Approved

Chapter 3

WATER QUANTITY STRESS ASSESSMENT

APPROVED ASSESSMENT REPORT
for the
Northern Bruce Peninsula Source Protection Area

October 15, 2015

This page intentionally left blank.

APPROVED ASSESSMENT REPORT
for the
Northern Bruce Peninsula Source Protection Area

Table of Contents

List of Figures

List of Tables

List of Maps

This page intentionally left blank.

3.0 Water Quantity Stress Assessment

3.1 Summary of Conceptual Water Budget Results

The goal of any water budget is to characterize, as accurately as possible, the fluxes of water through the hydrologic system one is attempting to define. In order to do this, a basic understanding of the processes and components within the area and the flow between specific components of that cycle must be understood. This process of developing a basic understanding of the processes and components of the hydrologic cycle and developing a methodology for quantifying and correcting these fluxes is referred to as a conceptual water budget. Such a conceptual water budget was completed for the Saugeen, Grey Sauble, Northern Bruce Peninsula Source Protection Region (2007a) and the summary of the pertinent aspects of that report are presented below for the Northern Bruce Peninsula Source Protection Area (SPA).

3.2 Description of Region

The Watershed Characterization Report (SGSNBP SPR, 2008) provides an overview of how physiography, topography and soils generally influence the surface hydrology of the planning region and the SPA. The conceptual water budget document provides a more detailed description of the character of each of the main surface systems by presenting the historical observations and summarizing the findings and outcomes from earlier hydrologic modelling exercises that focused on these surface water systems.

3.2.1 Climate of the Northern Bruce Peninsula Source Protection Area

The climate of a region is a significant factor affecting its overall water budget. Precipitation, either in the form of rain or snow, provides the major input to a region's water cycle. Air temperatures influence the form of precipitation, runoff patterns, evapotranspiration rates and soil and ground cover conditions, all affecting water balance. Wind patterns at a macro level affect air moisture and precipitation patterns, particularly as they are influenced by Lake Huron in the SPA. At the local level, winds affect evapotranspiration in the growing season and the drifting and accumulation of snow across the landscape.

Map 3.2 shows the location of the main active or recently active gauges located within or in close proximity to the Northern Bruce Peninsula Source Protection Area, including those that have been developed through the years by the local conservation authorities, primarily for flood forecasting purposes. There is only one flow station located within the Northern Bruce Peninsula SPA and details are listed below in Table 3.2.1.

TABLE 3.2.1 – Climate and Streamflow Monitoring Stations in the Northern Bruce Peninsula SPA Operated by Water Survey of Canada (WSC)

Station Name	*WSC_ID*	*Drainage Area*	*Data Collected*	*Years of Flow Data*	*Status*
Bruce Peninsula	Stokes River Near Ferndale	02FA002	50.5	Flow, Levels	1976-2005

3.2.1.1 Precipitation

Precipitation data was acquired from the Environment Canada National Climate Archive (http://climate.weatheroffice.ec.gc.ca/). A total of 27 stations were used to characterize average precipitation inputs across the planning region. At each station, 30-year average annual precipitation values were calculated from 1971 to 2000 (inclusive) to create a weighted average of precipitation inputs into each subwatershed. The locations of climate stations used for the data analysis are shown in Map 3.2.

Missing precipitation data were interpolated in order to create a continuous time series using the Inverse Weighted Distance (IWD) method. With IWD, data points are weighted during interpolation so that the influence of one data point, relative to another, declines with distances from the interpolation points. Data from each active gauge (see Table 3.2.1) were compiled and screened for gaps in the record. These gaps were then filled according to the methodology described above in order to develop a continuous data set. Precipitation data was generated and summarized for each subwatershed on an annual basis. These data are presented in Table 3.10.1 for the period of 1971-2000 (inclusive).

Precipitation amounts vary from approximately 746-1,138 mm year, and are highest in the areas that are in the lee of Lake Huron, largely as a result of lake-effect precipitation during the winter months. The seasonal distribution of rainfall for four stations is shown in Figure 3.2.1 below.

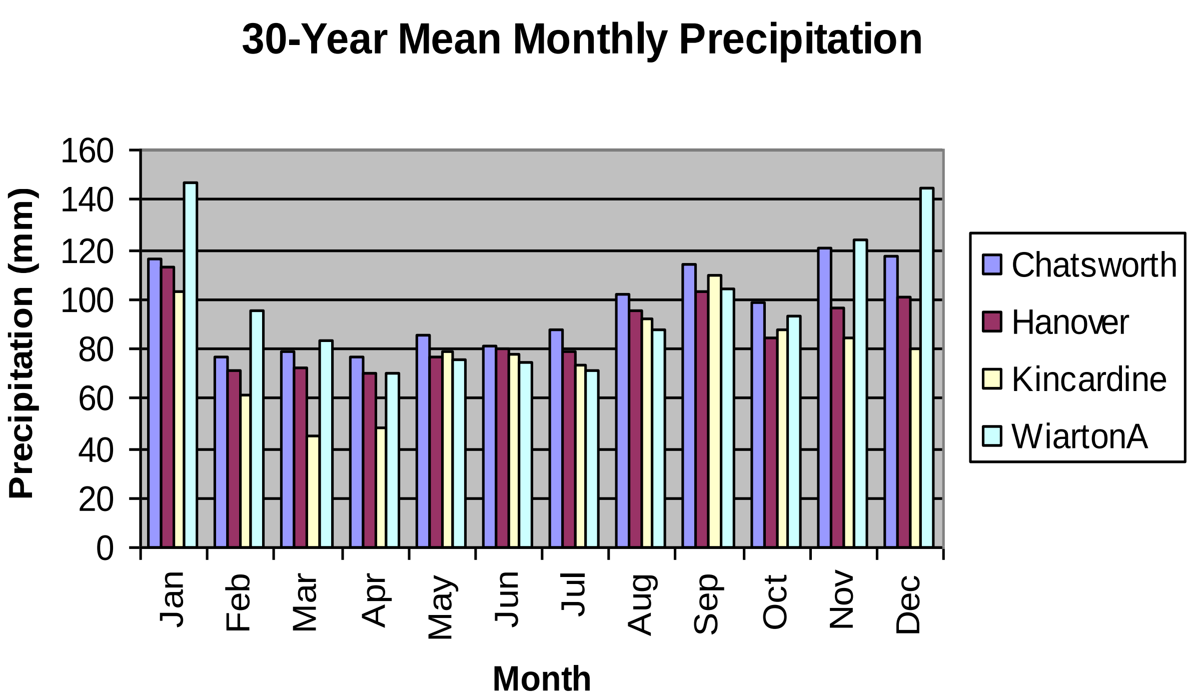

FIGURE 3.2.1 – Seasonal distribution of monthly precipitation for selected sites in the Saugeen, Grey Sauble, Northern Bruce Peninsula Source Protection Region

As mentioned, the sites were chosen primarily on the completeness of the data record. Wiarton is considered representative of the Northern Bruce Peninsula SPA. Based on the available data, there is a large amount of precipitation that falls over the region from November through January. Snowfall may represent as much as 40-50% of the annual precipitation, highlighting the importance of the spring freshet to runoff conditions in the region.

In addition, total precipitation is higher in the winter months (i.e. November-March), although this trend is more pronounced in the northern portion of the region. Monthly precipitation amounts typically decrease from January to April and gradually increase from May to December. These trends are typical at the four stations. The mean annual precipitation amounts were found to be 1,169 mm at the Wiarton station.

3.2.1.2 Air Temperature

In total, data from the climate stations operated by Environment Canada were analyzed for the area (Map 3.2). Data from all of the stations are uploaded to Environment Canada and are stored in a centralized database in a common data format, facilitating analysis of these data.

Ecodistricts, reflecting the overall suitability of land of specific agricultural activities were developed based on temperature and soils data for the study area by Agriculture and Agri-Food Canada. Temperature is a key measured variable used in the definition of ecodistricts and relies on minimum 30-year climatic normals derived for each area (Agriculture and Agri-Food Canada, 1997). Therefore, variations in ecodistricts are largely reflective of the differences in temperature within the study area and are the most reliable means for graphically representing this variation, due to the widely spaced nature of temperature data available from other sources.

Ecodistrict data suggests that temperatures in the area of the SPA along the shore of Lake Huron are relatively warmer than the remaining areas, largely as a result of their physical setting proximal and surrounded by large water bodies. The coldest zones seem to be located along the western slope of the Niagara Escarpment in the northern portion of the Bruce Peninsula.

3.2.1.3 Evaporation and Transpiration

Evaporation and transpiration (collectively referred to as ET) can only be derived for the study area, as they are not directly measured. In the development of ecodistricts for the study area, Agriculture and Agri-Food Canada derived ET values based on 30-year climate normals were available for the area. The ecodistrict ET data was then intersected with the subwatershed boundaries to produce average ET values. It is understood that these values represent modelled and/or calculated values based on 30-year climate normals and significant variation may occur on an annual basis. Estimated ET values for the study area are shown in Table 3.10.1.

ET is inherently tied to variables such as heat, sunlight, length of growing season, and average wind. As a result, southern areas, which are warmer and have longer growing seasons, and those areas along the Lake Huron shoreline known to have high consistent winds, exhibit higher ET values. Low ET values in the eastern portion of the study area are likely a reflection of the elevation of the area.

3.2.2 Land Use and Land Cover

The primary sources of land use data for the SPA are the Canada Land Inventory (1966-1988) and municipal official plans and zoning by-laws. For the purpose of water budgeting, the Canada Land Use Inventory is the most useful data source, as it provides uniform data across the entire region and is readily available in a geo-referenced format. Map 3.1 shows land cover separated into three broad categories: agriculture; woodland; and built-up/transportation/extraction.

Official Plan information is available for the area and categorizes lands according to their present or anticipated land uses. These data commonly separate information into broad categories of agricultural, natural environment, and urban/developed lands and are defined for municipal purposes. Although official plans may be useful for predicting the areas that will undergo substantial land use changes in the immediate future (i.e. the next 5 years), they do not provide enough accurate information on whether to develop a water budget model, as they often include existing and planned land use. They also do not discern between forms of agriculture, a critical exercise in estimating the proportions of runoff from different contributing areas to surface water bodies.

Historical Trends in Land Use

The Northern Bruce Peninsula Source Protection Area is not considered to have undergone, nor is expected to undergo, significant changes in land use. The development pressure of the area is primarily focused on the waterfront areas, especially along the shores of Lake Huron and Georgian Bay. The existing urban areas are not anticipating significant growth. The growth that is anticipated will not likely exceed over 2% of the existing land area, will likely still remain restricted to the waterfront areas, and is not considered significant.

3.2.3 Soils

Soils mapping is available for the entire Northern Bruce Peninsula SPA based on county-scale soils surveys completed in the 1950-1955 period, with some minor updates completed in the 1980's. These surveys have been digitized and attributed and are available in a GIS format from the Ministry of Natural Resources and Forestry (2002).

One of the main objectives of the water budget exercise is to account for the amount of infiltration at the surface interface to the ground. In order to develop an estimation of infiltration, accurate and detailed descriptions of the soil series are required. Map 2.8 shows the soil textures for the SPA.

3.3 Runoff and Streamflow

This section provides a characterization of the surface water resources of the source protection area, including the contributing watersheds for the Stokes River.

The surface water characterization is based on the surface water drainage areas contributing to streamflow gauges located in the above rivers as shown on Map 3.2. These assessment areas have been altered from those originally defined for water budgeting analysis in order to accommodate the best quality data available to perform these analyses.

This section provides a summary of the data sources used to carry out the surface water characterization. The characterization is based on a discussion of the land cover, physiography, and hydrology of the Northern Bruce Peninsula SPA. Where possible, hydrological response is discussed with relevance to the land cover and physiography of the drainage area.

Streamflow monitoring is carried out by a gauge operated by the Water Survey of Canada under the HYDAT program (Hydroclimatological Data Retrieval Program) as listed in Table 3.2.1. WSC currently maintains 1 active station. Gauged data collected by WSC undergoes an extensive quality assurance/quality control process to correct observed problems with the data including:

- Backwater effects due to ice and aquatic plant effect, which artificially raises the water level resulting in falsely high calculated streamflow.
- Equipment malfunctions, sensor drift or estimates data lost due to equipment failure.

A rating curve is prepared by gauge operators to relate measured streamflow to water depth. This curve is generated by physically measuring river discharge and relating it to a river stage. Multiple measurements of flow and stage are combined to develop a rating curve for a particular station. Errors in streamflow records can arise when considering infrequent flows, such as extreme low flows or high flows that are on the high and low ends of the rating curve. This is particularly an issue with extreme low flows, as changes in channel morphology can significantly impact the stage/discharge relationship. The effects of ice and vegetation on streamflow measurements are similar. This limitation needs to be kept in mind when analyzing low flows.

Mapping

Several sources of GIS mapping were used when completing the surface water characterization as summarized below:

- Digital Elevation Model (DEM) and enhanced flow direction grid provided by the Ministry of Natural Resources and Forestry (MNRF) (See Map 2.4);
- Drainage catchment boundaries delineation. Drainage catchment boundaries were based on the DEM (See Map 2.4) and flow direction grid;
- Evaluated Wetlands, Natural Resources Values Information System (NRVIS), MNRF (See Map 2.9);
- Hummocky Topography dataset from the Ministry of Northern Development, Mines and Forestry (MNDMF). A supplementary dataset included with the Quaternary Geology of Ontario Seamless Coverage;
- Land use layer from the Canada Land Inventory (CLI) – Natural Resources Canada (NRCan). Based on land use classifications from 1966-1988 (See Map 2.13); and
- Quaternary Geology, dataset produced by the Ontario Geological Survey, MNDMF (See Map 2.6).

3.3.1 Streamflow Analysis

To describe the hydrologic response of the catchment areas within this SPA, daily average flow data from the climate stations was imported into a relational database (Microsoft Access) and analyzed to produce reports summarizing the data. The station selected for the analysis is currently active with a relatively long period of record.

The physical characteristics of the gauge were calculated for the contributing drainage area of each gauge using GIS analysis of the datasets presented in the previous section. The physical characteristics are summarized as follows:

- Quaternary Geology: Quaternary geology was simplified to seven groupings as shown, including six primary groupings and one left blank for areas without quaternary geology mapping coverage. Quaternary geology classifications were selected instead of soil classifications, primarily due to the simplified mapping. As soil types are typically a reflection of quaternary geology, the groupings shown are expected to be reflective of their influence on hydrological response. Wetlands are included within these groupings.
- Percentage of hummocky topography and karst deposits are also included; and
- Percentage of forest cover.

Results of this analysis are shown in Table 3.3.1.

TABLE 3.3.1 – Gauged Catchment Characteristics

Station Name	Station	Drainage Area (ha)	Physiography		Soil / Surficial Classification							Forest
			Hummocky	Karst	Unclassified	Impervious / Bedrock	Clay / Clayey Tills	Silty Tills	Sandy Tills	Sand / Gravel	Wetland Deposits	
Stokes River near Ferndale	02FA002	5,981	0%	1%	100%	0%	0%	0%	0%	0%	0%	63%

3.3.1.1 Streamflow

All available flow data from WSC stream gauges was organized within a relational database for ease of analysis. The selected time period for analyzing the data was from 1980-2003. Where the full time period was not available for a gauge, any available data in the 1980-2003 period was used. In order to describe the hydrology of the catchments, the following parametrics were calculated and are shown in Table 3.3.2:

- Mean Monthly Streamflow: Mean monthly streamflow volumes were calculated to represent the average volume of water seen at the gauge, and illustrate how that changes seasonally.

- Ranked Duration: Similar to calculating percentiles, ranked duration plots were also constructed for the gauging station. This allows one to determine the percent of time flows are above a certain threshold.

- Median Monthly, 10th and 90th Percentile Monthly Streamflow: As streamflow data do not obey normal (Gaussian) distributions, mean flow values were not considered appropriate for this analysis. Median monthly flows, defined by the flow observed 50% of the time, is a better indicator of typical conditions. Additionally, the 10th percentile flow is an indicator of typical high flows and represents streamflow that is exceeded only 10% of the time, while the 90th percentile streamflow is an indicator of typical low flows and represents low flows that are exceeded 90% of the time. The median, 10th and 90th percentile flows are referred to as parametric statistics and are calculated monthly.

- Flashiness. The amount of flashiness, or how quickly a catchment responds to a precipitation event, and returns to pre-event flow conditions, can be quantified by calculating the 10:90 ratio. The 10:90 ratio refers to the ratio of the flow rate equalled or exceeded 10% of the time to the flow rate equalled or exceeded 90% of the time. A high 10:90 ratio would indicate a watershed with highly variable flow, usually characterized by a well-defined drainage network, and low permeability surficial materials, with little to no sustained flow during non-runoff periods. A low 10:90 ratio would be indicative of a steady, well-buffered catchment, with poorly defined drainage networks, large storage elements, such as wetlands or lakes, permeable surficial materials, and sustained dry weather flows. This ratio was calculated for the gauged catchment.

This assessment was performed for the sole gauge in the Northern Bruce Peninsula Source Protection Area.

TABLE 3.3.2 – Flow Characteristics for Gauged Catchments

Station Name	***Station Number***	***Mean Annual Streamflow (m^3/s)***	***Streamflow Depth (mm)***	***Mean Annual Baseflow (m^3/s)***	***Baseflow Depth (mm)***	***BFI****	***Annual Median Flow (m^3/s)***	***10% Flow Exceed-ance (m^3/s)***	***90% Flow Exceed-ance (m^3/s)***	***90:10 Ratio***
Stokes River Near Ferndale	02FA002	1.2	610	0.5	244	0.4	0.5	3.0	0.0	86

** BFI (Baseflow Index)*

3.3.1.2 Baseflow

Baseflow typically refers to the component of streamflow that would be observed in the absence of direct runoff from a precipitation event. Although baseflow is generally thought of as a result of groundwater discharge to streams, it can also be supported by the release of water from natural and controlled reservoirs and lakes as well as wetlands.

A baseflow separation exercise was carried out on selected stream gauges to isolate the streamflow hydrograph into runoff and baseflow components. Although there are a wide variety of baseflow separation techniques, the baseflow separation routine used in this analysis is the Baseflow Separation Program. This program simulates a daily record of estimated baseflow, coinciding with streamflow records. It also calculates a Baseflow Index (BFI) that represents the fraction of mean annual flow that is a result of a baseflow contribution.

It is very important to note that baseflow should not be considered to be entirely due to groundwater discharge. Baseflow is a result of the slow release of water from storage contained within a contributing upstream drainage area. This water released from storage could originate in groundwater, and hence be termed groundwater discharge, but also could originate from wetlands or reservoirs. Other anthropogenic impacts, such as sewage treatment plant discharges, may constitute a portion of baseflow as well. Within the study area, significant wetland complexes are a major contributing factor to baseflows. However, for the purposes of this exercise, it was necessary to assume that most baseflow originates from groundwater discharge.

3.3.2 Topography and Watercourses

The primary source of data for the topography in the region is available as a digital elevation model, provided by the MNRF (2002). These data are based on existing Ontario base mapping completed during the 1980s. Map 2.4 shows the surface elevation (topography) of the Northern Bruce Peninsula SPA. Watercourses are available from existing Conservation Authority datasets, which are commonly attributed to include cold and warm water fisheries present in the watercourses. Map 2.11 includes the known cold and warm watercourses and existing stream network information.

3.3.3 Inland Lakes, Reservoirs and Wetlands

Inland lakes, reservoirs and waterways provide critical storage of water and are important for development of an overall water budget. These features are shown in Map 2.11 for the Northern Bruce Peninsula SPA. These features are important sources of baseflow for the region.

3.4 Groundwater Recharge Estimates

Recharge values were initially estimated using a physical based approach that considers the geology, topography, land use, and land cover of the SPA. Recharge values were further refined during the Tier I water budget and in the delineation of significant groundwater recharge areas (SGRAs), details of which are shown in section 3.13.

3.5 Surface Water System Characterization

Stokes River

The Stokes River catchment is relatively small (< 60 km^2) and is located on the Bruce Peninsula. Streamflow in the catchment is represented by the Ferndale gauge (02FA002). Due to a lack of quaternary geology mapping in the area, the surficial material composition is unknown; however, it is likely dominated by exposed, or near to surface, bedrock. The catchment has the highest proportion of forest cover of any catchments investigated. The high proportions of forests are likely to reduce runoff and promote groundwater recharge.

Mean annual streamflow is quite high and is likely due to the impervious nature of bedrock at surface. Evapotranspiration rates are likely lower than average due to the reduced ability of the surficial material to hold water. Without this moisture holding capacity, evapotranspiration rates cannot be sustained into summer months. The 10:90 ratio is very high, with this gauge having the 2^{nd} highest ratio for all investigated catchments in the Source Protection Region. This would indicate a very flashy system, which responds quickly to precipitation events. This type of hydrologic response is expected in a bedrock-dominated situation.

The calculated BFI is lower than average, and streamflow exhibits a high amount of variability in the summer months. This would suggest that there is relatively little sustained baseflow with little regional groundwater discharge, which is expected due to the small size of the catchment area. The ranked duration plot confirms this, with low flows dropping from 0.1 m^3/s to 0.001 m^3/s below 20% of the time.

Monthly mean flows vary, peaking during the spring months during the snowmelt, declining to a minimum in the summer, and recovering in the fall and winter.

3.6 Groundwater System

3.6.1 Geology

3.6.1.1 Precambrian Basement Rocks

Underlying all of the study area and a large majority of the North American continent are the metamorphic rocks associated with the large physiographic feature called the Canadian Shield. These rocks are not exposed in the study area and what is known of them is only from oil and gas exploration wells, which were terminated in the Precambrian rocks. From this drilling data, the rocks that underlie the study area have been correlated with rocks of the Grenville Province, understood to be between 1.7 and 2.5 billion years ago. East and north of the study area these rocks are exposed to the surface. In these areas, metamorphosed plutonic rocks with thin bands of meta-volcanic and meta-sedimentary sequences dominate the rocks. These rocks form the foundation upon which the later carbonate rocks were deposited.

Although the Precambrian geology of the area is not considered to have a significant influence on the hydrogeology of the area, it has played a significant role as a regional control on the deposition of later rocks. Two major features that have acted as regional-scale controls on the deposition and are attributed to these rocks are the development of the Michigan Basin and the Algonquin Arch.

The Michigan Basin is composed of younger carbonate rocks but is centered along a failed rift zone (the North American rift) that unsuccessfully began to open approximately 1.1 billion years ago. The basin that formed as a result provided the initial depression into which the younger carbonate rocks were deposited, beginning approximately 545 million years ago. The basin is centered in the middle of the main peninsula (the “thumb”) of Michigan and is the regional structure with which the carbonate rocks of the study area are associated.

The second major Precambrian feature that has controlled the deposition of the younger carbonate rocks in our area is the Algonquin Arch. The Algonquin Arch is a linear uplift of the Precambrian rocks that extends roughly from the Algonquin Park in central Ontario southwest through to the Windsor area. The Algonquin Arch is poorly understood, but may have formed during an early phase of orogeny in the Appalachians. The arch likely acted as a barrier between waters circulating between the Michigan Basin and those associated with the fore-arch basinal waters of the Appalachians. As such it has had a profound effect on the depositional facies of similar aged rocks on either of its flanks. It is of particular note to our study area that the Algonquin Arch, during deposition of the Lucas Formation, likely restricted flow in the western portion of the Michigan Basin leading to development of Sabkha sequences in these rocks with which modern-day karst features have developed. In fact, the Algonquin Arch has had such a significant influence on the topography of the area through time that, even today, the boundaries between the Lake Huron and Lake Erie and Ontario basins still can be roughly traced along the crest of the arch.

Some smaller Precambrian features may have also had an effect on present-day topography, as it has been noted that major bedrock valleys in the younger carbonate rocks (i.e. the "Dundas Bedrock valley") and even modern river valleys have similar orientations as some of the larger Precambrian faults (see Johnson et al., 1992 and references therein).

3.6.1.2 Paleozoic Carbonate Rocks

After a non-conformity spanning approximately 600 million years, deposition of the sedimentary rocks of the Michigan Basin commenced. The Michigan Basin was the dominant regional structure controlling deposition of rocks in central North America during this time. The Michigan Basin is a roughly circular depression centered within the present day State of Michigan and on the failed North American paleo-rift. The entire sequence of rocks within the Michigan Basin was deposited in warm seas analogous to modern-day deposition in tropical regions. Periodic climatic and sea level changes led to the slight differences in the lithologies that were deposited. As an example of this, during periods of relatively high sea level, deeper water sediments, such as shales and mudstones were deposited, while during lower stands, shallow water limestone, Sabkha and reefal facies dominated. Indeed, there are several points during the deposition of these rocks that evidence exists suggesting that they were aerially exposed and eroded (Liberty and Bolton, 1971; Johnson et al., 1992). In addition, differences in water chemistry led to slightly different chemical compositions of the rocks themselves.

The rocks of this area dip slightly towards the interior of the Michigan Basin (southwest of the study area) and as such, the oldest rocks are exposed in the far northeastern portion of the study area. Map 2.5 shows the major bedrock units in the study area. For the purposes of this document, only bedrock units that subcrop or outcrop in the study area will be discussed, from oldest to youngest beginning with the Blue Mountain Formation. These formations are used as domestic and municipal sources of drinking water throughout the study area, which will be dealt with in section 3.7.1 of this report.

3.6.1.3 Blue Mountain Formation

The Blue Mountain is the oldest formation, which subcrops/outcrops throughout the planning region, and is found along a thin, northwesterly trending band situated at the base of the Niagara Escarpment. The Blue Mountain formation is approximately 60 m thick and is composed of soft grey to bluish shales and is defined largely by the presence of the trilobite genus *Tirathrus*. Due to its fine-grained nature, the Blue Mountain formation is considered an aquitard throughout the study area.

3.6.1.4 Georgian Bay Formation

Often outcropping at the very base of the Niagara Escarpment throughout the planning region is the Georgian Bay Formation. This 125-200 m thick sequence of grey limestone and greyish blue shale directly overlies the Blue Mountain group and records a transition from deeper, quiet conditions (shales) to shallower, warmer conditions (limestones). The Georgian Bay formation is known to be complicated by numerous sets of faults and joints, and these fractures are likely good conduits for groundwater flow in the area. The extent to which this formation is utilized as an aquifer is not known at this time; however, it is a likely source of groundwater for a significant portion of private well owners due to its widespread occurrence along the Bruce Peninsula.

3.6.1.5 Queenston Shale

The Queenston shale is a regionally significant marker horizon for southern Ontario, and extends from Queenston, along the Niagara Gorge northwest to the northern extent of the Bruce Peninsula where it subcrops in a thin layer. The Queenston Shale is known predominantly from drill core, as areas where the shale is exposed to the air break down easily into characteristic red soils.

These shales are red and argillaceous, generally without any fossils and thickness that varies from 45-335 m. Within these shale sequences exist some minor reefal facies. The Queenston shale's upper contact marks the boundary between the Ordovician and Silurian Eras.

Due to the fine-grained nature of these shales, they must be considered a regionally significant aquitard, with very low hydraulic conductivities, although extensive fracturing may allow for limited water movement through the formation.

3.6.1.6 Manitoulin Formation

The Manitoulin formation overlies a very thin layer of quartzose sandstone that has been broken out and named the Whirlpool formation (named after the famous whirlpools that exist within it in the Niagara Gorge). The Whirlpool formation overlies the Queenston shales and is the oldest Silurian sequence in the area. Yet, the Whirlpool formation is only 3 m thick and, as such, does not warrant significant discussion herein, as it subcrops over too small an area to be shown on a geological map at the scale of the study area.

The Manitoulin formation is a 25 m thick sequence of grey, finely crystalline fossiliferous dolostones that are found outcropping along the entire length of the steep face of the Niagara Escarpment through the area.

Little is known about the hydrogeological significance of the Manitoulin formation, though it is likely to be the source of water for a large number of private wells located south and west of the Niagara Escarpment.

3.6.1.7 Cabot Head Formation

The Cabot Head formation was proposed as a name for a sequence of rocks that outcrop along the steep cliff face of the Niagara Escarpment and are located between the dolostones of the

Manitoulin group and the rocks of the Lockport formation that form the top of the Escarpment. These rocks are composed of a series of different members, namely: the Cabot Head, Dyer Bay, Wingfield, and St. Edmund members. The Cabot Head formation is composed primarily of red-green shales with small amounts of buff-brown limestones.

This formation is not thought to be a significant aquifer for the area, rather is considered at a regional scale to be an aquitard. The upper contact of the Cabot Head formation with the Amabel formation is well known as a source of many springs in the area.

3.6.1.8 Amabel Formation

The thick sequence of dolomitic rocks that overlie the Cabot Head formation have been historically considered very difficult to subdivide, but have recently been identified as being a separate formation, named the Amabel. In the planning area, particularly along a narrow band just south and west of the Niagara Escarpment, these rocks have been targeted for extraction as building stone. The generally accepted terminology for these rocks within the study area is to split them into the Amabel and overlying Guelph Formations.

The Amabel is the primary target for extraction of building stone and is also a host to good quality and quantity aquifers. It is composed of thinly to massively bedded, grey to bluish-grey dolostones.

3.6.1.9 Guelph Formation

Overlying the Amabel formation is the Guelph Formation. The Guelph formation is well known from areas outside of the planning region, yet subcrops along a wide band through the region. Outcrops of the Guelph formation can be in an almost continuous band along the Lake Huron shore from Tobermory to Oliphant.

The Guelph formation is composed of buff-brown, crystalline dolostones that represent a true reefal sequence, with large biohermal “pinnacle” reefs surrounded by more massive, fine-grained and crystalline inter-reefal facies.

The Guelph formation is a host to good quality and quantity aquifers.

3.6.2 Pleistocene Glacial Deposits

3.6.2.1 Paleozoic-Pleistocene Non-Conformity

Following deposition of the Paleozoic carbonate rocks, a long non-conformity of approximately 300 million years ensued (Barnett, 1992; Chapman and Putnam, 1984; Karrow and Occheitti, 1989). During this period the bedrock was exposed aerially and was eroded extensively. Erosion during this period was a major factor in the development of bedrock valleys in the study area, while weathering and fracturing of the upper surface of the rocks produced zones of high permeability that are important hydrogeological features for the study area. The bedrock surface was altered dramatically during this unconformity and during subsequent glacial events. The topography of the bedrock surface is shown on Map 3.3.

3.6.2.2 Wisconsinan Glaciation

Numerous cycles of glacial advance (stades) and retreat (interstades) covered the study area, further eroding the bedrock and depositing unconsolidated materials. The latest glacial sheets of ice, which reached their furthest extents during the late Wisconsinan Glaciation approximately 10,000 to 12,000 years ago, are responsible for all of the unconsolidated overburden in the study area. During this period, major lobes of the Wisconsinan ice sheet covered the area, eroding pre-existing glacial deposits as well as the bedrock surface. In particular, the deposits of the planning region can be associated with two separate advances of the Wisconsinan Glaciation, the Port Bruce Stade and the Port Huron Stade, as well as the correspondent Mackinaw and Twocreeken interstades.

The dominant features associated with Port Bruce Stade are the deposition of tills. During the subsequent retreat of the ice sheets during the Mackinaw Interstade, glacial Lake Arkona was formed leaving behind paleoshoreline deposits and scarps. The re-advance of the ice sheets during the Port Huron Stade led to the formation of many of the physiographic features that dominate the landscape today, such as the large glacial re-entrant valleys that form deep indentations along the shore of Georgian Bay (Hope Bay, Isthmus Bay, etc). During the latest retreat of the glaciers during the Twocreeken Interstade, Lake Warren was formed leading to the deposition of a shoreline deposit at the base of the Wyoming moraine. Subsequent melting and recession led to the establishment of Lakes Algonquin and Nipissing.

Map 2.6 shows the surficial geology of the study area and Map 3.4 shows, at a crude scale, the distribution and thickness of glacial deposits. The Bruce Peninsula area has been almost completely denuded of any Pleistocene deposits, with only sporadic and discontinuous deposits of till and other glacial sediment.

3.6.2.3 Post Glacial Lakes

During and immediately following the recession of the glaciers, large lakes were formed. The shoreline deposits from these lakes, and the deltaic deposits from the rivers that had outlet in them, form important deposits of sand and gravel material for the watersheds. Shorelines tended to leave cuestas behind, which have become important topographical features. In the study area, four major postglacial lakes are documented, in order of development, Lakes Warren (the oldest), Nipissing, Algonquin, and present day Lake Huron (which includes Georgian Bay). A fifth glacial lake, Lake Stanley, is documented under Lake Huron, and was formed below the existing Lake Huron shoreline.

3.6.3 Holocene Erosion and Deposition

Erosion and deposition of sediment continues today. The rivers of the SPA continue to erode and transport sediment, which is eventually deposited into Lake Huron, and shape their respective valleys. Lake Huron is a major erosional force and continues to erode the glacial sediments along its shoreline, in the process mining and transporting sediment in cells along the shore. Along large beaches in the study area, large deposits of this sediment have been and continue to be altered by wind, forming large sand dunes that migrate inland from the shore of Lake Huron.

3.7 Hydrogeology

Major aquifers in the planning region can be divided grossly into two major types – bedrock and overburden. Bedrock aquifers are by far the most important source of drinking water for the region. Water supplies located away from the shore of Lake Huron rely almost exclusively on groundwater from the bedrock aquifers for their drinking water. A large number of documented private wells also rely on the bedrock aquifers for their water supplies.

3.7.1 Bedrock Aquifers

The bedrock aquifers are composed of an aggregate of the bedrock formations discussed in section 3.6.1. Within each specific bedrock formation, ambient water quality and quantity can differ dramatically, which is largely a consequence of the chemical and physical characteristics of the rocks themselves.

The bedrock aquifer itself is exposed throughout the majority of the SPA, particularly near the Niagara Escarpment, (see Map 3.4) and is known to have a potentiometric surface well above Lake Huron water levels (Map 3.5). Groundwater extraction from these aquifers is typically confined to the upper portion of the bedrock. Large water takings and municipal wells often extend deeper into the bedrock, accessing multiple water bearing horizons.

3.7.1.1 Regional Groundwater Flow

Groundwater flow within the bedrock aquifers generally flows away from the crest of the Niagara Escarpment and follows a generally west to southwesterly flow path towards Lake Huron or east and north towards Georgian Bay. It should be noted that groundwater levels indicate that most of the groundwater inside the study area originates from within the study area. Map 3.5 shows the regional potentiometric surface for the bedrock aquifer system.

3.7.1.2 Groundwater-Surface Water Interactions

With existing data it is difficult to delineate recharge areas for the study area. Through the southern portion of the watershed region the bedrock aquifer is not exposed at the surface, so any recharge must be transient through the overburden deposits. However, an approximation of the location of any recharge areas has been developed and is discussed in section 3.13.

Karst features, formed by the dissolution of bedrock by infiltrating waters, are well documented within the Northern Bruce Peninsula SPA and are manifested by numerous sinkholes and disappearing streams (WHI, 2005; Brunton et al., 2006). These features represent areas where surface waters are directly accessing bedrock groundwater, with little to no infiltration through overburden materials. Preliminary investigations (WHI, 2005; Brunton et al., 2006) have focussed predominantly at locating the known karst features. The impacts these features have on the regional groundwater flow system is poorly understood.

Similarly, little is known about the discharge of water from the bedrock aquifer. Based on piezometric surfaces for the bedrock aquifer, it is thought that the bedrock aquifer likely discharges into the overlying overburden aquifers in the area, but the extents of such an interaction is unknown. In the lower reaches of the major rivers, bedrock is exposed in the river beds and it is assumed that the bedrock aquifers in these areas are discharging directly into the area's rivers. Ultimately, the bedrock aquifers are thought to discharge directly into Lake Huron in the offshore.

3.7.2 Overburden Aquifers

Located within the unconsolidated glacial deposits overlying the bedrock aquifers are numerous overburden aquifers. Locally, these aquifers are important sources of drinking water and are essential for their contribution to surface water and recharge of the bedrock aquifers. For the most part, these aquifers are unconfined and are generally much more susceptible to contamination from surface waters than the bedrock aquifers.

Unfortunately, little information exists on the overburden aquifers for the watershed region. Due to the preference of local drillers for the bedrock aquifers, few well records exist for the overburden aquifers. As such, little information exists for these aquifers and flow directions, water quality and quantity are poorly understood.

There are no significant overburden aquifers identified in the Northern Bruce Peninsula Source Protection Area.

3.7.3 Groundwater/Surface Water Interactions

Shallow overburden aquifers are important sources of baseflow for many surface water streams. These aquifers help to moderate flow and provide cold water, which is valuable for specific fisheries. Shallow overburden aquifers, particularly unconfined aquifers, are areas of increased infiltration due to their coarse-grained composition and topography.

3.7.4 Cold-Water Fisheries

Map 2.11 shows the cold-water fisheries throughout the SPA. Cold-water fisheries are indicative of areas where significant discharge from shallow overburden aquifers is occurring. In fact, a large portion of flows in the surface water systems can be attributed to groundwater discharge. This component of surface water flow is critical for maintaining baseflow and ecological health of the surface water system. Cold-water fisheries, as a general rule, tend also to have a higher quality of water as well as quantity due to the dilution of overland runoff from groundwater discharge. This is an example of how the issues of water quantity and quality cannot be considered discretely, yet should be viewed as a single component within the framework of a water budget.

3.7.5 Hummocky Terrain

Hummocky terrain is described as areas with broad, gently sloping swales, within which there is increased depressional storage and increased flow lengths for overland flow. These factors lead to slower runoff to surface waters and a coincident increase in infiltration. Indeed, hummocky terrain tends to predominate within very coarse-grained materials where overland flow is not likely to occur. Hummocky terrain is important, as it may produce a disproportionately high volume of recharge to underlying aquifers.

Section 3.13.1.3 has additional discussion on hummocky terrain.

3.8 Water Use

3.8.1 Data Sources

A number of sources of data for water usage are available for the SPA. These data include the Provincial Permit to Take Water (PTTW) database, the Water Well Information System, agricultural water usage and census data, municipal well annual reports and Certificates of Approval, and existing groundwater studies. These data are useful for approximating the amount of water being extracted in the region. Takings from surface and groundwater sources are represented graphically in Maps 3.6 and 3.7.

3.8.2 Municipal Water Takings

Water takings for municipal drinking water supplies in the SPA are exploiting the bedrock aquifer and Georgian Bay.

As part of the Grey and Bruce Counties Groundwater Study (WHI, 2003), municipal water takings were quantified based on Permit to Take Water values. It was recognized in this study that these values represent daily maximums and therefore could, be misleading. These permitted values were then reduced by examining the water system annual reports as well as any other inflow data provided by municipalities that have been required to install flow meters and report annual water consumption since 2001.

Table 3.8.1 lists these municipal water takings by municipality for Grey and Bruce Counties. According to the data, there were no municipal takings in the Northern Bruce Peninsula.

Surface water takings were estimated based on the maximum daily amounts as defined by the PTTW for each supply.

TABLE 3.8.1 – Groundwater Use by Municipality and Sector for Grey and Bruce Counties*, from Grey and Bruce Counties Groundwater Study, 2003

Municipality	Municipal Groundwater Takings (m^3/day)	Agricultural Groundwater Takings (m^3/day)	Private Well Groundwater Takings (m^3/day)	Other Takings** (m^3/day)
Georgian Bluffs	208	719.7	1,660	8,769
Chatsworth	170	1,128.6	985	32,869
West Grey	1,463	2,065.5	1,627	53,818
Southgate	660	1,578.8	864	1,014
Hanover	1,753	0	47	0
Grey Highlands	3,490	1,280.5	1,260	9,157
Owen Sound	0	0	0	1,650
Meaford	0	2,083.5	1,025	0
Blue Mountains	0	3,649.4	760	2,781
Arran-Elderslie	1,262	1,680.9	512	197
South Bruce Peninsula	198	550.2	858	464
Brockton	5,756	1,757.6	801	546
Huron-Kinloss*	2,030	1,271.7	137	267
South Bruce	1,047	2,333.9	676	25,911
Kincardine	579	1,549.4	667	67,534
Saugeen Shores	0	244.6	327	5,245
Northern Bruce Peninsula	0	478.5	542	0
Native Reserves	0	0	221	0
Total (m^3/day)	**18,615**	**22,373**	**12,696**	**210,588**

** includes some takings that are part of the Ausable Bayfield Maitland Valley Source Protection Region*
*** includes industrial, commercial, recreational, and some communal water system takings, both consumptive and non-consumptive*

3.8.3 Agricultural Water Takings

Agriculture, including livestock feeding operations and irrigation, represents the largest land use within the SPA. As a result, it is also expected that the highest water takings will also be associated with these operations.

Agricultural operations rely heavily on the bedrock aquifers as a water supply, with relatively few takings from surface water. As part of the Grey and Bruce Counties Groundwater Study, (WHI, 2003) municipal water takings were first quantified based on Permit to Take Water values. However, most livestock facilities are not required to obtain a PTTW, and as such estimates of usage are best approximated from the distribution and estimated usage of different agricultural sectors.

Several previous studies have been completed in order to estimate the usage of water for the SPA and were summarized in the Grey and Bruce Counties Groundwater Study (WHI, 2003). Based on 2001 Statistics Canada agricultural census data, water takings were estimated on a township scale and are summarized in Table 3.8.1 above. Total consumption for Northern Bruce Peninsula SPA is estimated at 478.5 m^3/day.

3.8.4 Consumptive Commercial Water Takings

Consumptive water takings are those takings in which water is directly exported outside of the watershed, and includes such activities as water bottling, food processing, and beer and beverage production. These takings are important as they represent the only net removal of water from the hydrologic system within the planning region.

As part of the Grey and Bruce Counties Groundwater Study (WHI, 2003), consumptive groundwater takings were quantified and summarized by municipality, and are included as part of the “other takings” shown above in Table 3.8.1. There are no consumptive groundwater or surface water takings for Northern Bruce Peninsula.

3.8.5 Non-Consumptive Commercial Water Takings

Non-consumptive commercial water takings are those takings in which water is returned to the natural water system after use, and includes activities such as golf course irrigation, aggregate washing, quarry dewatering, aquaculture, and takings for dams and reservoirs.

As part of the Grey and Bruce Counties groundwater Study (WHI, 2003), non-consumptive groundwater takings were quantified and summarized by municipality, and are included as part of the “other takings” shown in Table 3.8.1. There are not any non-consumptive groundwater or surface water takings for the Northern Bruce Peninsula SPA.

3.8.6 Private Domestic Water Takings

Private consumption within the SPA almost exclusively exploits overburden and bedrock aquifers. The typical taking utilizes a drilled or, less commonly, a bored well, which is then redirected into shallow overburden aquifers via a septic system.

Estimates of private usage of groundwater was developed on a municipal scale using population data, water well records and estimated usage per capita in the Grey and Bruce Counties Groundwater Study (WHI, 2003). The summary of this estimated water usage is included within Table 3.8.1, above. Total estimated usage for the Northern Bruce Peninsula SPA is estimated at 542 m^3/day.

There are no known private surface water takings in the region, although the possibility exists that some rural residents may be exploiting surface water for domestic water supplies.

3.8.7 Recreational Water Usage

Recreational water use is a large economic driver within this SPA. These uses include outdoor recreation, hobby fishing, canoeing, and tourism and are focussed on the major river systems, Lake Huron and Georgian Bay. Recreational usage of water within the region tends to be generally non-consumptive and is not generally considered to impact the quantity of water in the system; however, adequate availability of water is required for the continued recreational use of these resources.

3.9 Conceptualization of the Hydrologic System

3.9.1 Key Components and Processes

For the Northern Bruce Peninsula Source Protection Area, the key components and processes considered for water budgeting are shown in Figure 3.9.1. This schematic strives to explain the pathways and fluxes of water between the key reservoirs. In order to complete a successful numeric water budget, these fluxes will have to be quantified, whether empirically or through modelling.

3.9.1.1 Ground Surface

The initial inputs into the system as a whole are in the form of precipitation. Precipitation falling to the ground is initially partitioned into surface runoff, which moves directly to surface systems or into infiltration. Storage on or within the ground surface occurs as soil field capacity and depressional storage. From this point, a portion of the water on or in the ground surface is released back into the atmosphere via evapotranspiration (referenced as ET on Figure 3.9.1). Evapotranspiration occurs throughout the system whenever water is exposed to the atmosphere or within the root zone of plant life. During dry periods, precipitation is augmented from the river systems, overburden aquifers and bedrock aquifers via irrigation.

3.9.1.2 River Systems

River systems receive direct runoff from the ground surface as well as groundwater discharge from both the overburden and bedrock aquifers. Interflow from infiltrating water is also diverted to river systems. Runoff into the riverine surface water systems eventually makes its way to Lake Huron (and Georgian Bay). River systems are not heavily exploited as sources of water in the planning region but an unknown amount of irrigation is documented, removing water from the river systems and placing it on the ground surface.

3.9.1.3 Interflow

A portion of infiltrating water is redirected to surface water systems before entering the saturated zone via interflow. Tile drainage acts as a conduit that may accelerate interflow throughout the planning region.

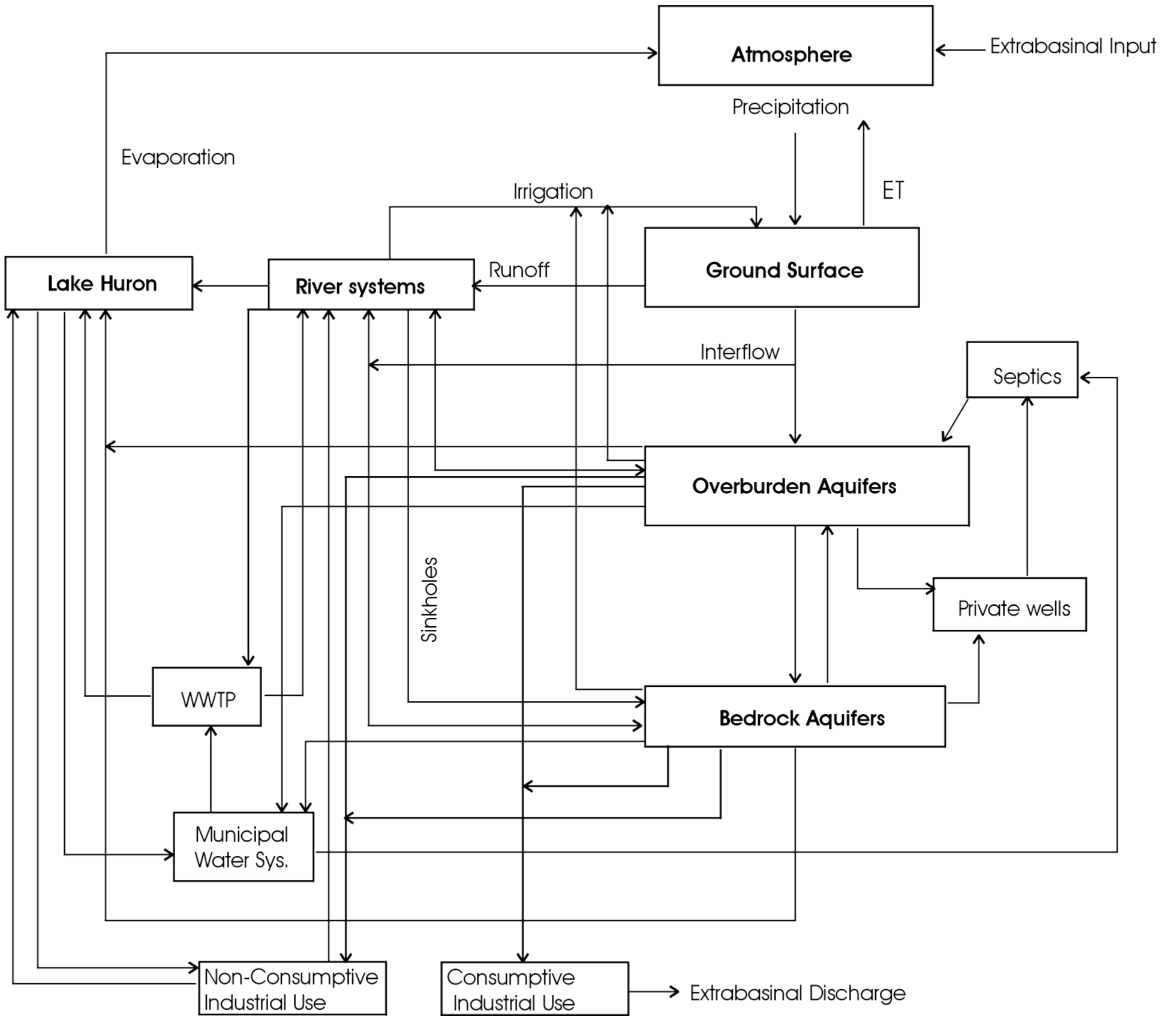

FIGURE 3.9.1 – Components and flux of water in the Northern Bruce Peninsula Source Protection Area

3.9.1.4 Overburden Aquifers

The remainder of infiltrating water reaches the saturated zone within either the overburden or bedrock aquifers as recharge. The overburden aquifers also receive inputs of water from river systems via losing streams, septic systems and potential discharge from the underlying bedrock aquifers. These overburden aquifers discharge water to the bedrock aquifers, private wells and most importantly to the surficial river systems where they represent high quality sources of groundwater discharge for cold-water streams. Water extracted for domestic consumption into private wells is subsequently discharged back into the overburden aquifers via septic systems.

3.9.1.5 Bedrock Aquifers

Inputs into the bedrock aquifers include recharge originating from the ground surface where the bedrock is exposed, recharge from overlying overburden aquifers, and recharge from river systems via losing streams and via sinkholes, which act as direct conduits for runoff into the bedrock aquifers. The vast majority of input into the bedrock aquifers is derived from within the

Northern Bruce Peninsula Source Protection Area itself. Water from the bedrock aquifers naturally discharges into Lake Huron and, in certain areas, into river systems. In addition, large volumes of water are extracted from the bedrock aquifers for commercial and municipal water uses. The majority of this water is treated in municipal waste water treatment facilities (referenced as WWTP in Figure 3.9.1) and released into the river systems. However, an unknown portion of this water is diverted to the overburden aquifers via private wells or municipal wells and septic systems.

3.9.1.6 Lake Huron

Lake Huron is the ultimate destination for water within the system. Lake Huron receives water from all the components shown in Figure 3.9.1. River systems, overburden aquifers and bedrock aquifers all naturally discharge toward the Great Lakes. Water from WWTP is also outlet directly into Lake Huron. The key process for Lake Huron is the extraction of water from the Lake for drinking water purposes. The Lake Huron shoreline within the Northern Bruce Peninsula Source Protection Area is host to one municipal water system (ferry terminal). This system forms a closed loop, as water is treated and subsequently released back into Lake Huron.

3.10 Summary of Tier I Water Budget

A Tier I water budgeting exercise is intended to estimate the hydrologic stress of subwatersheds for the purpose of screening out areas from further, more detailed assessment. This is to be done using the best available data for the major hydrologic components and processes of these subwatersheds (“watershed elements”). The data is then compared to the amount of consumptive water demand within a given subwatershed to determine the degree of stress in the hydrologic system due to human water usage.

This section is a summary of the Saugeen, Grey Sauble, Northern Bruce Peninsula Source Protection Region Tier I Water Budget Reports (AquaResource, 2008a; 2008b), which have been completed in compliance with the Technical Rules: Assessment Reports, issued by the Ministry of the Environment and Climate Change (MOECC, 2009).

TABLE 3.10.1 – Tier I Water Budget Values for the Northern Bruce Peninsula SPA (all values expressed as mm/year of equivalent precipitation)

Subwatershed	***Precipitation*** (mm/year)	***ET*** (mm/year)	***Runoff*** (mm/year)	***Recharge*** (mm/year)	***Water Takings*** (mm/year)
Crane River/Willow Creek/Tobermory	1,049	410	378	261	0
Stokes River/Ferndale	1,049	420	438	191	7
Sucker Creek/Judges Creek/Cape Croker	1,049	533	347	170	0

3.10.1 Subwatersheds for Tier I Water Quantity Stress Assessments

For the Tier I water budget, new subwatersheds were proposed for the purposes of performing subwatershed stress assessments. These subwatersheds were delineated according to a hierarchy of factors, developed with the assistance of the Peer Review Committee, including: total water contributing area for municipal water supplies; limits of existing subwatersheds used for modelling purposes; areas of concentrated water usage; and physiographic and hydrologic characteristics. Tier I subwatersheds were developed separately for surface and groundwater analyses, and are shown in Maps 3.8 and 3.9, respectively. A detailed rationale for the delineation of Tier I subwatersheds can be found in the Tier I water budget reports (AquaResource, 2008a; 2008b). A total of three (3) subwatersheds were analyzed as part of the Tier I water budget in the Northern Bruce Peninsula SPA.

3.10.2 Modelling

Quantitative estimates of the flow of water between the watershed elements for these subwatersheds were derived from existing surface and groundwater models.

3.10.2.1 Surface Water Modelling

Surface water modelling was carried out for the entire Northern Bruce Peninsula Source Protection Area using the Guelph All Weather Sequential Event Runoff (GAWSER) model. This tool was used to simulate long-term evapotranspiration, streamflow and deep drainage for all the major river systems located within the Northern Bruce Peninsula Source Protection Area. A report outlining the steps required to complete the modelling was developed by AquaResource Inc (2008b). The simulated quantification of these watershed elements is essential in determining the Tier I subwatershed stress assessments for the region.

3.10.2.2 Groundwater Modelling

A fully calibrated 3D groundwater flow model was developed for the region using FEFLOW groundwater modelling software. Details on this model, including information on development and calibration of the conceptual and groundwater flow models is available in the Tier I water budget report (AquaResource, 2008a).

The groundwater flow within the model was calibrated against static water levels from MOECC Water Well records, Provincial Groundwater Monitoring Network wells throughout the region and to 4th order or greater streams. Water Well records were screened based on confidence in locations, and elevations from these Water Well records were adjusted using the digital elevation model (DEM) for the area.

For the purposes of that project, each of the Tier I subwatersheds were separated and refined from the regional scale model. In order to extract models, the regional scale model was overlain with a layer outlining the Tier I subwatersheds. As the individual elements within the model were of a coarse scale, some elements traversed subwatershed boundaries. Boundary conditions, including groundwater flow between subwatersheds, for each Tier I subwatershed were developed using FEFLOW from the fully calibrated, regional-scale model and are shown in Table 3.10.4.

Tier I subwatershed models were simulated for the period from 1985 to 2005. Groundwater fluxes were developed using the continuous boundary flux methodology within the FEFLOW water budgeting module and are shown for the entire SPA in Table 3.10.4.

3.10.3 Surface Water Supply Estimate

At any given time, the available drinking water supply in a river or stream is limited to the instantaneous flow rate. Surface water supply is a method for determining the amount of flow available based on streamflow data for the Northern Bruce Peninsula Source Protection Area. The prescribed approach for determining the surface water quantity stress takes into consideration seasonal variability and is evaluated using an estimate of expected monthly flow values.

For each subwatershed within the study area, median flows were calculated to provide an estimate of surface water supply. Fiftieth percentile flows were derived from the daily GAWSER analyses for each month and are shown in Table 3.10.2. These values represent the surface water supply values for use in the surface water stress assessment.

TABLE 3.10.2 – Monthly Median Flow (L/s) per Subwatershed (Surface Water Supply)

Subwatershed	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Crane River/Willow Creek/Tobermory	2,140	1,253	5,161	11,002	3,215	2,057	1,430	1,364	2,219	3,729	5,686	4,236
Stokes River/Ferndale	1,815	1,063	4,376	9,329	2,726	1,744	1,213	1,157	1,881	3,162	4,821	3,592
Sucker Creek/Judges Creek/Cape Croker	1,606	940	3,872	8,254	2,412	1,543	1,073	1,023	1,664	2,798	4,265	3,177

3.10.4 Surface Water Reserve Estimate

The water reserve estimate for a surface water system in Tier I is based on the maximum of a statistical measure of low flow or a known anthropogenic need (i.e. wastewater assimilation). The water reserve estimate is the means by which a portion of water may be protected from being considered within the stress calculations. The concept behind its use is to support other uses of water within the watershed, including both ecosystem requirements (instream flow needs) as well as other human uses (primarily permitted uses). The reserve quantity is subtracted from the total water source supply prior to evaluating percent water demand.

For the scale of this Tier I assessment, surface water reserve is not complicated by the need for assimilative capacity and is; therefore, most simply expressed as the 90th percentile flows for each subwatershed. Ninetieth percentile flows were derived from the daily GAWSER analyses for each month and are shown in Table 3.10.3. In order to be consistent with MOECC guidance, for the Tier I surface water stress assessment, reserve values are used for the months with the lowest monthly water supply estimates, rather than the lowest monthly water reserve estimates.

TABLE 3.10.3 – Monthly 90th Percentile Flow (L/s) per Subwatershed (Water Reserve)

Subwatershed	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Crane River/Willow Creek/Tobermory	806	566	713	3,532	1,544	894	548	553	753	1,560	2,120	1,717
Stokes River/Ferndale	683	480	605	2,995	1,309	758	465	469	638	1,323	1,798	1,456
Sucker Creek/Judges Creek/Cape Croker	605	425	535	2,650	1,158	671	411	415	565	1,170	1,590	1,288

3.10.5 Groundwater Supply Estimate

An estimation of the amount of groundwater available to supply a subwatershed's groundwater users is determined as a summation of groundwater recharge and lateral groundwater flow into the subwatershed. The percent water demand can then be calculated as both average annual and average monthly conditions for current and future scenarios. For this Tier I analysis, aquifer storage is not considered and as such, the water supply terms for the subwatersheds are assumed to be consistent on an average annual basis.

Groundwater Flux through the system was developed from the FEFLOW model. Tier I subwatersheds were refined and extracted and flux values determined using continuous boundary flux within the FEFLOW water budgeting module.

For the study area, two sources of recharge data are available: estimates derived from the groundwater model (annual only); and from the GAWSER analysis (monthly and annual). Table 3.10.4 summarizes groundwater flux through the Tier I subwatersheds derived from FEFLOW. These recharge values derived from FEFLOW for the groundwater model will be used for the Tier I assessment. These data are considered to be the more conservative value, which is consistent with expectations for a Tier I water budget.

Groundwater supply is the sum of the groundwater flow in and the recharge for each subwatershed, and does not take into account groundwater flow out of the subwatershed.

TABLE 3.10.4 – Groundwater Budget Expressed in Equivalent mm/year Precipitation

Subwatershed	Area (km^2)	Recharge (mm/yr)	External Boundary Flux (mm/yr)	Discharge to Great Lakes (mm/yr)	Discharge to Lakes and Streams (mm/yr)	Interbasin Transfer (mm/yr)	Water Taking (mm/yr)
Crane River/Willow Creek/Tobermory	346.74	183	0	-66	-45	-73	0
Stokes River/Ferndale	294.16	204	0	-49	-104	-50	0
Sucker Creek/Judges Creek/Cape Croker	257.23	155	0	-45	-48	-62	0

3.10.6 Groundwater Reserve Estimate

The groundwater reserve for Tier I analysis is determined by estimating the reserve quantity as 10% of the existing groundwater supply.

3.10.7 Consumptive Groundwater Usage Estimate

3.10.7.1 Permitted Usage

Permitted groundwater usage is primarily documented through the PTTW database, as well as through municipal drinking water supply records. Similar to the permitted surface water takings, the best available water taking data (actual, estimated average, maximum permitted) was used to estimate permitted amounts, which were subsequently adjusted using the consumptive factor outlined in MOECC guidance. Groundwater use by Tier I subwatershed is included in Table 3.10.5.

3.10.7.2 Non-Permitted Agricultural Usage

Agricultural usage, particularly those not related to crop irrigation are exempt from requiring a Permit to Take Water. As a result, no documentation of this usage is available for analysis. Estimates of agricultural usage were developed based on agricultural data and projected watering requirements from the 2001 census data as part of De Loë (2002). This information is broken into watersheds for all of southern Ontario and was incorporated into the consumptive usage estimates. Estimated takings were then adjusted according to consumptive use factors provided by the MOECC's Technical Rules. Groundwater use by Tier I subwatersheds are included in Table 3.10.5.

3.10.7.3 Private-Domestic Usage

Private domestic usage is not considered within the MOECC guidance document (MOECC, 2006). It was felt, due to the high reliance on groundwater for private potable water sources, that this taking should be incorporated into this Tier I water budgeting exercise.

Private well records for each subwatershed, available in the Ministry of the Environment and Climate Change's Water Well Information System (WWIS), were assigned a minimum taking value of 450 L/day (0.45 m^3/day) based on usage requirements set out in MOECC best practice documents for the sizing and evaluation of septic systems. These values were then adjusted according to consumptive use factors for domestic water takings provided by the MOECC's Technical Rules. Groundwater use by Tier I subwatersheds are included in Table 3.10.5.

TABLE 3.10.5 – Groundwater Use by Tier I Subwatershed

Subwatershed	***Municipal Demand (avg) (m^3/day)***	***Agricultural Demand (m^3/day)***	***Private Wells (m^3/day)***	***Permitted Use (m^3/day)***
Crane River/Willow Creek/Tobermory	0	173.5	405.9	81.8
Stokes River/Ferndale	0	150.7	457.7	0
Sucker Creek/Judges Creek/Cape Croker	0	153.4	318.6	0

3.10.8 Consumptive Surface Water Usage Estimate

3.10.8.1 Permitted Surface Water Usage

Permitted users are the only reliable source for surface water takings for the area. Surface water takings are generally confined to irrigation activities, with the exception of the Lake Huron-based municipal (and private) water supply systems, which are excluded from the Tier I water budgeting exercise. The best available water taking data (actual, estimated average, maximum permitted) was used to estimate permitted amounts, which were subsequently adjusted using the consumptive factor outlined in the MOECC's Technical Rules. Surface water use by Tier I subwatershed are included in Table 3.10.6.

TABLE 3.10.6 – Surface Water Use by Tier I Subwatershed

Subwatershed	***Permitted Takings (m^3/day)***	***Non-Permitted Agricultural Demand (m^3/day)***
Crane River/Willow Creek/Tobermory	0	172.8
Stokes River/Ferndale	5,702.4	172.8
Sucker Creek/Judges Creek/Cape Croker	0	172.8

** Values converted by DWSP staff from L/s in Tables 3.3 and 3.4 (AquaResource, 2008b) to m^3/day.*

3.10.9 Future Usage Projections

Future increases in the usage of both (non-Lake Huron) surface water and groundwater are not considered significant for the study area. The study area is considered to be "fully developed" in that it has very little natural area that will likely be converted to either agricultural or residential land uses.

Population growth is projected to be minimal in the immediate future, with growth centered along the shore of Lake Huron and in existing towns and villages. Given the low consumptive water uses in the area it seems unlikely that future usage, based on today's projections, will lead to any additional stress on the natural system. Caution should be added that not all future uses can be accounted for or anticipated, and that no additional stresses are anticipated for the subwatersheds at the scale being investigated; however, large takings within specific areas may still lead to significant problems.

3.11 Tier I Surface Water Stress Assessment

The Tier I surface water stress assessment is designed to screen and flag those subwatersheds where the degree of stress is considered moderate or significant for further study. The stress assessment evaluates the ratio of the consumptive demand for permitted and non-permitted users to water supplies, minus water reserves within a given subwatershed.

Within the study area, for each subwatershed, the monthly water reserve (10^{th} percentile flows) was subtracted from the monthly water supply (median flows) for the month with the lowest monthly water supply in order to determine water availability. The percentage water demand was then calculated as a percentage of the consumptive demand versus this water availability, where:

$$\%\ \text{water demand} = \frac{\text{consumptive demand}}{(\text{water supply} - \text{water reserve})} \times 100$$

Table 3.11.1 shows the percent water demand by subwatershed on a monthly basis.

TABLE 3.11.1 – Monthly Percent Water Demand for Tier I Subwatersheds

Subwatershed	***Jan***	***Feb***	***Mar***	***Apr***	***May***	***Jun***	***Jul***	***Aug***	***Sep***	***Oct***	***Nov***	***Dec***
Crane River/Willow Creek/Tobermory	0.2	0.3	0.0	0.0	0.1	0.2	0.2	0.2	0.1	0.1	0.1	0.1
Stokes River/Ferndale	0.2	0.4	0.1	0.0	0.1	0.2	0.3	0.3	0.2	0.1	0.1	0.1
Sucker Creek/Judges Creek/Cape Croker	0.2	0.3	0.1	0.0	0.1	0.2	0.3	0.3	0.2	0.1	0.1	0.1

Subwatershed stress levels are defined as:

- less than 20% - low
- between 20 and 50% - moderate
- more than 50% - significant

Table 3.12.1 outlines the water supplies, reserves, availability, consumptive demand, percentage water demand, and surface water quantity stress levels for each subwatershed in the study area. The stress levels are presented graphically in Map 3.8 and summarized in Table 3.11.2. Several subwatersheds are considered to have potential stressed systems based on percentage water demand.

However, as there are no municipal water systems utilizing surface water systems in the Northern Bruce Peninsula SPA, there is no need for further analysis of the surface water system.

TABLE 3.11.2 – Summary of Potential for Surface Water Stress per Subwatershed

Watershed	***Subwatershed Name***	***Potential for Stress***
Bruce Peninsula	Crane River/Willow Creek/Tobermory	Low
Bruce Peninsula	Stokes River/Ferndale	Low
Bruce Peninsula	Sucker Creek/Judges Creek/Cape Croker	Low

3.11.1 Surface Water Stress Assessment Uncertainty

To increase confidence in the surface water stress assessment presented above, the percent water demand equation was repeated for four different scenarios. Each scenario represents uncertainties associated with the water supply and consumptive demand estimates used in the stress assessment calculation and determines if variation in those terms can cause a change in the final stress classification. Should the stress classification remain the same with all four scenarios, one can be confident that the uncertainties inherent in estimating water supply and water demand terms are not impacting the final stress assessment.

Both the water supply and water demand estimates were varied by ±25%, independent of one another. These variations resulted in the four scenarios summarized in Table 3.11.3. Subwatersheds where the stress classification remained the same for all four scenarios and the best estimate are considered to have low uncertainty. Those subwatersheds that vary between low and moderate/significant are considered uncertain. As the outcome is the same for subwatersheds classified as having a moderate or significant potential for stress, fluctuations between these stress classifications does not result in an uncertain stress assessment.

TABLE 3.11.3 – Sensitivity of Surface Water Stress Classification

Subwatershed Name	***Surface Water Stress Classification***				
	Best Estimate	***+25% Water Supply***	***-25% Water Supply***	***+25% Water Demand***	***-25% Water Demand***
Crane River/Willow Creek/Tobermory	Low	Low	Low	Low	Low
Stokes River/Ferndale	Low	Low	Low	Low	Low
Sucker Creek/Judges Creek/Cape Croker	Low	Low	Low	Low	Low

3.12 Tier I Groundwater Stress Assessment

Similar to the Tier I surface water stress assessment the Tier I stress assessment for groundwater is designed to determine the degree of stress within each subwatershed. The stress assessment evaluates the ratio of the consumptive demand for permitted and non-permitted users to water supplies, minus water reserves within a subwatershed.

Within the Northern Bruce Peninsula Source Protection Area, the groundwater reserve (10% of supply) was subtracted from the groundwater supply (recharge plus groundwater influx) in order to determine groundwater availability. The percentage water demand was then calculated as a percentage of the consumptive demand versus this water availability, where:

$$\%\ \text{water demand} = \frac{\text{consumptive demand}}{(\text{water supply} - \text{water reserve})} \times 100$$

Subwatershed stress levels are defined for average annual fluxes, as:

- less than 10% - low
- between 10 and 25% - moderate
- more than 25% - significant

For monthly (maximum demand) fluxes, the stress levels are defined as:

- less than 25% - low
- between 25 and 50% - moderate
- more than 50% - significant

Table 3.12.1 outlines the water supplies, reserves, availability, consumptive demand, percentage water demand, and groundwater quantity stress levels for both average (annual) and monthly (maximum) basis for each subwatershed in the study area.

The stress levels are presented graphically in Map 3.9 and summarized in Table 3.12.2.

There are no subwatersheds within the Northern Bruce Peninsula Source Protection Area that are identified as having moderate or significant water quantity stress.

TABLE 3.12.1 – Groundwater Stress Assessment

Subwatersheds	***Area (km^2)***	***Supply and Demand (m^3/day)***					***% Water Demand***	
		Recharge	***Q Reserve***	***Flow In***	***Q_{Avg} Demand***	***Q_{Max} Demand***	***% Avg.***	***% Max.***
Crane River/Willow Ck/Tobermory	346.7	174,014	10,497	-	269	289	0%	0%
Stokes River/Ferndale	294.2	164,060	12,371	-	242	242	0%	0%
Sucker Ck/Judges Ck/Cape Croker	257.2	109,344	6,578	-	217	217	0%	0%

Approved

TABLE 3.12.2 – Subwatershed Groundwater Stress Classification

Watershed		*Area (km^2)*	*Potential Stress (Avg Demand)*	*Potential Stress (Monthly Max Demand)*
Bruce Peninsula	Crane River/Willow Ck/Tobermory	346.7	Low	Low
	Stokes River/Ferndale	294.2	Low	Low
	Sucker Ck/Judges Ck/Cape Croker	257.2	Low	Low

3.12.1 Groundwater Stress Assessment Uncertainty

This section describes the sensitivity analysis carried out to determine the level to which the uncertainty associated with the underlying components of the stress assessment may affect the potential stress classifications.

To be conservative, consumptive factors and water demand numbers were chosen to be the highest range possible. For example, unpermitted agricultural use was considered to have a 100% consumptive factor. The assumptions used to estimate demand are based on both average and maximum conditions and were verified with reported information (percentage of permitted rate pumped), feedback from the governing facilities and model simulations.

Despite the validation of the assumptions associated with the estimates of water demand, a level of uncertainty remains. One focus of this uncertainty analysis is on municipal and domestic use and testing the sensitivity of the final stress classifications to population changes within the study area. This was completed by increasing water demand by 25%, which reflects a marginal growth rate of < 1% per year, for the next 25 years.

In addition, calculations were carried out by varying the water supply terms upwards and downwards by 25%. This is seen as a large range, as it would be unlikely that water supply volumes, at the scale of the subwatersheds, would vary by more than 25% (this range is equal to >+/-100 mm of recharge for pervious subwatersheds).

Table 3.12.3 summarizes the results of the sensitivity analysis. The sensitivity analysis presented above has confirmed that all subwatersheds can be confidently classified as having a low potential for stress.

TABLE 3.12.3 – Summary of Sensitivity Analysis

Subwatershed		*Potential for Groundwater Stress (Either Avg or Peak Demand)*
Bruce Peninsula	Crane/Willow	Low Potential for Stress (Certain)
	Stokes River	Low Potential for Stress (Certain)

The results of this analysis indicate that the stress assessment is largely insensitive to significant changes in the primary stress assessment terms, agricultural water demand and water supply. This suggests that uncertainties associated with these terms would not significantly alter the stress assessment identification.

3.13 Significant Groundwater Recharge Areas

Under the *Clean Water Act, 2006*, Technical Rules for development of an Assessment Report have been established. These rules outline the delineation of four types of vulnerable areas within which policies will be developed and implemented to protect water, namely: wellhead protection areas, intake protection zones, highly vulnerable aquifers, and significant groundwater recharge areas.

Significant groundwater recharge areas are to be developed using existing models and data from Tier I water budgets, and the Technical Rules allow for the use of professional judgment in the form of a technical Peer Review Committee. Specifically, the rules state:

> 44. Subject to rule 45, an area is a significant groundwater recharge area if,
>
> (1) the area annually recharges water to the underlying aquifer at a rate that is greater than the rate of recharge across the whole of the related groundwater recharge area by a factor of 1.15 or more; or
>
> (2) the area annually recharges a volume of water to the underlying aquifer that is 55% or more of the volume determined by subtracting the annual evapotranspiration for the whole of the related groundwater recharge area from the annual precipitation for the whole of the related groundwater recharge area.
>
> 45. Despite rule 44, an area shall not be delineated as a significant groundwater recharge area unless the area has a hydrological connection to a surface water body or aquifer that is a source of drinking water for a drinking water system.
>
> 46. The areas described in rule 44 shall be delineated using the models developed for the purposes of Part III of these rules and with consideration of the topography, surficial geology, and how land cover affects groundwater and surface water.

(Technical Rules: Assessment Report, November 2009)
Clean Water Act, 2006

Further guidance was provided by the Ministry of Natural Resources and Forestry on the development of significant groundwater recharge areas (SGRAs) in the form of a Technical Bulletin (MNRF and MOECC, 2009). This bulletin highlighted what aspects of the methodology require professional judgment. Specifically, key decisions that require professional judgment are:

- Which methodology is to be used in order to determine SGRAs (i.e. Technical Rule 44 (1) or (2)).
- The scale at which these methodologies will be applied.
- Incorporation of local geological and hydrological knowledge into the SGRA delineation process.

3.13.1 Hydrologic Response Units

In order to determine SGRAs, an approach was selected that incorporated results from the Tier I and II surface water modelling efforts, incorporating hydrologic response units. This approach was designed to account for the geology, soils, land cover, and topography of the Region. In order to do this, a series of unique hydrologic response units (HRUs) were created using available geology, land cover and topographical mapping. HRUs were developed as part of the Saugeen, Grey Sauble, Northern Bruce Peninsula Source Protection Region. Once HRUs have been developed, they are used as key inputs in to the GAWSER modelling process and are adjusted as part of the calibration process.

Hydrologic response units were created by reclassifying and intersecting a number of datasets, the details of which are described below.

3.13.1.1 Surficial Geology

Surficial geological units were reclassified according to the texture of the materials of which they are composed. It should be noted that the surficial geological classifications also account, to a large extent, for the soil texture distribution and topography of the region and are; therefore, considered redundant with respect to determining SGRAs. The reclassification of the surficial geological units are listed below in Table 3.13.1.

TABLE 3.13.1 – Surficial Geology Reclassification for HRU Derivation

Geologic Grouping	***Quaternary Geology Description***
Impervious	Open Water, Alluvium
Clay Tills	St. Joseph Till, Glaciolacustrine Deep Water Deposits, Lacustrine Clay and Silt, Man-Made Deposits, Tavistock Till Fluvial Deposits, Modern Fluvial Deposits, Flood Plain Deposits[1]
Silt Tills	Bruce Till, Dunkeld Till, Elma Till, Rannoch Till, Newmarket Till, Tavistock Till
Sand Tills	Catfish Creek, Wentworth Till
Sand and Gravels	Eolian Deposits, Fan or Cone Deposits, Aeolian Deposits, Glacial-outwash Sand, Glaciofluvial ice-contact Deposits, Glaciofluvial Outwash Deposits, Glaciolacustrine Deposits Beach Bar, Glaciolacustrine Deposits Shallow Water, Glaciolacustrine Shoreline Deposits, Modern Beach Deposits, Ice-contact deposits
Bedrock	Exposed Bedrock or Bedrock with Thin Drift.

3.13.1.2 Land Cover

Land cover datasets were created by overlaying the following existing datasets: forested areas (Ministry of Natural Resources and Forestry (MNRF) Forest Resource Inventory); wetland areas (MNRF wetlands); and urban areas identified on the municipal parcel fabric. Land areas that did not fall into one of the three categories (forest, wetland or urban) are assigned as agricultural.

3.13.1.3 Hummocky Topography

Hummocky topography is those areas typified by highly variable, gentle slopes that have high depressional storage and closed depressions with no outlets. They are commonly associated with moraines in the region. These areas typically have enhanced recharge rates due to the lack of outlet and increase depressional storage. Areas of hummocky topography were identified in the Grey Bruce Groundwater Study (WHI, 2003). These areas were then overlain on the land cover data set to create unique HRUs. All areas of identified hummocky topography were given the hummocky land cover designation. Final land cover categories are listed below in Table 3.13.2.

TABLE 3.13.2 – Land Cover Reclassification for HRU Development

Land Cover Reclassification
Wetland
Forested
Urban
Agricultural
Hummocky

3.13.2 Hydrologic Response Unit Creation

Hydrologic response units (HRUs) were then created by combining all four reclassified datasets – quaternary geology, land cover, karst, and hummocky topography – into 16 HRUs, as shown in Table 3.13.3.

It should be noted that clay till and silt till were grouped together into the “low permeability” category, while sand till and sand and gravel were grouped into the “high permeability” category for forested and hummocky land cover groups. This was done to be consistent with HRU development methodologies in abutting Source Protection Regions.

3.13.2.1 Assigning Recharge Values to HRUs

Recharge values for individual HRUs were derived from a surface water model calibration exercise using the GAWSER modelling package.

TABLE 3.13.3 – HRU Classifications

HRU	Description
1	Impervious
2	Wetland
3	Clay / Clay Till Agricultural
4	Silt Till Agricultural
5	Sand Till Agricultural
6	Sand & Gravel Agricultural
7	Low Permeability Forest
8	High Permeability Forest
9	Low Permeability Hummocky
10	High Permeability Hummocky Vegetation
11	Clay / Clay Till Urban
12	Silt Till Urban
13	Sand Till Urban
14	Sand & Gravel Urban
15	Bedrock
16	Karst

3.13.2.2 Determination of Groundwater Recharge Areas

In order to determine which HRUs would be considered significant groundwater recharge areas, the Peer Review Committee recommended the approach outlined in Technical Rule 44 (1); whereby any HRU with an annual recharge rate more than 1.15 times the average for the SPA would be considered an SGRA.

Accordingly, mean annual adjusted recharge values for all HRUs in the Northern Bruce Peninsula Source Protection Area was developed, and all HRUs with values more than 1.15 times this mean were identified as potential SGRAs. The mean recharge in the Northern Bruce Peninsula SPAs was 214 mm/year, and the corresponding threshold for identifying potential SGRAs was set at (214 mm/year X 1.15) 246 mm/year. Therefore, all HRUs with modelled recharge values greater than 246 mm/year were identified as potential SGRAs.

3.13.2.3 Determination of Significance

In order to determine significance under Technical Rule 45, the identified SGRA must have a drinking water system located within it. In order to assess this, the HRUs identified as having annual adjusted recharge rates greater than 1.15 times the SPA mean were assembled into new, larger polygons. These polygons were then screened, and any areas less than 1 ha were removed. Due to the prevalence of wells throughout the area, an assumption was made that all remaining recharge areas reasonably have the potential to be hydraulically connected to a drinking water system, consistent with Technical Rule 45. Significant groundwater recharge areas are shown in Map 3.10.

3.13.3 Data Limitations and Uncertainty

The data used for the development of the SGRAs is based on existing climate data, Tier I surface water modelling outputs, and existing geological and land cover data. These datasets were not developed for the explicit purposes of delineating SGRAs, and have certain limitations that can be attributed to them, specifically:

- Climate data has been filled and corrected to try and account for missing data for discrete time intervals and locations where no monitoring stations exist.
- Surface water modelling has been completed for the entire source protection area, yet has not been calibrated in certain regions due to a lack of monitoring data. In such cases models were calibrated to similar subwatersheds.
- Land cover data is valid only at the time it was collected, and has not been altered or corrected for changes in land use since the time of collection.

The SGRAs have not been evaluated with respect to their hydrologic connection to specific aquifers themselves. Rather, they have been calculated to the nearest surficial aquifer. Recharge areas for confined regional aquifers may lie outside areas. Future use of this delineation, specifically at local scales, should consider the aquifer of interest before employing this methodology.

Uncertainty for SGRAs is a measure of the reliability of the delineations with respect to providing protection to the overall groundwater system, rather than specific aquifers. In this light, the methodology for calculating SGRAs is highly reliant on the surficial geology of the area and can be considered reliable for the overall groundwater system. Therefore, the uncertainty for the SGRAs is considered low for the source protection area.

3.14 Peer Review

The water budget process was completed in consultation and with the approval of a peer review committee. This committee was formed at commencement of the water budgeting exercise and met regularly throughout the process. The following were part of the peer review committee:

Brad Benson, P.Geo, *hydrogeologist*, Genivar Consultants
Stan den Hoed, P.Eng, *hydrogeologist* , Harden Environmental
Miln Harvey, P.Eng, *hydrogeologist*, Schlumberger Water Services
Alge Merry, P.Eng, *hydrogeologist*, Schlumberger Water Services
Lynne Milford, *water budget analyst*, Ministry of Natural Resources and Forestry

REFERENCES

Agriculture and Agri-Food Canada, 1997. Ecozones Mapping for Canada.

AquaResource, Inc., 2008a. Saugeen, Grey Sauble, Northern Bruce Peninsula Conceptual Geologic and Numerical Modelling Report.

AquaResource, Inc., 2008b. Saugeen, Grey Sauble, Northern Bruce Peninsula Tier 1 surface water budget and stress assessment report.

Barnett, P.J., 1992. Quaternary Geology of Ontario, in: Geology of Ontario, Ontario Geological Survey, Volume 4, Part 2, p1011-1090.

Brunton, F.R., J.E.P. Dodge, and J. Shirota, 2006. Karst Compilation for Southern Ontario: An Update. In: Summary of Fieldwork and Other Activities 2006, Ontario Geological Survey, Open File Report 6192, p31-1 to 31-9.

Canadian Parks Service, 1994. Surface Geomorphological Inventory: St. Edmunds Township, Cabot Head and Islands between Tobermory and Manitoulin, Volume 1. Prepared for Canadian Parks Service, Ontario Region by Geomatics International Inc.

Chapman, L.J. and D.F. Putnam, 1984. The Physiography of Southern Ontario. Ontario Geological Survey.

De Loë, R., 2002. Agricultural Water Use in Ontario by Watershed: Estimates from 2001. Rob de Loe Consulting Services. Prepared for the Ontario Ministry of Natural Resources.

Environment Canada. National Climate Archive. Accessible at: http://climate.weatheroffice.ec.gc.ca/.

Ford, D.C. and P.W. Williams, 1989. Karst Geomorphology and Hydrology. UnWin Hyman Ltd., London.

Gillespie, J.E. and N.R. Richards, 1954. Soil Survey of Grey County.

Hoffman, D.W. and N.R. Richards, 1954. Soil Survey of Bruce County.

Johnson, M.D., D.K. Armstrong, D.K., B.V. Sanford, P.G. Telford and M.A. Rutka, 1992. Paleozoic and Mesozoic geology of Ontario, in: Geology of Ontario, Ontario Geological Survey, Volume 4, Part 2, p907-1010.

Karrow, P.F. and S. Occheitti, 1989. Quaternary Geology of the St. Lawrence Lowlands; in: Quaternary Geology of Canada and Greenland, R.J. Fulton (ed.), Geological Survey of Canada, Geology of Canada, no. 1 p321-390.

Liberty, B.A., and T.E. Bolton, 1971. Paleozoic Geology of the Bruce Peninsula Area, Ontario. Memoir 360, Geological Survey of Canada, Department of Energy, Mines and Resources. Ottawa, Canada.

MNRF, 2002. Ontario Ministry of Natural Resources. Digital Soils Mapping.

MNRF, 2002. Ontario Ministry of Natural Resources. Digital Elevation Model.

MNRF and MOECC, 2009. Ontario Ministry of Natural Resources and Ontario Ministry of the Environment. Technical Bulletin: Delineation of Significant Groundwater Recharge Areas. Queen's Printer for Ontario, April 2009.

MOECC, 2006a. Ontario Ministry of the Environment. *Clean Water Act, 2006*. Queen's Printer for Ontario, 2006.

MOECC, 2006b. Ontario Ministry of the Environment. Draft Guidance Module 7. Water Budget and Water Quantity Risk Assessment. October 2006. Accessible at: http://www.ene.gov.on.ca/envision/gp/5600e_waterbudget.pdf

MOECC, 2009. Technical Rules: Assessment Report to the *Clean Water Act, 2006*. Section 107. Ontario Ministry of the Environment. Queen's Printer for Ontario, 2009.

Owen Sound Field Naturalists, 2004. Guide to the Geology and Landforms of Grey and Bruce Counties.

Saugeen, Grey Sauble, Northern Bruce Peninsula Source Water Protection Committee, 2007a. Conceptual Water Budget for the Saugeen, Grey Sauble, Northern Bruce Peninsula Source Protection Region.

Saugeen, Grey Sauble, Northern Bruce Peninsula Source Water Protection Committee, 2007b. Watershed Description for the Saugeen, Grey Sauble, Northern Bruce Peninsula Source Protection Region.

SGSNBP SPR, 2008. Watershed Characterization Report. Saugeen, Grey Sauble, Northern Bruce Peninsula Source Protection Region. Drinking Water Source Protection Project Report, 2008.

Singer, S.N., C.K. Cheng, and M.G Scafe, 2003. The Hydrogeology of Southern Ontario, 2nd Edition. Environmental Monitoring and Reporting Branch, Ontario Ministry of the Environment, Toronto, Ontario.

Smith, D., 2002. Improving the Sustainability of River Systems Through the Removal of Dams on the Saugeen River, Southwestern Ontario. Unpublished M.A. Thesis, Royal Roads University.

Statistics Canada, 2001. 2001 Census of Agriculture, Farm Data and Farm Operator Data.

Waterloo Hydrogeologic Inc., 2002. Phase 1 Sinkhole Study: Final Report. Prepared for the Ausable Bayfield Conservation Authority and the Ontario Ministry of the Northern Development and Mines.

Waterloo Hydrogeologic Inc., 2004. Phase 2 Sinkhole Study: Final Report. Prepared for the Ausable Bayfield Conservation Authority and the Ontario Ministry of Northern Development, Mines & Forestry.

Waterloo Hydrogeologic Inc., 2003. Grey and Bruce Counties Groundwater Study: Final Report. Prepared for the County of Bruce, County of Grey and the Ontario Ministry of the Environment.

Waterloo Hydrogeologic, Inc., 2005. Technical Memorandum: AEMOT Study results and Grey & Bruce Counties Karst Mapping.

Waterloo Hydrogeologic, Inc., 2005. Grey Bruce Counties Municipal Groundwater Supply Vulnerability Pilot Study.