AquaResource
A Division of Matrix Solutions Inc.

INNISFIL CREEKS SUBWATERSHED

TIER TWO WATER BUDGET & WATER QUANTITY STRESS ASSESSMENT

AND

ECOLOGICALLY SIGNIFICANT GROUNDWATER RECHARGE AREA ASSESSMENT

Report Prepared for:

LAKE SIMCOE REGION CONSERVATION AUTHORITY

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1 INTRODUCTION

1.1 Overview

The Lake Simcoe Protection Act (2008) was brought into force to protect Lake Simcoe as “an essential part of Ontario’s natural environment and a critical resource”, and to provide environmental protection for this area “in the face of climate change, invasive species, and the pressures of population growth and development”.

As part of the Lake Simcoe Protection Act, the Lake Simcoe Protection Plan (2009) was published by the Ministry of the Environment (MOE) to protect, improve and restore the ecological integrity of the watershed and its natural heritage features. The Plan requires Tier Two Water Budget Studies to be completed for all subwatersheds within the Lake Simcoe Basin that were not previously completed through Source Water Protection initiatives. This requirement is part of an initiative to monitor progress in achieving the water quantity-related objectives of the Lake Simcoe Protection Plan (LSPP); namely, to support the maintenance of adequate flows to maintain healthy aquatic ecosystems in the Lake Simcoe watershed. Additionally, in efforts to maintain and restore the integrity of local natural heritage features, the LSPP aims to identify and protect primary Ecologically Significant Groundwater Recharge Areas (ESGRAs) that sustain discharge to important surface water features within subwatersheds such as streams and wetlands. ESGRAs are intended to complement significant Groundwater Recharge Areas (SGRAs) developed through source protection studies. SGRAs encompass areas of higher volume recharge, and thus the ESGRA methodology was developed to delineate additional contributing areas and enhance protection for ecological features.

While a Tier Two Water Budget study was completed for the areas adjacent to the Innisfil Creeks subwatershed, such studies were not previously completed for this subwatershed. Tier One Water Budget and Stress Assessment work completed by LSRCA (2009) determined that the Innisfil Creeks subwatershed had a low potential for hydrologic stress and thus this area was not included in the subsequent Tier Two Stress Assessment (Golder and AquaResource, 2010) nor the City of Barrie Tier Three Risk Assessment (AquaResource et al, 2012a). The modelling tools developed for the Tier Three Risk Assessment Study (AquaResource et al, 2012a) were expanded and used as the basis for the Tier Two analysis in this study as they were considered the most reliable and representative tools available.

All earlier Tier One, Tier Two and Tier Three water budget studies were completed under the Clean Water Act (2006), whereas efforts described herein are completed under the Lake Simcoe Protection Act (2008). In addition to completing Tier Two Water Budgets for all subwatersheds within the Lake Simcoe Basin, ESGRAs are required to be delineated under the LSPP.

1.2 Project Objective and Approach

The overall objective of this assessment is to characterize surface water and groundwater behaviour under different scenarios and to protect sensitive areas within the Innisfil Creeks Subwatershed such as coldwater streams and wetlands. A two-part study has been outlined to complete this objective; a Tier Two Water Budget and Water Quantity Stress Assessment and Ecologically Significant Groundwater Recharge Areas (ESGRA) delineation.

To complete the required assessment, appropriate modelling tools were adapted to represent the best-available characterization of the geologic and hydrologic conditions to enhance understanding of the three-dimensional groundwater flow system and how it interacts with local surface water features.

The groundwater model described in this document has been developed based on the Barrie Tier Three FEFLOW model (AquaResource et al, 2012b). This model was built upon the conceptualization of the geology and hydrogeology throughout the region completed by Golder (2004, 2009) as summarized in the Barrie Tier Three Conceptual Understanding Report (AquaResource et al, 2012c).

Completion of the required Tier Two Water Budget and ESGRA mapping includes the following steps:

1. Calculate local water budget components;

2. Assess the potential for hydrologic stress,

3. Evaluate environmental impacts of drought on groundwater discharge to surface water features; and

4. Delineate ecologically significant recharge areas (ESGRAs).

Steps 1 and 2 above follow the process described in the Technical Rules (MOE, 2009) and the Water Budget & Water Quantity Risk Assessment Guide (MNR and MOE, 2011). However, given the focus shift from drinking water to Ecologically Significant Areas, the methodology to assess risk (step 3) was modified to evaluate the availability of groundwater to sustain their current discharge to surface water features in drought conditions, rather than the availability of groundwater to municipal drinking water supply wells.

1.3 Background and Path Forward

As summarized in Section 2.3, hydrogeologic characterization of the Study Area was completed as part of the Simcoe County Groundwater Protection Study (Golder, 2004) and updated throughout the Source Protection Studies. Source Protection studies that have incorporated water budget evaluation of the Innisfil Creeks subwatershed (partially or in full), include:

1) The Tier One Stress Assessment (LSRCA, 2009);

2) The Tier Two Stress Assessment for the South Georgian Bay West Lake Simcoe (SGBWLS), (Golder and AquaResource, 2010), completed for the LSRCA;

3) The Barrie Tier Three Water Quantity Risk Assessment (DRAFT: AquaResource et al, 2012a), completed for the LSRCA.

The Tier One Stress Assessment (LSRCA, 2009) study was completed for the entirety of the LSRCA and thus incorporated the entirety of the Innisfil Creeks Subwatershed. The Tier One Stress Assessment incorporated estimates of water budget components to evaluate the potential for hydrologic stress within each subwatershed. Through that assessment, the Innisfil Creeks Subwatershed was identified as having a low potential for hydrologic stress and thus no further detailed water budget assessments were required under the Source Water Protection Act. However, neighbouring subwatersheds were required to undergo additional water budget assessments.

The SGBWLS Tier Two Stress Assessment (Golder and AquaResource, 2010) study area encompassed the entirety of the Innisfil Creeks Subwatershed. Numerical water budget simulations were completed as part of this study using a set of water budget tools including a regional numerical groundwater flow model (FEFLOW) and two concurrently developed surface water models. These models covered the Nottawasaga Valley Watershed, the Severn Sound Watershed, as well as the western portion of the Lake Simcoe Watershed, which included the Innisfil Creeks subwatershed. Within the Nottawasaga Valley portion of the area, the surface water model HSPF was used to calculate recharge for the area. The surface run-off model PRMS was used to determine recharge for the Lake Simcoe portion of the model. Because of the large extent of the model, calibration efforts of the groundwater model focused only on the subwatersheds that were flagged as having a moderate or significant potential for stress within the framework of the Tier One Stress Assessment (LSRCA 2009). As the Innisfil Creeks Subwatershed was identified as having a low potential for hydrologic stress through the Tier One study, no additional calibration effort was undertaken for this subwatershed. The SGBWLS Tier Two study identified the Barrie Creeks Subwatershed as being potentially stressed, meriting a Tier Three Risk Assessment.

The Tier Three Risk Assessment was completed for the Barrie Creeks Subwatershed and surrounding area; this area included a large portion of the Innisfil Creeks Subwatershed. As a requirement of the Tier Three study, more refined and detailed numerical models were developed for both the surface and groundwater systems. For the surface water system, the two separate surface water models that had been completed over the area in the SGBWLS Tier Two study were replaced with one comprehensive surface water model (MIKE SHE) to ensure consistency across the study area. The calibration of the MIKE SHE model benefitted from the use of measured data within both Conservation Authorities. The groundwater system was simulated using a refined and focused FEFLOW model. That FEFLOW model also extended beyond the Barrie Creeks Subwatershed as accurate calculations of interbasin flow with adjacent areas was essential for the Tier Three Assessment.

Although the Innisfil Creeks Subwatershed was included in the modelling domain of the SGBWLS Tier Two study, the Innisfil Creeks Subwatershed had not been the focus of detailed calibration or enhanced characterization effort. However, refined numerical modelling tools were necessary to complete the Tier Two Stress Assessment required under this study. The Tier Three models were considered most appropriate for carrying out this Tier Two assessment, due to the most refined characterization and calibration completed under the Tier Three study. Therefore, those models were taken as a foundation and expanded to incorporate the entirety of the Innisfil Creeks subwatershed to complete this Tier Two Assessment.

These revised and refined numerical modelling tools were essential to completing the water budget and ESGRA delineation steps described in Section 1.2.

1.4 Report Organization

This report is organized into the following sections:

1. Introduction – describes the framework for this study as well as the purpose and scope

2. Physical Setting – description of the study area
3. Water Demand – presents a summary of all municipal, permitted and non-permitted water demand within the Study Area
4. Conceptual and Numerical Model updates – describes the updates made to the Barrie Tier Three Conceptualization, MIKE SHE surface water model and FEFLOW groundwater model
5. Water Quantity Stress Assessment – presents the findings of a water budget and quantitative stress assessment of the Innisfil Creeks subwatershed. This section also contains the results of a two year and ten year drought assessment.
6. Ecologically Significant Groundwater Recharge Area (ESGRA) Methodology – describes the methodology for delineating recharge areas associated with natural heritage features.
7. Ecologically Significant Groundwater Recharge Area (ESGRA) Mapping – describes the results for delineating recharge areas associated with natural heritage features.
8. Uncertainty Analysis – describes the uncertainty involved in delineating recharge areas.
9. Limitations and Uncertainty
10. Summary – provides an overview of the analysis and results, discussing the key finding and recommendations for moving forward.

2 PHYSICAL SETTING

2.1 Study Area, Land Use and Municipal Water Supply.

The Study Area includes the Innisfil Creeks Subwatershed and the surrounding area (Figure 2.1). The Innisfil Creeks Subwatershed has an area of 107.2 km^2 (approximately 5km wide by 20 km long) and is located along the western edge of Cook's Bay, Lake Simcoe. As shown in Figure 2.1, the subwatershed is almost entirely within the Town of Innisfil, in Simcoe County, with a small portion extending into the Town of Bradford-West Gwillimbury. A small portion of the subwatershed also extends into the City of Barrie, on the south east edge of the city.

The Innisfil Creeks subwatershed is not as densely populated as some of its neighbouring subwatersheds (Figure 2.2), but is expected to experience some increase in population as the City of Barrie grows towards this area. At present, the population within the subwatershed is concentrated along the shore of Lake Simcoe, particularly in Alcona and Sandy Cove. Land Use within the Innisfil Creeks subwatershed is currently dominated by agriculture (45%) and natural heritage cover (33%). Urban areas, including commercial and other industrial land uses, account for 21% of the subwatershed land use.

The majority of municipal water supply within the subwatershed is currently based on surface water (for Barrie and Alcona); however groundwater supply wells are utilized within the communities of Gilford, Goldcrest and Sandy Cove Acres. Groundwater supply wells are illustrated on Figure 2.1. Municipal / communal systems previously operated for Alcona (Alcona Woods) and Crossroads (Golder, 2004) have changed from groundwater to surface water sourced water supplies. Outside of the subwatershed, the community of Churchill also is served by groundwater, which may induce flow from the subwatershed to the Nottawasaga Valley Watershed.

2.2 Topography and Physiography

The topography within the Study Area is illustrated on Figure 2.1. Topography ranges from a high of 300 m amsl along the subwatershed divide north of Churchill, to a low of 218 m amsl at Lake Simcoe. Elevation along the majority of the subwatershed divide varies between 280 and 260 m amsl with a gradual slope of approximately 1% toward Lake Simcoe. This results in a relatively flat terrain across the study area. Also evident in Figure 2.1 is a relatively low sloping plateau (below elevation 240) that follows the current Lake Simcoe shoreline and reflects an historic shoreline location.

Two main physiographic regions dominate the Study Area (Figure 2.3): the Peterborough Drumlin Field and the Simcoe Lowlands (Chapman and Putnam, 1984). Along the coast of Lake Simcoe, the physiography is mainly comprised of the Simcoe Lowlands, which are dominated by sand plains. Morphologically, this regime is characterized by flat, low-lying plains composed of silts and sands, and numerous Algonquin-aged shorecliffs, terraces and beach ridges throughout the area. Within the upland portions of the subwatershed, the Peterborough Drumlin field, a drumlinized till plain, dominates the landscape. Within this Study Area, relatively few drumlins are present and the dominant physiographic landform is the till plain and its associated low topographic slope. Lowland areas also include steep-walled, flat floored valleys (e.g., Barrie Creeks valley, LSRCA and Innisfil Creek, NVCA).

Poor drainage in the upland till areas leads to some riverine wetlands along the headwater valleys (riparian wetlands), as well as small ponded and isolated intermittent wetland features. The drainage channels that originate in the upland areas in the Subwatershed are typically small creeks with sluggish flow due to the relatively low topographic slope. Further discussion of surface water features is contained in section 2.4.

2.3 Geologic and Hydrogeologic Conditions

The surficial geology (Figure 2.4) of the study area is represented by a variety of surficial deposits resulting from a series of glacial and post glacial events. The upland areas are dominated by well-draining glacial silty tills. The Halton Till, a sandy silt to sand till is the oldest till found in the area, forms the core of the drumlinized till plain in the upland regions. The younger silty clay to silt Kettleby Till overlied the Halton Till west of Gilford. Ice contact stratified drift consisting of sand and gravel outwash deposits overlie the till soil on the flanks of the upland areas. Glaciolacustrine clayey silt and silt rhythmite deposits occur in isolated pockets overlying the upland areas and represent a deep water glaciolacustrine phase. Beach and bar deposits consisting of sandy gravel and gravely sand have been deposited by glacial Lake Algonquin in low-lying areas along the Lake Simcoe shoreline. Glaciolacustrine beach deposits along the shore of Cooks Bay have been identified by the OGS (1991) as selected sand and gravel resource areas of primary significance.

The area is underlain by a relatively thick sequence of glacial till overburden deposits that vary between 60 to 70 metres thick along the Lake Simcoe shoreline to about 140 metres thick beneath the upland areas. The characterization of the overburden has been completed throughout a number of background studies in the past 10 years, most comprehensively in the South Simcoe Groundwater Studies (Golder, 2004). Figure 2.5 presents some sample cross-sections through the Innisfil Creeks subwatershed that illustrate the hydrogeologic interpretations of the local subsurface conditions.

The hydrogeologic characterization includes a sequence of aquifer and aquitard units that have been consistently identified throughout the entire Simcoe County area. Aquifer units (A1, A2, A3, A4) are numbered from the shallowest to the deepest and were classified based on similar elevation range across Simcoe County. Intervening aquitard units (C1, C2, C3, and C4) are also numbered from the ground surface downward, with C1 being the aquitard underlying A1. A surficial unit (UC) is also used to delineate an upper confining unit, where present.

Within the Innisfil Creeks study area, aquifers A1 and A2 are found to be discontinuous and are associated with shallow ice contact deposits or the Lake Simcoe shoreline deposits. These aquifer units represent local, discontinuous aquifer units. The deeper aquifer systems are regionally known as A3 or A4. These are the aquifers from which most groundwater drinking supply is drawn, and are the only continuous aquifer units across the Study Area. These deep aquifers are protected by thick sequences of overlying till, as illustrated in Figure 2.5.

There are no bedrock exposures in the area, the underlying bedrock has been determined from a few deep wells in the area but is not well documented. This bedrock consists mainly of the limestone and dolostone formations of the Simcoe and Ottawa groups (Ontario Geological Survey, 1991). This unit is not considered an aquifer within the Study Area because of the depth to that unit. As a result of its depth, flow paths and residence times within the bedrock are very long, leading to high concentrations of dissolved minerals.

2.4 Surface Water Features

Figure 2.6 illustrates the surface water features of the Innisfil Creeks subwatershed. Within the subwatershed boundary, there are 11 primary streams, as well as a few small creeks draining separately into Lake Simcoe. Most of the streams have headwaters in agricultural Upland regions and flow from west to east, through the Lowland sand plains before entering Lake Simcoe (approximately 5-10 km in length, with a gradual slope on the order of 1%). As a result, stream flow within these features is relatively low.

With very little base flow observed, groundwater discharge is not a substantial contributor of flow to most of the streams within the subwatershed. A base flow survey was completed by LSRCA in 2005 and was used to map incremental base flow discharge along successive stream reaches. The majority of streams were found to not receive any groundwater discharge, but rather lose water to the groundwater system. Only a few reaches were mapped to receive a relatively low base flow (0.01 to 5 L/s/km). The relatively low base flow throughout the Study Area is a reflection of the predominance of till.

Another result of the relatively low slope and predominance of lower permeability till materials is the creation of wetland areas (Figure 2.6). Many of those wetlands are riparian wetlands adjacent to streams. Where streams are mapped to have low base flow conditions, the expectation is that associated wetlands would also receive little groundwater discharge and may be perched above the regional water table by intervening aquitard materials. Similarly, isolated smaller wetlands within the till plain may be perched above the regional groundwater table and fed by local runoff and/or perched aquifer conditions. There is little field data regarding these wetlands, including their observed hydrologic function; characterization within this report relies on inferences made based on their elevation relative to the predicted shallow water table. There is no high quality water level data available to evaluate wetland conditions and minimal shallow water level available from water well records.

The subwatershed also has three Provincially Significant wetlands: Leonard’s Beach Swamp, Little Cedar Point Swamp, and Wilson’s Creek Marsh (Figure 2.6). Leonard’s Beach Swamp is located north and northwest of Alcona and is bisected by Leonard’s Creek. It is a wetland complex made up of five individual wetlands with two wetland types consisting of approximately 99% swamp and 1% marsh (NHIC, 2012), and covers an area of 2.3 km2. Little Cedar Point Swamp is located northeast of Lefroy. This area is comprised of a diverse wetland complex with two wetland types which consist of approximately 97% swamp and 3% marsh (NHIC, 2012) and covers an area of 1.3 km2. The dominant vegetation cover is deciduous trees and the sub-dominant vegetation types are comprised of tall shrubs, coniferous trees and ground flora. Wilson’s Creek Marsh is generally located just south of Lefroy. This area is comprised of approximately 46% swamp and 54% marsh (NHIC, 2012), and covers an area of 0.5 km2. The vegetation community is made up of a variety of free-floating plants, tall shrubs, deciduous trees and an associated ground flora.

3 WATER DEMAND

This section provides a summary of the consumptive groundwater demands for the Innisfil Creeks subwatershed assessed as part of the Tier Two Stress Assessment. Consumptive groundwater demands were also estimated for the entire study area for modelling purposes (see Section 4) and are not discussed in detail within this section.

Consumptive water demand refers to water that is taken and not returned to its original source (i.e., stream or aquifer) within a reasonable amount of time. Understanding this type of water demand is critical to the development of a water budget framework. An estimate of the extent and variability of water use throughout the Study Area is required to identify if the subwatershed may be under a significant degree of potential hydrologic stress, and thus guide future water budget management efforts.

The total consumptive water demand is estimated based on the following components:

- Municipal water demand: Municipal water demand estimates were generated based on pumping rates reported by municipalities, where available, or from the 2009 Water Taking Reporting System (see Section 3.1);

- Permitted water demand: the Province of Ontario issues Permits to Take Water for water takings greater than 50,000 litres per day (L/d). Permitted water demand was estimated using reported pumping rates from the 2009 Water Taking Reporting System (WTRS) or by combining the permitted rate with the months of expected active pumping. Consumptive factors were then applied to determine the amount of pumped water that is not returned to the original source in a reasonable amount of time; and,

- Non-permitted water demand: Pumping rates for non-permitted takings were pro-rated by area based on the Tier One Stress Assessment (LSRCA, 2009).

Future consumptive water demand was also estimated as part of the Tier Two Stress Assessment. As per the Technical Rules (MOE, 2009), the future consumptive water demand is only estimated for subwatersheds that are not identified as potentially stressed under existing conditions. The future water demand and the stress assessment are documented in Section 5 of this report.

It is recognized that there are a number of non-consumptive water users (i.e., water for waste assimilation or for sustaining ecological health) that are not included in estimations of consumptive water demand. These water needs however, do not remove water from its source and as such are not considered to be consumptive water takings in this assessment.

3.1 Municipal Water Use

Water extracted to meet municipal demand represents the majority of the permitted use within the Innisfil Creeks Subwatershed. As such, accurate estimates of municipal water use are a critical component of the consumptive water demand estimate. For this Tier Two Stress Assessment, 2011 reported municipal pumping rates were obtained from the municipalities or from the 2009 Water Taking Reporting System (WTRS), described in Section 3.2.1. Table 3.1 lists the municipal systems within the subwatershed, the source and year of the reported pumping rates, and the average annual pumping rate (total annual pumping divided by days per year). Note that the volume pumped on a particular day may be more or less than the average annual rate.

Table 3.1: Municipal Water Supply Systems

Community	Well Name	Source of Data	Average Annual Pumping Rate		
			(m^3/day)	(L/s)	(mm/yr)
Goldcrest	Well 2	Reported 2011	27	0.3	0.10
	Well 1	Reported 2011	25	0.3	0.08
Golf Haven	Well 1	Reported 2011	44	0.5	0.15
	Well 2	Reported 2011	44	0.5	0.15
Sandy Cove Acres*	Well 1	WTRS 2009	185	2.1	0.63
	Well 2	WTRS 2009	182	2.1	0.62
	Well 3	WTRS 2009	190	2.2	0.65
Total			**697**	**8**	**2.38**

* Communal System

These municipal rates are comparable to those applied in the Tier One Stress Assessment (LSRCA, 2009), which totaled 704 m^3/day. Although the total amount of pumping is similar, it should be noted that Sandy Cove Acres was not incorporated into the Tier One municipal supply systems and that Alcona Crossroads was included. Alcona Crossroads has since been taken offline, as that community now obtains its supply from surface water.

3.2 Permits to Take Water

The Ministry of Environment’s Permit to Take Water (PTTW) Program began in the early 1960s. It requires any person (or organization) taking more than 50,000 L/d of water to have an active PTTW. Exceptions are granted for un-serviced domestic water use, livestock watering, and water taken for firefighting purposes. The Province’s PTTW database stores information on permits, including the permit number, source name and location, the maximum permitted yield, and the general and specific purpose of the water taking. PTTWs within and surrounding the Study Area are illustrated in Figure 2.1. Since 2005, and depending on the water use, the PTTW program has required permit holders to report their actual pumping rates, which are collected within the WTRS, as described in the Section 3.2.1. The WTRS stores information on the permit number, source name and reported rates, but does not store spatial information. As such it is necessary to match the reported rates from the WTRS with the spatial coordinates of the PTTW database using the permit number and source name. In some cases, it is not possible to match up the permitted takings, as the permit numbers or source names have changed or may be recorded slightly different. In addition, as the WTRS program is still in its early stages of use, not all permitted takings have been reported to the MOE. As such, the data within the PTTW database was utilized to estimate actual water use where no reported rates were available within the WTRS. When using the PTTW database to estimate actual water demands, the following considerations are made:

- When specifying the amount of water required for their specific use, permit holders often request a volume of water that exceeds their requirements. This may be done to ensure compliance in dry years, or to secure sufficient water for possible future expansion of the operation;

- The permitted volume is often derived from the capacity of the pumping equipment rather than the requirements of the user, often significantly over-estimating the user's demand;

- The database does not maintain a record of seasonal water demand requirements;
- Multiple wells or sources may be included on a particular permit, and the permitted rate refers to the total for all sources associated with that permit. As an example, two nearby municipal wells may operate under one permit but the wells may never operate simultaneously. In this case, each well source could pump at the maximum permitted rate, but not at the same time. To estimate total demand in this case, the total permitted rate was logically divided amongst the active source locations;
- The spatial location of water taking sources 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); and
- Historic water takings may be "grandfathered" and do not require a permit. As a result, there may be some significant water takings not reflected by the PTTW database.

A copy of the PTTW database current to January 2010 was used in this assessment. Only active permits, or permits representing a sustained water taking, were included in this analysis. Temporary permits, such as pipeline testing, pumping tests, or temporary construction permits, were not included. Table 3.2 below summarizes the groundwater takings permitted in the subwatershed, including municipal permits, as well as the total rate of water permitted through the PTTW application process. 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 that limit the amount of water withdrawn, which is not reflected in this total. As such, the maximum permitted rate specified in the PTTW, is not necessarily an accurate estimate of water demand and requires local knowledge to improve the data for purposes of stress assessment.

Table 3.2: Maximum Permitted Takings

Permit	Well	Purpose*	Maximum Permitted Takings		
			(m^3/day)	(L/s)	(mm/yr)
00-P-1381	Goldcrest Well 1	Water Supply	324	3.8	1.1
00-P-1381	Goldcrest Well 2	Water Supply	324	3.8	1.1
8482-758HN2	Golfhaven Well 1	Water Supply	459	5.3	1.6
8482-758HN2	Golfhaven Well 2	Water Supply	108	1.3	0.4
0206-7HFH8Q	Golf Course Well	Commercial	13	0.1	0.0
87-P-3008	Sandy Cove Acres Well 1	Water Supply	1114	12.9	3.8
87-P-3008	Sandy Cove Acres Well 2	Water Supply	1114	12.9	3.8
87-P-3008	Sandy Cove Acres Well 3	Water Supply	1114	12.9	3.8
Total			**4570**	**53**	**15.6**

* Water Supply includes municipal, communal and campgrounds water supply.

As municipal water supply is the largest taking within the Study Area, the collection of reported pumping rates was focused on these takings (Section 3.1). The rates for non-municipal permitted takings within subwatershed were not found within the Water Taking Reporting System. Therefore, these were estimated based on the methodology included in the Water Budget and Water Quantity Risk Assessment Guide (MNR and MOE, 2011). That methodology can be summarized as follows:

- The maximum permitted rates were combined with the months in a year that the pumping associated with the PTTW will be active (e.g., a snow making permit was assumed to be active in the period of December to February) to generate monthly pumping volumes. These monthly values were then summed to achieve estimated annual pumping rates (m^3/yr) and divided by the number of days in a year to produce average daily rates (m^3/d).

- The estimated pumping rates were adjusted 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.

Sections 3.2.2 and 3.2.3 document how this methodology was applied to PTTWs to generate consumptive water demand for the Tier Two Stress Assessment, as well as for use within the groundwater flow model (Section 4.3).

3.2.1 Reported Pumping Rates - Water Taking Reporting System

The Water Taking and Transfer Regulation (O. Reg. 387/04) came into effect January 1, 2005. This regulation introduced mandatory monitoring and reporting by all PTTW holders. Permit holders must record their daily water takings for each calendar year (i.e., January 1 to December 31) and report these volumes by March 31 of the following year to the MOE. The data collection and reporting were phased in from 2005 to 2008 based on the purpose of the water use as stated in the permit. Data are stored within the WTRS.

As permitted pumping rates are typically overestimates of actual water use, WTRS reported pumping rates were used whenever possible. However, as the WTRS is still in its introductory stages, many permits do not have reported pumping rates available at this time. In such cases, pumping rates were estimated as outlined in the Section 3.2.2.

The MOE supplied the Lake Simcoe Conservation Authority with the WTRS data, which included data for 2005 through 2009. The WTRS data for 2009 was used in this assessment. The 2009 reported pumping rates for Sandy Cove Acres is listed in Table 3.1. Comparison to the maximum rates listed in Table 3.2 illustrates the importance of using reported pumping rates wherever possible, as the reported rates are typically less than permitted. Reported rates from the WTRS for the private Golf course well within the subwatershed were not found within the WTRS.

As the data contained within the WTRS are reported directly by permit holders, data entry errors are present and these arise from permit holders entering data in incorrect units (e.g., gallons/day vs. L/day), inaccurate measurement practices, or number keying issues. To identify sources of error associated with number keying errors, the maximum daily reported rate was queried from the WTRS dataset, and compared to the maximum daily permitted rate (from the PTTW database) at each source. If the maximum daily reported rate was significantly larger than the maximum daily permitted rate, the reported data for that source was manually inspected and corrected.

Monthly volumes were extracted from the WTRS for each permit source for use in the maximum monthly stress assessment (Section 5).

In general, reported pumping rates do not consider the consumptive nature of the taking, as the permit holders are required to report total pumping but not the returned water volume. As such, in order to obtain consumptive demand, the reported rates were modified by a consumptive factor, as outlined in Section 3.2.3.

3.2.2 Estimated Pumping Rates - Monthly Usage Factors

Where no reported rates were available (i.e., where non-municipal takings were not in the 2009 WTRS), estimated water demand was required. Monthly estimates of water use were required to represent the seasonal changes in total water use across a subwatershed and calculate the maximum monthly stress (see Section 5). The months where a water taking is expected to be active, based on the purpose of that water taking are shown on Table 3.3; where 1 designates the permit is active, and 0 designates it is inactive. 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 in December, January and February). The monthly demand adjustments shown in Table 3.3 were combined with the maximum permitted days per year specified in each PTTW (where available) to calculate monthly water use estimates.

Table 3.3: Monthly Demand Adjustments based on Active Months of Takings

General Purpose	Specific Purpose	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Agricultural	Field and Pasture	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	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	1	1	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

(Source: MOE, 2006)

3.2.3 Consumptive Use Factors

As discussed in detail in the Water Budget and Water Quantity Risk Assessment Guide (MOE, 2011), water consumption refers to the amount of water removed from a hydrological system and not returned back to the same system in a reasonable time period. To assess the portion of pumped water that is being removed from the hydrologic system, estimates of water demand must consider consumptive use, as opposed to the total amount of water that may be pumped from a system.

Estimating consumptive water demand requires a proper consideration of scale as well as the physical water taking operation. Some water takers may have large extraction volumes associated with their permits while actually consuming very little of that water. As an example, aggregate washing operations are permitted to pump large volumes of water between washing and settling ponds, and a relatively small percentage is lost to evaporation, or is removed offsite within the washed material. Another example is a dewatering activity where groundwater that is pumped to lower the water table is discharged to a nearby creek. At the scale of a subwatershed very little of this water is actually consumed; however, this water taking would be fully consumptive with respect to the pumped aquifer.

The percent water demand calculation (Section 5) requires an estimation of water that is consumed and not returned to the original source within a reasonable amount of time. Therefore, for a groundwater assessment, if water is removed from the groundwater system and not returned to the groundwater system, the taking is assumed to be 100% consumptive. Groundwater takings are typically 100% consumptive, since wastewater is seldom returned to the groundwater system (i.e., aquifer), but rather discharged to surface water systems. Exceptions would include irrigation, where a portion of the applied irrigation water would saturate surficial soils and percolate beneath the evaporative root zone, returning to the groundwater system. Table 3.4 provides a list of consumptive use factors that were used to estimate consumptive water demand for water takings where water is returned to the same source from which it is taken. These values correspond to the 'Specific Purpose' assigned by the MOE to each permit. Where water was not returned to the same source, a consumptive factor of 1 was used.

The consumptive factors listed in Table 3.4 are based on the default consumptive use factors listed in Appendix D of the Risk Assessment Guide (MNR and MOE, 2011). These default factors are generalized and can be modified for each permit or source if more information is available (MNR and MOE, 2011).

Table 3.4: Consumptive Use Factors

Category	Specific Purpose	Consumptive Factor	Category	Specific Purpose	Consumptive Factor
Agricultural	Field and Pasture Crops	0.80	Institutional	Hospitals	0.25
Agricultural	Fruit Orchards	0.80	Institutional	Other - Institutional	0.25
Agricultural	Market Gardens / Flowers	0.90	Institutional	Schools	0.25
Agricultural	Nursery	0.90	Miscellaneous	Dams and Reservoirs	0.10
Agricultural	Other - Agricultural	0.80	Miscellaneous	Heat Pumps	0.10
Agricultural	Sod Farm	0.90	Miscellaneous	Other - Miscellaneous	1.00
Agricultural	Tender Fruit	0.80	Miscellaneous	Pumping Test	0.10
Agricultural	Tobacco	0.90	Miscellaneous	Wildlife Conservation	0.10
Commercial	Aquaculture	0.10	Recreational	Aesthetics	0.25
Commercial	Bottled Water	1.00	Industrial	Manufacturing	0.25
Commercial	Golf Course Irrigation	0.70	Industrial	Other - Industrial	0.25
Commercial	Mall / Business	0.25	Industrial	Pipeline Testing	0.25
Commercial	Other - Commercial	1.00	Industrial	Power Production	0.10
Commercial	Snowmaking	0.50	Recreational	Fish Ponds	0.25
Construction	Other - Construction	0.75	Recreational	Other - Recreational	0.10
Construction	Road Building	0.75	Recreational	Wetlands	0.10
Dewatering	Construction	0.25	Remediation	Groundwater	0.50
Dewatering	Other - Dewatering	0.25	Remediation	Other – Remediation	0.25
Dewatering	Pits and Quarries	0.25	Water Supply	Campgrounds	0.20
Industrial	Aggregate Washing*	0.10	Water Supply	Communal	0.20
Industrial	Brewing and Soft Drinks	1.00	Water Supply	Municipal	0.20
Industrial	Cooling Water	0.25	Water Supply	Other - Water Supply	0.20
Industrial	Food Processing	1.00			

(Sources: MOE, 2011; *OSSGA, 2006)

While these factors are generalized, they provide a consistent approach for the initial estimation of consumptive water use. It is recognized that within a specific water use sector, the proportion of pumped water consumed may significantly vary between individual operations; the generalized factors, presented in Table 3.4, represent a source of uncertainty.

3.3 Non-Permitted Water use

In addition to permitted water use, there are various types of non-permitted water uses, such as livestock watering and un-serviced domestic use (typically rural residents). Non-permitted agricultural and un-serviced domestic water were estimated as part of the Tier One Water Budget and Stress Assessment (LSRCA, 2009). These estimates were utilized to quantify non-permitted water use for the existing Tier Two Stress Assessment, and are discussed below.

3.3.1 Non-Permitted Agricultural Water Use

Legal non-permitted agricultural water use includes livestock watering, equipment washing, pesticide/herbicide application or any other use of water related to agriculture, with the exception of irrigation. The non-permitted agricultural water use was estimated for the Lake Simcoe watersheds as part of the Tier One Stress Assessment (LSRCA, 2009), however these estimates included both surface water and groundwater assessments, therefore they were divided in half for Two Tier analysis. These estimates are listed in Table 3.5.

Due to the census-based estimation technique, it is not possible to reliably determine the source of water for the agricultural water users. In the absence of this information, for the Tier Two Stress Assessment, it was assumed that half of the demand is serviced through groundwater sources, and half is serviced through surface water sources.

The consumptive nature of the non-permitted agricultural water use is also a source of uncertainty. In the absence of such information, and to arrive at a conservative estimate of the consumptive non-permitted agricultural water demand, this study assumes that 100% of the water taken is consumed.

3.3.2 Un-serviced Domestic Water Use

Un-serviced domestic water use is considered 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 un-serviced domestic water use estimates were completed as part of the Tier One Stress Assessment. Although the consumptive nature of the takings is uncertain, due to the return of pumped water to the groundwater system within a reasonable amount of time via septic systems, the un-serviced domestic water takings were assumed to be 20% consumptive. The un-serviced domestic water use is listed in Table 3.5.

Table 3.5: Non-Permitted Agricultural and Un-serviced Domestic Water Use

Water Use	**Average Demand**		
	(m^3/day)	**(L/s)**	**(mm/yr)**
Non-Permitted Agricultural	46	0.5	0.2
Un-serviced Domestic	552	6.4	1.9
Total	598	6.9	2.0

3.4 Consumptive Water Demand Estimates

Table 3.6 presents the consumptive demand for each permit on a monthly basis. To arrive at consumptive demand estimates the consumptive use factors (Section 3.2.3) were applied to the reported (Section 3.2.1) and estimated (Section 3.2.2) pumping rates, and then combined with the non-permitted water use (Section 3.3). The values contained within Table 3.6 are the sum of the consumptive demand associated with PTTWs (municipal and non-municipal) as well as non-permitted agricultural demand and un-serviced domestic demand.

The components of the subwatershed consumptive water demand are contained in Table 3.7, which presents the percent of average consumptive water demand used by water use sectors. Also included in Table 3.7 is the proportion of consumptive demand that is derived from reported values, as well as the portion that is estimated by information contained within the PTTW database. Consumptive water demand values based on reported information are more defensible than consumptive water demand values based on estimated pumping rates.

Municipal water supply is the water use sector with the largest consumptive water demand. The only other water use sectors are agricultural and a golf course.

Water demand estimates generated through use of reported (actual) pumping rates from the WTRS provide more-reliable estimates of the consumptive demand. As shown in Table 3.7, nearly half of the consumptive water demand for the subwatershed is based on reported rates.

Table 3.6: Monthly Consumptive Demand

Permit Number	**Well**	**Consumptive Demand (m^3/day)**													
		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	***Avg***	***Max***
00-P-1381	Goldcrest Well 1	22	11	27	28	23	41	56	38	28	18	15	22	*27*	*56*
00-P-1381	Goldcrest Well 2	21	30	15	20	27	30	37	22	21	26	30	24	*25*	*37*
8482-758HN2	Golfhaven Well 1	43	41	40	44	54	62	82	57	51	51	3	0	*44*	*82*
8482-758HN2	Golfhaven Well 2	43	41	40	44	54	62	82	57	51	51	3	0	*44*	*82*
0206-7HFH8Q	Golf Course Well	0	0	0	9	9	9	9	9	9	0	0	0	*5*	*9*
87-P-3008	Sandy Cove Well 1	185	185	185	185	185	185	185	185	185	185	185	185	*185*	*185*
87-P-3008	Sandy Cove Well 2	182	182	182	182	182	182	182	182	182	182	182	182	*182*	*182*
87-P-3008	Sandy Cove Well 3	190	190	190	190	190	190	190	190	190	190	190	190	*190*	*190*
Unserviced Domestic		552	552	552	552	552	552	552	552	552	552	552	552	*552*	*552*
Nonpermitted Agricultural		0	0	0	0	135	144	139	135	0	0	0	0	*46*	*144*
Total		**1238**	**1233**	**1231**	**1254**	**1411**	**1457**	**1514**	**1427**	**1270**	**1255**	**1159**	**1155**	**1300**	***1514***

Table 3.7: Percentage of Consumptive Water Demand

Agricultural		Commercial		Industrial		Miscellaneous	Recreation	Remediation	Private Water Supply		Municipal Water Supply	Livestock and Rural Domestic	Total Estimated	Total Reported
Est.	Rep.	Est.	Rep.	Est.	Rep.	Est.	Rep.	Rep.	Est.	Rep.	Rep.	Est.	Est.	Rep.
-	-	0.3%	-	-	-	-			43%		54%	4%	54%	46%

Notes: Est. = Estimated; Rep. = Reported; Totals may differ slightly due to rounding.

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3.5 Uncertainty

Water demand estimates are subject to various levels of uncertainty. Recognizing the limitations of relying on PTTW information for water demand estimation, an effort was made by the LSRCA to survey for reported pumping rates and to incorporate reported rates from the WTRS. Although all uncertainty is not removed by using reported rates, it reduces uncertainty associated with the generated consumptive water demand estimates. Groundwater takings associated with non-municipal water use sectors are subject to higher levels of uncertainty due to the reliance of PTTW information in estimating water demands; however, the small volume of non-municipal water takings within the subwatershed minimizes this uncertainty. The rates reported within the WTRS were verified to identify sources of error associated with number keying errors. Uncertainty associated with estimated pumping rates was minimized by applying seasonal use factors to the maximum pumping rates, and closely inspecting permits for errors. As additional reported water use rates become available, from either new PTTW regulations or additional surveys, the certainty of estimated consumptive water takings will increase.

Uncertainty is also present in the water use estimates for the non-permitted water uses (i.e., domestic and livestock water use). However, as these water uses are relatively small rates and a conservative approach was taken with respect to the consumptive nature of the takings, the impact of this uncertainty on the stress assessment is not significant.

4 CONCEPTUAL AND NUMERICAL MODEL UPDATES

As described in Section 1.3, the numerical modelling tools developed for the Barrie Tier Three Risk Assessment were refined and updated to complete the steps within this study. All conceptual model modifications accomplished throughout previous and ongoing studies were thus incorporated. The numerical model updates are outlined in the following sections.

4.1 Hydrogeologic Conceptual Model Overview

As outlined in section 2, the hydrostratigraphic layer structure of this region consists of eight major overburden units: there are four main aquifers (A1-A4) and four main aquitards (C1-C4) that constitute the numerical model layers within those studies. Within the numerical model layer structure, the uppermost main aquifer was subdivided further throughout model calibration. Recognizing its importance to municipal water supply, the main production aquifer, A3, was subdivided into four layers to increase the vertical resolution and better support numerical simulation. Furthermore, a confining layer (UC) over the uppermost aquifer, A1, was added to accommodate stream bed conductance and control excessive drainage in till-draped highland regions (Figure 4.1).

Table 4.1 presents a summary of the hydrostratigraphic units in the Study Area, including a description of the hydrostratigraphic unit name and the specific geologic units identified within the hydrostratigraphic unit. This hydrostratigraphic structure provides the basis for the layer structure of the numerical model. Table 4.1 shows a generalized cross section through the Study Area.

Table 4.1: Hydrostratigraphic units within the Model Boundary

Model Layer	Unit Name	Unit Description
Layer 1	SrfG	Represents conductance in stream beds, mapped surficial geology. 0.10-3 m in thickness.
Layers 2, 3	UC, A1	Represents confining layer over A1, mostly present in upland areas; where missing then A1 properties used
Layer 4	A1	Uppermost aquifer, present in upland areas. Frequently exists as surficial and unconfined, stratigraphically equivalent to the Oak Ridges Moraine, generally is associated with coarse-grained glacial and interglacial sediments mapped as ice-contact stratified drift.
Layer 5 , 6, 7	C1	Upper Aquitard
Layer 8	A2	Intermediate Aquifer, stratigraphically equivalent to interstadial units within the Northern Till. Within the lowland areas it is often the uppermost coarse-grained unit, commonly used for private water supplies, as well as some of the smaller municipal water supply wells (i.e. Innisfil Heights)
Layer 9, 10, 11	C2	Intermediate Aquitard, providing protection to the municipal aquifer
Layer 12, 13, 14, 15	A3	Main municipal production aquifer, stratigraphically equivalent to the Thorncliffe deposits in the Upland regions. Represents the bulk of the Barrie-Borden channel aquifer.
Layer 16, 17, 18	C3	Lower Aquitard
Layer 19	A4	Lower aquifer, thin and sometimes combined with A3 in the Barrie City Core, where C3 is thin or absent
Layer 20	C4	Lower Aquitard, also represents weathered bedrock

4.2 Surface Water Model Update

The Innisfil MIKE SHE integrated surface water model was prepared by updating the Barrie Tier Three MIKE SHE model. Since the Innisfil study area intersects the south-east corner of the Barrie model study area, the Barrie Tier Three model domain was extended to cover the Innisfil Creeks Subwatershed study area. The extended portion of the model could not however be calibrated due to a lack of continuous streamflow records within the Innisfil Creeks Study Area. As a result, the same approached and physical parameters calibrated through the development of the Barrie Tier Three model were extended to this area. The following subsections document the Mike She model applied for this Tier Two Stress Assessment; details of the model development are also contained in The Barrie Tier Three – Recharge Estimation using MIKE SHE technical memo (AquaResource, 2012).

Simulation Period:

The simulation period for the Innisfil Creeks Subwatershed MIKE SHE model was consistent with the time period selected for the Barrie Tier Three model, which was based on available climate date. The model was calibrated with data from the time period covering 1987 – 2005 and both steady state and monthly recharge estimates were produced for use within the FEFLOW model from this simulation time period.

Model Domain:

The Innisfil Creeks Subwatershed MIKE SHE model domain was delineated by expanding the Barrie Tier Three MIKE SHE model domain south-east along the Lake Simcoe shoreline, so that the Innisfil Creeks Subwatershed was included in its entirety. The model extents are shown on Figure 2.1 and 2.2. The surface water model domain was chosen to coincide with the groundwater model domain, which is described further in the groundwater model section of this report.

The resolution of the model grid (200 m by 200 m) is consistent with the Barrie Tier Three MIKE SHE model.

Climate Data:

The climate dataset used for Barrie Tier Three MIKE SHE model was also used for the Innisfil Creeks Subwatershed model. That dataset contains data from 1950-2005 for a selection of in-filled Environment Canada climate stations. The Innisfil Creeks Subwatershed area was found to be represented by climate data observed at the Cookstown climate station (based on a Thiessen polygon approach), as referenced in the Barrie Tier Three Recharge Memo (AquaResource, 2012).

Topography and Drainage:

A new topography input file was created using a 5 m resolution Digital Elevation Model (DEM) supplied by the LSRCA. The topography of the area is shown on Figure 2.1.

The simplified stream network created for the Barrie Tier Three MIKE SHE model was modified to include the streams in the Innisfil Creeks Subwatershed Study Area. The same simplification methods documented for the Barrie Tier Three Recharge Memo (AquaResource, 2012) were used in this study.

Stream cross-sections were developed for the streams within the Study Area at intervals of 400 m to 1,000 m. The complete stream network used in the Innisfil Creeks Subwatershed MIKE SHE model is shown on Figure 2.6.

Land Use:

The Barrie Tier Three model land use layer was extended for the Innisfil Creeks Subwatershed model. The Study Area land use was simplified to match the eight land use classes used in the Barrie Tier Three model. Other parameters including Leaf Area Index values, monthly root depth values, surface roughness, depression storage, and paved runoff coefficients were kept consistent with the values in the Barrie model for similar areas in the Innisfil Creeks Subwatershed. Land use classes of the study area are shown on Figure 2.2.

Unsaturated Zone:

The unsaturated zone in the Innisfil Creeks Subwatershed model was characterized using the surficial geology from the Ontario Geological Survey (OGS, 2010). The same methodology for grouping OGS classifications in the Barrie Tier Three model was used for the Innisfil Creeks Subwatershed area. The four simplified classes of gravel, sand, silt/till and clay for the study area are shown on Figure 2.4.

Saturated Zone:

The three-layer representation of the saturated zone shown in AquaResource (2012) was not modified; however, the extent of the hydrostratigraphic surfaces in the Barrie Tier Three model did not cover the current Study Area entirely. These hydrostratigraphic surfaces were extended using layer surfaces from the NVCA Tier Two model as a guide.

Calibrated horizontal and vertical hydraulic conductivity parameters were extended from the Barrie Tier Three model to cover the extended area.

To calculate initial potential heads for the three layers, a water table elevation was taken from observed water levels and used as the initial input for the three layers in the transient Innisfil Creeks Subwatershed MIKE SHE model. After running the model from 1987-2005, the water table elevations dropped substantially for each layer stabilizing in the final five years of the simulation. The final heads of each layer from the first model run were then used in subsequent model runs, producing results similar to running the model in steady state mode.

Specific yield and specific storage parameters were kept constant.

Subsurface Drains:

Subsurface drainage is determined spatially through user-defined drainage boundaries, called drain codes. All drainage generated within the same drain code is discharged to the nearest river node within that drainage boundary. For the Innisfil Creeks Subwatershed MIKE SHE model, a drain elevation grid was created by adding 1 m to the average saturated zone water levels from Layer 1 after the initial model run. The drain codes used in the Study Area followed subwatershed boundaries, as shown on Figure 2.1.

4.2.1 MIKE SHE Calibration Update

No continuous streamflow calibration targets were available within the Innisfil Creeks Subwatershed Study Area; therefore, detailed calibration of parameters was not possible. However, to verify that the revised MIKE SHE model was appropriate for groundwater recharge characterization, predicted streamflow values were compared to available observations at three streamflow gauges in the Barrie Tier Three model area (Table 4.2). Statistical measures of fit to observed streamflows are comparable to the results produced for the Barrie Tier Three model (Table 4.2).

The underlying assumption is that the hydrologic response expected from this region is similar to what is evident in adjacent areas, i.e., the Barrie Tier Three model area. Given the similar land use, hydrogeologic characteristic, and climate, regionalization of parameters calibrated in the Barrie Tier Three model is an appropriate modelling approach.

As the required MIKE SHE model output was a recharge distribution for use in the FEFLOW groundwater model, the match to recharge values produced from the Barrie Tier Three model was used as a secondary "check". Mean recharge by soil class (Table 4.3) shows a good match between the two models. Recharge in gravel, sand, and till soil classes, which are the classes most significantly represented in the extended Innisfil Creeks Subwatershed Study Area, are within 10% of the results produced by the Barrie Tier Three model. The overall mean annual recharge rate for the study area is within 5 mm/yr of the Barrie Tier Three model results. The recharge distribution is presented on Figure 4.2.

Table 4.2: R2 and Nash Sutcliffe Efficiency Calibration Statistics

Station Name	Calibration Period	R^2	Nash-Sutcliffe Efficiency	R^2 (Barrie Tier Three Model)	Nash-Sutcliffe Efficiency (Barrie Tier Three Model)
02ED009 - Willow Creek above Little Lake	1990 - July 1995	0.65	0.56	0.73	0.61
02ED010 - Willow Creek at Midhurst	1990 - May 1998	0.65	0.62	0.75	0.50
LS0101 - Lovers Creek at Tollendal	2001-2004	0.56	0.51	0.57	0.53

Table 4.4.3: Innisfil MIKE SHE Model Mean Recharge Rates

Soil Class	Mean Groundwater Recharge (mm/yr)	Groundwater Recharge (mm/yr) (Barrie Tier Three Model)
Gravel	344	370
Sand	345	351
Silt/Till	170	181
Clay	63	30
Study Area	238	243

4.3 Groundwater Flow Model Update

The groundwater flow model for the Study Area was developed based on the FEFLOW model of the Barrie Tier Three study area (AquaResource et al, 2012b). The Barrie Tier Three model was extended to include the entire Innisfil Creeks Subwatershed and updated both in terms of local detail and calibration efforts as described below.

4.3.1 FEFLOW Model Construction Updates

Model Domain and Mesh:

The model boundary was extended to include the Innisfil Creeks Subwatershed in its entirety, expanding beyond it in the west to incorporate influence from adjacent subwatersheds. The resulting model domain is approximately 14.5 km in width (west-east) and it extends approximately 13 km in length (north-south) covering an area of 800 km^2, and the entire western portion of the Lake Simcoe Watershed.

An important consideration during the development of the model is that the finite elements be aligned with significant features in the model including locations of all wells and streams. Once this is achieved, boundary conditions can be applied at their exact locations to improve representation of their relation to the groundwater flow system (e.g., GW / SW interaction). Additionally, the mesh can be discretely refined to a higher resolution along these significant features.

The mesh for this model was refined within the LSRCA subwatersheds. Within the ambient regions of Study Area (i.e., areas outside of the LSRCA), the average element length is approximately 200 m while within the LSRCA portion of the model, the average element length is approximately 100 m. Well locations were refined to a resolution of 15 m. Streams that were not previously included during earlier versions of the model were delineated and included in the mesh design at a higher resolution than previously (15 m). The resulting mesh is shown in Figure 4.3.

Boundary Conditions:

Figure 4.4 illustrates the spatial distribution of boundary conditions assigned in the FEFLOW groundwater model.

Lateral Boundary Conditions

As mentioned above, the model domain was delineated to correspond to natural groundwater flow boundaries (groundwater divides). To revise the lateral boundary conditions around the expanded area of the model, water level contours were reviewed. Where water level trends suggested that natural flow boundaries exist (e.g., groundwater divides or along flow lines), no-flow boundaries were applied. In other cases, particularly where the deeper groundwater flow regime did not exhibit the same boundaries as the shallow regime, boundary conditions were required to allow in/outflow along these features. These boundary conditions were set as specified head according to measured water levels in the area and monitored throughout calibration to obtain the observed gradient across the boundary.

Surface Water Boundary Conditions

Within the Barrie Tier Three model, perennial surface water features were simulated in the model using specified head boundary conditions, assigned where stream discharge is known or expected to occur. Perennial streams, ponds and wetlands were initially identified using mapping provided by the LSRCA, but confirmed and modified by air photo analysis and/or field observations before being represented in the FEFLOW model (Figure 4.4). The boundary conditions were set at the stage elevations of the surface water feature, and hydraulically corrected to ensure downstream flow.

This stream network for the Innisfil Creeks Study Area ensures that all perennial streams are included within the model. To prevent streams from recharging the groundwater system, numerical constraints were applied to these boundary conditions so that flux from the nodes into the subsurface is not allowed. Numerical constraints ensure that groundwater can discharge, but do not allow the boundary condition to recharge the groundwater system. Because of the significant computational expense that such constraints have on simulation time, these constraints were only applied when needed. Typically this would occur in the headwaters areas of streams, whose upper reaches may not be perennial.

As in the Barrie Tier Three model, Lake Simcoe (including Kempenfelt Bay and Cook's Bay) was simulated in the model using specified boundary conditions applied in the upper overburden layers with a head elevation set to 218.8 metres above sea level (masl). The available bathymetry of Lake Simcoe was incorporated into the expanded area of the model so that boundary conditions of the lakes could be set in the deeper layers that they exist within, and to ensure that the locations where the hydrogeologic layers intersect the lake basin (i.e., where surface water/groundwater exchange occurs) is realistic.

Only wetland features that were known to be in direct contact with the underlying groundwater system were included as boundary conditions within the numerical groundwater model. For the majority of wetland features, particularly those where the wetland classification is not field verified, it is uncertain whether the wetland feature should be represented as an enhanced recharge zone or a discharge zone. To avoid overconstraining the simulated groundwater conditions, Where wetland conditions are unknown, such features are not included as boundary conditions on the numerical model; omitting such features allows an un-inhibited simulation of water table conditions.

Pumping Wells:

As noted above, the mesh was refined around the pumping wells to more accurately simulate the groundwater flow patterns surrounding the wells and to reduce model instability caused by high-velocity flow. The wells that are simulated under steady state conditions, along with their average daily pumping rates, are presented in the table below. The Innisfil Creeks Subwatershed has a total of 13 pumping wells, which can be seen in Figures 2.1 and 4.4, as well as summarized in Table 4.4. As described in Section 3, consumptive demand rates were updated to that obtained from the municipalities for 2011, where available, or otherwise from the 2009 WTRS.

Table 4.4: Modelled Pumping Wells

Subwatershed	Permit	Municipal System	Well Name	Pumping Rate (m^3/day)	Data Source	Easting	Northing	Purpose
Innisfil Creek (NVCA)	6313-7JMRF5	Churchill	Well 1	1.3	Churchill 2011	611517	4901437	Municipal
	6313-7JMRF5	Churchill	Well 2	0.9	Churchill 2011	611500	4901012	Municipal
	6313-7JMRF5	Churchill	Well 3	124.5	Churchill 2011	610174	4900252	Municipal
	99-P-1002		Dugout Pond	37.97	Estimated	610087	4898945	Flowers
	8531-6ASQXU		Well 1	248.55	WTRS 2009	608252	4903121	Bottl. Water
Innisfil Creeks (LSRCA)	00-P-1381	Goldcrest	Well 77-2	28	Goldcrest 2011	613277	4896669	Municipal
	00-P-1381	Goldcrest	Well 88-1	24	Goldcrest 2011	613261	4896727	Municipal
	8482-758HN2	Golf Haven	Well 1	43.99	Golfhaven 2011	616799	4898573	Municipal
	8482-758HN2	Golf Haven	Well 2	43.99	Golfhaven 2011	616801	4898564	Municipal
	0206-7HFH8Q		Well	4.43	Estimated	617102	4905839	Golf Course
	87-P-3008		Well 1	184.66	WTRS 2009	614679	4911754	Communal
	87-P-3008		Well 2	182.49	WTRS 2009	614638	4911757	Communal
	87-P-3008		Well 3	190.23	WTRS 2009	614512	4911771	Communal
Hewitts Creek	00-P-1368	Stroud	Well 1	9	Stroud 2011	610360	4909456	Municipal
	00-P-1368	Stroud	Well 2 stby	3	Stroud 2011	610356	4909438	Municipal
	00-P-1368	Stroud	Well 3	465	Stroud 2011	610386	4909474	Municipal
Lovers Creek	8306-7JYPWU	Innisfil Heights	Well 2	305	Stroud 2011	605518	4905031	Municipal
	8306-7JYPWU	Innisfil Heights	Well 3	129	Stroud 2011	605560	4904863	Municipal
	4755-73RHNU		Clubhouse	7.99	WTRS 2009	606539	4908998	Golf Course
	4755-73RHNU		Dugout Pond	129.91	WTRS 2009	606872	4909093	Golf Course
	5813-6U2S3J		Irrigation	59.59	WTRS 2009	607415	4907971	Golf Course
	5813-6U2S3J		Well 1	3	WTRS 2009	607151	4908478	Golf Course
	6824-68XPUW		Irrigation	11.31	WTRS 2009	606744	4910509	Golf Course
	8141-7BYRP2		Well 2	200	WTRS 2009	607723	4904671	Bottl. Water
	8141-7BYRP2		Well 3	200	WTRS 2009	607723	4904671	Bottl. Water
West Holland	99-P-1274		Pond	358.7	Estimated	616586	4895314	Crops

Model Properties:

The primary hydrogeologic properties assigned within the FEFLOW model for simulation of steady-state (average annual) conditions includes the hydraulic conductivity, porosity and unsaturated zone pressure-saturation properties. Since this study requires transient simulations for the drought assessment, storage was also estimated using values established through the Barrie Tier Three calibration exercise.

Hydraulic conductivity is the primary variable that controls the calculated hydraulic head distribution throughout the model domain (based on boundary condition values). In developing a groundwater model, initial estimates of hydraulic conductivities are specified and refined through the calibration process to achieve an acceptable fit to observed data. Initial conductivity estimates are based on the conceptual understanding of the geologic/hydrostratigraphic units and their hydrogeologic properties.

The majority of hydraulic conductivity estimates within the area were obtained from the final calibrated model for the Barrie Tier Three study. These estimates were reviewed alongside previous studies in the area (i.e., PTTW reports). The hydraulic conductivity distribution within each unit is represented by zones, and the conductivity within these zones is adjusted during calibration of the model.

4.3.2 Groundwater Model Calibration

Updating the model calibration included the following steps:

1. Initial model simulation using previously calibrated hydraulic conductivity values and boundary conditions as well as average annual recharge estimate obtained via surface water modelling,

2. Modification of model properties (such as hydraulic conductivity) and boundary conditions (such as interbasin flow) to improve regional calibration,

3. Provide qualitative and quantitative feedback from the groundwater model to the surface water model (i.e. changes in model properties or boundary conditions)

4. Local refinement and review of model properties and boundary conditions to improve the local model calibration,

5. Evaluation of the model flows followed by refinement of boundary conditions and hydraulic conductivity values at streams and rivers to improve simulated interaction with streams,

6. Additional identification of streams that are channelized, ephemeral or in an area known to have perched water table conditions.

During the model calibration process, the model input parameters are changed, the model is run, and the results are reviewed. The approach in this study was to initially focus on the ability of the model to represent regional flow conditions. The overall goal of the calibration was to ensure that simulated discharge to streams and wetlands was realistic. Throughout this process, checks are conducted with borehole lithologies from drill logs and background reports containing hydraulic test results, to maintain geological veracity.

Calibration Dataset:

Observed water levels (hydraulic head data) and groundwater discharge estimates are often used as targets when calibrating steady-state groundwater models. The sections below outline the calibration targets used in the groundwater flow model and the approach taken in this study to calibrate the groundwater flow model.

While a total of 2260 well water levels (obtained from the MOE WWIS) distributed across the entire Study Area were used to calibrate the Barrie Tier Three model, only 1053 of these were close enough to the Innisfil Creeks Subwatershed to be considered for local calibration. All data from those wells are considered to be of acceptable reliability (well location reliability within 100 m, as assigned through the South Simcoe Groundwater Studies, Golder, 2004), and were completed from 1980-2010. Figure 4.5 illustrates these boreholes within the Study Area. As illustrated, the majority of the available water level observations are near the Lake Simcoe shoreline.

Calibration Measures:

To ensure that the model reflects observed conditions, the simulated conditions are compared with observed conditions, including water levels and known discharge areas. Quantitative assessment of predicted and observed water levels can provide an assessment of the model calibration; however, a qualitative assessment is usually also helpful. Quantitative measures of calibration are based on residual values (the difference between simulated and observed water levels or discharge flows at a point) and include:

- Residual mean (average of all residuals)
- Absolute residual mean (average of the absolute value of all residuals)
- Root mean squared error (square root of the sum of the squares for all residuals)
- Normalized root mean squared error (root mean squared error divided by model water level range)

For this modelling effort, the normalized root mean squared (NRMS) error and the absolute residual mean (ARM) error are considered the most important. The NRMS is used to evaluate the overall calibration of the model, while the ARM is used to evaluate the calibration in more localized areas. The distribution of residuals (error between model and observed heads) should also be considered. The distribution of residuals presented as a histogram can show if there is a bias in the calculated heads, with the goal of having a normal (bell-shaped) distribution of residuals. Cumulative probability plots can show similar effects, indicating whether or not the majority of the residuals approximate a normal distribution, suggesting that the residuals are distributed randomly.

Given the expected end uses and our ability to characterize the groundwater flow system within the Study Area, a well calibrated model should exhibit the following traits:

- Normal distribution of residuals (difference between measured and observed groundwater levels) with the greatest number of residuals close to 0 m;
- Normalized root mean squared error less than 5% for groundwater level residuals. This is common

calibration target used in groundwater models and indicates a good match between observed and calculated water levels;

- Mean absolute error for groundwater level residuals for the different well fields to be less than 5 to 10 m or within the range of annual groundwater fluctuations and measuring error for the different groundwater levels; and
- Predicted equipotentials similar to equipotential maps generated using monitored data with similar flow directions and gradients where high quality information is available.

Calibration Results – Quantitative Assessment:

Figure 4.6 presents the scatter plot of observed and simulated hydraulic heads for the calibration target points. A good agreement between simulated and observed water levels was achieved. Although some small local trends can be seen, calculated water levels appear to be scattered randomly about the line of perfect fit. This distribution suggests that there is no large systematic bias in the model results. This regional match of observed and simulated water levels suggests that the numerical model represents the regional scale groundwater flow pattern to an acceptable degree. Calibration statistics for the hydraulic head calibration within the subwatershed measures are explained further below.

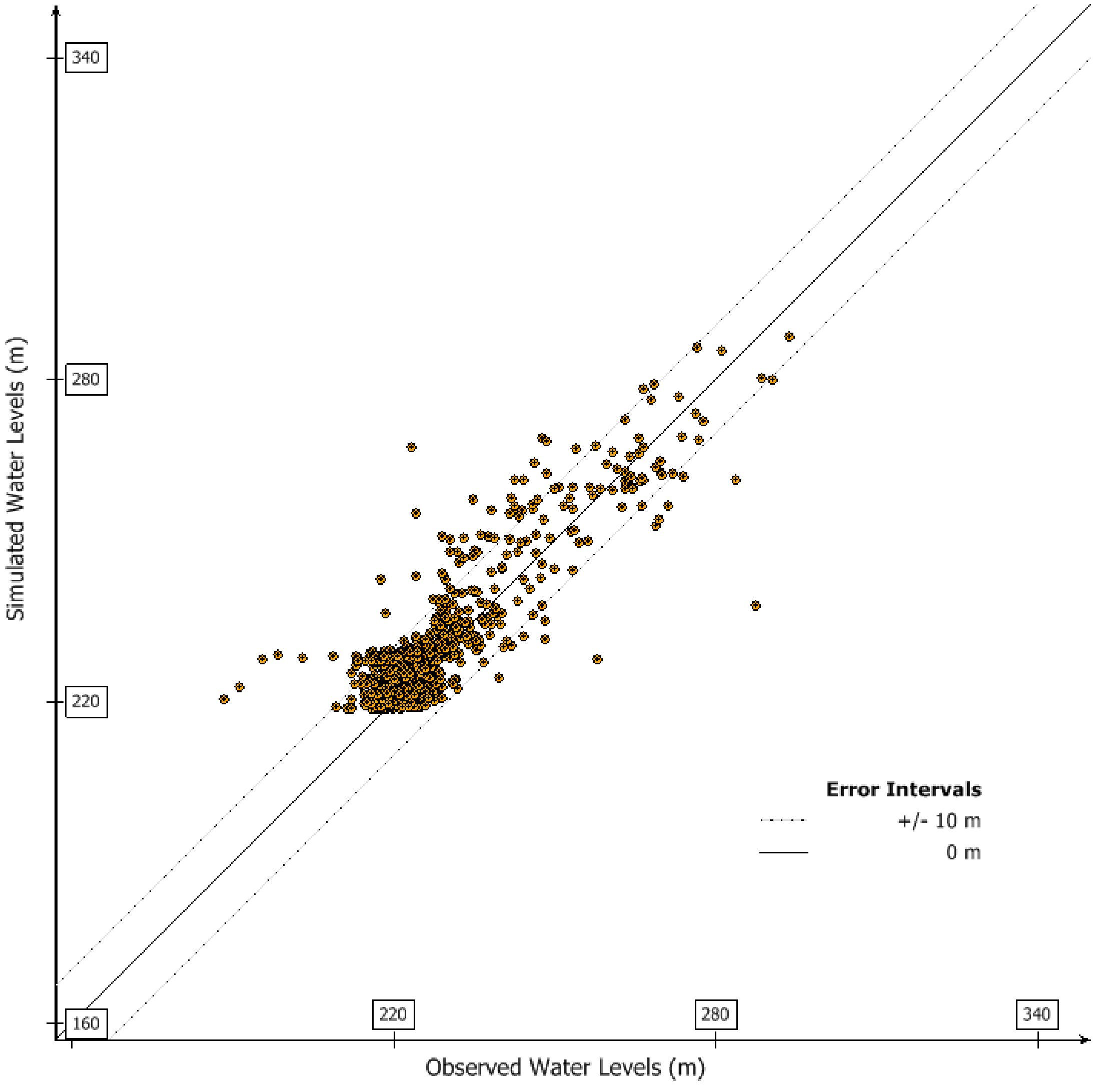


Figure 4.6: Scatter Plot

Normalized root mean squared (NRMS) error = 1.8%. This percentage value allows the goodness-of-fit in one model to be compared to another, regardless of the scale of the model. Typically, a model is considered representative with a 10% NRMS (Spitz and Moreno, 1996).

Root mean squared (RMS) error = 6.6 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 of the statistical population of predicted water levels would fall within 6.6 m of the observed value. An error of ±5 m is generally expected to be inherent in the use of water well record data, reflecting inaccuracies in well elevation and measurements. Upon inspection of the residuals, most unmatched water levels appear to be from local anomalies within the data set.

Mean Error (ME) = 2.7 m. The mean error is a measure of whether, on average, predicted water levels are higher or lower than those observed. Ideally, the mean error should be close to zero. This statistic indicates that on average, the simulated water levels overestimate the observed water level by 2.7 m, indicating that a good balance has been achieved between water levels higher and lower than simulated. This further indicates that the regional trends in water levels are well simulated.

Mean Absolute Error (MAE) = 4.6 m. The mean absolute error is a measure of the average deviation between observed and simulated water levels. The mean absolute error of 4.6 m is less than the population statistic (RMS). 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. Consequently, the value achieved within this model is only marginally above the expected noise in the data.

As previously discussed, calibration efforts were focused on the Innisfil Creeks Subwatershed and the immediate area surrounding it. Considering the entire model dataset, the calibration statistics are as follows: NRMS = 2.0, RMS = 8.0 m, ME = 1.1 m, and MAE = 5.7 m, indicating that there is also a good match to observed water levels within a regional context.

Figure 4.7 illustrates the spatial distribution of calibration residuals (simulated - observed hydraulic head) for all water level calibration targets. As this figure illustrates, there are no significant trends in residual values. Oppositely coloured symbols next to one another reflect the uncertainty in the underlying data.

A cumulative probability distribution of the model results is show in Figure 4.8. The residuals resemble a straight line in the centre portion of the normal distribution plot. This confirms that the local mismatches between the observed data and the model are random, and that there is no systematic bias in the model results. Spitz and Moreno (1996) and Hill (1998) suggest that the residuals from a calibration should be normally distributed, with a mean of zero. This infers that the largest portion of the residuals plotted on a probability plot should approximate a straight line; with the residual corresponding to 50% probability close to zero (Neville, pers. Comm. 2011). The results from the model calibration satisfy this criterion. The plot also shows that the majority of the residuals are 5 m or less.

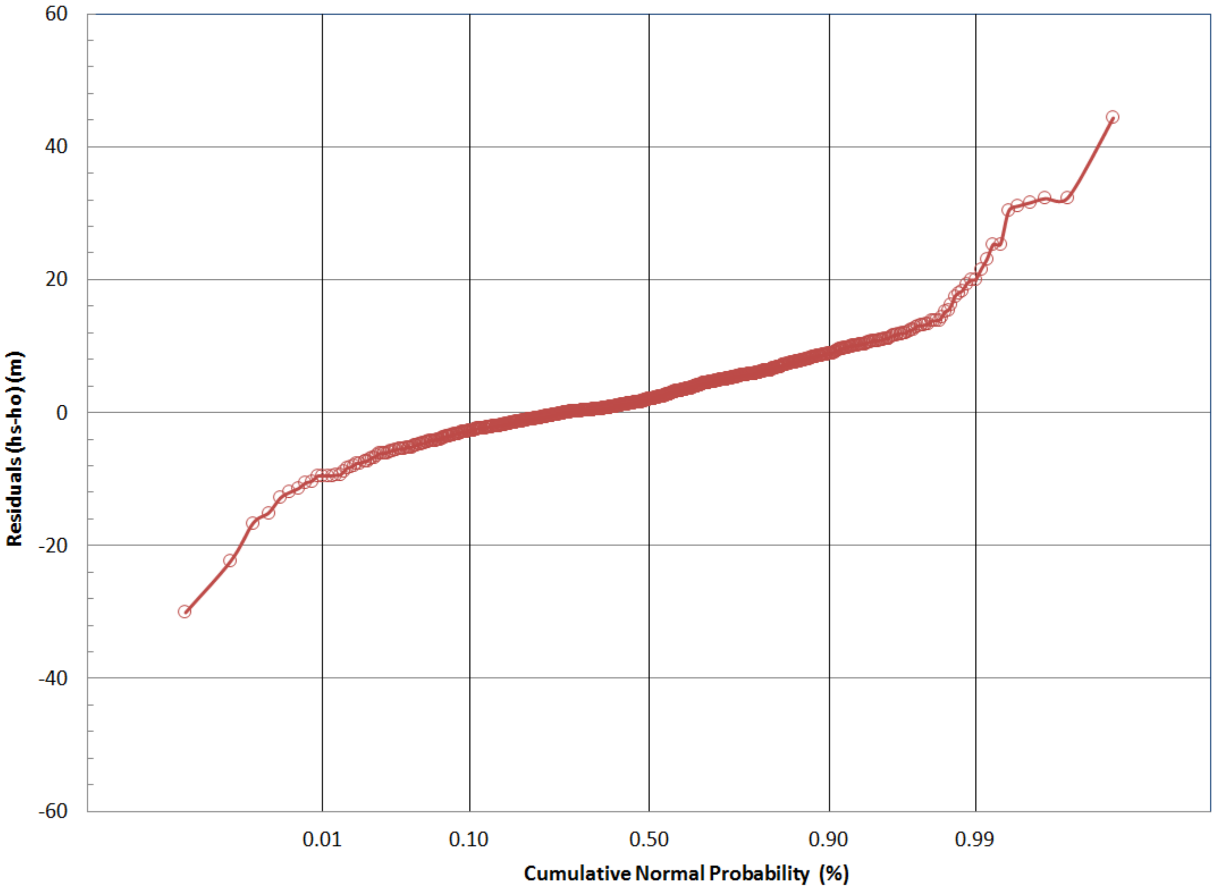


Figure 4.8 Cumulative Probability Distribution Plot

Calibration Results - Qualitative Assessment

The following section presents the model predicted water levels in the shallow (A1) and deep (A3) systems across the Study Area, as well as discharge to surface water features. These maps are compared and contrasted with the observed water level maps produced by contouring the water levels reported in the MOE water wells.

Figure 4.9 illustrates the predicted water level contours produced in the steady state groundwater flow model in the shallow aquifer. As illustrated on the figure, water table contours generally mimic the ground surface topography, and flow converges towards the higher order streams and Lake Simcoe. The largest gradients (tightly spaced contours) are observed at regional discharge locations, which include the flanks of upland regions leading towards Lake Simcoe. The lowest gradients are observed within the flat regions located within the centre of upland areas.

Figure 4.10 illustrates the deep aquifer water level elevation contours within the Study Area. The water level contours are similar to the shallow water levels however the deep water levels exhibit a more subdued expression. As with the shallow system, although the simulated equipotentials reflect the same flow gradients as the observed equipotentials, some local features within the simulated results are absent. The upgradient area between Lovers Creek and Innisfil Creeks subwatersheds is smaller in extent than that in the shallow, indicating that downward gradients are the strongest in this area.

Figure 4.11 illustrates the location and magnitude of the simulated groundwater discharge zones along streams and wetlands incorporated within the groundwater flow model. On this figure, the darkest blue circles represent the river reaches with the largest groundwater discharge. Conversely, water shown in pink on the figure indicated that the stream is either losing water to the groundwater system, or intermittent in these areas. A comparison of the discharge mapping from the model with maps produced by the Fisheries Habitat Plan (NVCA and Fisheries and Oceans Canada, 2009) and LSRCA (2010) shows that most coldwater and coolwater fishery stream reaches, both of which are known to be groundwater discharge areas, are well represented within the model. During the calibration process, stream segments that were simulated to be recharging the aquifer were compared to coldwater mapping and given a low conductance value, if warranted, such that the volume of water recharging along streams is minimal and does not negatively impact the overall water budget.

As an additional qualitative calibration check, the cross-boundary flows simulated within the larger watershed scale model (SGBWLS) were compared to those simulated within the Innisfil Creeks Subwatershed model. This comparison is helpful because the watershed scale model contains hydrogeologic information beyond the boundary of the current model and observed water levels beyond this boundary were used for calibration of that model. This comparison showed compatibility between the two models, in both flow direction and magnitude.

4.4 Model Update Summary

The modeling tools developed for the Innisfil Creeks Subwatershed Tier Two Stress Assessment have been shown to be well calibrated and appropriate for Tier Two Water Budget Assessment.

The ability of the updated groundwater model to simulate the flow system in the Study Area was evaluated both qualitatively and quantitatively. Qualitatively, the simulated groundwater level contours are consistent with observed conditions. The elevations of prominent wetlands in the area were also overlain with model results to ensure modelled water levels were representative of these wetland elevations. Modelled stream discharge was also compared to mapped coldwater regimes. Quantitatively, simulated hydraulic head values closely match observed values within the acceptable statistical range, while reproducing observed flow directions and gradients. Regionally, the error based on the difference between observed and simulated water levels is minimized and there are no significant spatial trends in this error that would potentially impact predictions. Overall, the calibration results show that the model is suitably calibrated for a Tier Two Assessment and that the model can be used as a tool for Ecologically Significant Groundwater Recharge Area mapping.

5 WATER QUANTITY STRESS ASSESSMENT

The approach for conducting a Tier Two Stress Assessment is outlined in the Province's Guidance Module for Water Budget and Water Quantity Risk Assessment (MNR and MOE, 2011). This Guidance Document prescribes an approach for evaluating subwatershed stress based on estimates of water supply, water reserve, and water demand in each subwatershed. While the Technical Rules (MOE, 2009) and the Water Budget and Risk Assessment Guide (MNR and MOE, 2011) provide a standard approach for carrying out the Tier Two Stress Assessment, this approach was tailored for this study within the context of the Lake Simcoe Protection Plan, in which the interconnection of groundwater to surface water features are a priority. The methodology and results of the Tier Two Water Budget and Stress Assessment for the Innisfil Creeks Subwatershed are discussed in detail in the following sections.

5.1 Stress Assessment Methodology

A subwatershed's potential for hydrologic stress is evaluated by comparing the amount of water consumed with the amount of water available, by utilizing the Percent Water Demand calculation. As outlined in Technical Rules (MOE, 2009) and the Water Budget and Risk Assessment Guide (MNR and MOE, 2011), the Percent Water Demand is calculated using the following formula:

$$\textit{Percent Water Demand} \quad = \quad \frac{Q_{DEMAND}}{Q_{SUPPLY} - Q_{RESERVE}} \times 100\%$$

The terms are defined below:

- Q_{DEMAND} is equal to the consumptive demand calculated as the estimated rate of locally consumptive takings.
- Q_{SUPPLY} is the water supply term, calculated for groundwater supplies as the estimated annual recharge rate plus the estimated groundwater inflow to a subwatershed.
- $Q_{RESERVE}$ is the water reserve, defined as the specified amount of water that does not contribute to the available water supply. Groundwater reserve is calculated as 10% of the total estimated groundwater discharge to surface water within a subwatershed.

For groundwater systems, the stress assessment calculation is carried out for the average annual demand conditions and for the monthly maximum demand conditions; groundwater supply is considered constant under both these conditions. The stress level for groundwater systems is also categorized into three levels (significant, moderate or low) according to the thresholds listed in Table 5.1.

Table 5.1: Groundwater Potential Stress Thresholds

Groundwater Potential Stress Level Assignment	Average Annual Percent Water Demand	Monthly Maximum Percent Water Demand
Significant	> 25%	> 50%
Moderate	> 10%	> 25%
Low	0 – 10%	0 – 25%

Percent Water Demand is calculated for three different demand scenarios: 1) existing water demand; 2) planned water demand; and 3) future water demand estimates. Under each scenario, the potential for stress is evaluated by comparing the amount of water consumed (consumptive water demand) with the amount of water available (water supply). Only those subwatersheds identified as having a low potential for stress under the existing demand require assessment for the planned and future demand scenarios (i.e., once a subwatershed stress assessment is determined to be moderate or significant, further scenarios are not warranted).

Once the existing, planned, and future demand scenarios are completed, the subwatersheds still classified as having a low potential for stress are subject to the drought assessment scenario. Typically, the drought scenario involves evaluating the ability of the existing or planned wells to maintain the ability to meet demand throughout potential drought conditions (a two-year and ten-year period of drought). The two-year drought is intended as a screening tool to represent a relatively short duration, acute climatic condition that would impact shallow groundwater systems. This drought period is simulated by removing all groundwater recharge over a two-year period. If the screening scenario shows possible impacts on groundwater levels over the two-year period, a drought scenario should be completed using a longer term (i.e., ten years) climate period that represents historical drought conditions.

While the two year drought is intended to represent acute conditions that impact the shallow system, the ten-year drought represents long-duration conditions where impacts may reach deep groundwater systems. This approach recognizes the elasticity of deep groundwater systems and their inherent ability to naturally compensate for short-duration drought periods. However, for the purposes of the LSPP, the Drought Assessment Scenario involved assessing the impacts on discharge to surface water features.

As this study is focused on the potential impact to surface water features, the drought assessment scenario is based on potential changes to the available water supply to surface water features.

5.2 Water Budget Results

As part of the water budget process, estimates of the water budget component fluxes were examined across the Study Area. it is important to note that the Lake Simcoe boundary is considered as its own subwatershed area, so that shallow discharge occurring on the Lake's boundary conditions, as well as deep cross boundary flow within the subsurface below the Lake, can both be quantified. Both components are considered discharge to the lake.

Table 5.2 summarizes the estimated overall groundwater fluxes for the Innisfil Creeks subwatershed. The table summarizes watershed inflows including recharge and groundwater inter-basin flow. Outflows include stream discharge, groundwater pumping, and groundwater inter-basin flow. The water budget parameters are calculated based on information derived from both the surface water and groundwater flow models and are presented in units of m^3/d and mm/year. In addition to hydraulic head, Figure 5.1 illustrates the estimated cross-boundary groundwater flow between the Innisfil Creeks subwatershed and adjacent subwatersheds. These values are referenced in Table 5.2.

Table 5.2: Water Balance

	Flows		
Inflow Components	**(m^3/d)**	**(L/s)**	**(mm/yr)**
Groundwater Recharge	63,500	735	216
Flow from Innisfil Creek Subwatershed (NVCA)	1,570	18	5.3
Flow from Hewitts Creek Subwatershed	80	1	0.3

Total Groundwater Inflow	**65,150**	**754**	**221**
Outflow Components	**(m³/d)**	**(L/s)**	**(mm/yr)**
Surface Water Discharge	43,900	508	149
Streams and Wetlands	*18,500*	*212*	*63*
Lake Simcoe (Top Slice)	*25,400*	*294*	*86*
Permitted Wells	700	8	2
Flow to Lovers Creek Subwatershed	40	0	0.1
Flow to Cooks Bay (Subsurface flow)	13,510	156	46
Flow to Kempenfelt Bay (Subsurface flow)	7,000	81	24
Total Groundwater Outflow	**65,150**	**754**	**221**

*Notes:
1) Groundwater takings presented in this table do not include non-permitted water demand, as this was not simulated within the groundwater flow model.
2) Totals may differ due to rounding

Average annual recharge in this area is approximately 216 mm/year. Average annual base flow is 63 mm/year from all streams and wetlands across the subwatershed. Approximately 155 mm/yr of groundwater flows out of the subwatershed to the subsurface under Lake Simcoe.

As stated above, the Innisfil Creeks subwatershed was not incorporated within the SGBWLS Tier Two water budget calculations. However, a comparison of water budget terms to the Lake Simcoe Tier One water budget (LSRCA, 2009) show consistency between the two assessments, with slightly lower pumping quantities within the present study. Lower pumping rates are attributed to the shutdown of the Alcona Well field as well as using updated WTRS reporting estimates, as opposed to applying assumptions based on the permitted rates of privately permitted wells. It should also be noted that groundwater cross boundary flows between subwatersheds were not explicitly considered within the Tier One Water Budget calculations.

5.3 Stress Assessment

This section documents the evaluation of the Tier Two Water Quantity Stress Assessment for groundwater supplies in the Innisfil Creeks subwatershed. Ultimately, the goal of the Water Quantity Stress Assessment is to identify if there is a potential for water quantity-related stress. The potential for stress is estimated by comparing the ratio of water demand to water supply under existing, planned and future conditions. A drought scenario identifies any streams that have the potential to be threatened by drought conditions.

5.3.1 Percent Water Demand - Existing Conditions

5.3.1.1.1 Groundwater Consumptive Water Use

The consumptive groundwater demand refers to all groundwater which was removed from the groundwater system and not returned to the same system within a reasonable amount of time. This was estimated for both permitted and non-permitted groundwater takings. These estimates (shown in Table 5.3) are used to compute the subwatershed potential stress under existing conditions.

Table 5.3: Consumptive Use

Demand	**Takings (m^3/day)**	**Source**
Non-permitted Agricultural	46	LSRCA Tier One Study
Un-serviced Domestic	552	LSRCA Tier One Study
Private Permits	4.4	2009 Water Taking Reporting System, Estimates from 2009 PTTW database
Municipal Permits	697.4	2011 Municipality Pumping Data
Total	**1300**	

5.3.1.1.2 Groundwater Supply and Reserve

Groundwater supply is calculated as the average annual groundwater recharge plus the amount of groundwater flowing laterally into the subwatershed (Flow In – See Table 5.2). The expanded MIKE SHE model predicted groundwater recharge over the Study Area. The FEFLOW model estimated the groundwater flow between subwatersheds.

Groundwater reserve is calculated as 10% of the estimated groundwater discharge to surface water streams within the subwatershed. Groundwater discharge to streams was estimated by the FEFLOW groundwater flow model.

5.3.1.1.3 Percent Water Demand Results

Percent Water Demand for groundwater was calculated for the subwatershed using estimates of groundwater supply, groundwater reserve, and consumptive demand described above, with the Percent Water Demand equation presented in Section 5.1. The results of the Stress Assessment under existing conditions are shown in Table 5.4.

Table 5.4: Stress Assessment Components and Percent Water Demand

Component		**Flow (m^3/day)**
Groundwater Supply	Recharge	63,500
	Flow In	1,650
	Total	65,150
Groundwater Reserve		4,390
Consumptive Demand	Annual Average	1,300
	Monthly Max	1,514
% Water Demand	Annual Average	2%
	Monthly Max	2%

As presented in Table 5.4, potential for stress levels using the Percent Water Demand under existing conditions is below the “low” thresholds presented in Table 5.1 (10% for annual average, and 25% for monthly maximum). Therefore, further analysis under future conditions is warranted. A comparison to the Tier One stress assessment shows that the level of risk is comparable. The groundwater consumption in 2011 compared to that in 2008 is slightly lower, due to the switch to a surface water drinking water supply within the town of Alcona.

5.3.2 Percent Water Demand - Future Conditions

To evaluate the Percent Water Demand under future conditions, the consumptive water demand was estimated for a future population throughout the planning horizon. In general, this planning horizon is intended to extend to the year 2031. Future conditions were estimated as follows:

1. Future municipal demand for the average annual demand and monthly max was estimated by applying a factor of 1.5. This was determined using the growth factors determined from the SGBWLS Tier Two study.

2. The water supply component was computed using future land use projections to estimate changes in groundwater recharge. This was accomplished by modifying the recharge rates according to projected changes in urban land use. Recharge modification for future conditions was assumed to be based on the change in urban area alone. For this subwatershed, the total recharge volume was decreased by 4%, based on estimates supplied in the SGBWLS project and assuming that any additional urbanized area would have a 50% impervious cover. The projected groundwater recharge rates were used with the groundwater flow in under existing conditions as the water supply term for the Percent Water Demand under future conditions.

3. Water reserve and groundwater inflows were assumed to remain unchanged from existing conditions.

The results of the Percent Water Demand (Table 5.5) under future conditions indicate that the potential for stress level is low.

Table 5.5: Stress Assessment Components and Percent Water Demand – Future Conditions

Component		Flow (m^3/day)
Groundwater Supply	Recharge	60,960
	Flow In	1,650
	Total	62,610
Groundwater Reserve		4,390
Consumptive Demand	Future	1,651
	Monthly Max	2,408
Water Demand %	Annual Average	3%
	Monthly Max	4%

As presented in Table 5.4, potential for stress levels using the Percent Water Demand under projected future conditions is below the “low” thresholds presented in Table 5.1 (10% for annual average, and 25% for monthly maximum). Therefore, further analysis under drought conditions is warranted.

5.4 Drought Scenario

According to the Technical Rules (MOE, 2009), subwatersheds can also be identified as having a potential for moderate stress if water levels at pumping wells (Rule 35.2.e) are not sufficient for either normal operation or requires shutdown. The Technical Rules identify a two-year and a ten-year drought scenario (Rule 35.2.f/g) to identify these risks, as discussed in Section 5.1. These scenarios are designed to capture probable periods of drought conditions for both short- and long-durations. For the purpose of this study, the same scenarios were designed, but were employed to analyze the effect of drought on the health of local streams and wetlands, rather than at municipal pumping wells. The simulation of drought scenarios offers an excellent opportunity to evaluate the change in frequency, duration and timing of the groundwater contribution to surface water features within the subwatershed. These aspects of the discharge regime are important to consider when evaluating impacts to important ecological features.

It is important to note that time-varying water level and stream discharge data were not available to calibrate the model to such conditions, and as such the model simulation of drought conditions is used to indicate potential for drought impacts, rather than expected variability under drought conditions.

5.4.1 Two Year Drought Assessment - Methodology

The two-year drought scenario represents a period where all groundwater recharge is eliminated for a period of two years, while pumping is maintained at average conditions. With this scenario, initial conditions for the transient groundwater flow model were set equal to the steady-state calibrated conditions, all recharge is eliminated and the model is run for two years. At the end of the drought scenario period, modelled groundwater discharge to streams are compared to steady state conditions to quantify a relative decrease in discharge to the streams from the groundwater system.

Two Year Drought Assessment - Results

As seen in Table 5.6, all of the creeks and wetlands experienced drastic decreases in simulated discharge throughout the two year drought scenario. A comparison of the tabular and spatial discharge information indicates that the portions of the surface water discharge most impacted by the recharge elimination (drought) are those that contribute the majority of discharge to the streams. In addition, field observations (LSRCA, 2008) indicate that the streams in the watershed are prone to intermittent conditions, indicating that they are supplied mainly with either shallow groundwater discharge, or surface water drainage. However, since a scenario in which recharge is eliminated entirely for two years is highly improbable, a ten-year drought scenario is warranted to further quantify the impacts on surface water features.

Table 5.6 indicates the steady state discharge conditions, the discharge conditions after two years of eliminating recharge and the percent difference in each surface water feature within the Study Area. Figure 5.2 shows a map of the spatial distribution of impacts along each surface water feature, illustrating which stream segments are predicted to experience higher or lower degrees of impact. Flow reductions at individual nodes are presented on Figure 5.2 to reflect the hypothetical nature of this simulation (low: 0-25%, moderate: 26-50%, significant: >50%).

As seen in Table 5.6, all of the creeks and wetlands experienced drastic decreases in simulated discharge throughout the two year drought scenario. A comparison of the tabular and spatial discharge information indicates that the portions of the surface water discharge most impacted by the recharge elimination (drought) are those that contribute the majority of discharge to the streams. In addition, field observations (LSRCA, 2008) indicate that the streams in the watershed are prone to intermittent conditions, indicating that they are supplied mainly with either shallow groundwater discharge, or surface water drainage. However, since a scenario in which recharge is eliminated entirely for two years is highly improbable, a ten-year drought scenario is warranted to further quantify the impacts on surface water features.

Table 5.6: Two Year Drought Assessment Results

Water Body	**Average Groundwater Discharge under Normal Conditions (m3/day)**	**Average Groundwater Discharge under Drought Conditions (m3/day)**	**Percent Reduction**
Banks Creek (#5)	200.30	0.04	100%
Belle Aire Creek (#7)	56.37	0.17	100%
Big Bay Point Wetland	9.31	0.00	100%
Bon Secours Creek (#4)	957.88	17.11	98%
Carson Creek (#8)	76.09	0.29	100%
Gilford Creek	18.08	0.00	100%
Holland Marsh Wetland	6,236.83	0.00	100%
Leonard's Beach Swamp	1,747.29	0.00	100%
Leonard's Creek (#3)	605.93	16.99	97%
Little Cedar Point Wetland	5,878.21	356.19	94%
Mooselanka Creek (#2)	18.10	0.02	100%
Sandy Cove Creek (#1)	6,738.34	26.90	100%
Unnamed Innisfil Wetland	477.27	0.00	100%
Upper Marsh Creek	1.37	0.00	100%
White Birch Creek (#10)	250.31	0.20	100%
Wilson Creek (#9)	223.34	0.01	100%
Wilson Creek Marsh	1,228.97	0.00	100%

5.4.2 Ten Year Drought Analysis - Methodology

The ten-year drought scenario consisted of transient groundwater flow modelling using estimated monthly recharge rates over a prolonged, observed period of drought. Initial conditions for the transient groundwater flow model were set equal to steady-state conditions. Throughout the drought scenario period, base flows as well as water levels at wetlands were compared to steady state conditions to quantify the decrease in discharge to the streams from the groundwater system. Features monitored throughout those simulations are illustrated on Figure 2.6.

Transient recharge data from January 1995 to December 2005 (10 years) was obtained from the calibrated MIKE SHE model. This time period was selected to simulate the effects of a drought period similar to that which was experienced in the late 1990s (see Figure 5.3).

To apply the MIKE SHE recharge data, the magnitude of recharge produced throughout precipitation events was characterized for four separate surficial soil types: clay, till, sand, and gravel. Figure 5.4 illustrates the recharge variation for each of these four soil classes. Monthly recharge multipliers were derived for each of the four surficial soil types throughout the 10 year simulation and are shown on Figure 5.4.

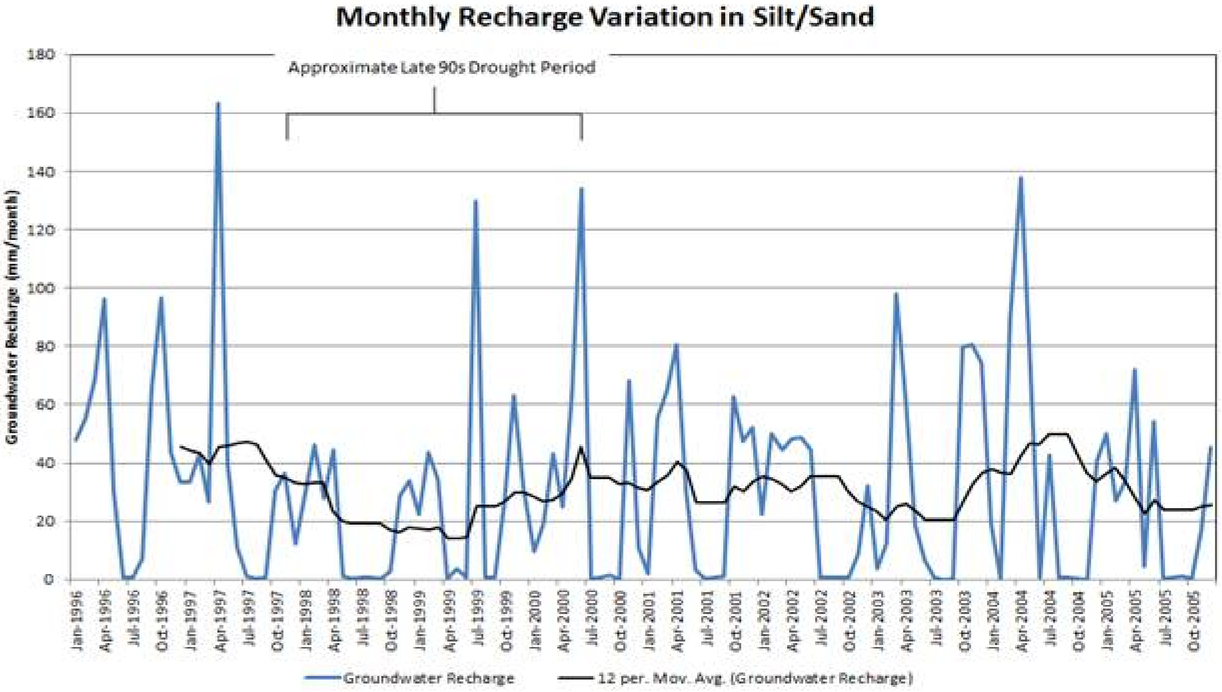


Figure 5.3: Estimated Recharge Variability with Moving Average

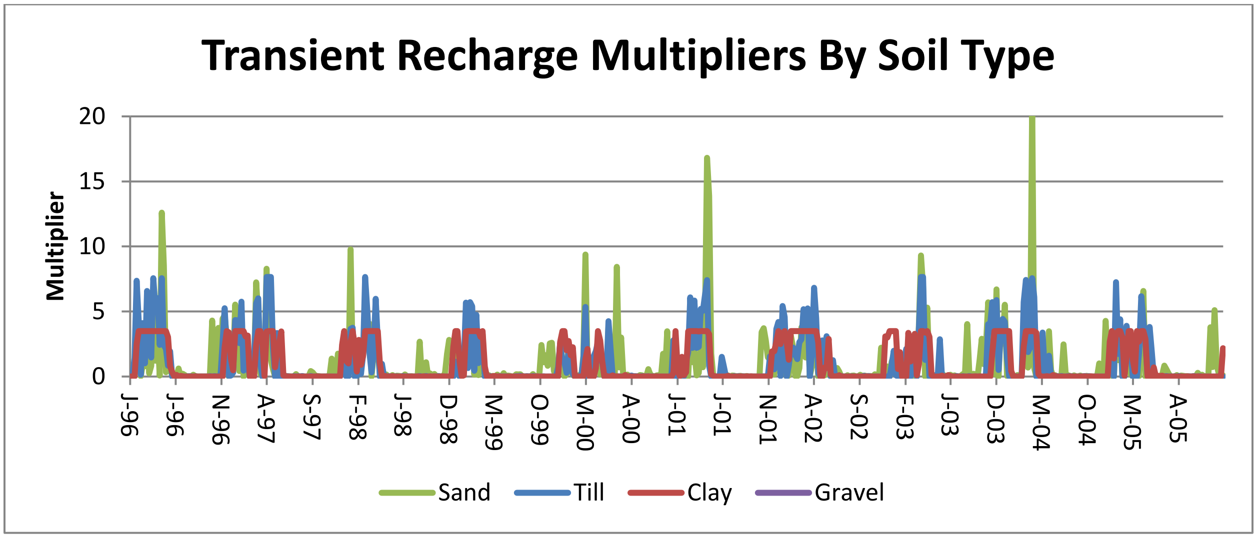


Figure 5.4: Transient Recharge Variation

These recharge multipliers represent variability from the average annual groundwater recharge and are assumed to be representative of relative changes in the climate across the Study Area over the simulation period. Similarly, it is assumed that monthly adjustments to recharge are an appropriate temporal simplification of the daily recharge estimates.

The FEFLOW steady-state groundwater flow model, described in Section 4, was configured to use the time series of monthly recharge adjustment factors for the complete 1995-2005 simulation. Within each month, the simulation time step was automatically adjusted to achieve a mass-conservation numerical solution, and the multipliers illustrated above were applied to the calibrated steady state recharge value in the FEFLOW model. It should be noted that the FEFLOW model used for this analysis has not been calibrated to transient observations (neither surface water nor water level information) within this portion of the Study Area. As such, the results from the drought scenario are considered to provide an indication of potential water level fluctuations only.

The FEFLOW model was adapted using in-house programming modules to capture the response of the streams and wetlands during the drought period. The simulated response of the wetlands was assessed by monitoring the water levels below the area of the wetland relative to that in the steady state model. The response of the streams was assessed by monitoring changes in modelled base flow. The purpose of the ten-year drought analysis was to identify any natural heritage feature within the Innisfil Creeks subwatershed that has the potential to be affected by a sustained period of low recharge such as those experienced during historical drought conditions.

5.4.3 Ten Year Drought Analysis - Results

Stream nodes within the Innisfil subwatershed were represented by Type I boundary conditions, which facilitated transient monitoring of base flow through FEFLOW 6.1's rate budget tool. Nodal selections were created for each individual reach and the sum of those nodes was calculated to determine the total budget rate (i.e. discharge) for a particular reach. A total of 11 reaches were monitored. Prior to the transient run, the water budget at each reach was reviewed at steady state, and nodes recharging suspiciously large quantities of water to the model under steady state (i.e. nodes supplying greater than 5 m^3/d, typically found near headwaters) were identified and constrained in an effort to prevent unlikely water sources throughout the drought period.

The discharge for each reach was recorded at monthly time steps as shown in Figure 5.5. This figure shows the absolute change in groundwater contribution to streams throughout the transient simulation on a log scale. Gilford and Upper Marsh Creek were simulated to not have sustained base flow conditions, and therefore could not be plotted on a log scale. This indicates that both Gilford and Upper Marsh Creek receive little groundwater contribution; this is consistent with field observations (LSRCA, 2008).

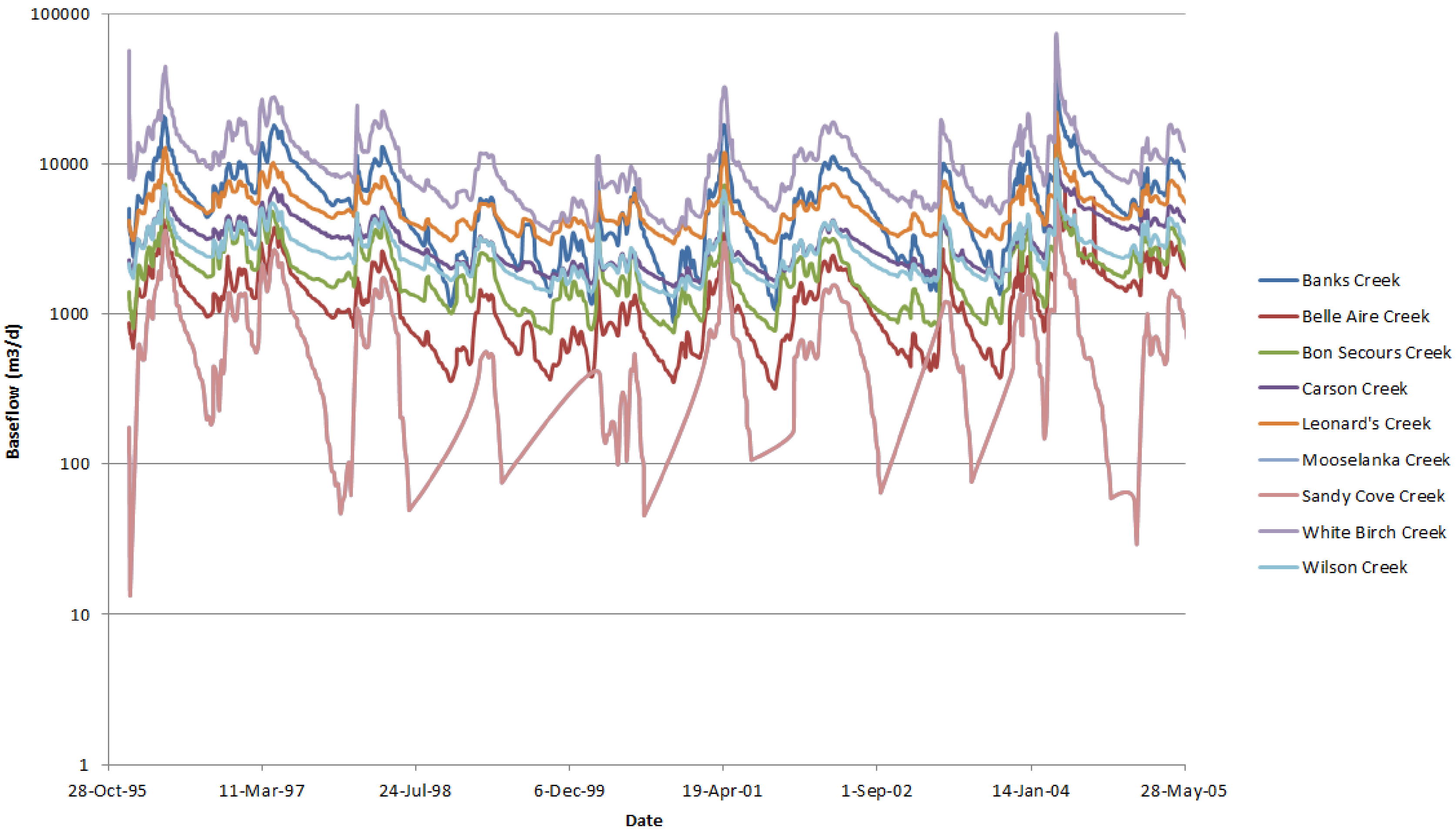


Figure 5.5: Simulated Temporal Groundwater Discharge to Stream Reaches (1995 - 2006)

The simulated groundwater contribution to Gilford, Upper Marsh, Mooselanka, Banks and Sandy Cove Creeks was found to be more sensitive to changes in recharge than the other creeks in the Study Area. Carson, Leonard's and Wilson Creek showed relatively little change in groundwater contribution throughout the simulation. This indicates these streams may not be as susceptible to maintaining a cold water discharge conditions throughout periods of drought. Table 5.7 presents the amount of time that the streams received decreased amounts of groundwater discharge, in percentage of the entire simulation period. For example, for 41.7% of the simulation period, Mooselanka Creek received 30% less groundwater discharge during the drought period, as it receives on an average annual basis.

Table 5.7: Simulated Base flow Changes throughout Drought Period

	% Time During Simulation Period		
Reach	**Base flow below Steady State Conditions**	**Base flow at least 15% below Steady State Conditions**	**Base flow at least 30% below Steady State Conditions**
Mooselanka	**45.8%**	**45.0%**	**41.7%**
Sandy Cove	**45.8%**	**45.0%**	**41.7%**
Gilford	**91.7%**	**61.7%**	**39.2%**
Upper Marsh	**97.5%**	**59.2%**	**34.2%**
Banks	**34.2%**	**28.3%**	**21.7%**
Belle Aire	**35.8%**	**29.2%**	**20.0%**
White Birch	**40.8%**	**29.2%**	**18.3%**
Bon Secours	**34.2%**	**21.7%**	**12.5%**
Wilson	**35.8%**	**20.8%**	**5.8%**
Carson	**31.7%**	**13.3%**	**0.8%**
Leonard's	**35.0%**	**13.3%**	**0.8%**

Wetlands were monitored via a customized module created and tested specifically for this study. This module exports heads from the FEFLOW model at specified nodes over a series of specified time steps. As no transient water level observations were available to calibrate the model, simulation results are used to provide an indication of potential variability only.

For each wetland complex within the Innisfil Creeks Subwatershed, the average groundwater level was monitored throughout time. Approximately 4000 nodes, representing portions of the spatial footprint of each of the 5 wetland features, were monitored monthly over the ten-year time period. For each time step, heads for each wetland complex were averaged to represent that wetland's average water level variability. The relative change in this average water level was monitored over time (relative to steady state) to evaluate the relative water level variability beneath each wetland complex.

Figure 5.6 shows relative water levels at five major wetland complexes monitored throughout the transient simulation. Several wetland features were simulated to have significant fluctuations in groundwater levels beneath the wetland, which may indicate susceptibility to varying climatic conditions.

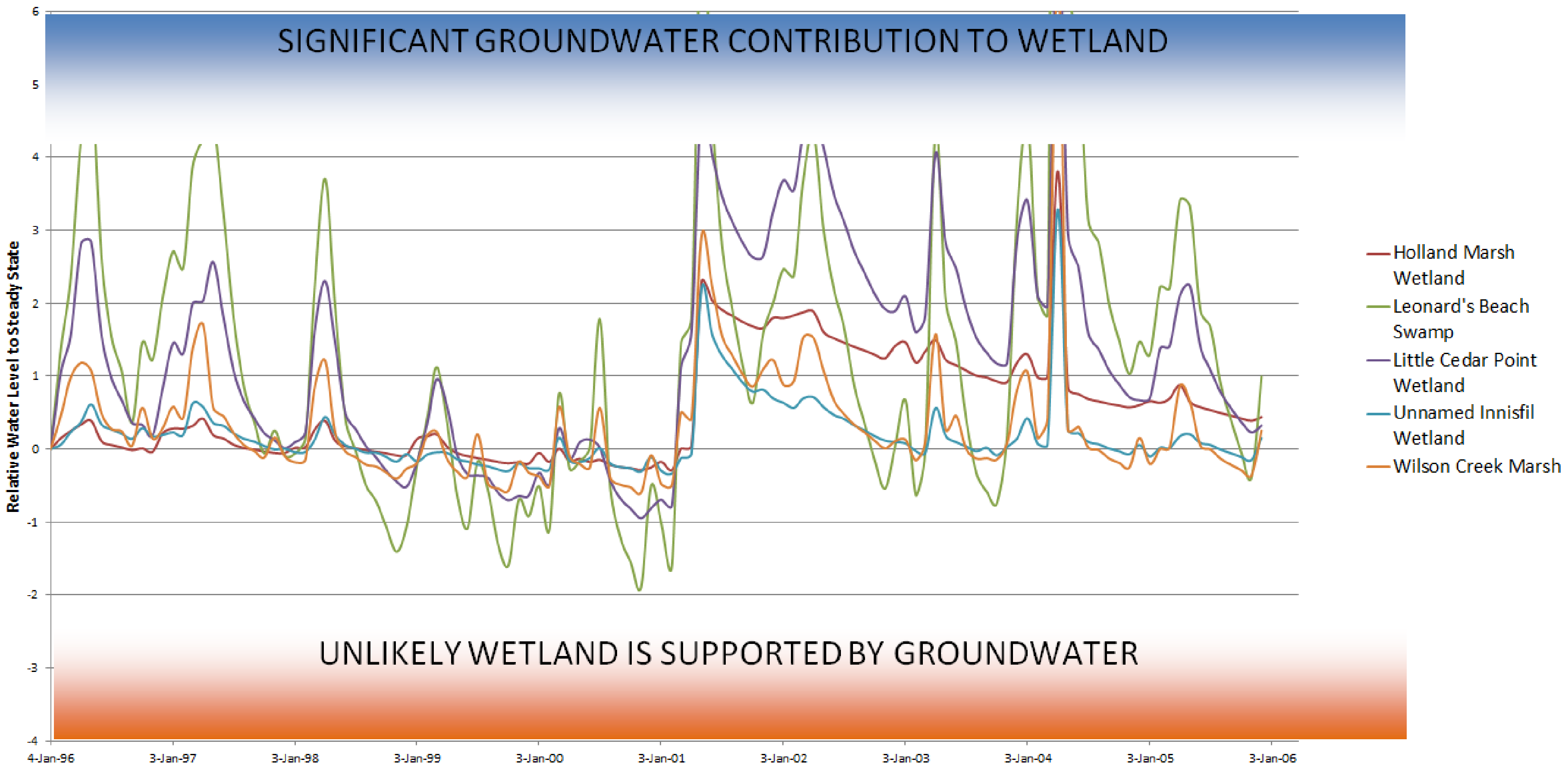


Figure 5.6: Simulated Temporal Response of Groundwater Levels Below Major Wetlands (m)

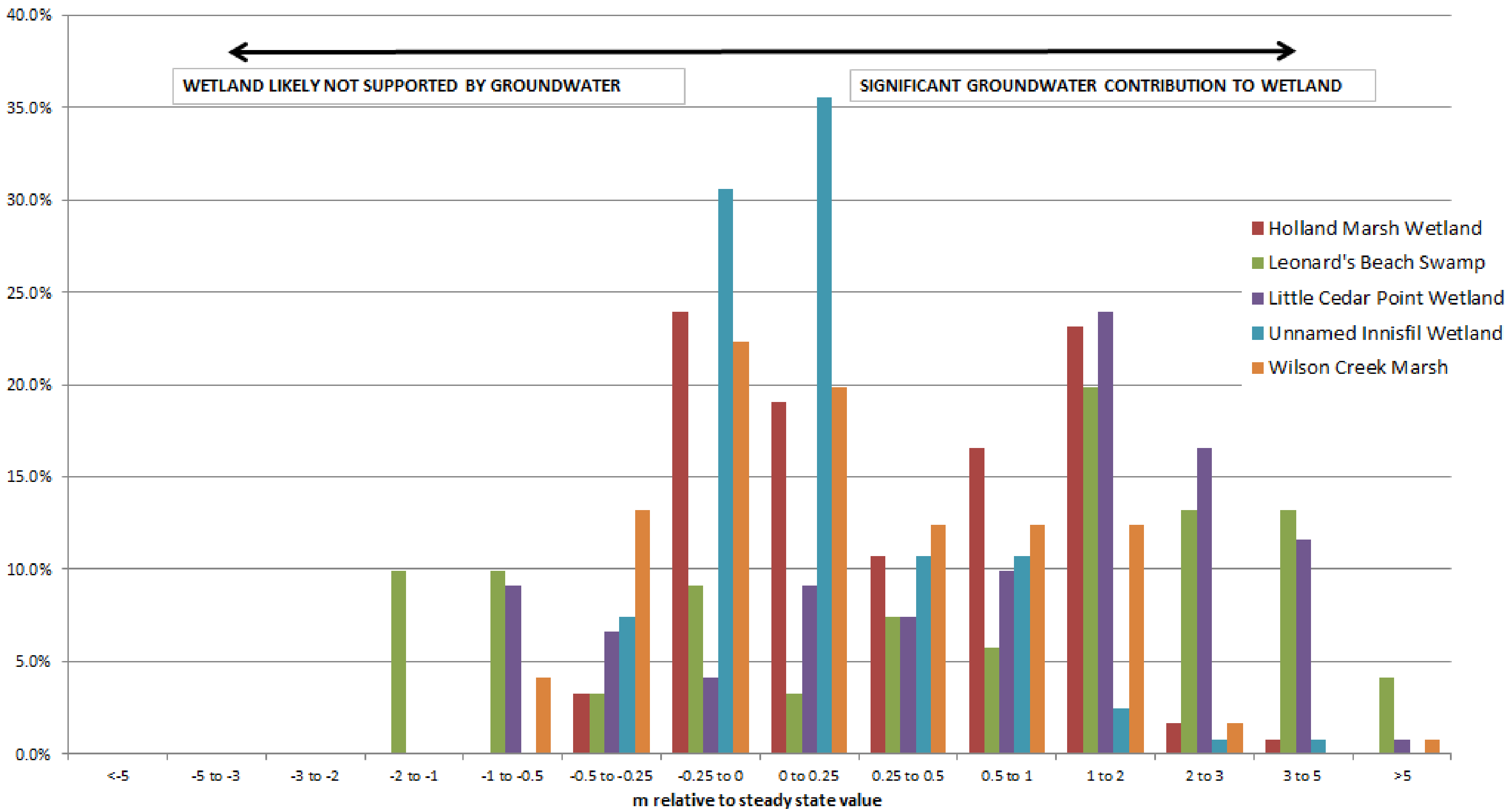


Figure 5.7: Simulated Water Levels Relative to Steady State

All wetland stages dropped significantly through the late 1990s drought period, indicating that each wetland may be susceptible to prolonged drought conditions. Figure 5.7 shows that some wetlands fluctuate more under changes in recharge than others (Leonard's Beach Swamp, Little Cedar Point) while others experienced minimal changes in water level throughout the simulation (Wilson Creek Marsh and the Unnamed Innisfil Wetland).

5.5 Summary and Discussion of Groundwater Stress Assessment Results

Based on the Percent Water Demand for existing and future conditions, the overall groundwater Tier Two Stress Assessment of the Innisfil Creeks Subwatershed indicated that there is a Low Potential for stress both with average and maximum demand. It should be noted that there are no planned systems within the subwatershed; therefore the calculation for planned systems was not necessary. Furthermore, it has been established during the completion of this assessment that the community of Golfhaven (Gilford) has transitioned to a surface water supply, indicating that the potential for stress has further decreased.

As part of the Tier Two assessment, a drought evaluation was also completed. Rather than assess the risk of drought conditions to the groundwater supply wells, the simulations monitored the response of the streams and wetlands in the area. It is important to note that time-varying water level and stream discharge data were not available to calibrate the model to such conditions, and as such the model simulation of drought conditions is used to indicate potential for drought impacts, rather than expected variability under drought conditions.

A preliminary two-year drought scenario applied to the groundwater model showed that most of the streams within the subwatershed responded drastically to this scenario, therefore a more complex ten-year drought scenario was completed. A historical time period of 1995-2005 was selected to simulate the effects of a drought period similar to that which was experienced in the late 1990s. Within this drought scenario, all creeks experienced reductions in base flow during the simulated drought period; however, Mooselanka, Sandy Cove, Banks, Gilford, and Upper Marsh Creeks showed a higher level of sensitivity to the drought period. Wetlands that were simulated to have a higher sensitivity to the simulated drought period include Leonard's Creek Swamp and Little Cedar Point wetland.

6 ECOLOGICALLY SIGNIFICANT GROUNDWATER RECHARGE AREA (ESGRA) DELINEATION METHODOLOGY

Ecologically Significant Groundwater Recharge Areas (ESGRAs) are areas of land that support groundwater systems which in turn sustain sensitive features like coldwater streams and wetlands. To establish ecological significance, a linkage must be defined between areas of recharge and discharge.

The approach established to delineate ESGRAs, as documented in (EarthFX, 2012), was applied wherever practical. This approach results in the delineation of portions of recharge areas within this study as being ESGRAs. ESGRAs are intended to complement significant Groundwater Recharge Areas (SGRAs) developed through source protection studies. SGRAs encompass areas of higher volume recharge, and thus the ESGRA methodology was developed to delineate additional contributing areas and enhance protection for ecological features.

Consistent with the established ESGRA methodology, the required approach for this study was to employ reverse particle tracking as the main method of delineation and rely on alternative methods only where particle tracking was not feasible (i.e. in cases when a feature is not simulated to receive discharging groundwater). For those areas where particle tracking was effective, the areas designated as an ESGRA were delineated as a subset of the contributing area using a statistical method known as Kernel Density Estimation (sometimes referred to as cluster analysis). The following sections define these techniques and outline how they were employed to delineate areas of contribution to a significant feature.

Beyond the established ESGRA approach, it is acknowledged that several techniques may be used to determine recharge-discharge linkages, including topographic analysis (particularly for shallow perched aquifers above the regional system), forward and reverse particle tracking (numerical models), or contaminant transport methods (numerical models).

6.1 Particle tracking techniques

Particle tracking is a technique commonly used in many types of numerical modelling to illustrate the pathways a fictitious particle of water (and associated dissolved solute) may take through porous media. This approach can be used to illustrate potential linkages between recharge and discharge zones and provides an estimation of advective travel times associated with those pathways. The same approach is commonly used to delineate zones of contributions to production wells, commonly referred to as capture zone analysis. A zone of contribution is defined as a geographical area where recharging water that enters the groundwater flow system that will be eventually discharged at the receptor.

Particle tracking techniques can be executed two ways: forward tracking in the direction of flow, or reverse tracking in the reverse flow direction. Forward particle tracking involves releasing a set of particles proximal to a recharge location (e.g. surficial recharge, injection well, losing surface water feature etc.) and tracking them forward in time and space to the point where they reach a discharge condition (e.g., production well, gaining surface water feature etc.). Reverse particle tracking involves releasing a set of particles at the discharge receptor (e.g. pumping well or groundwater discharge location) and tracking each particle’s path line backwards in time and through space to its potential origin.

The primary advantage of forward particle tracking is that multiple particles are allowed to converge on a discharge feature without limitation. As such, particles are less sensitive to release location; this allows forward particles released proximal to each other to converge on the same discharge location and provides for an improved representation of a feature's zone of contribution. The primary disadvantage to forward particle tracking is that typically a much larger quantity of particles are released to ensure that all path lines leading to significant ecological features are represented. This makes forward particle tracking more computationally expensive.

The primary advantage of reverse particle tracking is that it typically requires fewer particles to delineate a zone of contribution as particles are only released up-gradient of the discharge feature of interest. As a result, this approach is considered a fast and computationally efficient method. One primary disadvantage of reverse particle tracking is that due to the convergent nature of flow toward discharge locations, areas of contribution can be missed. This phenomenon is illustrated in Figure 6.1. Contrary to common assumptions, areas missed are not necessarily less important than areas represented using this approach. In the example below, the reverse pathway may identify path (b) and bypass (a) simply based on the geometries of the characterization elements at the point of convergence. It is important to note that forward particle tracking, such as that illustrated in Figure 6.1 can be applied to illustrate that portions of the area of contribution can be missed by only using reverse particle tracking.

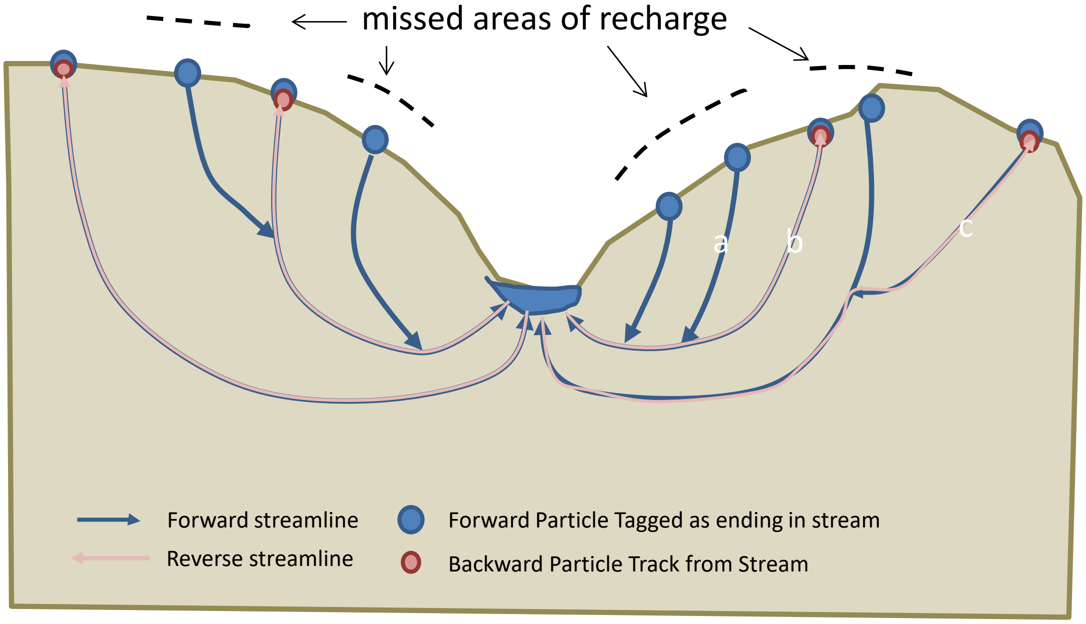


Figure 6.1: Incomplete Zone of Capture Representation using Backward Particle Tracking

In addition to the built-in particle tracking in FEFLOW, a custom particle tracking tool was also applied in this study. Key advantages of this custom tool include:

1) Ability to store attributes of the particle location at all points along the particle track. This allows thematic mapping of the particle track elevation, depth, model layer, and hydrogeologic unit;

2) Streamlined output to facilitate efficient post-processing;

3) Representation of particle track inflection between travel within high and low conductivity units without the need for additional discretization; and

4) Accurate representation of particle travel time through low hydraulic conductivity units without the need for additional discretization.

The use of multiple particle tracking tools allows us to efficiently extract additional information regarding particle pathways and timing.

6.2 Kernel Density Estimation

The method of ESGRA delineation developed for application within the LSRCA includes polygon generation around clusters of reverse particle tracking endpoints; the method developed uses polygons generated using a cluster analysis technique called kernel density estimation.

In statistics, kernel density estimation (KDE) is a non-parametric technique to estimate probability density functions and a popular tool for visualizing distribution of data (Simonoff, 2006). The goal of density estimation is to take a finite sample of data and to make inferences about the underlying probability density function everywhere, including where no data is observed. The contribution of each data point is smoothed out from a single point into a region of space surrounding it. Aggregating the individually smoothed contributions gives an overall picture of the structure of the data and its density function. In other words, the resulting picture gives a likeliness of data occurring at any point in space within a defined area. The function is defined by:

$$\hat{f}_h(x) = \frac{1}{n}\sum_{i=1}^{n} K_H(x - x_i)$$

Where:

- x = $(x_1, x_2, \ldots, x_n)$ is the sample set of real data values;
- $K_H()$ is the kernel function; and
- H is the bandwidth (or window width, aka smoothing factor).

In the example of particle track endpoints, the equation is extended to that of a bivariate formula, where the kernel function is carried out over two dimensions (i.e. $(x - x_i)$ and $(y - y_i)$) The kernel function employed for this study is Gaussian, that is:

$$K_H(x - x_i) = \frac{1}{\sqrt{2\pi}H} e^{\frac{(x - x_i^2)}{2H^2}}$$

Kernel density estimation is calculated over a defined space at a defined resolution and smoothing factor, H. The choice of H is the most crucial factor, as it controls the amount of smoothing involved when estimating density probability. For each cell in the space, the density function is estimated, which creates a surface that can be normalized to the maximum value. This normalization allows us to reference each point in the distribution in relation to the maximum density found, i.e. 1/10th of the max, etc. By contouring the distribution key areas of high density (or clusters) can be visualized, and the kernel density value can be contoured (ε). Figure 6.2 illustrates an example of the contoured density function for an H of 300m; using the contoured valued a threshold ε value can be selected to delineate the area where the kernel density is greater than the threshold value.

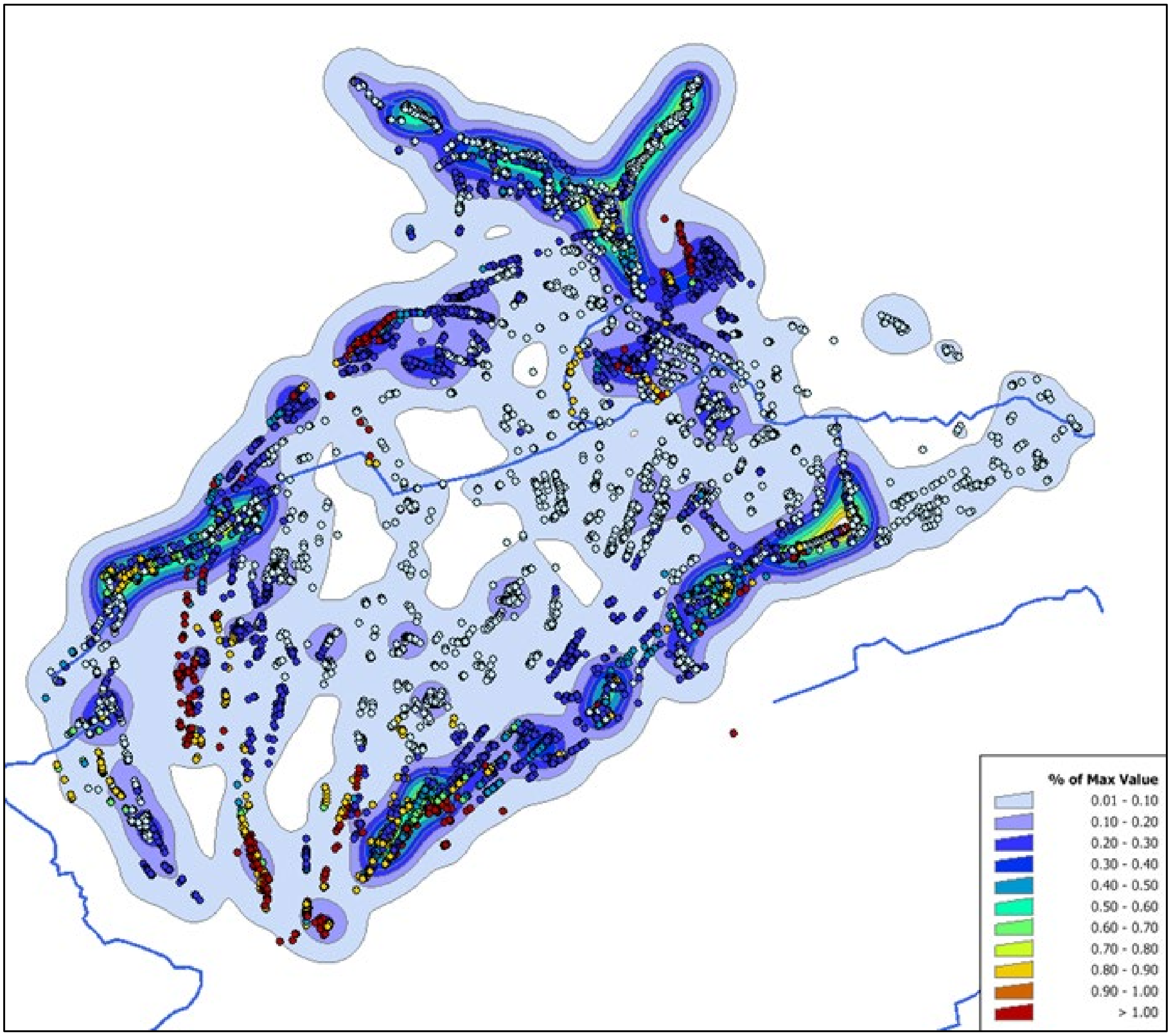


Figure 6.2: Example of a normalized and contoured density distribution derived from reverse particle track end points (H = 300), illustrating each contour level (ε) as a percentage of the maximum density value over the area.

It is important to note that probability density functions are valid for randomly generated or naturally occurring data sets; reverse particle tracking endpoints do not strictly qualify as a random data set.

6.3 ESGRA Delineation

The approach used to delineate ESGRAs within the Innisfil Creeks Subwatershed followed that documented in EarthFX (2012). In general, this methodology includes the following steps:

1) Reverse particle tracking from simulated stream or wetland features with consideration for number and placement of particles released;

2) Kernel density estimation of the reverse particle tracking endpoints technique to delineate the area with the maximum number of endpoints;

3) Simplification of delineated ESGRA polygons where their size (or holes within the polygon) are less than a threshold value.

In addition to the above methodology, additional considerations and steps applied for ESGRA delineation within the Innisfil Creeks subwatershed included:

1) Forward particle tracking released across the landscape, used to identify potential contribution areas for all wetland features. For features included as boundary conditions (Figure 4.4), particles discharging at these locations were flagged. However, as described in section 2 and 4, not all wetland features were simulated as boundary conditions in the groundwater model as their connection to the saturated zone is uncertain; regardless flow paths to the area underlying such features were flagged as potential contribution areas;

2) Delineation of topographic areas of potential contribution for features that were not adequately represented through the forward particle tracking. Such features include those not expected to be in contact with the regional groundwater system, or which may only be in contact for a limited time period during a typical year. Such features may exist as part of a local perched groundwater system; and

3) Identification of potential contributions due to tile drainage areas. Tile drainage areas were considered as a potential water source for ecological features where they were in close proximity and there was inadequate representation using forward particle tracking.

7 ECOLOGICALLY SIGNIFICANT GROUNDWATER RECHARGE AREA (ESGRA) MAPPING

The following section documents the steps performed to complete the ESGRA assessment as documented by EarthFX (2012). Limitations and uncertainty regarding the approach are documented in section 9.

7.1 Natural Heritage Features

Natural Heritage Features designated to be analyzed within this study are shown on Map 7.1. The map labels refer to the list of Natural Heritage Features in Appendix A. Three sources were used to identify these features:

- Fisheries Habitat Mapping (LSRCA, 2010)
- Ecological Land Classification Mapping (LSCRA, 2011)
- EcoSensitive Areas Mapping (MNR, 2012)

It was recognized during the early phases of this study that many of the features are ephemeral or intermittent (as opposed to perennial), and therefore not receiving groundwater discharge on a year round basis. However, on a seasonal basis, the features present important wildlife habitat and may depend on some groundwater contribution throughout the wetter seasons. Because there is very little monitoring data in terms of groundwater and surface water interaction, the relationship of each feature with the simulated groundwater table was assessed on a case by case basis to see if it would be appropriate to represent it as a year-round discharging feature. Supporting evidence included: metadata within the mapping itself indicating how the data was derived (i.e. from field studies, roadside checks or orthoimagery, field knowledge or reports), inspection of water levels from the WWIS database in the vicinity of the feature, or air/land photo analysis (i.e., Google Maps imagery).

Features that do not receive groundwater on an average annual basis are not appropriate for inclusion as boundary conditions within a steady state groundwater flow model. In other words, it is not appropriate to assign boundary conditions to represent such features as having a specified constant water level on a year round basis. As such, it was not practical to apply reverse particle tracking to delineate ESGRAs for such features. In contrast, recharge areas contributing water to the vicinity of such features can be specified using forward particle tracking to determine flow paths that travel under or near a feature. Therefore, in this study, coldwater streams were assessed using reverse and forward particle tracking, whereas wetlands and EcoSensitive areas were assessed using only forward particle tracking. Both are described in the following sections.

7.2 Reverse Particle Tracking from Streams

Initial locations for particle traces along streams were placed in circular pattern around each stream node within the model. The density of particles was calculated such that there would be approximately 2000 start locations per km of stream reach (consistent with the pilot project (EarthFX, 2012)). This density of release locations resulted in the application of approximately 200,000 particles. The distant between stream nodes in the pilot project was much greater than in this model, therefore that project was required to use more particles per stream node to obtain the same level of density. With a finite element node spacing of 15 m along the streams in the model, this resulted in 30 start locations for each stream node, released at a radius of approximately 10 m; less in areas where nodes were closer together (Figure 7.2). The area represented through reverse particle tracking was similar regardless of the density of reverse particles released; future applications would not necessarily require this level of particle density.

Particle release elevation was chosen to be 0.25 m below each stream node. Uncertainty analysis regarding release elevation is presented in section 8.

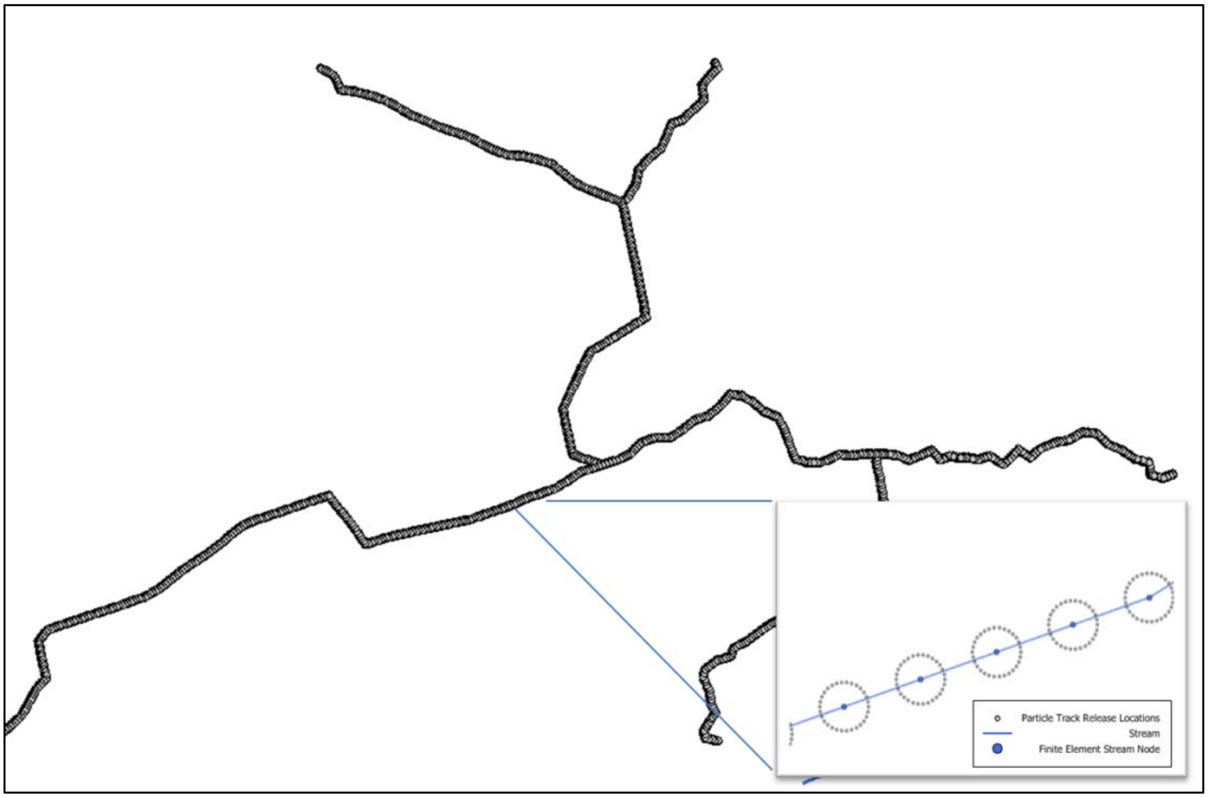


Figure 7.2: Reverse Particle Tracking Release Locations Example

Based on the established release locations, reverse particle tracking was simulated until the particles reached the water table surface; particles were then attributed according to the stream reach they originated from. Figure 7.3 illustrates the reverse particle tracking endpoint locations that are associated with each major stream within the Innisfil Creeks subwatershed. As this figure illustrates, particle endpoints tend to be grouped along the headwaters portion of the subwatershed and along the stream channels. It is also evident that smaller stream reaches, such as Upper Marsh Creek, illustrate fewer particle endpoints than longer streams (e.g., Banks Creek). It is also noted that particles for streams with lower topography (e.g., Sandy Cove Creek) tend to be more dispersed, while streams with more topographic relief tend to have stronger clusters of particles along the headwater areas (e.g., Wilson and White Birch Creeks).

Endpoints which were located within known mapped discharge areas were removed, because these areas are likely discharging for at least for part of the year, although there is little data to confirm this. In addition, it is noted that known wetland and streams are already afforded a level of protection policy via other measures.

7.3 Forward Particle Tracking

As discussed in Section 6.2, forward particle tracking was utilized to delineate contributing areas for all wetland features. This method was chosen over reverse particle tracking as it provides a more comprehensive capture area and not all wetlands could be confidently classified as perennial groundwater discharge zones and thus could not be applied as constant head boundary conditions. To evaluate ESGRAs for these features, forward-tracking particles were released from the centroid of each element within the shallow sub-surface and tracked forward until they reached or came close to a wetland feature; approximately 50,000 forward particles were released and tracked forward through the flow field.

Particles travelling immediately beneath a wetland, within the upper 2 element layers (upper few meters), were flagged as potentially discharging to the wetland. Figure 7.4 illustrates the forward particle release locations that are associated with each wetland or EcoSensitive area.

It should be noted that the release distribution for reverse-tracking particles was more-dense than the forward particle traces released from element centroids used to depict recharge contribution to wetland areas. As a result, areas of contribution to wetlands have a lower density of particles than areas contributing to streams; this has no inference on their relative importance or recharge volume.

7.4 Kernel Density Estimation

An analysis using the formulation presented within Section 6.1.1 was implemented to delineate ESGRAs, as determined from the reverse and forward particle tracking results. This was performed over the the particle track origins, with known discharge areas removed.

Density distributions for the particle tracks were created over a 25 m grid spacing using varying degrees of smoothness. These distribution surfaces were normalized by their maximum value and contoured. Each contour level (ε) represents a percentage of the maximum value within the density distribution. To determine the optimal H and ε parameters that would capture the majority of endpoints, an analysis was completed to estimate the number of particles captured by each combination, as well as the percentage of the subwatershed that the selection covered. Tables 7.1 shows the results of this analysis with respect to the percentage of particles captured and the percentage of the area designated.

Table 7.1: Percent of Endpoints Covered

total endpoints	162844									
	% endpoints	% area	% endpoints	% area	% endpoints	% area	% endpoints	% area	% endpoints	% area
ε	**h=50**		**h=75**		**h=100**		**h=125**		**h=150**	
0.001	97%	19%	99%	31%	99%	41%	99%	50%	100%	57%
0.005	87%	7%	91%	13%	93%	18%	94%	24%	95%	29%
0.0075	83%	5%	88%	10%	90%	14%	92%	19%	93%	24%
0.01	79%	4%	85%	8%	88%	12%	90%	16%	92%	20%
0.025	62%	2%	72%	4%	76%	6%	80%	8%	82%	11%
0.05	42%	1%	56%	2%	61%	3%	66%	4%	70%	6%
0.1	24%	0%	32%	0%	39%	1%	44%	1%	49%	2%

A smoothing parameter of H = 75 m and a threshold of $\varepsilon = 0.001$ were selected to delineate the ESGRAs. These parameters were chosen through consultation with LSRCA staff to maximize the amount of particles (99%) enclosed in the least amount of subwatershed area (31%). This threshold was chosen to reduce areas that may not contribute any recharge to ecological features (i.e. reduce buffers around identified areas of contribution using reverse particle tracking) and thereby reflect more-defensible protection policies.

For planning purposes, small isolated polygons or windows were removed from the mapping. Such removal decreases the percentage of particle capture to 97% (Table 7.2); most of the removed particles represent recharge to wetlands (12% of wetland-associated particle traces) because the selected H value was smaller than the selected release locations, resulting in lower particle density areas contributing recharge to wetlands. Figure 7.5 illustrates the mapped ESGRA polygons using the selected ε and H values with known discharge areas and small polygons (less than 200 m^2) removed. SGRA mapping for the subwatershed is also provided on this map to permit comparison and contrast of protection initiatives.

Table 7.2: Percent of Endpoints Covered after the Removal of Known Discharge Areas and Small Polygons

total endpoints	152377							
	% endpoints	% area	% endpoints	% area	% endpoints	% area	% endpoints	% area
ε	**h=75**		**h=100**		**h=125**		**h=150**	
0.001	97%	29%	99%	39%	99%	50%	99%	57%
0.005	89%	12%	93%	17%	94%	24%	96%	29%
0.0075	84%	8%	90%	14%	92%	19%	94%	24%
0.01	80%	7%	84%	11%	90%	16%	93%	20%

7.5 Alternate ESGRA Methodology

An important aspect of this study was the ability to delineate ESGRA mapping that included all possible ecologically sensitive habitats. These habitats included: coldwater stream mapping (LSRCA, 2010), wetlands (Ecological Land Classification mapping, LSRCA, 2012) and “EcoSensitive” habitats (MNR, 2012) (Figure 7.1). It is recognized that some features do not have groundwater discharge on an average annual basis, or that such discharge may be from local perched aquifers for which little data exists; such features cannot be fully represented within a steady state groundwater flow model. As a result, an important task was to identify such features and establish an alternative for delineating their contributing recharge areas. Without the presence of continuous monitoring data, efforts to identify these features include:

- locating perched systems as indicated by water level data;
- identifying features located within tile drainage areas;

- observation of the feature's situation within the watershed (topography, surficial geology, Upland vs. Lowland region);
- identifying Air Photo Analysis; and
- Field observations of streams (i.e. dry or flowing) included in the LSRCA Integrated Watershed Management Plan (2008).

As discussed in Section 6.2, an alternative approach was required to map ESGRAs where wetlands (including EcoSensitive features) were under-represented through the particle tracking approach (i.e., where only a few forward particles ended at the feature). Features where this was necessary (see Figure 7.6) are those that were relatively small (Table 7.3). Such features may or may not be groundwater dependent, and the information required to determine that is not available for the majority of such features. Even where a seasonal groundwater contribution is considered to occur, such a condition may be supported by local perched aquifer systems that are isolated from the regional water table and thus are not simulated within the regional groundwater modelling tools.

The approach used to delineate the ESGRA for all natural heritage features is illustrates on Figure 7.6. Tile drainage area mapping obtained from OMAFRA (OMAFRA, 2011) is also shown on this figure, illustrating the proximity between tile drainage and natural heritage features. As illustrated on Figure 7.6, the recharge areas for the majority of the larger wetlands have been delineated using particle tracking. The remainder either show that contribution of water to the feature is likely due to adjacent tile drainage areas, shallow topographically induced flow, or both; in general there is little documentation describing these features.

Table 7.3 lists the features where the alternative approach to ESGRA mapping was required and the considerations toward completing ESGRA mapping for each feature. Of particular note is the distance to tile drainage fields that may contribute to the feature, and the percentage of the feature that is located above the regional water table. As indicated, the majority of these features are small (1 to 8 hectares).

Table 7.3: ESGRA Considerations for Potentially Perched ELC and EcoSensitive Features

Feature ID	Wetland Name	Type	Area (ha)	Distance to Tile Drainage Area (m)	Percent Area Above Water Table	Alternate ESGRA Representation
15	Carson Creek EcoSensitive Area 1	EcoSensitive Area	0.5	92	100%	Tile Drainage Area
18	Carson Creek Headwaters Wetland 2	ELCWetland	4.9	43	100%	Tile Drainage Area
26	EcoSensitive Area 6	EcoSensitive Area	3.1	2145	50%	Topographical
41	Leonard's Creek Riverine Wetland 7	ELCWetland	2.0	0	100%	Tile Drainage Area
42	Little Cedar Creek Wetland East	ELCWetland	2.0	0	100%	Tile Drainage Area
54	Unnamed Wetland 1	ELCWetland	5.5	3187	100%	Topographical

Feature ID	Wetland Name	Type	Area (ha)	Distance to Tile Drainage Area (m)	Percent Area Above Water Table	Alternate ESGRA Representation
55	Unnamed Wetland 10	ELCWetland	3.8	271	100%	Topographical
56	Unnamed Wetland 11	ELCWetland	1.7	285	100%	Topographical
58	Unnamed Wetland 13	ELCWetland	2.3	2162	0%	Topographical
59	Unnamed Wetland 14	ELCWetland	1.6	612	100%	Topographical
60	Unnamed Wetland 15	ELCWetland	3.7	21	100%	Tile Drainage Area
61	Unnamed Wetland 18	ELCWetland	1.2	1670	0%	Topographical
62	Unnamed Wetland 19	ELCWetland	2.9	509	100%	Topographical
65	Unnamed Wetland 22	ELCWetland	2.8	0	0%	Tile Drainage Area
67	Unnamed Wetland 5	ELCWetland	3.1	1991	100%	Topographical
68	Unnamed Wetland 7	ELCWetland	2.5	505	100%	Topographical
69	Unnamed Wetland 8	ELCWetland	1.5	419	100%	Topographical
70	Unnamed Wetland 9	ELCWetland	8.6	0	100%	Tile Drainage Area

To evaluate areas of contribution for such features, topographic mapping and tile drainage considerations were undertaken. Figure 7.7 illustrates the mapped ESGRAs for the ELC and EcoSensitive features in Table 7.3, as delineated using topography and proximity to tile drainage fields. As noted on this Figure, tile drained fields were classed as 1) potentially contributing water to the feature, and 2) probably contributing water; such classification was based on proximity to the ELC or EcoSensitive feature and their relative elevation. The potential contributing areas delineated in Figure 7.7 are independent of the ESGRAs delineated in Figure 7.5. Such areas should be field verified prior to being incorporated into protection mapping.

8 ESGRA UNCERTAINTY ANALYSIS

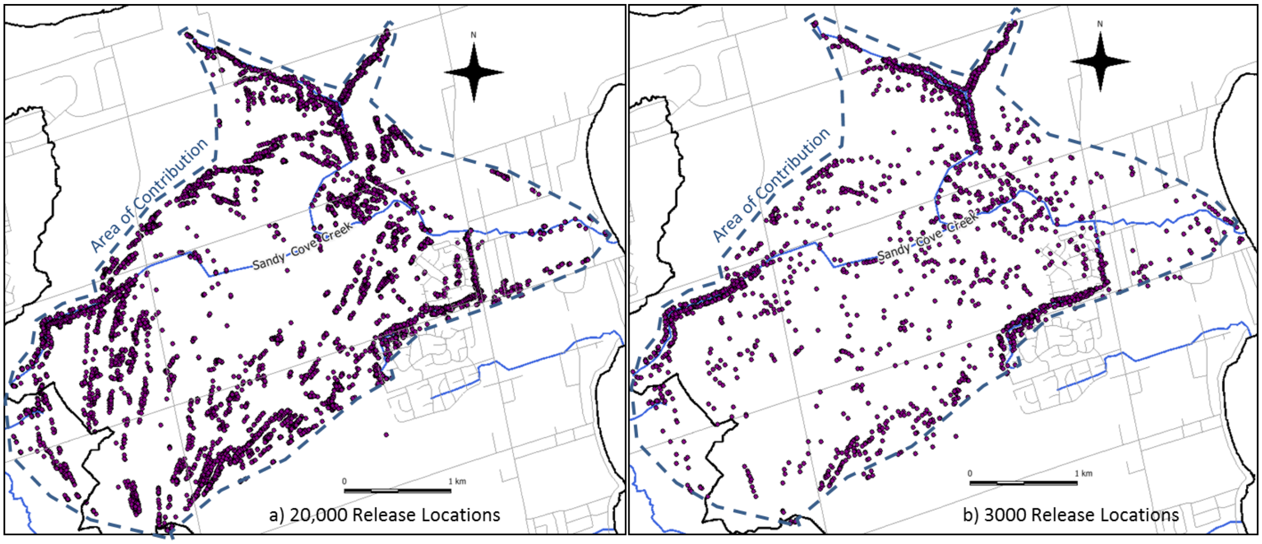
To evaluate the potential uncertainty surrounding the delineation of ESGRAs, the following steps were completed:

1) Evaluation of the uncertainty of ESGRAs using reverse particle tracking based on the <u>density</u> of reverse particle release locations along the stream. This is accomplished by comparing a distribution along the stream vs. concentric circles released around each stream node;
2) Evaluation of the uncertainty of ESGRAs using reverse particle tracking based on the <u>depth</u> of reverse particle release locations beneath stream nodes; and
3) Use of forward particle tracking to illustrate the relation of recharge source areas to the ESGRAs.

8.1 Density of Reverse-Tracked Particles Release Locations

To evaluate the requirement for dense reverse-tracked particles to be released along a stream, the ESGRA results were compared to reverse particle traces released at the centroid of elements adjacent to streams. The approach to define ESGRAs utilized over 2000 particles per stream kilometer, released in concentric circles surrounding individual stream nodes and tracked backward through the groundwater flow field to potential recharge locations (see section 7.2). To understand the uncertainty of the area that would be identified with fewer particles, reverse particle traces were also released at the centroid of elements adjacent to a stream; this resulted in utilizing 120-150 particles per stream kilometer, distributed in a relatively uniform fashion along the stream.

Figure 8.1 illustrates the reverse-tracked particle endpoints (i.e., recharge locations) from Sandy Cove Creek for the two sets of particles outlined above, namely: a) for the uncertainty case where particles were released from element centroids adjacent to the stream; and b) for the case applied to delineate the ESGRAs where particles were released in concentric circles around each stream node.



a) 20,000 Release Locations

b) 3000 Release Locations

Figure 8.1: Comparison of Reverse Particle Tracking Endpoints Based on Release Location Density: Sandy

Cove Creek. a) Particles released in concentric circles around each stream node (used for ESGRA delineation). b) Particles released at element centroids along the stream.

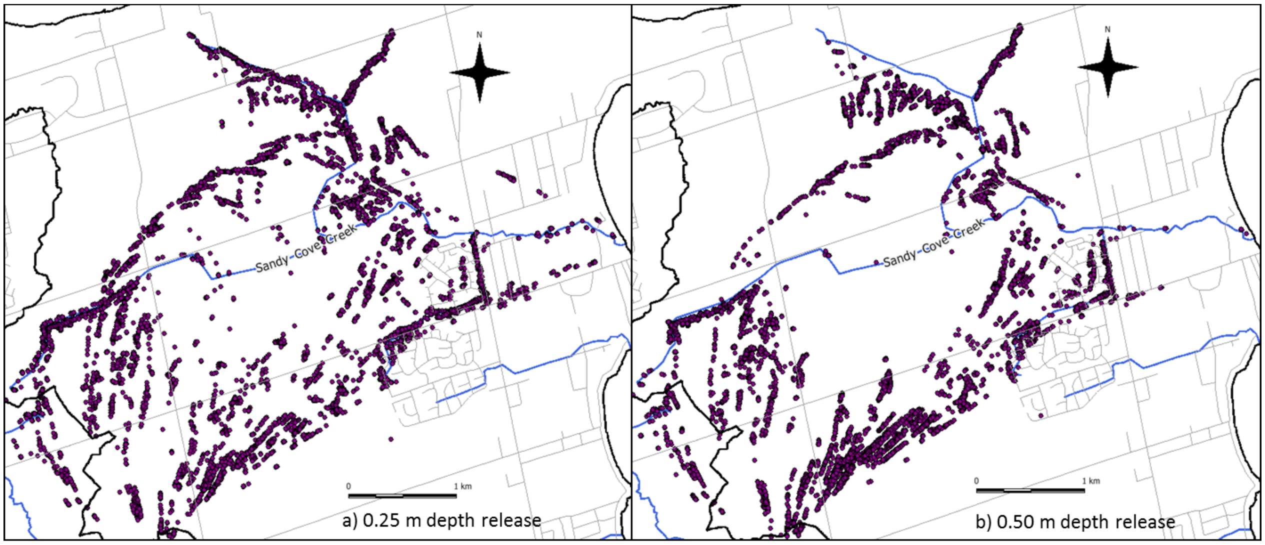
This analysis indicates that both approaches identify the same areas of contribution and similar areas of clustering, while case a) uses much fewer particles than case b). Note that much of the clustering is found to occur in two zones as follows: 1) at the outer perimeter of the area of contribution, and 2) along stream reaches that are dominated by local flow (e.g., that do not receive regional discharge).

This uncertainty analysis indicates that the area identified as contributing to the stream is not highly dependent on the density of reverse particle track release locations along the stream. So long as a uniform distribution of particles along the stream is applied, the area of contribution can be achieved.

8.2 Depth of Reverse-Tracked Particles Release Locations

To evaluate the potential impact of the depth of reverse-tracked particles released along a stream, the ESGRA results were compared to reverse particle traces released at differing depths. Particle release depths of 0.5 m beneath the stream node elevation were compared to the default value of 0.25 m below the stream node, as applied for the ESGRA delineation; the same set of concentric circles were applied at each depth, leading to a density of 2000 particles per stream kilometer.

Figure 8.2 illustrates the reverse-tracked particle endpoints for the 0.25m and 0.5m deep particles released from concentric circles around stream nodes for Sandy Cove Creek. As illustrated on this Figure, the particles released at greater depth below the stream node tend to travel further from the stream. In essence, deeper particles dominantly represent the regional groundwater flow component that discharges at the stream and therefore they extend to recharge areas that are dominantly distal to the stream.



a) 0.25 m depth release

b) 0.50 m depth release

Figure 8.2: Comparison of Reverse Particle Tracking Endpoints Based on Release Location Depth Below Stream Nodes: Sandy Cove Creek.

This uncertainty analysis indicates that the particle release depth is important for identifying the area of contribution, particularly where only reverse particle tracking is applied. This is further evidence of the challenges in capturing all portions of the flow system using reverse particle tracking; the application of both forward and reverse particle tracking would resolve this issue.

The release depth also has an evident effect on the particle endpoint clustering and as such is expected to affect the kernel density analysis.

8.3 Forward-Tracked Particles

To evaluate the uncertainty of applying backward particle tracking for ESGRA delineation, ESGRAs delineated using backward particle tracking were compared to the area of recharge contribution to a stream segment (as depicted using forward-tracked particles). Forward-tracked particles were released at the centroid of every element across the top layer of the model, throughout the entire Innisfil Creeks subwatershed (~50,000 particles). In accordance with the water budgeting results presented in section 5, the majority (~80%) of the forward particle tracks discharge to Lake Simcoe, while the remaining (~20%) discharge at streams and wetlands. In contrast to reverse particle tracking, forward particle traces released in a uniform manner are allowed to converge on the stream or other discharge location and provide a more complete delineation of the area of contribution (see Figure 6.1).

Using forward particle tracking, particles captured by a stream were flagged. Captured particles, representing recharge areas that led to discharge at the stream, are illustrated as points on Figure 8.3. The area encompassing all particle endpoints shown reflects the area of contribution to creeks and wetlands.

For comparison purposes, Figure 8.3 also illustrates the following protection areas:

- ESGRAs delineated as described in section 7;
- Wetland areas considered discharge areas where forward-tracked particles were omitted; and
- SGRAs developed through earlier Tier Two and Tier Three Source Protection studies (EarthFX, 2009; AquaResource, 2012).

On this figure, the forward particle trace start locations (of particles discharging at streams) are themed based on inclusion within these protection areas.

As this figure illustrates, the protection areas (ESGRAs, SGRAs and wetlands) encompass the majority of the forward particle traces (~80%), while the remaining forward particle locations (~20%) are not represented within these protection areas. The streams where a higher percentage of forward particles are not captured by the mapped protection areas include: White Birch Creek (40%), Wilson Creek (32%) and Sandy Cove Creek (30%).

This analysis demonstrates that some areas of contribution are not represented by the established protection areas, indicating that additional protection measures may be beneficial in selected areas.

9 LIMITATIONS AND UNCERTAINTY OF THE TIER TWO AND ESGRA ANALYSIS

The work presented herein reflects the best available knowledge at the time of this report and utilizes the best available data and analysis tools. Despite this, there are a number of limitations for consideration when applying the results of this analysis, including the following:

1) The conceptual understanding of the groundwater and surface water systems and particularly their interaction is incomplete and limited by the available data. Hydrogeologic characterization is limited by the available data, which is primarily water well record data that is known to be individually of questionable quality, but provide valuable insight when applied as a group of relatively poor quality. Recent efforts by the Ontario Geologic Survey (OGS) will improve characterization over time. Surface water data within the subwatershed is also limited, such that there is little data on stream baseflow and insufficient streamflow records for reliable characterization.

2) Wetland characterization, specifically at those features that are not designated as Provincially Significant is limited. This is particularly true with regard to the potential interconnection with the regional groundwater flow system; perennial groundwater discharge is speculative and based on broad-scale interpretations of regional groundwater elevations. For the majority of the smaller features within the ELC mapping, field observation data is limited to orthoimagery or roadside checks, and very little evidence is available to verify and characterize interaction with the groundwater system.

3) Numerical models have been developed using state-of-the-practice commercial codes, and as such represent advanced modelling tools for water budget analysis. The reliability of these tools however is limited by the level of characterization and calibration data available. The consequence of poor conceptual understanding and a lack of hydrogeologic, streamflow and wetland data is that predictions made with models should be viewed as indications of potential impacts, given the best available conceptualization and calibration. Despite this uncertainty, it is unlikely that the predicted stress level classification is in error as it is well below the threshold value for all scenarios tested.

4) Drought impact predictions are the best available given the level of reliability of the numerical modelling tools that could be developed for this study. Recognizing this uncertainty, predictions of potential drought impact should be viewed as an indication of potential impacts, such that identified areas may warrant field data collection and sentry monitoring.

5) ESGRA evaluation is a relatively new approach that is intended to protect significant portions of the groundwater recharge area and thus sustain streamflow. ESGRAs combined with SGRA and wetland areas are intended to protect recharge that sustains streamflow. The methodology documented by EarthFX (2012) provides a consistent means of outlining some contributing areas to ecologically significant features, but it should be recognized that:

    a. Reverse particle tracking results are sensitive to the release location and generally results in an incomplete representation of the potential contributing area. Forward particle tracking from points uniformly spread across the surface of the study area is one means of achieving a more-comprehensive understanding of the contributing recharge area for a stream or wetland. Utilizing both methods, the complete area of contribution to a stream can be achieved.

b. The groundwater recharge area that contributes water to a stream or wetland extends beyond that delineated with the current ESGRA methodology. SGRAs and wetlands can also represent portions of the recharge area, but in general they will not cover the entire recharge area;

c. Areas delineated using the density estimation methodology represent potential recharge pathways without rationalization of representing significant groundwater recharge. The area delineated does not represent areas of more significant recharge volume contribution to the stream (however many high recharge areas are covered by SGRA mapping), nor a given travel time, depth or distance (i.e., which could be perceived as representing cold water discharge or flow that would offset a short term drought), nor connection to a particular important discharge reach (i.e., a known spawning bed).

d. Removal of small isolated polygons generated using small H and ε values, can reduce coverage of recharge areas contributing to smaller features. Therefore, care must be taken when selecting appropriate values.

e. Kernel density estimation using endpoints of reverse particle traces violates the underlying assumption that the data being evaluated is randomly distributed (Silverman, 1986).

f. Application of uniform H and ε values for the density analysis across an entire study area can result in omission of important recharge areas for some features (typically smaller features, represented with fewer particle). However, this can be reduced by selecting a smaller threshold value (ε) to encompass a greater portion of endpoints; therefore care needs to be taken when selecting the appropriate H and ε values.

10 SUMMARY AND CONCLUSIONS

This report presents the results of the Tier Two Stress Assessment as well as the delineated ESGRA mapping for the Innisfil Creeks Subwatershed, located within the western portion of the Lake Simcoe Region Conservation Authority.

The Tier Two Stress Assessment builds on previous work completed within the subwatershed and the surrounding area. The following presents the steps completed and findings:

1) Water demand within the subwatershed was more precisely defined, particularly for permitted water takings;
2) Refined groundwater and surface water tools were developed and calibrated to the degree afforded by the available characterization information and calibration data;
3) Average annual and maximum monthly stress levels were evaluated for both existing and future planned conditions. The percent water demand computed under each of these scenarios suggested that there is a low potential for hydrologic stress induced by pumping within the Innisfil Creeks Subwatershed; and
4) The potential impact of drought conditions on stream baseflow discharge and regional groundwater discharge to wetlands was evaluated to help identify features susceptible to long-term drought. Consistent with the topographic and hydrogeologic setting, several stream and wetlands were identified as being susceptible to drought conditions, including the following:
    a. Within the drought scenario, all creeks experienced reductions in base flow during the simulated drought period; however, Mooselanka, Sandy Cove, Banks, Gilford, and Upper Marsh Creeks showed a higher level of sensitivity to the drought period.
    b. Wetlands that were simulated to have a higher sensitivity to the simulated drought period include Leonard’s Creek Swamp and Little Cedar Point wetland.

In efforts to maintain and restore the integrity of local natural heritage features, Ecologically Significant Groundwater Recharge Areas (ESGRAs) were delineated to help sustain discharge to important surface water features. ESGRAs are designed to complement Significant Groundwater Recharge Areas (SGRAs) developed through Source Protection studies (EarthFX, 2012 and AquaResource, 2012). SGRAs encompass areas of higher volume recharge, and thus the ESGRA methodology was developed to capture additional contributing areas and enhance protection for ecological features.

ESGRAs, as defined through a pilot project (EarthFX, 2012) were delineated for all streams in the Innisfil Creeks Subwatershed. Alternative approaches were however required for wetlands and EcoSensitive areas within the Innisfil Creeks Subwatershed. Steps completed include:

1) ESGRAs for streams followed the methodology documented in Earthfx (2012), utilizing reverse-tracked particles from stream nodes to identify areas of clustered particle endpoints. Consistent endpoint cluster analyses were applied across the Study Area. ESGRAs developed using this technique are presented on Figure 7.5;
2) ESGRAs for most wetland areas were delineated using forward particles released at every

element centroid across the surface of the model, and flagging those that flowed to, or immediately beneath each wetland feature. ESGRAs developed from this step are included on Figure 7.5;

3) ESGRAs for ELC and EcoSensitive features where forward particle tracking was insufficient to represent the area of contribution (e.g., for relatively small features), were delineated using an alternative approach based on topography and proximity to tile drained areas. Particle tracking at these features was not considered appropriate as these features are expected to receive local contribution from surface runoff or perched groundwater conditions only (i.e., features are located primarily above the predicted water table). ESGRAs for such features were delineated to encompass topography sloping toward the feature and tile drainage fields that probably or potentially drain into a nearby ELC or EcoSensitive feature.

4) An uncertainty analysis on the ESGRAs delineated was completed to evaluate the potential uncertainty in the delineated ESGRAs and their relationship to potential areas of contribution. The uncertainty analysis found:

    a. The area of contribution to a stream can be delineated with a range of particle densities along the stream however the clustering of particle endpoints is dependent on the number of particles applied. This analysis indicates that the area identified as contributing to the stream is not highly dependent on the density of reverse particle track release locations along the stream.

    b. Variation of release location depths for reverse particle tracking can lead to differing areas of contribution and clusters of particle endpoints. Varying particle release depth is important for identifying an area of contribution, particularly where only reverse particle tracking is applied. The application of both forward and reverse particle tracking can resolve this issue, but is not appropriate for cluster analysis.

    c. Forward particle tracking analysis demonstrated that some areas of contribution are not represented by the established protection areas (including ESGRAs, SGRAs and wetland areas) indicating that additional protection measures may be beneficial in selected areas.

The ESGRAs presented herein will help to provide additional protection of recharge areas that sustain discharge to important surface water features. ESGRAs, in concert with SGRA and wetland protection zones provide protection of the majority of recharge areas for ecological features within the Innisfil Creeks Subwatershed.

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APPENDIX A: NATURAL HERITAGE FEATURE TARGETS

Feature ID	WetlandName	Area (m2)	Distance to Tile Drain (m)	Source	Wetland Type	Verification Method	System	Class	Topographic Landscape
1	Banks Creek EcoSensitive Area 7	135622	0	EcoSensitiveArea Mapping	Evaluated	Field Check	Unknown	Unknown	Unknown
2	Banks Creek Headwaters Wetland	607992	138	ELC Mapping	Interpreted	Roadside Check	Wetland	Swamp	Bottomland
3	Banks Creek Riverine EcoSensitive Area 6	58400	394	EcoSensitiveArea Mapping	Evaluated	Field Check	Unknown	Unknown	Unknown
4	Banks Creek Riverine Wetland 1	47387	1983	ELC Mapping	Interpreted	Roadside Check	Wetland	Swamp	Table land
5	Banks Creek Riverine Wetland 2	33482	1587	ELC Mapping	Interpreted	Orthophotography	Wetland	Swamp	Bottomland
6	Banks Creek Riverine Wetland 3	59168	910	ELC Mapping	Interpreted	Orthophotography	Wetland	Swamp	Riverine
7	Banks Creek Riverine Wetland 4	71631	467	ELC Mapping	Interpreted	Roadside Check	Wetland	Swamp	Riverine
8	Banks Creek Riverine Wetland 5	28850	153	ELC Mapping	Interpreted	Roadside Check	Wetland	Swamp	Riverine
9	Belle Aire Creek EcoSensitive Area 1	177191	0	EcoSensitiveArea Mapping	Evaluated	Field Check	Unknown	Unknown	Unknown
10	Belle Aire Creek EcoSensitive Area 2	10872	199	EcoSensitiveArea Mapping	Evaluated	Field Check	Unknown	Unknown	Unknown
11	Belle Aire Creek Headwaters Wetland	71131	90	ELC Mapping	Interpreted	Orthophotography	Wetland	Swamp	Riverine
12	Belle Aire Creek Riverine Wetland 1	10725	0	ELC Mapping	Interpreted	Roadside Check	Wetland	Swamp	Riverine
13	Big Bay Point Wetland	327639	4239	ELC Mapping	Interpreted	Orthophotography	Wetland	Swamp	Bottomland
14	Bon Secour Riverine Wetland	28128	883	ELC Mapping	Interpreted	Orthophotography	Wetland	Swamp	Riverine

Feature ID	WetlandName	Area (m2)	Distance to Tile Drain (m)	Source	Wetland Type	Verification Method	System	Class	Topographic Landscape
15	Carson Creek EcoSensitive Area 1	5335	92	EcoSensitiveArea Mapping	Evaluated	Field Check	Unknown	Unknown	Unknown
16	Carson Creek EcoSensitive Area 2	7488	30	EcoSensitiveArea Mapping	Evaluated	Field Check	Unknown	Unknown	Unknown
17	Carson Creek Headwaters Wetland 1	86200	152	ELC Mapping	Interpreted	Orthophotography	Wetland	Swamp	Bottomland
18	Carson Creek Headwaters Wetland 2	48662	43	ELC Mapping	Interpreted	Orthophotography	Wetland	Swamp	Riverine
19	Carson Creek Riverine Wetland 2	11417	209	ELC Mapping	Interpreted	Orthophotography	Wetland	Swamp	Riverine
20	Carson Creek Riverine Wetland 3	78954	200	ELC Mapping	Interpreted	Orthophotography	Aquatic	Marsh	Riverine
21	Carson Creek Wetland 1	61158	889	ELC Mapping	Interpreted	Orthophotography	Wetland	Swamp	Riverine
22	EcoSensitive Area 2	254155	3209	EcoSensitiveArea Mapping	Evaluated	Field Check	Unknown	Unknown	Unknown
23	EcoSensitive Area 20	162623	867	EcoSensitiveArea Mapping	Evaluated	Field Check	Unknown	Unknown	Unknown
24	EcoSensitive Area 3	128514	2678	EcoSensitiveArea Mapping	Evaluated	Field Check	Unknown	Unknown	Unknown
25	EcoSensitive Area 4	123340	2905	EcoSensitiveArea Mapping	Evaluated	Field Check	Unknown	Unknown	Unknown
26	EcoSensitive Area 6	30767	2145	EcoSensitiveArea Mapping	Evaluated	Field Check	Unknown	Unknown	Unknown
27	Gilford Creek Wetland	170313	403	ELC Mapping	Interpreted	Roadside Check	Wetland	Swamp	Bottomland

Feature ID	WetlandName	Area (m2)	Distance to Tile Drain (m)	Source	Wetland Type	Verification Method	System	Class	Topographic Landscape
28	Holland Marsh Wetland Complex North	1249889	5	ELC Mapping	Evaluated PSW	Orthophotography	Wetland	Marsh	Riverine
29	Leonard's Beach Swamp 1	386907	1668	ELC Mapping	Evaluated PSW	Field Check	Wetland	Swamp	Table land
30	Leonard's Beach Swamp 2	152530	1222	ELC Mapping	Evaluated PSW	Roadside Check	Wetland	Swamp	Bottomland
31	Leonard's Beach Swamp 3	410310	1590	ELC Mapping	Interpreted	Orthophotography	Wetland	Swamp	Bottomland
32	Leonard's Beach Swamp 4	1624358	136	ELC Mapping	Evaluated PSW	Roadside Check	Wetland	Swamp	Table land
33	Leonard's Beach Swamp 5	18270	2015	ELC Mapping	Interpreted	Orthophotography	Wetland	Swamp	Riverine
34	Leonard's Beach Swamp 6	57128	1975	ELC Mapping	Interpreted	Orthophotography	Wetland	Swamp	Bottomland
35	Leonard's Creek Riverine Wetland 1	13203	0	ELC Mapping	Interpreted	Orthophotography	Wetland	Swamp	Table land
36	Leonard's Creek Riverine Wetland 2	39572	293	ELC Mapping	Interpreted	Orthophotography	Wetland	Swamp	Riverine
37	Leonard's Creek Riverine Wetland 3	41905	562	ELC Mapping	Interpreted	Roadside Check	Wetland	Swamp	Riverine
38	Leonard's Creek Riverine Wetland 4	74008	370	ELC Mapping	Interpreted	Field Check	Wetland	Marsh	Bottomland
39	Leonard's Creek Riverine Wetland 5	7374	613	ELC Mapping	Interpreted	Roadside Check	Wetland	Swamp	Bottomland
40	Leonard's Creek Riverine Wetland 6	6835	695	ELC Mapping	Interpreted	Orthophotography	Wetland	Swamp	Riverine
41	Leonard's Creek Riverine Wetland 7	19758	0	ELC Mapping	Interpreted	Orthophotography	Wetland	Swamp	Table land

Feature ID	WetlandName	Area (m2)	Distance to Tile Drain (m)	Source	Wetland Type	Verification Method	System	Class	Topographic Landscape
42	Little Cedar Creek Wetland East	20201	0	ELC Mapping	Evaluated PSW	Roadside Check	Wetland	Swamp	Bottomland
43	Little Cedar Point Wetland North	877770	50	ELC Mapping	Evaluated PSW	Orthophotography	Wetland	Swamp	Riverine
44	Little Cedar Point Wetland South	751713	24	ELC Mapping	Interpreted	Roadside Check	Wetland	Swamp	Bottomland
45	Mooselanka Wetland 1	150041	549	ELC Mapping	Interpreted	Orthophotography	Wetland	Swamp	Bottomland
46	Moyer Creek EcoSensitive Area	83017	1583	EcoSensitiveArea Mapping	Evaluated	Field Check	Unknown	Unknown	Unknown
47	Moyer Creek Wetland	122457	1647	ELC Mapping	Interpreted	Roadside Check	Wetland	Swamp	Bottomland
48	Sandy Cove Creek Headwaters Wetland 5	1168848	0	ELC Mapping	Interpreted	Roadside Check	Wetland	Marsh	Bottomland
49	Sandy Cove Creek Wetland 1	12197	1429	ELC Mapping	Interpreted	Orthophotography	Wetland	Swamp	Riverine
50	Sandy Cove Creek Wetland 2	53190	2058	ELC Mapping	Interpreted	Roadside Check	Wetland	Swamp	Bottomland
51	Sandy Cove Creek Wetland 3	862489	1152	ELC Mapping	Interpreted	Orthophotography	Wetland	Swamp	Riverine
52	Sandy Cove Creek Wetland 4	205794	985	ELC Mapping	Interpreted	Field Check	Wetland	Swamp	Riverine
53	Sandy Cove Creek Wetland 6	45486	1253	ELC Mapping	Interpreted	Roadside Check	Wetland	Swamp	Riverine
54	Unnamed Wetland 1	54627	3187	ELC Mapping	Interpreted	Roadside Check	Wetland	Swamp	Bottomland
55	Unnamed Wetland 10	37553	271	ELC Mapping	Interpreted	Orthophotography	Wetland	Swamp	Bottomland
56	Unnamed Wetland 11	16999	285	ELC Mapping	Interpreted	Roadside Check	Wetland	Swamp	Table land
57	Unnamed Wetland 12	44295	0	ELC Mapping	Interpreted	Orthophotography	Wetland	Swamp	Bottomland

Feature ID	WetlandName	Area (m2)	Distance to Tile Drain (m)	Source	Wetland Type	Verification Method	System	Class	Topographic Landscape
58	Unnamed Wetland 13	22855	2162	ELC Mapping	Interpreted	Orthophotography	Wetland	Swamp	Bottomland
59	Unnamed Wetland 14	15932	612	ELC Mapping	Interpreted	Roadside Check	Wetland	Swamp	Table land
60	Unnamed Wetland 15	37037	21	ELC Mapping	Interpreted	Roadside Check	Wetland	Swamp	Bottomland
61	Unnamed Wetland 18	11750	1670	ELC Mapping	Interpreted	Orthophotography	Wetland	Swamp	Table land
62	Unnamed Wetland 19	28866	509	ELC Mapping	Interpreted	Roadside Check	Wetland	Swamp	Table land
63	Unnamed Wetland 2	447643	3899	ELC Mapping	Interpreted	Orthophotography	Wetland	Swamp	Bottomland
64	Unnamed Wetland 20	161291	1183	ELC Mapping	Interpreted	Orthophotography	Wetland	Swamp	Bottomland
65	Unnamed Wetland 22	27922	0	ELC Mapping	Interpreted	Roadside Check	Wetland	Swamp	Table land
66	Unnamed Wetland 4	36876	2870	ELC Mapping	Interpreted	Orthophotography	Wetland	Marsh	Bottomland
67	Unnamed Wetland 5	30939	1991	ELC Mapping	Interpreted	Orthophotography	Aquatic	Marsh	Bottomland
68	Unnamed Wetland 7	24740	505	ELC Mapping	Interpreted	Orthophotography	Wetland	Swamp	Bottomland
69	Unnamed Wetland 8	15282	419	ELC Mapping	Interpreted	Orthophotography	Wetland	Swamp	Bottomland
70	Unnamed Wetland 9	85583	0	ELC Mapping	Interpreted	Orthophotography	Wetland	Swamp	Table land
71	White Birch Creek Headwaters Wetland 1	90466	0	ELC Mapping	Interpreted	Orthophotography	Wetland	Swamp	Riverine
72	White Birch Creek Headwaters Wetland 2	58820	45	ELC Mapping	Interpreted	Orthophotography	Wetland	Marsh	Bottomland
73	White Birch Creek Riverine Wetland 1	93158	5	ELC Mapping	Interpreted	Roadside Check	Wetland	Marsh	Riverine
74	White Birch Creek Riverine Wetland 2	217768	190	ELC Mapping	Interpreted	Orthophotography	Wetland	Swamp	Riverine
75	Wilson Creek EcoSensitive Area	97834	637	EcoSensitiveArea Mapping	Evaluated	Field Check	Unknown	Unknown	Unknown
76	Wilson Creek Headwaters	238457	580	ELC Mapping	Interpreted	Roadside Check	Wetland	Swamp	Riverine

Feature ID	WetlandName	Area (m2)	Distance to Tile Drain (m)	Source	Wetland Type	Verification Method	System	Class	Topographic Landscape
77	Wilson Creek Marsh	503604	65	ELC Mapping	Evaluated PSW	Orthophotography	Wetland	Swamp	Riverine
78	Wilson Creek Marsh North	67645	900	ELC Mapping	Evaluated PSW	Orthophotography	Wetland	Swamp	Bottomland
79	Wilson Creek Marsh South	333883	1572	ELC Mapping	Evaluated PSW	Roadside Check	Wetland	Swamp	Bottomland

APPENDIX B: DIGITAL FILES

The following digital files have been provided with this report:

Model Related Files:

Innisfil Tier Two FEFLOW Model.fem: contains pumping wells, lateral boundaries, recharge distribution, and hydraulic conductivities.

Observed Water Levels.xls: contains a table of all observation water data extracted from the WWIS database for use in model calibration

ESGRA Mapping Related Files:

Natural Heritage Features.shp
ESGRAs.shp
Additional Protection Areas.shp
Particle Tracking Release Locations Forward.shp
Particle Tracking Release Locations Backward.shp
Particle Tracking End Locations – Forward.shp
Particle Tracking End Locations – Backward.shp