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Chapter 3

WATER QUANTITY STRESS ASSESSMENT

APPROVED ASSESSMENT REPORT
for the
Grey Sauble Source Protection Area

October 15, 2015

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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 Grey Sauble 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 overview material presented is organized by major watershed/drainage system present in the study area, specifically:

- Sauble River
- Beaver River
- Big Head River
- Georgian Bay shoreline Streams and Gullies

The conceptual water budget document provides a more detailed description of the character of each of these 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 Grey Sauble 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 to the west of the study area. 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 Grey Sauble Source Protection Area, including those that have been developed through the years by the local conservation authorities, primarily for flood forecasting purposes. Table 3.2.1 lists the gauge stations in or near the Grey Sauble SPA, along with the period of record for the stations.

TABLE 3.2.1 – Climate and Streamflow Monitoring Stations in the Grey Sauble SPA Operated by Water Survey of Canada (WSC).

Station Name	WSC_ID	Drainage Area	Data Collected	Years of Flow Data	Status
Sauble River Above Tara	02FA005	223	Levels, Precip		Active
Sauble River at Allenford	02FA004	301	Flow, Levels	1987-2003	Active
Sauble River at Sauble Falls	02FA001	927	Flow, Levels	1957-2003	Active
Sydenham River Near Owen Sound	02FB007	181	Flow, Levels, Precip	1915-2003	Active
Beaver River Near Clarksburg	02FB009	583	Flow, Levels	1957-2003	Active
Bighead River Near Meaford	02FB010	293	Flow, Levels, Precip	1957-2003	Active
Beaver River Near Feversham	02FB004	81.6	Flow	1914-1915	Inactive
Beaver River Near Kimberley	02FB003	262	Flow	1915-1951	Inactive
Bighead River at Meaford	02FB005	342	Flow	1915-1917	Inactive
Mill Creek Near Red Wing	02FB006	127	Flow	1915-1915	Inactive
Beaver River at Eugenia	02FB008	179	Flow	1910-1914	Inactive
Beaver River Above Eugenia Power House	02FB001	254	Flow	1918-1951	Inactive
Bighead River Near Strathavon	02FB014	20	Flow, Levels, Precip, Air Temp, Water Temp		New
Mill Creek Near Red Wing	02FB012	104	Flow, Levels, Precip, Air Temp, Water Temp		New
Beaver River Near Vandeleur	02FB013	277	Flow, Levels, Precip, Air Temp, Water Temp		New
Sauble River Above Tara	02FA005	223	Levels, Precip		Active

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) was 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.

As mentioned, the sites were chosen primarily on the completeness of the data record. Kincardine is considered representative of the western portion of the SPR and Hanover is considered representative of the southeastern portion, Wiarton for the Bruce Peninsula, and Chatsworth for the central and northern portions of the SPR. 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.

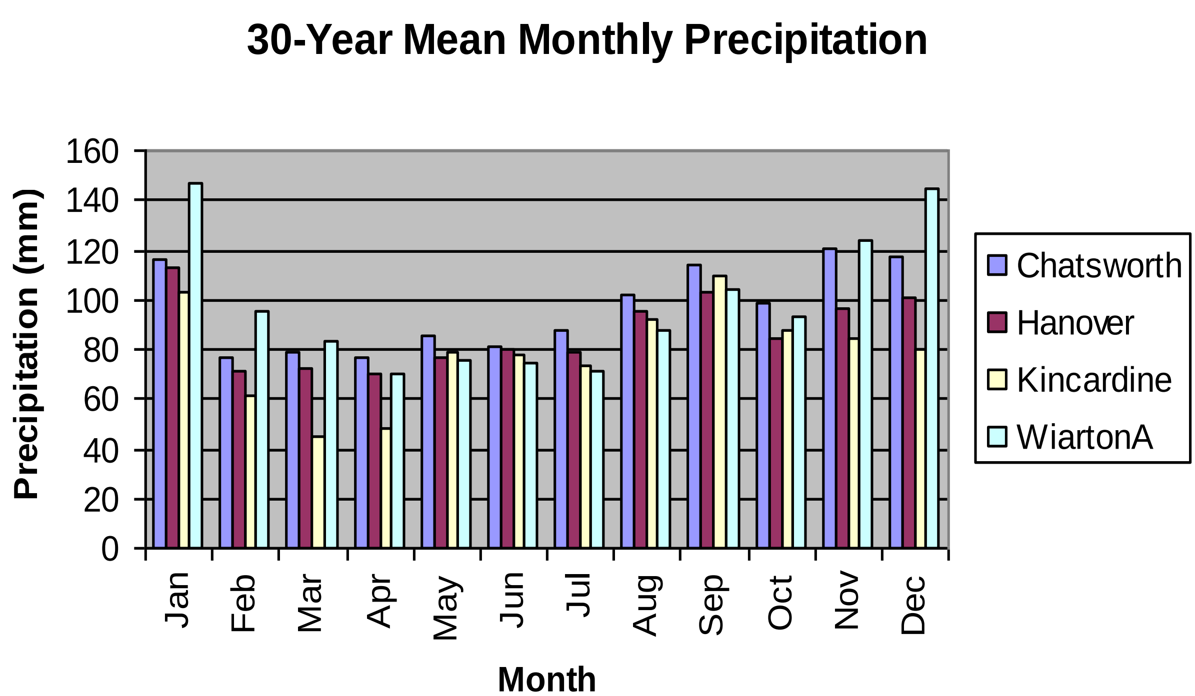

FIGURE 3.2.1 – Seasonal distribution of monthly precipitation for selected sites in the Saugeen, Grey Sauble, Northern Bruce Peninsula Source Protection Region

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 highest mean annual precipitation amounts were found at the Wiarton station (1,169 mm), followed by Chatsworth (1,054 mm), Hanover (1,044 mm), and Kincardine (941 mm) climate stations.

3.2.1.2 Air Temperature

In total, data from 27 climate stations, operated by conservation authorities and 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 Owen Sound area, as well as in the southwestern portion of the SPR along the shore of Lake Huron, are relatively warmer than the remaining areas, largely as a result of their physical setting in a confined valley and/or proximal to large water bodies, respectively. The coldest zones seem to be located along the western slope of the Niagara Escarpment and 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 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 and the resultant shorter growing season.

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. Map 2.13 shows the land uses as derived from the official plans for Bruce County and Grey County. 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 Grey Sauble 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, where adult lifestyle-type housing is growing in popularity. The existing urban areas, with the exception of moderate growth in Owen Sound, 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 Grey Sauble SPA based on county-scale soils surveys completed in the 1950-1955 period, with some minor updates completed in the 1980s. These surveys have been digitized and attributed and are available in a GIS format from the Ministry of Natural Resources and Forestry (2002).

A compilation of the soils textures from county soil reports within the study is shown in Map 2.8. 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.

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 following four (4) rivers:

- Sauble River
- Sydenham River
- Beaver River
- Big Head 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 Grey Sauble SPA. Where possible, hydrological response is discussed with relevance to the land cover and physiography of the drainage area.

Streamflow monitoring is carried out within the SPA by a collection of gauges operated under a federal/provincial cost share agreement. Water Survey of Canada (WSC) maintains gauges under the federal/provincial cost share agreement under the HYDAT program (Hydroclimatological Data Retrieval Program). As listed in Table 3.2.1, there are a total of 16 existing and historic streamflow gauging stations in the region.

WSC currently maintains 7 active stations, and recently installed an additional 3 gauges in 2005. Historical data for 6 inactive WSC gauges is also available. 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 and flow direction grid (See Map 2.3);
- 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 6 stations was imported into a relational database (Microsoft Access) and analyzed to produce reports summarizing the data for each gauge. The stations selected for the analysis must be currently active with a relatively long period of record. In addition, stations that exhibited questionable results were not considered.

Table 3.3.1 lists gauges that were used in this analysis, as well as some of the hydrologically important physical characteristics of each of the gauged catchments. These physical characteristics 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. Areas left blank are those with unclassified surficial geology, which is noticeably absent on the northern portion of the Bruce Peninsula due to a data gap;
- 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	
Sauble River at Allenford	02FA004	31,178	0%	1%	0%	1%	21%	65%	0%	13%	1%	23%
Sauble River at Sauble Falls	02FA001	91,273	1%	4%	13%	10%	9%	46%	0%	16%	6%	40%
Stokes River Near Ferndale	02FA002	5,981	0%	1%	100%	0%	0%	0%	0%	0%	0%	63%
Sydenham River Near Owen Sound	02FB007	17,876	1%	2%	0%	1%	20%	54%	0%	13%	11%	35%
Bighead River Near Meaford	02FB010	30,185	3%	6%	0%	8%	10%	63%	0%	10%	8%	35%
Beaver River Near Clarksburg	02FB009	58,735	3%	3%	0%	4%	4%	64%	3%	16%	9%	35%

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:

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

- Ranked Duration: Similar to calculating percentiles, ranked duration plots were also constructed for the 6 gauging stations. 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 all gauged catchments.

Tabulated results of the analysis are presented for all 6 streamflow gauges in Table 3.3.2; discussion of the streamflow characteristics is limited to the largest catchment areas identified in Table 3.3.2.

Table 3.3.2 includes the mean annual streamflow and baseflow, both in m^3/s as well as mm over the upstream area. Calculated runoff and base flows expressed as equivalent precipitation in millimetres are shown for the study area in Table 3.3.2, Baseflow Index (BFI) for each gauge station has been calculated and is included as well. BFI is the ratio of baseflow to total streamflow, and is used to characterize the proportion of total streamflow that is baseflow. Annual median, 10th percentile and 90th percentile flows are included, as is the 10:90 ratio.

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-ence (m^3/s)*	*90% Flow Exceed-ence (m^3/s)*	*90:10 Ratio*
Sauble River at Allenford	02FA004	4.3	435	1.6	165	0.38	1.9	10.3	0.3	36
Sauble River at Sauble Falls	02FA001	13.7	473	7.7	265	0.56	9.2	31.5	1.8	18
Stokes River Near Ferndale	02FA002	1.2	610	0.5	244	0.4	0.5	3.0	0.0	86
Sydenham River Near Owen Sound	02FB007	2.9	513	1.5	267	0.52	1.9	5.9	0.6	11
Bighead River Near Meaford	02FB010	4.6	482	2.3	236	0.49	3.0	10.7	0.7	15
Beaver River Near Clarksburg	02FB009	8.1	435	4.9	265	0.61	6.7	17.0	2.5	7

**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. Table 3.3.2 presents the Baseflow Index (BFI) at each of the selected gauges.

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 Grey Sauble 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 Grey Sauble 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 3.14.

3.5 Surface Water Characterization

3.5.1 Sauble River

The Sauble River watershed is approximately 913 km^2 upstream of the Sauble Falls gauge (02FA001). The Sauble River originates near the community of Desboro in the Township of Chatsworth in the County of Grey and discharges into Lake Huron at the community of Sauble Beach. The headwaters of the watershed, as monitored by the Allenford gauge (02FA004), are comprised primarily of silty tills with some less permeable clay and more permeable sand/gravel deposits. The larger basin including the tailwaters is characterized by having less silty till, but more wetlands and exposed bedrock. There is a higher proportion of forests and karst topography in the lower areas of the catchment. The wetland areas including the Rankin River, Arran Lake, Mountain Lake, and Shallow Lake wetlands occupy a significant amount of the lower portion of the watershed.

The hydrologic significance of reservoirs and dams along the Sauble River and its tributaries is uncertain; however, the Rankin River dam, located at the outlet of Rankin Lake and the Rankin River wetland system, is used to control water levels in Rankin Lake. It is expected that the low flows are augmented by the Rankin River joining the Sauble River at Sauble Beach.

Average annual streamflow between the headwaters and tailwaters varies by only 10%. However, the hydrologic response between the upstream and downstream areas is evident when comparing differences between the baseflow and 10:90 ratios. Estimated baseflow depths show a large difference with Sauble Falls estimated to be 265 mm and Allenford estimated to be 165 mm (Table 3.3.2). This may be an indication of higher rates of groundwater discharge into the tailwaters in addition to potential wetland effects and, potentially, the Rankin River dam.

With the upstream gauge, Sauble at Allenford has a 10:90 ratio of 36 while the downstream gauge has a ratio of 18, suggesting that the flashiness of the headwaters is twice that of the tailwaters. This is consistent with having less forest, fewer wetlands and less permeable soils in the headwaters. Plots of monthly variation in streamflow show a similar level of variability for the headwaters and tailwaters all seasons, with the exception of fall. The headwaters exhibit much more variability during fall months, which may be caused by decreased groundwater discharges ceasing during dry periods. This is indicative of headwater systems, whereas larger river systems will be less variable due to more regional groundwater discharges and larger drainage areas. Monthly mean flows vary as expected, peaking during the spring months during the snowmelt, declining to a minimum in the summer, and recovering in the fall and winter.

3.5.2 Sydenham River

The Sydenham River originates near the community of Holland Centre in the Township of Chatsworth and discharges into Georgian Bay at the City of Owen Sound. The headwaters of the river are monitored by the Sydenham River near the Owen Sound gauge (02FB007). The drainage area to this gauge is approximately 179 km^2. The catchment is comprised primarily of silty and clayey tills, with an average level of forest cover. The Sydenham River lowlands wetlands are of significant size and are located just upstream of the gauge.

Significant dams located along the Sydenham River include the Owen Sound Mill Dam, located within Owen Sound, and the South Inglis Falls Dam, located just upstream of the gauge. The Owen Sound Mill Dam controls recreational water levels on the Sydenham River in the city, and the South Inglis Falls dam was built to support historical water supplies for the City of Owen Sound.

The Sydenham River has a fairly high average annual streamflow of 513 mm. Approximately half of the annual streamflow, or 267 mm, is estimated to be baseflow, resulting in a BFI of 0.52.

Streamflow appears to be fairly well buffered, with a 10:90 ratio that is lower than nearby areas (e.g. Bighead River). Summer low flows are very consistent, with the summer low decile and median differing by approximately 0.2 m^3/s. These are likely a reflection of the low flow augmentation effects of the South Inglis Falls Dam and the Sydenham River lowlands wetlands, located just upstream of the gauge. Monthly mean flows exhibit expected seasonal patterns.

3.5.3 Bighead River

The Bighead River originates near the community of Holland Centre in the Township of Chatsworth and discharges into Georgian Bay in the community of Meaford. Streamflow is monitored by the Bighead near the Meaford gauge (02FB010). This drainage area is approximately 300 km^2 and the predominant surficial material is a silty till. Forest cover is average when compared to other catchments. Karst has been identified in this area, which may have an effect on hydrology.

Average annual streamflow is estimated to be 482 mm, of which 236 mm is estimated to be baseflow, producing an average BFI of 0.49. Most of this baseflow is expected to be a result of groundwater discharge, as there are no significant dams or large wetland complexes along the river or its tributaries.

This catchment seems to exhibit a typical amount of flashiness with a 10:90 ratio of 15. Monthly mean flows exhibit expected seasonal patterns.

3.5.4 Beaver River

The Beaver River is located in the Grey Sauble SPA and is monitored by the Beaver River near the Clarksburg gauge (WSC). It drains approximately 600 km^2 and is primarily comprised of silty tills and sand/gravels. It has an average forest cover when compared to other catchments. There are a number of significant wetland complexes throughout the Beaver River watershed, including the Wodehouse Marsh wetland, the Eugenia Lake wetland complex, the Kolapore Headwaters Wetland, and the Beaver Valley lowlands. There are numerous dams along the Beaver River, with the Eugenia Lake Dam and Reservoir that regulates flows for the production of power, having the most hydrological significance. The Clarksburg gauge itself is installed at the Slabtown dam, but the effect of this structure on streamflow is not known.

The Beaver River has the lowest average annual streamflow from any watershed draining to Georgian Bay at 435 mm. This may have to do with the increased distance from Lake Huron, and not as much lake effect precipitation. There is also the potential for a significant amount of groundwater flow directly into streams that discharge into Georgian Bay, which would result in lower flow through this river itself.

Of the 435 mm of streamflow, 265 mm is estimated to be baseflow, which produces the second highest BFI of all gauges analyzed, 0.61. It also has the second lowest 10:90 ratio at 7. This suggests that flows are very constant throughout the entire year, with a significant portion of the hydrograph being derived from baseflow. This likely reflects regulation of the watercourse for the production of power at Eugenia Lake. It is difficult to determine what percentage of this flow is a result of groundwater discharge into the river.

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 with 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 a well-known location of 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 found along the valley walls of the Rocky Saugeen River, and 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.

3.6.1.10 Salina Formation

The Salina formation subcrops through a northwest oriented band of the southern portion of the study area and underlies at depth a large section of the study area to the west of a line from approximately Walkerton to Southampton. The Salina Formation, deposited during the Silurian Era approximately 410 to 440 million years ago, is composed of between 50 and 200 metres (true thickness) of interbedded shales, dolostones and evaporates. The Salina is well known throughout the study area for its ample deposits of evaporites, particularly that of halite (rock salt) from which it gets its name. Historic mining of these deposits has occurred in the study area and continues today just south of the study area, with the large salt extraction facilities (both a mine and a brine well/evaporation system) at Goderich. A major feature of the Salina is a large dissolution front from which the salt deposits are absent (likely dissolved during diagenesis), which extends on a roughly north-south line situated just east of Kincardine. The effect of this dissolution front on the deposition of younger rocks is unknown, but it is speculated to have a relationship to the development of karstic features in overlying formations.

Through the study area and extending both north and south of the study area right to Lake Huron and Lake Erie, the easily erodible Salina formation has led to the development of a large bedrock valley. This valley extends from Walkerton in the south part of the study area to Southampton in the west, as it is followed by the Saugeen River on its course to Lake Huron (see Map 3.3).

This bedrock valley is an important bedrock topographical feature that has a profound effect on the regional flow of groundwater (see Map 3.3). The bedrock valleys tend to have been filled with coarse-grained gravels and sands that preferentially concentrate flow into the valleys. In the study area the predominant west-southwest direction of regional groundwater flow is reversed in the Salina, discharging into the bedrock valley and eventually Lake Huron, either via the Saugeen River or through preferential subterranean flow in the valley itself (WHI, 2003).

The Salina formation is an important source of drinking water in the planning region, however it is often associated with water quality problems, particularly high sulphate content, associated with the abundant sulphate minerals gypsum and anhydrite. Several municipal wells penetrate and are drawing water from the Salina formation as well as numerous private domestic supplies.

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.

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 deposition of the St. Joseph’s till in the study area, as well as the formation of many of the physiographic features that dominate the landscape today, such as the Wyoming and horseshoe moraines as well as many of the glacial outwash features. 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 most prominent feature in the southern part of the area is the prevalence of till deposits that exist through the study area and underlie a significant portion of the watershed. Perched atop these till deposits, particularly in the northern portion of the area, are numerous moraines, spillways, eskers, and syn-glacial and post-glacial lake deposits. These deposits are extremely important features as they tend to include coarser grained gravels and sands, which serve as valuable sources of aggregate, and also tend to host many surficial aquifers. These deposits will be dealt with in more detail in the section 3.7.2.

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). The lakes formed extensive, largely flat clay plains offshore of the shoreline deposits. These clay plains are a key element in the hydrology of the shoreline streams of the southwestern portion of the study area.

3.6.3 Holocene Erosion and Deposition

Erosion and deposition of sediment continues today. The major 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. Municipal supplies located away from the shore of Lake Huron rely almost exclusively on groundwater from the bedrock aquifers for their drinking water. A large majority 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, water quality and quantity can differ dramatically, which is largely a consequence of the chemical and physical characteristics of the rocks themselves.

Throughout the southern portion of the SPA, an overlying layer of clay and silt till confines the bedrock aquifer. The bedrock aquifer itself is exposed at the surface in the northern portion of the SPA near the Niagara Escarpment (see Map 3.4) and is known to have a potentiometric surface well above its contact with the overlying glacial deposits (Map 3.5). Groundwater extraction from these aquifers is typically confined to the upper portion of the bedrock, near the contact with the overlying glacial sediments. 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 radiates away from the Dundalk area and follows a generally west to southwesterly flow path towards Lake Huron 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, of which a significant portion flows through and is eventually discharged outside the study area, particularly to the south into the Saugeen Valley Conservation Authority 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 3.14.

Karst features, formed by the dissolution of bedrock by infiltrating waters, are well documented within the northern portion of the planning region and is 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.

Water quality issues are a major concern in areas with karst development. Specific to the study area, two municipal systems are reliant on groundwater (spring-fed) in karst areas. These systems have significant water quality issues as a result (Ford and Williams, 1989).

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 extent 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.

3.7.2.1 Flesherton Aquifer

Located south of the village of Flesherton. It consists of gravel and sand deposits that range in thickness from several metres to 23.0 m and is covered by ice-contact sand and gravel, outwash, and till deposits. Where the aquifer is exposed at the surface, it is under water table condition, but otherwise it is confined.

This aquifer is considered of good quality and quantity, with some wells yielding up to 225 L/min. The extent to which this aquifer is utilized is not known at present, due to the lack of reliable well records for this area.

3.7.2.2 Chesley Aquifer

Occurs in proximity and north of Chesley, this aquifer consists of gravel and sand deposits that range in thickness from 10-44 m. These deposits are overlain by clay and till up to a depth of 21 m. Where the sand and gravel deposits are at the surface, the aquifer is unconfined.

This aquifer is considered of good quality and quantity, with some wells yielding up to 50 L/min. The extent to which this aquifer is utilized is not known at present, due to the lack of reliable well records for this area. This aquifer has static water levels that are very close to ground surface that may have an impact on the placement of septic systems and foundations.

3.7.2.3 Dundalk Aquifer

Centred near Dundalk, this composite aquifer consists of gravel and sand deposits that range in thickness of 7-15 m. It is overlain by 18 m of a till-like deposit where the sand and gravel deposits are at the surface. The aquifer has both unconfined and confined portions.

The extent to which this aquifer is utilized is not known at present, due to the lack of reliable well records for this area. This aquifer has static water levels that are very close to ground surface that may have an impact on the placement of septic systems and foundations. This aquifer is considered of good quality and quantity, with some wells yielding up to 120 L/min.

3.7.2.4 Meaford Aquifer

The term Meaford aquifer is used to describe a confined aquifer situated near the Town of Meaford. It consists mainly of coarse, gravely deposits with unknown association and ranges in thickness from several metres up to 24 m. The aquifer is covered with deposits of glaciolacustrine sand and clay with some areas of till. This aquifer is considered of good quality and quantity, with some wells yielding up to 100 L/min. The extent to which this aquifer is utilized is not known at present, due to the lack of reliable well records for this area.

3.7.2.5 Thornbury Aquifer

Located south of Thornbury, this aquifer consists of gravel and sand deposits associated with glacial lake deposits and ranges from several metres up to 32 m. It is mainly covered by deposits of till, glaciolacustrine sand, sand and gravel. The aquifer is mostly confined but in some places is exposed at ground level.

This aquifer is considered of good quality and quantity, with some wells yielding up to 225 L/min. The extent to which this aquifer is utilized is not known at present, due to the lack of reliable well records for this area.

3.7.2.6 Markdale Aquifer

Located in the vicinity of Markdale, this aquifer is situated within gravel and sand deposits that range in thickness of 18-41 m. In some places it is overlain by up to 25 m of clay and till. The elevation on top of the unconfined part of the aquifer ranges from 396-426 m amsl and the elevation of the top of the confined part ranges from 408-430 m amsl. Water is available at 358-421 m amsl, and depth of the static water levels range 1-18 m. Yields range from 15-90 L/min, with an exception of one well having 1,800 L/min. The specific capacities range between 10-50 L/min/m.

The extent to which this aquifer is utilized is not known at present, due to the lack of reliable well records for this area. This aquifer has static water levels that are very close to ground surface that may have an impact on the placement of septic systems and foundations.

3.7.2.7 Priceville Aquifer

Located near Priceville, this aquifer is situated within gravel and sand deposits with thicknesses of 21-71 m. In some places these deposits are overlain by 30 m of a till-like deposit. It is mainly unconfined within gravel and sand deposits that are exposed at the surface.

The extent to which this aquifer is utilized is not known at present, due to the lack of reliable well records for this area. This aquifer has static water levels that are very close to ground surface that may have an impact on the placement of septic systems and foundations. This aquifer is considered of good quality and quantity, with some wells yielding up to 50 L/min.

3.7.2.8 Lake Huron Beach Aquifer

Located within the beach deposits along the present day shoreline of Lake Huron, this aquifer is used sporadically as a source of drinking water by various cottagers. This aquifer is an aggregate aquifer composed of a number of unconfined aquifers that are likely recharged *in situ* with some contribution from surface runoff from nearby bluffs, where they exist. Flow within this aquifer is likely towards Lake Huron.

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 3.14.1.3 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 Grey Sauble 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. Takings are represented both by permitted takings at locations, as well as expressed as depth of equivalent precipitation over each subwatershed.

3.8.2 Municipal Water Takings

Water takings for municipal drinking water supplies comprise a high volume of water takings within the SPA. A large portion of these takings are exploiting bedrock aquifers with only a few supplies reliant on overburden aquifers. Surface water is exploited extensively along the Lake Huron and Georgian Bay shoreline, with no municipal water takings from rivers.

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.

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*

Five municipal water supply systems in the SPA exploit Georgian Bay as a water source. Each of these systems has an outlet into Georgian Bay directly or via river systems and small lakeshore gullies. Surface water takings were estimated based on the maximum daily amounts as defined by the PTTW for each supply.

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 estimations 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

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.

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.

In the SPA these takings represent large and important takings from the system, and commonly result in removal of water from one component of the hydrologic system (in this case, often the bedrock aquifer) and artificially directing it to another component (surface waters). This redistribution may have both positive impacts, such as augmenting stream flow in periods of drought, and negative impacts, such as releasing contaminated water, on the natural water system.

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

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.

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 the Grey Sauble Source Protection Area. These uses include outdoor recreation, hobby fishing, canoeing, and tourism and are focused 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 Grey Sauble Source Protection Area, the key components and processes to be 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

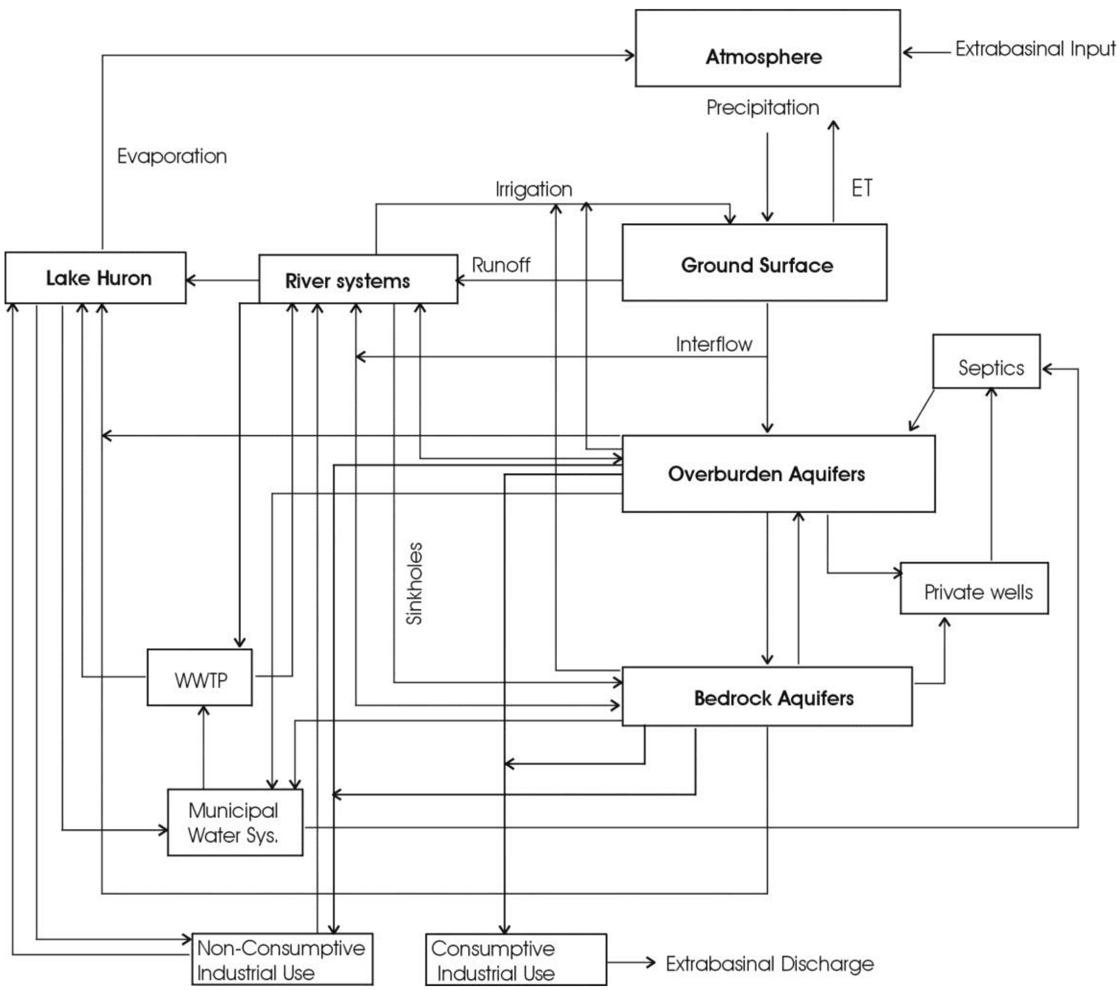

FIGURE 3.9.1 – Components and flux of water in the Grey Sauble Source Protection Area

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 Grey Sauble 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 Grey Sauble Source Protection Area is host to two large municipal water systems that are exploiting Lake Huron These systems form a closed loop as water from them 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”). This 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).

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). There are a total of 16 subwatersheds identified for the Tier I water budget analysis in the Grey Sauble SPA.

TABLE 3.10.1 – Tier I Water Budget Values for the Grey Sauble 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)
Craigleith	1,057	582	185	290	24
Beaver River/Kimberley	988	594	202	192	24
Beaver River/Feversham	988	596	190	202	11
Beaver River/Clarksburg	930	573	179	178	3
Bighead River/Georgian Bay Shore	1,057	554	141	362	9
Bighead River	1,057	576	269	212	23
Sucker Creek/Judges Creek/Cape Croker	1,049	533	347	170	0
Colpoys Bay	1,049	530	339	180	0
Indian Creek	1,141	488	381	272	1
Johnson Creek/Meaford Tank Range	1,057	448	318	291	1
Bothwell's Creek/Keefer Creek	1,057	519	274	265	2
Sydenham River/Owen Sound East	1,057	543	300	214	3
Pottawatomi River/Owen Sound West	1,141	562	350	230	1
Oliphant	1,049	521	176	351	1
North Sauble River	1,049	488	367	194	17
Sauble Falls/Huron Shore	1,060	495	205	360	143
Sauble River/Hepworth	1,141	552	329	260	291
South Sauble River	1,134	604	359	171	1
Lower Sauble River	1,049	533	235	281	7

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 Grey Sauble 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 Grey Sauble Source Protection Area including the Sauble River, Sydenham River, Big Head River, Beaver River and the extensive set of lakeshore gullies and streams situated along the SPA's Lake Huron and Georgian Bay shoreline. 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).

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
Craigleith	1,066	806	3,084	3,261	1,189	893	382	255	273	793	1,482	1,399
Beaver River/Kimberley	4,926	4,672	6,272	10,889	6,400	4,370	2,418	1,984	1,842	3,028	4,496	5,436
Beaver River/Feversham	1,297	1,006	2,437	5,578	2,106	1,283	557	422	336	464	1,297	1,547
Beaver River/Clarksburg	7,172	6,814	12,623	16,692	8,653	5,809	3,461	2,473	2,297	3,966	6,509	8,114
Bighead River/Georgian Bay Shore	306	231	884	935	341	256	110	73	78	227	425	401
Bighead River	3,376	2,551	9,764	10,325	3,766	2,826	1,210	807	865	2,510	4,691	4,430
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
Colpoys Bay	912	534	2,200	4,690	1,371	877	610	582	946	1,590	2,424	1,806
Indian Creek	3,718	2,632	10,438	15,575	4,088	2,666	1,344	790	940	2,433	5,874	5,896
Johnson Creek/Meaford Tank Range	1,778	1,343	5,142	5,437	1,983	1,488	637	425	456	1,322	2,470	2,332
Bothwell's Creek/Keefer Creek	1,081	816	3,125	3,304	1,205	904	387	258	277	803	1,501	1,418
Sydenham River/Owen Sound East	1,979	1,495	5,724	6,053	2,208	1,657	710	473	507	1,471	2,750	2,597
Pottawatomi River/Owen Sound West	2,908	2,059	8,165	12,182	3,198	2,085	1,051	618	735	1,903	4,594	4,612
Oliphant	285	167	687	1,465	428	274	190	182	296	497	757	564
North Sauble River	1,384	810	3,336	7,112	2,078	1,330	924	882	1,434	2,411	3,675	2,738
Sauble Falls/Huron Shore	22,826	18,368	52,423	61,868	24,044	19,284	11,718	9,506	8,476	16,213	27,857	28,625
Sauble River/Hepworth	5,595	3,961	15,707	23,436	6,152	4,011	2,022	1,188	1,414	3,661	8,839	8,872
South Sauble River	3,294	2,366	10,641	14,733	3,342	2,269	940	380	514	2,110	5,285	5,422
Lower Sauble River	7,816	5,266	23,065	35,953	9,659	6,178	3,618	2,647	3,367	6,999	13,311	12,720

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 Grey Sauble 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.

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 90^{th} 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.

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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
Craigleith	320	456	749	1,234	687	315	166	138	145	165	246	426
Beaver River/Kimberley	3,582	3,405	3,765	6,181	3,910	2,598	1,817	1,646	1,532	1,641	2,034	2,530
Beaver River/Feversham	263	465	727	2,499	1,160	563	348	262	195	198	245	228
Beaver River/Clarksburg	4,674	4,874	5,580	9,435	5,442	3,431	2,244	2,064	1,885	1,991	2,515	3,536
Bighead River/Georgian Bay Shore	92	131	215	354	197	90	48	40	42	47	71	122
Bighead River	1,014	1,445	2,370	3,907	2,175	998	525	437	459	521	779	1,350
Sucker Creek/Judges Creek/Cape Croker	605	425	535	2,650	1,158	671	411	415	565	1,170	1,590	1,288
Colpoys Bay	344	241	304	1,506	658	381	234	236	321	665	904	732
Indian Creek	1,253	1,322	2,270	5,148	2,434	934	504	436	384	532	992	1,565
Johnson Creek/Meaford Tank Range	534	761	1,248	2,058	1,145	526	277	230	242	275	410	711
Bothwell's Creek/Keefer Creek	324	462	759	1,250	696	319	168	140	147	167	249	432
Sydenham River/Owen Sound East	594	847	1,390	2,290	1,275	585	308	256	269	306	457	791
Pottawatomi River/Owen Sound West	980	1,034	1,776	4,027	1,904	731	394	341	301	416	776	1,224
Oliphant	107	75	95	470	206	119	73	74	100	208	282	229
North Sauble River	521	366	461	2,283	998	578	354	357	487	1,008	1,370	1,110
Sauble Falls/Huron Shore	8,457	10,076	14,456	26,512	17,029	10,205	5,848	4,918	3,506	3,953	7,386	12,217
Sauble River/Hepworth	1,886	1,989	3,416	7,747	3,662	1,406	758	656	578	800	1,493	2,354
South Sauble River	984	1,212	2,096	4,369	1,809	535	216	161	133	233	598	1,200
Lower Sauble River	3,057	2,398	4,306	11,979	5,532	2,398	1,389	1,235	1,298	2,658	4,002	4,540

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 1 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 1 assessment. These data are considered to be the more conservative value, which is consistent with expectations for a Tier I water budget.

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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 (km²)	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)
Beaver River	Craigleith	78.3	15	120	0	-54	0	-66
	Beaver River/Kimberley	162.54	49	172	0	0	-332	161
	Beaver River/Feversham	243.02	50	198	-13	0	-60	-118
	Beaver River/Clarksburg	263.46	51	189	0	-5	-170	-14
Bighead River	Bighead River	382.05	12	149	0	-4	-136	-2
Bruce Peninsula	Sucker Ck/Judges Ck/Cape Croker	257.23	4	155	0	-45	-48	-62
	Colpoys Bay	149.51	5	140	0	-64	-27	-49
Owen Sound	Indian Creek	145.53	8	109	0	-37	-54	-17
	Johnson Creek	186.3	9	118	0	-60	-56	-2
	Bothwell's Creek/Keefer Creek	113.02	11	123	0	-13	-74	-35
	Sydenham River/Owen Sound E.	209.67	13	163	0	-5	-167	67
	Pottawatomi River/Owen Sound W.	116.16	14	186	0	0	-161	-25
Sauble River	Oliphant	44.87	6	314	0	-199	27	-139
	North Sauble River	222.91	7	143	0	0	-123	-20
	Sauble Falls/Huron Shore	60.49	10	272	0	-184	-81	-1
	Sauble River/Hepworth	170.26	34	188	0	0	-163	-19
	South Sauble River	420.45	35	175	0	0	-163	-12
	Lower Sauble River	93.61	36	205	0	-3	-214	13

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, is 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 subwatershed is 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 subwatershed is 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)*
Craigleith	0	453.9	226.4	2011.8
Beaver River/Kimberley	100.0	697.5	248.4	1438.7
Beaver River/Feversham	120.0	1048.0	375.3	30547.8
Beaver River/Clarksburg	0	1118.6	374.0	2086.8
Bighead River	8.7	1042.3	381.6	12544.3
Sucker Creek/Judges Creek/Cape Croker	0	153.4	318.6	0
Colpoys Bay	0	152.4	173.7	0
Indian Creek	0	173.1	338.9	0
Johnson Creek/Meaford Tank Range	0	627.6	136.4	0
Bothwell's Creek/Keefer Creek	0	374.2	205.2	1987.5
Sydenham River/Owen Sound East	664.6	455.3	330.8	36271.2
Pottawatomi River/Owen Sound West	29.0	141.2	254.3	93.0
Oliphant	279.2	49.3	229.5	702.2
North Sauble River	98.2	191.2	216.0	460.0
Sauble Falls/Huron Shore	372.6	54.5	102.6	1120.6
Sauble River/Hepworth	350.0	329.9	286.2	4050.4
South Sauble River	442.1	822.2	345.2	2127.8
Lower Sauble River	556.8	179.6	148.5	1666.1

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 is 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)*
Craigleith	18,144	604.8
Beaver River/Kimberley	59,616	864
Beaver River/Feversham	5,875.2	864
Beaver River/Clarksburg	10,972.8	950.4
Bighead River/Georgian Bay Shore	3,628.8	86.4
Bighead River	21,168	950.4
Sucker Creek/Judges Creek/Cape Croker	0	172.8
Colpoys Bay	0	172.8
Indian Creek	1,900.8	172.8
Johnson Creek/Meaford Tank Range	0	604.8
Bothwell's Creek/Keefer Creek	1,641.6	345.6
Sydenham River/Owen Sound East	1,123.2	432
Pottawatomi River/Owen Sound West	432	172.8
Oliphant	0	86.4
North Sauble River	10,281.6	172.8
Sauble Falls/Huron Shore	39,484.8	172.8
Sauble River/Hepworth	171,331.2	432
South Sauble River	3,628.8	777.6
Lower Sauble River	1,728	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 (10th 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.
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.

TABLE 3.11.1 – Monthly Percent Surface Water Demand for Tier 1 Subwatersheds

Subwatershed	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Craigleith	6.1	13.0	0.3	0.4	1.6	18.1	50.6	93.7	81.2	1.3	0.7	4.7
Beaver River/Kimberley	19.5	20.7	0.6	0.3	0.9	1.3	3.9	6.9	7.5	1.1	0.6	9.0
Beaver River/Feversham	1.5	2.8	0.9	0.5	1.7	2.2	9.0	11.8	11.4	6.1	1.5	1.2
Beaver River/Clarksburg	0.5	0.7	0.2	0.2	0.4	0.5	5.5	16.4	3.1	0.6	0.3	0.3
Bighead River/ Georgian Bay Shore	0.5	1.0	0.2	0.2	0.7	11.1	48.3	89.3	50.0	0.6	0.3	0.4
Bighead River	6.9	14.8	2.2	2.5	10.3	8.9	23.8	44.1	40.1	8.2	4.2	5.3
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
Colpoys Bay	0.3	0.6	0.1	0.1	0.2	0.3	0.5	0.5	0.3	0.2	0.1	0.2
Indian Creek	0.1	0.2	0.0	0.0	0.1	0.8	1.5	3.7	2.3	0.1	0.0	0.0
Johnson Creek/ Meaford Tank Range	0.6	1.2	0.2	0.2	0.9	0.8	2.0	3.7	3.4	0.7	0.4	0.4
Bothwell's Creek/Keefer Creek	0.6	1.2	0.2	0.2	0.9	1.8	4.9	9.0	8.2	0.7	0.3	0.4
Sydenham River/Owen Sound East	0.4	0.8	0.1	0.1	0.6	0.5	1.5	2.8	2.2	0.5	0.2	0.3
Pottawatomi River/ Owen Sound West	0.1	0.2	0.0	0.0	0.1	0.1	0.5	1.3	0.4	0.1	0.0	0.0
Oliphant	0.3	0.6	0.1	0.1	0.3	0.4	0.5	0.5	0.3	0.2	0.1	0.2
North Sauble River	0.4	0.7	0.1	0.1	0.3	0.4	0.5	0.6	0.3	0.2	0.1	0.2
Sauble Falls/Huron Shore	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0
Sauble River/Hepworth	0.4	0.7	0.1	0.1	0.6	0.6	1.2	2.7	1.8	0.5	0.2	0.2
South Sauble River	0.4	0.8	0.1	0.1	0.6	0.5	3.9	12.9	2.3	0.5	0.2	0.2
Lower Sauble River	0.0	0.1	0.0	0.0	0.0	0.1	0.1	0.2	0.1	0.0	0.0	0.0

Moderate Potential for Stress
Significant Potential for Stress

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

Watershed	***Subwatershed Name***	***Potential for Stress***
Beaver River	Craigleith	Significant
Beaver River	Beaver River/Kimberley	Moderate
Beaver River	Beaver River/Feversham	Low
Beaver River	Beaver River/Clarksburg	Low
Bighead River	Bighead River/Georgian Bay Shore	Significant
Bighead River	Bighead River	Moderate
Bruce Peninsula	Sucker Creek/Judges Creek/Cape Croker	Low
Bruce Peninsula	Colpoys Bay	Low
Owen Sound Bay	Indian Creek	Low
Owen Sound Bay	Johnson Creek/Meaford Tank Range	Low
Owen Sound Bay	Bothwell's Creek/Keefer Creek	Low
Owen Sound Bay	Sydenham River/Owen Sound East	Low
Owen Sound Bay	Pottawatomi River/Owen Sound West	Low
Sauble River	Oliphant	Low
Sauble River	North Sauble River	Low
Sauble River	Sauble Falls/Huron Shore	Low
Sauble River	Sauble River/Hepworth	Low
Sauble River	South Sauble River	Low
Sauble River	Lower Sauble River	Low

However, as there are no municipal water systems utilizing surface water systems other than the Great Lakes in the Grey Sauble SPA, there is no need for further analysis of the surface water system.

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***
Craigleith	Significant	Significant	Significant	Significant	Significant
Beaver River/Kimberley	Moderate	Low	Moderate	Moderate	Low
Beaver River/Feversham	Low	Low	Low	Low	Low
Beaver River/Clarksburg	Low	Low	Moderate	Moderate	Low
Bighead River/Georgian Bay Shore	Significant	Significant	Significant	Significant	Significant
Bighead River	Moderate	Moderate	Significant	Significant	Moderate
Sucker Creek/Judges Creek/Cape Croker	Low	Low	Low	Low	Low
Colpoys Bay	Low	Low	Low	Low	Low
Indian Creek	Low	Low	Low	Low	Low
Johnson Creek/Meaford Tank Range	Low	Low	Low	Low	Low
Bothwell's Creek/Keefer Creek	Low	Low	Low	Low	Low
Sydenham River/Owen Sound East	Low	Low	Low	Low	Low
Pottawatomi River/Owen Sound West	Low	Low	Low	Low	Low
Oliphant	Low	Low	Low	Low	Low
North Sauble River	Low	Low	Low	Low	Low
Sauble Falls/Huron Shore	Low	Low	Low	Low	Low
Sauble River/Hepworth	Low	Low	Low	Low	Low
South Sauble River	Low	Low	Low	Low	Low
Lower Sauble River	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 Grey Sauble 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.

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TABLE 3.12.1 – Groundwater Stress Assessment

Subwatershed	Area (km²)	swsID	Supply and Demand (m³/day)					% Water Demand	
			Recharge	Q Reserve	Flow In	Q_{Avg} Demand	Q_{Max} Demand	% Avg.	% Max.
Craigleith	78.3	15	25,838	1,157	-	511	573	2%	2%
Beaver River/Kimberley	162.5	49	76,772	14,786	71,505	1,161	2,186	1%	2%
Beaver River/Feversham	243.0	50	132,036	4,010	-	3,503	3,943	3%	3%
Beaver River/Clarksburg	263.5	51	136,576	12,605	-	1,204	1,258	1%	1%
Bighead River	382.1	12	155,931	14,648	-	8,433	9,096	6%	6%
Craigleith	78.3	15	25,838	1,157	-	511	573	2%	2%
Sucker Ck/Judges Ck/Cape Croker	257.2	4	109,344	6,578	-	217	217	0%	0%
Colpoys Bay	149.5	5	57,201	3,731	-	187	187	0%	0%
Indian Creek	145.5	8	43,274	3,642	-	241	241	1%	1%
Johnson Creek	186.3	9	60,297	5,931	-	655	655	1%	1%
Bothwell's Creek/Keefer Creek	113.0	11	38,078	2,698	-	473	588	1%	2%
Sydenham River/Owen Sound E.	209.7	13	93,844	9,894	38,407	34,133	34,918	28%	29%
Pottawatomi River/Owen Sound W.	116.2	14	59,273	5,141	-	221	285	0%	1%
Oliphant	44.9	6	38,542	2,121	-	374	667	1%	2%
North Sauble River	222.9	7	87,546	7,521	-	498	498	1%	1%
Sauble Falls/Huron Shore	60.5	10	45,002	4,397	-	482	1,082	1%	3%
Sauble River/Hepworth	170.3	34	87,545	7,615	-	2,952	3,396	4%	4%
South Sauble River	420.5	35	202,035	18,771	-	1,497	2,037	1%	1%
Lower Sauble River	93.6	36	52,691	5,567	3,247	882	1,580	2%	3%

The following sections summarize the subwatersheds classified as having a potential for stress relating to groundwater takings above, at or close to the moderate or significant threshold under average annual and/or maximum monthly demand conditions. The hydrologic factors influencing the classification are discussed and municipal supplies located within the subwatershed are identified.

3.12.1 Sydenham River/Owen Sound East Subwatershed

The percent water demand for the Sydenham River subwatershed was calculated to be 28% for average demand conditions and 29% for maximum monthly demand conditions. The subwatershed was assigned a significant potential for stress under average pumping and moderate potential for stress under peak pumping. There were 16 permits in the area that account for the majority of the total demand. Ten of these were municipal permits, two were for agricultural (nursery) purposes and the remaining four were for aquaculture purposes. The aquaculture permits account for 90% of the total taking. The taking from the aquaculture permits was confirmed during this study, and so the potential for stress was considered realistic.

TABLE 3.12.2 – Subwatershed Groundwater Stress Classification

Watershed	***Area (km^2)***	***Potential Stress (Avg Demand)***	***Potential Stress (Monthly Max Demand)***
Craigleith	220.8	Low	Low
Beaver River/Kimberley	193.2	Low	Low
Beaver River/Feversham	206.8	Low	Low
Beaver River/Clarksburg	111.0	Low	Low
Bighead River	59.4	Low	Low
Sucker Ck/Judges Ck/Cape Croker	10.7	Low	Low
Colpoys Bay	22.5	Low	Low
Indian Creek	177.8	Low	Low
Johnson Creek	154.5	Low	Low
Bothwell's Creek/Keefer Creek	127.3	Low	Low
Sydenham River/Owen Sound E.	63.2	Moderate	Significant
Pottawatomi River/Owen Sound W.	148.0	Low	Low
Oliphant	373.4	Low	Low
North Sauble River	304.0	Low	Low
Sauble Falls/Huron Shore	60.5	Low	Low
Sauble River/Hepworth	170.3	Low	Low
South Sauble River	420.5	Low	Low
Lower Sauble River	93.6	Low	Low

A review of the permitted water takings shows that the large aquaculture takings were located 6 km up-gradient of the closest municipal supply wells (Chatsworth). Simulations to date have shown a large potential impact due to pumping at these wells, and the potential for water quantity concerns at the Chatsworth municipal wells was considered valid. Subject to the uncertainty analysis, this area was considered to be an area of potential concern for water quantity stresses.

3.12.2 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 were 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 was 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 was 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 was 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 confirmed that all but one subwatershed can be confidently classified as having a low potential for stress.

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.

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TABLE 3.12.3 – Summary of Sensitivity Analysis

Subwatershed	***Potential for Groundwater Stress (Either Avg or Peak Demand)***
Craigleith	Low Potential for Stress (Certain)
Beaver River/Kimberley	Low Potential for Stress (Certain)
Beaver River/Feversham	Low Potential for Stress (Certain)
Beaver River/Clarksburg	Low Potential for Stress (Certain)
Bighead River	Low Potential for Stress (Certain)
Sucker Ck/Judges Ck/Cape Croker	Low Potential for Stress (Certain)
Colpoys Bay	Low Potential for Stress (Certain)
Indian Creek	Low Potential for Stress (Certain)
Johnson Creek	Low Potential for Stress (Certain)
Bothwell's Creek/Keefer Creek	Low Potential for Stress (Certain)
Sydenham River/Owen Sound E.	**Potential for Stress (Certain)**
Pottawatomi River/Owen Sound W.	Low Potential for Stress (Certain)
Oliphant	Low Potential for Stress (Certain)
North Sauble River	Low Potential for Stress (Certain)
Sauble Falls/Huron Shore	Low Potential for Stress (Certain)
Sauble River/Hepworth	Low Potential for Stress (Certain)
South Sauble River	Low Potential for Stress (Certain)
Lower Sauble River	Low Potential for Stress (Certain)

3.13 Summary of Tier II Water Budget

The Tier II subwatershed stress assessment used more refined water demand estimates and a more advanced water budget model than those used for the Tier I assessment. The percent water demand calculations were the same as those used in a Tier I assessment and the same threshold values for stress assessment were used. Tier II subwatershed stress assessments were developed at the subwatershed scale (similar to the Tier I) using a continuous surface water model and, where necessary, a groundwater flow model.

Municipal water supplies located within subwatersheds that are confirmed to have a moderate or significant potential for stress, proceed to a locally-focused, Tier III water quality risk assessment.

The Tier I groundwater stress assessment (AquaResource, 2008a) concluded that one of the areas within the SPR had a moderate or significant potential for stress. The goal of the current Tier II investigation is to refine and potentially confirm the Tier I results through a more detailed analysis. This analysis included:

- Updating the geologic conceptual understanding within the potentially stressed areas.

- Updating the groundwater flow model with the refined geologic understanding and recharge rates estimated using the continuous surface water model.
- Refining the consumptive groundwater use estimates.
- Performing a Tier II water quantity stress assessment for identified areas.

3.13.1 Tier II Subwatershed Delineation

Under the requirements of the Technical Rules (MOECC, 2009), the water quantity stress assessment is carried out on a subwatershed basis. Tier I subwatershed boundaries were updated (see description below) as part of the Tier II assessment to better capture the local groundwater flow system(s) in areas previously identified as potentially stressed in the Tier I assessment (AquaResource, 2008a).

Map 3.10 illustrates a modified set of Tier II subwatershed areas delineated to better represent aquifer systems. Table 3.13.1 lists the Tier II assessment areas. There is only one Tier II subwatershed (assessment area) identified in the Grey Sauble SPA. The following sections describe the revisions to each of the assessment areas.

TABLE 3.13.1 – Tier II Subwatershed Area Summary

Tier II Subwatershed	***Area (km^2)***	***Municipal Supplies***
Sydenham	210	Chatsworth (Wells #1 & #2)

3.13.1.1 Sydenham

The Tier II Sydenham River-Owen Sound East assessment area was not modified from the Tier I Groundwater Stress Assessment (AquaResource 2008b) subwatershed boundary. The assessment area includes the municipal wells for Chatsworth.

3.13.2 Model Updates

Models developed as part of the Tier I water budget were refined in order to assess groundwater quantity stress for the Grey Sauble SPA. Details of these updates are outlined in the section below.

3.13.2.1 Groundwater Model Updates

The FEFLOW steady-state groundwater-flow model was developed as a tool to assess groundwater flow at the regional scale as part of the Tier I water budget exercise. The hydrogeological characterization reflected by the model includes regional-scale groundwater aquifers and aquitards. As a result, the model’s predicted water levels and groundwater discharge rates are consistent with groundwater flow conceptual models at the larger (i.e., subwatershed) scale.

The Tier II assessment represents a refinement of the Tier I assessment and includes a more detailed review of data on a subwatershed basis. The conceptual hydrostratigraphic layer structure for the Tier II assessment areas were revisited as part of the Tier II assessment.

Specifically, the hydrostratigraphic layer elevations were refined locally to improve on the hydrogeologic characterization developed in the Tier I Conceptual Geologic and Water Budget Assessment (AquaResource, 2008a).

The hydrostratigraphic layer structure within the Tier II subwatershed areas was updated as part of this study. Based upon interpreted cross-sections, the elevations of the hydrostratigraphic layer structure was modified within the Tier II subwatershed areas. The focus of this refinement was on significant hydrogeologic features within Tier II subwatershed areas, or on areas not previously characterized as part of the Tier I stress assessment. This refinement has led to better characterization than was included within the Tier I assessment.

The three-dimensional groundwater flow model developed as part of the Tier I groundwater stress assessment (AquaResource, 2008a), has been updated and refined for use within the current Tier II stress assessment. Most notably, this refinement included modifying groundwater recharge rates to those estimated from the calibrated GAWSER model, developed as part of the Tier I surface water stress assessment (AquaResource, 2008b). Other refinements included modifications to the hydrostratigraphic layer elevations as described in Section 2.1. Based on the consumptive demand estimates, pumping wells were updated. The hydrostratigraphic layer structure, or the finite element mesh used within the FEFLOW model, was not modified as part of the Tier II stress assessment.

Following the refinements made to the FEFLOW model, a calibration exercise was carried out to ensure the model was able to reasonably estimate groundwater inflows to the Tier II subwatershed areas. Calibration metrics for the entire model domain, as well as for individual Tier II assessment areas, indicate that the major flow processes are well represented at the subwatershed scale, and that the model is able to support the Tier II stress assessment.

3.13.2.2 Surface Water Model Updates

No major updates of the existing Tier I surface water (GAWSER) models were undertaken as part of the Tier II assessment. The existing models were considered sufficient for the purposes of completing the Tier II assessment. Recharge values derived from the GAWSER models were used to update the FEFFLOW groundwater model within the Tier II subwatershed areas.

3.13.3 Consumptive Water Use Update

Consumptive water demand refers to water that is taken and not returned to its original source (i.e. stream or aquifer) within a reasonable amount of time. Understanding this type of water demand is critical to the development of a water budget framework. An estimate of the extent and variability of water use throughout the study area is required to identify the assessment areas that may be under the highest degree of potential hydrologic stress, and to guide future efforts to refine water budget tools in those areas.

The following sections determine total consumptive water demand by quantifying municipal water demand, permitted water demand and non-permitted water demand. Reported pumping rates were utilized to generate municipal water demand estimates. Estimated pumping rates were generated by combining the permitted rate with the months of expected active pumping. Pumping rates for non-permitted takings were area-prorated from the Tier I stress assessments

(AquaResource, 2008a). Consumptive factors were then applied to determine the amount of pumped water that is not returned to the original source in a reasonable amount of time.

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

3.13.3.1 Municipal Water Takings

Municipal water use is a predominant water use sector within the assessment areas; it accounts for approximately half of the total extracted groundwater. Municipal pumping rates reported in the Tier I groundwater stress assessment were utilized for this analysis. All municipal takings were assumed to be 100% consumptive, as wastewater discharges are discharged to the surface water system and not returned to the groundwater system.

3.13.3.2 Permits to Take Water

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

Originally designed to manage the fair sharing of water, data collected in support of the PTTW program can be used to estimate current water demands. Although the program is currently adapting to collect records of actual water takings, the datasets provided by the MOECC only include maximum permitted water takings, and must be manipulated to estimate realistic water demands. The PTTW program is now requiring PTTW holders to report their actual pumping rates; however, this new information was not available for this assessment. When using the PTTW database to estimate actual water demands, the following considerations are made:

- When specifying the amount of water required for their specific use, permit holders often request a volume of water that exceeds their requirements. This may be done to ensure compliance in dry years or to secure sufficient water for possible future expansion of the operation.
- Permitted volume is often derived from the capacity of the pumping equipment rather than the requirements of the user, often significantly over-estimating the user's demand.
- The database does not maintain a record of seasonal water demand requirements.
- Multiple wells or sources may be included on a particular permit, and the permitted rate refers to the total for all sources associated with that permit. As an example, two nearby municipal wells may operate under one permit but the wells may never operate simultaneously. In this case, each well source could pump at the maximum permitted rate, but not at the same time. To estimate total demand, the total permitted rate should be logically divided amongst the active source locations.

- The spatial location of water taking sources is not always accurate.
- The PTTW database is not current with respect to the MOECC's actual permitting activities (recent permit numbers may not be included within the database).
- Historic water takings may be "grandfathered" and do not require a permit. As a result, there may be some significant water takings not reflected by the PTTW database.

A copy of the PTTW database current to January 2009 was used in this assessment. Only active permits, or permits representing sustained water taking, were included in this analysis. To aid in the proper characterization of water taking permits, the Environmental Bulletin Registry was used. Searching the Environmental Bulletin Registry allowed the permit application details and the granted paper permit to be viewed for many water takings. Temporary permits, such as pipeline testing, pumping tests or temporary construction permits, were not included. Additionally, groundwater takings, where the water source was identified as a spring, were assumed to be surface water takings and removed from the groundwater stress assessment.

Estimating consumptive demand from information contained within the PTTW database was completed by following the methodology included in the Technical Rules: Assessment Report (MOECC, 2009). This procedure is summarized below:

- Maximum permitted rates were combined with the number of days each source is permitted to pump. The resultant volume was then evenly distributed through months in which it was assumed the PTTW would be active (e.g. snowmaking permit was assumed to be active Dec-Feb).

- The pumping rate was adjusted using a consumptive use factor. Consumptive use refers to the amount of water that is pumped but not returned back to the original water source.

Monthly estimates of water use are required to accurately quantify the annual volume of water withdrawn, as well as to represent the seasonal changes in total water use within the assessment area. The months where a water taking is expected to be active, based on the purpose of that water taking, were evaluated to facilitate estimates of actual water used in a Tier II subwatershed area, recognizing that many types of water taking operations only take water during a specific time period each year (e.g. snow making generally is active December, January and February). Monthly demand adjustments were combined with the maximum permitted days per year, and the maximum permitted withdrawal, both specified in the PTTW database, to obtain monthly water use estimates.

As discussed in detail in Part I.1 – Definitions of the Technical Rules: Assessment Report (MOECC, 2009), "consumptive use" refers to the amount of water removed from a hydrological system and not returned back to the same system in a reasonable time period. To assess the portion of pumped water that is being removed from the hydrologic system, estimates of water demand must consider the consumptive use.

The percent water demand calculation requires the estimate of water that is consumed and not returned to the original source within a reasonable amount of time. Therefore, for a groundwater assessment, if water is removed from the groundwater system and not returned to the groundwater system, the taking is assumed to be 100% consumptive. Groundwater takings are typically 100% consumptive, since wastewater is seldom returned to the groundwater system, but rather discharged to surface water systems. Exceptions would include irrigation, where a portion of the applied irrigation water would saturate surficial soils and percolate beneath the evaporative root zone, returning to the groundwater system.

Consumptive water demand was estimated for each permitted water taking. These rates, when combined with the municipal rates represent the majority of water extraction from each Tier II subwatershed area.

3.13.3.3 Non-Permitted Water Takings

In addition to permitted water use, there are various types of non-permitted water uses, such as livestock watering and unserviced domestic use (typically rural residents). Non-permitted agricultural and unserviced domestic water were estimated as part of the Tier I water budget and stress assessment (AquaResource, 2008a). These estimates were utilized to quantify non-permitted water use for the current Tier II stress assessment.

Non-permitted agricultural water use includes livestock watering, equipment washing, pesticide/herbicide application, or any other minor use of water. The Tier I study (AquaResource 2008a) quantified the water demands for this particular water use sector by combining agricultural water use coefficients with Census of Agriculture data. This study adapted this data and proportioned it based on the area of the assessment area

There is currently no information regarding the water source that is used to supply water for the non-permitted agricultural users; water may be obtained from shallow or deep groundwater sources, online ponds, or nearby creeks or rivers. In the absence of this information, it is assumed that half of the demand is serviced through groundwater sources, and half is serviced through surface water sources.

Unserviced domestic use is any household water use that is not supplied by a municipal water supply system. Typically, these are households in rural areas, and almost exclusively are supplied from groundwater. This water demand was previously estimated within the Tier I groundwater stress assessment by combining a per capita rate to the serviced population.

3.13.3.4 Tier II Consumptive Water Use

Table 3.13.2 summarizes estimated total consumptive demands for each Tier II subwatershed area by month; maximum monthly demand and annual average demand are also provided. On an average annual basis 11,022 m^3 /day of water is estimated to be removed from groundwater aquifers within the Sydenham Tier II subwatershed area and not returned to the original aquifer.

TABLE 3.13.2 – Tier II Consumptive Water Demand Summary (m^3/day)

Subwatershed	***Avg***	***Max***
Sydenham	11,022	11,022

Consumptive use estimates tend to be lower than the reported maximum permitted pumping rates documented in the PTTW database**,** representing more realistic estimates than what would be estimated by simply summing the permitted volumes. This highlights the need for effective understanding and assessment of demand volumes.

Included in Table 3.13.3 is the consumptive water use for each assessment area, broken down by major sector. For all areas, with the exception of the Sydenham/Owen Sound East (Chatsworth), municipal withdrawals comprise the majority of consumptive withdrawals, with other water use sectors being relatively minor. The exception to this is the Chatsworth assessment area, which has a large permitted water taking for commercial aquaculture purposes.

TABLE 3.13.3 – Consumptive Water Use Breakdown by Sector (Percent of total)

Subwatershed	***Commercial***	***Industrial (Permitted)***	***Recreational***	***Private Wells***	***Municipal***	***Agricultural***
Sydenham	89	4	0	1	1	5

3.13.4 Tier II Groundwater Quantity Stress Assessment

The approach for conducting a Tier II stress assessment is outlined in Part III.4 of the Technical Rules (MOECC; 2009). The Technical Rules prescribe an approach for estimating subwatershed stress based on estimates for water supply, water reserve and water demand in each assessment area. The estimated values for water supply and water reserve are calculated using the groundwater model and the surface water model (AquaResource, 2008a; 2008b).

Tier II stress assessment was evaluated for each assessment area that was identified at the Tier I level (AquaResource, 2008a; 2008b) as having a moderate or significant potential for stress, and which contained a municipal groundwater supply. The purpose of the Tier II stress assessment is to confirm the results of the Tier I and to identify municipal water supply systems where a Tier III water quantity risk assessment is required. Although the Tier I surface water stress assessment did identify certain subwatersheds as having a moderate or significant potential for stress, there are no inland surface water drinking sources. As such, the Tier II stress assessment is solely focused on evaluating the groundwater system.

3.13.4.1 Groundwater Consumptive Use

The procedure used to estimate consumptive groundwater demands under current conditions is documented in Section 3.13. The consumptive groundwater demand refers to all groundwater that is removed from the groundwater system and not returned to the same system within a reasonable amount of time. Consumptive demand estimates included in Section 3.13 include both permitted and non-permitted groundwater takings. These estimates are used to compute the percent water demand for current conditions

3.13.4.2 Groundwater Supply and Reserve

Groundwater supply is calculated as the average annual groundwater recharge plus the amount of groundwater flowing laterally into each assessment area. The GAWSER model developed by the Tier I surface water budget and stress assessment (AquaResource, 2008b) predicted groundwater recharge over the study area. The FEFLOW model refined as part of the current study estimated the groundwater flowing laterally into each assessment area. The groundwater flow in for each assessment area is calculated from the model results as the sum of all positive flow vectors into each area.

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

3.13.4.3 Percent Water Demand

Percent water demand for groundwater is calculated for each assessment area using estimates of groundwater supply, groundwater reserve and consumptive demand described above. The results of the stress assessment for existing conditions are shown in Table 3.13.4.

TABLE 3.13.4 – Percent Water Demand under Existing Conditions

Subwatershed	*Groundwater Supply (m^3/day)*			*Groundwater Reserve (m^3/day)*	*Demand (m^3/day)*		*Percent Water demand (%)*	
	Recharge	*Flow In*	*Supply*		*Avg*	*Max*	*Avg Water Demand*	*Max Water Demand*
Sydenham	124,300	51,800	176,100	10,300	11,022	11,022	7	7

The Sydenham subwatershed area has a percent water demand that is below the provincial thresholds (Table 3.13.4**)**. At 7%, the percent water demand for this assessment area is well below the moderate threshold of 10% and is, therefore, classified as having a low potential for stress.

3.13.5 Tier II Future Use Assessment

The Technical Rules requires that any assessment area not already identified as having a moderate or significant potential for stress, undergo an additional scenario where future municipal pumping and future land use be considered.

To evaluate the percent water demand under future conditions the population projections contained within each municipality's official plan were summarized. This summary is included in Table 3.13.5.

TABLE 3.13.5 – Future Population Summary

System	*Current Population*	*Future Population (2026)*	*Percentage Increase*
Sydenham	6,600	8,200	24%

Population increases were combined with current per capita water use rates to estimate the increase in municipal water demand. Future non-municipal water demand was assumed to be equal to current non-municipal water demand.

Changes in land cover due to population growth are typically associated with increased urbanization, with resulting reductions in recharge. To consider how changes in land use may affect the future percent water demand, the urban area associated with each assessment area was increased by the population growth rate. This increase in urban area was conservatively assumed to be 100% impervious, thereby reducing the total recharge for the assessment area.

TABLE 3.13.6 – Percent Water Demand under Future Conditions

Subwatershed	Groundwater Supply (m^3/day)			Groundwater Reserve (m^3/day)	Demand (m^3/day)		Percent Water demand (%)	
	Recharge	Flow In	Supply		Avg	Max	Avg Water Demand	Max Water Demand
Sydenham	124,200	51,800	176,000	10,300	11,061	11,061	7%	7%

The increased municipal pumping and the revised assessment area recharge was combined with the groundwater flow in and groundwater reserve calculated for the current condition scenario to calculate the future percent water demand, and is shown in Table 3.13.6. This assessment assumes that neither the groundwater inflow, nor the groundwater discharge, would be modified significantly given the expected increases in urban area (0.1-1.1%). As shown in Table 3.13.6, all the Sydenham Tier II subwatershed area remains well below the thresholds for moderate potential for stress. As a result, the area is classified as having a low potential for stress under future conditions.

3.13.6 Tier II Drought Assessment

According to the Technical Rules, groundwater assessment areas can also be classified as having a potential for moderate stress if either of the following circumstances occurs within the assessment area during observed or simulated drought conditions:

(i) the groundwater level in the vicinity of a well was not at a level sufficient for the normal operation of the well; or

(ii) the operation of a well pump was terminated because of an insufficient quantity of water being supplied to the well.

This study proceeded with running the entire 1950-2005 period through the groundwater flow model. By investigating the range of precipitation/recharge fluctuations that might be expected to occur throughout the historic 55-year period, this approach captures two-year and ten-year periods of drought.

The FEFLOW steady-state groundwater flow model was configured to use the time series of monthly recharge adjustment factors for the complete 1950-2005 simulation based on variations in recharge derived from the GAWSER model. Water levels resulting from the steady-state groundwater flow simulation were set as initial conditions for the 1950-2005 transient simulation.

The groundwater flow model was configured to export groundwater levels at each municipal well during the simulation. Should the simulated water level fluctuations at a specific well be greater than what can be accommodated by that well (i.e. greater fluctuation than the average depth of water over the intake), the well would be deemed to be sensitive to drought conditions, and a classification of a moderate potential for stress would be assigned to the assessment area. As the goal of this scenario is to investigate whether current pumping regimes could be sustained throughout historical drought conditions, the simulation also assumes constant pumping from each of the wells.

The results of the drought assessment are shown in Table 3.13.7. In this table, the maximum water level decline over the 1950-2005 period is shown for each municipal well. The maximum decline for each well is compared to the depth of water that is above the well intake elevation. Should the maximum water level decline be greater than the depth of water above the intake, it would indicate that the water level in the well would drop below the intake, and normal operations would cease. The assessment area would then be classified as having a moderate potential for stress.

TABLE 3.13.7 – Drought Results Summary

Municipal System	***Well***	***Simulated Maximum Water Decline (m)***	***Water Depth Above Intake (m)***
Chatsworth	Well #1	<1	>2
	Well #2	<1	>2
	Well #3	<1	>2

The depth of water above the well intake elevation for each municipal well was assumed to be at least two metres. This value was considered an initial, conservative assumption. For those wells that were simulated to experience more than two metres, specific information related to the depth of water above the well intake was requested of the municipal water supply managers to more accurately evaluate the significance of the simulated drawdown impact.

As seen in Table 3.13.7, there are no municipal wells susceptible to drought conditions; no wells are predicted to experience drawdown that would exceed their estimated available drawdown.

3.13.7 Tier II Uncertainty Assessment

While the stress classification is based on best estimates of consumptive water demand, water supply, and water reserve, there is uncertainty with these estimates that may affect the classification. The Technical Rules require that each assessment be assigned an uncertainty classification of low or high uncertainty in regards to the stress assessment classification assigned to each assessment area

This section describes a sensitivity analysis designed to evaluate whether the uncertainty associated with the water demand or supply components is sufficient to modify the stress assessment classification. Where the sensitivity analysis indicates that the classification may change from moderate to low potential, or low to moderate potential, an uncertainty classification of high is assigned. For subwatershed areas that do not change stress levels within the sensitivity analysis, an uncertainty classification of low is assigned.

Table 3.13.8 summarizes the results of one sensitivity scenario; the percent water demand is re-calculated with the estimated portion of both water demand and the groundwater recharge increased and decreased by a factor of 20%. Each sensitivity scenario is completed independent to one another.

TABLE 3.13.8 – Sensitivity Analysis Summary

Subwatershed	***120 % Water Demand***		***80% Water Demand***		***120% Recharge***		***80% Recharge***		***Uncertainty***
	Avg	***Max***	***Avg***	***Max***	***Avg***	***Max***	***Avg***	***Max***	
Sydenham	8	8	5	5	6	6	8	8	Low

For the assessment area, the stress classification did not differ from the stress classification under current conditions. The sensitivity analysis shows that the stress assessment results are not sensitive to uncertainty ranges of 20% applied to water demand and groundwater recharge estimates. As such, the uncertainty classification assigned to all assessment areas is low. This confirmation of the stress classification provides additional confidence in the Tier II stress assessment.

3.13.8 Summary of Tier II Stress Assessment Results

Based on historical conditions, current percent water demand, future percent water demand, the drought assessment, and the uncertainty consideration, the Tier II groundwater stress assessment classifications for each assessment area is summarized in Table 3.13.9 and displayed in Map 3.10.

Assessment areas identified as having a moderate or significant potential for stress are discussed below.

TABLE 3.13.9 – Summary of Tier II Stress Assessment Results

Tier II Subwatershed	***Municipal Supplies***	***Tier II Stress***	***Uncertainty***
Sydenham	Chatsworth	Low	Low

As per the Technical Rules (Nov 2009), no municipal supplies in the Grey Sauble SPA require a Tier III water quantity risk assessment.

3.13.9 Tier II Significant Groundwater Recharge Area Update

Tier II recharge estimates utilized existing Tier I GAWSER modelling results, which were deemed sufficient for the purposes of the Tier II water quantity stress assessment. As a result, Significant Groundwater Recharge Areas were not updated as a result of the Tier II work (Map 3.11)

3.14 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.

3.14.1 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.

3.14.1.1 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 3.14.1.

TABLE 3.14.1 – 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.

3.14.1.2 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.

3.14.1.3 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 3.14.2.

TABLE 3.14.2 – Land Cover Reclassification for HRU Development

Land Cover Reclassification
Wetland
Forested
Urban
Agricultural
Hummocky

3.14.2 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 3.14.3.

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.

3.14.2.1 Assigning Recharge Values to HRUs

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

3.14.2.2 Determination of Groundwater Recharge Areas

In order to determine the 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 Grey Sauble 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 Grey Sauble SPA was 270 mm/year, and the corresponding threshold for identifying potential SGRAs was set at (270 mm/year X 1.15) 310 mm/year. Therefore, all HRUs with modeled recharge values greater than 310 mm/year were identified as potential SGRAs.

TABLE 3.14.3 – 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

3.14.2.3 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. Due to the prevalence of wells throughout the area, an assumption was made that all recharge areas greater than 1 ha 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 3.11.

3.14.3 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. The uncertainty for the SGRAs is considered low for the source protection area.

3.15 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.

AquaResource, Inc., 2010. Saugeen Valley, Grey Sauble, Northern Bruce Peninsula Tier Two Subwatershed Stress Assessment.

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.

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

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

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.