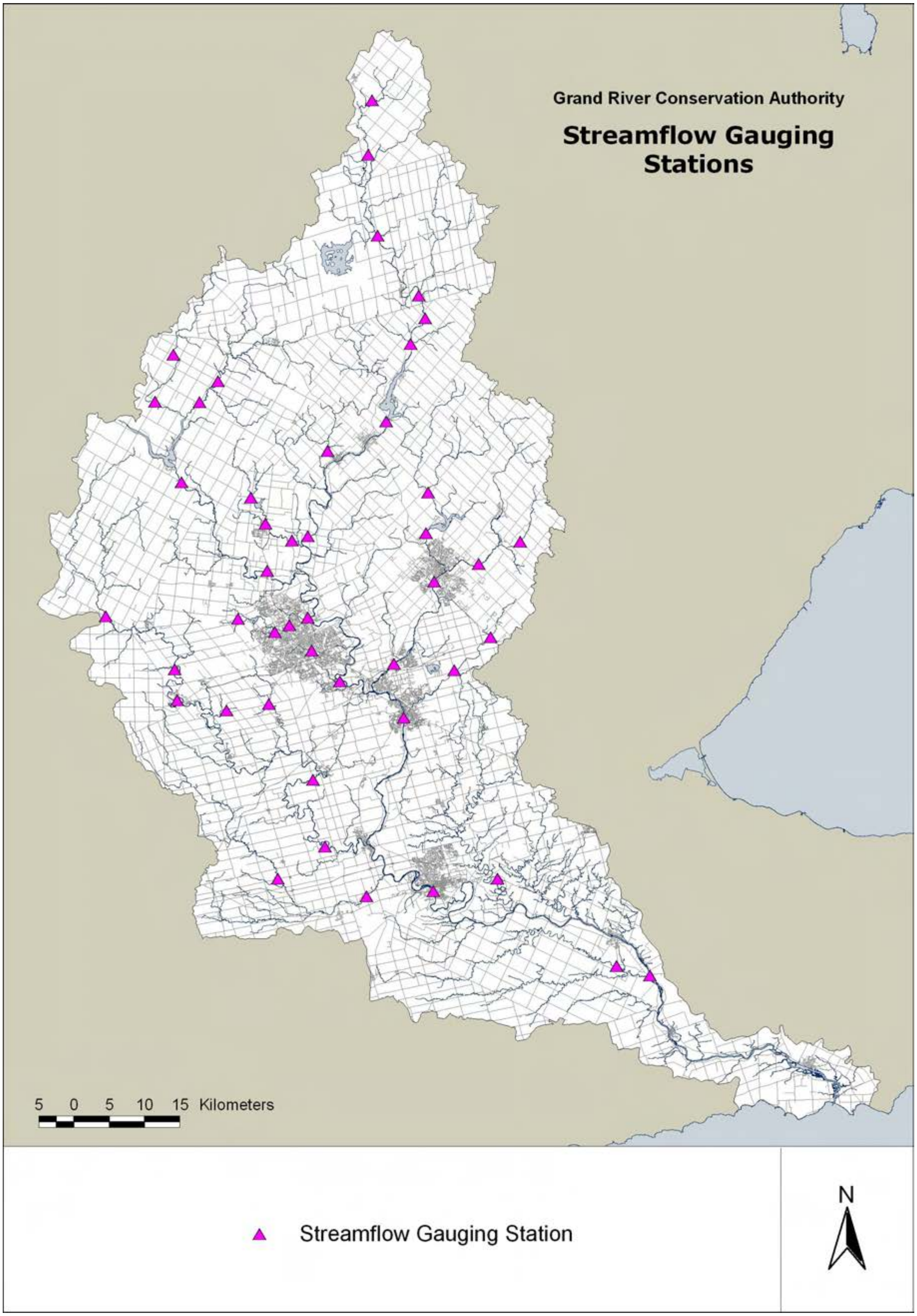

Figure 28
Stream Flow Gauging Stations

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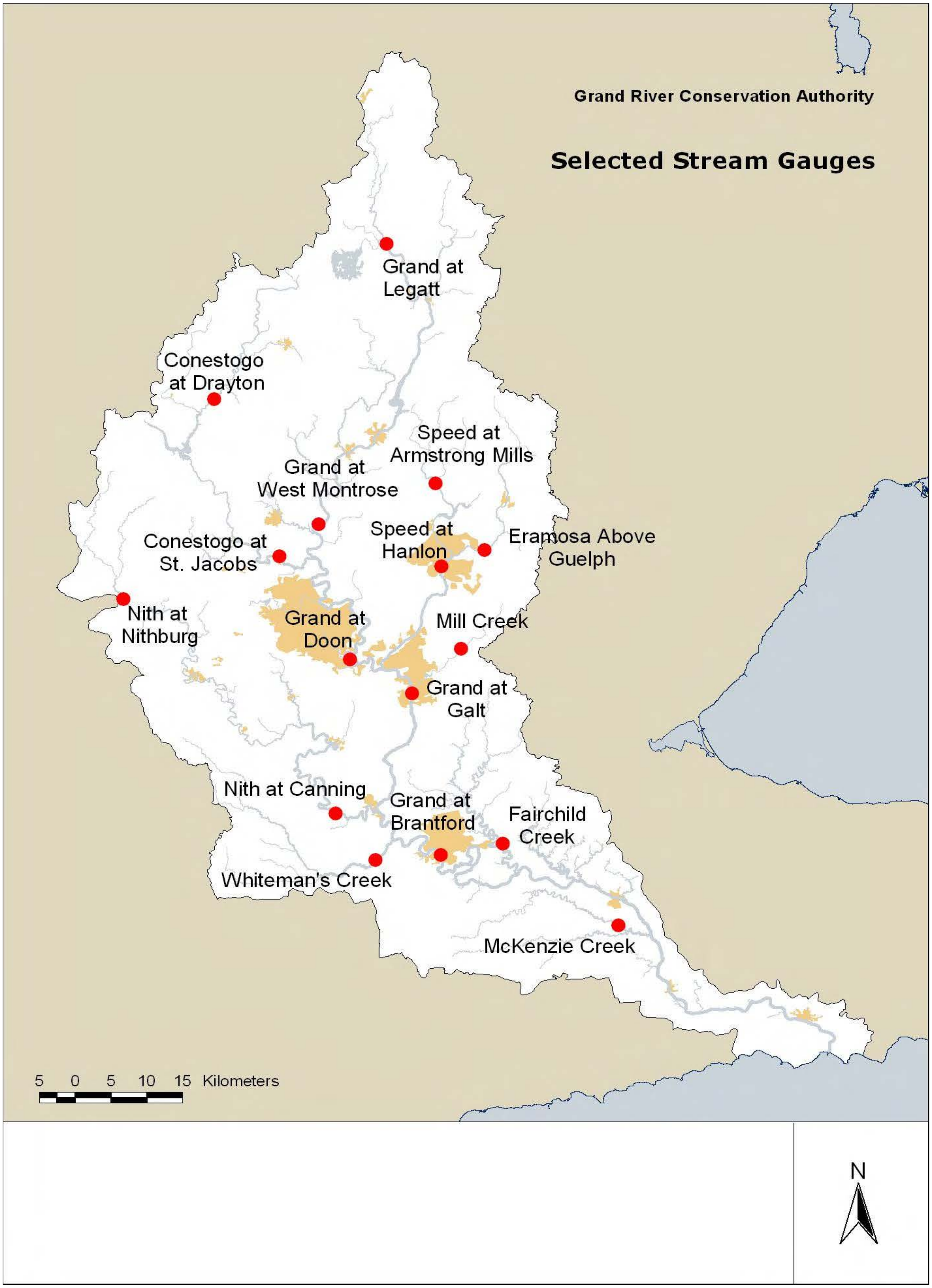

Figure 29
Selected Gauging Stations

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Table 2.8 - Summary of Subwatershed Average Flow Characteristics

Gauge	Average Flow (m^3/s)	Drainage Area (km^2)	Average Flow (mm/y)
Grand at Legatt	5.4	380	445
Grand at West Montrose	14.4	1,170	390
Conestogo At Drayton	3.5	324	340
Conestogo at St Jacobs	9.8	772	400
Grand at Doon	29.5	2,508	370
Eramosa Above Guelph	2.6	236	340
Speed Above Grand to Dam	2.2	167	410
Speed River at Hanlon	5.9	593	310
Grand at Galt	40.9	3,520	370
Mill Creek	1.1	83	420
Nith at Nithburg	4.4	326	430
Nith at Canning	12.5	1,030	380
Whiteman's at Mt Vernon	4.8	383	400
Grand at Brantford	63.1	5,210	380
Fairchild Creek	3.6	360	310
McKenzie Creek	1.9	171	350

The following sections describe hydrologic conditions throughout the watershed areas, and make reference to a series of charts summarizing monthly flow distributions at the above noted gauges. These charts show median monthly flow, the 10th percentile monthly flow, and the 90th percentile monthly flow. The median monthly flow is considered to represent typical streamflow conditions. The 10th percentile monthly flow can be considered to represent typical low flows (the flowrate is less than this value 10% of the time) and the 90th percentile monthly flow can be considered to represent typical high flows (the flowrate is less than this value 90% of the time).

2.4.5.1 Upper Grand River Watershed Area

The Upper Grand River Watershed Area extends from the headwaters in Dufferin County south to the Conestogo River. The area's surficial deposits largely consist of the Clayey Tills of the Tavistock Till Plain (47%); it has high surface runoff and soils with low infiltrability. The river valley is distinct through the region, with well defined banks and flood plains. Through part of its length, the river has cut a steep sided gorge through exposed bedrock. The Upper Grand Watershed Area is subdivided into three subwatersheds: the Grand Above Legatt, the Grand Above Shand to Legatt, and the Grand Above Conestogo to Shand.

Luther Marsh, situated on the Dundalk Plateau, is a significant hydrological feature in the Upper Grand River Watershed Area. A dam, built across a tributary of the Grand River at Black Creek in 1954, created a large shallow reservoir, forming Luther Marsh. The Marsh is one of southern Ontario's most significant wetlands and wildlife habitat areas. Surrounding the 1,400 ha open marsh reservoir are lowland swamps, shrubby bogs, plantations, natural forest and crop land. Luther Marsh stores water in times of surplus and releases it slowly in times of drought. Summer flow augmentation associated with the dam and

Marsh often exceeds 80% of the total flow in the upper Grand River. This flow augmentation helps to maintain water quality during the summer months.

A second streamflow control structure is also located in the Upper Grand River Watershed Area. Shand Dam, the largest and the oldest water control structure in the Grand River Watershed, is located upstream of Fergus. The Grand River Conservation Commission completed the Shand Dam in 1942 in response to historical spring floods and summer droughts. This dam, along with others in the Grand River Watershed, is used by the GRCA today to reduce downstream flood damages and augment low flows.

Woolwich Dam, constructed upstream of Elmira on the Canagagigue Creek is also located in the Upper Grand River Watershed Area. Woolwich Dam and reservoir is smaller than Luther and Shand. Nevertheless reservoir operations reduce flood damage in the village of Elmira and augment summer low flows in Canagagigue Creek.

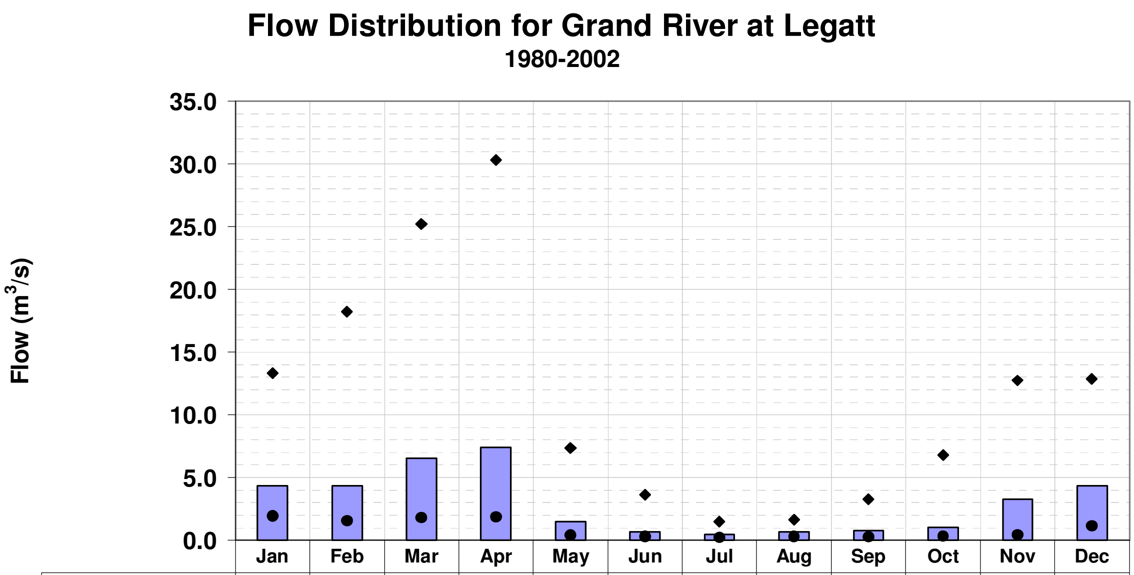
Stream flow in the upper reaches of the Grand River is measured by the stream gauge at Legatt (Figure 30a). The monthly distribution of flows shows a strong spring snowmelt runoff component with 90th percentile flows. Snowfall is high in the headwaters of the Watershed Area. Large snowpack storage, combined with the low permeability soils, explains the high spring flows in response to snowmelt. Baseflow is low, as shown by low median and 10th percentile flows throughout the summer months. The large difference between high and low flows can be attributed to the high proportion of low permeability soils in the subwatershed, and consequent high surface runoff and low recharge to groundwater.

Downstream of Shand Dam the flow regime is modified by reservoir operations as shown by the flow distribution for the stream gauge at West Montrose (Figure 30b). The monthly flow distribution at West Montrose shows the low flow augmentation effect of the upstream reservoir, with a relatively constant median and 10th percentile flow for most months of the year.

2.4.5.2 Conestogo River Watershed Area

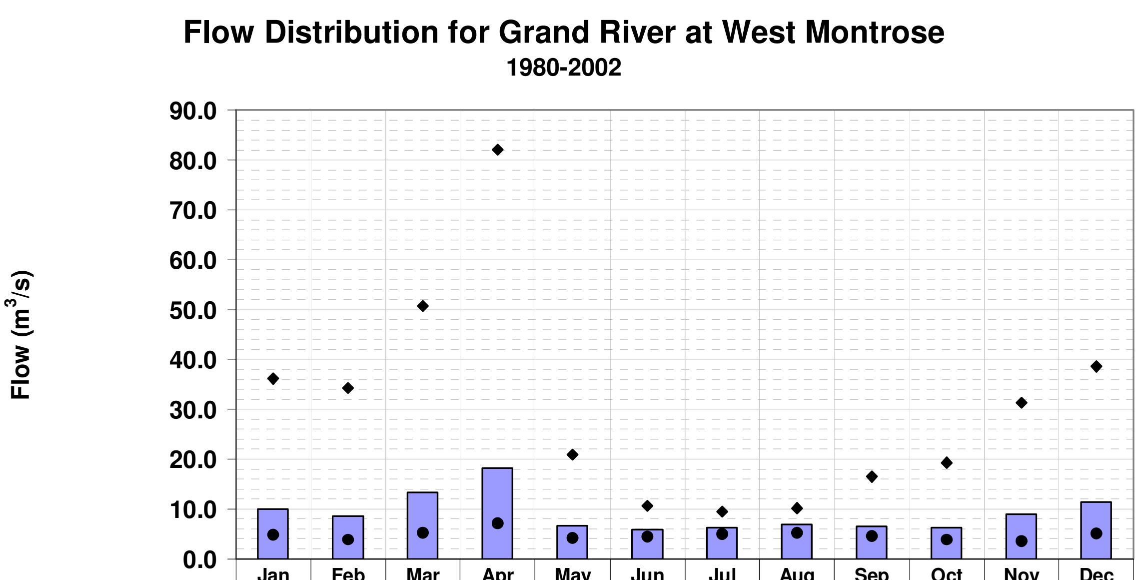
The Conestogo River Watershed Area drains approximately 820 km^2. There are two subwatersheds in this Watershed Area: Conestogo Above Dam and Conestogo Below Dam Subwatersheds. The Watershed Area is mainly composed of Tavistock Till, having 72% of its land area classified as Clayey Till. Hummocky topography is significant (31%) in the Conestoga Below Dam Subwatershed. The most significant hydrological feature in the Conestogo River Watershed Area is Conestogo Lake and Dam, built in 1958 for flood control and low flow augmentation. At times, Conestogo Lake and Dam are responsible for sustaining a large proportion of the baseflow in lower reaches of the Conestogo River.

As expected from low permeability soils, the upper part of the Watershed Area generates very high runoff rates with minimal amounts of groundwater recharge and discharge. Streamflow in the Conestogo Above Dam Subwatershed is measured at the Drayton gauge and summarized on Figure 31a. Flow above Conestogo Dam during summer periods is very low, with virtually no flow during extreme dry periods. Stream flow in the lower portion of the river is controlled by discharges from Conestogo Dam; this flow is represented by the Conestogo River at St. Jacobs streamflow gauge as shown on Figure 31b. The Conestogo Dam controls flooding for downstream communities and adds significant flow augmentation during the summer dry period. The monthly flow distribution for the St. Jacobs streamgauge shows the modifying effect of the upstream reservoir, with stable median and 10th percentile flows throughout the year. While the lower Conestogo River does receive some groundwater discharge from the northern flank of the Waterloo Moraine, the majority of summer flows are from the reservoir augmentation.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Median Flow	4.4	4.4	6.5	7.4	1.5	0.7	0.5	0.7	0.8	1.0	3.3	4.3
10th Percentile Flow	1.9	1.6	1.8	1.9	0.4	0.3	0.2	0.3	0.3	0.3	0.4	1.2
90th Percentile Flow	13.3	18.2	25.2	30.3	7.4	3.6	1.5	1.6	3.3	6.8	12.7	12.9

Figure 30a



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Median Flow	10.0	8.6	13.3	18.2	6.7	5.8	6.3	6.9	6.4	6.2	8.9	11.4
10th Percentile Flow	4.8	3.9	5.2	7.1	4.2	4.5	5.0	5.2	4.6	3.9	3.6	5.0
90th Percentile Flow	36.2	34.3	50.7	82.1	20.9	10.6	9.5	10.2	16.5	19.3	31.3	38.6

Figure 30b

Figure 30
Flow Distribution for Legatt and West Montrose

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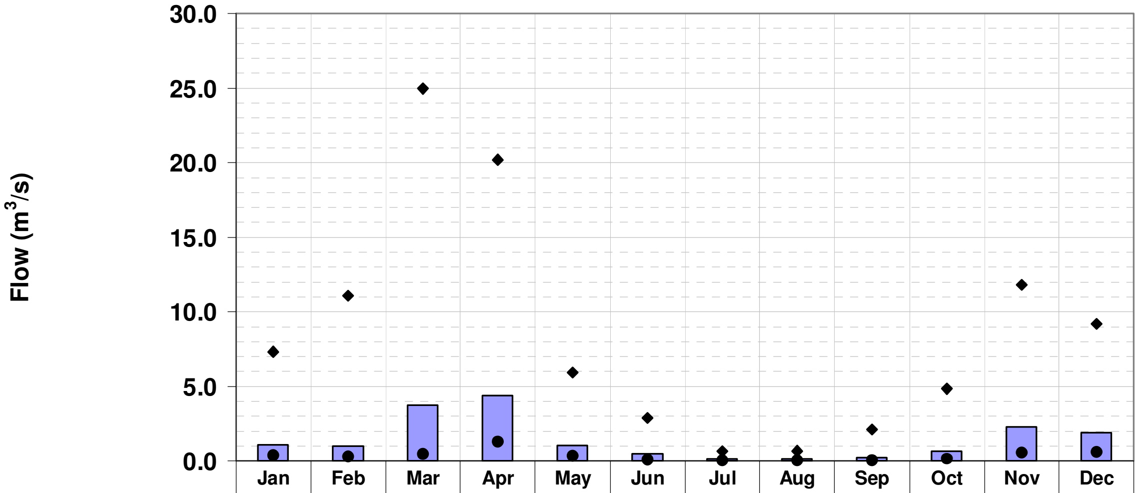
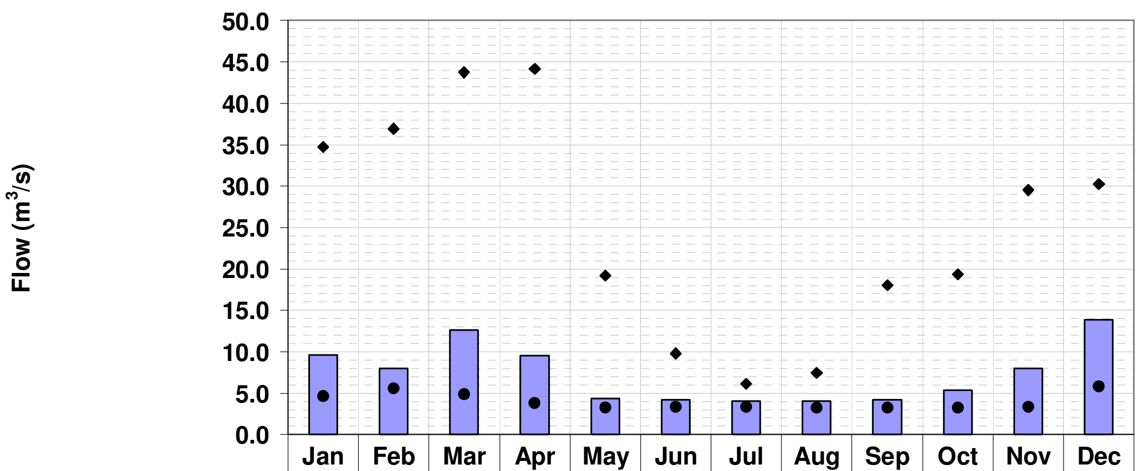
Flow Distribution for the Conestogo River at Drayton
1980-2002



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Median Flow	1.1	1.0	3.7	4.4	1.1	0.5	0.1	0.1	0.2	0.6	2.3	1.9
10th Percentile Flow	0.4	0.3	0.5	1.3	0.4	0.1	0.0	0.0	0.1	0.2	0.6	0.6
90th Percentile Flow	7.3	11.1	25.0	20.2	5.9	2.9	0.6	0.7	2.1	4.8	11.8	9.2

Figure 31a

Flow Distribution for the Conestogo River at St. Jacobs
1980-2002



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Median Flow	9.6	8.0	12.6	9.5	4.3	4.2	4.1	4.0	4.2	5.3	8.0	13.9
10th Percentile Flow	4.6	5.6	4.9	3.8	3.3	3.3	3.4	3.2	3.2	3.2	3.3	5.8
90th Percentile Flow	34.7	36.9	43.7	44.2	19.2	9.8	6.1	7.4	18.0	19.4	29.5	30.3

Figure 31b

Figure 31
Flow Distribution for Drayton and St. Jacobs

2.4.5.3 Speed and Eramosa Rivers Watershed Area

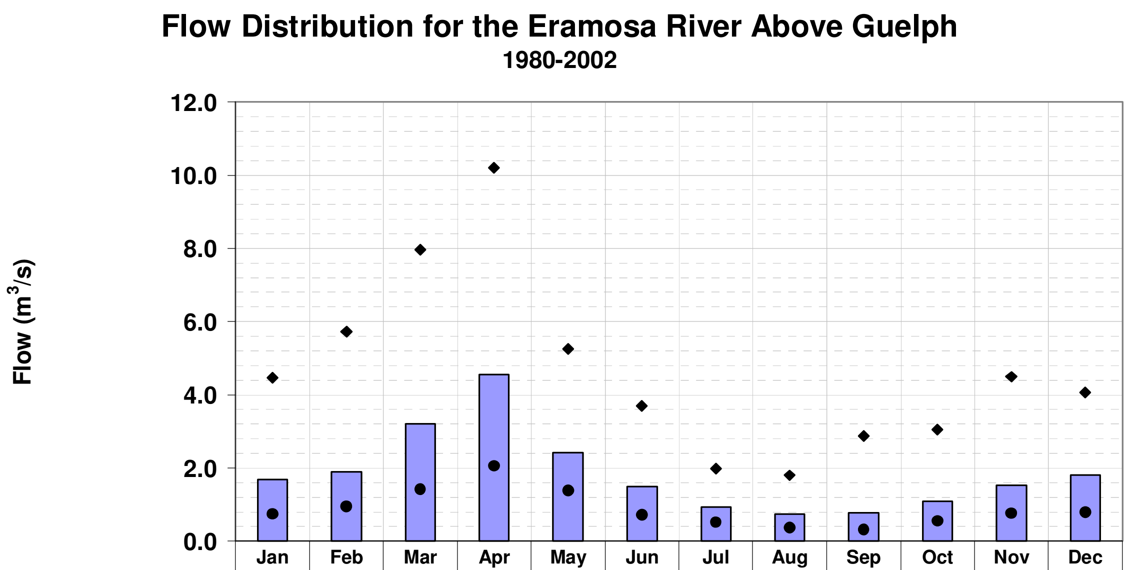
The Speed River and its tributary the Eramosa River drain an area of approximately 780 km^2. There are three subwatersheds in this Watershed Area: Speed Above Dam, Eramosa Above Guelph, and Speed Above Grand to Dam Subwatersheds. The Upper Speed River and the Eramosa River Watershed Areas consist of a balance of silty tills, sandy tills, and sand and gravel. The Eramosa River Subwatershed includes a portion of the Galt/Paris Moraines, while the headwaters of the Speed River are situated within the Orangeville Moraine. The subwatersheds include a number of large and significant wetland complexes, including the Speed/Lutteral/Swan Creek Wetland Complex and the Eramosa-Blue Springs Wetland Complex. Combined, these provincially significant wetlands represent the greatest concentration of wetlands in the Grand River Watershed and have important hydrologic, hydrogeologic, and ecological functions.

The Eramosa River is located on the eastern side of the Grand River Watershed just northeast of the City of Guelph, joining with the Speed River in the City of Guelph below Guelph Dam. It is a medium sized river with significant groundwater discharge. The Eramosa River Subwatershed has the most extensive network of forest habitat in the Watershed. Valleys between the hills of the Guelph Drumlin field are forested areas, while the lower elevations are wetlands and floodplain areas.

The Eramosa River Subwatershed is characterized by having highly permeable surficial materials and a high percentage of forest cover. A proportion of the land area (36%) is described as hummocky as the drainage area includes a significant portion of moraines. In these hummocky areas, runoff that is unable to reach a watercourse collects in large scale depressions, then either evaporates or infiltrates into the groundwater. With its permeable soils, significant forest cover and hummocky topography, conditions in this Subwatershed support high recharge rates. This is reflected by the high baseflow component and high summer flows in Figure 32a.

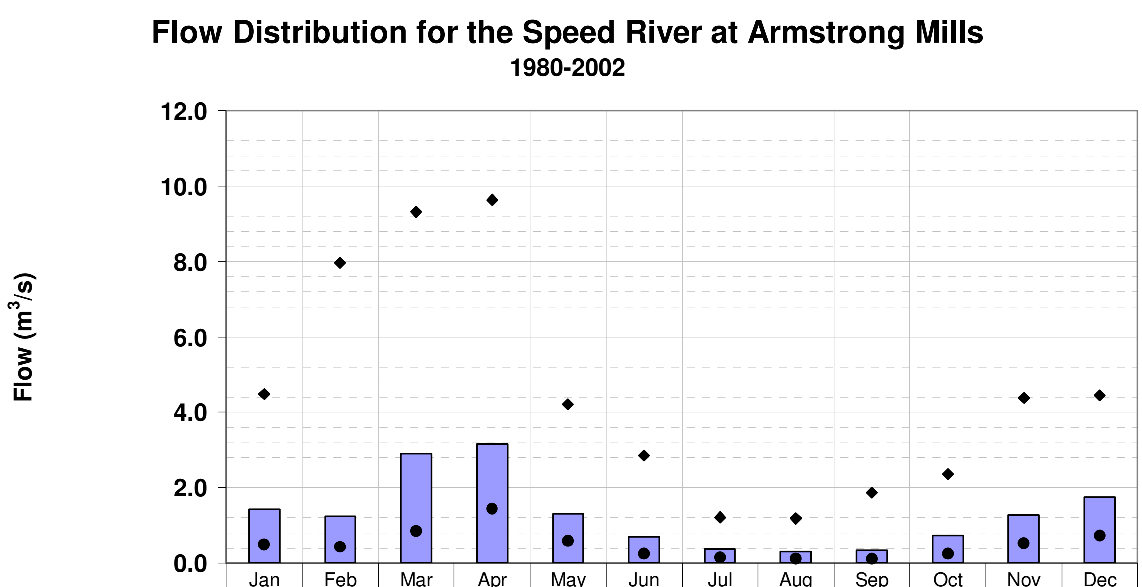
The Upper Speed Above Dam Subwatershed includes parts of the Orangeville Moraine. Due to the eroded nature of the Orangeville Moraine the area has a defined drainage network and therefore does not produce as much groundwater recharge as the Eramosa River Subwatershed. This results in a more variable and often lower, groundwater discharge component of the flow regime as shown in Figure 32b. The distribution shows a moderate baseflow component with relatively lower median flows in the summer months.

The Guelph Dam and reservoir was built in 1976 for flood control and low flow augmentation. The lower portions of the Speed River are regulated with discharge from Guelph Dam to augment low flow for wastewater effluent assimilation purposes and to control flooding in the City of Guelph. The influence of the Guelph Dam and the contribution of the Eramosa River can be seen in the flow distribution for the Speed River at Hanlon streamflow gauge (Figure 33a). The distribution shows the modifying effect of the upstream reservoir with sustained median and 10th percentile flows during the summer months. Outflows from Guelph Dam are managed to meet a streamflow target of 1.7 m^3/s at the Hanlon streamflow gauge during the summer, and to a streamflow target of 1.1 m^3/s from October to May. The Speed River joins the Grand River in the City of Cambridge.



Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Median Flow	1.7	1.9	3.2	4.5	2.4	1.5	0.9	0.7	0.8	1.1	1.5	1.8
10th Percentile Flow	0.7	1.0	1.4	2.1	1.4	0.7	0.5	0.4	0.3	0.6	0.8	0.8
90th Percentile Flow	4.5	5.7	8.0	10.2	5.2	3.7	2.0	1.8	2.9	3.0	4.5	4.1

Figure 32a

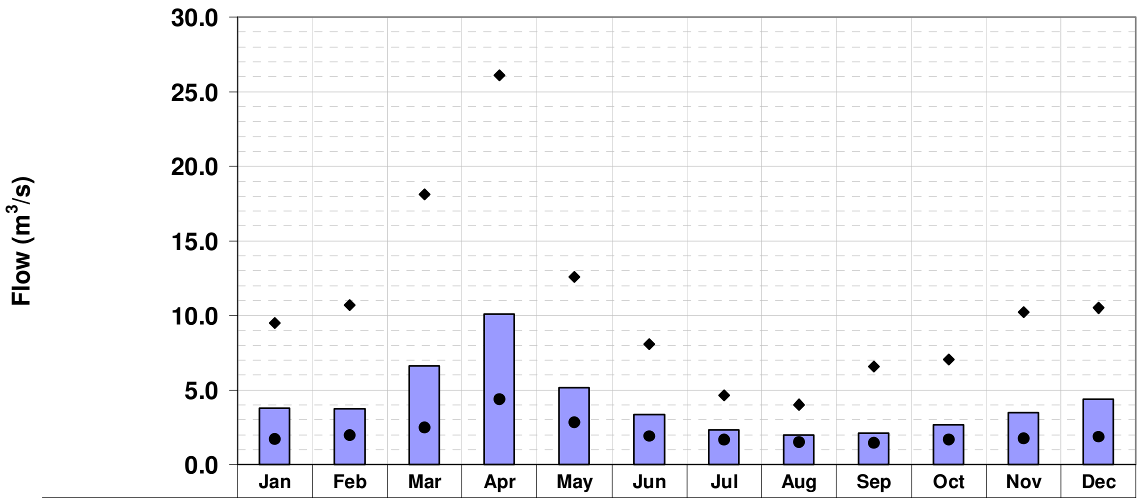


Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Median Flow	1.4	1.2	2.9	3.2	1.3	0.7	0.4	0.3	0.4	0.7	1.3	1.8
10th Percentile Flow	0.5	0.4	0.9	1.4	0.6	0.3	0.2	0.1	0.1	0.2	0.5	0.7
90th Percentile Flow	4.5	8.0	9.3	9.6	4.2	2.9	1.2	1.2	1.9	2.4	4.4	4.4

Figure 32b

Figure 32
Flow Distribution for Eramosa Above Guelph and Speed River at Armstrong Mills

Flow Distribution for the Speed River at Hanlon
1980-2002



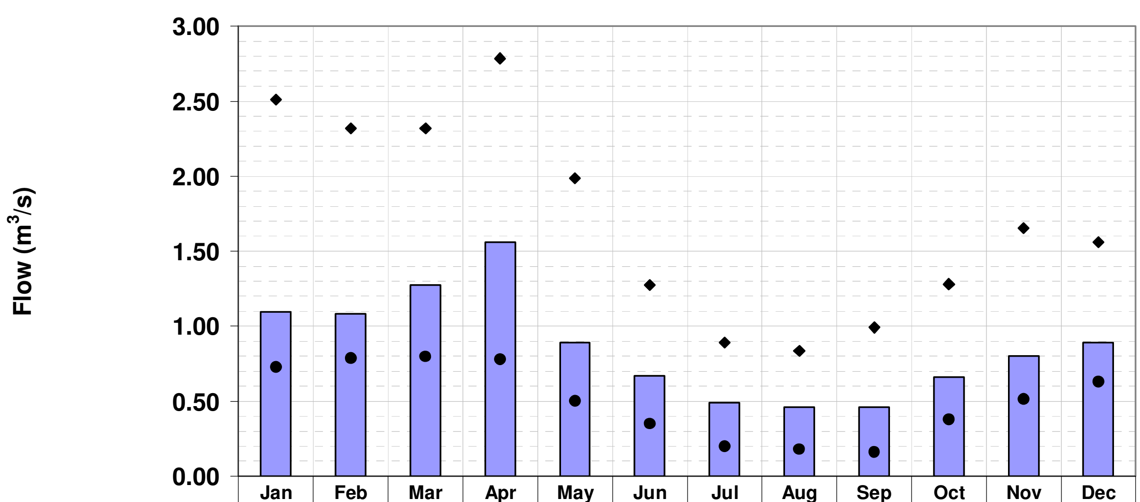
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Median Flow	3.8	3.8	6.6	10.1	5.2	3.4	2.3	2.0	2.1	2.7	3.5	4.4
10th Percentile Flow	1.7	2.0	2.5	4.4	2.8	1.9	1.7	1.5	1.5	1.7	1.7	1.9
90th Percentile Flow	9.5	10.7	18.1	26.1	12.6	8.1	4.6	4.0	6.6	7.1	10.2	10.5

Month

Figure 33a

Median Flow • 10th Percentile Flow ◆ 90th Percentile Flow

Flow Distribution for Mill Creek at Side Rd 10
1990-2002



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Median Flow	1.10	1.08	1.28	1.56	0.89	0.67	0.49	0.46	0.46	0.66	0.80	0.89
10th Percentile Flow	0.73	0.79	0.80	0.78	0.50	0.35	0.20	0.18	0.16	0.38	0.51	0.63
90th Percentile Flow	2.51	2.32	2.32	2.79	1.99	1.27	0.89	0.84	0.99	1.28	1.65	1.56

Month

Figure 33b

Median Flow • 10th Percentile Flow ◆ 90th Percentile Flow

Figure 33
Flow Distribution for Speed at Hanlon and Mill Creek at Side Rd. 10

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2.4.5.4 Central Grand River Watershed Area

The central portion of the Grand River, from the confluence of the Conestogo River and the Grand River to the upstream extent of the City of Brantford, is the most urbanized part of the Grand River Watershed having 19% urban coverage. There are two subwatersheds in this Watershed Area: Grand Above Doon to Conestogo and Grand Above Brantford to Doon Subwatersheds. The Central Grand Watershed Area contains the Cities of Kitchener, Waterloo, and Cambridge. Soils within the area range primarily from silty tills to sands and gravels; when combined with hummocky areas (36%), high groundwater recharge rates are expected. Within this Watershed Area the Grand River is joined by the Speed River in Cambridge and various other tributaries including Mill Creek. The relatively small Laurel Creek and Shades Mill reservoirs are located in this Watershed Area.

Downstream of the confluence of the Conestogo River with the Grand River, and upstream of other main tributaries joining the Grand River, Figure 34a shows the flow distribution for the Grand River at Doon streamgauge location. Median flows throughout the year are relatively stable, regulated by the upstream Conestogo and Shand Dams in addition to smaller structures. Low flows during the summer months are fairly constant and 90^{th} percentile spring flows show the seasonal fluctuation in streamflow expected.

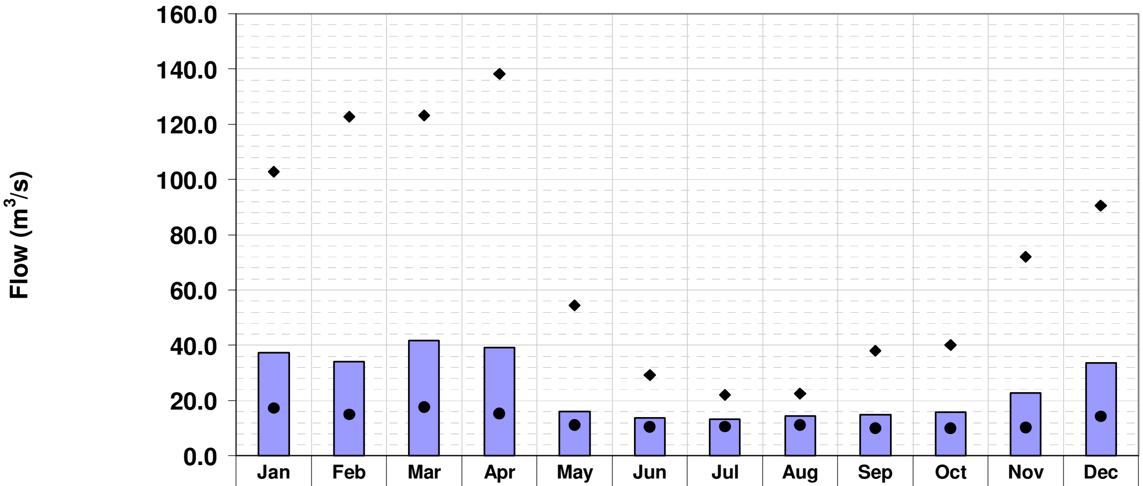
Mill Creek flows through Cambridge before joining the Grand River upstream of the Grand at Galt streamflow gauge. Mill Creek flows through a large glacial outwash deposit sandwiched between the Galt and Paris Moraines. This outwash deposit contains several aggregate operations, many of which are extracting aggregate below the water table. Groundwater discharge into Mill Creek and its surrounding wetlands is significant due to the high amounts of hummocky topography (50%) in the moraines, and due to the significant deposits of gravel within the outwash areas. The monthly flow distribution for Mill Creek is shown on Figure 33b. This figure illustrates the sustained summer baseflow, and relatively small difference between high flows and low flows throughout the year.

As shown on Figure 34b illustrating flow in the Grand River at Galt, the summer flows are regulated by upstream dams that include the Conestogo Dam, the Shand Dam, and the Guelph Dam. Spring flows are managed by the reservoirs which capture a large portion of spring snow melt. The monthly flow distribution shows the influence of the upstream reservoirs, with relatively constant 10th percentile and median flows. Although it is not presented here, the daily flow records show the effects of the upstream urban areas, with peak runoff in response to precipitation events over the urban areas

The GRCA, through the Grand River Fisheries Management Plan, delineated a reach of the central Grand River as an “Exceptional Waters” reach (GRCA, 1998); it is located between the Town of Paris and the City of Brantford. The river valley within this area is part of the Carolinian forests of southern Ontario and is known for its biodiversity and unique habitats. Fish communities in this reach of the River are a mixture of cold water, mixed water, and warm water communities. The reason for this diversity is the large amount of groundwater that enters this reach, directly from groundwater seepages and from the tributaries as well. As a result, some portions of this reach of river have "two storey" fisheries hosting both healthy warm water and coldwater fish communities. The coldwater communities are concentrated in the areas of highest groundwater discharges. These discharges moderate water temperature extremes allowing for suitable temperatures and thermal refuges for coldwater fish. This reach of the Grand River provides habitat for several species such as smallmouth bass, walleye, northern pike, brown trout, and rainbow trout.

Flow Distribution for the Grand River at Doon

1980-2002



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Median Flow	37.3	34.2	41.6	39.1	15.9	13.7	13.2	14.5	14.9	15.9	22.8	33.6
10th Percentile Flow	17.3	14.9	17.6	15.2	11.1	10.5	10.6	11.1	10.0	9.9	10.3	14.3
90th Percentile Flow	102.9	122.8	123.2	138.3	54.4	29.3	22.0	22.6	38.1	40.0	72.0	90.5

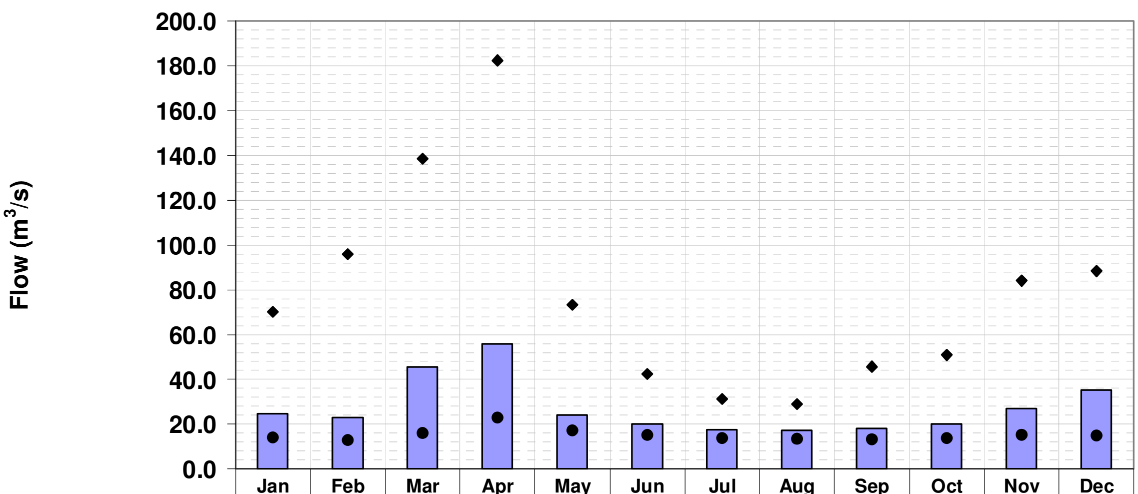
Month

Figure 34a

Median Flow • 10th Percentile Flow ◆ 90th Percentile Flow

Flow Distribution for the Grand River at Galt

1980-2002



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Median Flow	24.7	23.0	45.7	55.9	24.1	20.0	17.4	17.2	18.0	20.1	26.9	35.3
10th Percentile Flow	14.0	12.8	16.0	22.9	17.2	15.1	13.8	13.4	13.2	13.8	15.3	14.8
90th Percentile Flow	70.1	95.9	138.5	182.4	73.4	42.3	31.3	28.9	45.7	50.9	84.1	88.4

Month

Figure 34b

Median Flow • 10th Percentile Flow ◆ 90th Percentile Flow

Figure 34
Flow Distribution for Grand River at Doon and at Galt

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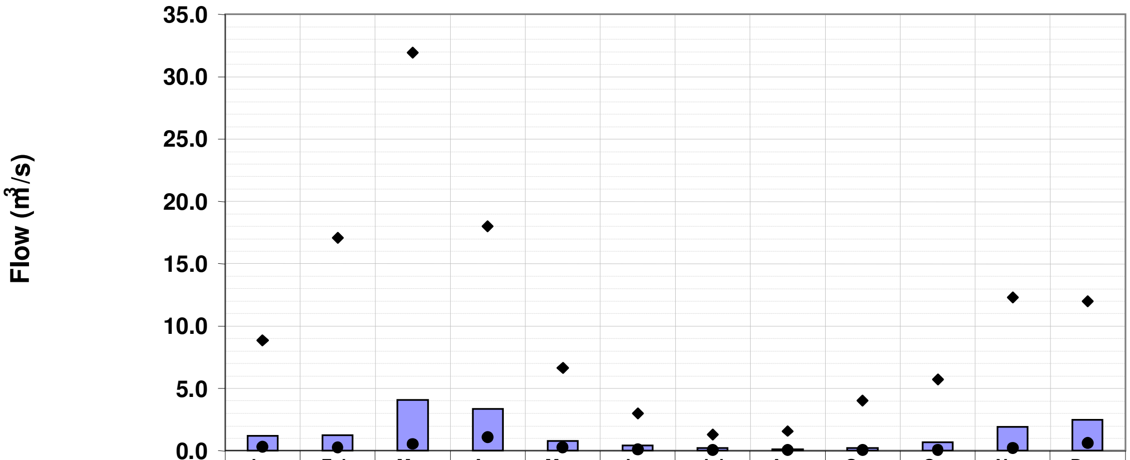
Significant groundwater contributions occur along the Exceptional Waters reach. Unpublished GRCA spot flow measurements taken during dry weather periods indicate an increase in streamflow of approximately 3.5 m^3/s in the Grand River between Cambridge and Brantford. It is assumed that the majority of this streamflow increase is groundwater discharge because of the limited anthropogenic inputs within this reach. This groundwater discharge is critical in allowing the River to assimilate wastewater treatment plant effluent from upstream communities, and to provide steady stream flow for lower reaches of the Grand River.

2.4.5.5 Nith River Watershed Area

The Nith River is a major tributary of the Grand River, draining 1,128 km^2 of the Grand River Watershed. The Nith River flows through the western side of the Grand River Watershed and joins the Grand River below the central portion of the Watershed in the Town of Paris. The upper subwatershed of the Nith River Watershed Area is a till plain composed primarily of clayey tills (72%); the lower subwatershed is primarily sand and gravel material (47%) associated with the Waterloo Moraine and the Norfolk Sand Plain. The Nith River Watershed Area has hummocky areas (28%) that are evenly distributed between the upper and lower subwatersheds. Agricultural activities are the dominant land use in the Watershed Area.

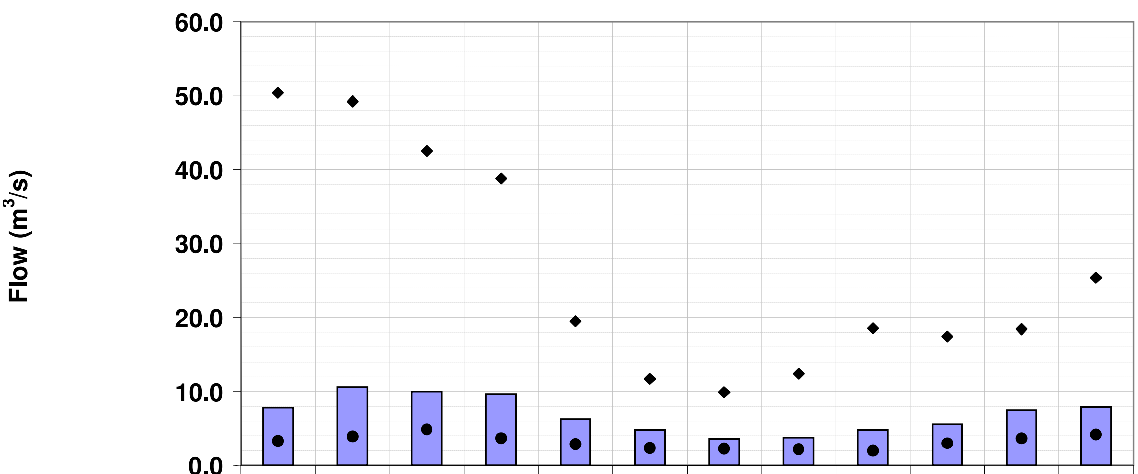
The upper Nith River Watershed Area drains the same geologic unit as the upper Conestogo River Watershed Area, and therefore has a similar hydrologic response. The low permeability Tavistock Till generates large volumes of runoff but very low recharge, leading to low summer baseflow as shown on Figure 35a. The distribution shows low median flow with a very high ratio of high flows to low flows suggesting a runoff dominated system with very little baseflow.

As the Nith River flows downstream of New Hamburg, it passes by the western and then the southern flank of the Waterloo Moraine. In this area the baseflow in the Nith River is increased by appreciable groundwater discharge. Figure 35b illustrates the flow distribution for the Nith River at the streamflow gauge at Canning. The surficial geology changes in the southern portion of the Nith River Watershed Area to include more pervious materials producing higher amounts of groundwater recharge. Due to the presence of these granular materials, numerous aggregate producers are located in the lower Nith River Watershed Area, particularly near Cedar Creek, which is a tributary of the Nith River near Ayr.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Median Flow	1.2	1.3	4.1	3.3	0.8	0.4	0.2	0.1	0.2	0.7	1.9	2.5
10th Percentile Flow	0.3	0.3	0.5	1.1	0.3	0.1	0.1	0.0	0.0	0.1	0.2	0.6
90th Percentile Flow	8.9	17.1	31.9	18.0	6.6	3.0	1.3	1.6	4.0	5.7	12.3	12.0

Figure 35a



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Median Flow	7.8	10.6	10.0	9.6	6.3	4.8	3.6	3.7	4.8	5.5	7.5	7.9
10th Percentile Flow	3.3	3.9	4.9	3.7	2.9	2.4	2.3	2.2	2.0	3.0	3.6	4.2
90th Percentile Flow	50.4	49.2	42.6	38.8	19.5	11.7	9.9	12.4	18.5	17.5	18.4	25.4

Figure 35b

Figure 35
Flow Distribution for Nithburg and Canning

2.4.5.6 Whiteman's and McKenzie Creeks Watershed Area

Whiteman's Creek is a tributary of the Grand River located in the lower southwestern portion of the Grand River Watershed. The Creek has two main tributaries, Horner Creek and Kenny Creek. Whiteman's Creek joins the Grand River just north of the City of Brantford.

Much like the Nith River Watershed Area, Whiteman's Creek Subwatershed has two distinct geologic areas. Furthest upstream, Horner Creek flows over Tavistock Till, then as it flows south, drains an area characterized by granular, more pervious material. The area drained by Kenny Creek is dominated by Port Stanley Till, another relatively impervious material. Below the Kenny Creek and Horner Creek confluence, where Whiteman's Creek is formed, the Whiteman's Creek Subwatershed is largely on the Norfolk Sand Plain; 42% of the Subwatershed is classified as sand and gravel in relation to this physiographic feature.

The Whiteman's Creek Subwatershed is predominantly agricultural in land use, with small hamlets and dispersed rural residences. The Norfolk Sand Plain is a dominant feature in the lower subwatershed, having well-drained soils contributing to the high permeability of the land, and low runoff capabilities. The shallow unconfined aquifer is well connected to watercourses; it contributes baseflow to Whiteman's Creek. Whiteman's Creek is a groundwater-fed coldwater stream through its lower reaches and supports brown trout and rainbow trout populations. This stream actually gets colder as it moves downstream through the Norfolk Sand Plain from Burford to the confluence with the Grand River (Unpublished GRCA monitoring data). Upstream, the creek supports northern pike and smallmouth bass.

The monthly flow distribution in Whiteman's Creek is represented by the streamflow gauge near Mount Vernon as shown on Figure 36a. Sustained baseflow is an important characteristic of the Subwatershed during the summer months; the agricultural irrigation water takings place a stress on summer dry-weather flows. The Ontario Low Water Response Program is active in this Subwatershed because of this water-taking stress.

McKenzie Creek drains 171 km^2, including portions of the Six Nations First Nations Lands and Haldimand County. The McKenzie Creek Subwatershed is largely composed of Haldimand Clay (79%), with the upper portion draining an area of the Norfolk Sand Plain. McKenzie Creek also has numerous online ponds, which further influence the hydrology and hydrogeology of the Subwatershed. Figure 36b summarizes the monthly flow distribution in McKenzie Creek. With the majority of the Subwatershed being clay, this Subwatershed exhibits higher runoff than the Whiteman's Creek Subwatershed. In spite of the high proportion of low permeability clayey tills, the monthly flow distribution shows a low but stable baseflow during the summer months; this may be due to groundwater discharge from the Norfolk Sand Plain.

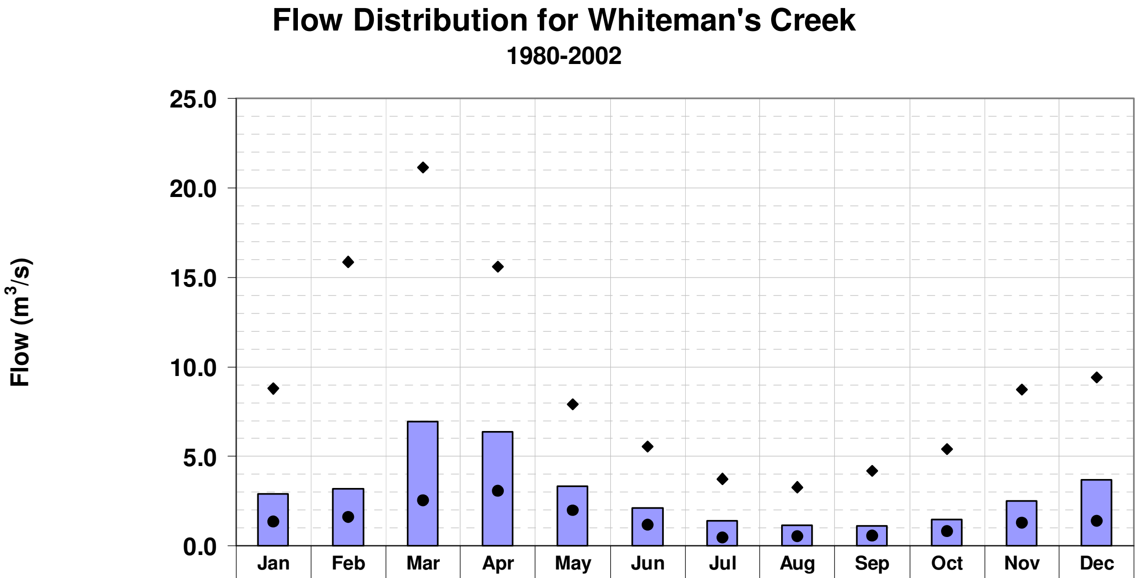
2.4.5.7 Lower Grand River Watershed Area

The Lower Grand River Watershed Area extends from the upstream extent of the City of Brantford to Lake Erie. Streamflow through this reach is largely influenced by upstream reservoir management as shown by the high summer flows on Figure 37a. Downstream of Brantford the Watershed Area is fairly flat and composed of Haldimand Clay Plain, with clayey tills representing more than 70% of the land area. The drainage area produces high runoff and little groundwater recharge and discharge. Tributaries in this area form a dense drainage network that quickly conveys water to the river. The main river channel itself is very broad as it meanders south to Lake Erie. The last streamflow gauge on the Grand River is at the community of York. The York streamflow gauge is operated by the GRCA and its flow distribution is similar to of the flow distribution of the Grand River at Brantford. After York, the Grand River continues southward through the communities of Cayuga and Dunnville, before it joins Lake Erie at Port Maitland.

Fairchild Creek drains an area of approximately 360 km^2 east of the City of Brantford, and joins the Grand River near the community of Onondaga, downstream of Brantford. The Fairchild Creek Subwatershed's surficial geology is a mixture of Haldimand Clay, Rockton Bedrock Plain, surficial sands, and portions of the Paris Moraine. The proportion of impervious area shown in Table 2.7 for the Fairchild Creek Subwatershed is related to the Rockton Bedrock Plain. In general, the drainage density in this portion of the Grand River Watershed is extremely high in comparison to other areas, indicative of high runoff rates, and low groundwater recharge. The monthly flow distribution shown on Figure 37b shows high runoff but also shows sustained baseflow during summer months that is uncharacteristic of nearby areas. This baseflow may be due to the influence of groundwater discharge from sand deposits, the Paris Moraine, and the Beverly Swamp.

The Beverly Swamp contributes to the headwaters of Fairchild Creek. The wetland is provincially significant and extends into the adjacent watersheds of Spencer and Bronte Creeks (Hamilton Conservation Authority). The wetland contains one of the largest lowland swamp forests in south central Ontario.

Flow contributions from Whiteman's, Fairchild, and McKenzie Creeks have minimal influence on the flow regime of the Grand River; the flow regime is dominated by flows from the large drainage area upstream of the Nith River confluence. The monthly flow distribution at Brantford (Figure 37a) displays a sustained baseflow component. This results from both upstream reservoir operations and groundwater discharge upstream of the streamflow gauge. The distribution shows a stable baseflow component and moderate peak flows.

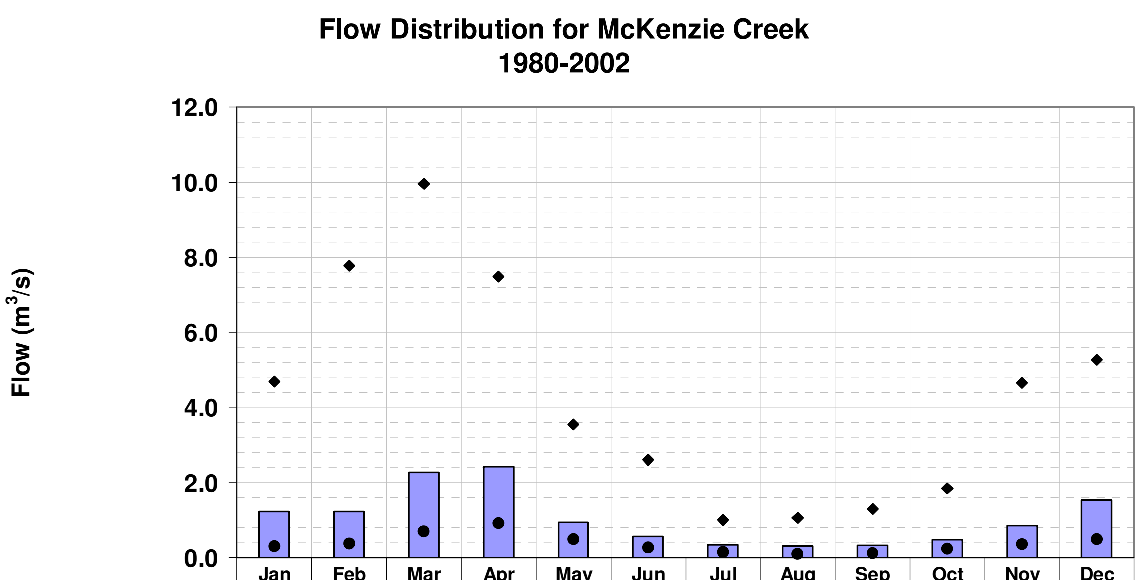


	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Median Flow	2.9	3.2	6.9	6.4	3.3	2.1	1.4	1.2	1.1	1.5	2.5	3.7
10th Percentile Flow	1.4	1.6	2.5	3.1	2.0	1.2	0.5	0.5	0.6	0.8	1.3	1.4
90th Percentile Flow	8.8	15.9	21.2	15.6	7.9	5.6	3.7	3.3	4.2	5.4	8.7	9.4

Month

Figure 36a

Median Flow • 10th Percentile Flow ◆ 90th Percentile Flow



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Median Flow	1.2	1.2	2.3	2.4	0.9	0.6	0.3	0.3	0.3	0.5	0.9	1.5
10th Percentile Flow	0.3	0.4	0.7	0.9	0.5	0.3	0.1	0.1	0.1	0.2	0.4	0.5
90th Percentile Flow	4.7	7.8	10.0	7.5	3.6	2.6	1.0	1.1	1.3	1.8	4.7	5.3

Month

Figure 36b

Median Flow • 10th Percentile Flow ◆ 90th Percentile Flow

Figure 36
Flow Distribution for Whiteman's Creek and McKenzie

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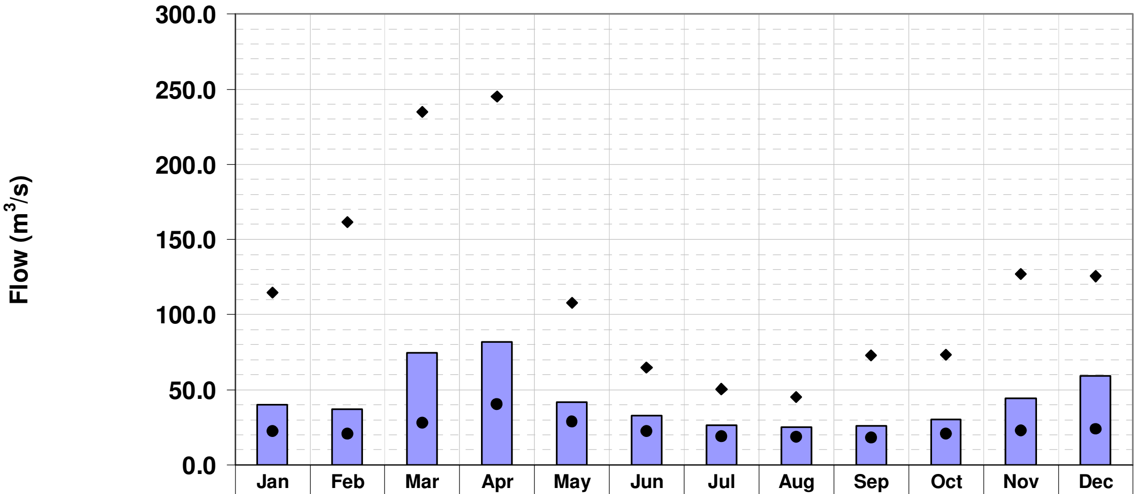
Flow Distribution for the Grand River at Brantford
1980-2002



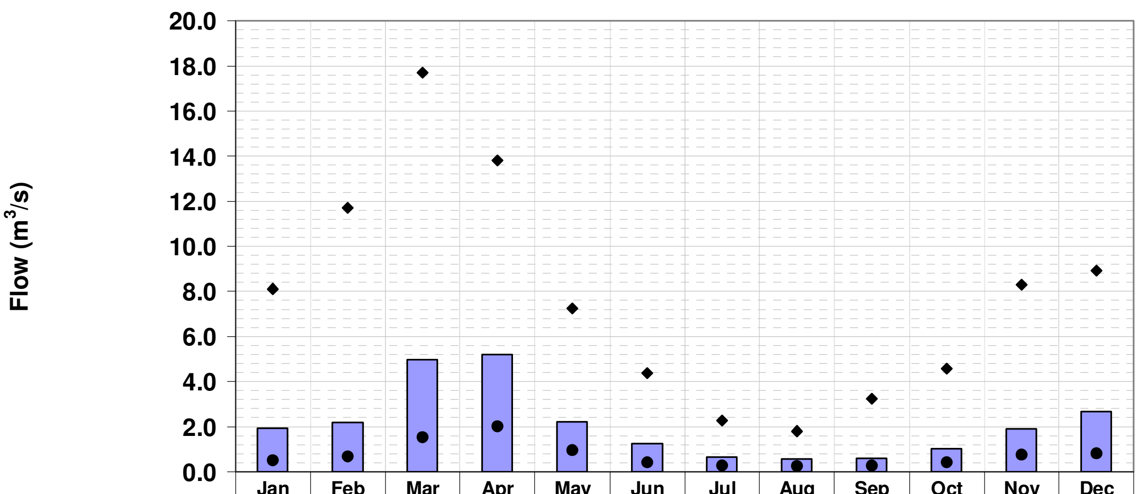
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Median Flow	40.0	37.0	74.6	82.0	41.6	32.7	26.4	25.1	26.0	30.3	44.2	59.0
10th Percentile Flow	22.5	20.7	28.0	40.5	28.8	22.4	19.0	18.7	18.2	20.8	22.8	23.9
90th Percentile Flow	114.8	161.4	235.0	245.0	107.6	64.8	50.5	45.0	72.9	73.2	127.1	125.6

Month

Figure 37a

Median Flow ● 10th Percentile Flow ◆ 90th Percentile Flow

Flow Distribution for Fairchild Creek
1980-2002



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Median Flow	1.9	2.2	5.0	5.2	2.2	1.3	0.7	0.6	0.6	1.0	1.9	2.7
10th Percentile Flow	0.5	0.7	1.5	2.0	1.0	0.4	0.3	0.3	0.3	0.4	0.7	0.8
90th Percentile Flow	8.1	11.7	17.7	13.8	7.2	4.4	2.3	1.8	3.2	4.6	8.3	8.9

Month

Figure 37b

Median Flow ● 10th Percentile Flow ◆ 90th Percentile Flow

Figure 37
Flow Distribution for Grand River at Brantford and Fairchild Creek

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3.0 Water Demand

This section summarizes the surface water and groundwater water demand estimates for each subwatershed. The water demand assessment is an important step in the development of a water budget framework.

The water demand estimate is based on the following components:

- Municipal Water Demand. Estimated water demand is based on surface water and groundwater pumping rates reported by municipalities, when these pumping rates are available;
- Permitted Water Use. The Province of Ontario issues Permits to Take Water (PTTW) for water takings greater than 50,000 L/d. This water demand utilizes estimated or reported pumping rates for PTTW holders and adjusts them to account for water used and not returned to the same source and seasonal use variability; and,
- Non-Permitted Water Use. In addition to water use that requires a PTTW, there are water uses that do not require a permit. These water uses include livestock watering, unserviced rural domestic use, and any other use that is taking less than 50,000 L/d. This report relies on non-permitted water use estimates in the Water Use Study completed by the GRCA (GRCA, 2005).

3.1 MUNICIPAL WATER USE

The Grand River Water Use Study (2005) concluded that water taken for municipal supplies is the largest water use in the Grand River Watershed. Table 3.1 summarizes estimated total annual water use for each municipality relying on groundwater or inland surface water sources. Municipal water takings from Great Lakes supplies (Caledonia, Cayuga and Dunnville) are not included. Most of the municipal water demand estimates in Table 3.1 are taken from the Grand River Water Use Study (2005). Where more recent reported values are used, the source is noted.

Table 3.2 groups total estimated municipal water use by subwatershed and source (groundwater vs. surface water). Municipal water takings are reported as both an average annual rate (L/s) and depth per unit area (mm/y) calculated over the subwatershed area.

The Grand River Water Use Study indicated that municipal water supply systems rely on both groundwater and surface water resources for their water supply. Approximately 65% of the municipal water supply is from groundwater sources, and the remaining 35% is from surface water sources. Most of this municipal water taking is returned to the river system through the wastewater treatment plant (WWTP) effluent discharge.

Table 3.1 - Summary of Municipal Water Demands (L/s)

Upper Tier Municipality	Municipal System	Subwatershed	Annual Water Demand (L/s)			Year of Data	Data Source
			Surface Water	Ground-water	Total		
Brant	Paris	Nith Above Grand To New Hamburg, Grand Above Brantford to Doon		91	91	2004	GRCA Water Use Study Update
Brant	Airport	Grand Above York to Brantford		2	2	2004	GRCA Water Use Study Update
Brant	St. George	Fairchild Creek		13	13	2004	GRCA Water Use Study Update

Upper Tier Municipality	Municipal System	Subwatershed	Annual Water Demand (L/s)			Year of Data	Data Source
			Surface Water	Ground-water	Total		
Brant	Mount Pleasant	Grand Above York to Brantford		13	13	2004	GRCA Water Use Study Update
City of Brantford	City of Brantford	Grand Above York to Brantford	547		547	2000	GRCA Water Use Study Update
City of Guelph	City of Guelph	Speed Above Grand To Dam, Eramosa Above Guelph	32	660	692	GW: 2006 SW: 1993-2002	City of Guelph Reported
City of Hamilton	Lynden	Grand Above York to Brantford		2	2	2004	GRCA Water Use Study Update
Dufferin	Grand Valley	Grand Above Shand to Legatt		5	5	2004	GRCA Water Use Study Update
Dufferin	Waldemar	Grand Above Shand to Legatt		2	2	2004	GRCA Water Use Study Update
Dufferin	Marsville	Grand Above Shand to Legatt		0	0	2004	GRCA Water Use Study Update
Grey	Dundalk	Grand Above Legatt		8	8	2004	GRCA Water Use Study Update
Oxford	Bright	Whiteman's Creek		1	1	2006	GRCA Water Use Study Update
Oxford	Drumbo	Nith Above Grand To New Hamburg		2	2	2006	GRCA Water Use Study Update
Oxford	Plattsville	Nith Above Grand To New Hamburg		7	7	2006	GRCA Water Use Study Update
Perth	Milverton	Nith Above New Hamburg		9	9	2000	GRCA Water Use Study Update
Regional Municipality of Waterloo (ROW)	Integrated Urban System (Cambridge, Kitchener, Waterloo, Elmira, St. Jacobs)	Nith Above New Hamburg, Nith Above Grand to New Hamburg, Grand Above Brantford to Doon, Grand Above Doon to Conestogo, Conestogo Below Dam, Grand Above Conestogo to Shand, Speed Above Grand to Dam	544	1,365	1,909	GW: 2006 SW: 2006	ROW
ROW	Baden, New Hamburg	Nith Above New Hamburg		25	25	2006	ROW
ROW	Ayr	Nith Above Grand To New Hamburg		12	12	2006	ROW
ROW	Wellesley	Nith Above New Hamburg		6	6	2006	ROW
ROW	St. Clements	Conestogo Below Dam		3	3	2006	ROW
ROW	Branchton Meadows	Grand Above Brantford to Doon		0	0	2006	ROW
ROW	Roseville	Nith Above Grand To New Hamburg		1	1	2006	ROW
ROW	Linwood	Conestogo Below Dam		2	2	2006	ROW
ROW	Heidelburg	Conestogo Below Dam		4	4	2006	ROW
ROW	New Dundee	Nith Above Grand To New Hamburg		3	3	2006	ROW
ROW	Foxboro Green	Nith Above New Hamburg		1	1	2006	ROW
ROW	St. Agatha	Nith Above New Hamburg, Nith Above Grand to New Hamburg		2	2	2006	ROW
ROW	Conestogo Golf Course	Grand Above Conestogo to Shand		2	2	2006	ROW
ROW	Conestogo Plains	Grand Above Conestogo to Shand		1	1	2006	ROW
ROW	Maryhill	Grand Above Doon to Conestogo		1	1	2006	ROW

Upper Tier Municipality	Municipal System	Subwatershed	Annual Water Demand (L/s)			Year of Data	Data Source
			Surface Water	Ground-water	Total		
ROW	West Montrose	Grand Above Conestogo to Shand		1	1	2006	ROW
ROW	Seagram	Grand Above Doon to Conestogo		2	2	2006	ROW
Wellington	Fergus	Grand Above Conestogo to Shand		44	44	2005	GRCA Water Use Study Update
Wellington	Elora	Grand Above Conestogo to Shand		18	18	2004-2005	GRCA Water Use Study Update
Wellington	Arthur	Conestogo Above Dam		14	14	2004	GRCA Water Use Study Update
Wellington	Rockwood	Speed Above Dam		10	10	2006	GRCA Water Use Study Update
Wellington	Drayton	Conestogo Above Dam		5	5	2005	GRCA Water Use Study Update
Wellington	Hamilton Drive	Speed Above Grand to Dam		5	5	2006	GRCA Water Use Study Update
Wellington	Moorefield	Conestogo Above Dam		1	1	2006	GRCA Water Use Study Update
TOTAL			**1,123**	**2,344**	**3,467**		

Table 3.2 - Summary of Municipal Water Demands

Subwatershed	Sub-Watershed Area (km^2)	Municipal Groundwater Demand		Municipal Surface Water Demand	
		L/s	mm/y	L/s	mm/y
Grand Above Legatt	365	8	1	0	0
Grand Above Shand To Legatt	426	7	1	0	0
Grand Above Conestogo To Shand	640	66	3	0	0
Conestogo Above Dam	566	20	1	0	0
Conestogo Below Dam	254	9	1	0	0
Grand Above Doon To Conestogo	248	169	22	544	69
Eramosa Above Guelph	230	258	35	32	4
Speed Above Dam	242	5	1	0	0
Speed Above Grand To Dam	308	540	55	0	0
Mill Creek	82	0	0	0	0
Grand Above Brantford To Doon	274	789	91	0	0
Nith Above New Hamburg	545	42	2	0	0
Nith Above Grand To New Hamburg	583	399	22	0	0
Whitemans Creek	404	1	0	0	0
Grand Above York To Brantford	476	17	1	547	36
Fairchild Creek	401	13	1	0	0
McKenzie Creek	368	0	0	0	0
Grand Above Dunnville To York	356	0	0	0	0
TOTAL	**6,768**	**2,344**	**11**	**1,123**	**5**

3.2 PERMITS TO TAKE WATER

The Ministry of Environment's Permit to Take Water (PTTW) Program began in the early 1960's. It requires any person (or organization) taking more than 50,000 L/d of water to have an active PTTW. Exceptions are granted for domestic water use, livestock watering, and water taken for firefighting purposes. The Province's PTTW database stores information on permits, including: the location, the maximum permitted rates, and the general and specific purpose of the water taking.

Figures 38 and 39 summarize the active surface water and groundwater PTTWs in the Grand River Watershed.

Historically, the PTTW program has not required permit holders to report their actual pumping rates, only the maximum potential water taking. This has led to challenges in accurately estimating water use from information stored within the PTTW database. As actual water use is typically less than the maximum permitted rate, water use estimates generated using maximum permitted rates can be conservatively high. Obtaining more detailed water taking information, including actual pumping rates, can reduce this error, and produce more accurate estimates of water use.

The PTTW program is now requiring PTTW holders to report their actual pumping rates; however, this new information was not available for this Study. As the reported pumping data is not available from the Province, the GRCA initiated a program to gather actual pumping rate data from PTTW holders within the Watershed.

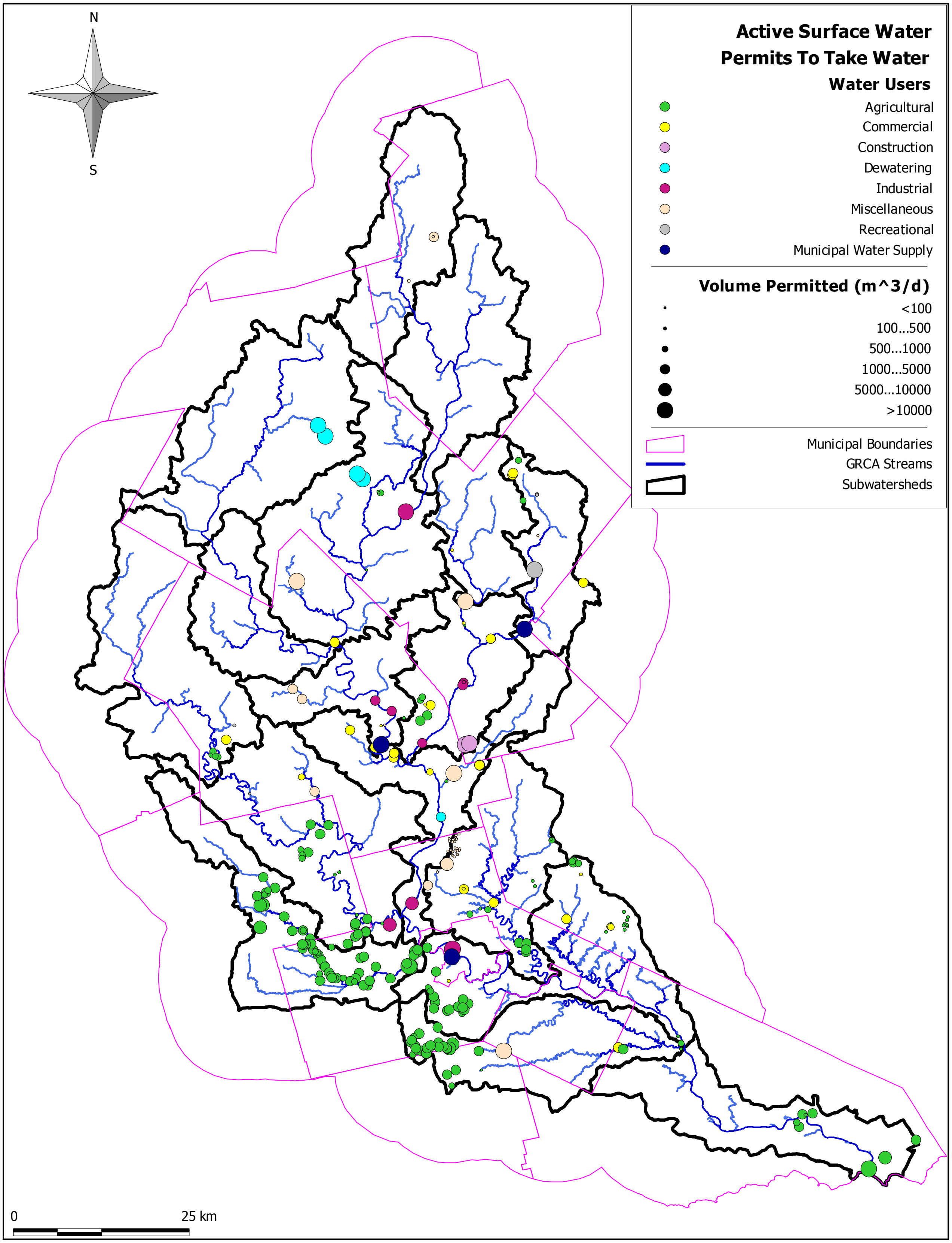

Figure 38
Surface Water Permits

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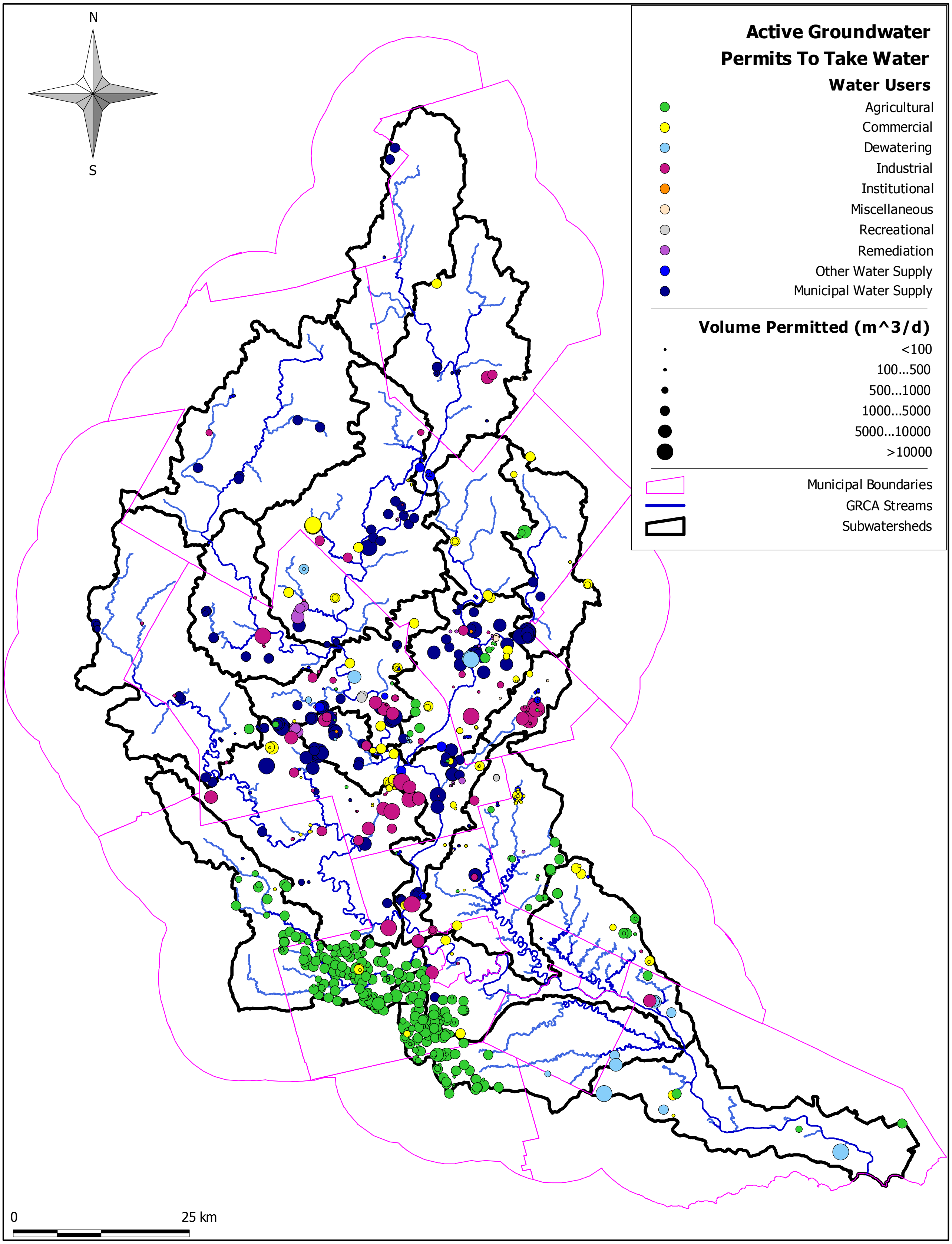

Figure 39
Groundwater Permits

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Table 3.3 and Table 3.4 below summarize the number of water takings permitted in each subwatershed for groundwater and surface water, respectively. The tables organize the number of takings by water use sector. The summary of water takings coincides with the permits shown on Figures 38 and 39.

Table 3.3 - Number of Groundwater Takings by Subwatershed and Sector

Subwatershed	Agric-ultural	Com-mercial	Dewat-ering	Indus-trial	Instit-utional	Misc.	Recre-ational	Reme-diation	Water Supply	Total
Grand Above Legatt		1							4	5
Grand Above Shand To Legatt				2		2			16	20
Grand Above Conestogo To Shand		16	3	5				27	20	71
Conestogo Above Dam				1					11	12
Conestogo Below Dam				9					14	23
Grand Above Doon To Conestogo	4	12	2	13			3	2	26	62
Eramosa Above Guelph	2	5							11	18
Speed Above Dam	1	3							2	6
Speed Above Grand To Dam	10	23	9	10	1	3		14	29	99
Mill Creek	1	2		13		2			9	27
Grand Above Brantford To Doon	3	22	1	19	1		1	20	49	116
Nith Above New Hamburg	2			4					14	20
Nith Above Grand To New Hamburg	8	18		27				3	27	83
Whitemans Creek	136	4							2	142
Grand Above York To Brantford	54	9	3	6					6	78
Fairchild Creek	12	18		4			3	1	13	51
Mckenzie Creek	74	1	3							78
Grand Above Dunnville To York	3	2	3							8
Total	310	136	24	113	2	7	7	67	253	919

Table 3.4 - Number of Surface Water Takings by Subwatershed and Sector

Subwatershed	Agric-ultural	Com-mercial	Const-ruction	Dewat-ering	Indus-trial	Misc.	Rec-reational	Water Supply	Total
Grand Above Legatt						3			3
Grand Above Conestogo To Shand	4	1		2	1	1			9
Conestogo Above Dam				2					2
Grand Above Doon To Conestogo	1	3			2	3		1	10
Eramosa Above Guelph	2	3				2	3	1	11
Speed Above Dam		1				1			2
Speed Above Grand To Dam	6	5	2		4				17
Grand Above Brantford To Doon	1	7		1	1	5			15
Nith Above New Hamburg	4	1					1		6
Nith Above Grand To New Hamburg	20	1			1	1	1		24
Whitemans Creek	54								54
Grand Above York To Brantford	35	5			1			1	42
Fairchild Creek	11	3				24			38
Mckenzie Creek	33	1				1			35

Subwatershed	Agric-ultural	Com-mercial	Const-ruction	Dewat-ering	Indus-trial	Misc.	Rec-reational	Water Supply	Total
Grand Above Dunnville To York	8								8
Total	179	31	2	5	10	41	5	3	276

The following sections outline the methodology used to estimate water demand from the PTTW data and, where available, the actual pumping rates. This methodology is based on the following:

- Estimate a permit-to-take-water holder's pumping rates, either from the PTTW database or use the actual pumping rate reported to the GRCA;
- Adjust the pumping rate using a consumptive use factor. Consumptive use refers to the amount of water that is pumped, but not returned back to the original water source; and,
- Account for seasonal water use by estimating the months in a year that the pumping associated with the PTTW will be active (e.g. snowmaking permit will be assumed to be active Dec-Feb).

The PTTW database used for this analysis was provided by the GRCA, and considered up to date to June 2008.

3.2.1 Consumptive Water Use

Records of permitted or reported water taking/pumping do not reflect the amount of water that is actually removed from the hydrologic system. For example, a water user may pump a large amount of water from a stream or a pond, and return much of the water back to the stream or pond quickly after it is used. As this water is not lost from the stream or pond, it has a smaller impact than a taking who did not return any water to the stream or pond. Water that is ***not*** returned back to the original source of water is referred to as "Consumptive Water Use", and is much more relevant to the water budget. The amount of consumed water may be a small percentage of the quantity of water pumped.

Similarly to pumping rates, consumptive water demands are not reported. As such, they need to be estimated. This is done by applying coefficients, based on the purpose of water use, which estimate the portion of total pumped water that is consumed.

Estimating consumptive water demand requires consideration of the point of discharge for wastewater and consideration of the physical water taking operation. While some water takers have large extraction rates associated with their permits, they consume very little of that water. For example, dams and reservoirs typically have large maximum permitted rates, associated with the water taken into storage during high flows; however, only a small percentage of that water is lost to evaporation. The remaining water is typically discharged downstream. Such takings are considered to be non-consumptive at the scale of the watercourse.

Other water users may consume very little water at the subwatershed scale, but may have significant impacts locally at the water source. Dewatering operations, where groundwater is pumped to lower the water table then discharged to a nearby creek, can impact the aquifer, but have a negligible impact on the water balance of the subwatershed as a whole. In this case, while the taking is not consumptive with respect to the subwatershed, it is 100% consumptive with respect to the aquifer.

Additional water users may take water from one subwatershed, and discharge it to an adjacent subwatershed. As the water is not returned to the source subwatershed or watercourse/aquifer, it is considered to be 100% consumptive at the scale of both the subwatershed, and the watercourse/aquifer.

Consumptive use is dependent on the scale of the assessment; the following three consumptive factors were created:

1. **Consumptive use with respect to the source.** If water is removed from a water source and not returned to the same water source as it was withdrawn, the taking is assumed to be 100% consumptive with respect to the source. Groundwater takings usually fall into this category, where it is common for water to be taken from a deep groundwater aquifer and returned to a surface water feature. An opposite situation with negligible consumptive use would exist where a small hydroelectric dam has a very high permitted water taking rate along a river (source), but doesn't consume any water from that river. In this situation the water taking is assumed to have a low consumptive rate (minor losses due to enhanced evaporation only). Table 3.3 lists default consumptive use factors (AquaResource, 2005) to be used for water takings where water is returned to the same water source from which it is taken. These default values correspond to the 'Specific Purpose' assigned to each permit-to-take-water by the MOE.

2. **Consumptive use with respect to the Subwatershed.** If water is taken and not returned to a water body within the same subwatershed, it is assumed to be 100% consumptive at the subwatershed scale. Municipal supply wells or river intakes, drawing water from one subwatershed and discharging it to another subwatershed by wastewater treatment plant effluent, would be considered 100% consumptive at this scale. If the water is returned within the same subwatershed, the specific purpose consumptive factor is used (Table 3.3). Dewatering operations that extract groundwater to lower local water levels and then discharge this water to the local surface water system would be assigned a consumptive factor specific to dewatering operations.

3. **Consumptive with respect to the Watershed.** When a water taking removes water from the watershed (grouping of subwatersheds) and does not return it within the watershed, it is assumed to be 100% consumptive at the watershed scale. Water bottling operations and other operations that place water into commercial products fall into this category. All other types of water taking operations would be assigned consumptive factors according to their specific purpose (Table 3.3).

Based on the sector specific consumptive use coefficients included in Table 3.3, likely wastewater discharge location, and water taking characteristics, each PTTW located in the Grand River Watershed has been assigned three consumptive use factors. These factors represent the portion of pumped water that is not returned to; 1) the source from which it was taken (e.g. aquifer); 2) the subwatershed from which it was taken (e.g. Nith Above Grand to New Hamburg); and 3) the Grand River Watershed.

Table 3.5 - Consumptive Use Factors

Category	Specific Purpose	Consumptive Factor	Category	Specific Purpose	Consumptive Factor
Agricultural	Field and Pasture Crops	0.75	Institutional	Hospitals	0.25
Agricultural	Fruit Orchards	0.75	Institutional	Other - Institutional	0.25
Agricultural	Market Gardens / Flowers	0.75	Institutional	Schools	0.25
Agricultural	Nursery	0.75	Miscellaneous	Dams and Reservoirs	0.005
Agricultural	Other - Agricultural	0.75	Miscellaneous	Heat Pumps	0.1

Category	Specific Purpose	Consumptive Factor	Category	Specific Purpose	Consumptive Factor
Agricultural	Sod Farm	0.75	Miscellaneous	Other - Miscellaneous	1
Agricultural	Tender Fruit	0.75	Miscellaneous	Pumping Test	0.1
Agricultural	Tobacco	0.75	Miscellaneous	Wildlife Conservation	0.005
Commercial	Aquaculture	0.005	Recreational	Aesthetics	0.25
Commercial	Bottled Water	1	Industrial	Manufacturing	0.1
Commercial	Golf Course Irrigation	0.7	Industrial	Other - Industrial	0.1
Commercial	Mall / Business	0.25	Industrial	Power Production	0.005
Commercial	Other - Commercial	1	Recreational	Fish Ponds	0.25
Commercial	Snowmaking	0.5	Recreational	Other - Recreational	0.005
Construction	Other - Construction	0.1	Recreational	Wetlands	0.1
Construction	Road Building	0.75	Remediation	Groundwater	0.5
Dewatering	Construction	0.005	Remediation	Other - Remediation	0.25
Dewatering	Other - Dewatering	0.005	Water Supply	Campgrounds	0.2
Dewatering	Pits and Quarries	0.005	Water Supply	Communal	0.2
Industrial	Aggregate Washing	0.1	Water Supply	Municipal	0.2
Industrial	Brewing and Soft Drinks	1	Water Supply	Other - Water Supply	0.2
Industrial	Cooling Water	0.25			
Industrial	Food Processing	1			

The consumptive use factors included in Table 3.3, although generalized, provide a consistent approach for the initial estimation of consumptive water use.

3.2.2 Monthly Usage Factors

To generate accurate estimates of the total rate of water pumped, it is necessary to consider the months that a water taking is active. With this information not being available in the PTTW database, additional detail is required to arrive at the number of active water taking months. The GRCA characterized the expected timing of water takings based on the purpose of the water taking, as outlined in Table 3.4. The Grand River Water Use Study indicated the months where typical water takings are active based on the recorded specific purpose in the PTTW database. This approach recognizes that many types of water taking operations only take water during a specific time period each year (e.g., snow making generally is active December, January and February).

Table 3.4 indicates when the water taking is assumed to be active. For all water takings, except the agricultural water takings, it is assumed that the water taking is active every day within the active water taking month. For agricultural permits-to-take-water an estimate of the number of irrigation days was made to calculate when the water would be actively taken.

Table 3.6 - Monthly Demand Adjustments

General Purpose	Specific Purpose	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Agricultural	Field and Pasture Crops	0	0	0	0	0	1	1	1	1	0	0	0
Agricultural	Fruit Orchards	0	0	0	0	0	1	1	1	1	0	0	0
Agricultural	Market Gardens / Flowers	0	0	0	0	0	1	1	1	1	0	0	0
Agricultural	Nursery	0	0	0	0	0	1	1	1	1	0	0	0
Agricultural	Other - Agricultural	0	0	0	0	0	1	1	1	1	0	0	0
Agricultural	Sod Farm	0	0	0	0	0	1	1	1	1	0	0	0
Agricultural	Tender Fruit	0	0	0	0	0	1	1	1	1	0	0	0
Agricultural	Tobacco	0	0	0	0	0	1	1	1	1	0	0	0
Commercial	Aquaculture	1	1	1	1	1	1	1	1	1	1	1	1
Commercial	Bottled Water	1	1	1	1	1	1	1	1	1	1	1	1
Commercial	Golf Course Irrigation	0	0	0	0	0	1	1	1	1	0	0	0
Commercial	Mall / Business	1	1	1	1	1	1	1	1	1	1	1	1
Commercial	Other - Commercial	1	1	1	1	1	1	1	1	1	1	1	1
Commercial	Snowmaking	1	1	0	0	0	0	0	0	0	0	0	1
Construction	Other - Construction	1	1	1	1	1	1	1	1	1	1	1	1
Construction	Road Building	1	1	1	1	1	1	1	1	1	1	1	1
Dewatering	Construction	1	1	1	1	1	1	1	1	1	1	1	1
Dewatering	Other - Dewatering	1	1	1	1	1	1	1	1	1	1	1	1
Dewatering	Pits and Quarries	1	1	1	1	1	1	1	1	1	1	1	1
Industrial	Aggregate Washing	0	0	0	0	1	1	1	1	1	1	1	0
Industrial	Cooling Water	1	1	1	1	1	1	1	1	1	1	1	1
Industrial	Food Processing	1	1	1	1	1	1	1	1	1	1	1	1
Industrial	Manufacturing	1	1	1	1	1	1	1	1	1	1	1	1
Industrial	Other - Dewatering	1	1	1	1	1	1	1	1	1	1	1	1
Industrial	Other - Industrial	1	1	1	1	1	1	1	1	1	1	1	1
Industrial	Pipeline Testing	1	1	1	1	1	1	1	1	1	1	1	1
Institutional	Other - Institutional	1	1	1	1	1	1	1	1	1	1	1	1
Institutional	Schools	1	1	1	1	1	1	0	0	1	1	1	1
Miscellaneous	Dams and Reservoirs	1	1	1	1	1	1	1	1	1	1	1	1
Miscellaneous	Heat Pumps	1	1	1	1	1	1	1	1	1	1	1	1
Miscellaneous	Other - Miscellaneous	1	1	1	1	1	1	1	1	1	1	1	1
Miscellaneous	Pumping Test	1	1	1	1	1	1	1	1	1	1	1	1
Miscellaneous	Wildlife Conservation	1	1	1	1	1	1	1	1	1	1	1	1
Missing	Missing	1	1	1	1	1	1	1	1	1	1	1	1
Recreational	Other - Recreational	1	1	1	1	1	1	1	1	1	1	1	1
Recreational	Wetlands	1	1	1	1	1	1	1	1	1	1	1	1
Remediation	Groundwater	1	1	1	1	1	1	1	1	1	1	1	1
Remediation	Other - Remediation	1	1	1	1	1	1	1	1	1	1	1	1
Water Supply	Campgrounds	0	0	0	0	1	1	1	1	1	0	0	0
Water Supply	Communal	1	1	1	1	1	1	1	1	1	1	1	1
Water Supply	Municipal	1	1	1	1	1	1	1	1	1	1	1	1
Water Supply	Other - Water Supply	1	1	1	1	1	1	1	1	1	1	1	1

3.2.3 Permitted Agricultural Water Use

The number of agricultural permits-to-take-water in the lower southwestern portion of the Watershed (Norfolk Sand Plain) is higher than the rest of the Watershed, as shown in Figures 38 and 39. This higher density of agricultural permits is located in the Whiteman's Creek and the McKenzie Creek Subwatersheds. A reliable estimate of the total rate of water removed for irrigation purposes is important because of this higher concentration of agricultural irrigation permits.

When estimating the rate of water consumed by an agricultural irrigation operation, consideration must be give to the following three factors:

1. Timing. Months of active irrigation or days of pumping.
2. Quantity. Rate of water pumped
3. Consumed. – Proportion of water that is not returned to the water source.

The Long Point Region, Catfish and Kettle Creek Water Budget and Water Quantity Stress Assessment (AquaResource, 2008) specifically focused on quantifying agricultural water use, and developed methodologies for estimating the three factors listed above. The assumptions and methodologies used for the Long Point study have been replicated for the Grand River Watershed, and are presented in the following subsections.

3.2.3.1 Timing

Irrigation is a category of water use that can vary significantly from year to year; it is almost exclusively determined by climate variability. Wet years may have little to no irrigation required, while dry years may require irrigation throughout the growing season.

Active irrigation is typically limited to the summer and early fall months. GRCA staff solicited feedback on typical irrigation months from the Canada-Ontario Water Supply Expansion Program (COWSEP) Steering Committee for Coordinating Crop Irrigation Use Across the Norfolk Sand Plain. The Steering Committee indicated that most irrigators were active from June until September (COWSEP Steering Committee Minutes, July 31st. 2007). All agricultural PTTW were therefore assumed to be active for these months.

While irrigation may be active for the period of June to September, each irrigation system will not operate every day during this time period. To estimate the number of pumping days , in absence of having reported pumping records, it is necessary to estimate the number of irrigation events (occurrence of the entire crop being irrigated), and to estimate the length of time required to fully irrigate the crop.

An irrigation model, created by the GRCA and documented within the Grand River Water Use Study (GRCA, 2005), was used to estimate the frequency of irrigation events. The irrigation model relies on synthetic soil water content simulated by the GAWSER continuous streamflow-generation model to estimate when crops would become water stressed. This crop stress threshold is reached when soil water content reaches approximately 50% of the soil water storage, or halfway between the field capacity and the wilting point. If this threshold is reached during a month of active irrigation, an irrigation event is triggered, increasing the soil water content by 25 mm. Moving to the next time step, the added water undergoes an evaporative process. When the soil water content again drops below the specified threshold, another irrigation event is triggered, provided at least a week has passed since the previous irrigation event.

The result of the irrigation demand model is a time series of when soil moisture conditions would require an irrigation event to sustain agricultural crops. This time series is then used to determine when agricultural irrigation PTTWs would be actively pumping. The irrigation event model was based on GAWSER output and climatic data from the Norfolk Sand Plain Region (Whiteman's Creek), which contains the majority of agricultural PTTWs in the Grand River Watershed. Although it does not take into account the geographic variability of climate across the Watershed, the irrigation event model output is assumed to be a good indication of irrigation needs due to annual trends in precipitation and soilwater.

The monthly averages and the minimum and maximum number of annual irrigation events for the period 1980-1999 is shown in Table 3.7.

Table 3.7 – Estimated Irrigation Event Frequency (1980-1999)

Description	Number of Irrigation Events
June Average	2
July Average	3
August Average	2
September Average	1
Minimum Annual	3
Maximum Annual	16
Average Annual	8

In addition to providing guidance on the months of active irrigation, the COWSEP Steering Committee also provided guidance on the number of days a farmer would need to fully irrigate a crop. While this number can vary based on amount of crop in rotation, it was suggested that four days of irrigation was appropriate (COWSEP Steering Committee Minutes, July 31st, 2007).

By multiplying the number of days of active pumping for each irrigation event (4 d) with the average number of irrigation events each month (e.g. 2 events in June), the typical irrigation system is estimated to be pumping water for 8 days in June, 12 days in July, 8 days in August, and 4 days in September. The volume of water pumped during irrigation events each month is averaged over the 30 or 31 days of the respective month to estimate the average monthly irrigation pumping rate. This reduces the total agricultural maximum permitted pumping rate to a more realistic pumped estimate each month.

It should be noted that while the total amount of water pumped for irrigation is averaged over an entire month and is much lower than the permitted rate, the maximum instantaneous pumping rate experienced during the period would be much higher, and may approach the permitted rate.

3.2.3.2 Water Quantity

It is estimated that an agricultural operator in the Norfolk Sand Plain irrigates for an average of 32 days per year. The total amount of water pumped can be determined by multiplying the water pumping rate (L/d) by the number of active pumping days. It is recognized that the permitted water taking rate may not be a good estimate of how much water is being withdrawn when actively pumping; it is frequently a high estimate. To adjust the permitted water taking rate, the GRCA staff compared agricultural PTTWs from the Norfolk Sand Plain which had actual pumping rates available, to the permitted maximum water taking rates for the same permits. Upon comparing 135 records, the reported water pumping rates were determined to be approximately 60% of the permitted maximum pumping rate.

Total irrigation demand was therefore, estimated by multiplying 60% of the maximum permitted pumping rate by the average number of active pumping days (32 days). This estimated water quantity volume was then averaged over the active irrigation season to arrive at an average pumping rate in units of cubic metres per day.

3.2.3.3 Consumptive Water Use

Consumptive water use is the portion of water taken from a water source that is not returned to that water source in a reasonable amount of time.

Previous literature indicated the consumptive proportion of water taken for agricultural irrigation purposes ranged from 80% to 90%. This indicates that 10 to 20% of the pumped water would eventually return to its original source, with the remaining 80 to 90% being transpired by the irrigated crops and lost from the subwatershed.

Feedback from the Long Point Region, Catfish and Kettle Creek Water Budget Peer Review Committee (Dr. Hugh Whiteley, Peer Review Meeting, May 31st, 2007) suggested that a consumptive factor of 0.8-0.9 was likely too high, and a more appropriate factor was 0.75. This factor was taken from Quilez and Aragues (2003), which estimated the consumptive factor of a “good” irrigation system to be from 0.65-0.85. The lower consumptive factor recognizes that any irrigation system will provide an uneven distribution of water; to provide a minimum water depth for the entire crop, some portions of the field will receive significantly more water. In these more heavily irrigated areas, saturated soil conditions may develop and thus return more water to the system.

3.2.3.4 Summary of Agricultural Water Use Assumptions

The assumptions outlined above result in a significant reduction in the estimated water demand from agricultural irrigation as compared to previous estimates which relied solely on the maximum permitted water taking rate. The reduction factors include: 26% of days having active water pumping; 60% of the permitted rate being pumped; and 75% of pumped water is consumed. These reduction factors yield an estimated agricultural water demand for irrigation permits-to-take-water equal to 11.7% of the maximum permitted water taking, for the months of June-September. Agricultural use is assumed to be insignificant throughout the rest of the year.

3.2.4 Survey of Actual Water Use

The GRCA carried out a PTTW survey of all permits that are used for dewatering, aggregate washing, golf courses, aquaculture and other miscellaneous uses, as these were identified among the top five water use sectors, as quantified by the GRCA Water Use Study (GRCA, 2005). The survey collected actual pumping rates from the water users. Reported actual pumping rates were also included from municipal water supply systems. Shown in Table 3.8 are the number of permits with reported water-taking amounts and the number with estimated water-taking amounts, for agricultural, municipal and other uses. The actual water use rates are used for water demand where available; for all other permits estimates are used.

Table 3.8 - Number of Permitted Takings with Reported and Estimated Water-Taking Amounts

	Groundwater		Surface Water	
PTTW Type	Reported	Estimated	Reported	Estimated
Agricultural	45	286	26	157
Municipal	172	0	3	0
All Other	178	269	16	82

3.3 UNPERMITTED WATER USE

In addition to water use that requires a PTTW, there are water uses that do not require a permit-to-take-water. These include livestock watering, and rural domestic water use.

While there is no procedure for estimating the amount of water used by operations that are below the PTTW limit of 50,000 L/d, the GRCA did quantify non-permitted agricultural and rural domestic water use as part of the Water Use Study (GRCA, 2005). This is further explored in the following sections.

3.3.1 Non-Permitted Agricultural Water Use

Non-permitted agricultural water use includes livestock watering, equipment washing, pesticide/herbicide application, or any other minor use of water. In order to quantify this water use sector, agricultural water use coefficients have been estimated and applied to Census of Agriculture data. The GRCA Water Use Study applied this methodology on a subwatershed basis. Table 3.9 lists the estimated non-permitted agricultural water use on a subwatershed basis (units of L/s), and Figure 40 spatially illustrates this data (units of mm/y).

Table 3.9 - Non-Permitted Agricultural Water Use

Subwatershed	Non-Permitted Agricultural Demand (L/s)	Non-Permitted Agricultural Demand (mm/y)
Grand Above Legatt	3	0.3
Grand Above Shand To Legatt	5	0.4
Grand Above Conestogo To Shand	28	1.4
Conestogo Above Dam	19	1.1
Conestogo Below Dam	25	3.1
Grand Above Doon To Conestogo	7	0.9
Eramosa Above Guelph	8	1.1
Speed Above Dam	7	0.9
Speed Above Grand To Dam	5	0.5
Mill Creek	1	0.2
Grand Above Brantford To Doon	5	0.6
Nith Above New Hamburg	14	0.8
Nith Above Grand To New Hamburg	14	0.7
Whitemans Creek	8	0.6
Grand Above York To Brantford	11	0.7

Subwatershed	Non-Permitted Agricultural Demand (L/s)	Non-Permitted Agricultural Demand (mm/y)
Fairchild Creek	17	1.3
McKenzie Creek	3	0.3
Grand Above Dunnville To York	3	0.3

Information regarding the source of water used to supply the non-permitted water uses was unavailable. Therefore, it was assumed that half of the water demand is serviced through groundwater sources, and the other half of the water demand is serviced through surface water sources.

The consumptive nature of the non-permitted agricultural water use is also unknown. To arrive at a conservative estimate of the consumptive non-permitted agricultural water demand, it is assumed that 100% of the water taken is consumed. Based on the relatively small water rates estimated in this category, it is anticipated that this will not significantly affect the total consumptive water demand.

3.3.2 Un-serviced Domestic Water Use

Un-serviced domestic water use is any household water use that is not supplied by a municipal water supply system. Typically these are households in rural areas, and almost exclusively are supplied from groundwater sources.

The GRCA Water Use Study (GRCA, 2005) estimated the amount of water taken for un-serviced domestic use by combining Census of Population data for areas known not to be serviced by a municipal system, and a per capita water use rate of 160 L/d. A per capita rate of 160 L/d was estimated by Vandierendonck and Mitchell (1997), and is consistent with the MOE Groundwater Studies Technical Terms of Reference (2001), which suggests an un-serviced per capita rate of 175 L/d These estimates on the subwatershed scale are listed in Table 3.10 (units of L/s). Figure 41 also shows the un-serviced domestic water use for each subwatershed in mm/y.

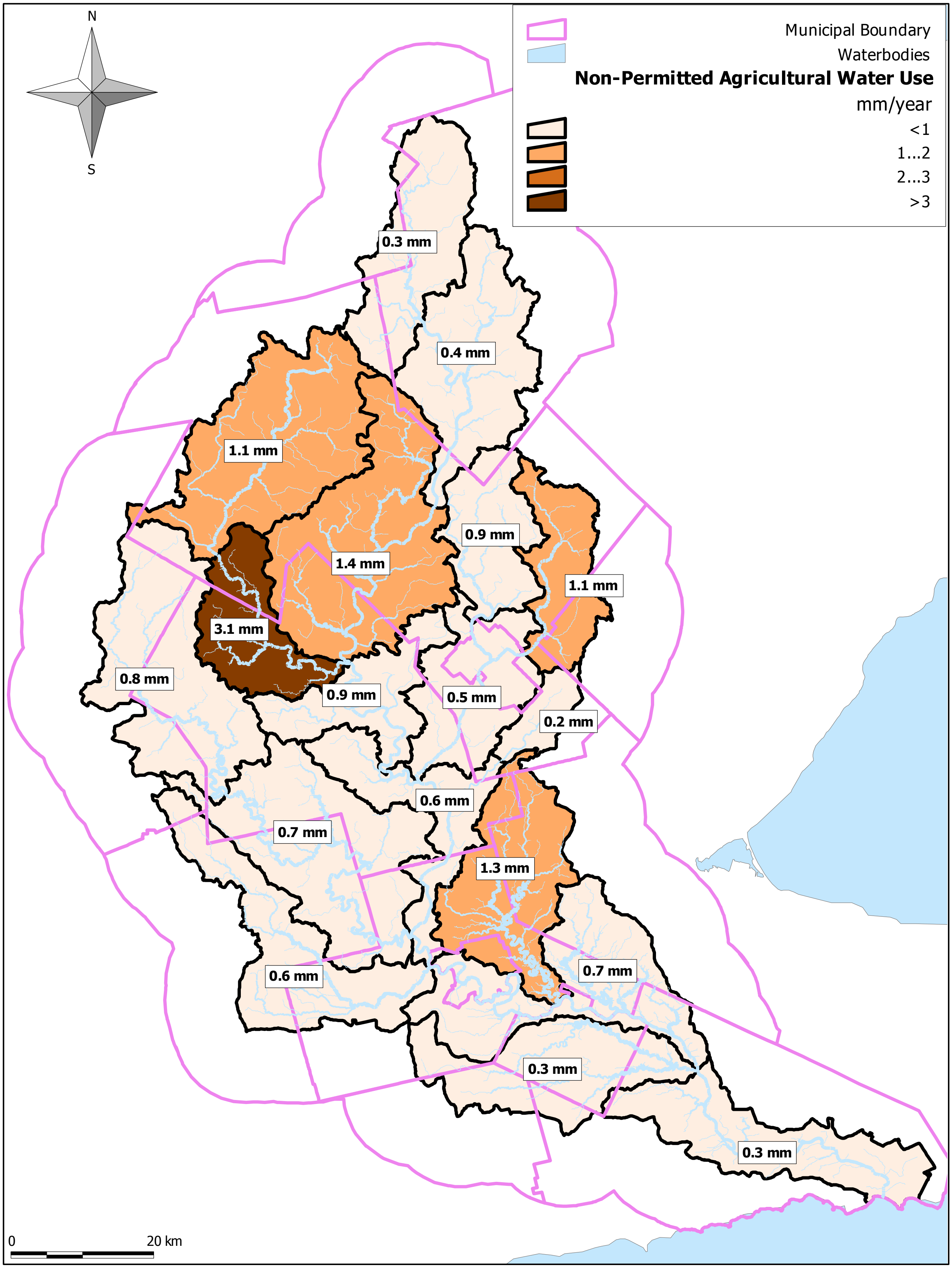

Figure 40
Non-Permitted Agricultural Water Demand

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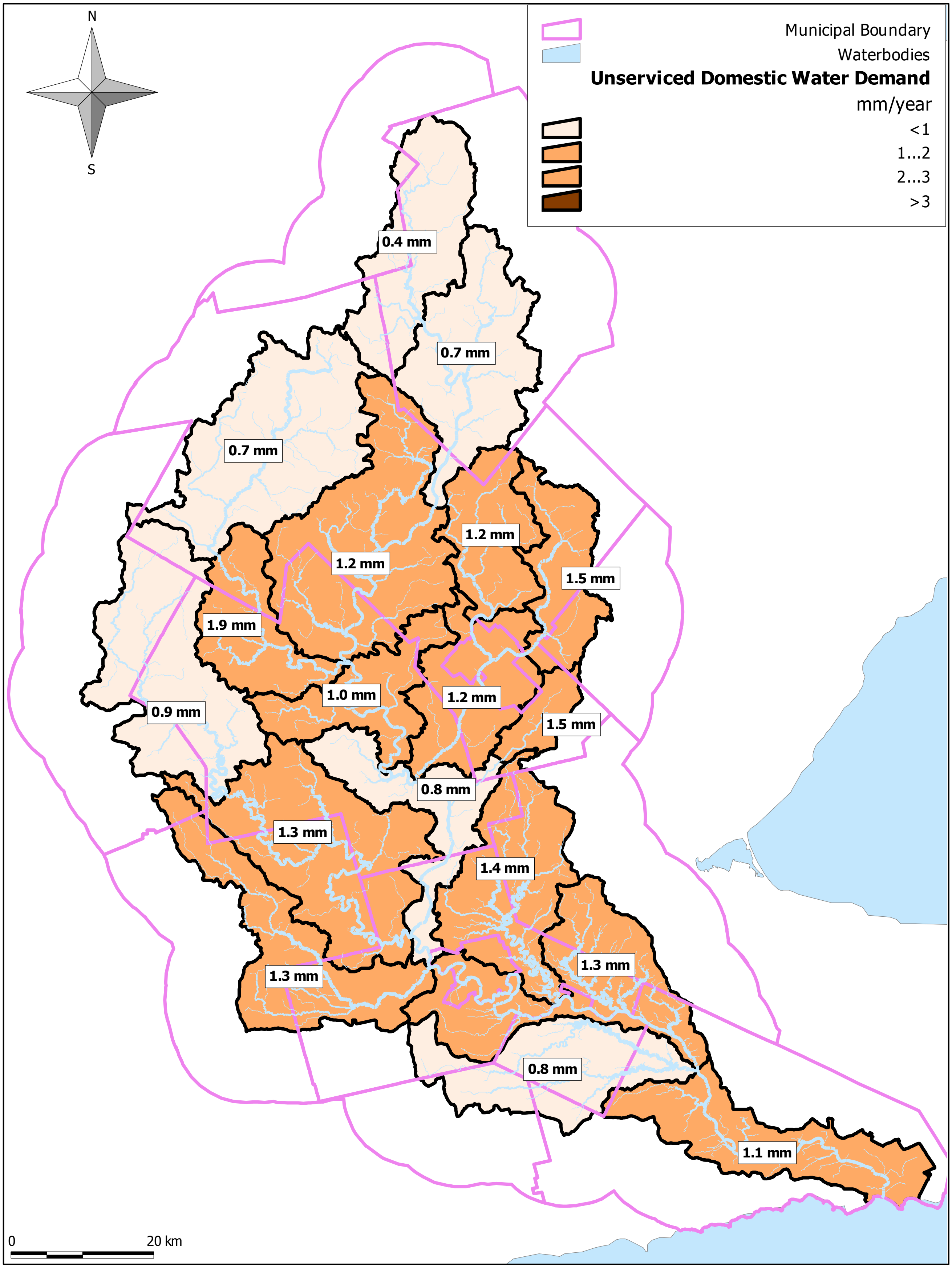

Figure 41
Un-serviced Domestic Water Demand

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Table 3.10 – Un-serviced Domestic Water Use

Subwatershed	Un-Serviced Domestic Water Use (L/s)	Un-Serviced Domestic Water Use (mm/y)
Grand Above Legatt	4	0.4
Grand Above Shand To Legatt	9	0.7
Grand Above Conestogo To Shand	22	1.2
Conestogo Above Dam	11	0.7
Conestogo Below Dam	14	1.9
Grand Above Doon To Conestogo	7	1.0
Eramosa Above Guelph	10	1.5
Speed Above Dam	8	1.2
Speed Above Grand To Dam	11	1.2
Mill Creek	3	1.5
Grand Above Brantford To Doon	7	0.8
Nith Above New Hamburg	15	0.9
Nith Above Grand To New Hamburg	21	1.3
Whitemans Creek	15	1.3
Grand Above York To Brantford	17	1.3
Fairchild Creek	17	1.4
McKenzie Creek	9	0.8
Grand Above Dunnville To York	11	1.1

Due to water quality concerns, it is unlikely that any un-serviced domestic demand is supplied by surface water sources. For this reason, it is assumed that all un-serviced domestic uses draw water from groundwater supplies. The consumptive use coefficient for these estimates is 0.2, similar to the Water Supply categories included in Table 3.5

3.4 WATER USE ESTIMATES

The following sections summarize water use estimates for municipal, permitted and non-permitted water uses. Permitted rate, pumped rate, and the total rate consumed at each consumptive scale are presented. Estimates include water takings permitted through the PTTW program, as well as non-permitted agricultural demands and un-serviced rural domestic demand.

3.4.1 Permitted Rate

Table 3.8 shows the total rate of water permitted through the PTTW process, broken down by subwatershed and by source. This rate is the maximum permitted rate allocated to each water taking, and is not considered to be representative of actual pumping. Many permits have restrictions which limit the amount of water removed, which is not reflected in this total.

Only active permits, or permits representing a sustained water taking, were included in this analysis. Temporary permits, such as pipeline testing or pumping tests, were not included. A total of 27,600 L/s of groundwater, and 27,300 L/s of surface water, are permitted to be withdrawn within the Watershed, for a total of 54,900 L/s or 55 m^3/s (Table 3.11). Figures 42 and 43 illustrate the permitted water taking rates for both surface water and groundwater.

Table 3.11 - Permitted Water Taking Rate

Subwatershed	Total Permitted Rate (L/s)	
	Groundwater	Surface Water
Grand Above Legatt	50	54
Grand Above Shand To Legatt	276	0
Grand Above Conestogo To Shand	1,639	8,412
Conestogo Above Dam	213	500
Conestogo Below Dam	312	0
Grand Above Doon To Conestogo	1,918	3,044
Eramosa Above Guelph	1,601	689
Speed Above Dam	142	2,021
Speed Above Grand To Dam	1,921	491
Mill Creek	850	0
Grand Above Brantford To Doon	5,865	510
Nith Above New Hamburg	182	52
Nith Above Grand To New Hamburg	3,293	409
Whitemans Creek	3,543	1,304
Grand Above York To Brantford	1,784	7,947
Fairchild Creek	580	311
McKenzie Creek	1,715	1,085
Grand Above Dunnville To York	418	308
Total	26,303	27,137

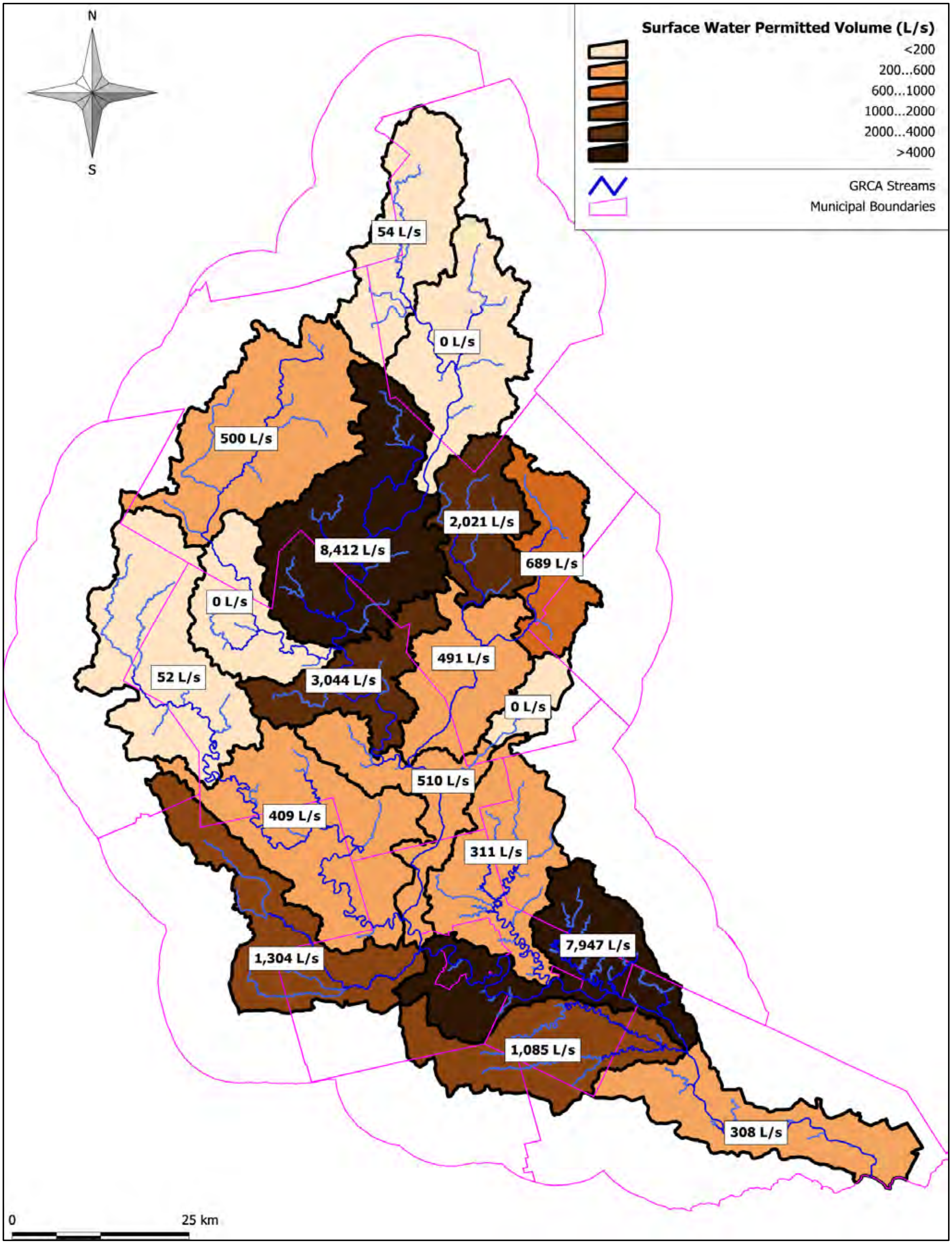

Figure 42
Permitted Surface Water Takings

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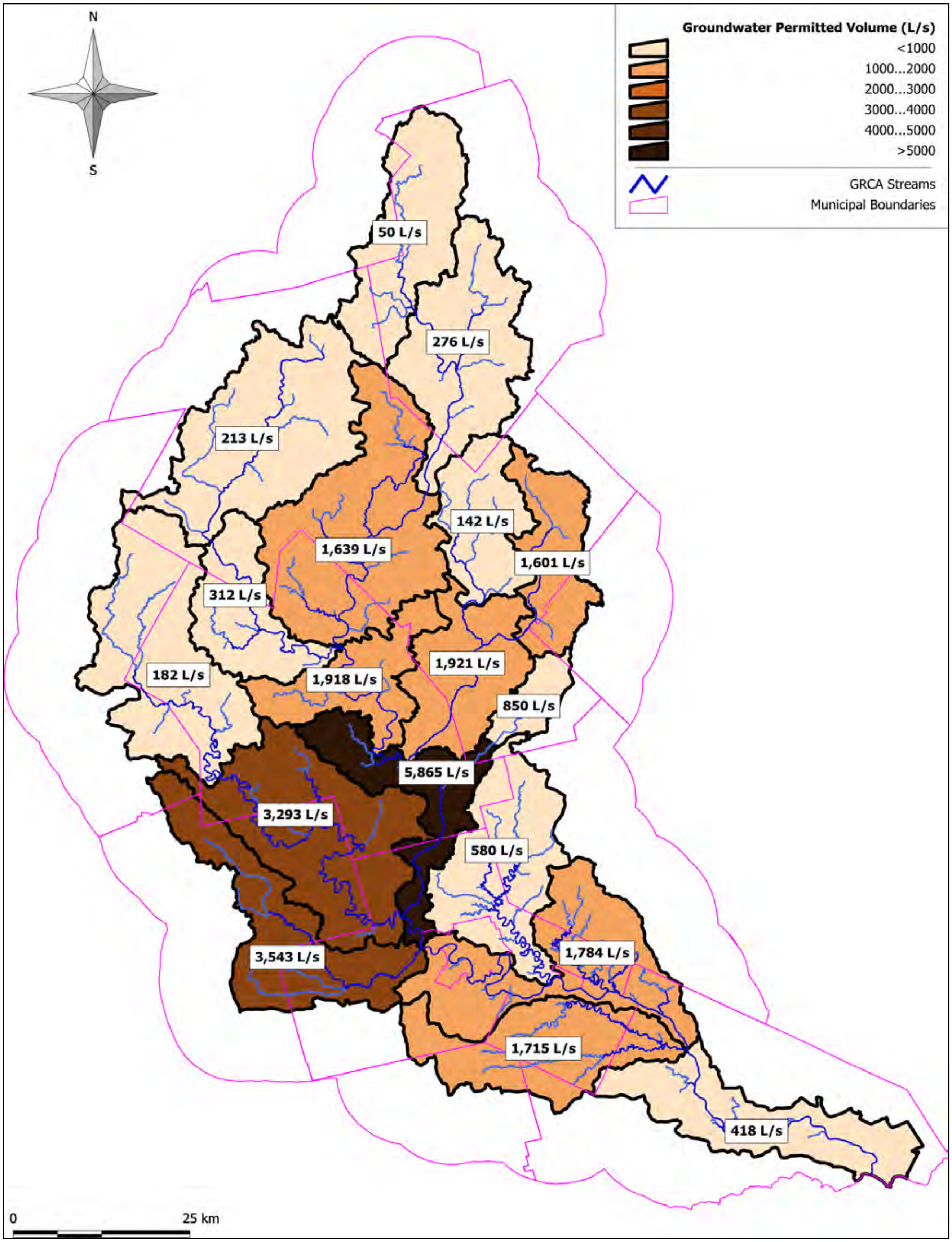

Figure 43
Permitted Groundwater Takings

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3.4.2 Pumped Rate

Table 3.12 summarizes the average rate pumped for each subwatershed. Two types of data exist from which total pumped water demand is determined: reported pumping rates and estimated pumping rates.

- Reported Pumping Rates. Reported rates are actual pumping rates given directly by the water user to the GRCA (e.g. municipal takings, water use surveys). The rate of water taken or pumped from a specific source was collected by the GRCA and recorded with the permit information. A reported rate is not dependent on the maximum permitted rate or seasonal use factors and is considered more accurate than an estimated pumping rate. When reported pumping rates are available, they are used instead of estimated pumping rates for that particular water taking.
- Estimated Pumping Rates. Estimated rates are required where no reported rates exist for a known water taking location. They are estimated based on maximum permitted rates from the PTTW database. Seasonal or monthly use factors (i.e. Table 3.6) or other known use factors (i.e. agricultural use factor described in Section 3.2.3.2) are used to modify the maximum permitted rate. These factors provide a more realistic estimate of actual pumping rates for a particular water taking. Estimated pumping rates are not as accurate as reported rates, as they are determined with no input from the actual permit holder or water user.

Subwatersheds that have a higher proportion of reported water pumping data have a greater certainty associated with water demand estimates than subwatersheds with mainly estimated water pumping data. The amount of water pumped, or the pumped rate, for each subwatershed is the amount of water that has been withdrawn from watercourses or aquifers without considering the consumptive demand.

Table 3.12 - Average Rate Pumped

	Groundwater (L/s)			Surface Water (L/s)		
Subwatershed	**Estimated**	**Reported**	**Total**	**Estimated**	**Reported**	**Total**
Grand Above Legatt	21	8	28	55	0	55
Grand Above Shand To Legatt	145	7	152	3	0	3
Grand Above Conestogo To Shand	88	184	272	8,402	0	8,402
Conestogo Above Dam	23	23	46	509	0	509
Conestogo Below Dam	43	56	99	13	0	13
Grand Above Doon To Conestogo	201	310	511	88	547	635
Eramosa Above Guelph	30	264	294	284	32	315
Speed Above Dam	27	7	34	2,022	0	2,022
Speed Above Grand To Dam	135	741	876	154	10	164
Mill Creek	241	99	339	1	0	1
Grand Above Brantford To Doon	488	796	1,283	358	3	361
Nith Above New Hamburg	31	44	75	11	2	13
Nith Above Grand To New Hamburg	496	454	950	129	0	129
Whitemans Creek	140	25	165	50	1	51
Grand Above York To Brantford	342	22	364	4,336	550	4,886
Fairchild Creek	99	15	115	132	0	132
McKenzie Creek	75	1	76	368	1	369
Grand Above Dunnville To York	232	28	260	9	12	21
Total	**2,856**	**3,083**	**5,939**	**16,922**	**1,158**	**18,080**

The difference between the total permitted and pumped rate for the Grand River Watershed is significant, with approximately 25,150 L/s (7,070 L/s+18,080 L/s) estimated to be pumped from aquifers and watercourses. The total permitted rate was shown in Table 3.9 to be 53,400 L/s. The average rate pumped for both surface and groundwater is illustrated on Figures 44 and 45.

Table 3.13 - Breakdown of Groundwater Pumped Demand by Subwatershed and Water Use Sector (L/s)

Subwatershed	Agric-ultural		Com-mercial		Dewa-tering		Industrial		Instit-utional	Misc.		Recre-ational		Remed-iation		Water Supply		Rural Domestic & Live-stock	Total
	Rep	Est	Rep	Est	Rep	Est	Rep	Est	Est	Rep	Est	Rep	Est	Rep	Est	Rep	Est	Est	
Grand Above Legatt	0	0	0	13	0	0	0	0	0	0	0	0	0	0	0	8	2	6	28
Grand Above Shand To Legatt	0	0	0	0	0	0	0	84	0	0	4	0	0	0	0	7	45	12	152
Grand Above Conestogo To Shand	0	0	74	27	0	18	8	5	0	0	0	0	0	35	3	66	0	36	272
Conestogo Above Dam	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	20	2	21	46
Conestogo Below Dam	0	0	0	0	0	0	48	10	0	0	0	0	0	0	0	9	7	27	99
Grand Above Doon To Conestogo	0	0	5	26	0	71	135	27	0	0	0	0	0	0	1	169	65	11	511
Eramosa Above Guelph	0	0	6	16	0	0	0	0	0	0	0	0	0	0	0	258	0	14	294
Speed Above Dam	0	3	1	11	0	0	0	0	0	0	0	0	0	0	0	5	2	12	34
Speed Above Grand To Dam	0	5	15	26	158	7	25	45	2	0	17	0	0	2	1	540	20	14	876
Mill Creek	0	0	28	3	0	0	68	222	0	0	0	0	0	0	0	3	13	4	339
Grand Above Brantford To Doon	0	0	5	36	0	5	2	353	2	0	0	0	2	0	50	789	30	10	1,283
Nith Above New Hamburg	2	0	0	0	0	0	0	7	0	0	0	0	0	0	0	42	2	22	75
Nith Above Grand To New Hamburg	0	9	1	39	0	0	54	394	0	0	0	0	0	0	24	399	2	28	950
Whitemans Creek	22	120	1	2	0	0	0	0	0	0	0	0	0	0	0	1	0	19	165
Grand Above York To Brantford	3	44	2	30	0	101	0	143	0	0	0	0	0	0	0	18	2	23	364
Fairchild Creek	0	6	2	22	0	0	0	11	0	0	0	0	8	0	2	13	25	26	115
Mckenzie Creek	1	64	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	76
Grand Above Dunnville To York	0	2	0	6	28	212	0	0	0	0	0	0	0	0	0	0	0	13	260
Total	**28**	**254**	**140**	**256**	**186**	**413**	**343**	**1,301**	**3**	**0**	**20**	**0**	**9**	**37**	**81**	**2,348**	**215**	**303**	**5,939**

Table 3.14 - Breakdown of Surface Water Pumped Demand by Subwatershed and Water Use Sector (L/s)

Subwatershed	Agricultural		Commercial		Const-ruction	Dewatering	Industrial		Misc.	Recre-ational	Water Supply	Livestock	Total
	Est	Rep	Est	Rep	Est	Est	Est	Rep	Est	Est	Rep	Est	
Grand Above Legatt	0	0	0	0	0	0	0	0	54	0	0	2	55
Grand Above Shand To Legatt	0	0	0	0	0	0	0	0	0	0	0	3	3
Grand Above Conestogo To Shand	1	0	4	0	0	900	6,716	0	767	0	0	14	8,402
Conestogo Above Dam	0	0	0	0	0	500	0	0	0	0	0	10	509
Conestogo Below Dam	0	0	0	0	0	0	0	0	0	0	0	13	13
Grand Above Doon To Conestogo	0	0	5	0	0	0	0	3	79	0	544	4	635
Eramosa Above Guelph	0	0	57	0	0	0	0	0	0	223	32	4	315
Speed Above Dam	0	0	2	0	0	0	0	0	2,016	0	0	4	2,022
Speed Above Grand To Dam	3	0	1	10	131	0	17	0	0	0	0	3	164
Mill Creek	0	0	0	0	0	0	0	0	0	0	0	1	1
Grand Above Brantford To Doon	0	0	19	3	0	28	59	0	248	0	0	3	361
Nith Above New Hamburg	0	0	0	2	0	0	0	0	0	4	0	7	13
Nith Above Grand To New Hamburg	11	0	3	0	0	0	91	0	17	1	0	7	129
Whitemans Creek	46	1	0	0	0	0	0	0	0	0	0	4	51
Grand Above York To Brantford	16	4	15	0	0	0	4,300	0	0	0	547	6	4,886
Fairchild Creek	7	0	8	0	0	0	0	0	109	0	0	9	132
Mckenzie Creek	20	1	4	0	0	0	0	0	342	0	0	2	369
Grand Above Dunnville To York	8	12	0	0	0	0	0	0	0	0	0	2	21
Total	**111**	**18**	**118**	**15**	**131**	**1,428**	**11,183**	**3**	**3,632**	**227**	**1,123**	**91**	**18,080**

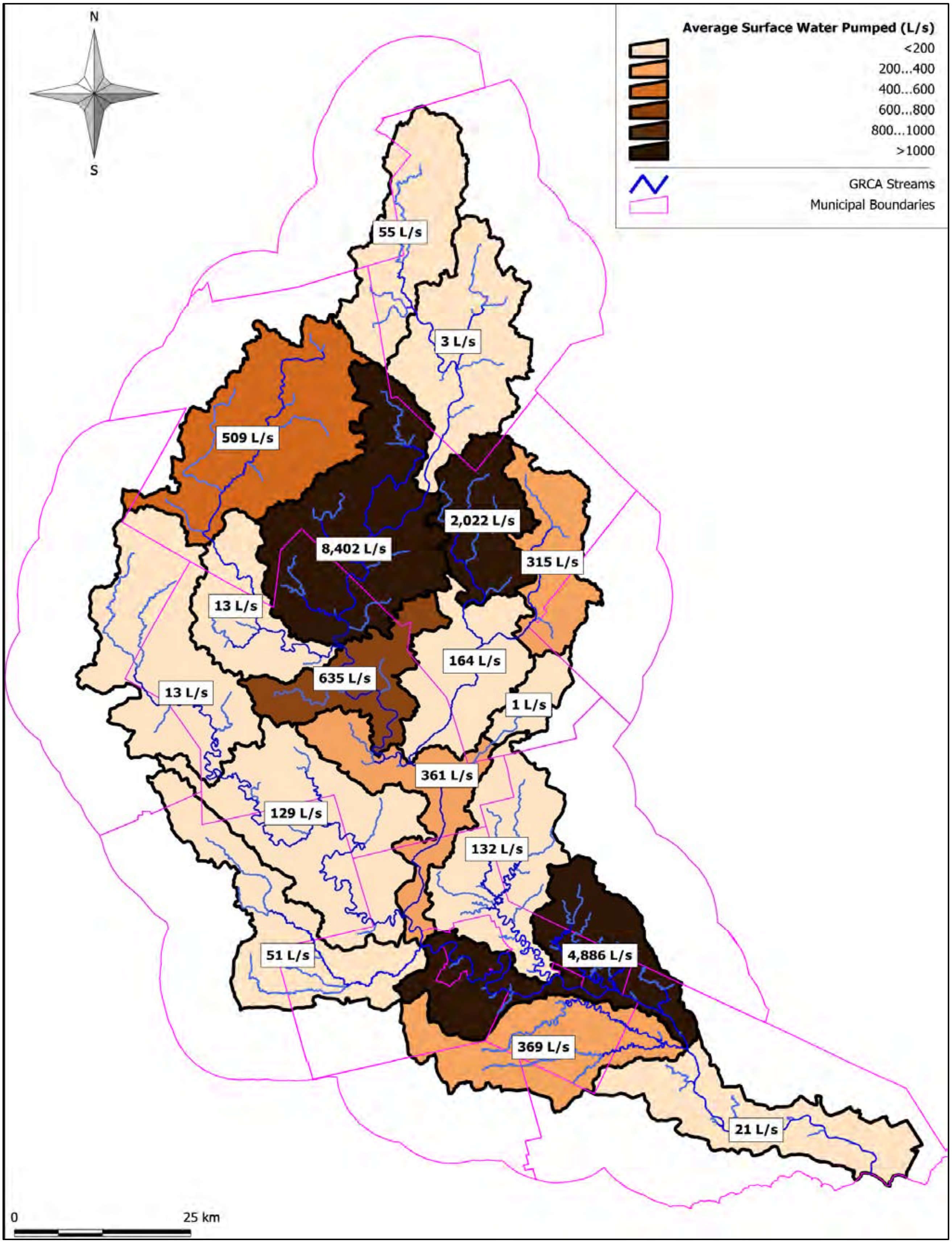

Figure 44
Average Surface Water Pumped

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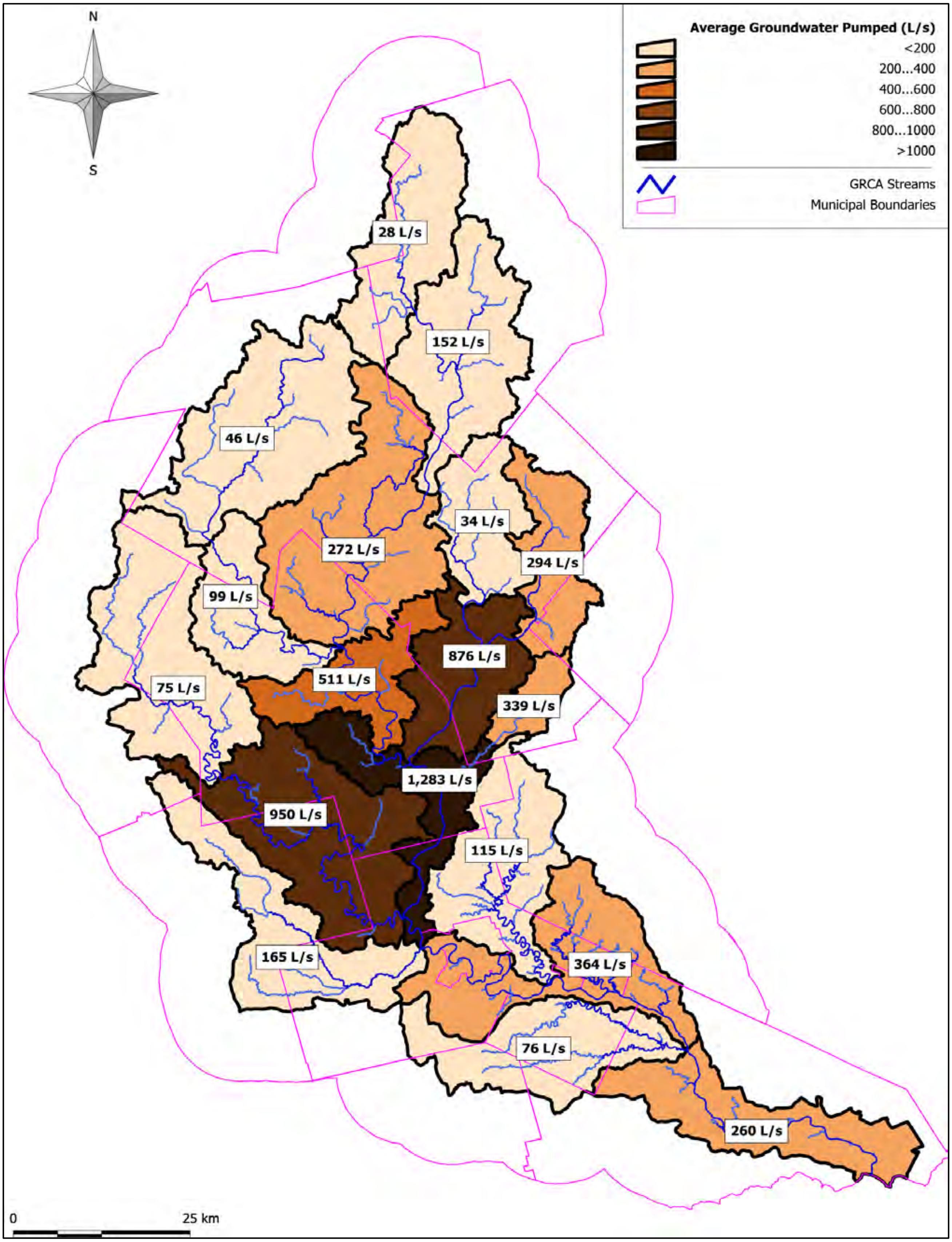

Figure 45
Average Groundwater Pumped

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3.4.3 Consumptive Estimate (Unit Scale)

Table 3.11 presents the unit consumptive demand for each subwatershed. The unit consumptive demand is defined as the amount of water pumped from a specific unit (aquifer, watercourse) and not returned to that same unit in a reasonable amount of time. Consumptive demands were calculated using the consumptive use factors given in Table 3.5 and are applied to both estimated and reported pumped rates.

The maximum and minimum monthly demand and the average annual unit consumptive water demand for both surface water and groundwater are presented in Table 3.11. On an average annual basis approximately 4000 L/s of water is consumed from aquifers and 580 L/s is consumed from rivers and creeks; consumed water is water that is pumped but is not returned to its original source.

Surface water takings occur mostly in larger river systems such as the Grand River, as shown in Figure 46. The maximum monthly consumptive surface water demand, shown in Figure 46, most often occurs during the summer months when agricultural or golf course irrigation is occurring. The average annual surface water consumptive demand estimates are shown in Figure 47.

The maximum monthly and average monthly groundwater unit consumptive demands for the Grand River Watershed are shown in Figures 48 and 49, respectively. The greatest concentration of groundwater takings is focused on the central moraine area and the Norfolk Sand Plain. In subwatersheds dominated by seasonal takings (e.g. Whiteman's Creek), there are large differences between monthly maximum, minimum and average demands. This is due to water demand rates for takings such as agricultural irrigation being highly variable throughout the year.

Typically, wastewater from groundwater extractions is discharged to the surface water system, not back to the original source (e.g. wells supply a municipal system, whose waste water treatment plant discharges to a river). This results in most groundwater takings having unit consumptive coefficients of 100%, and consequently, higher unit consumptive demands than surface water takings (that typically discharge back to the same source and have lower unit consumptive coefficients).

Table 3.15 – Consumptive Demand (By Source of Water)

Subwatershed	Groundwater Consumptive Demand (L/s)			Surface Consumptive Demand (L/s)		
	Monthly Maximum Demand	Monthly Minimum Demand	Annual Average Demand	Monthly Maximum Demand	Monthly Minimum Demand	Annual Average Demand
Grand Above Legatt	27	23	25	2	2	2
Grand Above Shand To Legatt	77	59	69	3	3	3
Grand Above Conestogo To Shand	267	235	250	35	22	26
Conestogo Above Dam	40	35	37	12	12	12
Conestogo Below Dam	54	39	46	13	13	13
Grand Above Doon To Conestogo	542	405	459	133	102	117
Eramosa Above Guelph	354	229	286	101	5	45
Speed Above Dam	62	11	27	17	14	15
Speed Above Grand To Dam	907	723	831	56	17	28

Subwatershed	Groundwater Consumptive Demand (L/s)			Surface Consumptive Demand (L/s)		
	Monthly Maximum Demand	Monthly Minimum Demand	Annual Average Demand	Monthly Maximum Demand	Monthly Minimum Demand	Annual Average Demand
Mill Creek	114	46	82	1	1	1
Grand Above Brantford To Doon	1,207	911	1,027	62	4	26
Nith Above New Hamburg	71	59	62	13	7	9
Nith Above Grand To New Hamburg	681	378	513	71	16	29
Whitemans Creek	465	9	117	218	4	51
Grand Above York To Brantford	412	156	227	245	105	145
Fairchild Creek	117	83	92	59	9	22
McKenzie Creek	223	3	53	108	3	29
Grand Above Dunnville To York	116	74	91	70	2	21
Total			**4,295**			**588**

The subwatershed consumptive water demand is examined in more detail in Table 3.16, which presents the percent of unit consumptive water demand used by water use sectors, broken down by subwatershed. Similar to the pumped water rate analysis, this analysis breaks down the percentage of the unit consumptive demand into an estimated portion, and a portion tabulated from reported data. An estimated unit consumptive demand is based on applying consumptive coefficients to estimated pumping rates and a reported unit consumptive demand is based on applying consumptive coefficients to reported pumping rates. This analysis is based on permits to take water, municipal information, and livestock watering/un-serviced domestic demand estimates. Each sector demand is presented as a percentage of the Average Annual Consumptive Water Demand for each subwatershed.

The total unit consumptive water demand of each sector in a subwatershed is obtained by adding the estimated and reported percentages. For example, in the Eramosa Above Guelph Subwatershed the commercial water use sector is estimated to use 9% of the average annual unit consumptive water demand. This percentage is calculated by summing the reported (2%) and estimated (7%) data as outlined on Table 3.16. Unit consumptive water demand values based on reported information are more certain than unit consumptive water demand values based on estimated pumping rates. Therefore, as all municipal pumping rates are reported, the consumptive demand based on municipal pumping has greater certainty than other sectors with a majority of estimated pumping rates. This provides further understanding of the certainty of unit consumptive water demand in the Grand River Watershed. The final row in Table 3.16 gives the total water use sector breakdown of consumptive water demand for the entire Watershed.

The main unit consumptive water use sector in the Watershed is municipal water supply, accounting for 47% of the total average annual unit consumptive water demand. The commercial, dewatering, and industrial sectors each use 10% of the Watershed's total average annual unit consumptive water demand. Agricultural use accounts for 7% of total average annual unit consumptive water demand, while non-municipal water supply and livestock/rural domestic uses each account for 5% of total average annual unit consumptive water demand. Remediation accounts for another 4% of the total average annual unit consumptive demand, and a final 2% is attributed to miscellaneous uses. Summing the Watershed totals for all reported categories shows that 58% of the total unit consumptive demand for the Grand River

Watershed has been generated based on reported water use values. The fact that the majority of the unit consumptive demand estimates have been generated through use of reported (actual) pumping rates increases the certainty of the unit consumptive demand estimates.

Table 3.16 - Percentage of Consumptive Water Use (Unit Scale) Utilized by Water Use Sectors in Each Subwatershed

Subwatershed	Commercial		Construct	Dewatering		Industrial		Institut.	Recreational		Remediation		Private Water Supply		Misc.		Agricultural Irrigation		Livestock & Rural Domestic	Munic. Water Supply
	Rep	Est	Est	Rep	Est	Rep	Est	Est	Rep	Est	Rep	Est	Rep	Est	Rep	Est	Rep	Est	Est	Rep
Grand Above Legatt	0%	50%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	7%	0%	1%	0%	0%	14%	28%
Grand Above Shand to Legatt	0%	0%	0%	0%	0%	0%	12%	0%	0%	0%	0%	0%	0%	63%	0%	5%	0%	0%	10%	10%
Grand Above Conestogo To Shand	27%	11%	0%	0%	8%	1%	2%	0%	0%	0%	13%	1%	0%	0%	0%	1%	0%	0%	12%	24%
Conestogo Above Dam	0%	0%	0%	0%	5%	7%	0%	0%	0%	0%	0%	0%	0%	5%	0%	0%	0%	0%	43%	40%
Conestogo Below Dam	0%	0%	0%	0%	0%	10%	16%	0%	0%	0%	0%	0%	0%	11%	0%	0%	0%	0%	48%	15%
Grand Above Doon To Conestogo	1%	5%	0%	0%	12%	15%	5%	0%	0%	0%	0%	0%	0%	11%	0%	0%	0%	0%	1%	48%
Eramosa Above Guelph	2%	7%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	3%	87%
Speed Above Dam	3%	29%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	4%	0%	24%	0%	6%	21%	13%
Speed Above Grand To Dam	3%	3%	2%	18%	1%	0%	4%	0%	0%	0%	0%	0%	0%	2%	0%	2%	0%	1%	1%	63%
Mill Creek	34%	3%	0%	0%	0%	9%	33%	0%	0%	0%	0%	0%	3%	15%	1%	0%	0%	0%	2%	0%
Grand Above Brantford To Doon	1%	5%	0%	0%	0%	0%	11%	0%	0%	0%	0%	5%	0%	3%	0%	0%	0%	0%	1%	75%
Nith Above New Hamburg	2%	0%	0%	0%	0%	0%	10%	0%	0%	0%	0%	0%	0%	3%	0%	0%	2%	1%	24%	59%
Nith Above Grand To New Hamburg	0%	7%	0%	0%	0%	1%	6%	0%	0%	0%	0%	4%	0%	0%	0%	0%	0%	3%	3%	74%
Whitemans Creek	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	11%	81%	7%	1%
Grand Above York To Brantford	0%	11%	0%	0%	27%	0%	8%	0%	0%	0%	0%	0%	0%	0%	0%	0%	2%	13%	4%	34%
Fairchild Creek	2%	24%	0%	0%	0%	0%	10%	0%	0%	0%	0%	2%	0%	22%	0%	0%	0%	10%	18%	12%
McKenzie Creek	0%	4%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	2%	2%	86%	6%	0%
Grand Above Dunnville To York	0%	5%	0%	25%	47%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	11%	8%	5%	0%
WATERSHED TOTAL	3%	6%	0%	4%	5%	2%	6%	0%	0%	0%	1%	2%	0%	4%	0%	1%	1%	6%	5%	53%

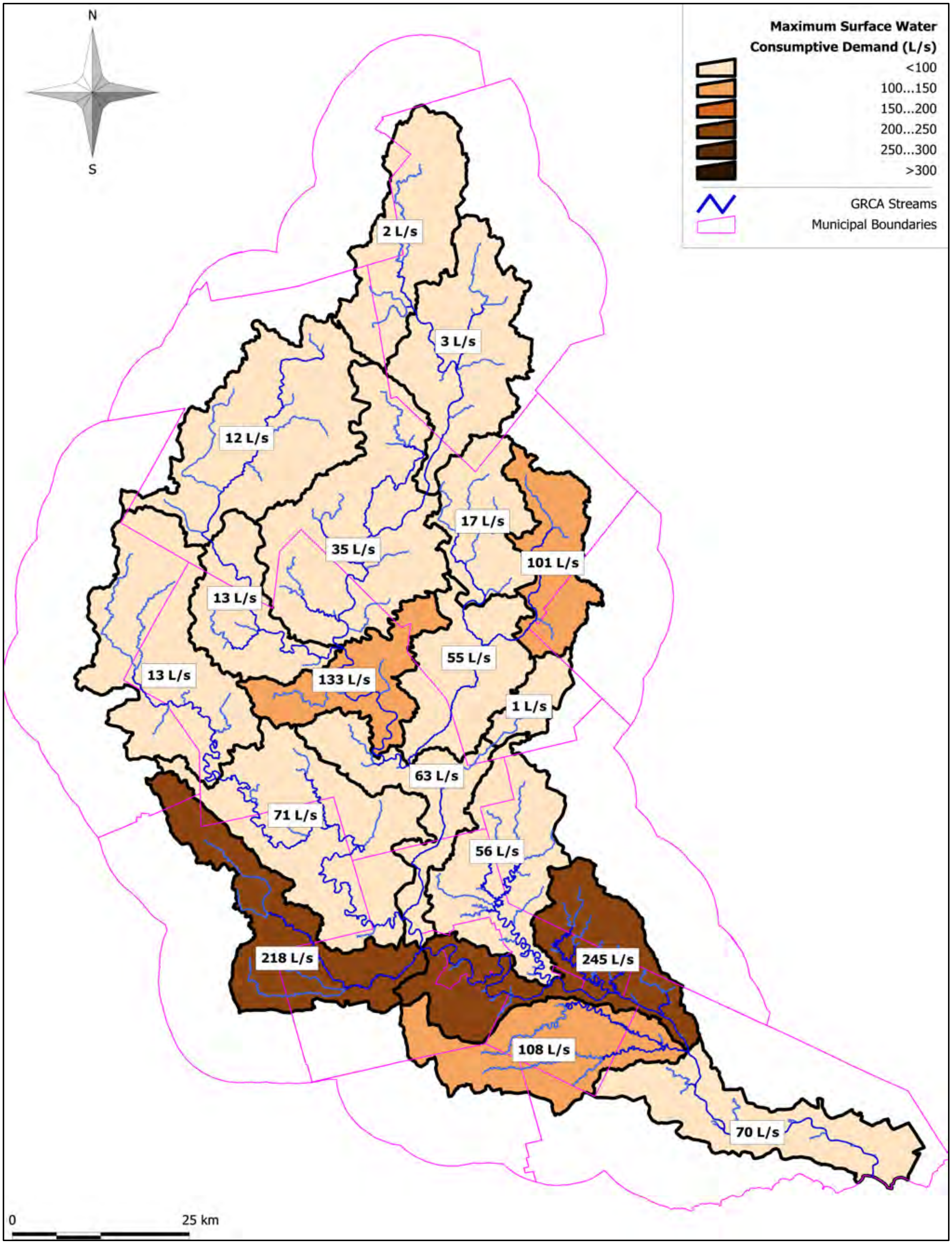

Figure 46
Maximum Surface Water Consumptive Demand

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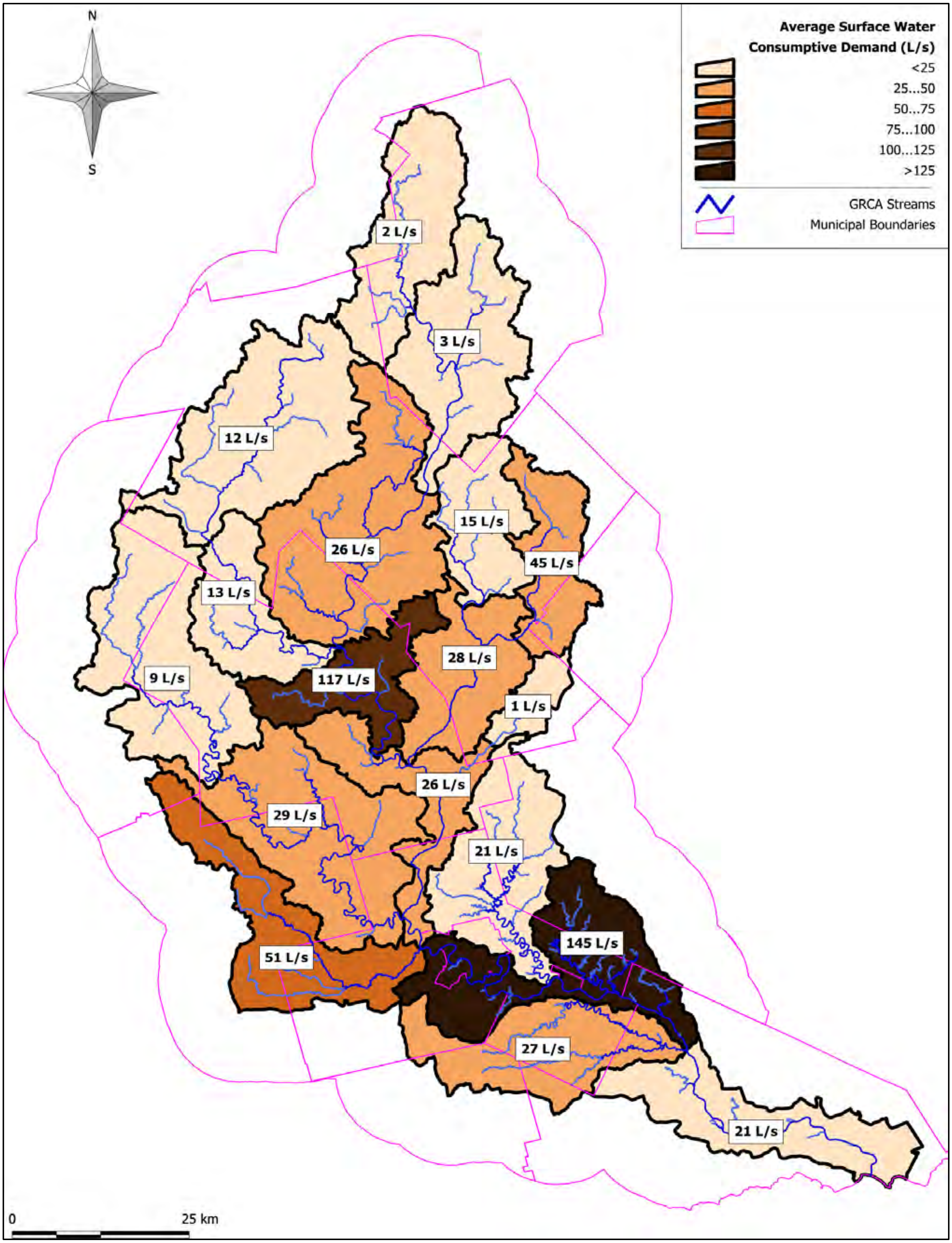

Figure 47
Average Surface Water Consumptive Demand

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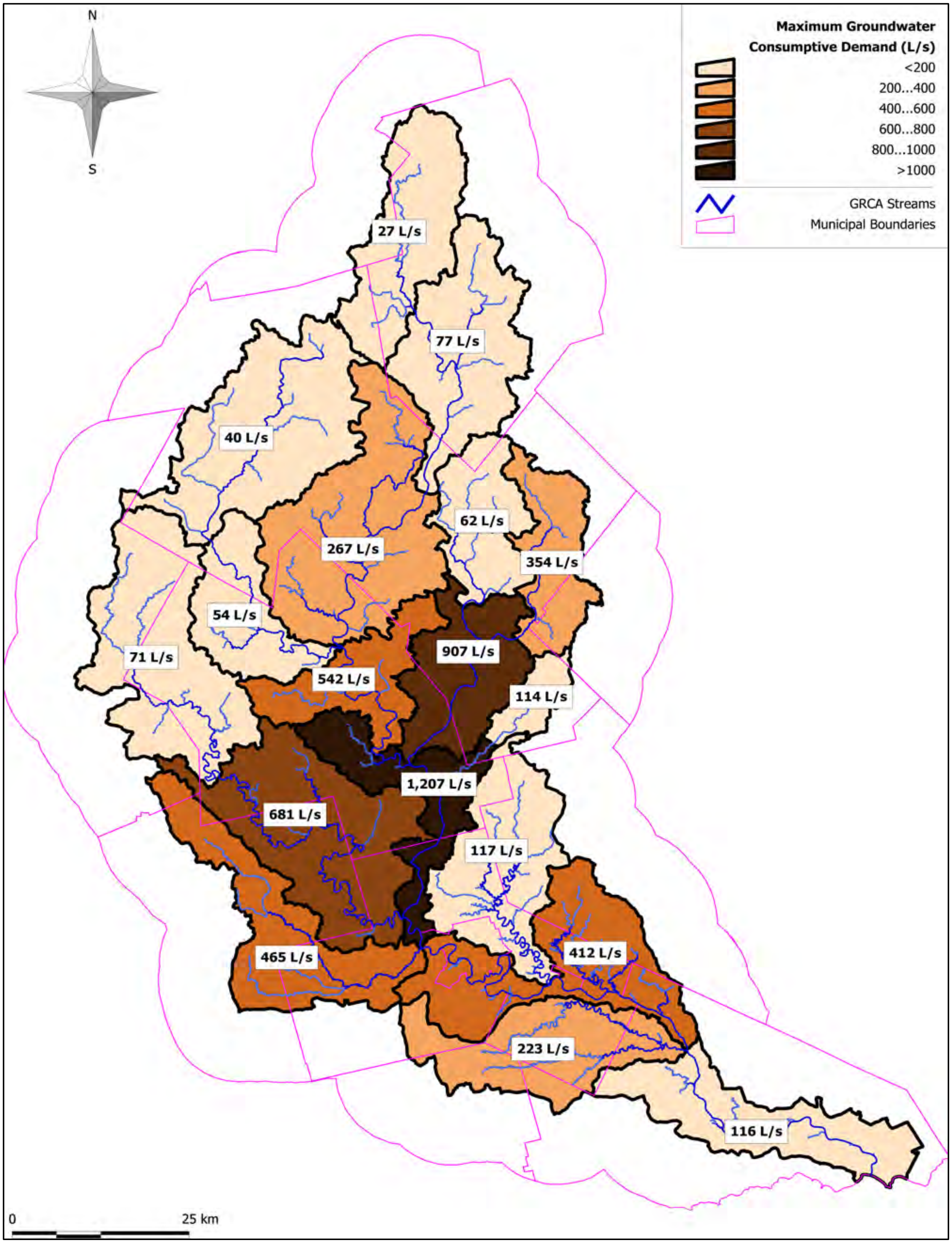

Figure 48
Maximum Groundwater Consumptive Demand

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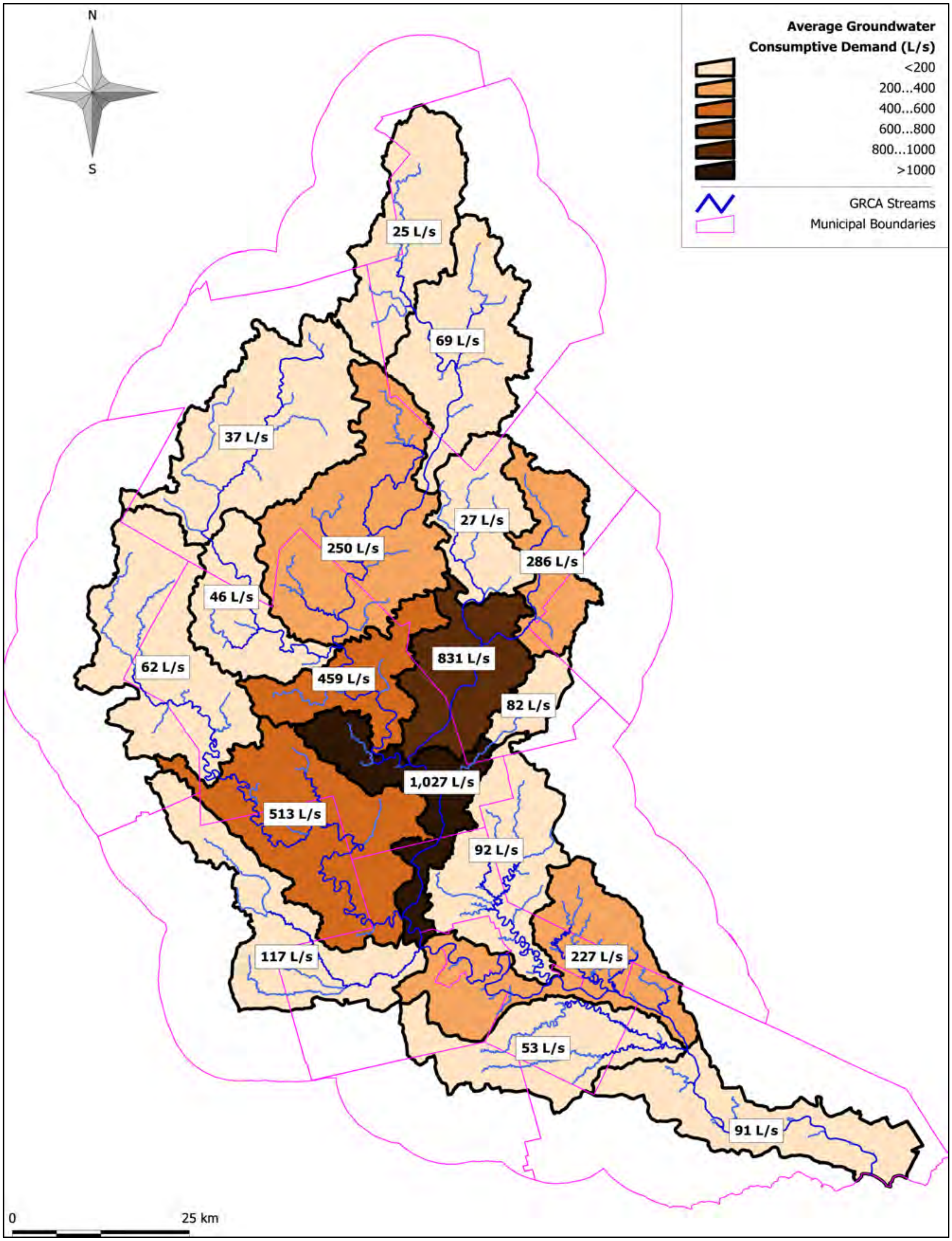

Figure 49
Average Groundwater Consumptive Demand

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3.4.4 Consumptive Water Demand Estimates (Subwatershed and Watershed Scale)

Table 3.17 summarizes subwatershed and watershed consumptive demands. The subwatershed scale consumptive demand is the amount of water taken from a subwatershed (e.g. Eramosa Above Guelph) and not returned to the same subwatershed. The watershed scale consumptive demand is the amount of water taken from the Grand River Watershed, and not returned to the Watershed.

The watershed scale consumptive demand represents the amount of water lost to evaporation (either direct or through plant transpiration) or incorporation of water into product (such as food processing). Differences between the subwatershed and watershed scales indicate where water is removed from one subwatershed, and discharged into another (e.g., groundwater from the Nith River being discharged to the Grand River). Subwatersheds where the subwatershed and watershed consumptive demands are the same do not experience such transfers of water to another subwatershed.

Table 3.17 – Subwatershed and Watershed Scale Consumptive Demand (all sources)

Subwatershed	Subwatershed Consumptive Demand (L/s)			Watershed Consumptive Demand (L/s)		
	Monthly Maximum Demand	Monthly Minimum Demand	Annual Average Demand	Monthly Maximum Demand	Monthly Minimum Demand	Annual Average Demand
Grand Above Legatt	9	8	9	9	8	9
Grand Above Shand To Legatt	31	16	25	31	16	25
Grand Above Conestogo To Shand	113	87	95	113	87	95
Conestogo Above Dam	25	24	24	25	24	24
Conestogo Below Dam	40	28	33	40	28	33
Grand Above Doon To Conestogo	278	188	217	278	188	217
Eramosa Above Guelph	432	222	316	134	57	88
Speed Above Dam	59	18	30	59	18	30
Speed Above Grand To Dam	250	149	183	250	149	183
Mill Creek	93	30	65	93	30	65
Grand Above Brantford To Doon	390	197	270	390	197	270
Nith Above New Hamburg	24	24	27	38	24	27
Nith Above Grand To New Hamburg	481	268	347	284	94	160
Whitemans Creek	624	10	152	624	10	152
Grand Above York To Brantford	502	158	253	502	158	253
Fairchild Creek	98	31	48	98	31	48
McKenzie Creek	306	6	74	306	6	74
Grand Above Dunnville To York	74	6	25	85	17	36
Total			**2,193**			**1,789**

3.5 SUMMARY OF ESTIMATED WATER USE IN THE GRAND RIVER WATERSHED

This water use assessment relies on information contained within the GRCA's Permit to Take Water database, some reported pumping rates from PTTW holders (municipal and non-municipal), and Census data to estimate water demand in the Grand River Watershed. The methodology developed approximates total pumping in the Watershed, and also consumptive demands at several scales. Consumptive demand refers to the amount of water that is not returned back to the hydrological unit, subwatershed, or watershed.

The calculated average pumping in the Watershed is 25,100 L/s (Table 3.12). Much of this total pumping rate is not consumptive water use, and water is returned or recycled. The average unit consumptive demand (water not returned to the source from which it is pumped) is estimated to be 4,524 L/s (Table 3.15). The estimated subwatershed-scale consumptive demand (water not returned to the subwatershed from which it is pumped) is 1,847 L/s (Table 3.17), and the watershed-scale consumptive demand (water that is not returned within the Grand River Watershed) is 1,732 L/s.

While large rates of water are redistributed or recycled due to anthropogenic activities, less than 7% of the water pumped in the Watershed is actually consumed, or lost from the Watershed. The difference between average annual permitted, pumped, and consumed rates (for the unit, subwatershed and watershed scales) is presented graphically on Figure 50. For the purpose of completing the companion Tier 2 Stress Assessment Report for the Grand River Watershed, the consumptive demands at the unit scale were used.

This assessment has estimated the breakdown of consumptive (by hydrologic unit) water demand by sector as follows;

1. Municipal Water Supply – 53%
2. Industrial Purposes – 8%
3. Dewatering – 9%
4. Commercial Purposes – 9%
5. Agricultural Irrigation – 7%
6. Private Water Supplies – 4%
7. Livestock & Un-serviced Domestic – 5%
8. Groundwater Remediation – 3%
9. Miscellaneous – 2%

Municipal water supply is the largest water use in the Grand River Watershed, responsible for approximately 50% of the total consumptive demand. Most of this water is returned to the Watershed, via wastewater treatment plant discharge to watercourses; however, groundwater takings (the majority of municipal supply) discharging to surface water are considered to be consumptive at the unit scale. Industrial demands (including aggregate washing), dewatering permits, and commercial uses (golf courses, aquaculture, water bottling) each account for just under 10% of the unit consumptive demand. Agricultural irrigation demands represent 7% of the total consumptive demand in the Watershed. All other water use sectors are each responsible for less than 5% of the total annual consumptive demand.

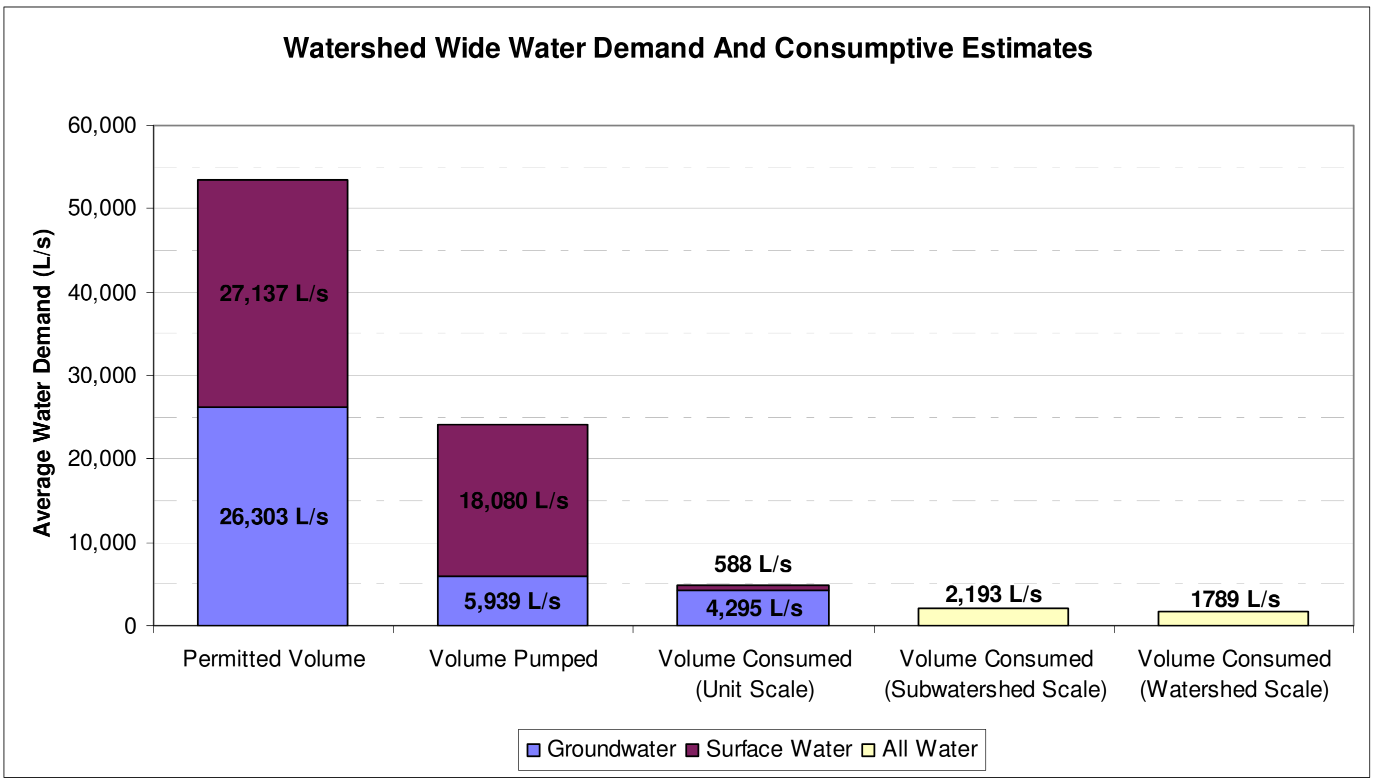

Figure 50
Permitted, Pumped and Consumed Water Demand Estimates

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3.6 UNCERTAINTY

Water demand estimates are subject to various levels of uncertainty. Municipal water demands are relatively certain because the actual water takings are recorded and reported. Other water uses/demands are subject to higher levels of uncertainty resulting from estimated water takings. Uncertainty associated with estimated pumping rates was minimized by applying seasonal use factors and additional agricultural water use factors to the maximum pumping rates.

Recognizing the limitations of relying on permit to take water information for water demand estimation, a significant amount of effort was made to survey the most significant water users for more realistic water taking information. The GRCA contacted permit-to-take-water holders in the top five water use sectors (i.e. dewatering, aggregate washing, golf courses, aquaculture, and the miscellaneous category) to determine actual water use rates. By focusing on the largest water use sectors, uncertainty was reduced while minimizing effort. In total, 65% of the total unit consumptive demand was established by reported pumping rates. As additional water use rates are reported, as required by the new permit to take water regulations or additional GRCA surveys, the certainty of estimated consumptive water takings will increase.

Although certainty is increased when using reported pumped rates, all uncertainty is not removed by using reported rates. Uncertainty in consumptive water demand still exists due to the estimated consumptive coefficients applied to both reported and estimated pumped rates.

Uncertainty is also present in the water use estimates for the non-permitted water uses, such as domestic water use and livestock use. However, as these water uses are relatively minor on the scale of the Watershed water budget, the impact of this uncertainty on the overall Watershed water budget is not significant.

3.6.1 Information Gaps

The current permit to take water database includes newly-reported actual water-pumping rates collected by the GRCA, which increases the certainty of water demand estimates for the Watershed. However, there remain a large number of permits with no reported pumping rates. Demands for these permits are estimated based on the maximum permitted water taking and the assumed months of active pumping.

When estimating water demands from the PTTW data, consideration must be given to the following:

- When specifying the amount of water required for their specific use, PTTW holders will often request a rate of water that exceeds their requirements. This is typically done to ensure compliance in dry years, or to secure sufficient water for possible future expansion of the operation. There is a lack of data surrounding how the actual or average pumping rates, so estimating pumping rates based on maximum permitted rates, instead of average pumping rates may yield higher estimates of pumped water use for non-reported permits;
- The PTTW database does not maintain a record of seasonal water use;
- Multiple wells or water sources may be included on one permit to take water, and the permitted rate refers to the total for all the water sources. There is a lack of information in the permit to take water database about the distribution of pumping between multiple sources;
- The location of water sources (wells or intakes) is not always accurate;

- The PTTW database is not current with respect to the MOE's actual permitting activities (recent permit numbers may not be included within the database due to the delay between approval and being entered in the database);
- The source of water may be characterized in the PTTW database as a surface water taking, groundwater taking, or "both", where both groundwater and surface water are used. However, the *source* information (which quantifies the maximum permitted rate and location of the water taking, for example), is *not* attributed with a standardized field for indicating whether a *specific* source is taking water from surface water or groundwater; and,
- Historic water wells, which may have large demands, may be "grandfathered" and do not require a permit. As such, those demands are not reflected in the PTTW database.

During this study, the GRCA carried out an extensive update of the PTTW database that addressed the above issues wherever possible. This update has increased the certainty of the water demand estimates and should be continued into the future.

4.0 GAWSER Continuous Streamflow-Generation Model

A comprehensive hydrologic model quantifies and characterizes key hydrologic components within a watershed. Although any model is a simplification of the movement of water through the environment, the appropriate model should make valid inferences regarding the key hydrologic processes within a watershed. A description of the key physical processes is given below to provide an overview of the surface water flow component of the hydrologic cycle.

4.1 SUMMARY OF THE HYDROLOGIC CYCLE

The hydrologic cycle refers to the movement of water through the earth-atmosphere system. This cycle begins with the transfer of water from land and ocean surfaces to the atmosphere as water vapour by evaporation, including the water transpired by vegetation. This is followed by the release of water from the atmosphere beginning with condensation (clouds) and return to the earth by precipitation. The precipitation is stored on the earth's surface (e.g., rivers, lakes, oceans), or stored below the earth's surface (groundwater), or is in transit toward the ocean as surface or subsurface flow. The cycle is then repeated as evaporation depletes the storages.

For this study, the hydrologic cycle begins with rain or snow (precipitation) falling to the ground. The amount and rate of precipitation that arrives at the ground surface is governed by the prevailing weather system that generated the precipitation on a regional scale. At the more localized scale, topography and land use cover influence the actual precipitation amounts arriving at the ground surface.

Liquid water (from rain, snowmelt or both) either runs off across the ground surface directly to a surface watercourse or infiltrates into the ground. The amount of water that actually infiltrates is controlled by the rate of precipitation input (rainfall or snowmelt), soil type (e.g., clay, silt, sand or gravel), ground surface conditions (e.g., frozen, cracking), and vegetative cover (e.g., pasture, forests). Water infiltrating the ground may follow a number of processes including: remaining in soil water storage to be returned to the atmosphere by evapotranspiration, discharging relatively quickly to surface water through interflow, or percolating into deeper soils and then recharging groundwater. In some areas (e.g., hummocky ground), the surface topography has created large depressions, which require up to several metres of water to pond before overland flow occurs. Consequently, water in these depressions can leave only by percolating downward and contributing to groundwater flow or by evaporating to the atmosphere.

Runoff water collects in stream channels leading to larger channels or discharges to ponds, wetlands or lakes. While in these ponds or lakes, a portion of this water returns to the atmosphere by evaporation, or it may percolate into the ground, or spill to downstream channels. The travel time of flow in these stream channels is governed by the length, slope, roughness, and cross-sectional shape of these channels. If the flow exceeds the capacity of the river channel, water may overtop the channel banks, flooding the adjacent land area.

Anywhere along the length of these stream channels, discharge from groundwater storage (regional, localized, or interflow) can contribute to channel flow. These groundwater contributions to stream flow are governed by the surrounding topography, surficial geology and bedrock geology.

4.2 MODEL SELECTION

As described in Section 1.4, the GRCA developed a continuous GAWSER continuous streamflow-generation model to simulate watershed hydrology. The hydrologic model was originally developed for flood forecasting purposes in the late 1980s, and it has remained in a continuous improvement process. The event based model was converted to continuous surface water flow model in the late 1990's at which time a substantial calibration/verification exercise was carried out. More recently, the GAWSER continuous streamflow-generation model was revisited based on feedback from the three-dimensional groundwater flow model. The current GAWSER continuous streamflow-generation model represents in excess of 15 years of continuous improvement; successfully tested in hundreds of real-time flood forecasting events.

The Guelph All-Weather Storm-Event Runoff (GAWSER) continuous streamflow-generation model (Schroeter and Associates, 2004) is a deterministic storm-event hydrologic model which simulates major hydrologic processes. The major model outputs are streamflow hydrographs that include direct overland runoff, subsurface stormflow, and baseflow. The GAWSER streamflow-generation model simulations are used widely in Ontario for planning, design, real-time flood forecasting, and evaluating the effects of physical changes in the drainage basin (Schroeter & Associates, 2004). Precipitation inputs are defined in terms of rainfall, snowmelt or a combination of both. For simulation, drainage basins are divided into a series of linked elements representing subcatchments, channels and reservoirs. Each element's physical effects are simulated using efficient numerical algorithms representing tested hydrologic models.

The GAWSER continuous streamflow-generation model includes algorithms to represent key hydrologic processes, including; snowmelt; infiltration; and routing for overland runoff, subsurface flow, baseflow, channels and reservoirs. The snowmelt sub-model uses a temperature index approach to calculate melt and refreeze, simulates compaction, and computes the liquid water holding capacity of the snowpack. Spatially variable infiltration at the soil surface, percolation rates within the soil, and overland runoff estimates are accounted for by considering a watershed comprising of impervious and pervious areas. Each pervious zone is modelled as two soil layers, with the Green-Ampt equation used for infiltration calculations. Overland runoff routing is accomplished by the area/time versus time method or two linear reservoirs in series. The subsurface and groundwater (baseflow) storage outflows are simulated using a single linear reservoir approach. Two channel routing methods are available: lag and route, and Muskingum-Cunge. Reservoir routing is uses either the storage indication or Puls method.

For multiple event runs (e.g., calibration and design flow work), the program reads input data from two files: the first file contains event related information (e.g., rainfall data, and observed hydrographs), and the second file contains watershed characteristics (e.g., soil parameters and channel cross-sections).

4.3 PURPOSE OF MODELLING

For the purposes of this study, streamflow-generation modelling is needed to quantify the surface water components of the water budget. The streamgauge network, while providing information on the seasonality and volume of streamflow for discrete locations within the Watershed, does not provide detailed information on the volume or spatial distribution of streamflow components (overland runoff, groundwater recharge/discharge). The streamflow-generation model will be used to quantify all significant aspects of the surface water budget (evapotranspiration, runoff, infiltration, soil water, groundwater recharge, etc.), and will determine the impact of climate variability on streamflow/water budget parameters.

A key output of the streamflow-generation model is estimates of groundwater recharge, which are a critical input to the groundwater flow model. Detailed mapping products for both groundwater recharge and overland runoff will be generated, as well as estimates of streamflow for a multitude of locations within the Grand River Watershed.

4.4 MODEL DEVELOPMENT

This section summarizes the relevant aspects of the GAWSER continuous streamflow-generation model for GRCA. Readers are encouraged to read the GAWSER Training Guide and Reference Manual (Schroeter and Associates, 2004) for additional details.

4.4.1 Climate Data

As discussed in Section 2.4, precipitation is spatially variable across the Watershed. To represent this variability, the GRCA divided the Watershed into “Zones of Uniform Meteorology” (ZUMs), as shown in Figure 51. A ZUM is a group of modelled subcatchments, and represents an area with similar climatic conditions. Each ZUM assumes a representative climate, based on meteorological observations from a local climate station. Due to an insufficient number of climate stations with long-term datasets, the full variability displayed in Section 2.4 cannot be represented within the model.

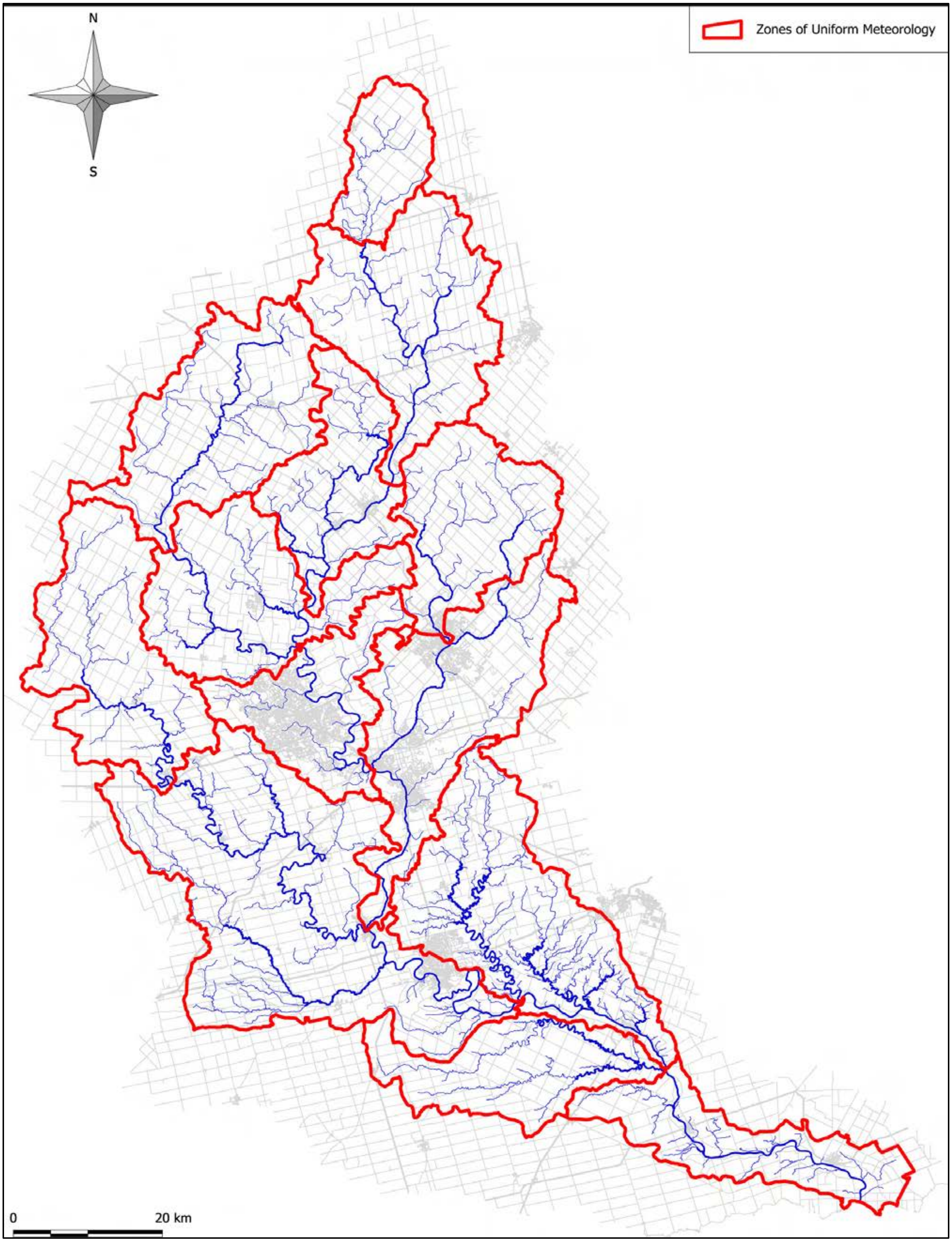

Figure 51
Zones of Uniform Meteorology

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Raw climate datasets typically include data gaps and errors due to temporary closure of climate stations, or equipment malfunction. The GRCA used data from adjacent stations to “fill-in” gaps using a process described in “Filling Gaps in Meteorological Data Sets Used for Long-Term Watershed Modelling” (Schroeter et al. 2000a). For the purposes of this study, the GRCA compiled a full climate dataset from November 1960 to November 1999. This period includes two severe droughts, one in the early 1960’s, and the other in the late 1990’s.

4.4.2 Subcatchment Delineation

The subcatchments for the continuous hydrologic model match the subcatchments delineated for the event based flood forecast model. The Grand River Watershed is divided into 136 subcatchments. The average subcatchment size is 50 km^2, with subcatchment size ranging from 3 km^2 to 154 km^2. Figure 52 illustrates the spatial resolution of the subcatchments. The subcatchments were delineated so as to provide simulated streamflow hydrographs at various points of interest (e.g. stream flow gauges or flood damage centres), and isolate watercourses of interest within the Watershed.

4.4.3 Response Units

To simulate how a subcatchment would respond to a precipitation event, the physical makeup, including soils or geologic materials and land cover of the subcatchment, must be represented in the model. Soil infiltrability then determines how it will respond to a precipitation event, whether it will quickly produce large volumes of runoff (low infiltrability), or if there is a delayed, subdued response in stream flow (high infiltrability). Soil infiltrability varies by soil type and also by soilwater content which changes throughout the simulation. The GAWSER continuous streamflow-generation model provides a monthly adjustment factor for soil infiltrability accounting for freezing and temporal changes in vegetation affecting evapotranspiration.

In order to promote integration between the surface water and groundwater flow models, the GRCA chose to use quaternary geology, as opposed to soil mapping, as the basis to define soil types within the model. This decision was made because the quaternary geology is more representative of the factors affecting groundwater recharge, and is often used within groundwater flow models to parameterize the hydraulic conductivity of the first layer. To reduce the number of Quaternary geology types represented in the hydrologic model, the GRCA grouped geology types that react hydrologically similar in response to a precipitation event. This classification scheme is very broad and is done from a point of view of hydrologic modelling data. All quaternary geologic types found in the Grand River Watershed were assigned to one of five groupings: Impervious, Clay Tills, Silt Tills, Sand Tills, and Sand and Gravels. The geology types assigned to each grouping can be found on Table 4.1. This grouping was completed on a hydrologic basis considering past modelling experience; it may differ from the geologic definition of the materials.

Table 4.1 - Quaternary Geology Grouping

Geologic Grouping	Quaternary Geology Description
Impervious[1]	Amabel Lockport Formations, Bertie Formations, Clinton & Cataract Groups, Dundee & Onondaga & Bois Blanc Formations, Guelph Deposits, Salina Formation, Open Water
Clay Tills	Canning Till, Glaciolacustrine Deep Water Deposits, Man-Made Deposits, Maryhill Till, Mornington Till, Tavistock Till, Wartburg Till, Fluvial Deposits[2], Modern Fluvial Deposists[2]
Silt Tills	Port Stanley Till, Stratford Till
Sand Tills	Catfish Creek Till, Elma Till, Wentworth Till

Geologic Grouping	Quaternary Geology Description
Sand and Gravels	Eolian Deposits, Glaciofluvial ice-contact Deposits, Glaciofluvial Outwash Deposits, Glaciolacustrine Deposits Beach Bar, Glaciolacustrine Deposits Shallow Water, Modern Beach Deposits

[1] Due to the regional nature of the hydrologic model, exposed bedrock was assumed to be impervious.
[2] Pervious deposits immediately adjacent to rivers and streams were assumed to have low infiltration due to high water tables and therefore lumped with the poorly drained clays.

Similar to geology, land cover was summarized into hydrologically similar groupings. 1992 MNR land cover was used (MNR, 1995) to be consistent with the 1990-2000 calibration period. The land cover categories are listed in Table 4.2.

Table 4.2 - Land Cover Grouping

Land Cover Grouping	MNR 1992 Land Cover Classification
Urban	Urban: Industrial/Commercial/Roads/Infrastructure, Urban: Residential
Wetland	Deep/Shallow Water Marsh, Meadow Marsh, Cattail Marsh, Hardwood Thicket Swamp, Conifer Swamp, Open Fen
Low Vegetation	Row Crops, Hay/Open Soil
Medium Vegetation	Pasture, Abandoned Fields, Savannah Prairie
High Vegetation	Dense Deciduous Forest/Shrubs, Dense Conifer, Dense Conifer: Plantations, Mixed Forest: Mainly Deciduous, Mixed Forest: Mainly Conifer, Sparse/Open Deciduous Cover

With both Quaternary geology and land cover grouped into manageable categories, the datasets were overlain to create Hydrologic Response Units (HRUs). Eighteen HRU classifications are needed to represent the combinations of soil type and land use covers shown in Table 4.3. Each of these HRUs can be further classified as being hummocky or non-hummocky. This overlay creates a very detailed coverage over the Grand River Watershed, and is used to define the hydrologic response of a subcatchment. An example of the spatial distribution of the HRU's is shown in Figure 53. Approximately 140,000 polygons make up the HRU coverage for the Grand River Watershed.

The GAWSER continuous streamflow-generation model represents each type of HRU as having similar hydrologic characteristics. These characteristics include infiltration rates and groundwater recharge parameters. Each HRU is assigned to provide groundwater recharge to either a fast responding groundwater reservoir, or a slow responding groundwater reservoir. The fast responding reservoir is intended to represent shallow groundwater flow systems that respond quickly to rainfall events, typically seen in less permeable materials (interflow or subsurface stormflow). The slow responding reservoir represents the deeper groundwater flow systems typically associated with more pervious materials that sustain streamflows during dry periods. Recharge rate estimates from the GAWSER continuous streamflow-generation model include recharge to both reservoirs. Streamflow hydrographs are generated by combining the outflows from both reservoirs, as well as overland runoff.

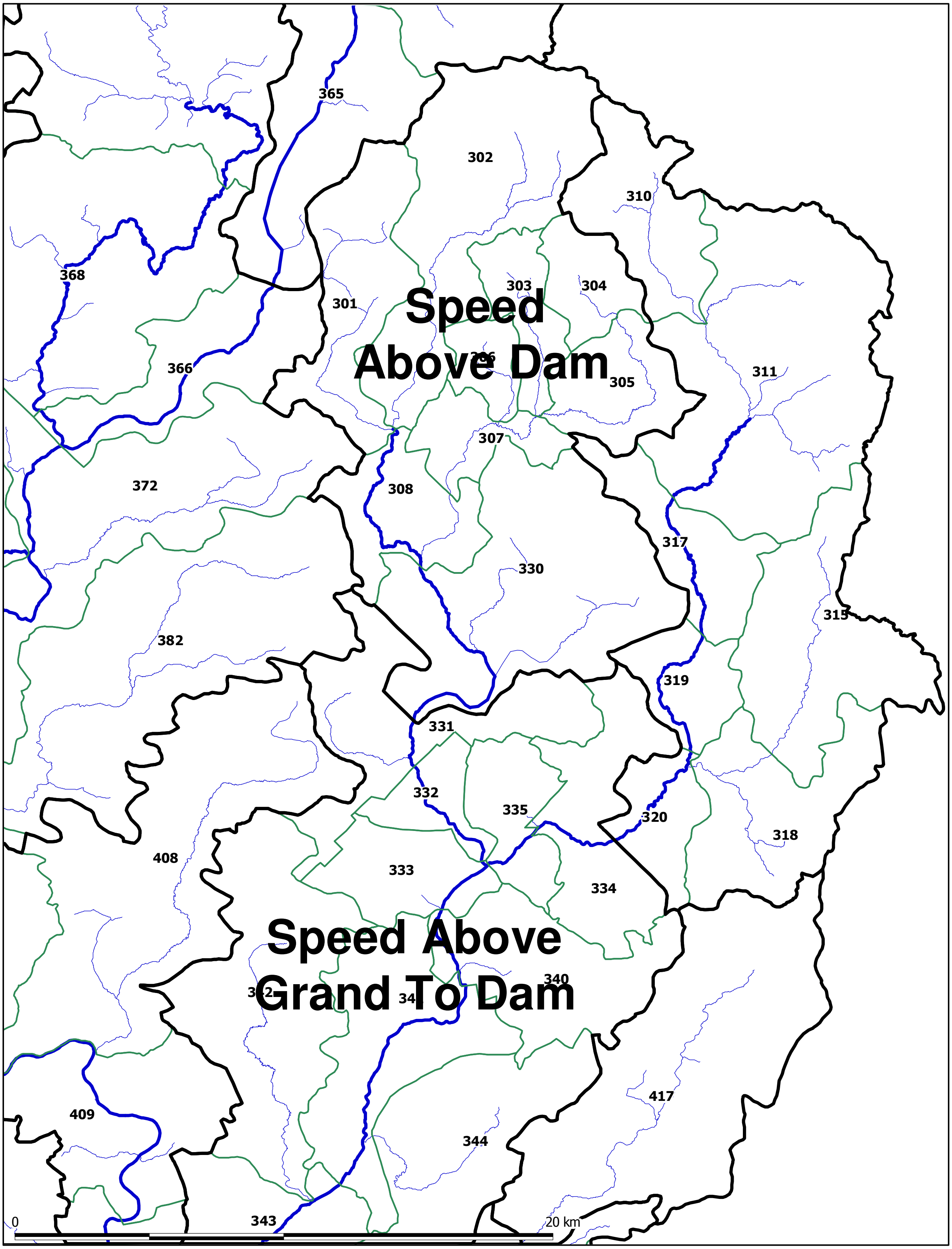

Figure 52
Catchment Delineation

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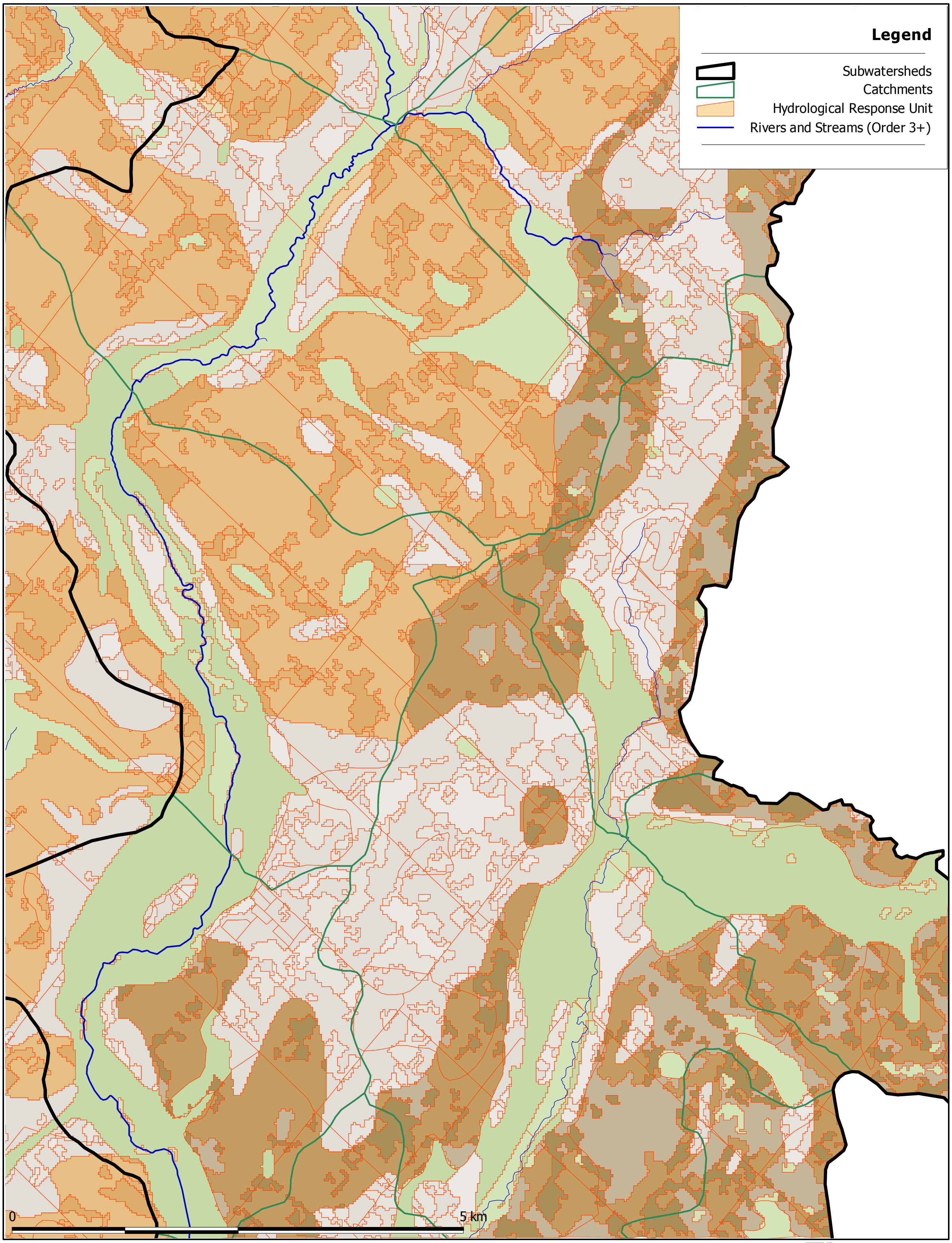

Figure 53
HRU Delineation

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Table 4.3 - Summary of HRUs

HRU	Description	Groundwater Reservoir	HRU	Description	Groundwater Reservoir
1	Impervious	NA	10	Sand Till Medium	Fast
2	Wetland	Fast	11	Sand Till High	Slow
3	Clay Till Low Vegetation	Fast	12	Sand Gravel Low	Slow
4	Clay Till Medium Vegetation	Fast	13	Sand Gravel Medium	Slow
5	Clay Till High Vegetation	Slow	14	Sand Gravel High	Slow
6	Silt Till Low Vegetation	Fast	15	Urban Clay	Fast
7	Silt Till Medium Vegetation	Fast	16	Urban Silt	Fast
8	Silt Till High Vegetation	Slow	17	Urban Sand	Slow
9	Sand Till Low Vegetation	Fast	18	Urban Sand Gravel	Slow

The top eight pervious HRUs, by drainage area, and one impervious HRU are selected to represent the hydrologic response of a particular subcatchment. Typically, this accounts for more than 90% of a subcatchment's drainage area. The remaining area is typically very small and therefore prorated across the top eight.

The GAWSER continuous streamflow-generation model performs water budget calculations for each type of HRU and, therefore any water budget process specific to a HRU can be output to file. The sum of all HRUs for a particular subcatchment, weighted by area, produces the outflow hydrograph for a subcatchment. Outflow hydrographs from other subcatchments are summed, and then routed to downstream locations, where calibration to observed streamflow is possible.

The breakdown of HRUs for each subwatershed is included in Table 4.4.

Table 4.4 - HRU Breakdown by Subwatershed

Subwatershed Name	Clay Till High	Clay Till Low	Clay Till Med	Sand Grvl High	Sand Grvl Low	Sand Grvl Med	Sand Till High	Sand Till Low	Sand Till Med	Silt Till High	Silt Till Low	Silt Till Med	Wet-Land	Urb Clay	Urb Sand	Urb SG	Urb Silt	IMP
GRAND ABOVE LEGATT	7.0%	25.6%	7.9%	4.7%	4.6%	1.1%	5.4%	21.6%	4.7%	0.0%	0.0%	0.0%	12.6%	0.0%	0.0%	0.0%	0.0%	4.7%
GRAND ABOVE SHAND TO LEGATT	4.5%	45.6%	7.3%	4.8%	21.5%	3.6%	0.2%	0.4%	0.1%	0.3%	0.3%	0.1%	8.6%	0.1%	0.0%	0.2%	0.0%	2.3%
GRAND ABOVE CONESTOGO TO SHAND	2.8%	39.9%	1.8%	3.3%	19.8%	0.9%	0.1%	0.4%	0.0%	1.7%	22.8%	1.1%	2.7%	0.6%	0.0%	0.2%	0.3%	1.7%
CONESTOGO ABOVE DAM	5.5%	56.1%	7.5%	2.5%	7.7%	1.1%	1.6%	14.0%	0.7%	0.0%	0.0%	0.0%	1.6%	0.0%	0.0%	0.0%	0.0%	1.6%
CONESTOGO BELOW DAM	5.1%	72.0%	0.7%	2.3%	15.3%	0.1%	0.1%	0.9%	0.0%	0.0%	1.0%	0.0%	1.0%	0.0%	0.0%	0.1%	0.0%	1.2%
GRAND ABOVE DOON TO CONESTOGO	1.6%	10.0%	0.9%	5.3%	23.1%	2.0%	0.0%	0.0%	0.0%	3.0%	27.2%	1.6%	4.7%	3.9%	0.0%	9.9%	4.6%	2.1%
ERAMOSA ABOVE GUELPH	0.8%	0.2%	0.1%	8.7%	15.5%	7.2%	7.0%	10.8%	5.6%	3.4%	18.8%	5.0%	9.6%	0.0%	0.0%	0.0%	0.0%	7.3%
SPEED ABOVE DAM	1.3%	1.4%	0.5%	10.5%	29.2%	7.7%	0.0%	0.0%	0.0%	4.6%	29.9%	5.7%	7.1%	0.0%	0.0%	0.0%	0.0%	2.1%
SPEED ABOVE GRAND TO Dam	1.3%	1.9%	0.7%	7.0%	27.9%	5.3%	1.2%	4.6%	1.9%	1.9%	23.7%	3.1%	5.1%	0.3%	0.1%	5.9%	5.2%	3.0%
MILL CREEK	0.7%	0.1%	0.4%	10.7%	18.0%	9.2%	11.4%	20.9%	12.6%	0.0%	0.0%	0.0%	14.0%	0.0%	0.0%	0.0%	0.0%	2.0%
GRAND ABOVE BRANTFORD TO DOON	1.5%	5.3%	0.7%	7.0%	27.2%	2.7%	5.1%	13.2%	2.4%	0.2%	1.8%	0.1%	3.7%	3.9%	1.8%	18.3%	1.4%	3.5%
NITH ABOVE NEW HAMBURG	5.3%	65.1%	1.7%	1.9%	9.3%	0.5%	0.2%	3.7%	0.0%	0.8%	8.0%	0.1%	2.7%	0.2%	0.0%	0.0%	0.0%	0.4%
NITH ABOVE GRAND TO NEW HAMBURG	3.0%	18.8%	0.5%	6.5%	39.6%	1.3%	0.4%	3.7%	0.1%	1.4%	19.3%	0.3%	3.4%	0.0%	0.0%	0.1%	0.0%	1.7%
WHITEMANS CREEK	3.4%	21.7%	0.4%	7.3%	34.1%	0.9%	0.1%	2.5%	0.0%	2.3%	23.0%	0.5%	3.6%	0.0%	0.0%	0.0%	0.0%	0.3%
GRAND ABOVE YORK TO BRANTFORD	6.4%	60.0%	6.0%	2.5%	16.3%	1.1%	0.2%	1.4%	0.1%	0.0%	0.0%	0.0%	0.4%	2.5%	0.0%	1.1%	0.0%	1.9%
FAIRCHILD CREEK	4.4%	34.6%	3.5%	1.9%	14.6%	1.4%	3.6%	14.7%	2.7%	0.0%	0.0%	0.0%	2.6%	0.9%	0.0%	2.1%	0.0%	13.0%
MCKENZIE CREEK	22.4%	45.3%	11.8%	2.6%	11.2%	0.5%	0.3%	2.8%	0.2%	0.0%	0.0%	0.0%	0.8%	0.0%	0.0%	0.0%	0.0%	2.1%
GRAND ABOVE DUNNVILLE TO YORK	13.5%	54.8%	10.5%	2.9%	6.0%	1.0%	0.2%	1.4%	0.2%	0.0%	0.0%	0.0%	1.4%	0.0%	0.0%	0.0%	0.0%	8.1%

4.4.4 Seasonal Variation

The large seasonal change in temperature experienced in Southern Ontario dramatically affects several hydrologic characteristics and must be represented in hydrologic and hydrogeologic modelling. Seasonal shifts are particularly noticeable in reference to infiltration parameters, such as the difference in infiltration rates between a frozen and a thawed soil. Areas dominated by soils with normally high infiltration rates, may produce a large proportion of runoff when frozen.

To account for this, the GAWSER continuous streamflow-generation model was developed with the ability to vary infiltration parameters with season. Monthly adjustment factors were used to modify the base infiltration rate as the model progresses through the year. These factors were determined through modelling experience in the Grand River Watershed and by Dr. Harold Schroeter's modelling experience in other southern Ontario watersheds. Table 4.5 lists the monthly adjustment factors for infiltration capacity used in the GAWSER continuous streamflow-generation model. These factors were estimated based on the calibration of numerous models throughout southwestern Ontario. The factors are representative of typical average monthly conditions.

Table 4.5 - Monthly Adjustment Factors for Infiltration Capacity

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0.02	0.03	0.03	0.1	0.4	0.65	0.75	0.9	0.65	0.25	0.1	0.03

4.4.5 Disconnected Drainage

Disconnected drainage patterns result from the hummocky topography associated with various moraine features in the Watershed. Disconnected drainage affects the hydrology by trapping runoff that would drain to the stream network in large depressions, allowing it to infiltrate over an extended period of time. Having no local drainage, this water can only infiltrate into the ground or evaporate. Even in areas with tighter soils, clays or silts, the landscape's ability to trap and retain runoff will increase the amount of water available for infiltration.

Disconnected drainage processes are replicated in the GAWSER continuous streamflow-generation model by overlying the hummocky topography dataset delineated on the Ministry of Northern Development and Mines (MNDM) quaternary mapping (Figure 13) with the GAWSER continuous streamflow-generation model subcatchments, and representation of a synthetic recharge pond at the subcatchment outlet. The portion of the runoff hydrograph that is generated from hummocky lands within the particular subcatchment is routed to the recharge pond and infiltrated, resulting in an increase in total subcatchment recharge volume, and a corresponding decrease in runoff volume.

As the GAWSER continuous streamflow-generation model does not directly account for disconnected drainage within an HRU, post-processing of GAWSER output was required to adjust the predicted average annual recharge and runoff rates within HRUs that are contained within the delineated hummocky topography areas. These calculations were performed by determining the total average annual recharge rates predicted by the 'recharge' ponds, and distributing this recharge amongst the HRUs situated in hummocky areas. Runoff rates for these HRUs were reduced accordingly.

4.4.6 Evapotranspiration

Evapotranspiration is one of the most dominant hydrological processes in southwestern Ontario. It accounts, on average, for more than 50% of the annual precipitation.

Evapotranspiration is calculated within the GAWSER continuous streamflow-generation model by applying a specified Potential Evapotranspiration rate to the soil column. Water that is held within depression storage is depleted first by evapotranspiration before soilwater storage is depleted. When water held in depression storage is reduced to zero, the evapotranspiration routines begin to remove soil water from the first modelled soil layer. Water is removed from the second soil layer when the first soil layer reaches half of its water holding capacity. After both soil layers reach wilting point, no additional water can be evaporated or transpired until the soil water is replenished. This approach, of removing the most readily available water first, progressing to deeper soil water, and then having evapotranspiration stop altogether when soil water reaches wilting point, most closely matches the physical process of evapotranspiration. This approach to handling evapotranspiration within a water budget is shared by other hydrologic models such as HSPF (Bicknell et al., 1997).

Two methods exist for specifying potential evapotranspiration rates in the GAWSER continuous streamflow-generation model. The first method utilizes average monthly lake evaporation rates for the general area, which are assumed to be representative of potential evapotranspiration rates and are input into the GAWSER continuous streamflow-generation model. Through linear interpolation, these average monthly rates are used to generate daily estimates of potential evapotranspiration. This evapotranspiration method is used in the current GAWSER continuous streamflow-generation model for the Grand River Watershed.

The GAWSER continuous streamflow-generation model also has the capability of utilizing the Linacre evapotranspiration model, a derivative of the Penman's equation. For a detailed explanation of the Linacre evapotranspiration model please refer to Linacre (1977). The Linacre model uses a number of assumptions, relating maximum and minimum temperatures (widely collected values) to solar radiation and dew point temperatures (infrequently collected values). The Penman equation, which requires solar radiation and dew point temperature, is simplified and can be used with the basic climate values. The ability to estimate potential evapotranspiration using temperature-based methods is essential when attempting to simulate the impacts of climate change, where future potential evapotranspiration may look markedly different.

4.4.7 Wastewater Treatment Plant Flows

Watershed modelling must take into account significant human influences. Since the Grand River and its tributaries receive significant volumes of wastewater treatment plant (WWTP) effluent, baseflow is elevated beyond which would naturally occur. This is important for the Grand River through Kitchener / Waterloo, where the WWTP effluent comprises up to 13% of the river's baseflow. Up to 30% of the summer baseflow for the Speed River, downstream of the City of Guelph is effluent discharged from the Guelph WWTP (Figure 54).

To account for the elevated baseflow the GRCA incorporated WWTP effluent discharges into the GAWSER continuous streamflow-generation model, wastewater treatment plant outflow hydrographs are summed with the streamflow hydrograph at the point of discharge. Figure 54 displays the location of WWTPs within the Watershed, as well as the population served by each facility.

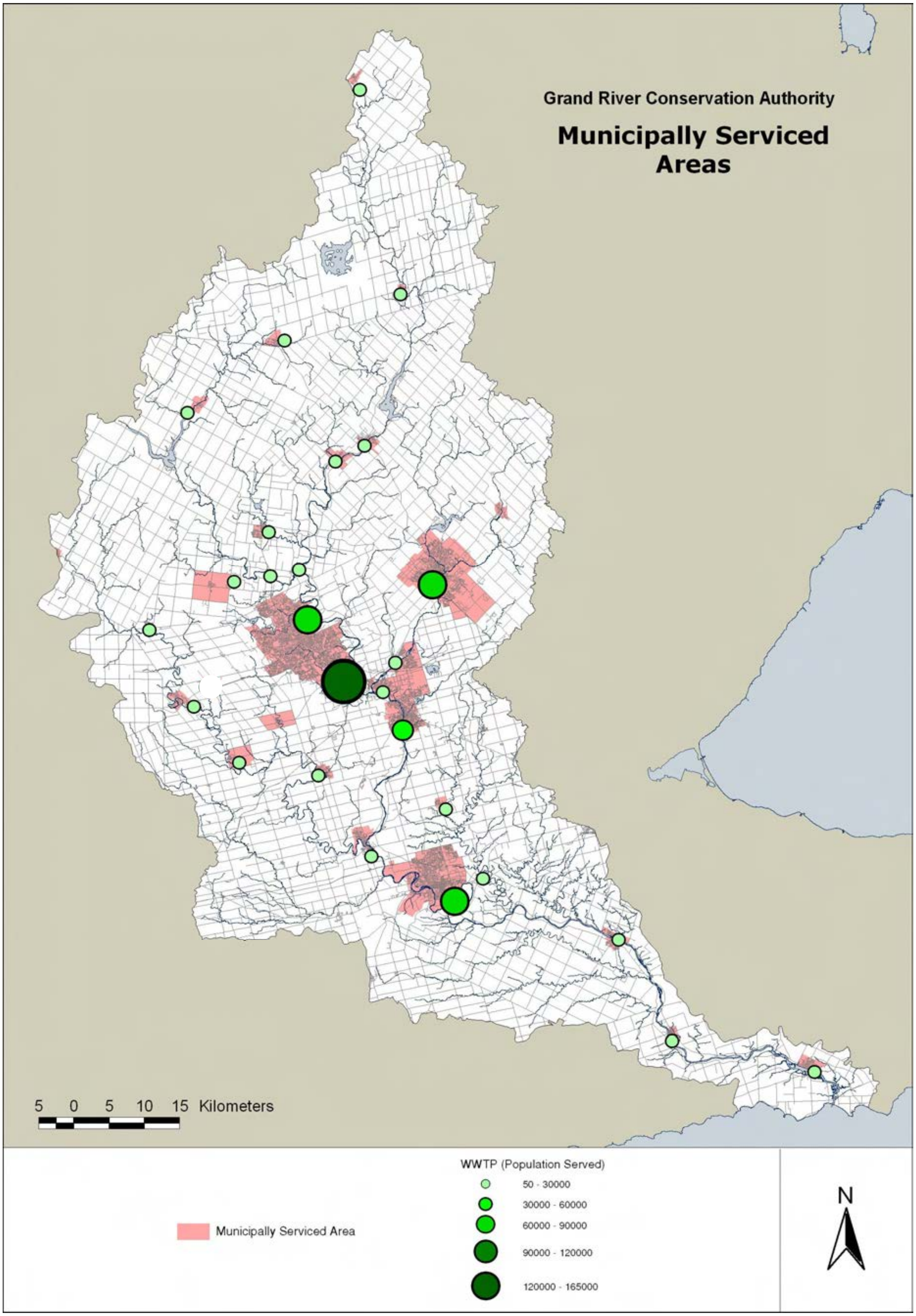

Figure 54
Wastewater Treatment Plant Flows

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4.5 CALIBRATION

The GAWSER continuous streamflow-generation model has of a long history in the GRCA. Originally developed for flood forecasting, the model has been continuously improved through the1990s into the 2000s. During this time, the model shifted from an event based model to a continuous model that quantifies all portions of the Water Balance. For this reason, significant resources and effort were expended calibrating/verifying the Grand River GAWSER continuous streamflow-generation model.

Past calibration exercises for the continuous GAWSER continuous streamflow-generation model were approached in a structured hierarchical manner. The model was calibrated to a longer temporal scale, and then sequentially moved to a shorter temporal scale. By initially calibrating to annual volumes, moving to monthly volumes, then finally to daily flows, regional processes, such as climate/evapotranspiration were considered before local processes, such as groundwater contributions. This allowed calibration to better isolate individual processes, and achieve a better fit between simulated and observed streamflow. In addition to comparing annual, monthly and daily volumes, ranked duration curves were compared for both the simulated and observed flow series. Ranked difference curves plotting the difference between simulated and observed flows were also created.

Initial feedback from the groundwater model indicated that the GAWSER continuous streamflow-generation model was producing insufficient recharge. As a result both the FEFLOW steady-state groundwater-flow model and GAWSER continuous streamflow-generation model underestimated groundwater discharge. For this reason, the calibration/verification was revisited to determine if recharge rates could be increased while maintaining the model's acceptable calibration of higher runoff flows.

Although the model was simulated for the entire climate period ranging from 1960 to 1999, the results for November 1990-November 1999 were considered for calibration.

4.5.1 Parametric vs. Non-Parametric Statistics

Previous calibration exercises, as described above, focused on parametric statistics (i.e. mean flow) to compare simulated and observed flow volumes. Calibrating to a mean annual or monthly flow is an important first step, as it satisfies an initial objective to ensure that the total available water budget and climate dataset is reflective of observed conditions. Due to the fact that streamflow follows a lognormal statistical distribution, the mean annual or monthly flow is heavily influenced by higher streamflows, which are typically only observed over a short period of time.

By definition, median flow is a parametric statistic representing streamflow which 50% of the observances will be higher, and 50% of the observances will be lower. The median flow is more reflective of baseflow conditions, and as a result, is a better calibration target when trying to estimate groundwater recharge. In the current study, the calibration approach focused on matching median flows to better represent monthly low flow conditions

4.5.2 Calibration Results

Plots of comparisons between observed and simulated medians were plotted for roughly 20 stream flow gauge stations in the Grand River. Monthly means and ranked duration plots were plotted to ensure a good simulation of other hydrograph components.

Initial comparisons of simulated and observed monthly median stream flow demonstrated that simulated flows were regularly lower than observed flows during low flow periods. This indicated that the GAWSER continuous streamflow-generation model was not producing sufficient recharge to sustain the most frequently observed stream flow during low flow periods. This confirmed the initial feedback from the groundwater model. Monthly mean streamflow, or overall volumes, matched well, which indicated that the total available water budget was broadly reflective of observed conditions.

By focusing on hydrologic processes within the GAWSER continuous streamflow-generation model that affect generated recharge, simulated median monthly flows match observed median flows much more closely. The modified processes are limited to the seasonal adjustments that vary water's movement through the soil column. This work focused on the seasonal parameters for the transition months between cold and warm seasons. Particular care is taken to ensure summer median flows are accurately represented.

Plots of mean monthly, median monthly and ranked duration comparisons for simulated and observed flows can be found in Figures 55-57 for the Nith River at Canning, the Eramosa River above Guelph and the Conestogo River at Drayton stream flow stations. All these stations measure stream flow discharging from unregulated basins and represent reliable representations of the Grand River Watershed.

As described in earlier sections, the Nith River at Canning stream gauge has a large drainage area of just over 1,000 km^2. The Watershed is composed of tight tills in the upper portion of the basin, changing to sandy-gravels associated with the Waterloo Moraine dominating the downstream portion. Both monthly median and mean flows match quite well. This is likely because more than one climate station is used to represent climate, therefore more accurately estimating total precipitation. The ranked duration curve deviates slightly in the 50-60% flow range; however, the overall fit is good. As would be expected, the transition seasons (spring / fall), where hydrologic parameters can radically shift, shows the poorest fit between simulated and observed flows.

The Eramosa River above Guelph stream gauge has a drainage area of 230 km^2 and is predominately a groundwater-fed system. High amounts of hummocky topography capture surface runoff, allowing increased infiltration to occur. As with the model performance for the Canning stream gauge, median low flows match very well. Mean simulated summer flows are on average higher than observed, which may point to an over-reliance on one climate station. Median and mean flows for the fall season demonstrate a much better fit than streamflows at the Canning gauge. However, simulated median spring flows are significantly lower than observed, which likely points to the timing of snowmelts being an issue.

The drainage area of the Conestogo River at Drayton stream gauge is a flashy, runoff-driven system, whose drainage area is approximately 330 km^2. Median simulated flows match observed median flows extremely well in the April-August period. Simulated and observed seem to deviate in September, but it is a relatively small difference of less than 0.1 m^3/s. Simulated summer mean flows, however, do not match observed flows well. This is due to the use of a single point value (rain gauge) amount as the mean event rainfall over the subwatershed. Most summer rain events have a small areal extent. Some events may be missed entirely by the single gauge while other events captured by the gauge are overestimated when extrapolated to the whole subwatershed. The effect of localized precipitation events is more pronounced in this case due to the well-drained, flashy, runoff driven nature of the drainage area. The match to the ranked duration curve is acceptable over most of the flow regime; however, simulated and observed flows seem to deviate for extreme low flows (>85%). This could either point to a small regional groundwater discharge that is sustaining flow in the upper Conestogo River, or that the rating curve for the gauge station not accurately translating river stage to flow at the low end of the regime.

While differences between the simulated and observed flow datasets do exist, it is important to keep in mind that any model is a simplification of reality. Models are not designed to simulate every process that may affect hydrology. Differences between simulated and observed data should be expected, due to both simplified representation of reality and measurement error in observed datasets. By comparing observed and simulated flows, the GAWSER continuous streamflow-generation model reasonably predicts the hydrologic response for areas within the Grand River Watershed. Plots of simulated versus observed monthly mean, median and ranked duration plots for a number of additional stream gauges are included in Appendix C.

4.6 SUMMARY OF GAWSER OUTPUT

As described previously, the GAWSER continuous streamflow-generation model continuously computes the primary water budget parameters for each of the Watershed's HRUs. This allows for a daily record of such hydrologic parameters as: infiltration, groundwater recharge, soil water content, direct overland runoff, evapotranspiration, and depression storage for the period from November 1960-November 1999. An example of such output is included in Figure 58. This graph, presented with two Y-axes, illustrates the response of Sand and Gravel with High Vegetation HRU. The right Y-axis, in reverse order, shows how soil water and infiltration varies throughout the year. When infiltration occurs following a precipitation event, the soil water correspondingly increases. Groundwater recharge and evapotranspiration are plotted with respect to the left Y axis.

The seasonal variation in soil water balance is evident with high soil water content during winter and spring months, sustaining groundwater recharge and causing overland runoff to occur. As the season progresses into the late spring and early summer months, soilwater content is reduced due to evapotranspiration. By mid to late summer, groundwater recharge generally ceases to occur, and overland runoff is only generated for intense thunderstorm events. During the summer, evapotranspiration typically removes any soilwater added to the soil column via infiltration. By mid fall, lessening potential evapotranspiration allows soilwater content to recover through infiltration of less intense rainfall events. By late fall, early winter, evapotranspiration has effectively ceased, and the soil layer reaches saturation, at which point, groundwater recharge occurs.

In addition to the individual water budget parameters, the GAWSER continuous streamflow-generation model can also output simulated hydrographs for any addition point (subcatchment or routing reach) within the model.

Included in Figures 59 and 60 are the annual totals of groundwater recharge and runoff on a HRU basis. As expected, recharge rates increase and runoff amounts decrease with higher permeability soils. Higher vegetation coverage has the effect of reducing runoff and increasing recharge. Runoff is minimized and recharge is increased for HRUs contained in hummocky areas. The hydrology of urban HRUs tends to be characterized by having very high runoff and low recharge rates. Wetland HRUs have a simulated average hydrologic response similar to clay tills.

Due to the climatic differences across the 13 Zones of Uniform Meteorology, the hydrologic response varies for the same HRUs located in different ZUMs. Table 4.6 summarizes the average and range of runoff and recharge rates (mm/y) predicted for each HRU. It also summarizes these values for HRUs contained within hummocky areas.

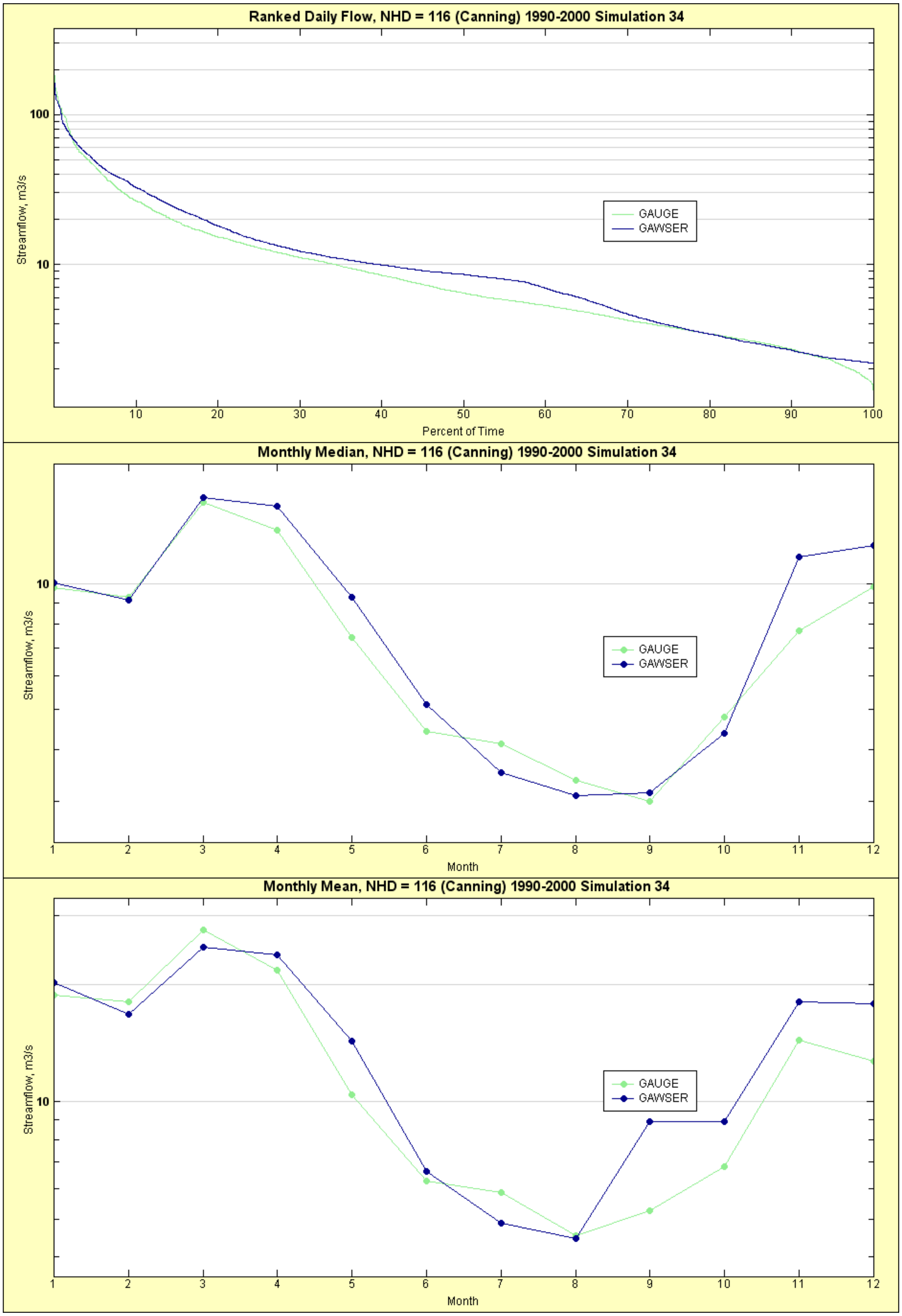

Figure 55
GAWSER Calibration (Nith at Canning)

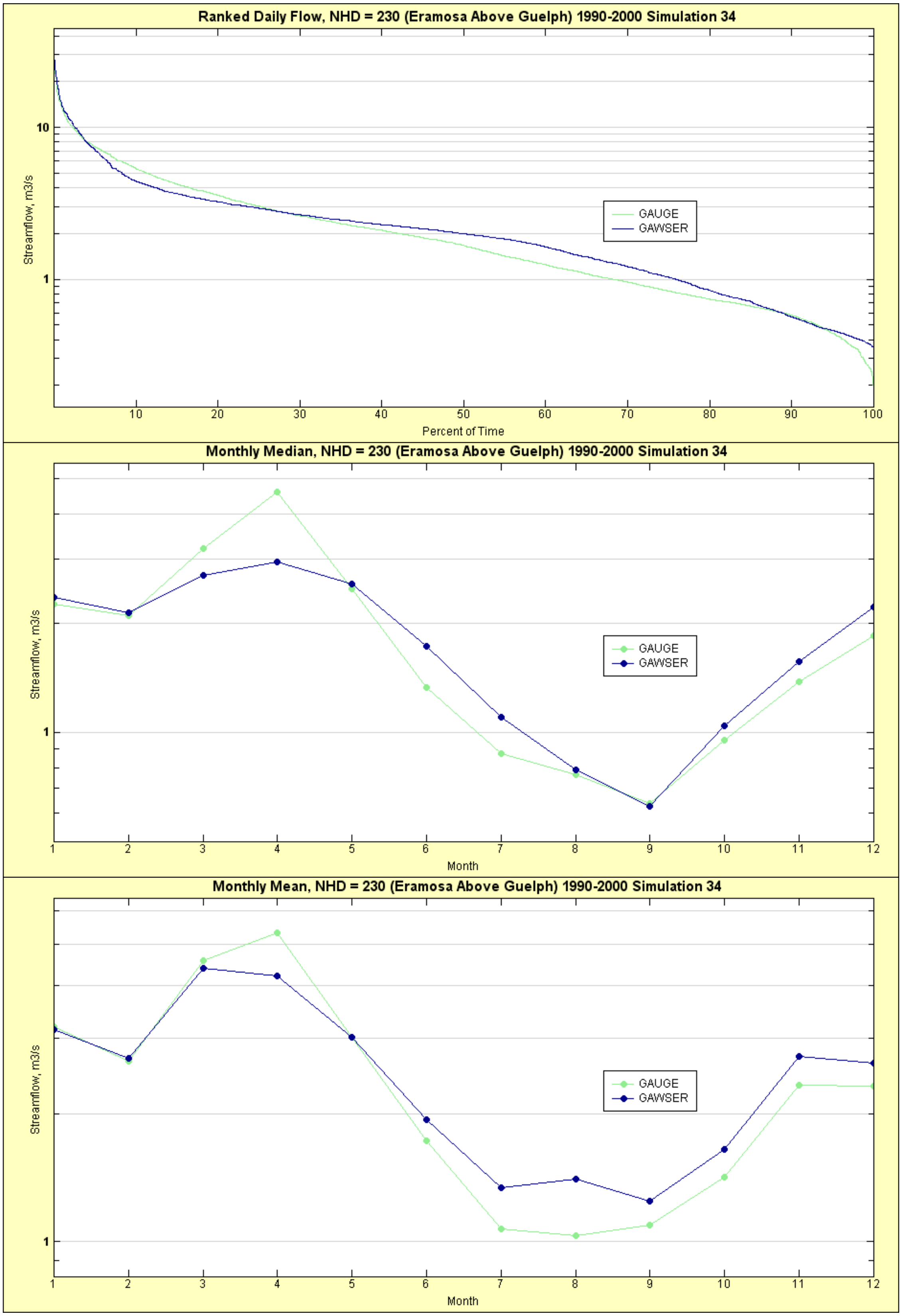

Figure 56
GAWSER Calibration (Eramosa River Above Guelph)

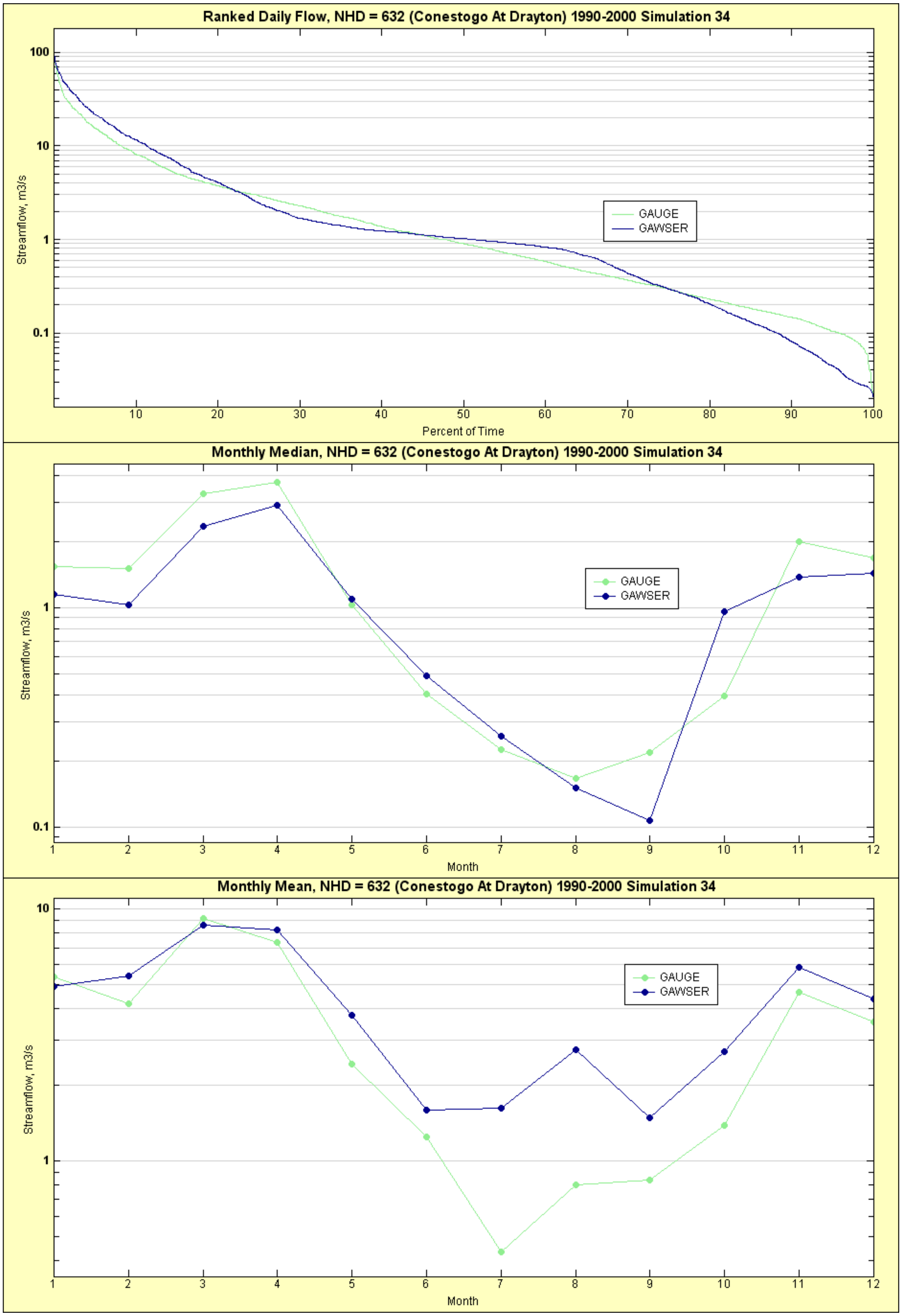

Figure 57
GAWSER Calibration (Conestogo at Drayton)

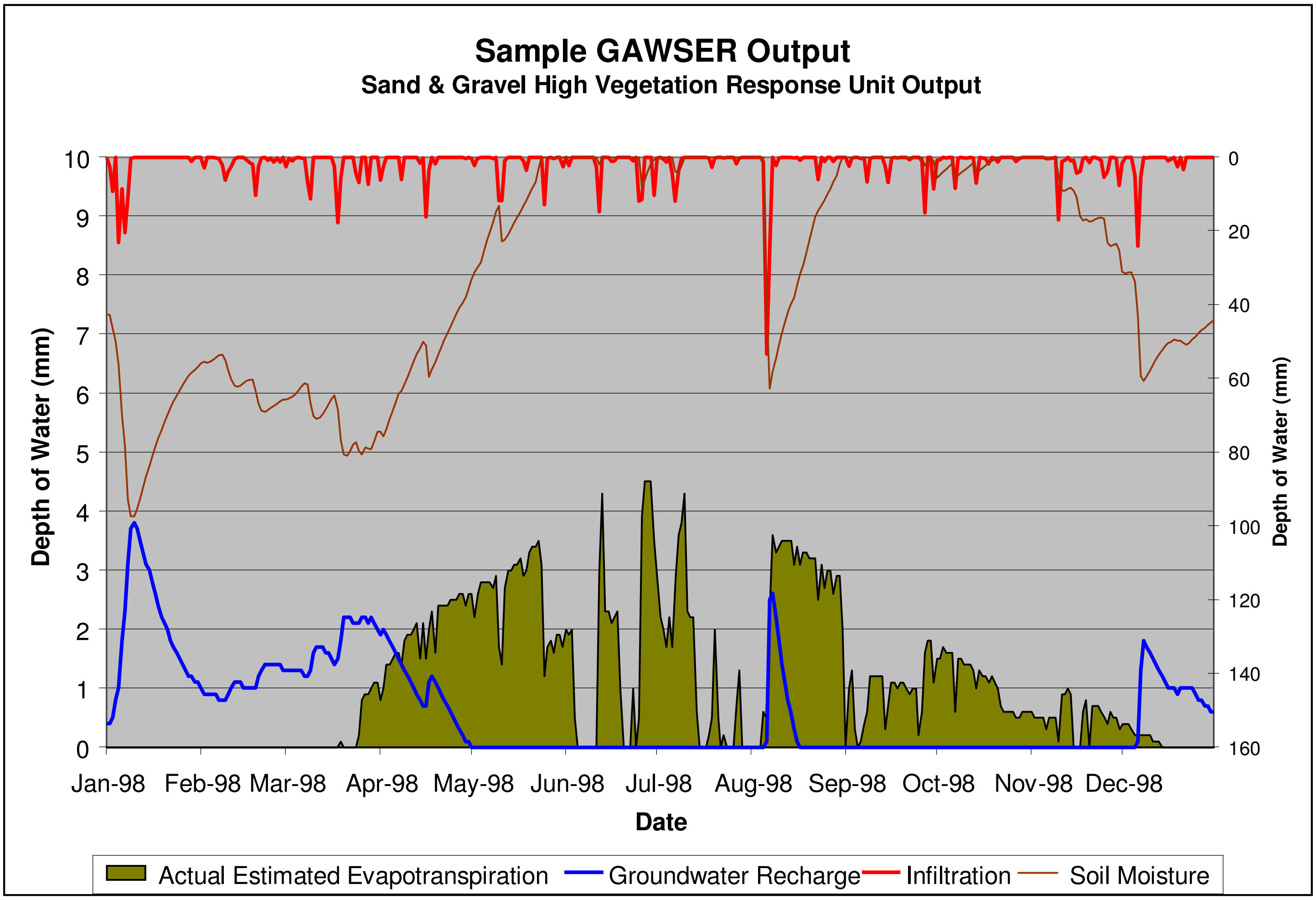

Figure 58
Sample GAWSER HRU Output

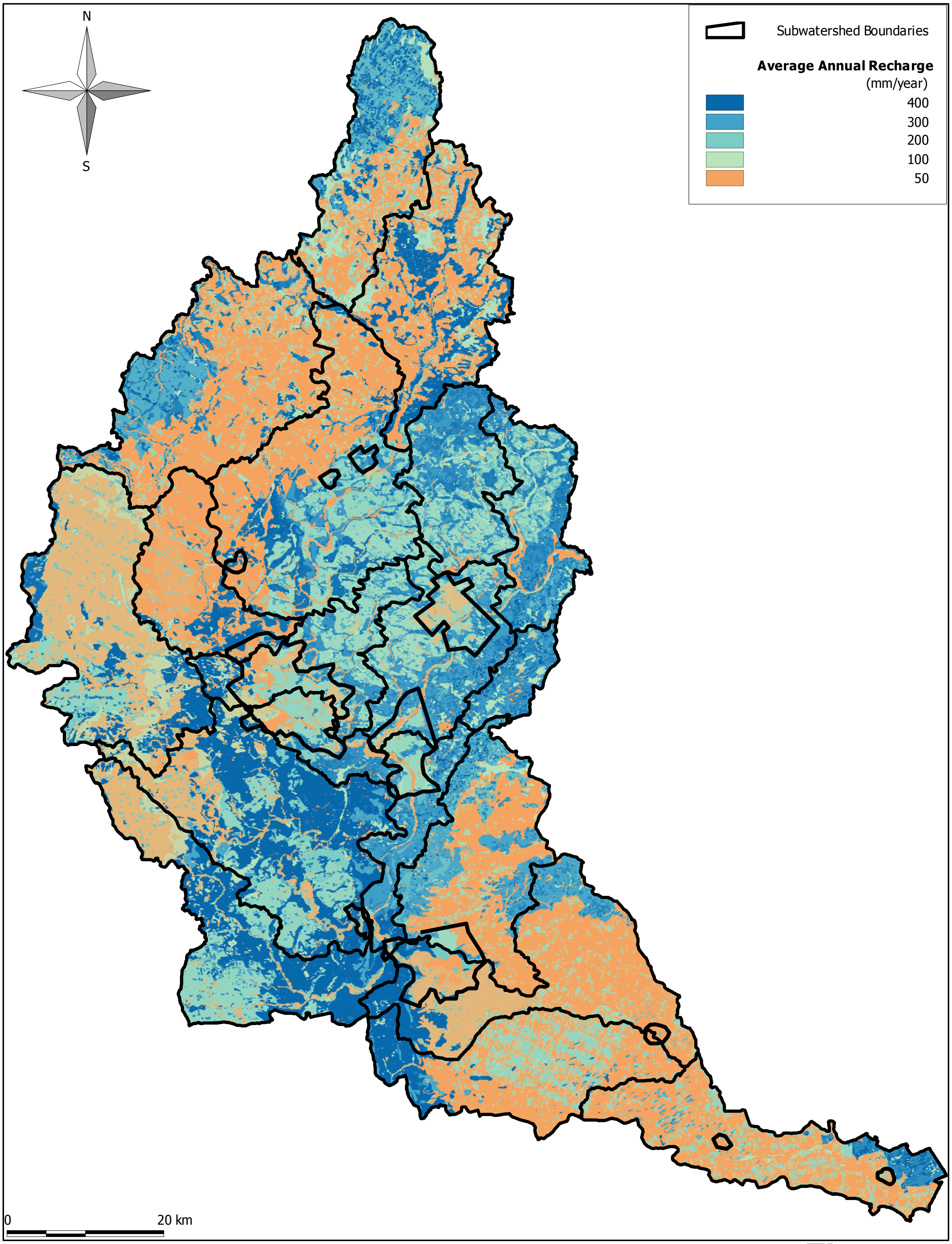

Figure 59
GAWSER Recharge (HRUs) 1980-1999

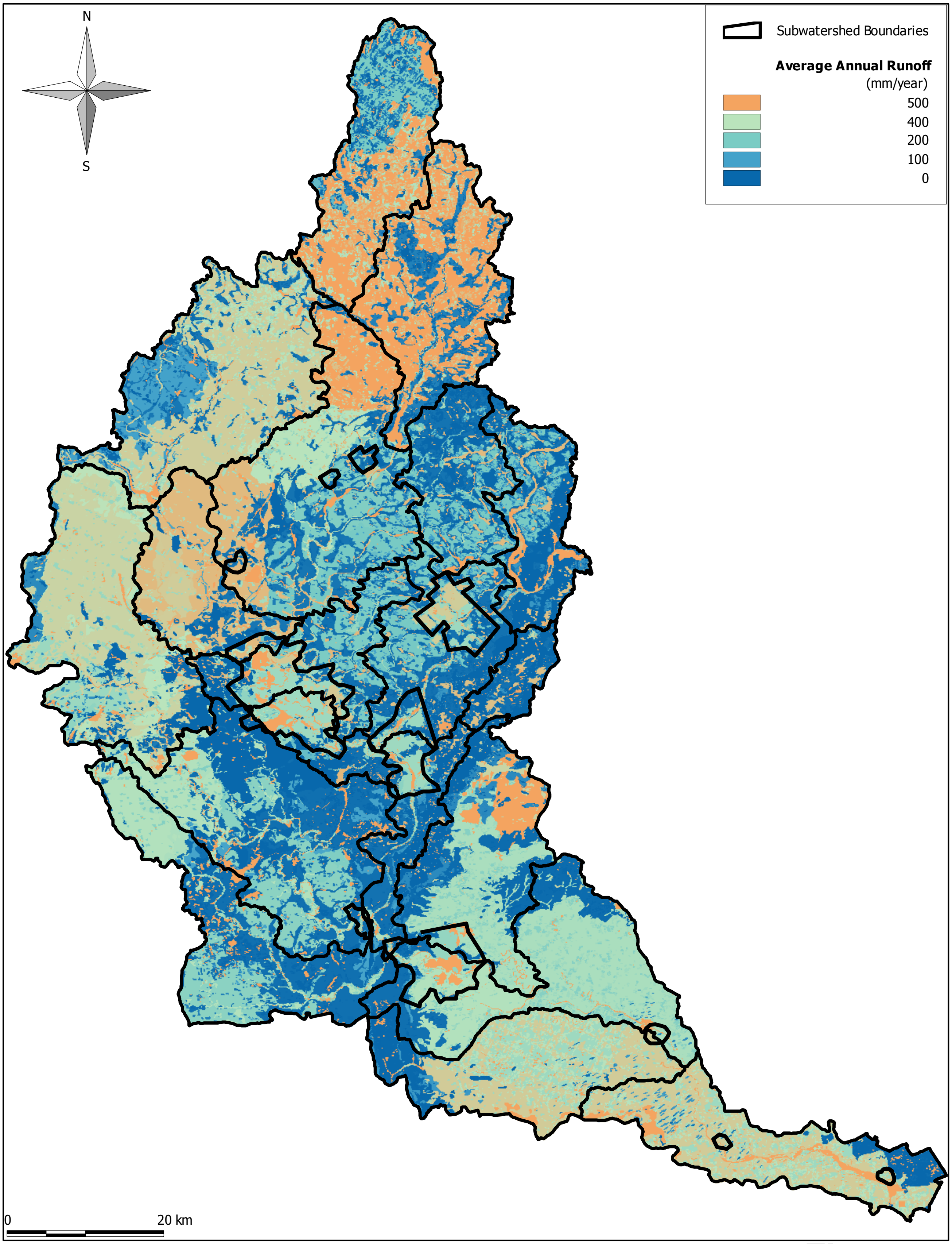

Figure 60
GAWSER Runoff (HRUs) 1980 - 1999

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Table 4.6 - Simulated Runoff and Recharge Rates

			Runoff (mm/y)			Recharge (mm/y)		
Soil / Land	Vegetation	Hummocky	Min	Max	Average	Min	Max	Average
Impervious	NA	NA	727	829	767	0	0	0
Wetland	NA	NA	457	573	499	111	113	112
Clay Till	Low	No	302	503	407	32	66	45
Clay Till	Low	Yes	0	480	292	55	89	68
Clay Till	Med	No	388	456	423	75	80	79
Clay Till	Med	Yes	0	433	304	98	103	102
Clay Till	High	No	180	375	278	150	209	175
Clay Till	High	Yes	0	352	202	173	232	201
Silt Till	Low	No	193	300	206	140	164	148
Silt Till	Low	Yes	0	268	78	172	196	180
Silt Till	Med	No	99	99	99	232	232	232
Silt Till	Med	Yes	0	67	21	264	264	264
Silt Till	High	No	34	65	37	270	363	277
Silt Till	High	Yes	0	33	2	302	395	307
Sand Till	Low	No	79	201	120	237	298	271
Sand Till	Low	Yes	0	58	7	318	387	342
Sand Till	Med	No	52	54	53	325	354	337
Sand Till	Med	Yes	0	0	0	379	430	410
Sand Till	High	No	0	10	2	286	423	366
Sand Till	High	Yes	0	0	0	287	423	309
Sand Gravel	Low	No	15	45	26	307	409	354
Sand Gravel	Low	Yes	0	0	0	325	497	390
Sand Gravel	Med	No	4	8	8	351	402	355
Sand Gravel	Med	Yes	0	0	0	359	479	377
Sand Gravel	High	No	0	1	0	351	482	410
Sand Gravel	High	Yes	0	0	0	355	527	430
Clay Till	Urban	NA	515	655	566	17	30	25
Silt Till	Urban	NA	436	477	447	70	80	73
Sand Till	Urban	NA	400	400	400	147	147	147
Sand Gravel	Urban	NA	305	337	312	154	204	167

4.7 TEMPORAL VARIABILITY OF GAWSER PREDICTIONS

The water budget parameters reported in Section 4.6 are based on average results of the 1980-1999 simulation period. Although these are aggregate results of the GAWSER continuous streamflow-generation model daily output, the results provide context into the spatial variability of water budget parameters across the Grand River Watershed, and insight into the average hydrologic response associated with combinations of geology and land cover.

In addition to spatial variability, water budget parameters also exhibit significant temporal variability. For hydrologic parameters, such as runoff and stream flow, this variability can be measured on the scale of hours, while the variability of hydrogeologic parameters, such as groundwater discharge, can be considered over a longer period. The following sections describe both the annual and monthly variability of groundwater recharge rates estimated the GAWSER continuous streamflow-generation model. While it is not possible to measure groundwater recharge in the field, the GAWSER continuous streamflow-generation model has been calibrated to measured streamflow and baseflow, and as a result, the temporal variability of recharge predictions is considered to be representative of actual conditions.

4.7.1.1 Annual Variability - Recharge

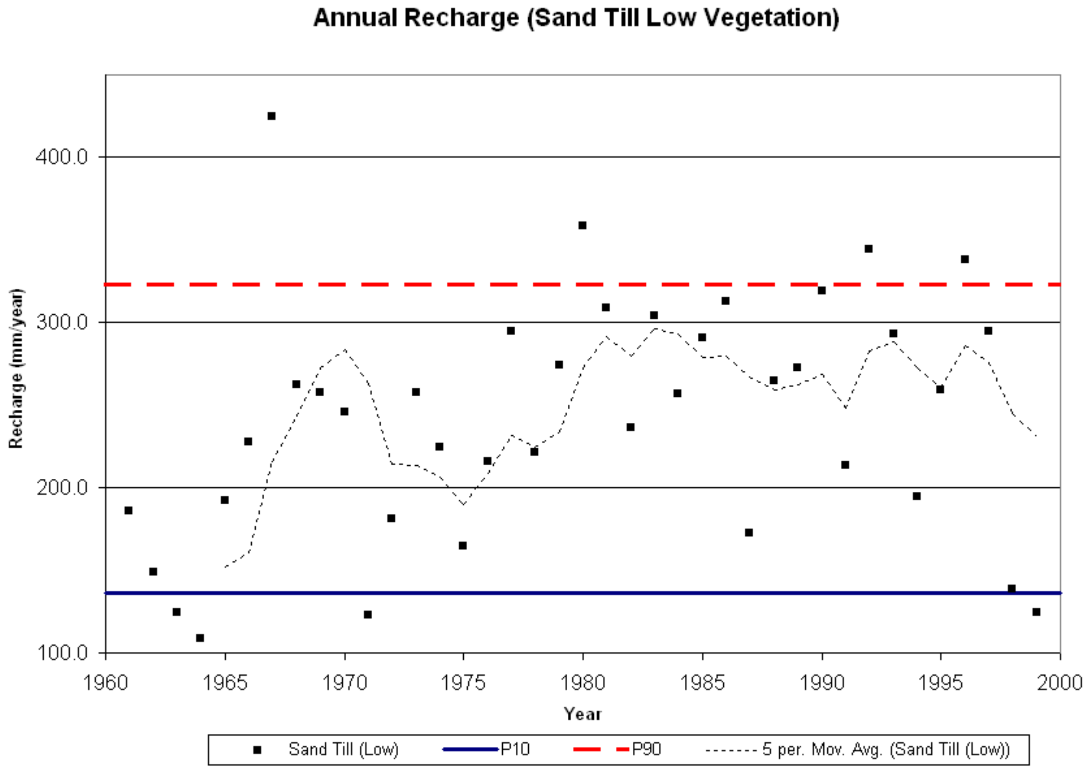
Figure 61 shows the annual recharge rates for the Sand Till (Low Vegetation) and Sand and Gravel (High Vegetation) for the upper Grand River Watershed as estimated by the GAWSER continuous streamflow-generation model. These HRUs were selected to assist in visualizing the expected annual variability in the water budget parameters. These plots show that the annual variability of groundwater recharge rates is significant, and that the average values presented in Section 4.6 do not fully represent the actual range that may be encountered.

In spite of high annual variability in groundwater recharge, groundwater flow systems typically move slowly, and on the regional scale do not respond immediately to annual fluctuations in recharge rates. The plots included in Figure 61 show the 10^{th} and 90^{th} percentile lines, which encompass 80% of the annual recharge estimates. In addition, a 5-y moving average of the annual recharge estimate is shown. This moving average period was selected to represent a time-period where groundwater systems may show significant response to a long-term change in groundwater recharge. Using this five-year moving average, it is shown that average groundwater recharge rates remained relatively consistent from 1980 to 1999, but displayed a higher level of variability during the 1965-1980 time period. These charts suggest that average recharge rates calculated over a long time period (i.e. 1960-1999) may not be as appropriate as those calculated over a shorter time period when the moving average remains somewhat constant.

4.7.1.2 Monthly Variability - Recharge

While steady-state estimates of groundwater recharge are typically made to satisfy groundwater investigations and assessments, monthly variations of recharge are important for shallow and local groundwater systems and ecological systems.

Figure 62 presents a box and whisker diagram summarizing the variability of monthly simulated recharge for a Sand and Gravel (High Vegetation) HRU from the GAWSER continuous streamflow-generation model in the Upper Grand Watershed. This HRU was selected to help visualize the monthly variability that water budget parameters are expected to experience. Similar to the case for the annual recharge variability, there is a large spread between the minimum and maximum monthly estimates. However, the differences between the 1st and 3rd quartiles are not as large, and the mean estimate demonstrates a clear seasonal groundwater recharge trend. Most of the annual recharge occurs in the March-May (spring) period, followed by the October-December (late-fall) period. Recharge rates in the summer months are typically zero when soil water is lower than field capacity. Although rare, extended wet periods during the summer months can produce groundwater recharge events, where soil water content is raised above field capacity.



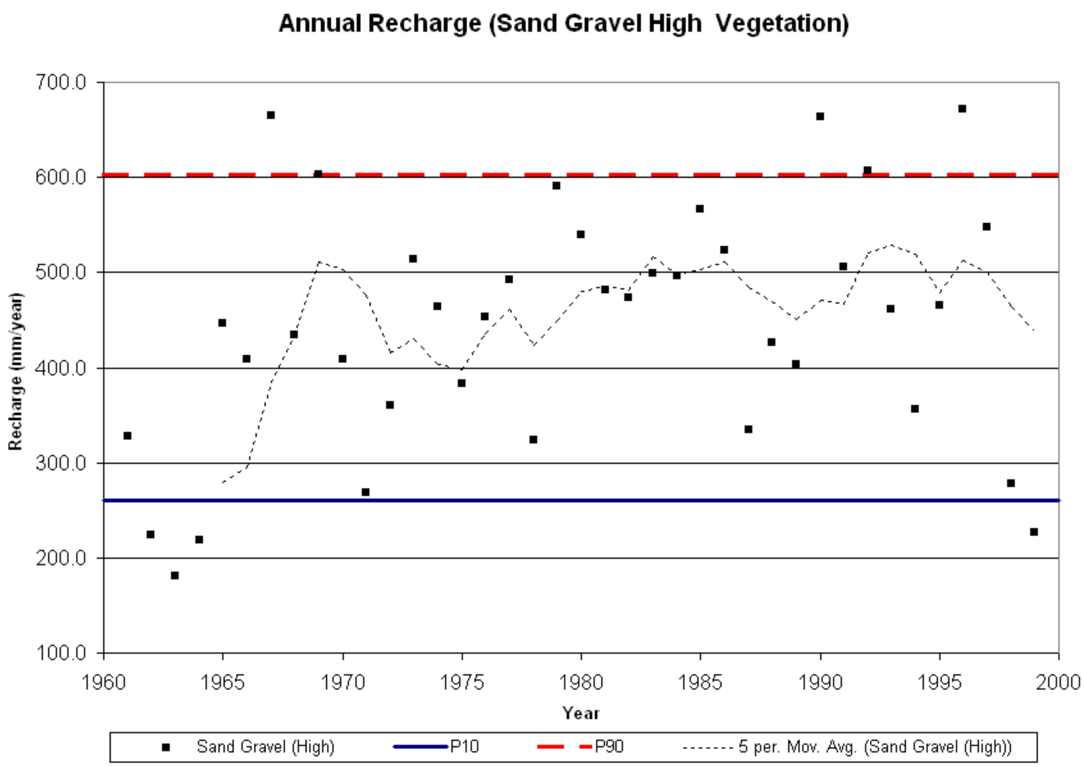


Figure 61
Annual Recharge Variability

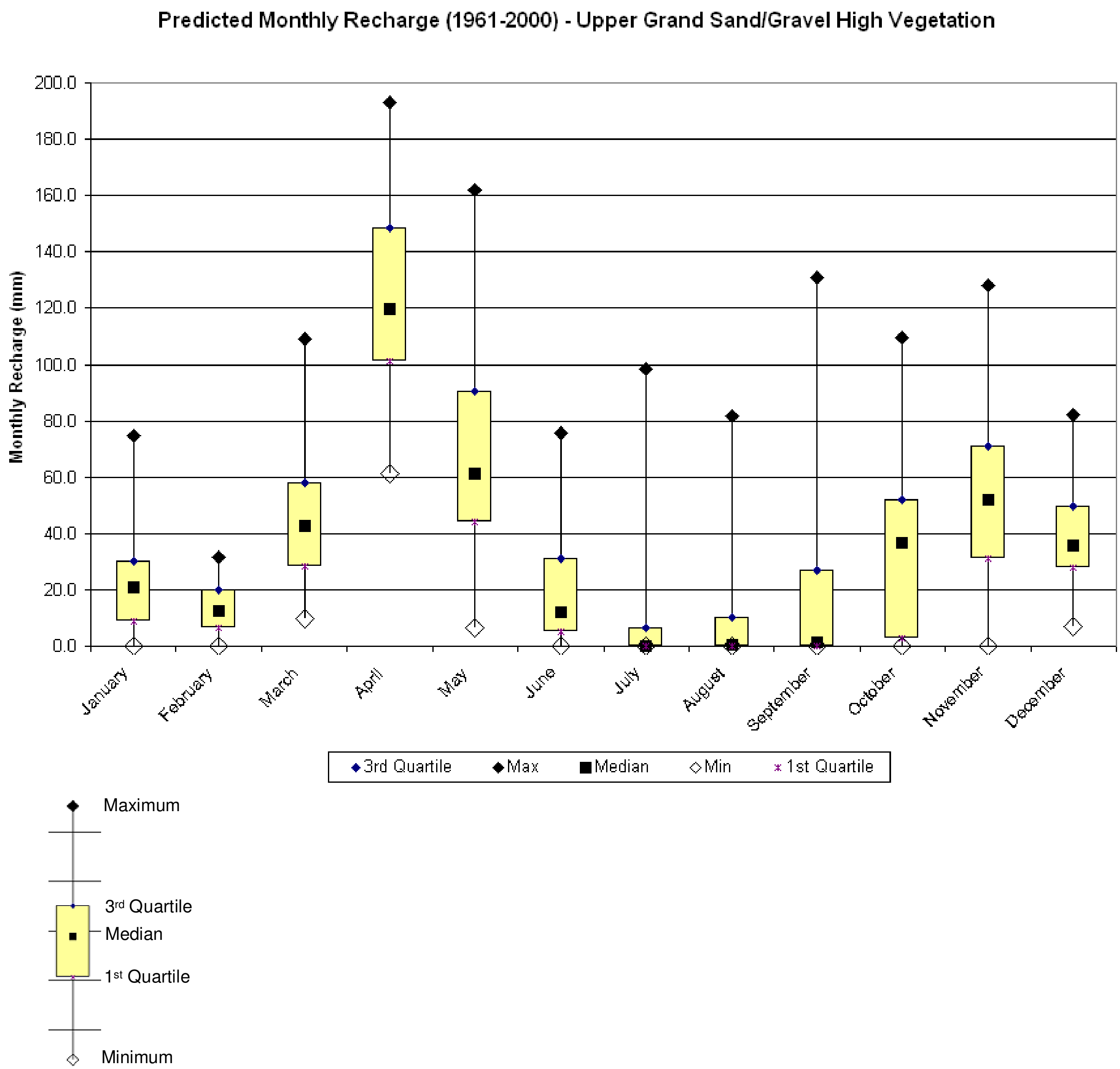


Figure 62
Monthly Recharge Box & Whisker Diagram (Sand/Gravel with High Vegetation HRU)

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4.8 UNCERTAINTY

Many elements of the water budget modelling process using the GAWSER continuous streamflow-generation model are subject to uncertainty. Although the calibration process is performed in an attempt to reduce uncertainty, the model results and water budgets reflect the uncertainty in the input parameters.

The following sections summarize some of the uncertainties associated with the GAWSER continuous streamflow-generation modelling process and discuss some of the potential impacts of this uncertainty.

4.8.1 Watershed Characterization

The GAWSER continuous streamflow-generation model is designed to reflect general characteristics of each subcatchment relating to land cover, soils and vegetation, and stream and river hydraulics. All model parameters are assigned and calibrated to represent streamflow across the Watershed; however, in many areas of the Watershed the level of characterization has not been refined to support local-scale calibration. As a result, local streamflow estimates may be subject to higher levels of uncertainty.

Important watershed characterization elements subject to uncertainty are listed below:

- Hydrologic Response Units

  GRCA has delineated the Watershed into 18 types of HRUs based on landuse, vegetation, and surficial geology to account for the variability in regional conditions across the Watershed. This simplification accounts for larger-scale differences in landcover, but may not reflect local conditions. The effects of slope on hydrologic response were not considered within HRU type and this may also impact local areas.

- Hummocky Topography Representation

  Hummocky topography mapping was used to delineate areas of the Watershed that do not have outlets directly connecting to the surface water drainage system. Runoff from such areas is directed to recharge ponds, which represent large scale depressions, or potholes, that are commonly found in hummocky topography areas. There is uncertainty regarding the exact area of hummocky topography. Inconsistent approaches to delineate hummocky areas introduce uncertainty about how these areas are represented in the model. Local hydrologic conditions within hummocky areas, such as varying evapotranspiration rates, also have not been accounted for in the model.

- Snow Processes

  Snow accumulation, redistribution and melt are significant hydrologic processes in Canadian watersheds. The rates of these processes are determined by the inter-relation of many factors including: land cover, albedo, solar radiation, wind speed/direction, cloud cover, temperature fluctuations, rainfall amount/temperature, and new snow density. The infrequent monitoring of these factors, as well as the level of scientific understanding with respect to the impact of these factors on snow processes, introduces a level of uncertainty into hydrologic modelling.

- Small Reservoirs / Online Ponds

  There are small reservoirs/online ponds within the Grand River Watershed that are not included in the GAWSER continuous streamflow-generation model. The ponds have no active reservoir operations, and are run-of-river structures. While these structures do not alter infiltration processes responsible for precipitation partitioning, they may have an impact on in-channel routing. This may introduce a small level of uncertainty into the simulated hydrographs used for event-based calibration. These effects, however, are considered small over the longer term.

- Wetlands

  The GAWSER continuous streamflow-generation model assigns a single hydrologic response to all wetlands, regardless of the specific hydrologic function. Wetlands found in a groundwater discharge area may have an unlimited supply of water to sustain vegetation growth and have high evapotranspiration rates. These types of wetlands would likely have an outlet to allow surface runoff/groundwater discharge to reach watercourses. Wetlands may also serve as groundwater recharge areas, having high evapotranspiration rates, but may not have an outlet to the surface water system. At the regional scale, the model's representation of wetlands is not significant in terms of water budget results; however, these effects may be more significant when evaluating local scale hydrologic conditions.

- Urban systems

  Storm water management infrastructure (storm water ponds, infiltration galleries, etc.) associated with urban systems are not explicitly modelled in the regional GAWSER continuous streamflow-generation model. Urban areas are represented in the model as having high imperviousness; the assumption of not including stormwater drainage would have an impact on the model's dynamic response to precipitation events. Due to the relatively small proportion of urban land within the Grand River Watershed, this assumption is not significant at the Watershed scale, but is more important at the local scale in urban areas.

4.8.2 Climate Data

The GAWSER continuous streamflow-generation model relies on climate data collected at climate stations to be representative of conditions over a larger geographic area. The current density of climate stations with long-term datasets is not enough to reflect all spatial climate variability, particularly during the summer months when localized precipitation events are common (thunderstorms).

Further uncertainty is introduced into the process by the measurement error in climate observations. The precipitation measurement uncertainty is estimated by Cumming Cockburn Limited (2000) to be approximately ±10%, with the uncertainty during winter months reaching ±20%. Precipitation measurement in winter months has a higher uncertainty due to the difficulty of measuring snowfall, which can be highly impacted by wind. These levels of uncertainty must be considered, particularly when calibrating the model to short term rainfall events.

4.8.3 Streamflow Data

Streamflow measurements have varying degrees of uncertainty which must be considered when calibrating a model. Manual flow measurements used to generate rating curves (allowing the translation of river stage to river flow) may contain error of approximately ±10% (Winter, 1981). Measurement error for extreme events (very low or very high flow) may be significantly higher.

In addition to uncertainty in measurements used to generate a rating curve, changes in river channel geometry may alter the accuracy of the rating curve with time. Changes in river channel geometry may be over the long term (riverbed erosion), or the short term (aquatic plant growth or river ice conditions causing backwater). Malfunctions in gauge station equipment may also lead to dataset gaps or incorrect streamflow estimates.

This uncertainty is mitigated by frequent inspections of gauge stations, manual measurements to verify rating curves, and extensive quality assurance/control carried out by both the Water Survey of Canada and the GRCA.

4.8.4 Limitations of the GAWSER Modelling Software Package

Although GAWSER is a comprehensive continuous streamflow-generation modelling software package, its development is subject to a number of assumptions and simplifications which will affect the certainty of the results. Some of these limitations are summarized below:

- Scale

  Scale is a limitation of any regional model, and is a key limitation of the Grand River GAWSER continuous streamflow-generation model. With the inability to represent every hydrologic process, the model focuses on key processes that are significant at the subwatershed scale. Some local scale features that are not present in the Watershed model may be locally important. These features may include stormwater management facilities, tile drains, and karst bedrock. When analyzing model output, it should be recognized that while results are representative of the subwatershed average, significant variability may exist within that subwatershed and this variability may not be accounted for within the model. Caution should be taken when temporally or spatially downscaling results from any watershed hydrologic model.

- Seasonal Adjustment Factors

  The monthly adjustment factors applied in the GAWSER continuous streamflow-generation model to infiltration parameters representing the freezing and thawing of soils are based on the calibration of numerous models. While these adjustments would be representative of hydrologic conditions over the long-term, they may not accurately replicate changing soil conditions seen under extreme situations, such as a late winter, or an early spring. This limitation is critical to when analyzing extreme events; particularly those events that may be occurring when winter, early spring, or late fall months deviate from normal. As an example, significant amounts of recharge may occur during years having warm late falls when rainfall may translate into recharge in December. The model may underestimate recharge in this case.

  Other comparable hydrologic models (i.e. HSPF) also represent monthly changes in hydrologic parameters using similar adjustment factors. The current state of hydrologic modelling knowledge must be enhanced before these models are able to reflect actual conditions.

- Groundwater Recharge

  Precipitation that infiltrates into the soil column and percolates through both evaporative soil layers is defined as groundwater recharge. The GAWSER conceptualization assumes that the depth to groundwater, and therefore the thickness of the lower soil layer, is relatively shallow and constant for a single HRU classification. While the GAWSER calibration process arrives at parameter estimations resulting in appropriate streamflow response, it is recognized that in reality the temporal response of groundwater recharge to precipitation events depends on the depth to the watertable and local hydrogeological conditions. In some cases, the depth to the watertable might be much larger, as is the case in the Waterloo Moraine, and this would have the impact of dampening recharge fluctuations. In other areas, the watertable might be closer to ground surface which might have the result of reducing groundwater recharge estimates, particularly during very wet periods when the water table is at ground surface.

- Interflow and Groundwater Discharge

  Precipitation that infiltrates into the soil column and percolates through both evaporative soil layers is defined as groundwater recharge. Groundwater recharge enters one of two linear reservoirs before being released to the surface water system. The linear reservoirs have different time coefficients that are used to represent either a slow groundwater response (well buffered groundwater discharges), or a quick groundwater response (transient groundwater discharge, or interflow). A single HRU can direct water to only one of these reservoirs. This limitation prevents a geologic/land cover combination that provides recharge to both linear reservoirs from being represented in the model.

- Deep Groundwater Storage

  The GAWSER continuous streamflow-generation model can redirect a specified fraction of groundwater recharge from a subcatchment to a regional groundwater storage element. Water from this regional storage element can then be returned back into the surface water system at a downstream subcatchment. This is a simple representation of a regional groundwater flow system. A limitation of this process is that the storage element is not mass conservative in the GAWSER continuous streamflow-generation model. If the water contained in the storage element is not withdrawn within a set time interval (24 days), the water is lost from the model. This limits the ability of the GAWSER continuous streamflow-generation model to replicate a regional flow system, where deep groundwater recharge may remain in the system for months or years, before discharging. This limitation is more noticeable during extreme low flow periods, where the surface water flow system may rely on a well buffered groundwater discharge for sustained flow.

- Evapotranspiration

  Similar to the seasonal adjustment factors, the GAWSER continuous streamflow-generation model relies on average potential evapotranspiration rates to determine the amount of available soilwater that can be removed. This representation of potential evapotranspiration may not fully represent the annual variability of actual evapotranspiration. Because evapotranspiration relies on both the availability of soil water and solar radiation (which is fairly constant), the consequence of using average evapotranspiration rates is less than using average seasonal infiltration adjustment factors, whose variations are caused by temperature alone.

  Evapotranspiration is the water budget parameter with the highest degree of uncertainty. This uncertainty is predominantly associated with a lack of measured parameters (e.g. wind speed, dewpoint temperature, relative humidity) used for detailed calculations of evapotranspiration. In place of detailed calculations, evapotranspiration is estimated through use of simplified algorithms, using readily collected meteorological data (temperature), or observed pan evaporation data (where available). The cumulative uncertainty for a subwatershed, associated with evapotranspiration, is minimized when differences between mean annual observed and simulated streamflow are negligible. Due to a lack of detailed calculations, local estimates of evapotranspiration (HRU scale), have a higher degree of uncertainty.

4.9 SUMMARY OF THE GAWSER CONTINUOUS STREAMFLOW-GENERATION MODEL

The current GAWSER continuous streamflow-generation model used to simulate the hydrology of the Grand River Watershed reflects over 20 years of continuous improvement. Originally created for flood flow estimation, the investment in the model has been leveraged to provide flood forecasting capability and continuous modelling for water budget purposes. The model has been successfully tested / verified in hundreds of real time flood events by GRCA staff.

In spite of uncertainties in the representation of certain hydrologic process, the GRCA GAWSER continuous streamflow-generation model remains one of the most advanced hydrologic simulation models in Ontario. It provides realistic water budget and streamflow estimates calibrated to represent observed conditions. The seasonal evaluation of model calibration completed in this project shows that the model is simulating seasonal conditions in varying types of hydrologic environments quite well. Gross watershed estimates of evapotranspiration match independent estimates of evapotranspiration reasonably well, and the groundwater modelling carried out as part of this study has verified the predicted groundwater recharge rates. Furthermore, high flow estimates and in-channel routing are very good.

The 20 years of advancement seen with the GRCA GAWSER continuous streamflow-generation model represents a continuous improvement process that should be the normal evolution of any regional surface water or groundwater flow model. Advancements in understanding of key hydrologic processes or refined watershed characterization made within local scale modelling exercises can be absorbed into the regional model, allowing a more accurate representation of the Watershed hydrology. Regional models should not be considered to be static tools, but rather tools that are continuously built upon, and improved.

5.0 FEFLOW Groundwater-Flow Model

This chapter describes the development and calibration of the Grand River Watershed steady-state groundwater-flow model (FEFLOW). The numerical model applied for the water budget assessment built upon earlier work completed by Waterloo Hydrogeologic Inc (WHI, 2005). The calibration of the WHI model was further refined by AquaResource and Waterloo Numerical Modelling Corp (2005). As such, details regarding the model development contained within these earlier reports are not repeated here. This section describes specifically how the geological conceptual model was improved, and how the modelling tools developed through the earlier work were expanded upon to further refine the suitability of the model.

The GRCA FEFLOW steady-state groundwater-flow model was developed primarily as a tool to assess groundwater flow at the regional scale. The hydrogeological characterization reflected by the model includes groundwater aquifers (e.g. Amabel Aquifer) and aquitards (e.g., Eramosa Member) that have a regional significance. As a result the model's predicted water levels and groundwater discharge rates are consistent with groundwater flow conceptual models at the larger (i.e., subwatershed) scale. However, actual hydrogeologic conditions at smaller scales (e.g., wellfields, wetlands) may not be consistent with the regional interpretation and as a result the model may not be as accurate at those smaller scales. Appendix C of this report (distributed on CD-ROM) contains a large set of information provided to support the content of this chapter. The Appendix contains stratigraphic cross-section through the groundwater model area, maps of calibrated model parameters, and maps, plots and tables of simulated versus observed groundwater levels.

All numerical modelling was completed using FEFLOW (WASY, 2005). The FEFLOW steady-state groundwater-flow model was selected for this area because of its advanced capabilities for the following:

- The ability for the mesh discretization to focus on areas of interest. To more precisely simulate observed physical features (pumping wells, rivers, etc.) and follow naturally complex boundary conditions;
- The efficiency of localized mesh discretization, requiring far fewer calculation points to achieve the same level of precision as with finite difference grids, which are forced to carry refinements to the model boundaries;
- The ability of the elements to conform to the pronounced vertical variation of aquifer / aquitard layers; and,
- The stable water table simulation that facilitates more accurate simulation of the shallow subsurface. This allows the modeler to focus on conceptual rather than numerical issues.

Given these considerations, the FEFLOW steady-state groundwater-flow model was initially selected by the GRCA to complete the regional groundwater modelling for the Grand River Watershed. As river discharge and pumping are thought to have a dominant influence on groundwater flow within the Grand River Watershed, the FEFLOW steady-state groundwater-flow model's enhanced capability to incorporate these features was considered beneficial.

5.1 PURPOSE OF MODELLING

From a groundwater perspective, modelling will be utilized to quantify and better understand water budget components related to the groundwater flow system. The three-dimensional groundwater flow model will quantify groundwater discharge at a spatial scale much finer than is possible through analysis of streamgauge records alone. The groundwater model will also allow subwatershed inflows to be quantified, which will facilitate a complete subwatershed water balance to be calculated. In addition to quantifying water budget components, the groundwater flow model will allow pathways between recharge and key discharge areas to be identified, which will assist in identifying critical recharge areas.

5.1.1 Model Structure

The model structure refers to the distribution of nodal calculation points in both the horizontal and vertical dimensions; these distributions create the 3D elements that represent the hydrogeologic setting.

The location and horizontal extent of the GRCA model mesh is presented in Figure 63. The mesh encompasses the entire Grand River Watershed, extending approximately 36 km in width (East-West) and approximately 300 km in length (North-South), resulting in a model area of approximately 6,800 km^2. Figure 63 also conveys the level of discretization contained within the GRCA mesh. As this figure shows, the mesh is refined in areas where it is important to have enhanced definition of groundwater flow. These areas include rivers, (the Grand River and its tributaries), and large pumping wells (identified in the PTTW dataset). The mesh was also designed to conform to the GRCA's 18 subwatersheds. It is important to note that the Watershed boundaries are not physical groundwater flow boundaries, but are represented in the mesh for the purposes of calculating water budget results. The mesh designed by WHI (2005) was not further modified during this study.

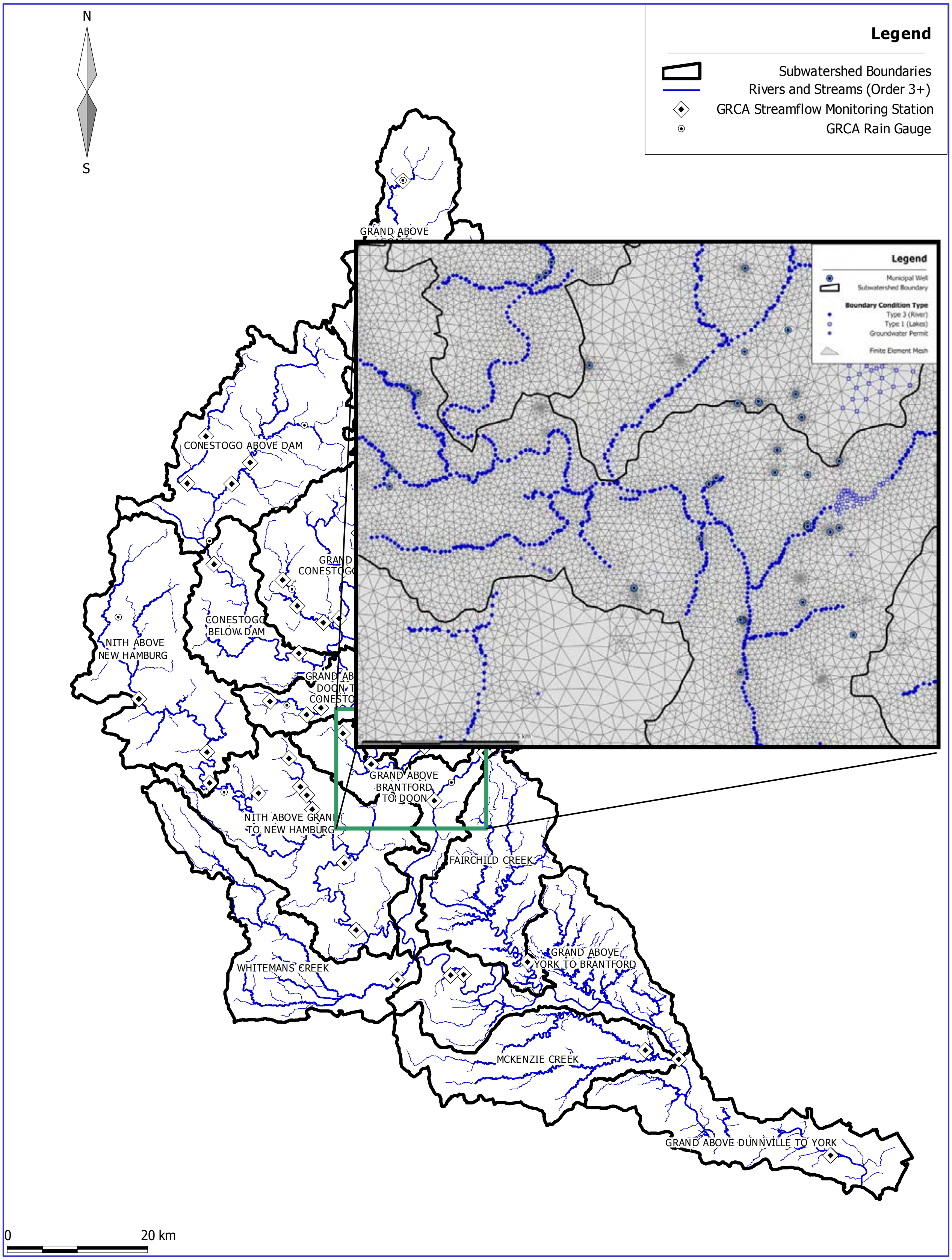

Figure 63
Finite Element Mesh and Boundary Conditions

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Vertically, the model layers were designed to follow the hydrostratigraphic units presented in Table 2.2. Each of the 13 primary hydrostratigraphic units presented in that table is simulated in the GRCA model using a separate layer for each. In addition, the shallow subsurface is subdivided into 2 layers to provide more detailed calculations at the groundwater / surface water interface. Table 5.1 presents the current model layer representation.

Table 5.1 - Model Representation of Hydrostratigraphic Units

Model Layer	Hydrostratigraphic Unit	General Lithology
1	Aquitard / Aquifer	Quaternary Geology (Aquifer / Aquitard)
2	Aquitard / Aquifer	Quaternary Geology (Aquifer / Aquitard)
3	Upper Overburden Aquifer	Sand and Gravel
4	Aquitard	Middle Till Unit
5	Lower Overburden Aquifer	Sand and Gravel
6	Aquitard	Lower Till Unit
7	Aquifer	Contact Zone (~3 m thick weathered bedrock zone)
8	Aquifer	Onondaga-Amherstburg / Bois Blanc / Bass Island Formations
9	Weak Aquifer*	Salina Formation
10	Aquifer	Guelph Formation
11	Aquitard	Eramosa Member
12	Aquifer	Amabel Formation
13	Aquitard	Cabot Head Formation
14	Aquitard	Queenston Formation

*In most areas of the Watershed, the Salina formation is viewed as an aquitard; however some wells use this geologic unit for a source of water. For this reason, it is listed as a weak aquifer.

Enhancements to the previous model structure included the division of the Guelph and Amabel Formations, and the inclusion of the Eramosa Member as separate model layers. To accomplish this, the former model layer, which ranged in thickness from about 10 m to greater than 150 m thick, was subdivided into additional layers. Based on recent characterization work in the Guelph-Puslinch Groundwater Study (Golder, 2006), the representative thickness of the Amabel Formation and the Eramosa Member was determined as 30 m and 11 m, respectively. As a result, these thicknesses were used to subdivide the former model layer, with the bottom 30 m being the Amabel Formation, and the 11 m above that being the Eramosa Member. Where the former model layer was less than 40 m thick, the existing layer was split into equal portions.

The addition of these two model layers provides the flexibility to incorporate the Eramosa Member as an aquitard that potentially separates the Guelph and Amabel Formations; this provides a more physical representation of these important bedrock aquifers. With these additional layers the model now contains over 3 million elements and almost 2 million nodes.

5.1.2 Model Properties

The primary hydrogeologic properties assigned within the FEFLOW steady-state groundwater-flow model include the hydraulic conductivity and the porosity. Hydraulic conductivity is the primary variable that controls the calculated hydraulic head distribution throughout the model domain (based on boundary condition values). Porosity refers to the volume of void space per unit volume of geologic materials and is used in the velocity calculations. When conducting groundwater flow modelling, porosity is only used when analyzing particle pathlines.

In developing a groundwater model, initial estimates of hydraulic conductivities are first specified and later modified through calibration. The initial specification is generally based on the conceptual understanding of the geologic/stratigraphic units and their hydrogeologic properties. Hydrogeologic properties can be determined through pumping / slug tests within the geologic formations. Where such tests are not available, conductivity values are estimated based on the typical value for a given lithology.

Initial estimates of hydraulic conductivity were specified throughout the three-dimensional model as follows:

- To provide continuity between the groundwater and surface water models, the hydraulic conductivity for the surficial model layers (1&2) was derived from the distribution applied within the GAWSER continuous streamflow-generation model. The values determined for the soil infiltration parameter through the GAWSER continuous streamflow-generation model calibration were multiplied by 10 (and translated into m/s) and applied in the FEFLOW steady-state groundwater-flow model. The factor of 10 was found to be necessary to allow the FEFLOW steady-state groundwater-flow model to accept the volume of recharge the GAWSER continuous streamflow-generation model predicts. The need for the multiplication factor is expected to result from a difference in the internal treatment of that value in the FEFLOW steady-state groundwater-flow model and the GAWSER continuous streamflow-generation model. Within the GAWSER continuous streamflow-generation model, the soil infiltration parameters are applicable for only the upper soil layers, whereas the hydraulic conductivities for the surficial model layer in the FEFLOW steady-state groundwater-flow model refers to deeper overburden. Regardless, using the same distribution in both models provides another level of continuity between the surface and groundwater models.
- Hydraulic conductivity values for overburden model layers 3-6 were estimated through an analysis of the lithologic logs in the MOE water well record database following the methodology outlined in Martin & Frind (1998). Using the lithology reported in the borehole logs, and a generalization of the relationship between hydraulic conductivity and lithology, a preliminary estimate of hydraulic conductivity within each hydrostratigraphic layer was developed for every borehole. These estimates were then interpolated and generalized to generate a realistic representation of hydraulic conductivity distribution within model layers 3-6. This process results in a highly heterogeneous distribution of hydraulic conductivity within these layers.
- All bedrock model layers, except for the Eramosa Member, were assigned uniform hydraulic properties representative of the bedrock materials. Where practical, hydraulic conductivities were taken from previously calibrated groundwater models, such as for the Guelph-Puslinch area (Golder, 2006). Where hydrostratigraphic layers pinched out, the hydraulic properties of the layer above were assigned. Special care was taken in specifying the hydraulic conductivity within the Eramosa Member. For that unit, a low conductivity was only specified within the sub-crop zone and was focused within the Guelph-Puslinch area, extending north toward Fergus, where it is also known to exist as an aquitard. In areas further west, it was treated as having a hydraulic conductivity similar to the Guelph Formation, as has been observed in Cambridge and the northwest part of Guelph.

Initial estimates of hydraulic conductivity were subsequently modified through the model calibration process. Layer thicknesses, however, were not modified during model calibration. Maps of layer thicknesses, calibrated hydraulic conductivity, and slice elevations are included in Appendix C. Nine cross sections and two block diagrams, displaying hydraulic conductivities, are also included in Appendix C.

Within the current model, it has been assumed that all hydrostratigraphic units contain fresh water (low TDS and salinity) and that the hydraulic conductivity of the deep fractured bedrock units is not affected by the weight of the overlying sediments. These assumptions have been applied to simplify the development of the numerical model. However, this may be an area where future modelling refinements are required.

5.1.3 Model Boundary Conditions

Beyond the hydrostratigraphic structure and the hydrogeologic properties, the other primary model parameters are the boundary conditions. Model boundary conditions provide the link between the hydrologic processes simulated within the model domain and the area surrounding it. Boundary conditions are inherently applied to all external faces of the 3D groundwater model, including the ground surface, the sides, and the bottom. Conditions applied along the top of the model include groundwater recharge (provided from the GAWSER continuous streamflow-generation model) and surface water bodies (streams, rivers, lakes). Important features of those boundary conditions will include the stream / lake / wetland stage and the conductance between the groundwater system and the surface water feature. Side boundary conditions define the interaction of the GRCA groundwater flow system and the surrounding watersheds. For the bottom boundary of the model, the model is designed to extend vertically throughout the active portion of the flow field, allowing the bottom boundary to be specified as a no-flow boundary.

In general, constant-head boundary conditions on the perimeter of the model domain were minimized through the latest revisions. Based on experience, minimizing these specified-head boundary conditions minimizes the potential for false adverse boundary effects, such as artificial flow between the Grand River Watershed and adjacent watersheds. Maps showing boundary conditions for all layers are included in Appendix C.

5.1.3.1 Recharge

As presented in Chapter 4, a key output of the GAWSER continuous streamflow-generation model is estimated groundwater recharge rates. These recharge rates are used as input to the FEFLOW steady-state groundwater-flow model. GAWSER calibration efforts were focused on the low flow regime to be able to better constrain the groundwater recharge estimates. Calibrated recharge estimates (see Figure 59) ranged from a low near 30 mm/y (Alma / Stratford Till Plain) to a high of over 500 mm/y (Waterloo Moraine). High recharge areas within the moraines are due to permeable soils and the hummocky terrain (lack of surface runoff). These recharge estimates are within the range of realistic values expected and are considered reasonable due to the methodology used to develop them. Since the GAWSER continuous streamflow-generation model is calibrated to available gauge data for low flow conditions, additional confidence is placed on the determined values and distribution.

5.1.3.2 Streams, Rivers & Lakes

Specification of stream and river boundaries involves applying a value for the stage (elevation) as well as the degree of “conductance” with the underlying groundwater system. The stage is taken from water levels represented in the available Digital Elevation Model (DEM). Further, the stream network was manually inspected to ensure that the stage specified at consecutive node locations was continuously falling in the downstream direction. As a result, the boundary conditions applied to the model are "hydraulically corrected". For the stream conductance, the base of all stream and river segments was assumed to contain a silty-sand sediment infill 10 cm thick (conductivity of $5x10^{-5}$ m/s). While this conductance value does not affect surface water / groundwater interaction in lower hydraulic conductivity soils, it is designed to limit interaction (within reason) where coarse grained materials are adjacent to stream / river features.

Boundary conditions for lakes and reservoirs within the GRCA were simulated using specified head values. Application of specified head values assumes that there is a good hydraulic connection between the lake and the underlying groundwater system. As with the streams, lake stage was taken from available elevations (DEM and reservoir operations).

5.1.3.3 Lateral Side Boundaries

To determine appropriate lateral boundary conditions for the model, water level trends around the perimeter of the model were carefully reviewed. Where water level trends suggested that natural flow boundaries exist (groundwater divides), a no flow boundary was applied. In other areas where water level trends indicated cross-boundary flow, fixed water level boundary conditions equivalent to the equipotential heads in those layers were applied. The review process also included evaluation of all cross-boundary flows to ensure that the direction and magnitude of cross-boundary flows was reasonable.

For the shallow groundwater system, the only boundaries where appreciable interchange is expected to occur are along the Whiteman's and Mackenzie Creek Subwatersheds. Within the deeper overburden and bedrock, exchange is expected to occur in more locations, most notably through the sediments infilling the buried Dundas Valley, within the Whiteman's and Mackenzie Creek Subwatersheds, the headwaters of the Conestoga River, the region near Orangeville and Erin (Eramosa River Subwatershed) and beneath the Haldimand Clay Plain (within the bedrock).

5.1.3.4 Pumping Wells

As outlined in Section 3, considerable effort was undertaken to better estimate the amount of water use within the Grand River Watershed.

The approach described in Section 3 utilizes the best available data to determine the pumping rate for wells. Reported "actual" pumping rates were used where available (municipal pumping wells and through surveys). For other permits to take water, the consumptive use estimate for the source was applied. Non-permitted water takings are not represented in the model at this point. All pumping well information, including the rate, location, and screened interval, was assembled in a relational database. For some wells, and particularly for dugout ponds, the screened interval was not known. In that case, wells were assumed to be screened within the most common local aquifer unit while dugout ponds were assumed to be taking water 3 m below ground surface. That information was then used to import well boundary conditions into the FEFLOW steady-state groundwater-flow model. All pumping well rates in the FEFLOW steady-state groundwater-flow model are applied in the units of cubic metres per day.

The FEFLOW steady-state groundwater-flow model treats the screened portion of all wells as an open borehole by superimposing a 1-dimensional line element onto the existing 3-dimensional finite element mesh. In most cases, the well nodes along the 1-D line element would span more than one layer of elements; however, in some cases only one node was selected.

A total of 721 wells are incorporated within the FEFLOW steady-state groundwater-flow model with a total demand of approximately 4 m^3/s. Some of largest non-municipal pumping wells include the dewatering wells at local quarries and some of the gypsum mine sites located within the southern portion of the Grand River Watershed. Municipal pumping from the groundwater system accounts for 2.2 m^3/s.

5.2 MODEL CALIBRATION

5.2.1 Calibration Approach

The typical approach to calibration is to alter the hydraulic conductivity value specified for discrete hydrogeological units (i.e. aquifers, aquitards), where each unit would encompass many elements and one or more layers. However, as the hydraulic conductivity field applied within this model is very heterogeneous, changing hydraulic conductivities manually for each unit is impractical. To overcome this challenge, the current calibration effort subdivided the Watershed into like “Aquifer Region” polygons used to modify elemental properties as a group. The calibration approach is to use a hydraulic conductivity multiplier for all elements within these aquifer regions on a layer-by-layer basis. Using multipliers within each zone and scaling (i.e. increasing or decreasing) the hydraulic conductivity helps control the flow conditions, increasing the accuracy of water level estimates, while maintaining the relative heterogeneity suggested by the variability of the borehole logs.

The delineation of aquifer regions was developed in a GIS by drawing polygons around areas with generally similar hydrogeologic properties or around distinct features. On average, each region is 100 to 200 km^2, resulting in a total of 48 aquifer regions (see Figure 64). These regions are incorporated for all overburden and shallow bedrock layers by projecting the region vertically across the layers, resulting in a total of 560 calibration zones. Table 5.2 lists all of the aquifer regions designed for the calibration effort.

Table 5.2 - Calibration Regions

ID	Aquifer Region	Description	Upper Overburden Aquifer	Lower Overburden Aquifer	Primary Bedrock Aquifer
1	Dundalk Highlands	Predominantly Catfish Creek and older Tills	Isolated outwash	Pre-Catfish Creek	Guelph and Amabel Fm.
2	Hwy 89 Plateau	Tavistock Till	minor pockets	minor pockets	Guelph-Amabel
3	Luther Marsh	Predominantly wetlands at surface, thick S&G at watershed boundary	isolated ice contact deposits	unknown - suspect northern end	Guelph-Amabel
4	Grand Valley Aquifer	Ice Contact Deposits	Extensive shallow deposits	none expected	Guelph-Amabel
5	Orangeville Moraine	Ice Contact and outwash deposits	prevalent on eastern flank of moraine	minor transmissivity	Guelph-Amabel
6	Damascus Esker and Aquifer	Ice Contact Stratified Drift	Surficial Esker	Deeper unit below Tavistock Till	Guelph - Amabel

ID	Aquifer Region	Description	Upper Overburden Aquifer	Lower Overburden Aquifer	Primary Bedrock Aquifer
7	Belwood Till Plain	Tavistock Till	isolated pocket east of Waldemar	none expected	Guelph-Amabel
8	Arthur Aquifer	Deeper deposits	only minor pockets expected	Thick deposits at depth	Salina
9	Arthur Area Till Plain	Tavistock Till	none expected	none expected	Salina
10	Drayton Aquifer	Tavistock - Alma Till	isolated pockets	deeper aquifer Drayton-Rothsay	Salina
11	Elmira Moraine	Elmira Moraine	isolated pockets, some continuity	deeper aquifer Hawksville-Flordale	Guelph – Amabel
12	Macton Moraine	Alma-Mornington Till	isolated pockets, none significant	none expected	Salina
13	Alma Till Plain	Tavistock Till	isolated pockets, none significant	isolated pockets, near Alma, toward Drayton	Salina
14	Belwood-Arthur Till Plain	Tavistock Till	1 major pocket south of Hwy9	none expected	Guelph-Amabel
15	Fergus-Elora Aquifer	Under Tavistock Till	pockets aligned between Elmira and Orangeville Moraines	isolated pockets, not extensive	Guelph-Amabel
16	Milverton Moraine	Mornington - Elma Till	none expected	Dundas valley near Poole	Bois Blanc / Onondaga
17	Waterloo Moraine North	Mornington Till	pockets, aligned Bamburg through Cross-hill	Pockets of lower aquifer, significant in Wellesley and CrossHill. Dundas valley north of Wellesley (Poole)	Salina
18	West Montrose	Port Stanley Till - Modern Alluvium / Outwash	local pockets of outwash	pockets Conestoga - Winterbourne	Salina - Guelph
19	Ariss Till Plain	Port Stanley Till	local pockets of outwash Centered on Ariss	local pockets, Cox Creek headwaters & Maryhill	Guelph-Amabel
20	Moffat Moraine South	Moffat Moraine - may be linked to flow in Blue Springs Creek	local pockets of outwash	none expected - close to Amabel subcrop	Amabel
21	Moffat Moraine - North	Moffat Moraine - Wentworth Till	local pockets of outwash	none expected, except maybe near Guelph - close to Amabel Fm subcrop	Guelph-Amabel
22	City of Guelph	Outwash deposits along Speed River - little overburden	local pockets of outwash	none expected - close to Guelph Fm subcrop	Guelph-Amabel
23	Rockwood-Acton Plain	Thin overburden on Eramosa-Amabel Fm.	local pockets of outwash - shallow	none expected	Amabel – Eramosa

ID	Aquifer Region	Description	Upper Overburden Aquifer	Lower Overburden Aquifer	Primary Bedrock Aquifer
24	Speed River Outwash	Outwash, Ice Contact and	Pockets of outwash - primarily shallow - area of higher K connecting Woolner Flats to the Speed River	none expected	Guelph
25	Paris Moraine North of Cambridge	Well sorted till - hummocky - important recharge for Mill Creek	Pockets of outwash - primarily shallow - area of higher K connecting Woolner Flats to the Speed River	none deep - some in Layer 4 near Mill Creek	Guelph – Amabel
26	Galt Moraine East of Grand River	Well sorted till - hummocky - important recharge for Mill Creek	pockets of outwash - primarily shallow	pockets of deep material irregularly scattered	Guelph – Amabel
27	Flamborough Plain	Thin till veneer over Guelph Fm.	very little overburden	very little overburden	Guelph Fm.
28	Easthope Moraine	Tavistock Till & Ice Contact Deposits	Isolated pockets of ice contact deposits	deeper pockets near New Hamburg - Layer 4	Bois Blanc / Bass Islands – Bertie
29	Waterloo Moraine - NW portion	Maryhill Till, Ice Contact Drift	Sections of surficial sands	Baden-St. Agatha and north	Salina
30	Waterloo Moraine - Core N portion	Maryhill Till, Ice Contact Drift	Erbsville sand hills	Erb Street area	Salina
31	Waterloo Moraine - East Flank - N portion	Port Stanley Till, Ice Contact Drift, Urban Area	Lacustrine outwash sands - Forwell area - Victoria St.	Farmer's Market area - North Waterloo	Salina – Guelph
32	Waterloo Moraine - East Flank - Woolner Flats	Port Stanley Till, Ice Contact Drift, Grand R. Outwash	Fluvial outwash sands near river - till cap - Layer 4 significant in Kitchener East - Chicopee	not extensive in this area - NE of Parkway	Guelph
33	Waterloo Moraine - East Flank - Parkway - Greenbrook	Ice Contact Drift over tills	Ice contact deposits - Homer Watson area - west of Parkway	Greenbrook - Parkway - Strasburg	Salina – Guelph
34	Waterloo Moraine - Core - Mannheim south to New Dundee	Ice Contact Drift over tills	Ice contact deposits eastern and western flanks - Mannheim	Along Core / city boundary	Salina
35	Waterloo Moraine - Western Flank - Baden to Plattsville	Ice Contact Drift over tills	Ice contact deposits western flank - Baden / Wilmot Centre	not much deep - along flank in Layer 4	Salina
36	Chesterfield Moraine	Port Stanley / Zorra / Tavistock Tills / Ice Contact Deposits	Significant ice contact and outwash deposits SW of Drumbo - - Layer 4 near boundary	none expected	Salina
37	Eastwood Area	Tavistock Till	none expected	none expected	Salina - Bass Islands – Bertie

ID	Aquifer Region	Description	Upper Overburden Aquifer	Lower Overburden Aquifer	Primary Bedrock Aquifer
38	Norwich Moraine	Tavistock Till / Outwash / Ice Contact drift	limited to along Nith River	North portion near Ayr and along 401, south outwash deposit adjacent to Whiteman's Creek.	Salina
39	Paris Moraine - Cambridge to Glen Morris	Lacustrine outwash / Glacial Outwash Gravels / Ice Contact drift	plentiful	interconnected pockets throughout the area	Guelph – Salina
40	Waterloo Moraine South - Roseville to Cedar Creek	Lacustrine outwash / Glacial Outwash / Ice Contact drift	pockets	interconnected pockets throughout the area, plentiful	Guelph – Salina
41	Paris Moraine South - Glen Morris to Burford	Lacustrine outwash / Glacial Outwash Gravels / Ice Contact drift	plentiful throughout	Burford north-west along Whiteman's Creek	Guelph – Salina
42	Galt Moraine South - Galt to Brantford	Lacustrine outwash / Ice Contact drift Wentworth Till	pockets	plentiful near St. George and north toward Galt	Guelph
43	Brantford Delta	Lacustrine outwash Delta deposits	plentiful	none expected	Salina
44	Moffat Moraine	Lacustrine outwash shallow water deposits	interconnected	plentiful	Salina - Bertie
45	Lynden - Dundas Valley	Lacustrine outwash shallow water deposits	interconnected	mapped as spotty - watch for Dundas Valley	Guelph and lower in Dundas Valley
46	Haldimand Clay Plain - St. George to Cayuga	massive laminated lacustrine silt and clay	none expected	none expected	Guelph - Salina
47	Haldimand Clay Plain - Cayuga to Lake Erie	massive laminated lacustrine silt and clay	none expected	none expected	Guelph - Salina
48	Dunnville outwash sands	sands overlying Haldimand silt and clay	shallow only within outwash	none expected	Guelph - Salina

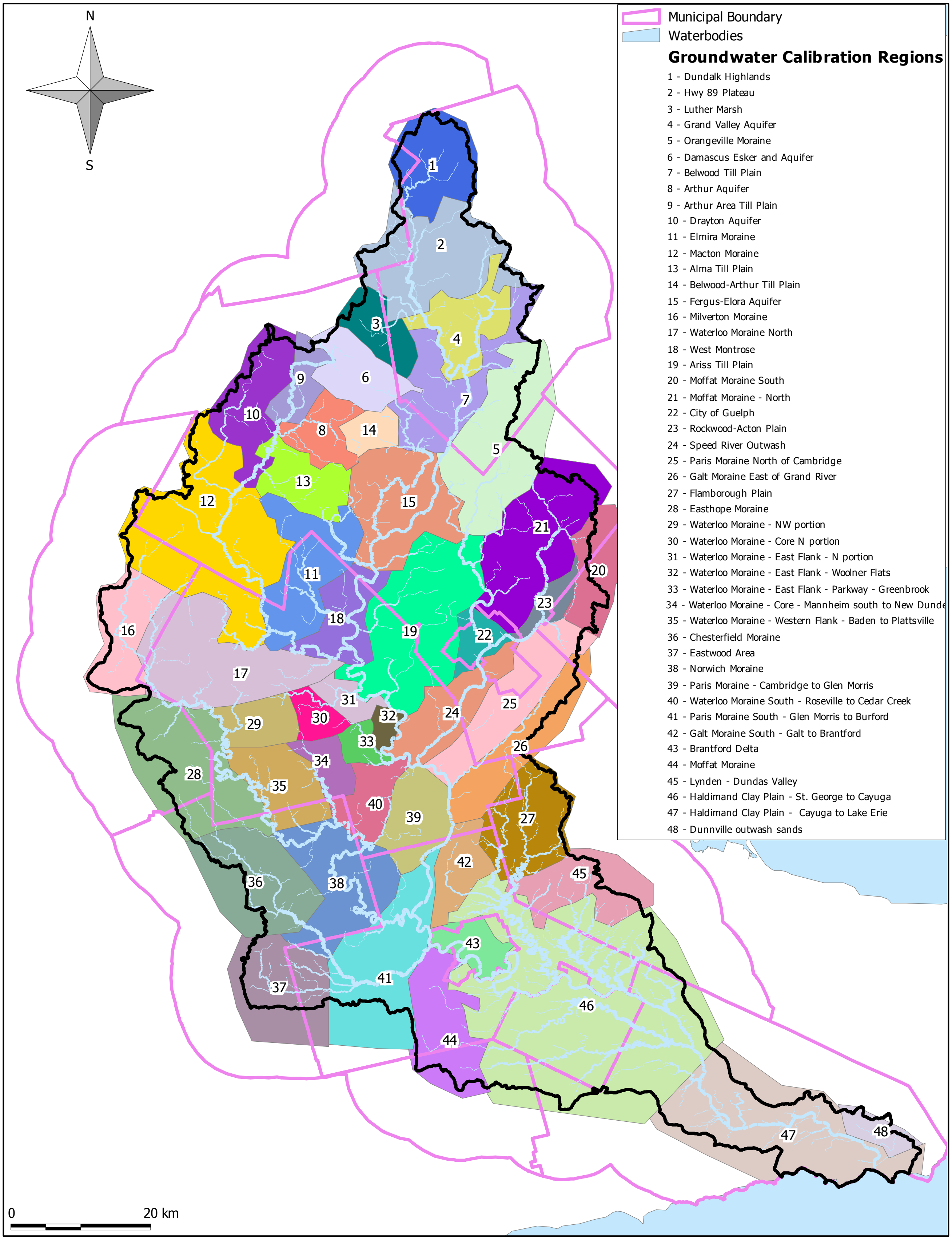

Figure 64
Calibration Focus Areas

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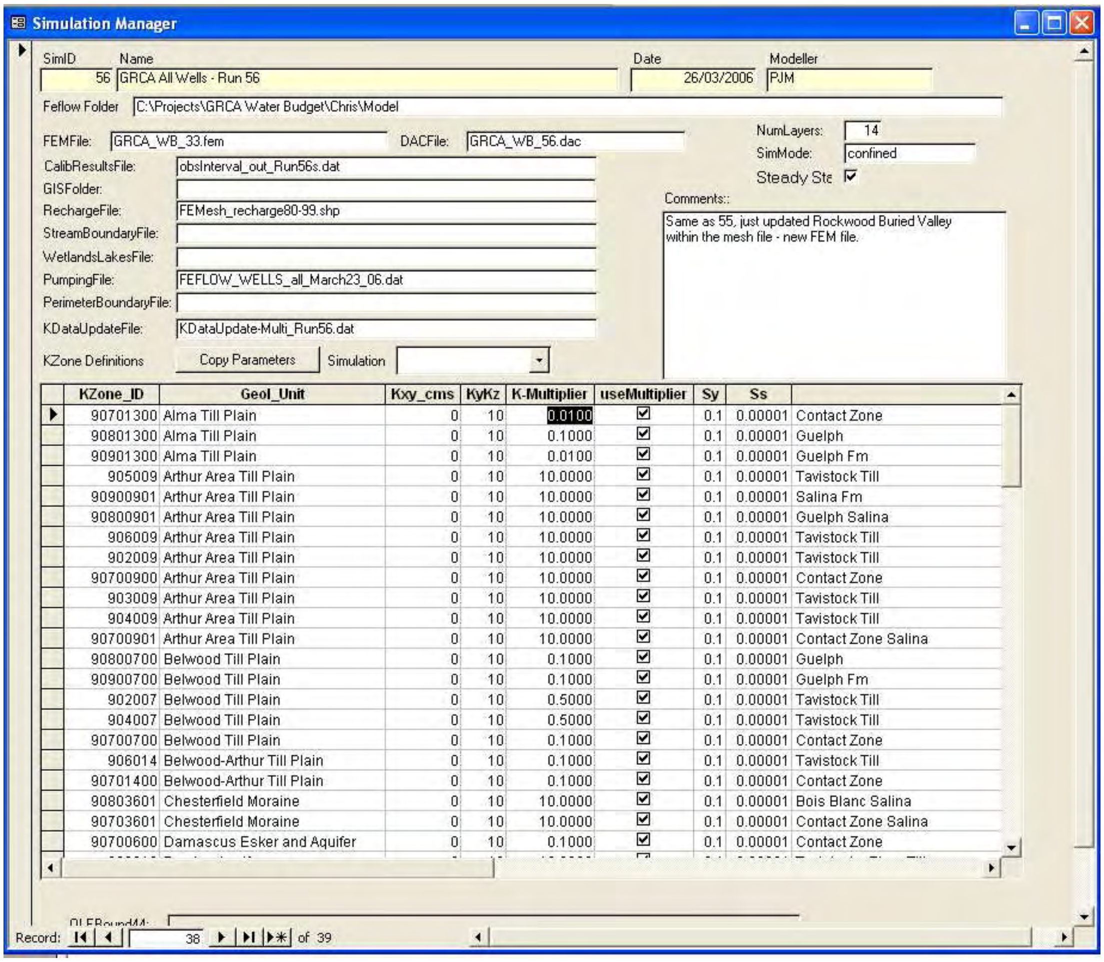
To support the calibration, a calibration database was developed to store input parameters, files and hydraulic conductivity multipliers, as well as, the qualitative and quantitative results of all calibration simulations. This database also provides a means of tracking parameter changes from one calibration simulation to the next. The image below illustrates the interface for the simulation manager database.


Simulation Manager

SimID: 56 | Name: GRCA All Wells - Run 56 | Date: 26/03/2006 | Modeller: PJM

Feflow Folder: C:\Projects\GRCA Water Budget\Chris\Model

FEMFile: GRCA_WB_33.fem | DACFile: GRCA_WB_56.dac

NumLayers: 14 | SimMode: confined | Steady Ste: ☑

CalibResultsFile: obsInterval_out_Run56s.dat

GISFolder:

RechargeFile: FEMesh_recharge80-99.shp

StreamBoundaryFile:

WetlandsLakesFile:

PumpingFile: FEFLOW_WELLS_all_March23_06.dat

PerimeterBoundaryFile:

KDataUpdateFile: KDataUpdate-Multi_Run56.dat

Comments:: Same as 55, just updated Rockwood Buried Valley within the mesh file - new FEM file.

KZone Definitions | Copy Parameters | Simulation

KZone_ID	Geol_Unit	Kxy_cms	KyKz	K-Multiplier	useMultiplier	Sy	Ss	
90701300	Alma Till Plain	0	10	0.0100	☑	0.1	0.00001	Contact Zone
90801300	Alma Till Plain	0	10	0.1000	☑	0.1	0.00001	Guelph
90901300	Alma Till Plain	0	10	0.0100	☑	0.1	0.00001	Guelph Fm
905009	Arthur Area Till Plain	0	10	10.0000	☑	0.1	0.00001	Tavistock Till
90900901	Arthur Area Till Plain	0	10	10.0000	☑	0.1	0.00001	Salina Fm
90800901	Arthur Area Till Plain	0	10	10.0000	☑	0.1	0.00001	Guelph Salina
906009	Arthur Area Till Plain	0	10	10.0000	☑	0.1	0.00001	Tavistock Till
902009	Arthur Area Till Plain	0	10	10.0000	☑	0.1	0.00001	Tavistock Till
90700900	Arthur Area Till Plain	0	10	10.0000	☑	0.1	0.00001	Contact Zone
903009	Arthur Area Till Plain	0	10	10.0000	☑	0.1	0.00001	Tavistock Till
904009	Arthur Area Till Plain	0	10	10.0000	☑	0.1	0.00001	Tavistock Till
90700901	Arthur Area Till Plain	0	10	10.0000	☑	0.1	0.00001	Contact Zone Salina
90800700	Belwood Till Plain	0	10	0.1000	☑	0.1	0.00001	Guelph
90900700	Belwood Till Plain	0	10	0.1000	☑	0.1	0.00001	Guelph Fm
902007	Belwood Till Plain	0	10	0.5000	☑	0.1	0.00001	Tavistock Till
904007	Belwood Till Plain	0	10	0.5000	☑	0.1	0.00001	Tavistock Till
90700700	Belwood Till Plain	0	10	0.1000	☑	0.1	0.00001	Contact Zone
906014	Belwood-Arthur Till Plain	0	10	0.1000	☑	0.1	0.00001	Tavistock Till
90701400	Belwood-Arthur Till Plain	0	10	0.1000	☑	0.1	0.00001	Contact Zone
90803601	Chesterfield Moraine	0	10	10.0000	☑	0.1	0.00001	Bois Blanc Salina
90703601	Chesterfield Moraine	0	10	10.0000	☑	0.1	0.00001	Contact Zone Salina
90700600	Damascus Esker and Aquifer	0	10	0.1000	☑	0.1	0.00001	Contact Zone

Record: 38 of 39

5.2.2 Calibration Targets and Results

Observed water levels (head) and groundwater discharge (portion of stream baseflow) are used as calibration targets to achieve an optimal calibration of a groundwater model.

To calibrate the GRCA groundwater model, water level information was carefully selected from the MOE water well information system. Water levels selected for use in calibration included those with high location reliability and with static water levels observed in the 1980-2000 period (7953 well water levels). In addition, water levels used in the Guelph-Puslinch Groundwater Study (Golder, 2005) and wells currently being used by the Region of Waterloo were also included as calibration targets. The number of water level targets provided from those sources was 6,596 and 2,056 respectively; however, many of those wells were duplicates of the wells extracted from the MOE database for the GRCA model calibration. There was no attempt in this study to remove the duplicates between various datasets.

Because the observed water elevations are taken from the MOE water well database, all observed targets should not necessarily be considered representative of long term average water levels. Water wells selected for the calibration exercise were constructed within the 1980-2000 period. Individually reported water levels may be influenced by temporal variations, measurement error, and well completion and installation techniques.

Figure 65a illustrates the match between the observed and calculated hydraulic head measurements for all water level calibration targets (~16,500). As this figure shows, good agreement between simulated and observed water levels was achieved. This regional match of observed and simulated water levels suggests that the numerical model represents the key hydrogeologic functions at the regional scale. Figures 65b and 65c contain the calibration charts for the Region of Waterloo and the Guelph-Puslinch calibration targets, respectively. As in the regional calibration, a good match to these data sets was obtained. For the Guelph-Puslinch data set, the scatter of calculated water levels is slightly less than for the overall model; this is reflected by the calibration statistics (Figure 65b). Figure 65d illustrates the spatial distribution of the residuals, and shows that the scatter is predominantly random with a minor trend toward low simulated water levels south of Guelph and underlying Mill Creek. Maps of residuals, separated into overburden and bedrock wells, are included in Appendix C.

The scatter diagram for the Region of Waterloo data (Figure 65c) illustrates additional scatter; a review of the spatial residual values (Figure 65e) indicates that significant drawdown was simulated around some overburden pumping wells. The excessive drawdown predictions reflect the fact that the model was not calibrated to local wellfield conditions; however, as these predictions are restricted to areas local to the wellfields the impact on the regional water budget is negligible. This error should, however, be addressed through future calibration. The remainder of the scatter is predominantly random (high and low dots exist next to one another); one exception is the SE-NW trend of low water levels following the mapped buried Dundas Valley feature north of Wellesley (western edge of map).

Calibration statistics for the hydraulic head calibration measures are illustrated on the figures and further explained below:

- Normalized root mean squared (NRMS) error = 2.11%. This percentage value allows the goodness-of-fit in one model to be compared to another, regardless of the scale of the model. This level of calibration is considered appropriate for a model and indicates that the key regional hydrologic functions are represented within the model;
- Root mean squared (RMS) error = 7.74 m. The RMS is similar to a standard deviation, providing a measure of the degree of scatter about the 1:1 best-fit line. The measure indicates that the majority statistical population of predicted water levels would fall within 7.9 m of the observed value. An error of ± 5 m is generally accepted to be inherent in the use of water well record data, reflecting inaccuracies in well elevation and measurements;
- Mean Error = -1.95 m. The mean error is a measure of whether on average predicted water levels are higher or lower than those observed (ideally it should be close to 0). This statistic indicates that on average, the simulated water levels are low by 1.95 m; and
- Mean Absolute Error = 5.68 m. The mean absolute error is a measure of the average deviation between observed and simulated water levels. The value of less than 6 m is less than the population statistic (RMS) and within the range of the expected level of error when using water levels from well records (± 5 m).

In addition to the water level calibration target's used, baseflow discharge estimates at 28 streamgauge locations throughout the Watershed for the 1980-2000 period were also used as calibration targets. These streamgauges include both active gauges which were used for the GAWSER continuous streamflow-generation model calibration, as well as historical streamgauges that are no longer operational.

To estimate groundwater discharge, streamflow records within the 1980-2000 period were separated into baseflow and runoff components using the software program, BFLOW, as described in Bellamy et al. (2003). While baseflow is commonly associated with groundwater discharge, this assumption is not always valid. Baseflow can be sustained by the release of water from any large hydrologic or hydrogeologic feature within the upstream watershed. Aquifers which are hydraulically connected to the watercourse can be such features, as can be significant wetland complexes or large lakes / reservoirs. Wastewater treatment plant effluent discharges also contribute to baseflow. In order to associate separated baseflow with groundwater discharges, observed streamflows were naturalized to remove the effects of reservoir augmentation, and wastewater treatment plant effluent discharges (Bellamy et al., 2003).

Recognizing the uncertainty in estimated groundwater discharge rates, the calibration approach relied on an estimated range, as opposed to a single value. The range was bounded by the annual average groundwater discharge (upper limit), and the average groundwater discharge observed during the ice-free period of May – Nov (lower limit). Estimating groundwater discharge for the ice-free period recognizes that measured winter streamflows may be overestimated due to backwater effects caused by river ice.

The match between observed and simulated baseflow is presented in Figure 66. Simulated baseflow from the FEFLOW steady-state groundwater-flow model is calculated from the calibrated model by adding up the total groundwater discharge to stream boundary conditions for all locations upstream of the observed location (i.e., stream gauge). As indicated in Figure 66, the range of observed groundwater discharge targets (light blue bars) are typically considered appropriate for comparison to discharge output from a steady-state model. This range is assumed because the method used to estimate baseflow rates is uncertain, and the range in groundwater discharge estimates is considered to encapsulate average annual values. The dark blue squares on the figures represent the simulated groundwater discharge conditions along the stream / river reach. The stations are listed from left to right in order of the relative groundwater discharge, with those on the left representing headwater streams, and those on the right representing major river segments (note the log scale for the flows).

Care was taken to match simulated and observed discharge wherever possible. In general, the match to observed flows along large stream reaches is good; however, the fit is not as good for smaller reaches. This is expected, as the numerical model has not been developed to represent local hydrogeologic conditions. Despite these limitations, the overall match to observed baseflow is considered reasonable and this suggests that overall, estimated recharge rates are of a reasonable magnitude. Future calibration efforts may focus on those reaches where the difference between the observed and simulated conditions is highest. For those areas, it is likely that local hydraulic conductivity modifications can be used to improve the local calibration to baseflow. Alternatively, the conceptual model may be updated in the future to better reflect local conditions where necessary.

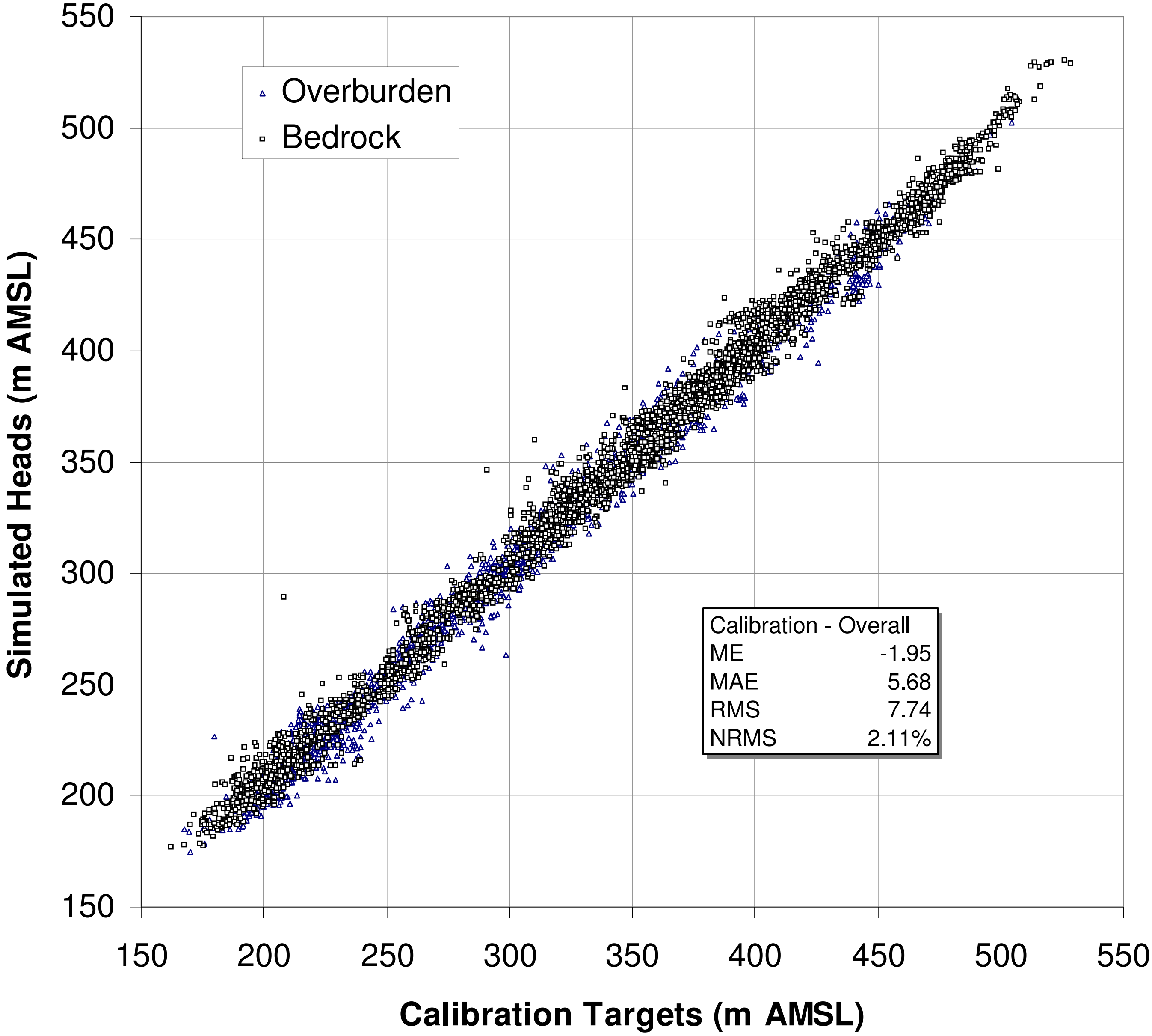


Figure 65a
Calibration Statistics (Heads)

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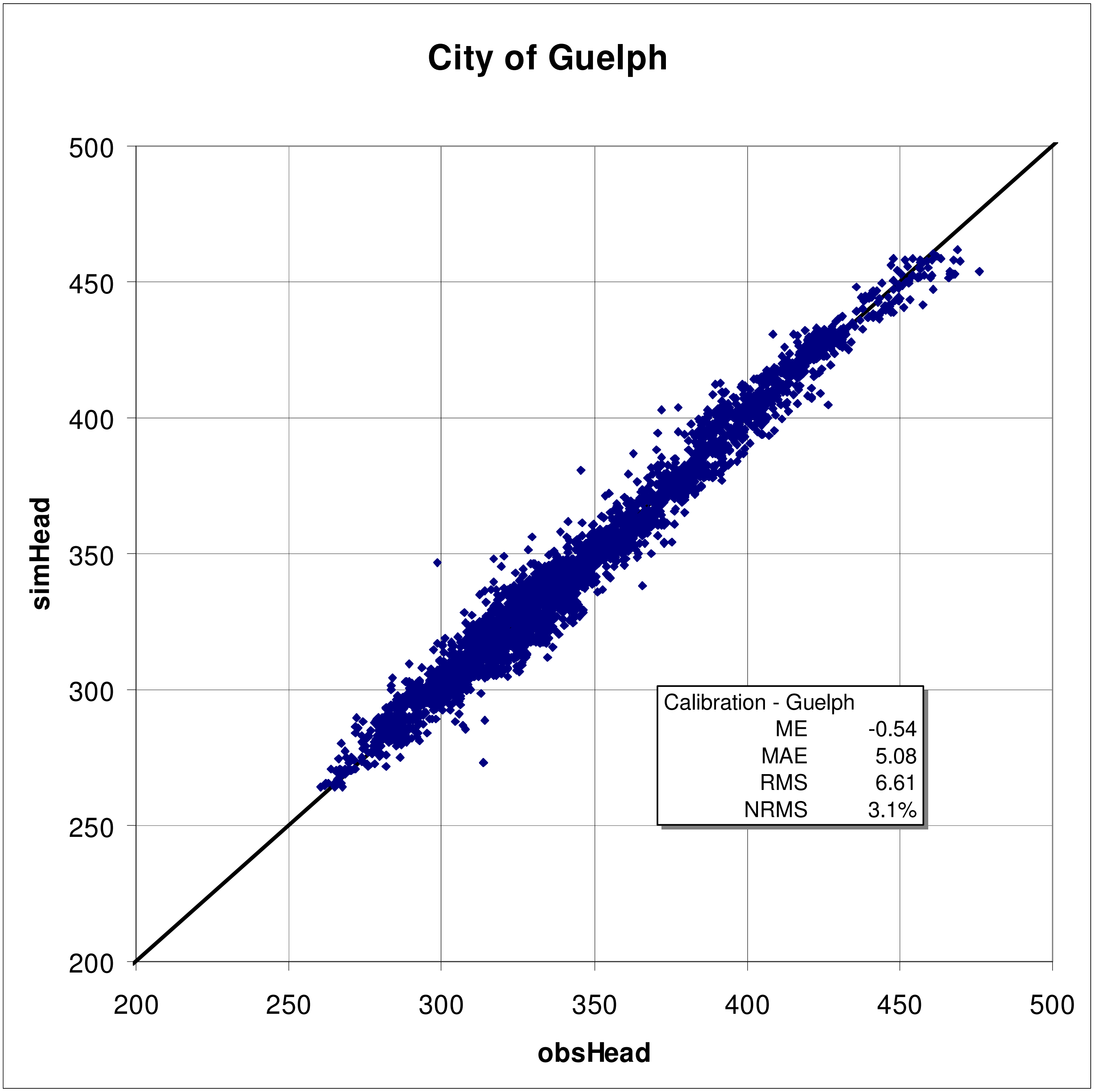

Figure 65b
Guelph-Puslinch Calibration Statistics (Heads)

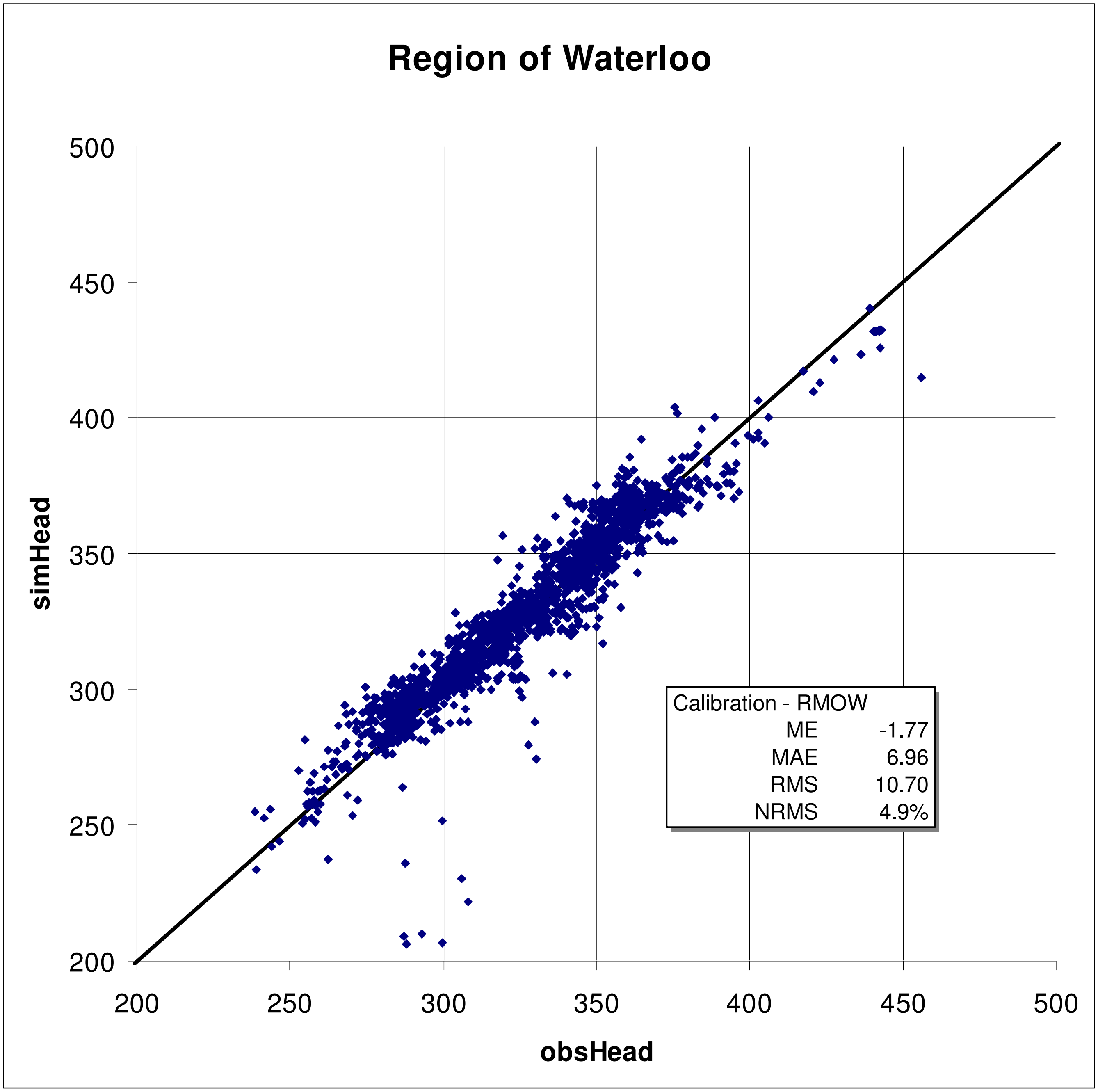

Figure 65c

Region of Waterloo Calibration Statistics (Heads)

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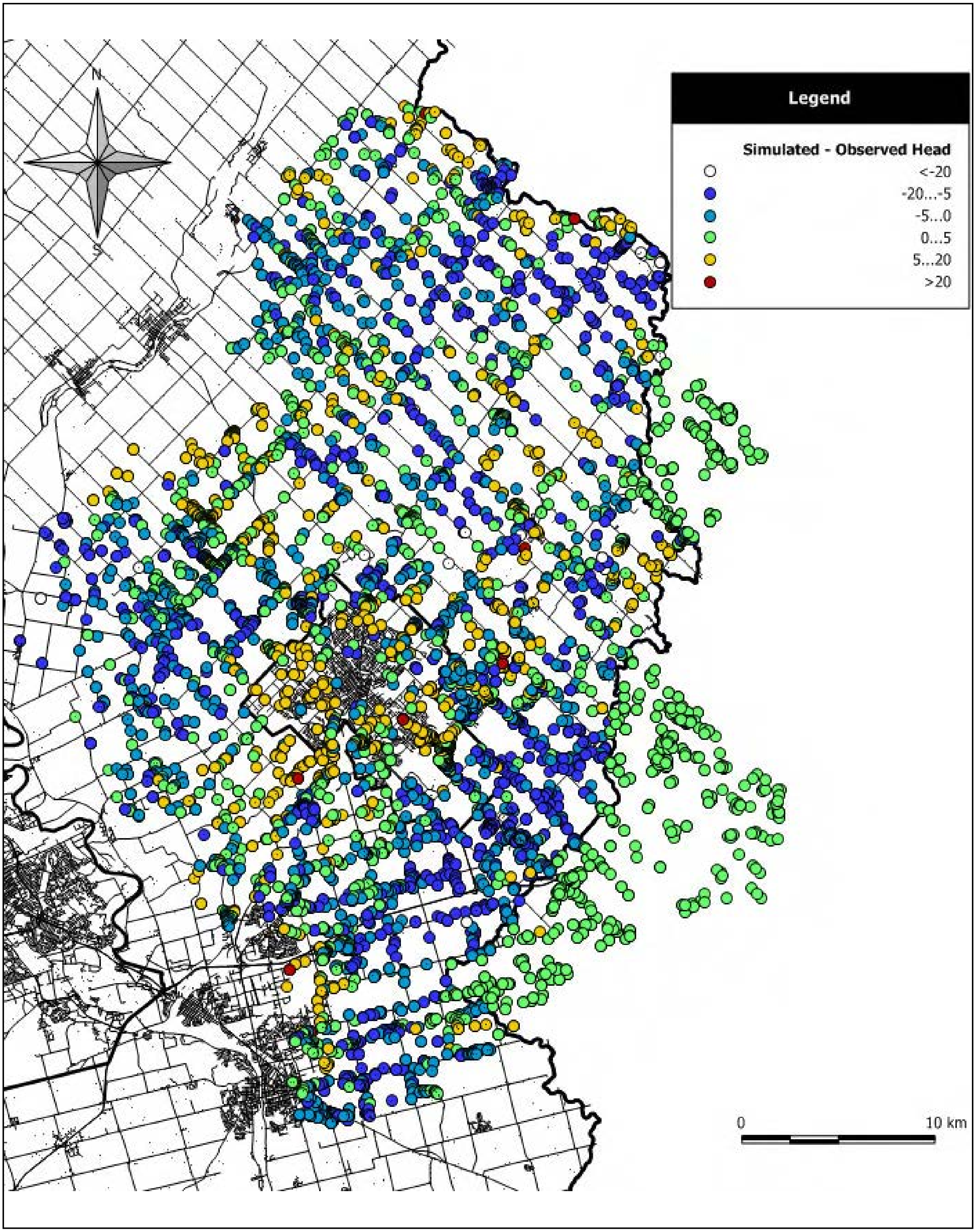

Figure 65d
Guelph-Puslinch Calibration Match

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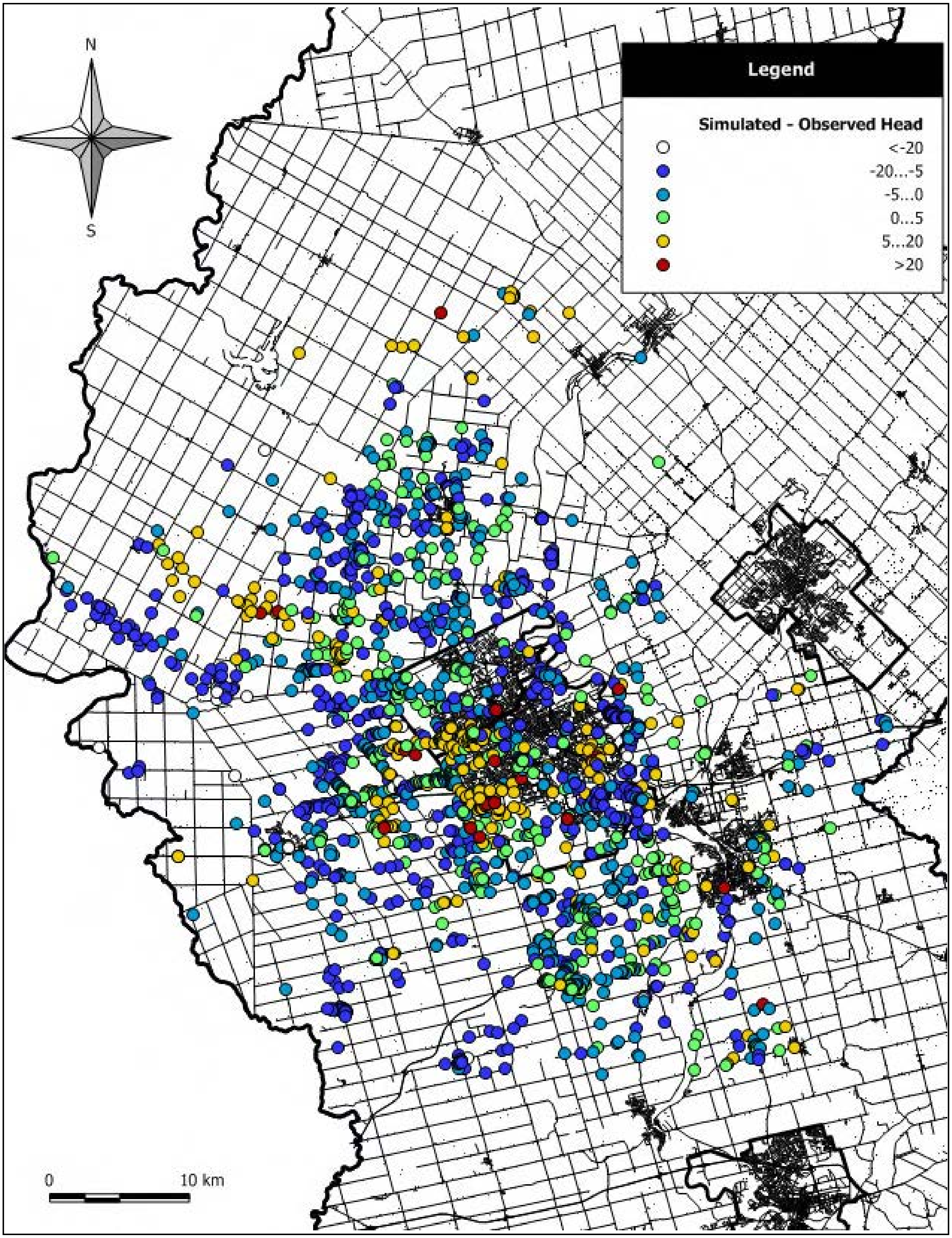

Figure 65e
Region of Waterloo Calibration Match

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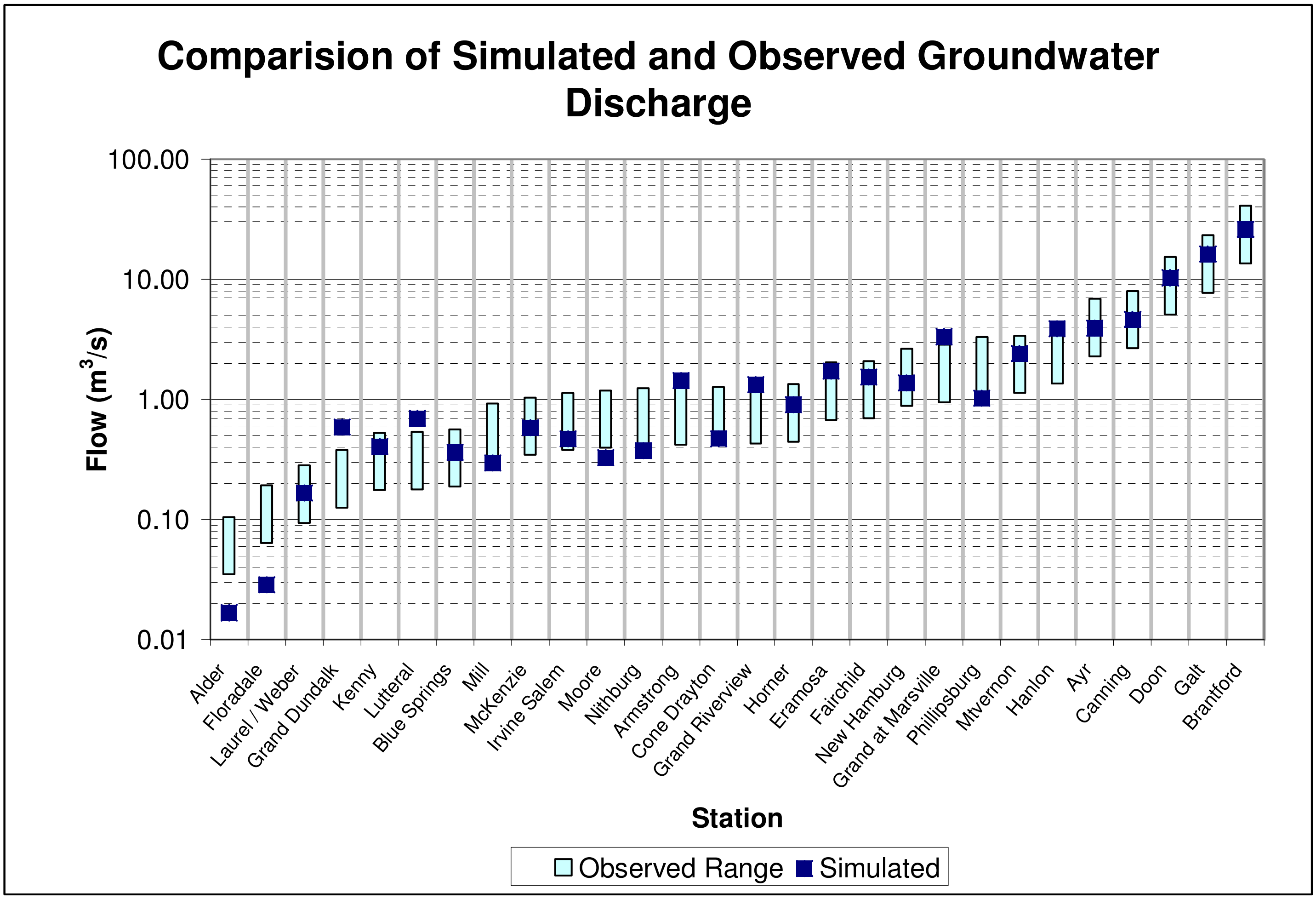

Figure 66
Groundwater Discharge Calibration

5.3 GROUNDWATER MODELLING ANALYSIS

The calibrated groundwater model provides a synthesis of available information that can be used to increase understanding about the groundwater flow system and its interaction with the surface water system. Typical tools for completing such an assessment include the following:

- Review of simulated hydraulic head patterns on two-dimensional maps for a hydrostratigraphic layer. This highlights areas of higher or lower hydraulic head, and provides insight into the general flow system. Sequential maps for multiple layers indicate areas of potential interaction between hydrostratigraphic units, for example flow between shallow and deep aquifer units.
- Groundwater discharge distribution can be used to visualize the areas of greater interaction between the groundwater and surface water systems. This information in conjunction with the water level maps provides insight into the groundwater flow system.
- Forward and backward particle tracking to better visualize the three-dimensional groundwater flow system. Backwards particle tracking from key areas of interest (such as areas of higher baseflow discharge) can also provide a great deal of insight into the interconnections between significant discharge zones and their recharge origin.

Figures 67 and 68 show the calibrated hydraulic head distribution throughout the Grand River Watershed for the watertable and contact zone (i.e. weathered bedrock) aquifer, respectively. Both figures illustrate the flow from the upper reaches of the Watershed (topographic high) toward Lake Erie. Both figures also exhibit the influence of primary surface water features, with this influence being greater on the watertable than on deeper groundwater. The irregularity of the watertable reflects the heterogeneity of the hydraulic conductivity field applied to the overburden layers in addition to strong local influences of surface water features. In contrast, the hydraulic conductivity within the contact zone aquifer is relatively uniform, resulting in a smoother contour distribution. Additionally, the direct influence of surface water features decreases for deeper hydrogeologic units.

Figure 69 presents the difference in hydraulic head between the bedrock and the watertable; this difference is derived from the two surfaces presented in Figures 67 and 68. Those areas where the difference in hydraulic heads between the watertable and the bedrock are less than 5 m are shown as white; these areas may not have a strong driving force for vertical flow and may be dominated by horizontal flow (unless the intervening material has a relatively high hydraulic conductivity). Areas in brown represent areas of dominantly downward hydraulic gradients. Conversely, green areas indicate regions where strong upward gradients exist and are potential locations of groundwater discharge; they are well correlated with the primary surface water features and areas known to have strong regional groundwater discharge trends.

Figure 70 illustrates simulated groundwater discharge throughout the Watershed. This information is presented as groundwater discharge per kilometer of stream and was calculated by delineating stream reaches into shorter lengths (i.e. 2-5 km), calculating total amount of groundwater discharge into each reach, and then dividing the total groundwater discharge by the length of the reach. On the figure, reaches of highest groundwater discharge are shown as thicker dark blue lines. Thin light blue lines indicate that the headwater regions primarily receive smaller discharge volumes. The highest groundwater discharge rates occur in major stream reaches in low lying areas, such as between Cambridge and Paris. These results provide an initial regional-scale visualization of groundwater / surface water interactions.

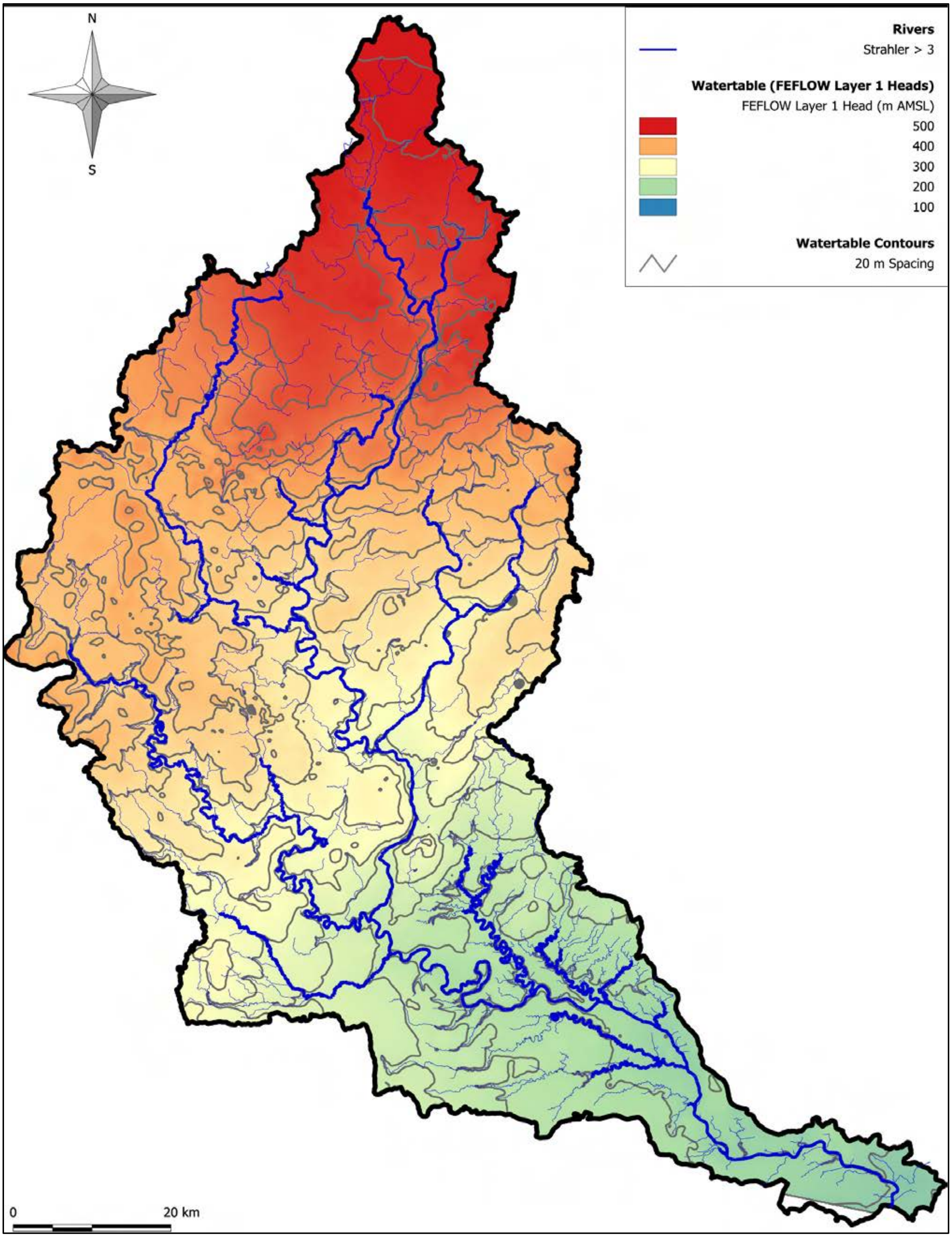

Figure 67
Calibrated Water Table

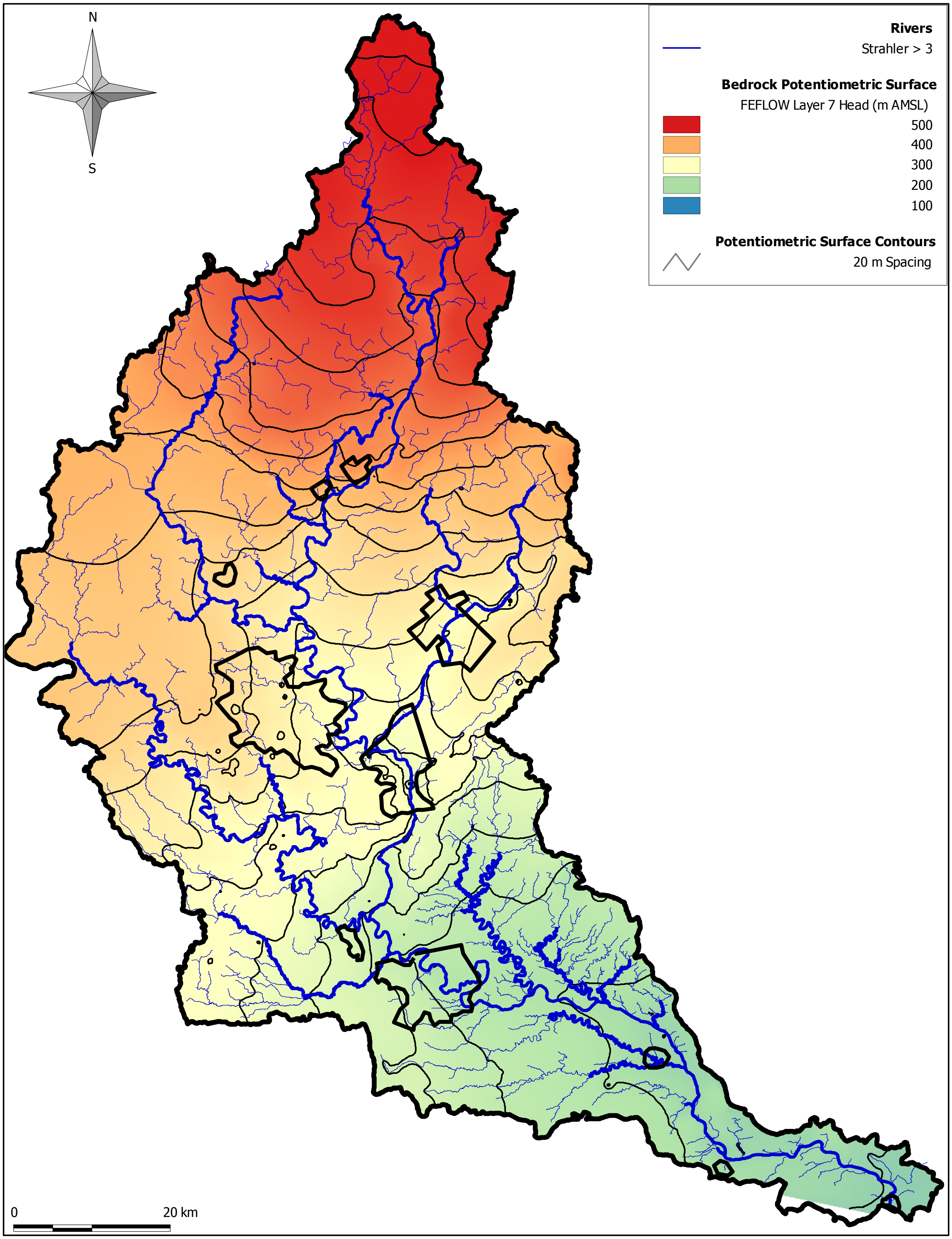

Figure 68
Calibrated Potentiometric Surface (Contact Zone)

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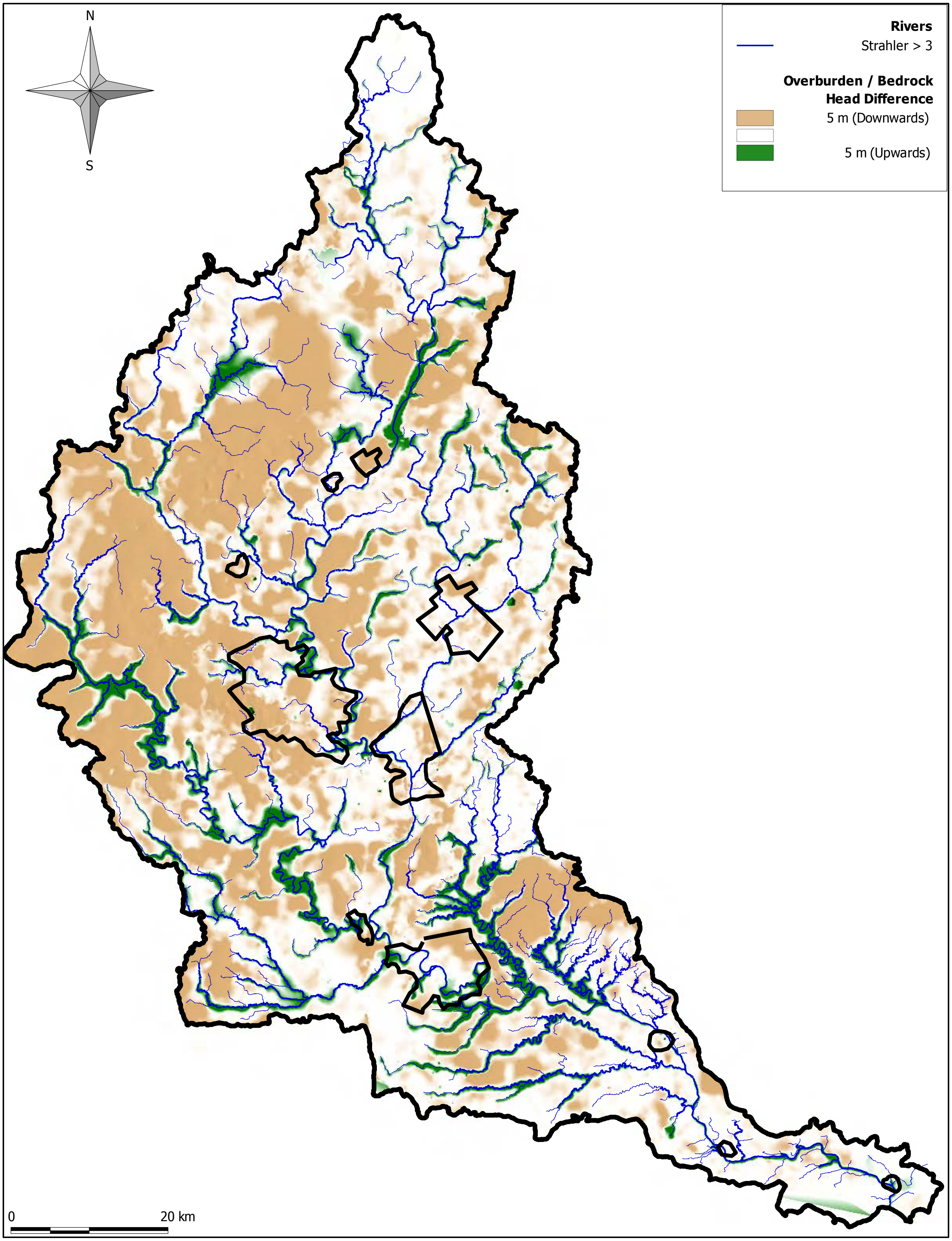

Figure 69
Overburden / Bedrock Vertical Flow Direction

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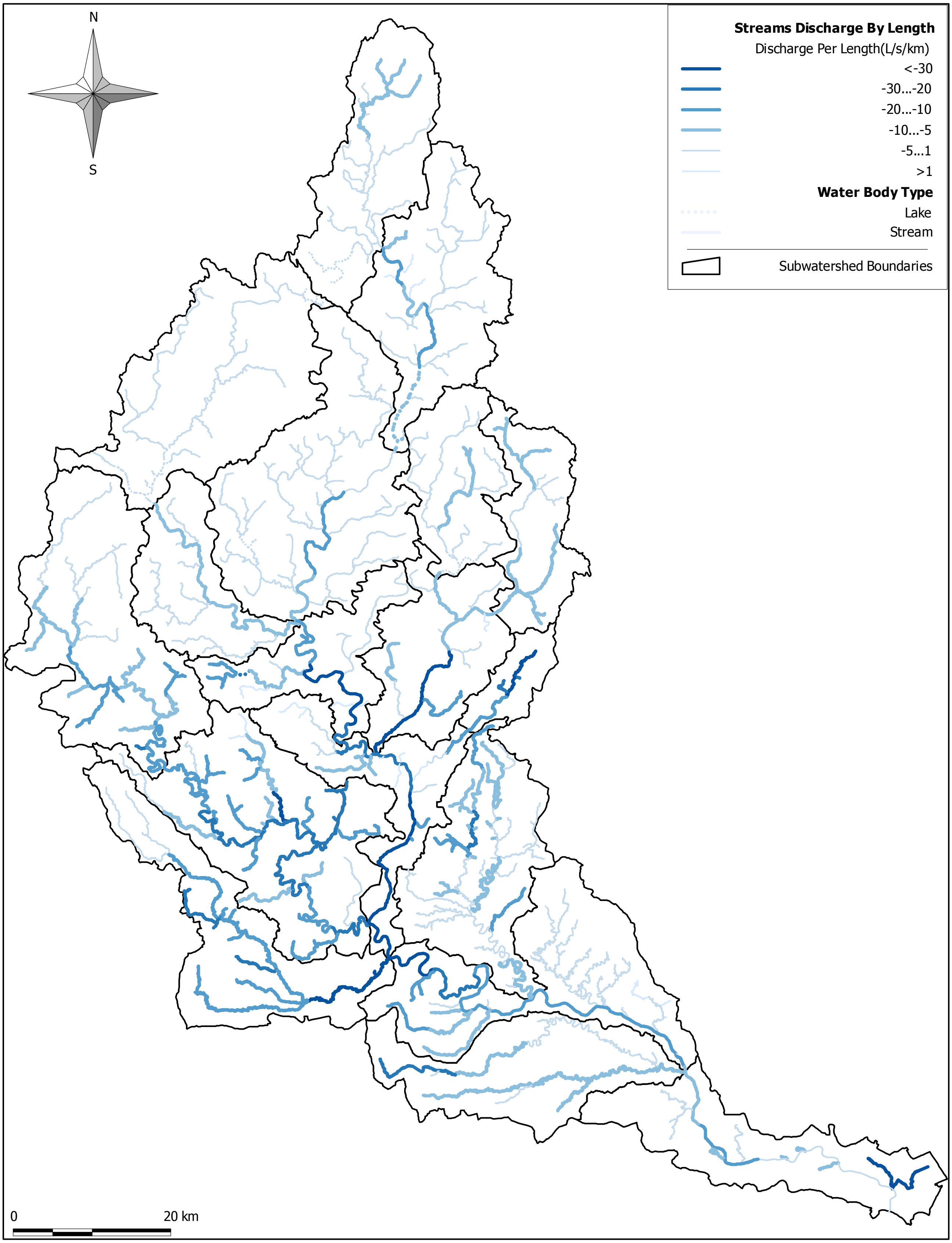

Figure 70
Groundwater Discharge

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5.4 UNCERTAINTY

All numeric models can be considered a simplification of the natural system. Part of the reason for this is that we can never know enough about the complexities of the physical system to incorporate all details into a numerical context. In reality, most of the scientific approach involves representing physical conditions observed using approximations of larger-scale functionality; hydraulic conductivity is an example of this. This approximation does not negate the ability of scientists and practitioners to utilize numerical models as tools to help understand and manage natural systems; we do, however, need to recognize the limitations of such tools when interpreting model results.

Many elements of the groundwater modelling process using any modelling code are subject to uncertainty. Although the calibration process is performed in an attempt to provide a realistic representation of physical conditions and reduce uncertainty, the model results and water budgets reflect the uncertainty in the model input parameters.

The following sections summarize some of the uncertainties associated with the FEFLOW steady-state groundwater-flow modelling process, and discuss some of the potential impacts of this uncertainty.

5.4.1 Watershed Characterization

The Grand River Watershed groundwater flow model is designed to incorporate the key hydrogeologic features of each subwatershed and their characteristics. Thus the model has been designed to evaluate the flows through the system at a subwatershed level by incorporating identified features and characteristics as understood through the characterization process and through local experience. The implication is that features at a smaller scale may not be adequately represented to support more local assessments; additional refinement and characterization is required to examine those features.

In most cases the limiting factor that results in uncertainty is the lack of available subsurface data. For the GRCA model, an attempt was made to utilize knowledge from all available data through the generation of hydraulic conductivity fields, based on the lithology recorded at individual boreholes.

Important watershed characterization elements subject to uncertainty are listed below:

- Hydrostratigraphic Interpretation. The interpretation throughout the Watershed was automated and therefore does not contain the conceptual insight that would be present through a more-rigorous approach. This automated approach was chosen to facilitate completion in a cost-effective manner for such a large area. It is expected that the hydrostratigraphic interpretation is significantly less detailed / more simplified than local-scale interpretations within the same area. The difference in interpretation is a significant source of uncertainty.
- Hydrogeologic Characteristics. The hydrogeologic characteristics were generated by interpolating point estimates of hydraulic conductivity based on borehole lithologies. As a result, there are numerous sources of uncertainty, including the following:
    - Driller's recorded lithology which is subject to the individual's subjective opinion of drill cuttings and the depth from which they originate;
    - Hydraulic conductivity associated with a lithology (each lithology could have a range of potential values that spans at least one order of magnitude, whereas the approach used assigns a "representative" value);
    - Lack of consideration for the stratigraphic unit (i.e. Maryhill or Catfish Creek Till) which may constrain the practical conductivity range; and

  - Linear interpolation between boreholes (assumes linear variation and ignores potential geologic controls on extrapolation of conductivity estimates).

- Rivers, Wetlands and Lakes. Surface water features are characterized as having a constant, specified water level that is representative of average conditions, and is independent of conditions within the groundwater system. Further, the hydraulic connection with the underlying aquifer system is characterized as having uniform properties. These simplifying assumptions overlook the natural seasonal variability in surface water levels, as well as, the spatial distribution of river / wetland and lake bottom materials (siltation) that may limit or resist interaction with the groundwater system. These assumptions result in uncertainty regarding local hydraulic controls on hydraulic heads and recharge to or discharge from the groundwater system.

- Groundwater Recharge Estimates (GAWSER). Recharge estimates from the calibrated surface water model are considered more physical than the traditional method of ad-hoc recharge assignment based on surficial soils, however there is also considerable uncertainty associated with these estimates. Calibration of the GAWSER continuous streamflow-generation model to observed streamflows, particularly low flows, ensures that the volume of recharge within a basin is realistic (within the uncertainty in Evapotranspiration). As such the cumulative recharge sum is calibrated and the local variability in recharge is assumed, based on available surficial geology mapping. Ideally, recharge through individual soil types would be calibrated to field observations, but this is beyond the state of the practice at this point.

- Perimeter Boundary Conditions. Boundary conditions around the perimeter of the GRCA FEFLOW steady-state groundwater-flow model allow flow into and out of the model domain to occur. Boundary conditions are established based on mapping of interpolated potentiometric surfaces for the watertable position and deep overburden / bedrock water levels. Application of boundary conditions was limited in this study to areas where interpolated potentiometric surfaces indicated potential for cross-boundary flows. As such, the perimeter boundary conditions are subject to the following uncertainty:

  - Water levels predicted in the relevant potentiometric surface and the assumptions inherent to the interpolation process;
  - Application of discrete potentiometric surface data to all aquifer units of the model (up to 9 of the available 14 model layers); and
  - Level of interaction is based on the hydraulic conductivity specified for each aquifer unit and its uncertainty.

  To minimize the uncertainty in the boundary conditions, the flow computed across each boundary segment was reviewed to ensure that it was consistent with the conceptual model and the current hydrogeologic understanding.

5.4.2 Calibration Data

The scale of the calibration effort is consistent to the scale of the model. As such, the focus of the design and calibration of the GRCA model is on regional-scale features that control groundwater flow at the subwatershed level. Accordingly, the calibration procedure designed for this was to spatially group parameters and vary them in proportion to one-another. During this procedure, calibration focused on spatial trends in observed water levels and discharge estimates; no attempt was made to match or explain individual outliers as isolated outliers are expected to occur within the MOE water well record database.

- Water levels from MOE Water Well Records. The expected range of uncertainty associated with water well records is in the order of 5 m. This is due to many factors, including the clogging of the aquifer materials due to the drilling method, measurement timing (may not have recovered to static conditions), variability of the water level relative to the time of measurement, measurement error or recording errors, measurement point elevation errors, etc. As a result it is common to see scatter with this type of data, such that individual values cannot be trusted, but the trends illustrated by multiple data points are expected to be realistic. Since natural fluctuations in groundwater levels are generally minor (~ 2 m or less where stress conditions are consistent), carefully measured water levels are considered to be more certain than most other calibration targets.
- Groundwater Discharge Estimates. Groundwater discharge is expected to be a component of the baseflow is most stream / river courses; the remainder of the baseflow is contributed from upstream wetland or other storage mechanisms. Since the proportion of groundwater discharge to wetland discharge is rarely known, this is one source of uncertainty. Further, baseflow discharge is estimated using streamflow recession approaches which are empirical and interpretive. Further, baseflow estimates are generally determined from a limited time period of available streamflow record, yet they are assumed to be representative of an average "static" condition. The approximation from highly variable natural and seasonally fluctuating river conditions results in uncertainty such that calibration of groundwater discharge to baseflow is generally targeted to be within an order of magnitude.

5.4.3 Limitations of the Modelling Approach

In addition to the characterization and calibration uncertainty, the numerical representation and simulation of groundwater flow systems also has limitations. Model simulation uncertainty comes from both the approximate solution of the equations using the finite element method, as well as, the limitations surrounding finite discretization and assumptions of steady-state.

- Galerkin Finite Element Solution. The Galerkin finite element method employed by the FEFLOW steady-state groundwater-flow model solves the system of equations using an iterative solver that attempts to minimize the residuals globally; it is expected that some numerical error can exist internally within the model domain, although this is generally minor.
- Finite Discretization. Practically, the solution of the equations is limited to calculation of groundwater head and flows at a finite number of points; the higher the number of points (smaller the elements) the more computer power and time is needed. More precision is achieved when using a higher number of calculation points, particularly in areas of larger water level changes (the change between 2 calculation points is assumed to be linear, so to represent a curve you need points close together). With watershed models, there is a balance between the level discretization (distance between calculation points) and the required computer power to efficiently run and calibrate the model (also financial budget). The practical limitation of discretization therefore presents some uncertainty in the water budget results.
- Steady-State Solution. Similarly to the spatial discretization, the time discretization chosen for modelling affects the computer power and time (budget) required to calibrate and apply a numerical model. As a result, one simplifying assumption that is commonly made is that the groundwater flow system can be adequately represented using a steady-state simulation approach. In general, since groundwater systems respond at relatively slow rates (months, years, decades) particularly at the watershed scale, a steady-state approximation is reasonable and provides general understanding. This assumption may, however, create differences between the simulated conditions and conditions observed in the field at any one particular time.

As noted above, there are a number of limitations in the numerical modelling process that lead to uncertainty in model predictions. The uncertainty due to the modelling process, however, it is considered to be relatively minor compared to the uncertainty in the physical characterization and calibration process.

5.5 SUMMARY OF THE FEFLOW GROUNDWATER-FLOW MODEL

In summary, there are many sources of uncertainty associated with numerical models and their application to regional settings. Any numerical model developed to represent a natural system will be inherently more simplified than nature, and thus will involve numerous approximations.

Nonetheless, models are commonly used throughout the water resources planning and management industry and are found to be essential planning tools; they are often the only way to address complex questions that require the integration of multiple data sets.

The GRCA FEFLOW steady-state groundwater-flow model has been developed as a regional groundwater flow model in concert with the GAWSER continuous streamflow-generation model, resulting in a loosely coupled “modelling system”. This modelling system includes both a physical representation of the surface water system (streamflow-generation model) and the groundwater system (groundwater flow model). The modelling system provides the ability to simulate and quantify the relative volume of water moving through the subwatersheds, and is calibrated to two independent data sets; 1) total streamflow and baseflow; and 2) water well levels. When assessing model performance, the use of multiple, but separate datasets increases the confidence that the modelling system is accurately representing the hydrologic processes. As presented in Section 4, the streamflow generation model is reasonably replicating observed streamflow volumes, as well as seasonal and inter-annual variability in streamflow. Recharge rates estimated from the streamflow generation model are used to constrain recharge rates within the groundwater flow model, which has been shown to reasonably replicate both water levels and baseflow estimates. Based on the overall performance of the modelling system in replicating these observed conditions, the modelling system is considered to be accurately replicating surface and groundwater flow volumes, and thus is able to provide realistic water budget estimates for the Study Area.

As with any model however, their application beyond the purpose for which it is designed is cautioned due to the uncertainty associated with predictions at a smaller scale.

6.0 Water Budget Summary

6.1 INTRODUCTION

Water budget modelling results have traditionally been presented from either a surface water or a groundwater point of view. With simplified hydrological or hydrogeological characterization having little interaction between the surface water and the groundwater systems, looking at the water budget from either the hydrological or hydrogeological perspective may be sufficient to understand key processes and pathways. However, in a highly integrated surface water and groundwater system such as the Grand River Watershed, the ability to assess the surface water and groundwater systems from an integrated perspective is fundamental to developing an understanding of the important hydrologic processes within the Watershed.

There are many areas where the integration of surface water and groundwater plays an important role relating to hydrology and ecology of the Grand River Watershed. The purpose of this chapter is to present some modelling results that can help to better understand these integrated processes. As presented in Section 4.4.1, surface water budget components may have significant temporal variability. This chapter simplifies the analysis by considering only average annual estimates of the hydrologic parameters over the 1980-1999 period, but recognizes that these results may vary significantly based on changing climate conditions. The analysis does not account for changes in water storage that would occur from one time period to the next. Through the use of some maps and hydrogeologic processes, this chapter also provides some visualization of the three-dimensional integration of surface water and the groundwater hydrology in selected areas of the Watershed.

The time period of 1980-1999 was selected to coincide with the implementation of the 1982 Grand River Basin Study, which designed the operation of the reservoir network, and is still used by the GRCA to manage river flows. River flows that were observed prior to the design of the present operational policy, or prior to the construction of the reservoir network are not applicable for the description of the watershed as it is today. Additionally, the FEFLOW model was calibrated to groundwater levels observed during the 1980-2000 period, using recharge rates provided by the GAWSER model for the 1980-1999 period. It is recognized that the selected time period differs from the 1960-1999 period commonly used for metrological analysis, as well as the 1971-2001 climate normal period. The difference in precipitation between the 1980-1999 period and the 1960-1999 and 1970-1999 time periods for the Upper Speed climate zone is included in Table 6.1, and is shown to be well within measurement error typically associated with rainfall measurement. This suggests that the analysis will fairly insensitive with regard to the time period selected, and the 1980-1999 time period will be representative of long term average climate conditions.

Table 6.1 - Differences in Average Precipitation for Varying Time Periods

Time Period	Average Precipitation (mm/year)	1980-1999 Average Precipitation (mm/year)	Percent Difference (%)
1960-1999	868	895	-2.9%
1970-1999	887	895	-0.9%

The following sections estimate and present the water balance components at a variety of spatial scales. The components presented are calculated assuming no net change in stored water over the time period. Inputs into a subwatershed (precipitation, groundwater inflows) are balanced by subwatershed outflows (streamflow, evapotranspiration, groundwater outflows).

6.2 WATERSHED-WIDE SUMMARY

As shown in Table 6.2 the average annual precipitation over the 1980-2000 period is 933 mm/y. Average annual evapotranspiration is 491 mm/y. Water that does not evaporate or transpire will either be runoff or groundwater recharge. The average runoff rate across the Watershed is 266 mm/y, and the average groundwater recharge rate is 176 mm/y. Although precipitation and evapotranspiration vary spatially, the runoff and recharge rates have the most significant spatial variability due to changing soils, surficial geology, and land cover.

Table 6.2 - Watershed Water Budget Summary (Surface Water)

Water Budget Parameter	Value (m^3/s)	Value (mm/y)
Precipitation	200	933
Evapotranspiration	105	491
Runoff	57	266
Recharge	38	176

Table 6.3 summarizes the watershed-wide groundwater budget; it is linked to the surface water budget by the groundwater recharge rate. Average annual groundwater pumping is estimated to be 4 m^3/s, or approximately 10% of the total groundwater recharge into the Watershed. Based on the results of the FEFLOW steady-state groundwater-flow model, average annual groundwater discharge to surface water features is approximately 33 m^3/s. Approximately 1 m^3/s of water is estimated to flow out of the Watershed boundary into adjacent watersheds.

Table 6.3 - Watershed Water Budget Summary (Groundwater)

Water Budget Parameter	Value (m^3/s)	Value (mm/y)
Recharge	38	176
Net Flow Out of Watershed	-1	-6
Net Discharge to Surface Water Features	-33	-152
Pumping	-4	-18

There are no reliable streamflow gauges at the outlet of the Grand River into Lake Erie, and where there are gauges upstream in the Grand River, streamflow is very much influenced by reservoirs within the contributing drainage area. As a result, estimates of total groundwater discharge volume using the FEFLOW steady-state groundwater-flow model cannot be reliably compared to baseflow estimates made from field data. However, as presented in Section 5 and on Figure 66, there is good agreement between predicted groundwater discharge and observed baseflow estimates. The results suggest that the groundwater recharge rates estimated by the GAWSER continuous streamflow-generation model are reasonable within areas where there is good calibration data. Due to the modelling system's ability to replicate observed conditions where high quality data is present, it can be assumed that the representation of the hydrologic system is reasonable for areas where there is a lack of calibration data, provided the major hydrologic processes remain similar throughout the watershed. It is expected that since the model is developed and calibrated to reflect regional conditions that there will be smaller-scale discrepancies between observed and simulated conditions. These may affect the certainty of predicted subwatershed water budgets, suggesting the need for further refinement in some areas.

6.3 SUBWATERSHED WATER BUDGET RESULTS

This section summarizes the water budget results for each of the subwatersheds. The detailed water budget parameters extracted from the GAWSER continuous streamflow-generation model and the FEFLOW steady-state groundwater-flow model analyses are summarized on Table 6.3.

Table 6.4 and Table 6.5 summarize the detailed GAWSER continuous streamflow-generation model and FEFLOW steady-state groundwater-flow model water budget components for each of the subwatersheds. In both tables, groundwater recharge rates estimated by the GAWSER continuous streamflow-generation model and the recharge rate represented in the FEFLOW steady-state groundwater-flow model are shown. There is a small discrepancy between the two values due to the method in which groundwater recharge was computationally assigned within the FEFLOW steady-state groundwater-flow model. This difference is small, however, and is not considered to be significant with respect to the overall water budget results. Figure 71 illustrates the four GAWSER continuous streamflow-generation model output parameters, and Figure 72 illustrates the estimated inter-basin groundwater flow.

The groundwater demand estimates provided in Table 6.4 and Table 6.5 are not equal those values reported in Section 3. The water demand estimates provided in Section 3 are more recent than the groundwater model simulations used to prepare these tables. These differences are not expected to have any bearing, however, on the intent of the discussion in this Chapter.

Table 6.4 - Summary of Water Budget Components

Parameter	Source	Description
Precipitation	Climate Monitoring Data	Climate data used to represent the precipitation over each of the subwatersheds is summarized by the GAWSER continuous streamflow-generation model and is presented here.
Evapotranspiration	GAWSER	Using potential evapotranspiration rates the GAWSER continuous streamflow-generation model estimates actual evapotranspiration by determining the amount of water available. This column summarizes that output.

Parameter	Source	Description
Groundwater Recharge	GAWSER	By calculating the amount of infiltration, net of evapotranspiration, the GAWSER continuous streamflow-generation model estimates the amount of groundwater recharge for a particular HRU. This column summarizes groundwater recharge for the subwatersheds. Subwatersheds with more pervious materials have a higher proportion of recharge.
Surface Water Runoff	GAWSER	When the precipitation exceeds the infiltration capacity of a soil, overland runoff is created. Subwatersheds with tighter surficial materials tend to have a higher proportion of runoff.
Groundwater Recharge	FEFLOW	The recharge rate predicted by the GAWSER continuous streamflow-generation model corresponds to the rate provided, as input, into the FEFLOW steady-state groundwater-flow model. As can be seen it varies slightly from that predicted by the GAWSER continuous streamflow-generation model; these slight differences are caused by errors introduced by the GIS process of transferring recharge depths from the HRU coverage to the FEFLOW steady-state groundwater-flow model mesh coverage.
Groundwater Flow Boundaries	FEFLOW	This component identifies groundwater flow through the boundaries of the groundwater flow model. This is representative of groundwater flow out of, or into, the Grand River Watershed. Negative flows indicate water leaving the basin; positive flows indicate water entering the basin.
Groundwater Discharge to Lakes	FEFLOW	This parameter quantifies the groundwater flux into or out of lakes. Negative values indicate that flow is leaving the groundwater system to the lakes.
Groundwater Discharge to Rivers	FEFLOW	This parameter quantifies the groundwater flux to rivers and streams in the particular subwatershed. Negative values indicate that flow is leaving the groundwater system to the surface water system
Wells	FEFLOW	This parameter refers to the flux of groundwater removed from pumping wells as reported in the actual water use estimates.
Inter-Basin Flow	FEFLOW	This parameter is the amount of groundwater flow to another subwatershed within the Grand River Watershed. Positive values indicate that the subwatershed is experiencing a net increase of groundwater flow from adjacent subwatersheds. Negative values indicate that the subwatershed is experiencing a net loss of groundwater flow to adjacent subwatersheds.

Parameter	Source	Description
Flow In Ratio	FEFLOW	This parameter is the ratio of groundwater discharge to the amount of recharge in a particular subwatershed. Where the value is negative, it indicates a percentage of recharge that is leaving the basin. Where the value is positive, it indicates how much water, with respect to existing recharge, is entering the subwatershed.

Table 6.5 - Integrated Water Budget Summary (Depth)

Basin	Area (sq km)	GAWSER (mm/year)				FEFLOW (mm/year)					
		Precip	ET	Runoff	Rech	Rech	External Boundary	Lake	River	Wells	Inter-SubW
Grand Above Legatt	365	988	469	345	174	173	-32	-9	-150	-1	18
Grand Above Shand To Legatt	426	988	464	356	168	168	0	-30	-136	-4	1
Grand Above Conestogo To Shand	640	925	487	282	156	157	-6	-2	-123	-12	-14
Conestogo Above Dam	566	936	485	327	123	124	1	-17	-56	-2	-51
Conestogo Below Dam	254	968	487	365	117	118	0	0	-211	-4	98
Grand Above Doon To Conestogo	248	897	500	197	199	202	0	-13	-197	-32	40
Eramosa Above Guelph	230	892	506	142	244	243	0	0	-246	-27	31
Speed Above Dam	242	894	529	123	242	245	4	-13	-225	-1	-10
Speed Above Grand To Dam	308	889	510	156	223	224	0	0	-174	-75	25
Mill Creek	82	888	507	89	292	287	10	0	-125	-40	-133
Grand Above Brantford To Doon	274	896	495	163	238	240	-49	-1	-218	-121	150
Nith Above New Hamburg	545	992	503	346	144	143	1	0	-81	-2	-60
Nith Above Grand To New Hamburg	583	945	508	154	284	282	0	0	-216	-32	-34
Whitemans Creek	404	945	512	176	257	254	0	0	-211	-14	-29
Grand Above York To Brantford	476	896	495	284	118	117	-25	0	-127	-10	45
Fairchild Creek	401	866	468	263	135	137	0	0	-134	-7	4
Mckenzie Creek	368	945	481	337	127	126	0	0	-94	-11	-20
Grand Above Dunnville To York	356	945	465	392	89	88	-3	-4	-82	-5	7
Total Watershed	**6,769**	**933**	**491**	**266**	**176**	**176**	**-6**	**-4**	**-147**	**-18**	**0**

Table 6.6 - Integrated Water Budget (m^3/s)

Basin	Area (sq km)	GAWSER (m^3/s) Precip	ET	Runoff	Rech	FEFLOW (m^3/s) Rech	External Boundary	Lake	River	Wells	Inter-Subw
Grand Above Legatt	365	11.4	5.4	4.0	2.0	2.0	-0.4	-0.1	-1.7	0.0	0.2
Grand Above Shand To Legatt	426	13.4	6.3	4.8	2.3	2.3	0.0	-0.4	-1.8	-0.1	0.0
Grand Above Conestogo To Shand	640	18.8	9.9	5.7	3.2	3.2	-0.1	0.0	-2.5	-0.2	-0.3
Conestogo Above Dam	566	16.8	8.7	5.9	2.2	2.2	0.0	-0.3	-1.0	0.0	-0.9
Conestogo Below Dam	254	7.8	3.9	2.9	0.9	0.9	0.0	0.0	-1.7	0.0	0.8
Grand Above Doon To Conestogo	248	7.1	3.9	1.5	1.6	1.6	0.0	-0.1	-1.6	-0.3	0.3
Eramosa Above Guelph	230	6.5	3.7	1.0	1.8	1.8	0.0	0.0	-1.8	-0.2	0.2
Speed Above Dam	242	6.9	4.1	0.9	1.9	1.9	0.0	-0.1	-1.7	0.0	-0.1
Speed Above Grand To Dam	308	8.7	5.0	1.5	2.2	2.2	0.0	0.0	-1.7	-0.7	0.2
Mill Creek	82	2.3	1.3	0.2	0.8	0.7	0.0	0.0	-0.3	-0.1	-0.3
Grand Above Brantford To Doon	274	7.8	4.3	1.4	2.1	2.1	-0.4	0.0	-1.9	-1.1	1.3
Nith Above New Hamburg	545	17.1	8.7	6.0	2.5	2.5	0.0	0.0	-1.4	0.0	-1.0
Nith Above Grand To New Hamburg	583	17.5	9.4	2.8	5.2	5.2	0.0	0.0	-4.0	-0.6	-0.6
Whitemans Creek	404	12.1	6.6	2.3	3.3	3.3	0.0	0.0	-2.7	-0.2	-0.4
Grand Above York To Brantford	476	13.5	7.5	4.3	1.8	1.8	-0.4	0.0	-1.9	-0.2	0.7
Fairchild Creek	401	11.0	5.9	3.3	1.7	1.7	0.0	0.0	-1.7	-0.1	0.0
Mckenzie Creek	368	11.0	5.6	3.9	1.5	1.5	0.0	0.0	-1.1	-0.1	-0.2
Grand Above Dunnville To York	356	10.7	5.2	4.4	1.0	1.0	0.0	0.0	-0.9	-0.1	0.1
Total Watershed	**6,769**	**200.4**	**105.4**	**57.1**	**37.8**	**37.8**	**-1.2**	**-1.1**	**-31.5**	**-4.0**	**0.0**

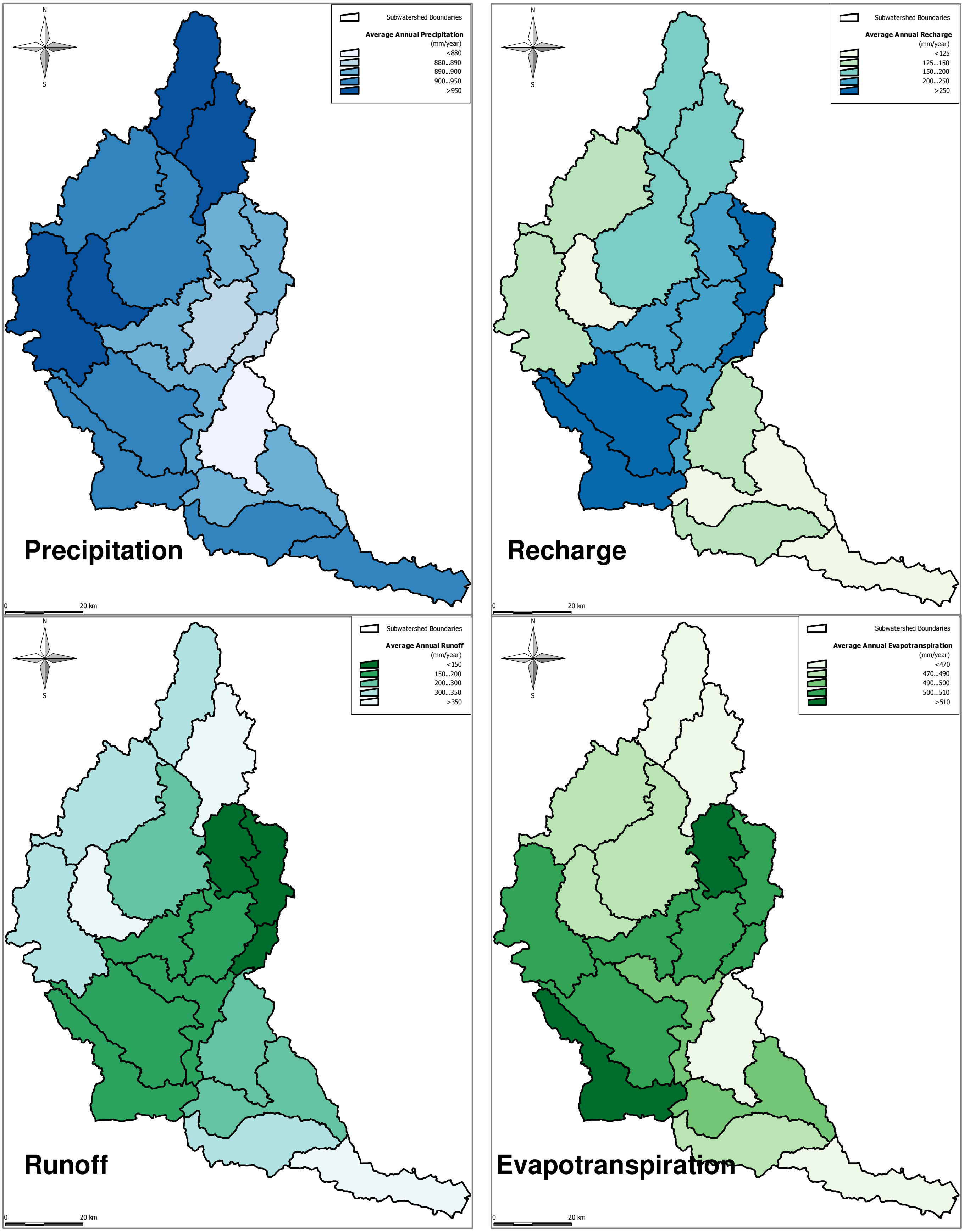

Figure 71
Average Annual Water Budget

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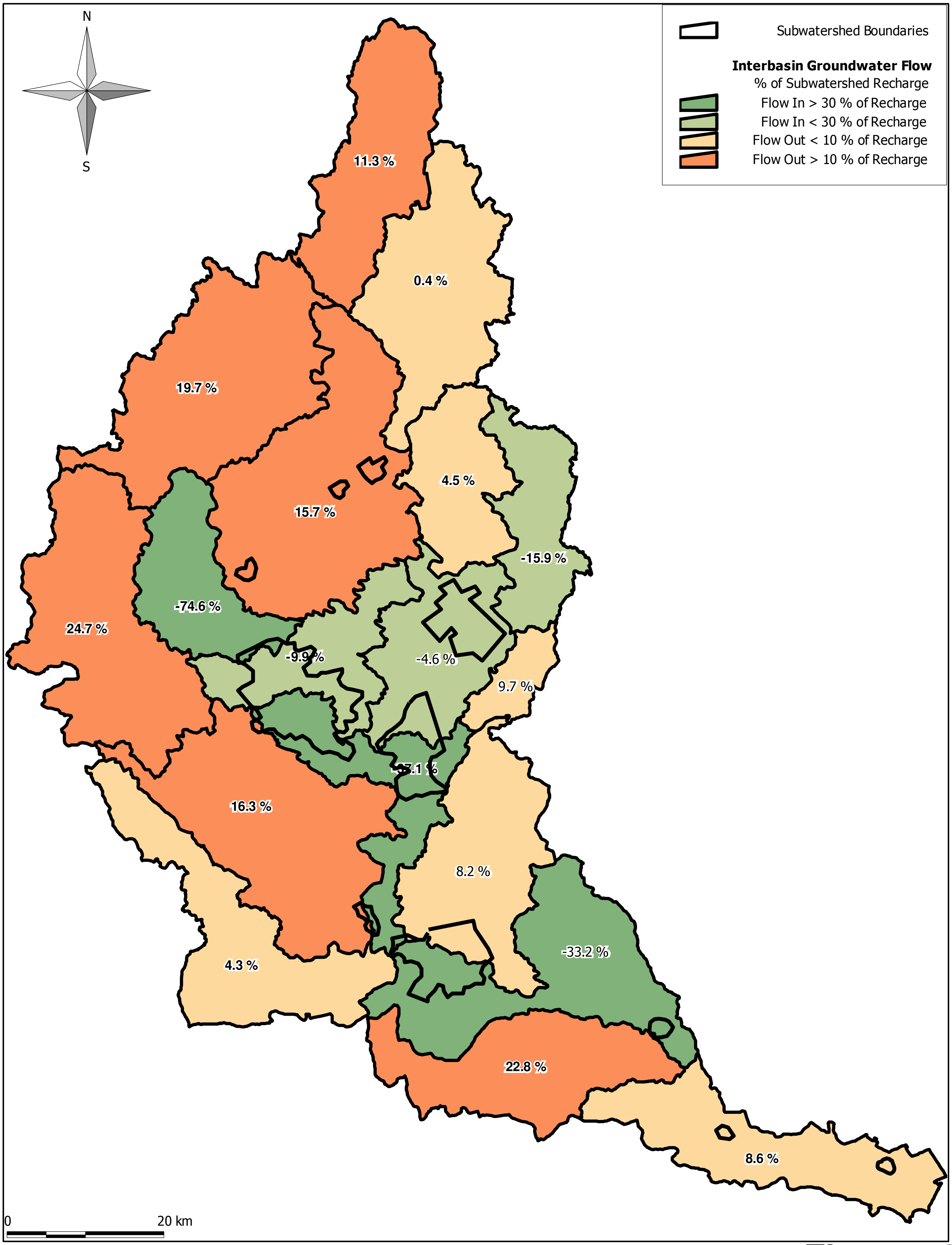

Figure 72
Inter-Basin Groundwater Flow

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The following sections summarize water budget results for each subwatershed. The regional perspective of the analysis used to generate the water budget components should be considered when reviewing the following results. Due to the focus on the regional spatial scale, the description of subwatersheds may lack locally important hydrologic or hydrogeologic details.

In addition to Table 6.4 and Table 6.5, the discussion provided in the following sections makes reference to consumptive water demand estimates summarized in Table 3.11 in Chapter 3 of this report. While Chapter 3 of this report presents a calculation of consumptive demand at the watershed and subwatershed scales, the following discussion focuses only on the hydrological unit consumptive demand.

6.3.1 Grand Above Legatt Subwatershed

The *Grand Above Legatt* Subwatershed is the most northern Subwatershed and is characterized by having a mixture of low to medium permeability surficial materials. Catfish Creek Till and Tavistock Till dominate the Subwatershed, with isolated glaciofluvial outwash deposits. The topography is generally flat, with no hummocky features. Some areas within the Subwatershed receive more precipitation (990 mm/y) than the Watershed average (935 mm/y) due primarily to lake effect snowfall. The spatial distribution of lake effect snowfall, however, may not be well represented due to a lack of long term climate stations. The Subwatershed experiences more surface runoff (340 mm/y) than the Watershed average (260 mm/y). Groundwater recharge (180 mm/y) is equal to the average groundwater recharge rates (180 mm/y), and is highest within the pervious Catfish Creek Till and glaciofluvial deposits.

Significant overburden aquifers within the Subwatershed are confined to pockets of pervious deposits, and the bedrock (Guelph/Amabel) contributes to the regional groundwater flow system. 1.8 m^3/s of groundwater discharge is estimated within this Subwatershed, with most of the groundwater discharge being predicted to occur in the upper reaches of the Subwatershed, where Catfish Creek Till is dominant (Figure 70).

Consumptive water use in this Subwatershed is low, with the estimated average annual consumptive groundwater demand equal to 25 L/s and the estimated average annual surface water demand equal to 2 L/s.

As shown in Figure 66 for the Grand Dundalk gauge, simulated baseflow (FEFLOW) estimates are higher than the range of estimated baseflow. Additionally, the GAWSER continuous streamflow-generation model over-predicts surface water flow. Additional model calibration would be recommended if using the models for future hydrologic or hydrogeological studies.

6.3.2 Grand Above Shand To Legatt Subwatershed

The *Grand Above Shand to Legatt* Subwatershed is mainly composed of the clayey soils (57%) of Tavistock Till, with glaciofluvial deposits over 30% of the area. There are some hummocky features where portions of the Orangeville Moraine extend into the southern portions of this Subwatershed. The Subwatershed's average annual precipitation (990 mm/y) is similar to the *Grand Above Legatt Subwatershed*, with similar uncertainty relating to the lake effect snow. The simulated hydrological response is very similar to that observed in the *Grand Above Legatt* Subwatershed. Evapotranspiration is estimated to be 465 mm/y. Surface runoff is estimated to be 350 mm/y, which is higher than the Watershed average (260 mm/y) due to the areas of clayey soils. The average groundwater recharge rate in the Subwatershed is 175 mm/y. Higher amounts of runoff would be observed in areas with surficial materials of Tavistock Till, where the majority of the groundwater recharge would be seen in the pervious glaciofluvial deposits.

Overburden aquifers in this Subwatershed include the shallow glaciofluvial deposits and a lower overburden aquifer below the Tavistock Till. The primary bedrock aquifer is the Guelph/Amabel bedrock formation. As shown on Figure 70, higher rates of groundwater discharge are predicted to occur along the Grand River throughout this Subwatershed.

Estimated consumptive water use within the Subwatershed is relatively low and a small proportion of the total water budget. Average annual groundwater demand is approximately 69 L/s and the average annual consumptive surface water demand is approximately 3 L/s.

6.3.3 Grand Above Conestogo To Shand Subwatershed

The *Grand Above Conestogo to Shand* Subwatershed is the largest in the Watershed. The Subwatershed is predominately Tavistock Till in the north and northwest sections (particularly the Irvine Creek). The central areas of the Subwatershed contain extensive deposits of outwash gravels, interspersed with Tavistock and Port Stanley Tills, and transitioning to Port Stanley Till in the southeast portion. Approximately 6% of the Subwatershed is classified as having hummocky topography. The average annual precipitation in the Subwatershed receives is 925 mm/y, which is close to the Watershed average of 935 mm/y. Evapotranspiration is estimated to be 485 mm/y. Surface runoff and groundwater recharge are estimated to be 275 mm/y and 160 mm/y, respectively.

The most significant aquifer in this Subwatershed is the Guelph/Amabel Formation bedrock aquifer, which supplies most of the municipal systems in the area. Overburden aquifers are generally confined to isolated patches of granular material, with more continuous overburden aquifers located near Elmira. Other areas where productive lower overburden aquifers can be found include the villages of Conestoga, Winterbourne, and Floradale.

As shown on Figure 70, higher groundwater discharge rates are predicted into the Grand River where it passes through the Elora Gorge and West Montrose, and again immediately upstream of the Conestogo/Grand confluence.

Estimated consumptive water use within the Subwatershed is moderate. The largest water demands include municipal supplies for Elora and Fergus, as well as permits for aquaculture and groundwater remediation. Average annual groundwater demand is approximately 250 L/s and the average annual consumptive surface water demand is approximately 26 L/s.

The surface water and groundwater models are reasonably calibrated to the hydrologic and hydrogeologic processes in the Subwatershed. However, groundwater supplies in the area are critical for the communities of Fergus and Elora in Centre Wellington. Further calibration and conceptualization would be beneficial to better understand the regional groundwater system with respect to those communities and validate the model's predictions of groundwater discharge in the area.

6.3.4 Conestogo Above Dam Subwatershed

The *Conestogo Above Dam* Subwatershed is characterized by having a large proportion of clayey soils belonging to the Tavistock Till as the primary surficial material. Elma Till is also present in the western portion of the Subwatershed, which is drained by Moorefield Creek. Granular glaciofluvial deposits are sparse and generally discontinuous.

The annual average precipitation is 935 mm/y. Lake effect snowfall may have an on influence total precipitation in certain areas of the Subwatershed; however this cannot be well characterized with the available long term climate stations. Evapotranspiration is estimated to be 485 mm/y. As a result of the abundant low permeability soils, surface runoff is approximately 320 mm/y, which is significantly higher than the Watershed average. Correspondingly, estimated groundwater recharge is relatively low and estimated to be 130 mm/y.

With the exception of an esker in the Damascus area, most upper overburden aquifers are very localized. Deeper overburden aquifers are present over the Subwatershed, typically below the Tavistock Till deposit. The Salina formation forms the uppermost bedrock formation over much of the Subwatershed, and the Guelph/Amabel Formation remains the primary bedrock aquifer in the extreme eastern portions of the Subwatershed. Typical of being a headwaters Subwatershed, the groundwater flow model predicts a net groundwater outflow into adjacent Subwatersheds (i.e., Inter-Basin Flow) equal to 0.46 m^3/s. Furthermore, an additional 0.55 m^3/s of groundwater flow leaves the Grand River Watershed and flows to the west from this Subwatershed. There are no significant reaches of groundwater discharge as seen in Figure 70.

Permitted water use within the *Conestogo Above Dam* Subwatershed is relatively low, with estimated average annual groundwater demand equal to 37 L/s and estimated average annual consumptive surface water demand equal to 12 L/s.

6.3.5 Conestogo Below Dam Subwatershed

Much like the Upper Conestogo Subwatershed, the surficial materials of the *Conestoga Below Dam* Subwatershed are primarily composed of low permeability materials (Mornington and Tavistock Tills). There are some deposits of ice-contact sands and gravels in the lower portions of the Subwatershed; however, the less permeable tills dominate the surficial geology. In the lower portions of the Subwatershed there are large areas with hummocky terrain. These areas include portions of the Waterloo, Elmira and Macton Moraine.

The Subwatershed receives approximately 970 mm/y of precipitation per year, which is higher than the Watershed average of 935 mm/y. The hydrologic response of the *Conestogo Below Dam Subwatershed* is very similar to the upstream Conestogo Above Dam Subwatershed. Surface runoff is estimated to be 360 mm/y, which is higher than the Watershed average of 260 mm/y. With the predominant low permeability soils, the average groundwater recharge rate is estimated to be 120 mm/y, which is lower than the Watershed average of 180 mm/y. The highest groundwater recharge rates are predicted in the lower portions of the Subwatershed where pervious deposits are present.

Significant overburden aquifers are not expected where the upper areas of the Subwatershed are dominated by Tavistock and Mornington Tills. In the lower portions of the Subwatershed, which intersect the northern flank of the Waterloo Moraine and the southern portions of the Elmira Moraine, there are isolated areas with upper and lower overburden aquifers near Wellesley and Crosshill. An extension of the buried Dundas Valley also extends through this Subwatershed, and may contain a productive lower aquifer. The Salina Formation is the uppermost bedrock in this Subwatershed and may form a weak aquifer.

The Conestoga River within the Subwatershed may receive higher rates of groundwater discharge than would be expected from the lower recharge rates in the Subwatershed. This is potentially a result of groundwater inflow from adjacent subwatersheds as simulated by the groundwater flow model. It is estimated that 0.73 m^3/s of groundwater flow is entering this Subwatershed as Inter-Basin Flow. The large amount of groundwater inflow supports the groundwater discharge zone predicted to along the lower Conestogo River, as shown in Figure 70.

Water use within the *Conestogo Below Dam* Subwatershed is relatively low, with estimated average annual groundwater demand equal to 46 L/s and estimated average annual consumptive surface water demand equal to 13 L/s.

6.3.6 Grand Above Doon To Conestogo Subwatershed

The surficial geology of the *Grand Above Doon to Conestogo* Subwatershed is highly variable. There are extensive ice-contact stratified drift, and Maryhill Till deposits associated with the Waterloo Moraine, as well as Port Stanley Till mapped on the eastern portion of the Subwatershed. The Waterloo Moraine is the most predominant physiographic feature, and contributes a large portion (24%) of hummocky area. Approximately 18% of the Subwatershed is urbanized.

The average annual precipitation is 925 mm/y. Surface water runoff is estimated to be approximately 195 mm/y, which is lower than the Watershed average due to the high percentage of pervious materials. Similarly, groundwater recharge is 202 mm/y, which is higher than the Watershed average.

In the western areas of the Subwatershed there are extensive upper and lower overburden aquifers. Upper overburden aquifers include surficial outwash and ice-contact deposits in the Erbsville, Homer-Watson, and Forwell areas, as well as deposits near the Grand River. Lower overburden aquifers include the Greenbrook, Parkway and Strasburg aquifers. In the eastern areas of the Subwatershed, there are local outwash deposits that may represent upper overburden aquifer, particularly around the Ariss area.

High groundwater discharge rates into the Grand River are shown on Figure 70.

Consumptive water demand in the Subwatershed is relatively high due to municipal demands. Average annual groundwater demand is 459 L/s, which represents nearly one-third of the recharge in the Subwatershed. Estimated consumptive surface water demand is 117 L/s. The Region of Waterloo's Mannheim surface water intake is located within this Subwatershed.

Water resources within this Subwatershed are critical to municipal drinking water supplies. The hydrogeological conditions within the Watershed tend to be very complex, particularly in the vicinity of the Waterloo Moraine. The Grand River Watershed FEFLOW steady-state groundwater-flow model is not calibrated to municipal observation well data, and as a result, the model may not be fully representative of hydrogeology in or near wellfields. Further calibration and conceptualization would be beneficial to better understand the regional groundwater system, and significant hydrologic processes in the Subwatershed.

6.3.7 Eramosa Above Guelph Subwatershed

The *Eramosa Above Guelph* Subwatershed has a highly variable geologic composition. Extensive deposits of glaciofluvial ice-contact deposits are distributed throughout area, in addition to Port Stanley and Wentworth Tills. Due to the presence of the Galt and Paris Moraines, hummocky topography is extensive, comprising 36% of the Subwatershed.

Average annual precipitation in the Subwatershed is 890 mm/y, which is lower than the Watershed average of 935 mm/y. Due to the pervious soils and high percentage of hummocky topography, runoff (135 mm/y) is much lower than the Watershed average and similarly, groundwater recharge (250 mm/y) is higher than the Watershed average. The highest groundwater recharge rates would occur where pervious materials are deposited, or where hummocky topography increases the potential for groundwater recharge on the Galt and Paris Moraines.

There are generally no significant overburden aquifers in the Subwatershed. The primary aquifer for this area is the Guelph/Amabel bedrock aquifer. Higher groundwater discharge rates, as seen in Figure 70, are focused in the lower reaches of the Eramosa River, Blue Springs Creek and the headwaters of the Eramosa River. These results are consistent with the area supporting significant coldwater aquatic systems.

Consumptive water use in the Subwatershed is relatively high due primarily to municipal demands. Average annual groundwater demand is approximately 286 L/s and average annual consumptive surface water demand is 45 L/s. Maximum monthly surface water demand is higher as a result of the City of Guelph's Eramosa River water supply intake.

Hydrological and hydrogeological conditions in the Eramosa Above Guelph Subwatershed are complex due to the variable complex surficial and bedrock hydrogeology. The predicted groundwater discharge rate is within the estimated baseflow range, but further work is warranted to better understand groundwater/surface water interactions, groundwater flow through the bedrock system, and the City of Guelph's water supply. Water resources within this Subwatershed are critical to municipal drinking water supplies. The Grand River Watershed FEFLOW steady-state groundwater-flow model is not calibrated to municipal observation well data, and as a result, the model should not be used for local or well-field scale assessments. Further calibration and conceptualization would be beneficial to better understand the regional groundwater system, and significant hydrologic processes in the Subwatershed.

6.3.8 Speed Above Dam Subwatershed

The *Speed Above Dam S*ubwatershed is primarily composed of ice-contact stratified drift, and outwash deposits, mixed with Port Stanley Till. Orangeville Moraine deposits cover a large part of this Subwatershed; however, the Moraine is eroded and only 14% of the Subwatershed is classified as hummocky.

Precipitation for this Subwatershed is 895 mm/y, which is slightly less than the Watershed average of 933 mm/y. Due to the high amount of pervious materials, runoff is estimated to be 155 mm/y, which is lower than the Watershed average (260 mm/y). Similarly, groundwater recharge (250 mm/y) is higher than the Watershed average (180 mm/y).

Because of the extensive deposits of ice-contact and outwash deposits, upper overburden aquifers are distributed through the Subwatershed. The uppermost bedrock unit in the area is the Guelph/Amabel Formation, and it is the primary aquifer for the area. Groundwater discharge, as shown in Figure 70, is most significant in the Lutteral Creek area, a tributary of the Upper Speed. This creek is recognized as a significant groundwater-fed coldwater stream. Other, more isolated areas of groundwater discharge are found on the eastern branch of the Upper Speed River.

Consumptive water demand in the *Speed Above Dam* Subwatershed is low. Average annual groundwater demand is 27 L/s and average annual consumptive surface water demand is 15 L/s.

6.3.9 Speed Above Grand To Dam Subwatershed

The *Speed Above Grand to Dam* Subwatershed, similar to the upstream *Speed Above Dam* Subwatershed, is primarily composed of ice-contact and outwash deposits, mixed with Port Stanley Till. 10% of the Subwatershed is classified as hummocky.

Annual precipitation for the Speed Above Grand to Dam is 890 mm/y, which is lower than the Watershed average of 935 mm/y. Due to the pervious materials and moderate level hummocky topography, runoff (155 mm/y) is much lower than the Watershed average (260 mm/y) and groundwater recharge (260 mm/y) is much higher than the Watershed average (180 mm/y).

Overburden aquifers are generally limited to areas of ice-contact and outwash deposits, with no significant lower overburden aquifers identified. As with other subwatersheds in this area, the primary water supply aquifer in this Subwatershed is the Guelph/Amabel bedrock aquifer. High groundwater discharge rates shown along the main Speed River (Figure 70), with the highest rates being predicted in the lower areas of the Subwatershed.

Consumptive water use in the Watershed is high due primarily to municipal water demands. Average annual groundwater demand is 831 L/s and average annual consumptive surface water demand is 28 L/s. In addition to municipal demands, other significant water users include the aggregate industry and golf courses (irrigation).

In general, the groundwater levels appear to be well calibrated. This calibration, however, does not include municipal observation wells. The Speed River is regulated by the Guelph Dam, and it is therefore difficult to develop an accurate estimate of groundwater discharge without having a series of instream baseflow measurements. The hydrogeology of the bedrock aquifer in the City of Guelph is complex, and the Grand River Watershed groundwater flow model may not be fully representative of hydrogeology in or near wellfields.

6.3.10 Mill Creek Subwatershed

The *Mill Creek* Subwatershed is situated between the Galt and Paris Moraines on the western edge of the Grand River Watershed. The Subwatershed's surficial materials include high permeability outwash deposits, and medium permeability Wentworth Till. 50% of the Watershed is classified as having hummocky topography associated with the moraines.

Precipitation for this Subwatershed is 890 mm/y, which is slightly below the Watershed average (933 mm/y). Estimated runoff is much lower (90 mm/y) than the Watershed average (260 mm/y). Similarly, groundwater recharge (295 mm/y) is higher than the Watershed average (180 mm/y).

The most significant overburden aquifers in the Subwatershed are contained within the large outwash deposits located between the Moraines. The Guelph/Amabel Formation bedrock is a significant regional aquifer within this Subwatershed. Relatively high rates of groundwater discharge, as shown on Figure 70, are predicted to occur along the Creek, which is consistent with the creek being identified as an important coldwater aquatic resource.

Permitted groundwater water demand is very high due to many aggregate washing operations in the Subwatershed. 850 L/s of total groundwater pumping and no surface water withdrawals are permitted. Actual consumption rates for aggregate operations are much lower than permitted pumping rates. While it is estimated that an average annual pumping rate is approximately 339 L/s in the Watershed, only 82 L/s of this water is estimated as being consumed and not returned to its original source.

The calibrated groundwater levels appear to be higher on average than observed, however the simulated groundwater discharge is within the estimated baseflow range. Currently, the GAWSER continuous streamflow-generation model is consistently under predicting streamflow in comparison to the measured conditions. This may be due to the GAWSER continuous streamflow-generation model's simplification of groundwater storage and baseflow, and the effects of this being shown for a small subwatershed. Further work is warranted to better understand the hydrology of the Watershed, and the potential interactions with the regional system.

The greatest water demands placed on the Subwatershed are by the aggregate resources industry, and the cumulative effects of these activities are poorly understood. Given the importance of maintaining groundwater and surface water interactions, additional surface water and groundwater characterization and modelling is recommended to improve the understand of the hydrologic processes, and aid in assessing potential future impacts. Integrated groundwater and surface water modelling may be beneficial for this Subwatershed.

6.3.11 Grand Above Brantford To Doon Subwatershed

The *Grand Above Brantford To Doon* Subwatershed is situated in the centre of the Watershed, and contains the urban areas of Kitchener and Cambridge. The surficial materials are predominantly ice-contact stratified drift and outwash deposits. This Subwatershed includes parts of both the Waterloo Moraine and the Galt/Paris Moraines and has a very high proportion of hummocky topography (42%).

Annual precipitation for the Subwatershed is 895 mm/y, which is lower than the Watershed average of 935 mm/y. Although it is heavily urbanized (25%), the high permeability soils result in low runoff (160 mm/y) and high recharge (240 mm/y).

Upper overburden aquifers are located in the vast deposits of outwash materials, and ice-contact drift. Lower overburden aquifers exist in interconnected pockets throughout the area. The primary bedrock aquifer in the eastern portion of the Subwatershed is found within the Guelph formation, whereas in the western portion of the Subwatershed, the Salina formation is the main bedrock aquifer. The Subwatershed receives approximately 0.71 m^3/s of groundwater flow from adjacent subwatersheds as part of a deeper regional groundwater flow system. The calibrated groundwater flow model identifies significant groundwater discharge rates along the entire reach of the Grand River, as shown in Figure 70.

Municipal groundwater consumption within the Subwatershed is relatively high. Estimated average annual groundwater demand is 1,027 L/s. Other significant groundwater use sectors include aggregate washing and golf course irrigation. Estimated average annual consumptive surface water demand is 26 L/s.

Similar to the Grand Above Doon to Conestoga Subwatershed, water resources within this Subwatershed are critical to municipal drinking water supplies. The hydrogeological conditions within the Watershed tend to be very complex, particularly in the vicinity of the Waterloo Moraine. The Grand River Watershed FEFLOW steady-state groundwater-flow model is not calibrated to municipal observation well data, and as a result, the model may not be fully representative of hydrogeology in or near wellfields. Further calibration and conceptualization would be beneficial to better understand the regional groundwater system, and significant hydrologic processes in the Subwatershed.

6.3.12 Nith Above New Hamburg Subwatershed

The *Nith Above New Hamburg* Subwatershed is similar to the *Conestogo Below Dam* Subwatershed, in that the surficial materials are primarily Mornington Till, interspersed with ice-contact deposits. Stratford Till is also present in the southwestern portion of the Subwatershed. The Subwatershed encompasses the northwestern flank of the Waterloo Moraine, as well as portions of the Milverton, Macton and Easthope Moraines. As a result of these moraine deposits, a large portion of the Subwatershed is classified as hummocky (27%). However, the primary surficial material over most of the hummocky areas is low permeability Mornington Till, which inhibits groundwater recharge.

Precipitation for this Subwatershed is 990 mm/y, which is higher than the Watershed average (933 mm/y). Due to the low permeability materials present in the Subwatershed, runoff (345 mm/y) is higher than the Watershed average (260 mm/y) and groundwater recharge (145 mm/y) is lower than the Watershed average (180 mm/y).

There are no significant upper overburden aquifers over most of the Subwatershed; however more continuous deposits of surficial sands and gravels are found in the southeastern portion of the Subwatershed within the Waterloo Moraine. An extension of the Dundas Valley is located within the Nith Above New Hamburg, and may also support a lower overburden aquifer. The primary bedrock aquifer is found within the Salina formation. The Nith Above New Hamburg Subwatershed has an estimated net groundwater outflow (Inter-Basin Flow) of 0.62 m^3/s to adjacent subwatersheds, and a net external groundwater outflow of 0.48 m^3/s to areas beyond the Grand River Watershed boundary. Groundwater discharge, as shown in Figure 70, is generally restricted to the lower reaches of the Nith River within the Subwatershed, closer to the western flank of the Waterloo Moraine.

Permitted water demands within the *Nith Above New Hamburg* are relatively low. Estimated average annual groundwater demand is 62 L/s and average annual consumptive surface water demand is 9 L/s.

Calibrated water levels appear to be reasonable across the Subwatershed, although there are local areas within the Subwatershed showing a trend of higher than observed water levels. Simulated groundwater discharge rates, however, are at the low end of the estimated baseflow range at several gauges. The result of this may be that the Inter-Basin Flow, or the amount of groundwater flow out of the Watershed, is over-estimated. Since groundwater and surface water demands in the Subwatershed are very small, the benefit of refining the conceptual model and calibration may not be significant.

6.3.13 Nith Above Grand To New Hamburg Subwatershed

The *Nith Above Grand to New Hamburg* Subwatershed is primarily composed of outwash and ice-contact materials, mixed with lower permeability materials such as Port Stanley, Maryhill and Tavistock Tills. The Subwatershed contains a large portion of the Waterloo Moraine, and therefore has 29% of the area being classified as having hummocky features.

Annual precipitation for the Subwatershed is 945 mm/y, consistent with the average Watershed precipitation of 935 mm/y. Due to the extensive deposits of pervious materials and hummocky features, runoff (155 mm/y) is much less than the Watershed average (260 mm/y), and the average groundwater recharge (285 mm/y) is much higher than the Watershed average (180 mm/y). Areas of very high groundwater recharge can be found in pervious areas containing hummocky topography on the southern flank of the Waterloo Moraine. Hummocky areas with granular materials, which drain the less permeable Maryhill Till cap, can provide estimated average annual groundwater recharge rates as high as 500 mm/y. To confirm these estimated high groundwater recharge rates, the Alder Creek groundwater study (CH2M Hill and S.S. Papadopulous, 2003) mapped localized depressions, infilled with granular material, which drain significant areas of Maryhill Till and have no drainage outlet. Very high recharge rates were estimated within these localized depressions.

Extensive upper overburden aquifers are located in this Subwatershed, coinciding with the pervious surficial materials. There are also significant lower overburden aquifers in the area, particularly in the eastern portion of the Subwatershed, located in the Ayr/Roseville area. The primary bedrock aquifer in the Subwatershed is found within the Salina formation. Groundwater modelling results suggest a very significant net outflow of groundwater, estimated to be 0.84 m^3/s, from the *Nith Above Grand to New Hamburg Subwatershed*. This water likely flows to the east, and partially contributes to groundwater discharge found in the Cambridge to Paris reach of the Grand River. Groundwater discharge, as shown in Figure 70, is predicted to occur throughout the Subwatershed, with particularly high discharge areas occurring along the Nith River immediately upstream of Plattsville, the lower reaches of Alder Creek, the Nith River near Ayr, Cedar Creek, and the lower Nith River near Paris.

Water demand is high in this Subwatershed, with the largest water users including municipal supplies, aggregate washing, golf course and agricultural irrigation. As reported in Chapter 3, estimated average annual groundwater pumping is 513 L/s and average annual consumptive surface water demand is 29 L/s.

6.3.14 Whiteman's Creek Subwatershed

The *Whiteman's Creek* Subwatershed is highly variable in terms of surficial materials, with Tavistock and Port Stanley Tills in the headwaters, and outwash and glaciolacustrine shallow water deposits in the lower reaches of the Subwatershed. Topography is generally flat, with 7% of the Subwatershed area containing hummocky features.

Average annual precipitation for this Subwatershed is 945 mm/y. Due to the high permeability materials in the middle and lower reaches of the Subwatershed, runoff (175 mm/y) is much lower than the Watershed average (260 mm/y) and groundwater recharge (260 mm/y) is greater than the Watershed average (180 mm/y). Due to the highly variable surficial materials, hydrologic conditions are variable across the Subwatershed, with the headwaters being runoff dominated and the lower Subwatershed having higher amounts of groundwater recharge.

There is an extensive unconfined overburden aquifer throughout much of the lower Subwatershed, where the Norfolk Sand Plain is present. In areas composed of Tavistock and Port Stanley Till, there are no significant overburden aquifers. Bedrock aquifers range from the Salina formation in the eastern portions of the Subwatershed, to Bass Island/Bertie Formation in the western portions. Groundwater discharge, as shown on Figure 70, is most significant in the lower sections of Whiteman's Creek, downstream of Burford, and the middle reach of Horner Creek, immediately upstream of Princeton.

Water use within *Whitemans' Creek* is high, with maximum permitted groundwater takings equal to 3,543 L/s and maximum permitted surface water takings equal to 1,304 L/s. The main water use in *Whiteman's Creek* is agricultural irrigation, and therefore water taking is seasonal in nature. Estimated maximum and average annual groundwater pumping is 465 L/s and 117 L/s, respectively. Similarly, maximum monthly and average annual consumptive surface water demand is 218 L/s and 51 L/s, respectively. The methodology followed to estimate irrigation demand is described Chapter 3, and there is a fair degree of uncertainty relating to these estimates.

Calibrated water levels appear reasonable in the Norfolk Sand Plain portion of the Watershed, however simulated water levels are higher than observed in the till areas, The predicted groundwater discharge rate is within the estimated baseflow range. Any future local-scale impact assessments may require refinements to the conceptual model and consideration of seasonal/transient groundwater flow conditions. An integrated surface water and groundwater flow model may be beneficial.

6.3.15 Grand Above York To Brantford Subwatershed

The *Grand Above York to Brantford* Subwatershed is characterized by the low permeability soils of the Haldimand clay plain and the sand deposits associated with the Norfolk Sand Plain in the upper reaches. Precipitation for this Subwatershed is 895 mm/y, which is below average Watershed precipitation of 935 mm/y. Due to the prevalence of low permeability materials over the majority of the Subwatershed, runoff (280 mm/y) is higher than the Watershed average (260 mm/y) and groundwater recharge (120 mm/y) is lower than the Watershed average (180 mm/y). Areas in the upstream reaches of the Subwatershed containing granular materials, such as Mt. Pleasant Creek, are estimated to have groundwater recharge rates higher than the Subwatershed average.

There are limited overburden aquifers with the majority of the Subwatershed being composed of a massive laminated lacustrine deposit. Unconfined aquifers would be found in the areas in the upper reaches having pervious surficial materials. The bedrock aquifer is the primary water bearing unit for much of the Subwatershed, with the Guelph formation being predominant in the eastern portions, and the Salina formation in the west. The *Grand Above York to Brantford* Subwatershed receives a net groundwater inflow (Inter-Basin Flow) of approximately 0.60 m^3/s from adjacent subwatersheds as part of the regional groundwater flow system. Highest groundwater discharge rates, shown on Figure 70, are located in the upstream reaches of the Subwatershed.

Water use in the *Grand Above York to Brantford* Subwatershed is relatively high. Major water users include municipal supplies, aggregate washing, and agricultural irrigation. Average annual groundwater pumping is approximately 227 L/s and average annual surface water consumptive demand is 145 L/s. The Brantford and Six Nations municipal surface intakes are located in the Subwatershed and represent the largest surface water demands.

6.3.16 Fairchild Creek Subwatershed

The *Fairchild Creek* Subwatershed is composed primarily of low permeability materials associated with the Haldimand Clay plain, exposed bedrock in the Rockton Bedrock Plain, and veneers of shallow water glaciolacustrine deposits. In the upper reaches of the Subwatershed, Fairchild Creek has some areas of Wentworth Till and hummocky topography where the Galt Moraine intersects the Subwatershed.

Precipitation for this Subwatershed is 865 mm/y, which lower than the average Watershed precipitation of 933 mm/y. Runoff is estimated to be 255 mm/y, which is similar to the Watershed average (260 mm/y) and groundwater recharge (140 mm/y) is lower than the Watershed average (180 mm/y). These results are expected given the amount of low permeability soils in the Subwatershed.

There are no significant upper overburden aquifers in the Subwatershed. While localized, unconfined aquifers exist in pervious deposits, they are not regionally significant. Bedrock aquifers (Guelph Formation) are the primary groundwater sources. Simulated groundwater discharge rates, as shown in Figure 70, show higher groundwater discharge in the headwaters of the Creek.

Consumptive water demand in the Subwatershed is relatively low. Estimated average annual groundwater demand is 92 L/s and average annual surface water consumptive demand is 22 L/s.

6.3.17 McKenzie Creek Subwatershed

Similar to the *Grand Above York to Brantford Subwatershed*, the *McKenzie Creek* Subwatershed is characterized by the low permeability surficial materials of the Haldimand Clay plain. In the upper reaches of *McKenzie Creek* there are sand deposits associated with the Norfolk Sand Plain. There are no areas within *McKenzie Creek* that are classified as hummocky topography.

Precipitation for this Subwatershed is 945 mm/y, which is similar to the average Watershed precipitation of 935 mm/y. Due to the prevalence of low permeability materials over the majority of the Subwatershed, runoff is estimated to be 335 mm/y, which is higher than the Watershed average (260 mm/y) and groundwater recharge (130 mm/y) is lower than the Watershed average (180 mm/y). Groundwater recharge rates for pervious areas in the upper reaches are higher.

Overburden aquifers are limited to the upper reaches of the Subwatershed, where the Norfolk Sand Plain forms an unconfined overburden aquifer. Bedrock aquifers are the main source of groundwater for this area, with the Guelph Formation forming the main bedrock aquifer in the east, and the Salina Formation forming the bedrock aquifer in the west. Higher groundwater discharge rates, as shown in Figure 70, are simulated in the upper reaches of *McKenzie Creek*, where pervious materials are most prevalent.

Similar to *Whiteman's Creek Subwatershed*, water demand is relatively high and seasonally variable, mostly due to agriculture demands. Estimated maximum monthly and average annual groundwater pumping is 223 L/s and 53 L/s, respectively. Maximum monthly and average annual consumptive surface water demand is 108 L/s and 29 L/s, respectively.

Calibrated water levels appear to be reasonable, and simulated groundwater discharge matches well with observed baseflow estimates. The results indicate that the water demands are relatively high in relation to water supply in this Subwatershed. In addition, there are historical observations of hydrologic stress due to low streamflow. Due to the seasonal water use sectors active in the Subwatershed, any future local-scale impact assessments may need to consider seasonal/transient groundwater in consideration of the shallow system and seasonal groundwater discharge variability. Furthermore, an integrated groundwater/surface water flow model may be useful in better representing the hydrology and hydrogeology of this Subwatershed.

6.3.18 Grand Above Dunnville To York Subwatershed

The *Grand Above Dunnville to York* Subwatershed is characterized by the low permeability surficial materials of the Haldimand Clay plain. There is also a thin localized deposit of outwash sands located near Dunnville. Average annual precipitation is 945 mm/y and evapotranspiration is 465 mm. Due to the amount of low permeability materials over the Subwatershed, average annual runoff is estimated to be 390 mm/y, which is much higher than the Watershed average (260 mm/y). Similarly, groundwater recharge (95 mm/y) is much lower than the Watershed average (180 mm/y).

There are no significant overburden aquifers expected within the *Grand Above Dunnville to York Subwatershed*. Many of the current domestic wells are completed within the Salina bedrock formation. Water use is relatively low in the *Grand Above Dunnville to York Subwatershed.* Average annual groundwater demand is 91 L/s and average annual consumptive surface water demand is 21 L/s.

There are no local baseflow estimates to compare against calibrated values; however, the impact of groundwater discharge to baseflow in the Grand River is considered to be minor in this Subwatershed. Calibrated groundwater levels tend to be higher than observed; however, due to groundwater and surface water demands being relatively low in the Watershed, further calibration and conceptualization may not be warranted.

6.4 GROUNDWATER RECHARGE AND DISCHARGE RELATIONSHIPS

Groundwater plays a very significant role in discharging colder water to streams and rivers to sustain baseflow throughout the Watershed. In this section, the calibrated groundwater flow model is used to visualize the relationships between groundwater recharge and discharge across the Watershed. This section shows that, while in a regional sense groundwater flow reflects surface water boundaries, there are many areas where groundwater flows across surface water divides. This analysis is carried out using a ‘forward particle tracking’ technique which involves the release of imaginary water particles at the water table surface and tracks them until their travel to either a pumping well, a surface water feature, or the model boundary. This forward particle tracking technique is also used to visualize the flow of groundwater, in cross-section, where groundwater flow paths may travel very deep into bedrock before discharging again into surface water features.

The objectives of this particle tracking task are to:

- Visualize where differences exist between surface water subwatershed divides and groundwater flow divides;
- Identify the recharge areas that supply key discharge features within critical stream reaches; and
- Visualize the pathways that groundwater is predicted to follow as it travels toward a discharge zone.

As with all results generated from the numeric tools developed for this Study, it should be recognized that the groundwater model has been calibrated at a regional level, meaning that it may not represent hydrogeological and hydrological features at a local scale. Therefore, the results should only be viewed from a regional perspective.

6.4.1 Methodology

Forward particle tracking was completed by releasing particles at a 200 m grid spacing throughout the entire model domain. This results in a total of 25 particles for every square kilometre. This grid spacing was considered appropriate for the regional nature of the analysis.

After being released, the three-dimensional pathline (i.e. path through the groundwater) for each particle is computed from the three-dimensional groundwater flow model solution until it is either discharged from the groundwater flow system up to a travel time of 2000 years. Particles can be discharged from the groundwater flow system under the following four conditions:

1. Particles may leave the model borders and enter adjacent watersheds;
2. Particles may discharge to lakes;
3. Particles may discharge to individual stream reaches within the model; and,
4. Particles may be captured by pumping wells.

When particles discharge to internal streams, the relationship between the location of groundwater recharge and the stream discharge location are recorded in a database. By storing this relationship, all particles discharging to a particular reach can be grouped together on a map.

6.4.2 Results – Groundwater Recharge Areas

Figures 73 and 74 illustrate the groundwater recharge areas associated with groundwater discharge areas in the upper and lower regions of the Watershed. These figures identify surface water reaches within each of the main subwatersheds and also highlight the groundwater recharge areas contributing groundwater that ultimately discharges in those areas.

All particles are coloured based on their classification into the four categories presented above. Particles which discharge directly to lakes or streams within a subwatershed area are coloured based on the subwatershed to which they discharge; particles leaving the model domain to adjacent Conservation Authorities are coloured beige; and particles that are captured by pumping wells are coloured grey. White areas in the presented results reflect regions where particle traces did not reach a discharge destination within 2000 years. The line thickness of each stream reach is also proportional to the estimated groundwater discharge rate, and highlights watercourses which produce higher amounts of groundwater discharge than average.

The reader should keep in mind that particle tracking results do not reflect actual recharge volume, and are only a single representation of the likely discharge location for a single water particle. As such, the results of the forward particle tracking analysis should be viewed alongside Figure 59, which illustrates the estimated recharge rate. Viewing the maps together will give a more complete understanding of both the volume and spatial distribution of groundwater recharge that sustains baseflow for a specific reach.

A surface water divide represents a topographic boundary where precipitation landing on either side of the boundary will flow overland towards different streams. Groundwater divides can be thought of similarly, where groundwater recharge will flow towards different streams on either side of the divide. While surface water divides can be measured and mapped very accurately, the location of groundwater divides can be much more uncertain, subject to the availability of existing data, the validity of a conceptual model, and the degree to which the model is calibrated to reflect actual conditions. While surface water divides can follow irregular paths, groundwater divides are generally much smoother reflecting the much gentler slopes of a watertable.

The results of the recharge/discharge analysis indicate that surface water and groundwater divides are generally similar for most subwatersheds. Given the size of the subwatersheds (200-500 km^2), this is not unexpected, as groundwater divides should follow surface water divides for larger areas. However, this analysis has identified a number of areas where groundwater flows across subwatershed boundaries. The identified areas are summarized below:

- Upper Watershed (Figure 73). There are significant differences between surface water and groundwater divides for the Conestogo Above Dam, Conestogo Below Dam and Upper Nith Subwatersheds. Recharge in a large proportion of the lower part of the Conestogo Above Dam Subwatershed is predicted to travel through the deeper groundwater flow system and discharge into the Conestoga River within the Conestogo Below Dam Subwatershed. The Conestogo Below Dam Subwatershed also captures groundwater that recharges in the western extent of the Grand Above Conestogo to Shand Subwatershed. A large eastern portion of the Upper Nith Subwatershed recharge area discharges to the Conestogo Below Dam Subwatershed.

- Lower Watershed (Figure 74). The most significant differences between surface water and groundwater divides are shown along the Grand Below Cambridge to Brantford Subwatershed. Recharge occurring in the Nith Above Grand to New Hamburg Subwatershed (Cedar and Charlie Creek area in North Dumfries) discharges into the main Grand River below Cambridge. Additionally, recharge that occurs in the headwaters of McKenzie Creek discharges into the Grand near Brantford. This reach of the Grand River has been identified by the GRCA as a key discharge area. By identifying the recharge areas that sustain this key discharge, the GRCA will be able to more effectively manage and protect this key hydrologic process.

This analysis has provided a means to better understand the groundwater system, and to identify where groundwater flow boundaries may differ from surface water boundaries. With this knowledge, water managers are provided a more complete representation of the watershed’s hydrology and are thus better able to manage the system appropriately.

6.4.3 Results – Local Recharge and Discharge Examples

In addition to producing maps identifying differences between groundwater and surface water divides, the groundwater flow model provides a large amount of insight into the three-dimensional pathways that groundwater follows as it travels from recharge areas to discharge areas. This section summarizes a more localized analysis of three-dimensional groundwater recharge and discharge pathways in several locations throughout the watershed.

6.4.3.1 Speed and Eramosa Rivers

Similar mapping as to Figures 73-74, but zoomed into City of Guelph/Speed/Eramosa River is presented in Figure 75. As shown on this figure, high groundwater discharge rates are shown along the Eramosa River and its main tributary, Blue Springs Creek. High groundwater discharge rates are also shown within the Lutteral Creek reach, a tributary of the Upper Speed River. The figure also illustrates high groundwater recharge areas, shown as hatched areas. These areas represent Significant Groundwater Recharge Areas (SRGAs) and are delineated using a methodology described in the companion Tier 2 Stress Assessment Report (AquaResource, 2009b).

Figure 76 illustrates a hydrogeological cross-section along profile A-A'. The figure shows the bedrock geology, as represented in the groundwater flow model, and the pathlines of selected groundwater flow particles as they travel from their recharge location to a discharge location. These pathlines are linearly projected from their three-dimensional trajectory to the cross-section profile location and may not represent actual groundwater flow conditions along the profile. The cross sectional representations of particle flow should be interpreted only for information purposes. As shown in Figure 76, both the Eramosa River and Blue Springs Creek receive groundwater discharge from deeper bedrock aquifers, through the Eramosa aquitard formation. Groundwater discharge into the Speed River, however, does not appear to have the same significant contribution from deeper bedrock. The interconnection with the deeper bedrock units may explain why Eramosa River baseflows are sustained well into dry periods, while the Upper Speed River, with limited interaction with bedrock, has been observed to have a less resilient baseflow component. Groundwater interactions with the Guelph Lake Tributary are localized.

6.4.3.2 Speed River and Mill Creek

Figure 77, shows illustrates a plan map of the groundwater recharge and discharge regime across the Lower Speed River and Mill Creek areas. Groundwater discharge into the lower Speed River and central Mill Creek are high, and this is consistent with field observations.

Figure 77 also shows the location of profile B-B'. Profile B-B', illustrated on Figure 78, illustrates that the Speed River influences groundwater flow paths over a large portion of the profile. While groundwater discharge into Mill Creek is more localized it is no less significant as Mill Creek supports an important cold water fishery.

Along the Speed/Mill profile (Figure 78), none of the particles projected to the cross-section flow through the Eramosa or Amabel Formations, which is a significant difference from the Speed and Eramosa River profile (Figure 76) cross-section. This is due to the increasing depth of the Amable and Eramosa formations and the degree to which they interact with surface water features.

6.4.3.3 Lower Nith River and Grand River

Throughout many locations within the Watershed, the Grand River has significant interactions with the groundwater flow system. Of particular note are the groundwater/surface water interactions that occur in the reach of Grand River below Cambridge to Brantford (shown in Figure 79). The figure shows the location of profile D-D', which extends across both the Lower Nith and Grand Rivers. As shown in Figure 80, many of the groundwater pathlines through his area travel into deep bedrock and discharge into the Grand River. The interactions between the Grand River and deep bedrock are very important, in contrast to the interactions between shallow groundwater and smaller streams, and likely explains why this groundwater discharge has been observed be sustained even during multiple years of extreme drought.

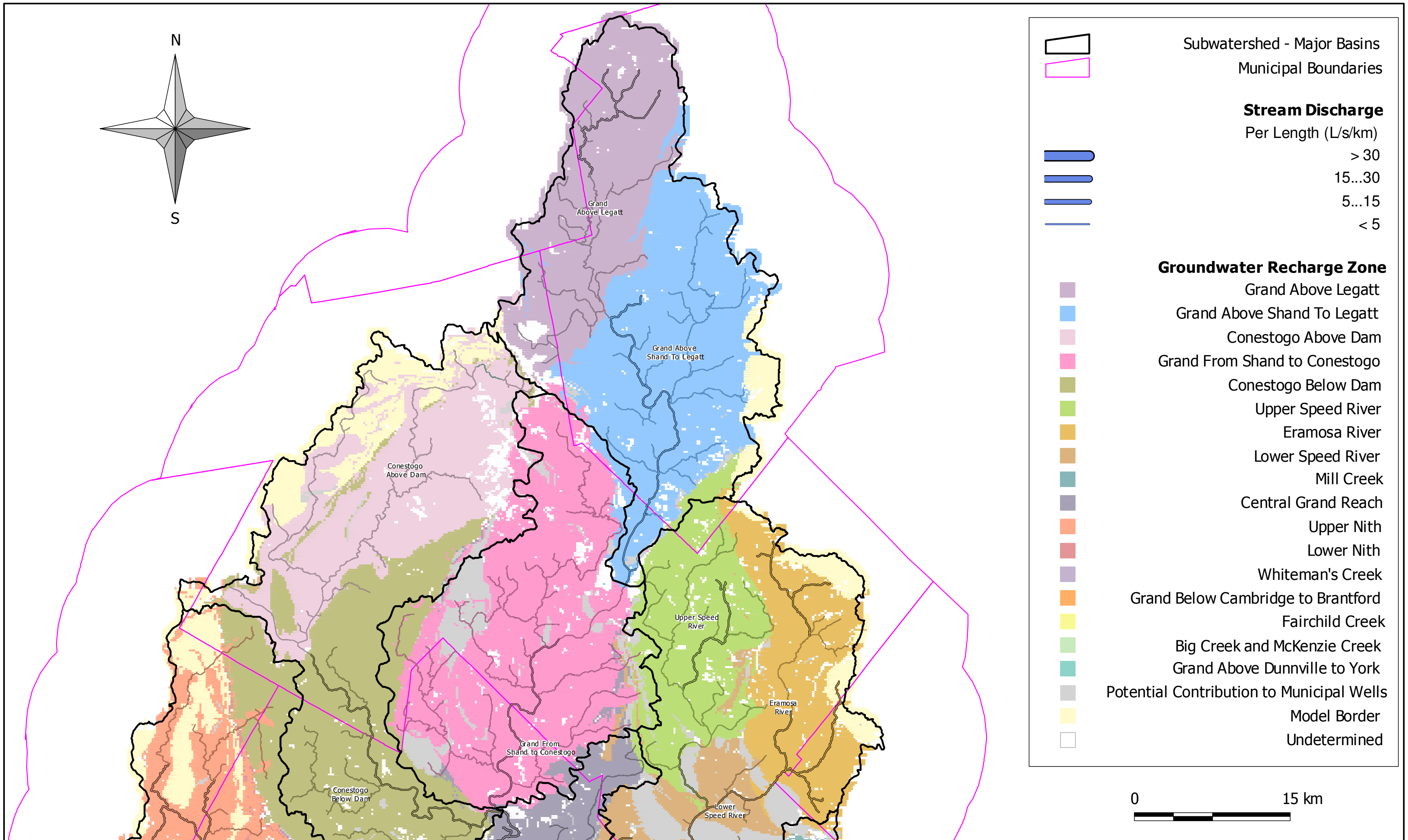

Figure 73 - Upper Watershed Recharge and Discharge

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Sanford, B.V. 1969 Geology of the Toronto–Windsor Area, Ontario; Geological Survey of Canada, Map 1263A.
Various Authors, 1975-1980, Paleozoic Geology, Southern Ontario, Ontario Division of Mines. Refer to GRCA metadata.

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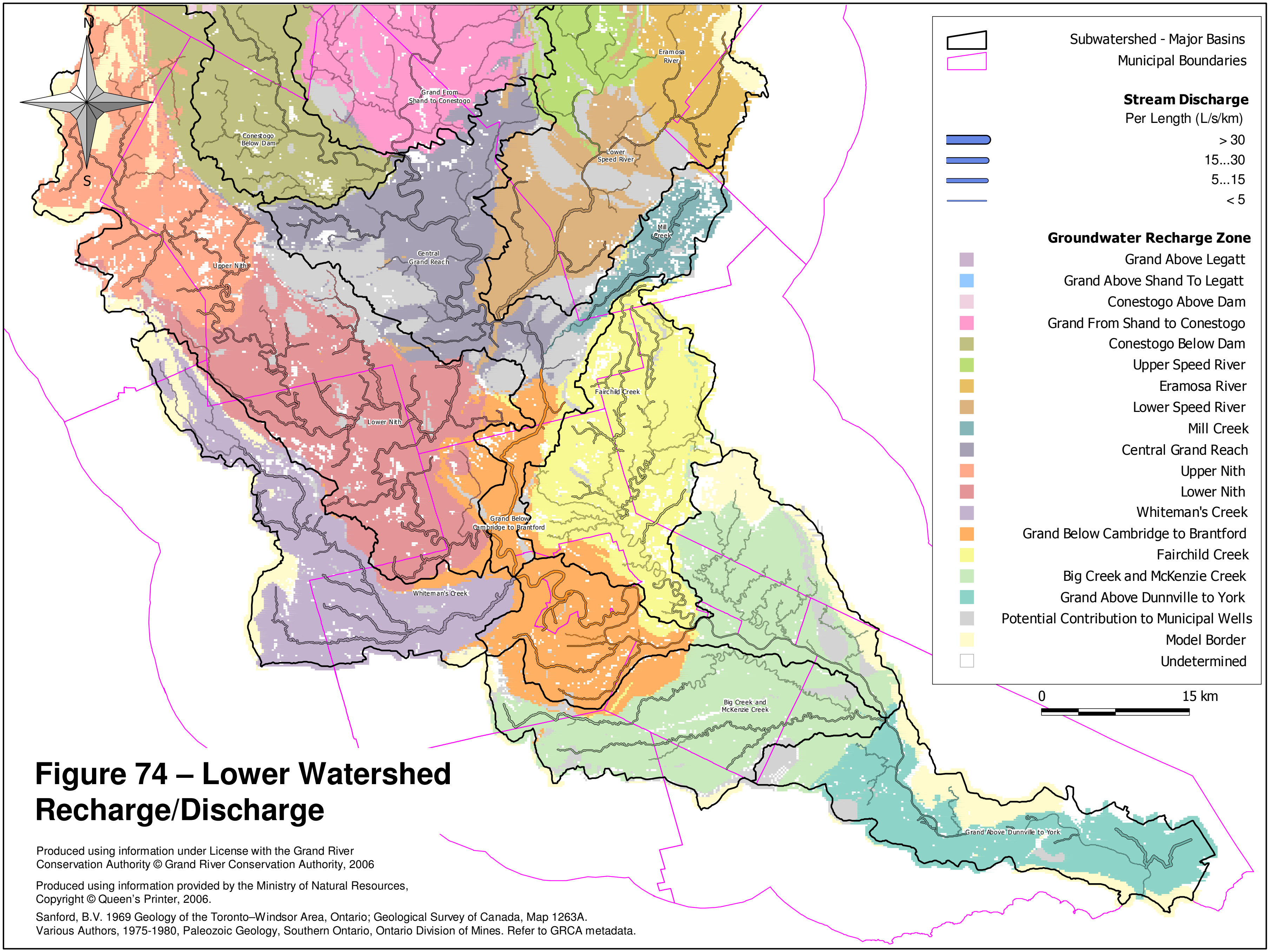

Figure 74 – Lower Watershed Recharge/Discharge

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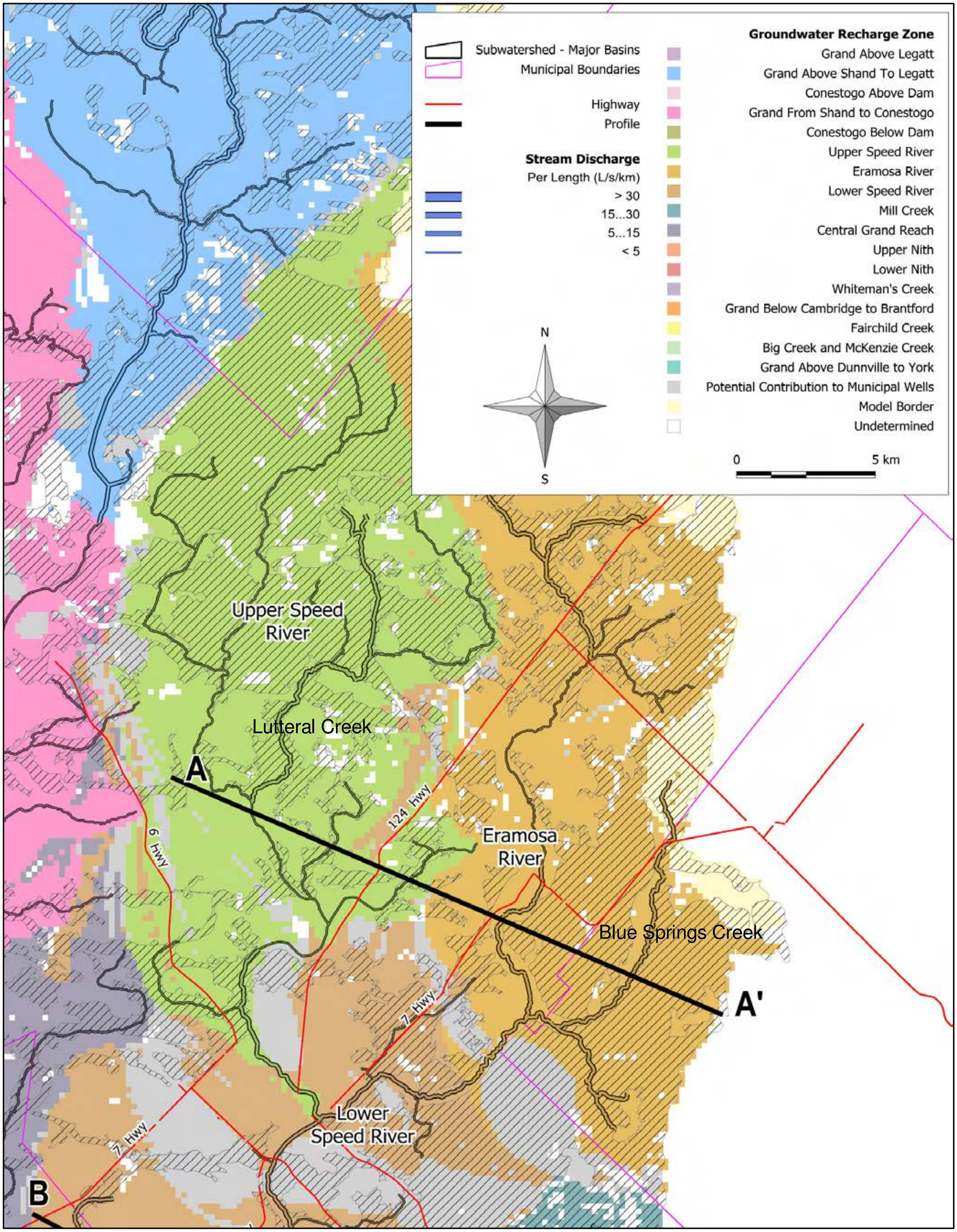
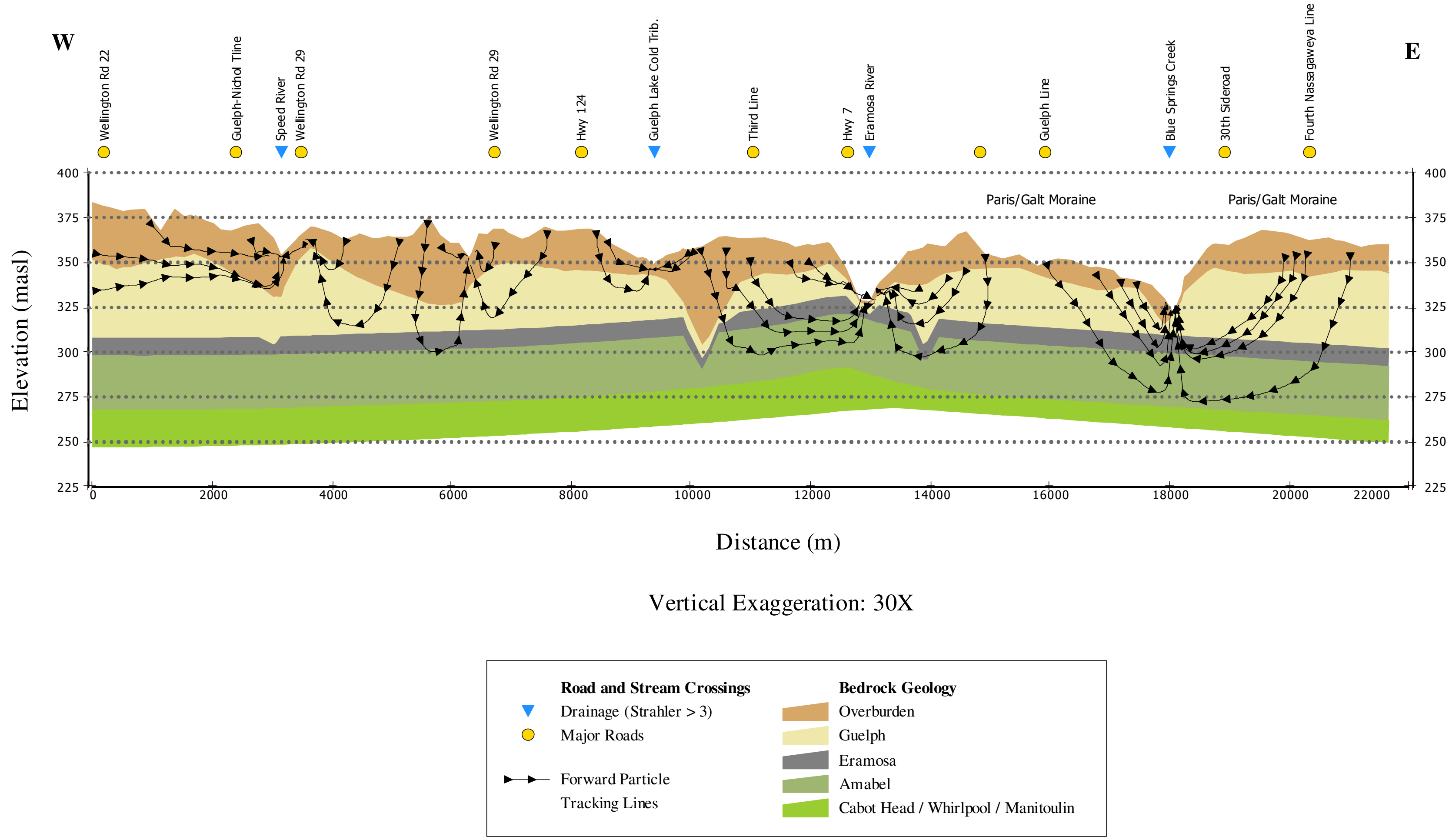


Figure 75
Speed and Eramosa – Recharge and Discharge



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Various Authors, 1975-1980, Paleozoic Geology, Southern Ontario, Ontario Division of Mines. Refer to GRCA metadata.

Figure 76 – Groundwater Pathlines (Profile A-A')

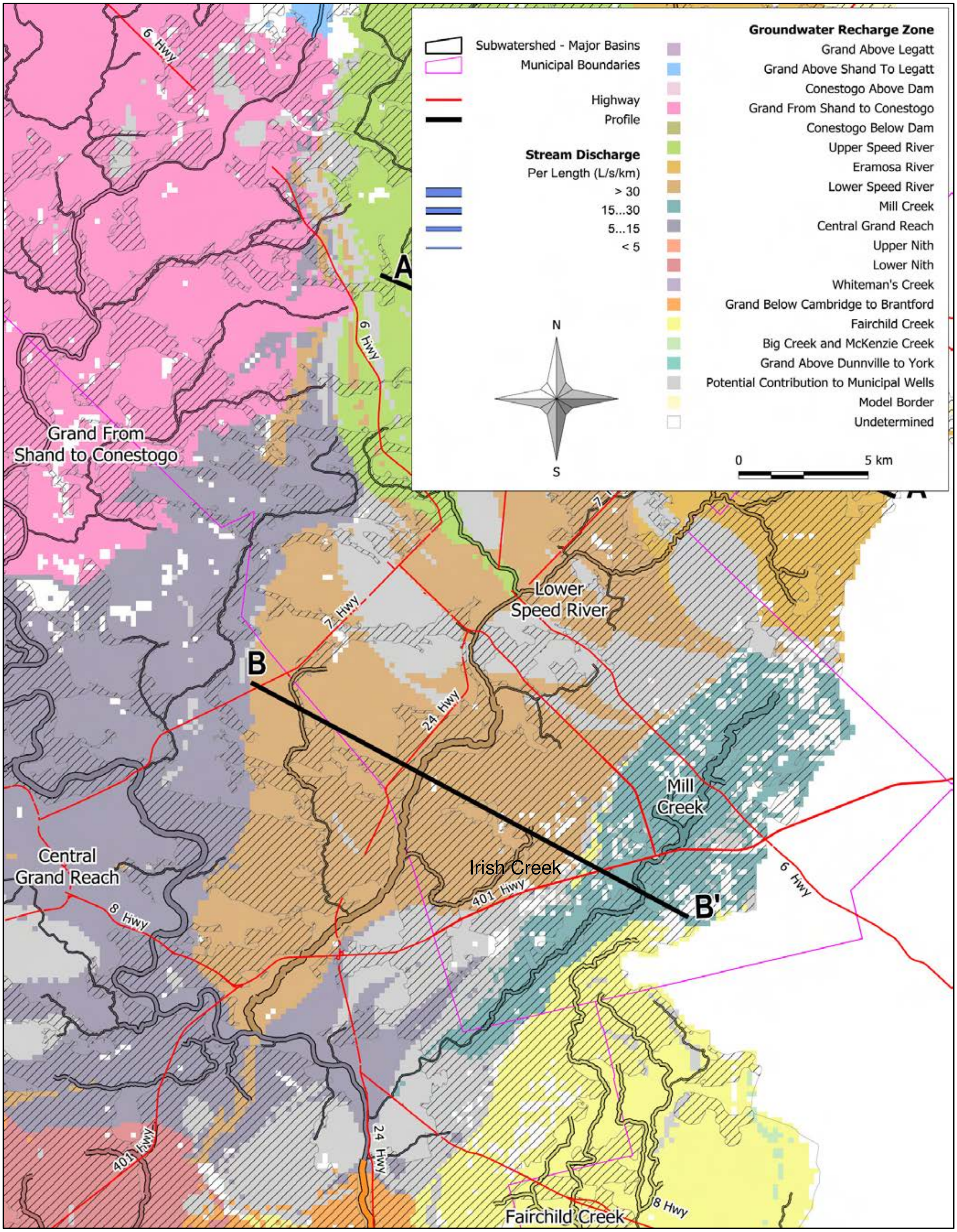
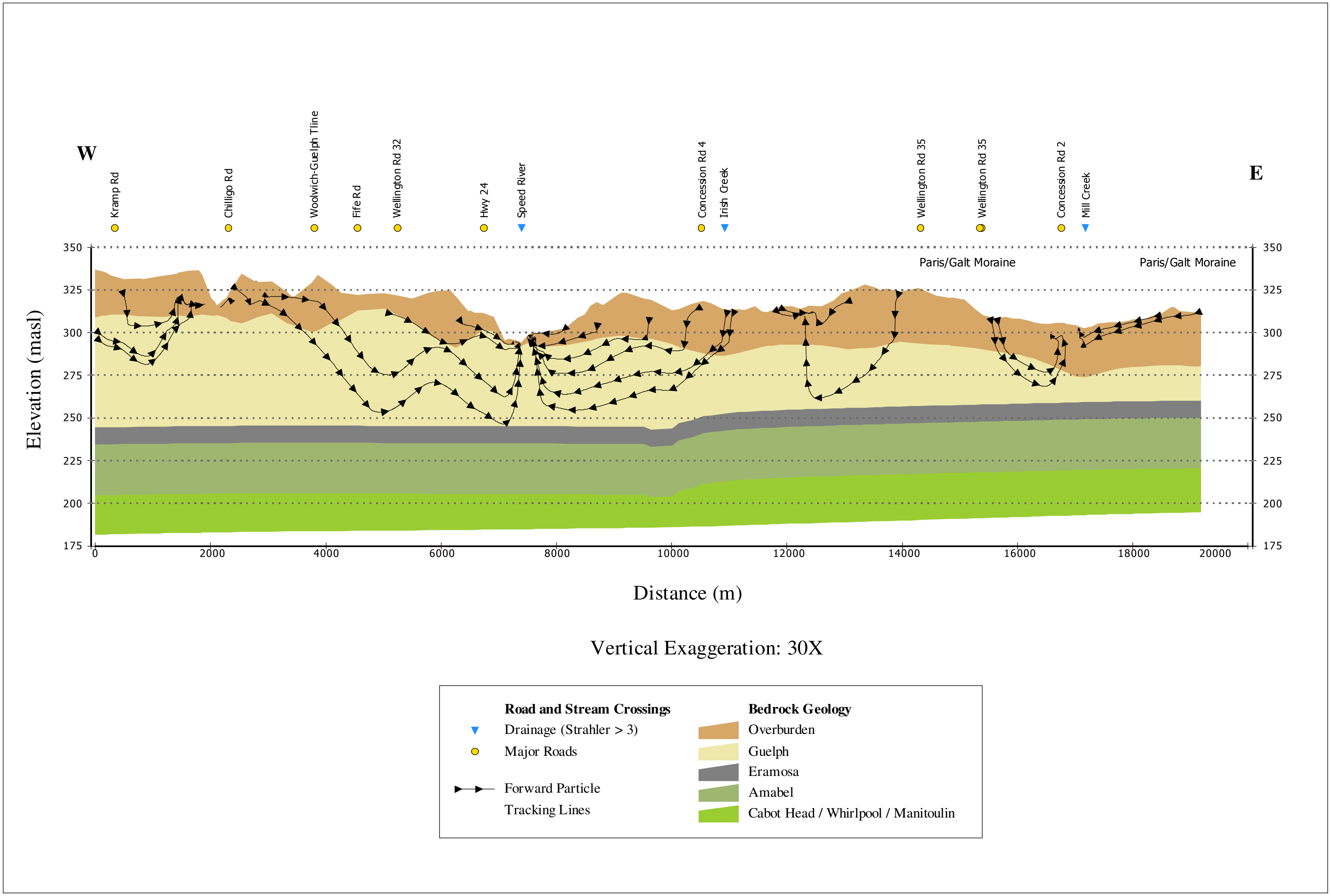


Figure 77
Speed and Mill – Recharge and Discharge



Sanford, B.V. 1969 Geology of the Toronto–Windsor Area, Ontario; Geological Survey of Canada, Map 1263A.
Various Authors, 1975-1980, Paleozoic Geology, Southern Ontario, Ontario Division of Mines. Refer to GRCA metadata.

Figure 78 – Groundwater Pathlines (Profile B-B')

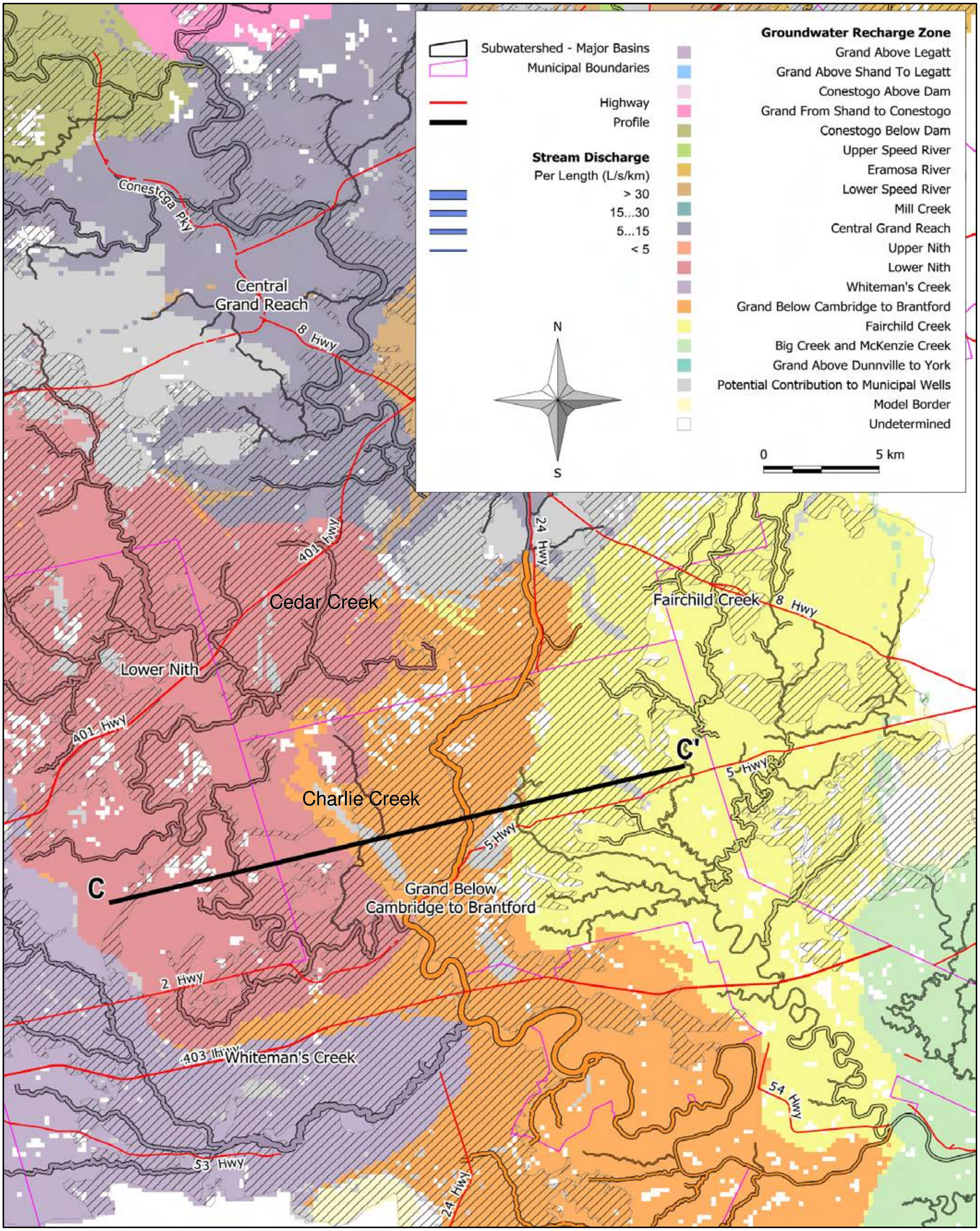


Figure 79
Lower Nith and Grand – Recharge and Discharge

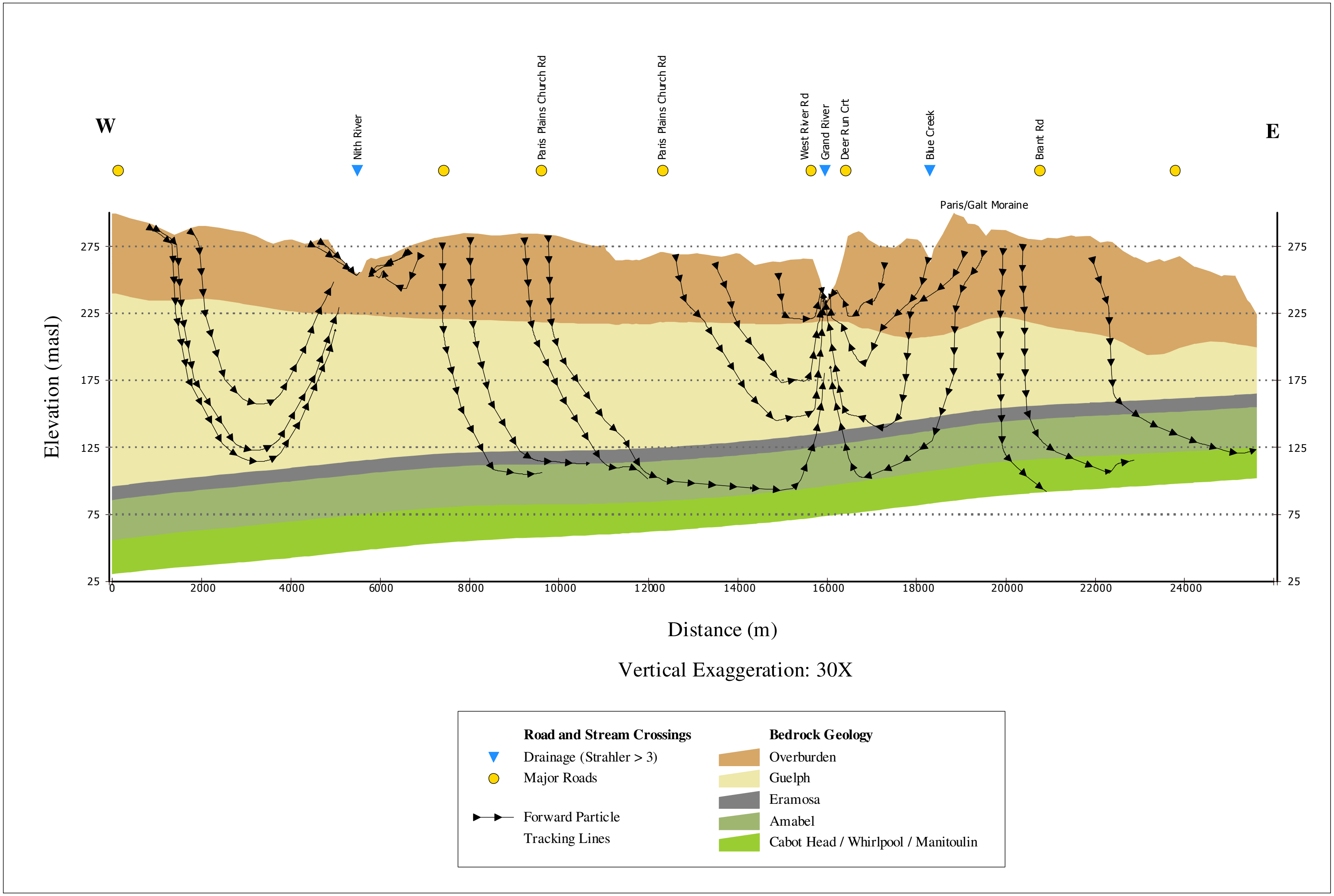


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Figure 80 – Groundwater Pathlines (Profile C-C')

7.0 Conclusions

This report summarizes the development and refinement of the water budget framework for the Grand River Watershed. This framework, initiated by the Grand River Conservation Authority, begins with an estimate of water demand across the Watershed and also includes calibrated streamflow and groundwater flow models developed to assess the flow of water through the Watershed. The technical efforts described in this report refine the previous work and provide a basis on which to make future refinements. These future refinements may be completed in areas where water demands are high with the potential to cause negative impacts on the hydrologic and ecologic environment. A companion report (AquaResource, 2009b) describes the Tier 2 Subwatershed Stress Assessment, which utilizes these water budget models to identify potentially stressed areas following the methodology developed by the Province of Ontario under the Clean Water Act.

7.1 WATER USE

Water use within the Watershed was initially estimated through the Grand River Water Use Study (GRCA, 2005). This current work builds upon the GRCA study by incorporating the consumptive nature of water takings into water demand estimates. Consumption considerations include spatial and scale dependence, distinguishing water takings that are simply moving water between hydrologic units and those that are removing water from the Watershed.

Actual water use information collected by GRCA for the most significant water use sectors (including municipalities) was incorporated into this study to increase the certainty of the water use estimates wherever possible.

The estimated average annual pumping in the Watershed is 25,150 L/s. Much of this total pumping rate is not consumptive water use and the water is returned or recycled directly to the source from which it was pumped. After accounting for actual consumption, the average source specific consumptive demand is estimated to be approximately 4,900 L/s. This consumptive demand estimate refers to the water that is not returned directly to the source from which it was pumped. As an example, a groundwater well is considered to be completely consumptive with respect to groundwater since the water is not returned directly to the aquifer. A sand and gravel pit operation may have a large Permit to Take Water for aggregate washing. However, much of the water used for aggregate washing is immediate returned back to a pond and is therefore not a consumptive use.

The water demand assessment estimates the breakdown of consumptive water demand by sector as follows;

1. Municipal Water Supply – 53%
2. Industrial Purposes – 8%
3. Dewatering – 9%
4. Commercial Purposes – 9%
5. Agricultural Irrigation – 7%
6. Private Water Supplies – 4%
7. Livestock & Un-serviced Domestic – 5%
8. Groundwater Remediation – 3%
9. Miscellaneous – 2%

7.2 WATER BUDGET MODELS AND WATER BUDGET PARAMETERS

The continuous streamflow-generation model (GAWSER) and steady-state groundwater-flow model (FEFLOW) are shown to be well-calibrated to subwatershed-scale conditions, meaning that they are generally reflective of the surface water and groundwater flow regime in each subwatershed. The conceptual models developed to build the GAWSER continuous streamflow-generation model and the FEFLOW steady-state groundwater-flow model do not necessarily account for local features that might locally influence surface water and groundwater flow. As an example, storm sewer networks are not represented in the GAWSER continuous streamflow-generation model in urban areas. Similarly, discretely characterized aquifer and aquitards are also not represented in the FEFLOW steady-state groundwater-flow model.

The surface and groundwater modelling results are consistent with the understanding of the key hydrologic and hydrogeologic processes at the watershed scale. These models provide the quantitative calculation capability to perform subwatershed water budget calculations.

The implication of not having local features represented in a regional model is only one of scale. The watershed models are the best starting place to understand and visualize the role of large scale physiographic and geologic features. The watershed model can also be effectively used to predict the impact of large-scale climate or landuse changes. However, smaller-scale hydrologic and hydrogeologic water budget models are necessary to represent detailed conceptual models and predict the impacts of local landuse changes. The watershed-scale models can provide effective boundary conditions and starting points for the local models.

The calibration of the water budget models undertaken in this Study represents one solution to a watershed system that has non-unique solutions. Additional calibration can be performed to further understand other non-unique modelling solutions for the Grand River Watershed. However, by coupling the groundwater flow model and the streamflow generation model, the representativeness of the modelled solution was confirmed and the accuracy of the calibration at the regional level was verified. The recharge results predicted by the calibrated streamflow-generation model were applied to an independent data set in the groundwater flow model and were shown to still reasonably replicate observed conditions in the groundwater system. Because the modelled recharge volume satisfies modelled solutions that were calibrated based on two independent data sets, the confidence level in the models is increased.

The Grand River Watershed GAWSER/FEFLOW combination provides an effective framework in which to assess the Watershed's water budget parameters from a surface water and groundwater perspective. On a regional basis, the predicted hydrologic response for various hydrologic units and subwatersheds is consistent with expectations and field observations.

7.3 UNCERTAINTY CONSIDERATIONS

The Grand River Watershed GAWSER continuous streamflow-generation model and FEFLOW steady-state groundwater-flow models have been developed and calibrated to assess subwatershed-scale and watershed-scale hydrology and hydrogeology. While the modelling efforts are shown to meet their original objectives, the role of uncertainty should be considered when interpreting results or making any conclusions from the model predictions.

Sources of uncertainty in water budget assessments include the representativeness of the model's framework, sparseness of data and knowledge gaps, assumptions in water demand estimates, modelling assumptions and simplifications, and possible deficiency in calibration. While the models have been calibrated at the watershed scale, these uncertainties will become more significant at smaller scales, such as near municipal wellfields, or near wetlands. The watershed model may be suitable for evaluating these types of local features; however, the potential implications of uncertainty should always be considered when using the results.

Water demand estimates are subject to uncertainty as follows:

- *Non-municipal water demands* – The uncertainty associated with these demands results from estimated water takings and seasonal and consumptive use factors;
- *Permitted water use* - To reduced uncertainty associated with permitted water use, the GRCA contacted many permit holders to determine actual water use rates. However, other sources of error associated with permitted water use include consumptive factors and seasonal water use;
- *Non-permitted water use* – Uncertainty exists for non-permitted agricultural use and rural unserviced domestic use; however, this is not a significant portion of the overall water budget.

The GAWSER continuous streamflow-generation model is subject to uncertainty as follows:

- *Watershed characterization* – Local features such as storm water management systems are not incorporated into the model and local streamflow estimates may be subject to higher levels of uncertainty;
- *Climate data* – There are relatively few climate stations with long term datasets to fully reflect all spatial climate variability; measurement errors also add to uncertainty;
- *Streamflow data* – Uncertainties in streamflow measurements may influence model calibration;
- *Model limitations* – The model development is subject to a number of assumptions and simplifications which will affect the certainty of the results.

Elements of the FEFLOW steady-state groundwater-flow model that are subject to uncertainty include:

- *Watershed characterization* – In most cases the limiting factor that results in uncertainty is the lack of available subsurface data and the interpretation of available data. Local hydrogeologic features are not characterized and represented in the model; and,
- *Calibration data* – Uncertainties associated with water well records and groundwater discharge as a component of baseflow.

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