Saugeen, Grey Sauble, Northern Bruce Peninsula
Source Protection Region

FINAL DRAFT

Conceptual Water Budget

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List of Acronyms

AWC- Available Water Capacity

BFI- Baseflow Index

BFLOW- Baseflow Separation Program

BRFU- Basin Runoff Forecast Unit

CA- Conservation Authority

CLI- Canada Landuse Inventory

DEM- Digital Elevation Model

ET- Evapotranspiration

GAWSER- Guelph All-Weather Sequential Event Runoff model

GIS- Geographic information system

GRCA- Grand River Conservation Authority

GSCA – Grey Sauble Conservation Authority

GUDI- Groundwater Under the Direct Influence of Surface Water

HSPF- Hydrological Simulation Program – Fortran

HYDAT- Hydroclimatological Data Retrieval Program

IWD- Inverse Weighted Distance

MNBP- Municipality of Northern Bruce Peninsula

MNR- Ministry of Natural Resources

NRCan- Natural Resources Canada

NRVIS- Natural Resources Values Information System

PTTW- Provincial Permit To Take Water

STATSGO- State Soil Geographic Database

STPs- Sewage Treatment Plants

SVCA- Saugeen Valley Conservation Authority

SWAT- Soil and Water Assessment Tool

SWP- Source Water Protection

USDA- United States Department of Agriculture

WOFOST- World Food Studies model

WRIP- Water Resource Information Project

WSC- Water Survey of Canada

WWTP- Waste Water Treatment Plant

1.0 Conceptual Water Budget

1.1 Introduction

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.

It is important to have a method for developing this conceptual understanding that first determines the goals and anticipated uses of the water budget, and using this information to determine the spatial boundaries for which the water budget will be developed. Once these items have been determined, the next step is to gather available data and to develop a conceptual understanding of the water flux within those spatial boundaries. The goal of a conceptual water budget is to provide an initial overview of the function of the flow system in the watershed.

This report endeavours to outline the conceptual water budget and further summarize, analyse and identify gaps in data available for the Saugeen-Grey-Sauble-Northern Bruce Peninsula Planning Region as outlined in Map 1. For an introduction to the region, readers are directed to the first chapter of this report, the draft watershed characterization.

1.1.1 Goals of the Conceptual Water Budget

A number of goals have been outlined for the development of water budgets for the purposes of Source Water Protection in Ontario. Specifically, the conceptual water budget is intended to answer the following questions:

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

It should be noted that the water budget exercise for this region is not a simple quantification of the flux of water between components in the system but also a description of the flow of water, the processes involved and the pathways for water between components.

The development of a water budget, for this initial phase of preparation, is intended to be completed at a regional scale. However, for the purposes of Source Water Protection, the water budget exercise is focused on municipal water supplies, and any potential water quantity stresses on those supplies. The initial water budget will subsequently be refined at a smaller scale in order to resolve local and site specific issues if identified. As such, this iteration of the water budget is intended to provide a background from which these issues can be further investigated, rather than to resolve all water quantity and quality related issues. It is important to identify these limits of the water budget in this context, and to understand that it is intended to be updated and recalculated on an ongoing basis.

1.1.2 Definition of Uniform Areas

A number of considerations have been identified in order to determine the scale to which the water budget should be developed, including Physiography/geology, Land use, water use among others. For the Saugeen-Grey-Sauble-Northern Bruce Peninsula planning region it was noted that similar land and water uses exist throughout and that difference in Physiography were already accounted for in the existing watersheds identified for Flood Forecasting purposes. In addition, historical meteorological and flow data exists for many of these watersheds, which facilitated a comparison of the relative responses of each surficial watershed. It was therefore decided that, in the initial iteration of the water budget, utilization of the existing continuous streamflow monitoring stations would be advantageous for the calibration of surface water flow models. Map 1 shows the approximate boundaries of these subwatersheds within the Saugeen-Grey-Sauble-Northern Bruce Peninsula Planning Region.

It is acknowledged at this point, that the usage of these “gauged” catchments as uniform areas may be altered upon gaining further data and as more refined (i.e. tier I or further) water budgeting exercises are carried out. These increased refinements will, however, occur within these initially defined gauged catchments. Any changes in uniform areas, or increased refinement of these uniform areas, will be discussed prior to commencement of a Tier I water budget for the region.

1.2 Surface Water System

1.2.1 Introduction

The Watershed Description provides an overview of how physiography, topography and soils generally influence the surface hydrology of the planning region.
The major surface water systems included in this study include the Saugeen, Sauble, Big Head, Beaver Rivers as well as numerous smaller streams that drain into Lake Huron and Georgian Bay directly. A detailed listing of the watersheds selected for analysis is included in section 3.2.6.

The following sections provide more detailed descriptions of the character of each of the surface systems of the region by presenting and summarizing historical observations pertinent to these surface water systems.

1.2.2 Background

The need to address localized flooding concerns in developed or developing areas was a major reason for the initial formation of both the Grey Sauble and Saugeen Valley Conservation Authorities. As a result, significant effort has been made in the past to attempt to characterize and conceptualize the area's surface hydrology. Permanent stream flow monitoring began in earnest at points on some of the area's river systems in the early 1950's through both federal (Water Survey of Canada), and provincial/local (Ministry of Natural Resources/Conservation Authority) initiatives. Meteorological monitoring through both Environment Canada's Atmospheric Environment Service and later local Conservation Authority networks, developed as part of their flood warning systems, have helped to characterize the air temperature and precipitation of the region. Studies aimed at developing hydrological models for the purposes of forecasting possible flood events have, in the past, assembled base data needed to characterize the hydrologic response of the major watersheds in the study area under designed or observed rainfall/snowmelt events.

Major watersheds in both the GSCA and the SVCA jurisdiction were modelled using the Basin Runoff Forecast Unit (BRFU) initially in the mid 1980's with continuous improvement since that time. The BRFU model was developed by John W. (Jack) MacPherson and, while under continuous improvement, was initially based on principles used in the Kentucky version of the Stanford Watershed Model. BRFU also provides the user with many computer modules to assist with polling watershed gauging and meteorological stations. It also provides routines to assist with data checking, analysis and archiving. It has been used by several Conservation Authorities, particularly in Ontario's southwest to assist in managing their hydrology-related datasets and in delivering their flood warning/forecasting program.

The BRFU software, although specifically tied to flood forecasting rather than long term water budget modelling, is primarily utilized to download and store pertinent climatic and stream flow data and is the predominant source of information for this study. The present density of these data sources, developed for flood and weather forecasting, can be considered appropriate for a region of this size. The exception is the collection of Evaporation data, of which there is no data available for the study area. With changing climate patterns and an overall shift towards more convective rainfall events, alternative methods of estimating the distribution of rainfall may be required.

1.2.3 Climate

1.2.3.1 Precipitation

Data Sources

Precipitation data was acquired from the Environment Canada National Climate Archive (http://climate.weatheroffice.ec.gc.ca/). A total of 42 stations were used to characterize average precipitation inputs across the planning region. A detailed listing of these stations and their respective periods of record are attached as Appendix A. 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. Initially, climate stations were chosen based on the level of data collection obtained at each site that reflected the most complete record as possible, and the other sites were chosen randomly for the purpose of creating the weighted average via Thiessen polygons. The location of climate stations and Thiessen polygons developed for the data analysis are shown in Map 2.

Adjustment of daily rain gauge measurement

Any daily precipitation amount less than 0.2 mm was below detection limits, and therefore considered as a “trace” amount, and not included in the total precipitation value. The inability to accurately quantify trace amounts of precipitation in this area has led to trace precipitation being approximated as a “zero” value in the time series.

Filling of temporal gaps in precipitation data

The method selected to fill missing data records and for a continuous time series is 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. The *IWD* method used for this report was the *Shepard's Weighted Interpolation,* which can be defined by:

$$Z_p = \frac{\sum_{i=1}^{n} Z_i W_i}{\sum_{i=1}^{n} W_i};$$

Where;

$$W_i = \frac{\left(1 - \frac{d_i}{R}\right)^2}{\left(\frac{d_i}{R}\right)^2}; for \frac{d_i}{R} \angle 1$$

$$W_i = 0; for \frac{d_i}{R} \geq 1$$

Z_p = Interpolated value at the station,
Z_i = Measured climate value at the respective stations,
W_i= Weighting function, and
n = no. of nearby stations used for spatial interpolation.
d_i = Distance between Z_p and Z_i
R = Radius around the interpolated station up to which measured stations will be selected for interpolation

The choice of R depends on the density of the data points and should be chosen so that the sampling circle includes at least five sample points (Yoeli, 1975).

Data Analysis

Data from each active gauge (See Map 2) 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. This data is graphically represented in Map 3 for the period of 1971-2000 (inclusive).

Spatial Distribution of Precipitation

Map 3 shows the spatial distribution of average annual rainfall data for the region based on the available and filled data. Precipitation amounts vary from approximately 746 – 1138 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.

Physical Distribution of Precipitation

The distribution of rainfall for four (4) stations is shown in Figure 1 below.

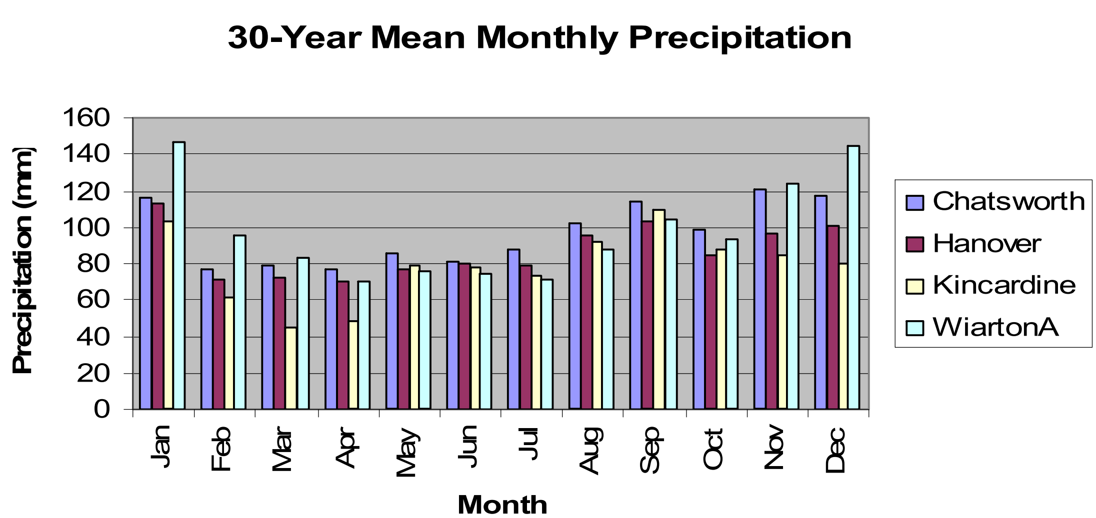


Figure 1. Physically distributed monthly precipitation for selected sites in the Grey Sauble-Saugeen-Northern Bruce Peninsula Region

As mentioned, the sites were chosen primarily on the completeness of the data record. Wiarton, located on the Bruce Peninsula, is considered representative of the northern portion of the study area, Chatsworth the north-central portion, Hanover the south-central portion and Kincardine the southeastern portion. Based on the available data, there is a large amount of precipitation that falls over the region from November through January. Snowfall may represent as much as 40-50% of the annual precipitation, highlighting the importance of the spring freshet to runoff conditions in the region.

In addition, total precipitation is larger 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 (1169 mm), followed by the Chatsworth (1054 mm), Hanover (1044 mm) and Kincardine (941 mm) climate stations.

At present, no snowfall records are available for the study area. Snow depth measurements are recorded bi-weekly in the winter months. The lackof snowfall data is considered a data gap for the area.

1.2.3.2 Air Temperature

Data Sources

In total, data from 16 climate stations, operated by the Conservation Authorities and Environment Canada were analyzed for the area. 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. Where warranted local authority's measurement (i.e. municipalities) were considered as additional information for gap fill-up of no measurements.

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). Variations in ecodistricts, therefore, 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.

Data Analysis

The Ecodistrict data were extracted from the Agriculture and Agri-Food Canada supplied data. Based on the available data, Map 4 was created in order to show the distribution of ecodistricts throughout the study area. This map shows that temperatures in the Owen Sound Area, as well as in the southwestern portion of the watershed along the shore of Lake Huron, are relatively warmer then the remaining areas, largely as a result of their physical setting in a confined valley and/or proximity 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.

Future Trends

It is generally accepted that the Great Lakes Region can anticipate an overall increase in temperature in the immediate future. This increase is likely to manifest itself in the region in several ways. Firstly, warmer winter temperature will result in a longer snow-free period, resulting in more precipitation falling as rainfall, thereby allowing more water to runoff directly to watercourses versus recharge to aquifers. This will also decrease the amplitude of the seasonal variation in runoff, presently concentrated during the spring freshet. Secondly, warmer summer temperatures will lead to increased evapotranspiration and convective rainfall events. This will lead to more and longer periods of dry weather and change the nature of predicting flows in the region. Flood forecasting systems are presently designed to provide warning in the case of large, systemic rainfall events and will have to adapt to focus more on the less areally distributed, higher intensity convective thunderstorms.

1.2.3.3 Wind

Data Sources

Wind data is an overall data gap for the region. There are no reliable wind measurement stations readily available at time of writing this report. It is anticipated that more data will become available as a result of the recent development of wind turbine electrical generation “farms” in the southwest portion of the region. This data will be located as part of a Tier I water budget analysis for the region, and allow for a more reliable, long-term analysis of wind data.

1.2.3.4 Barometric pressure

Barometric pressure data is an overall data gap for the region. No reliable barometric pressure data was located prior to the writing this report. It is anticipated that more data will be located and analyzed in the near future. This data will allow for a more reliable, long-term analysis of barometric pressure, if deemed necessary to meet the objectives of this study.

1.2.3.5 Solar Radiation

Only two solar radiation measurement stations are operated in the study area, located at Bells Lake and the SVCA headquarters Conservation Area. These stations have a period of record from 1992-present and 2000-present, respectively. These short periods of record do not allow for any meaningful analysis of the available data, however, data was compiled and annual average values are shown below in table 1.

Table 1. Average Annual Solar Radiation for Bells Lake and SVCA Headquarters, in Langleys.

Year	**Bell's Lake** (Langleys)	**SVCA HQ** (Langleys)
1992	692	
1993	698	
1994	723	
1995	674	
1996	700	
1997	724	
1998	622	
1999	669	
2000	789	875
2001	745	803
2002	534	855
2003	489	745
2004	494	496
2005	491	620

Data accumulated for the development of Ecodistricts also includes solar radiation data. This data was intersected with the uniform areas defined for this study and the results are shown in Map 5. As expected, solar radiation values increase in the southern portion of the study area and in the lee of Lake Huron, where increased cloud cover is encountered by the frequent lake-effect precipitation and fog.

1.2.3.6 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. These values were derived using both Penman and Thornthwaite methods, as utilized by the WOFOST Crop Simulation Model (van Diepen et al., 1988).

The Ecodistrict ET data was then intersected with the outlined uniform areas to produce average ET values for the subwatersheds. It is understood that these values represent modeled 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 Map 6.

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 and Georgian Bay 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.

The lack of any evaporating pan in the area makes ET the most obvious gap in data for the entire region. Although it is possible to estimate ET via numeric calculation, without actual data to calibrate it to these calculations must be viewed with a high degree of uncertainty. As a result, ET and the lack of calibrated data represents the least certain component of the water budget for the region.

1.2.4 Land Use and Land Cover

Data Sources

The primary sources of Land Use data for the region 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 7 shows the Land uses as defined by the Canada Land Use Inventory.

The Ontario Provincial Land Cover 28 (1998) includes primarily Land Cover information, and was developed from LandSAT 5 infrared imagery captured between 1991 and 1998 and broadly categorizes the region into 28 Land Cover classes based on vegetative cover. This data reflects the nature of the land surface rather than the actual land use.

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 8 and 9 show the respective official plan mapping for Bruce and Grey Counties, respectively. Although official plans may be useful for predicting which areas will undergo substantial land use changes in the immediate future (i.e. the next 5 years), they do not provide enough accurate information to develop a water budget model on, 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.

The Canada Land Use Inventory is based on air-photo interpretation, augmented by field surveys and census data. This additional data was utilized in order to develop land subclasses for the entire region. These subclasses include both land use and land cover, and include:

- Improved Pasture and Forage Crops
- Mines, Quarries, Sand/Gravel Pits
- Non-Productive Woodland
- Orchards and Vineyards
- Outdoor Recreation
- Productive Woodland
- Swamp, Marsh, or Bog
- Unimproved Pasture and Range Land
- Unknown (0.02% of whole area)
- Urban/Built Up Area
- Water

Data Analysis

The distribution of the Canada Land Use Inventory Data across the region is shown in Figure 2 as derived from Map 7. The respective land use classes are also shown in Appendix B, attached. Based on this information, it is clear that the region is dominated by agricultural usages, with “improved” and “unimproved pasture” constituting approximately 57% of the overall land use, and followed by productive and non-productive woodlots, which constitute approximately 37% of the Total area. Of particular importance for this region is the relatively low percentage of land area that can be categorized as urban, constituting less than 3% of the overall area.

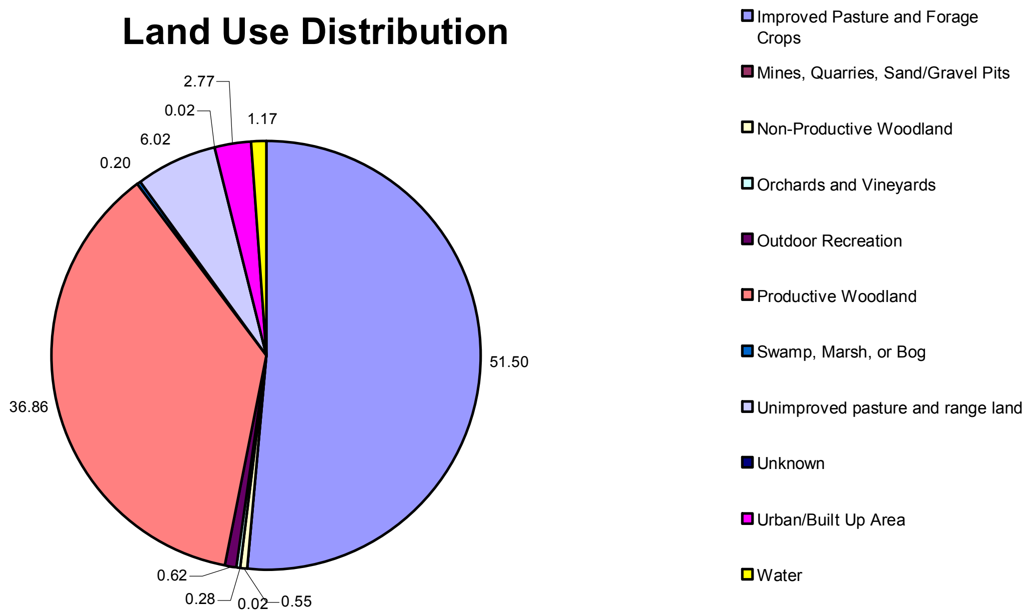


Figure 2. Distribution of land uses by category, from the Canada Land Use Inventory.

The remaining land uses include recreation, pits and quarries, and a significant portion (~1.2 %) of the area comprised of open water, including lakes and open wetlands.

Accordingly, the development of a water budget in the Grey-Sauble-Saugeen-Northern Bruce Peninsula Region will necessitate an accurate deposition of the impacts of the predominantly rural (agriculture and forested) land uses.

Based on the available data sources, the Canada Land Use Inventory is the most reliable and readily accessible information from which to base any further water budget analysis.

Historical trends in Land Use

The Saugeen-Grey-Sauble-Northern Bruce Peninsula Region is not considered to be a region that has undergone, or 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 the Saugeen Shores and Kincardine, in the very southwest of the region, 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 from the perspective of a gross-scale water budgeting exercise.

Data Gaps

The predominant gap in land use data is the lack of detailed information regarding agricultural practices. This information will be critical should the water budgeting exercise become more focused on specific sub-watersheds of interest.

1.2.5 Soils

Data Sources

Soils mapping is available for the entire region based on county-scale soils surveys completed in the 1950-1955 period, with some minor updates completed in the 1980's. These surveys have been digitized and attributed and area available in a GIS format from the Ministry of Natural Resources (2002). Appendix C shows the table of soils and their associated properties for the region. In addition, data from the Soil Survey Reports of Grey and Bruce County (Gillespie and Richards, 1954; Hoffman and Richards, 1954) were used to provide more detailed information on soil profiles and characteristics.

Data Analysis

A compilation of the soils map from county soil reports within the study is shown in Map 10. The list of different soil series of different counties within the study area is given and the specific hydrologic properties for each are provided in Appendix C. 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 detail descriptions of the soil series are required. Most of the information for soils was taken from the County's Soil Survey Reports covering in the study area. In addition, Soil Survey Reports and Maps are also good supplementary source of Land Use information.

Data Manipulation

A number of quantitative soil parameter values are required in order to estimate infiltration and other hydrological processes. These values can be estimated from standards derived from a number of measurements of certain types of soils. The parameters include:

(i) soil horizon,
(ii) horizon depth,
(iii) moist bulk density,
(iv) available water capacity of the soil layer,
(v) saturated hydraulic conductivity
(vi) clay content
(vii) silt content,
(viii) sand content,
(ix) rock fragment layer and

(x) moist soil albedo.

The soil horizon and its descriptions are available in different county soil reports.

Estimated percentage of clay, silt and sand can be derived from the USDA Soil Texture Chart for different types of soils. The limiting values for K_{sat} can then be derived for different kind of soil drainage conditions mentioned in the Soil Report. The Bulk Density (gm/cc) can be estimated from the regression map for different types of soil texture by interpolating the iso-bulk density lines. Available Water Capacity (AWC) is expressed as a volume fraction, as a percentage, or an amount of equivalent precipitation (e.g. mm).

Saturated Hydraulic Conductivity, $K_{sat,}$ is a measure of the ease of water movement through the soil. The vertical saturated hydraulic conductivity is the reciprocal, or inverse, of the resistance of the soil matrix to water flow. Resistance to water movement in saturated soil is primary a function of the arrangement and size distribution of pores. Measured values easily may vary by 10-fold or more for a particular soil property. In addition, measured hydraulic conductivity values for a soil may vary dramatically with the method used for measurement. Due to the highly variable nature of soil hydraulic conductivity, a single measured value is an unreliable indicator of the hydraulic conductivity of a soil. An average of several values will give a reliable estimate, which can be used to place the soil in a particular hydraulic conductivity class.

1.2.6 Runoff and Streamflow

1.2.6.1 Data Sources

This section provides a characterization of the surface water resources of the source protection area, including the contributing watersheds for the following nine (9) rivers:

- Beaver River
- Bighead River
- Penetangore River
- Pine River
- Sauble River
- Saugeen River
- Stokes River
- Sydenham River
- Teeswater 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 11. 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. Due to its size, the Saugeen River has been further delineated into the Lower Saugeen, Upper Saugeen, and South Saugeen areas.

The 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 eleven (11) areas shown in Map 11. 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 SVCA and GSCA by a collection of gauges operated under a Federal/Provincial cost share agreement, and gauges owned and operated by SVCA. Water Survey of Canada (WSC) maintains gauges under the Federal/Provincial cost share agreement under the HYDAT program. As listed in Table 2 and 3, there are a total of 43 existing and historic streamflow gauging stations in the region (32 HYDAT and 11 SVCA operated gauges).

HYDAT Gauges

WSC currently maintains 16 active stations, and recently installed 4 additional gauges in 2005. Historical data for 12 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; and
- 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.

Table 2: WSC Gauges

CA	Station Name	WSC_ID	Drainage Area	Data Collected	Years of Flow Data	Status
GSCA	Sauble River Above Tara	02FA005	223	Levels, Precip		Active
GSCA	Sauble River at Allenford	02FA004	301	Flow, Levels	1987-2003	Active
GSCA	Sauble River at Sauble Falls	02FA001	927	Flow, Levels	1957-2003	Active
GSCA	Sydenham River Near Owen Sound	02FB007	181	Flow, Levels, Precip	1915-2003	Active
GSCA	Beaver River Near Clarksburg	02FB009	583	Flow, Levels	1957-2003	Active
GSCA	Bighead River Near Meaford	02FB010	293	Flow, Levels, Precip	1957-2003	Active
GSCA	Beaver River Near Feversham	02FB004	81.6	Flow	1914-1915	Inactive
GSCA	Beaver River Near Kimberley	02FB003	262	Flow	1915-1951	Inactive

CA	Station Name	WSC_ID	Drainag e Area	Data Collected	Years of Flow Data	Status
GSCA	Bighead River at Meaford	02FB005	342	Flow	1915-1917	Inactive
GSCA	Mill Creek Near Red Wing	02FB006	127	Flow	1915-1915	Inactive
GSCA	Beaver River at Eugenia	02FB008	179	Flow	1910-1914	Inactive
GSCA	Beaver River Above Eugenia Power House	02FB001	254	Flow	1918-1951	Inactive
GSCA	Bighead River Near Strathavon	02FB014	20	Flow, Levels, Precip, Air Temp, Water Temp		New
GSCA	Mill Creek Near Red Wing	02FB012	104	Flow, Levels, Precip, Air Temp, Water Temp		New
GSCA	Beaver River Near Vandeleur	02FB013	277	Flow, Levels, Precip, Air Temp, Water Temp		New
Bruce Penn	Stokes River Near Ferndale	02FA002	50.5	Flow, Levels	1976-2003	Active
SVCA	Saugeen River Above Durham	02FC016	329	Flow, Levels, Precip, Temp	1976-1998	Active
SVCA	North Penetangore River at Kincardine	02FD003	154	Flow, Levels, Precip, Temp	2002-2003	Active
SVCA	Beatty Saugeen River Near Holstein	02FC017	130	Flow	1985-1994	Active
SVCA	Pine River at Lurgan Beach	02FD001	163	Flow, Levels, Precip, Temp	1974-2003	Active
SVCA	Teeswater River Near Paisley	02FC015	663	Flow, Levels	1972-2003	Active
SVCA	Carrick Creek Near Carlshrue	02FC011	163	Flow, Levels, Precip	1953-2003	Active
SVCA	Saugeen River Near Walkerton	02FC002	2150	Flow, Levels	1914-2003	Active
SVCA	Saugeen River Near Port Elgin	02FC001	3960	Flow, Levels	1914-2003	Active
SVCA	South Saugeen River Near Neustadt	02FC012	635	Levels		Active
SVCA	Rocky Saugeen River Near Traverston	02FC004	249	Flow	1915-1940	Inactive
SVCA	Rocky Saugeen River Near Markdale	02FC005	109	Flow	1920-1924	Inactive
SVCA	Armstrong Creek at Markdale	02FC009	9.32	Flow	1920-1920	Inactive
SVCA	North Saugeen River Near Paisley	02FC013	262	Flow	1972-1986	Inactive
SVCA	Saugeen River Near Durham	02FC014	381	Flow	1972-1977	Inactive
SVCA	Hamilton Creek Near Holland Centre	02FC019	59.8	Flow	1993-1994	Inactive
SVCA	Teeswater River at Teeswater	02FC020		Flow, Levels		New

SVCA Gauges

SVCA operates 11 gauge stations independent of the federal/provincial cost share agreement (Table 3). Data from these stations is considered provisional, with little no quality assurance/control processes carried out. The gauges are maintained primarily for higher flow and flood monitoring, and are not corrected for backwater due to ice or aquatic plant growth. As a result, low streamflow estimates in the winter and summer are likely to be overestimated at these gauges.

Table 3: Active SVCA Gauges

Station Name	SVCA_ID	Drainage Area	Data Collected	Years of Flow Data
Teeswater River at Bruce Rd. 20	SVCA_10	499	Levels, Precip, Temp	1986-2005
Rocky Saugeen at Aberdeen	SVCA_11	273	Levels	1988-2004
North Saugeen River Above Chesley	SVCA_12	216	Flow, Precip, Temp	1989-2005
South Saugeen River at Cedarville	SVCA_13	195	Levels, Precip, Temp	1995-2005
Pine River Above Ripley	SVCA_17	60	Levels, Precip	1993-2005

Station Name	SVCA_ID	Drainage Area	Data Collected	Years of Flow Data
Saugeen River Above Priceville	SVCA_18	216	Levels, Precip, Temp	1993-2005
Saugeen River Near Hanover	SVCA_2	904	Flow, Levels	1984-2005
Camp Creek at Allan Park	SVCA_20	112	Levels	
South Saugeen River Below Mount Forest	SVCA_6	419	Levels, Precip	1985-2005
Beatty Saugeen River Near Hanover	SVCA_2	249	Levels	1984-2005
Saugeen River Above Paisley	SVCA_9	2480	Levels, Precip, Temp, Radiation, Wind Speed	1984-2005

Mapping

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

- Digital Elevation Model and enhanced flow direction grid provided by the MNR; (see Map 15)
- Drainage catchment boundaries delineation. Drainage catchment boundaries were based on the DEM and flow direction grid (See Map 1);
- Evaluated Wetlands, Natural Resources Values Information System (NRVIS), MNR (See Map 16);
- Hummocky Topography dataset from the Ministry of Northern Development and Mines. A supplementary dataset included with the Quaternary Geology of Ontario Seamless Coverage - Data Set 14 (See Map 23);
- Land Use layer from the Canada Land Inventory (CLI) - NRCan. Based on land use classifications from 1966-1988 (See Map 7);
- Quaternary Geology, Dataset produced by the Ontario Geological Survey, Ministry of Northern Development and Mines; and (See Map 23)
- Water Virtual Flow Network from WRIP - Received July 2005 (See Map 1).

1.2.6.2 Streamflow analysis

To describe the hydrologic response of the catchment areas within the Source Protection Region, daily average flow data from 23 stations, for both WSC and SVCA gauges, 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. The Penetangore River was omitted for this analysis, as the period of record is insufficient for any meaningful analysis.
Table 4 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 7 groupings as shown, including six (6) primary groupings and one (1) 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.

Table 4: Gauged Catchment Characteristics

Area	Station Name	Station	Drain-age Area (ha)	Physiography		Soil / Surficial Classification							Forest
				Humm -ocky	Karst	Un Classifi ed	Imper-vious / Bedrock	Clay / Clayey Tills	Silty Tills	Sandy Tills	Sand / Gravel	Wetland Deposit s	
1. Sauble	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%
2. Stokes	Stokes River Near Ferndale	02FA002	5,981	0%	1%	100%	0%	0%	0%	0%	0%	0%	63%
3. Sydenha m	Sydenham River Near Owen Sound	02FB007	17,876	1%	2%	0%	1%	20%	54%	0%	13%	11%	35%
4. Bighead	Bighead River Near Meaford	02FB010	30,185	3%	6%	0%	8%	10%	63%	0%	10%	8%	35%
5. Beaver	Beaver River Near Clarksburg	02FB009	58,735	3%	3%	0%	4%	4%	64%	3%	16%	9%	35%
6. Lower Saugeen	Saugeen River Above Paisley	SVCA_9	251,264	13%	0%	0%	0%	10%	47%	1%	35%	7%	30%
	Saugeen River Near Port Elgin	02FC001	373,148	9%	0%	0%	0%	14%	47%	1%	32%	6%	30%
	North Saugeen River Above Chesley	SVCA_12	21,823	0%	1%	0%	0%	2%	43%	0%	37%	17%	44%
7. Upper Saugeen	Beatty Saugeen River Near Holstein	02FC017	5,190	47%	0%	0%	0%	7%	52%	4%	31%	5%	20%
	Beatty Saugeen River Near Hanover	SVCA_8	26,702	24%	0%	0%	0%	7%	51%	1%	34%	6%	28%
	Saugeen River Near Hanover	SVCA_2	26,702	13%	1%	0%	1%	4%	52%	1%	32%	10%	35%
	Saugeen River Above Priceville	SVCA_18	21,803	5%	0%	0%	1%	8%	62%	1%	11%	17%	41%
	Rocky Saugeen at Aberdeen	SVCA_11	27,011	10%	2%	0%	2%	3%	53%	1%	31%	10%	36%
	Saugeen River Above Durham	02FC016	31,071	16%	0%	0%	1%	8%	60%	1%	16%	14%	36%
	Saugeen River Near Walkerton	02FC002	213,469	12%	0%	0%	0%	9%	49%	1%	34%	7%	30%
8. South Saugeen	Carrick Creek Near Carlshrue	02FC011	15,631	23%	0%	0%	1%	10%	54%	2%	28%	4%	22%
	South Saugeen River Below Mount Forest	SVCA_6	42,021	1%	0%	0%	0%	0%	64%	0%	28%	7%	31%
	South Saugeen River at Cedarville	SVCA_13	21,354	0%	0%	0%	0%	0%	71%	0%	18%	11%	34%

Area	Station Name	Station	Drain-age Area (ha)	Physiography		Soil / Surficial Classification								Forest
				Humm -ocky	Karst	Un Classifi ed	Imper-vious / Bedrock	Clay / Clayey Tills	Silty Tills	Sandy Tills	Sand / Gravel	Wetland Deposit s	
	South Saugeen River Near Neustadt	02FC012	61,796	7%	0%	0%	0%	3%	59%	0%	31%	6%	29%
9. Teeswat er	Teeswater River at Bruce Rd. 20	SVCA_10	50,113	16%	0%	0%	2%	9%	43%	2%	39%	5%	28%
	Teeswater River Near Paisley	02FC015	66,940	13%	0%	0%	2%	16%	37%	1%	38%	6%	28%
10. Pine	Pine River at Lurgan Beach	02FD001	15,570	0%	0%	0%	0%	7%	87%	0%	6%	0%	16%

1.2.6.3 Streamflow

All available flow data from WSC and SVCA 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.

- 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.

- Ranked Duration. Similarly to calculating percentiles, ranked duration plots were also constructed for the 23 gauging stations. This allows one to determine the percent of time flows are above a certain threshold.

- 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.

Graphs of monthly mean streamflow/baseflow, monthly median, 10th, 90th percentiles, ranked duration, and daily hydrographs of streamflow and baseflow for an example year are included. While tabulated results of the analysis will be presented for all 23 streamflow gauges in Table 5, discussion of the streamflow characteristics will be limited to the 10 largest catchment areas identified in Table 4.

Table 5 includes the mean annual streamflow and baseflow, both in m^3/s as well as mm over the upstream area. Stream flows, expressed as equivalent precipitation in millimetres is shown for the study area in Map 12. Calculated Runoff and Base Flows expressed as equivalent precipitation in millimetres are shown for the study area in Maps 13 and 14, respectively, 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.

1.2.6.4 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, distributed with the SWAT hydrologic model. This program has previously been known as BFLOW, and has been selected as the optimum baseflow separation technique for a variety of CAs in Southern Ontario, including Ausable Bayfield, Maitland Valley, Niagara Peninsula and the Grand River. A review of common baseflow separation techniques was carried out by the Grand River Conservation Authority, and found BFLOW (using the 3rd pass), to be the most appropriate (Bellamy, et. al, 2003). The BFLOW 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 (e.g. Greenock Swamp) 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 5

Table 5: Flow Characteristics for Selected Gauges

Area	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 Exceedance (m^3/s)	90% Flow Exceedance (m^3/s)	90:10 Ratio
1. Sauble	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
2. Stokes	Stokes River Near Ferndale	02FA002	1.2	610	0.5	244	0.4	0.5	3.0	0.0	86
3. Sydenham	Sydenham River Near Owen Sound	02FB007	2.9	513	1.5	267	0.52	1.9	5.9	0.6	11
4. Bighead	Bighead River Near Meaford	02FB010	4.6	482	2.3	236	0.49	3.0	10.7	0.7	15
5. Beaver	Beaver River Near Clarksburg	02FB009	8.1	435	4.9	265	0.61	6.7	17.0	2.5	7
6. Lower Saugeen	Saugeen River Above Paisley	SVCA_9	49.9	627	27.5	345	0.55	34.8	98.2	11.3	9
	Saugeen River Near Port Elgin	02FC001	56.7	480	30.7	259	0.54	37.1	128.0	13.8	9
	North Saugeen River Above Chesley	SVCA_12	4.4	641	2.9	417	0.65	3.6	8.6	1.2	7
7. Upper Saugeen	Beatty Saugeen River Near Holstein	02FC017	0.6	371	0.3	171	0.46	0.4	1.4	0.1	15
	Beatty Saugeen River Near Hanover	SVCA_8	5.8	691	3.3	394	0.57	4.00	12.0	1.1	10
	Saugeen River Near Hanover	SVCA_2	22.2	722	12.4	404	0.56	15.9	47.0	5.0	9
	Saugeen River Above Priceville	SVCA_18	3.8	555	1.2	167	0.3	1.4	9.6	0.2	60
	Rocky Saugeen at Aberdeen	SVCA_11	5.1	593	3.4	397	0.67	4.1	9.0	1.9	5
	Saugeen River Above Durham	02FC016	4.7	481	2.0	207	0.43	2.5	10.6	0.7	15
	Saugeen River Near Walkerton	02FC002	30.5	451	16.5	244	0.54	21.2	65.0	8.3	8
8. South Saugeen	Carrick Creek Near Carlshrue	02FC011	2.1	429	1.00	193	0.45	1.2	4.9	0.3	15

Area	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 Exceedance (m^3/s)	90% Flow Exceedance (m^3/s)	90:10 Ratio
	South Saugeen River Below Mount Forest	SVCA_6	6.9	521	3.0	224	0.43	3.8	15.2	0.5	32
	South Saugeen River at Cedarville	SVCA_13	4.3	632	1.1	164	0.26	1.7	10.5	0.2	53
	South Saugeen River Near Neustadt	02FC012	9.4	480	3.6	183	0.38	4.3	22.4	1.2	19
9. Teeswater	Teeswater River at Bruce Rd. 20	SVCA_10	9.8	616	5.3	332	0.54	7.0	23.5	1.3	18
	Teeswater River Near Paisley	02FC015	11.0	517	5.5	258	0.5	6.2	27.0	1.8	15
10. Pine	Pine River at Lurgan Beach	02FD001	2.3	463	0.5	107	0.23	0.7	5.3	0.03	177

presents the Baseflow Index (BFI) at each of the selected gauges. The daily baseflow hydrograph values are shown in Appendix D.

1.2.7 Topography and Watercourses

Data Sources

The primary source of data for the topography in the region is available as a Digital Elevation model, provided by the MNR (2002). This data is based on existing Ontario Base Mapping completed during the 1980's. Watercourses are available from existing Conservation Authority Data sets, which are commonly attributed to include cold and warm water fisheries present in the watercourses. Map 15 includes the topography of the region, superimposed on that are the known cold and warm watercourses and existing stream network information.

Data Analysis

An alternative method for generating stream networks is available through GIS environments. This method develops stream networks by utilizing a flow accumulation method in order to define stream channels and major connecting points.

1.2.8 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 16 for the region. These features are important sources of base-flow for the region.

1.2.9 Groundwater Recharge Estimates

For large basins without significant low flow augmentation controls, it can be generally assumed that baseflow is a result of groundwater discharge. When this is the case, the calculated groundwater discharge rates can be used to estimate groundwater recharge within the contributing area.

Following the hydrologic cycle, precipitation that does not runoff the ground surface or immediately evaporate into the atmosphere will infiltrate into shallow soils. Water being held in shallow soils in excess of the soil's field capacity will percolate further downwards until it meets the watertable. Groundwater recharge refers to the amount of water that reaches the watertable. The amount of groundwater recharge distributed throughout a watershed is due to a number of factors, including landuse and vegetation, surficial soil type, physiography, and Quaternary geology.

1.2.9.1 Methodology

Recharge rates were estimated across the study area by achieving a balance between estimating recharge rates for different surficial geology classes within a gauged catchment area and the average annual baseflow estimated for the same area.
In more detail, the following methodology was used to estimate recharge rates across the study area:

1. *Baseflow Calculation*

Baseflow in the larger HYDAT gauged catchment areas was estimated as discussed previously. The areas considered included those supporting the following gauges:

- Sauble River at Sauble Falls
- Saugeen River near Port Elgin
- Saugeen River near Walkerton
- Teeswater River Near Paisley
- Bighead River near Meaford
- Beaver River near Clarksburg

Smaller gauged catchments were not considered for a number of reasons. Firstly, groundwater discharge observed within a small headwaters catchment may not be reflective of all recharge within the catchment due to the fact that a portion of the groundwater recharge into the area may flow out of the area, discharging in a surface water body outside of the catchment. Secondly, wetlands and other surface water features may play a more significant role on baseflow within a smaller catchment.

2. Surficial Geology Classification

To develop a preliminary understanding of amount of, and spatial distribution, of groundwater recharge, the distribution of the Quaternary geology classifications within each catchment area was considered to have the most significant influence on groundwater recharge rates.

3. Estimate and Balance Recharge and Baseflow

The recharge rates were estimated by iteratively selecting recharge rates for each surficial geology classification and comparing the resulting groundwater discharge calculated based on those rates against the baseflow calculated for the same catchment. Figure 3 summarizes the total recharge estimate for each catchment in comparison to the baseflow calculated for each catchment. The final rates were selected based on the sum of the differences between groundwater recharge and baseflow for each of the areas being zero.

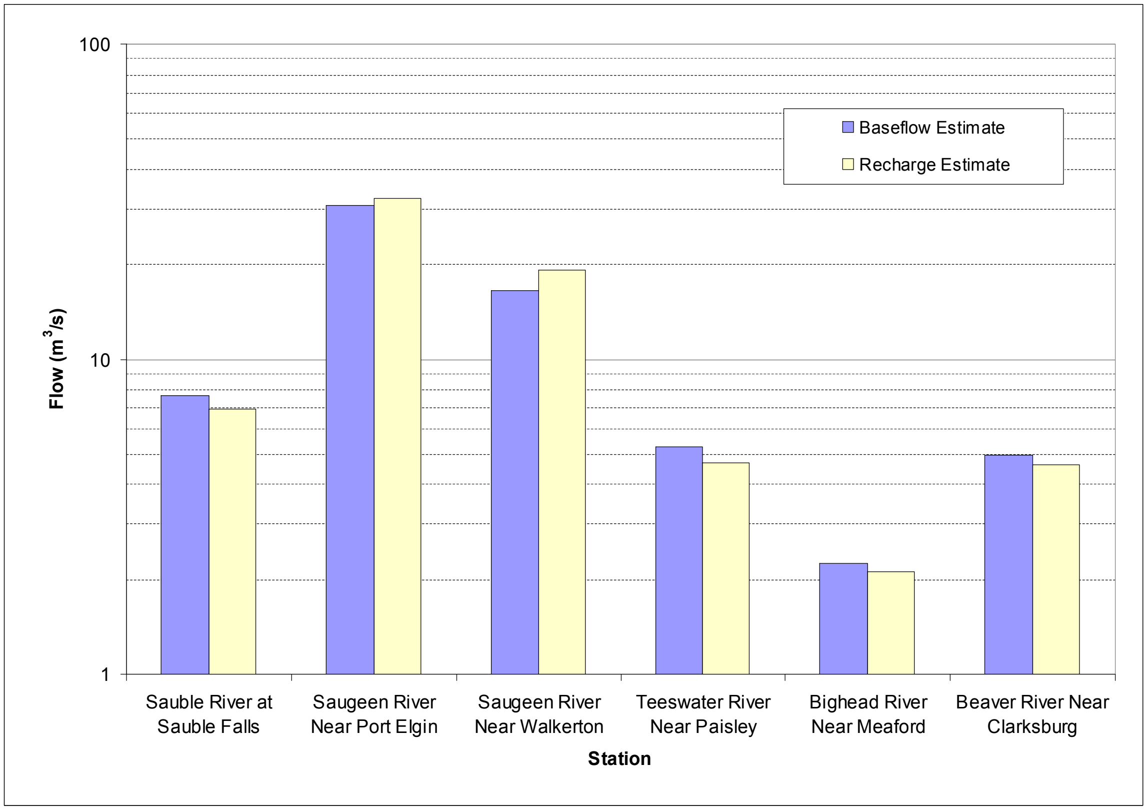


Figure 3- Estimated Baseflow and Recharge for Selected Catchments

1.2.9.2 Results

Table 6, below, summarizes the groundwater recharge rates that result in the best agreement with the baseflow rates estimated for each catchment area. The results are generally consistent with those estimated in the Grand River Watershed using a calibrated streamflow model (GAWSER). Note that this analysis does not consider other factors such as tile drainage, vegetation and hummocky topography, which would result in local adjustments to these estimated values. It is not known at this time to what extent these factors may control recharge estimates.

Table 6 - Estimated Recharge Rates

Surficial Geology Class	Estimated Recharge (mm/year)	GRCA Estimate (min)	GRCA Estimate (max)
Unclassified	287		
Impervious/Bedrock	115	NA	NA
Clay/Clayey Tills	140	45	201
Silty Tills	260	148	307
Sandy Tills	375	271	410

Sand & Gravel	400	354	430
Wetland[1]	0	NA	NA

Notes: [1]The recharge rates included in the GRCA model for wetlands have been incorporated to handle additional water storage within wetlands, and not for groundwater recharge

The recharge rates shown in Table 6 are likely overestimations of actual recharge rates, since the all of the baseflow was assumed to be a result of groundwater discharge. In reality, there are a significant amount of wetlands and inline lakes and reservoirs, which are likely to have an influence on baseflow. Actual groundwater recharge rates would also have a significant seasonal and annual variability. Accurate estimates of groundwater recharge could be obtained by calibrating a surface water flow model (i.e. GAWSER, HSPF) against streamflow records, and having the flow model incorporate significant hydrological features that may have an affect on baseflow.

1.2.10 Surface Water Characterization

Sauble River

The Sauble River watershed is approximately 913 km^2 upstream of the Sauble Falls gauge (02FA001). The Sauble River originates near the Town of Desboro in Chatsworth Township in the County of Grey and discharges into Lake Huron at the Town 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 from the Rankin River that are joining the Sauble River at Sauble Beach are augmented.

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 5). 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.

Stokes River

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

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

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

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

Sydenham River

The Sydenham River originates near the Town of Holland Centre in Chatsworth Township and discharges into Georgian Bay at the City of Owen Sound. The headwaters of the River are monitored by the Sydenham River Near 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 appear 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.

Bighead River

The Bighead River originates near the town of Holland Centre in Chatsworth Township and discharges into Georgian Bay in the Town of Meaford. Streamflow is monitored by the Bighead Near 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.

Beaver River

The Beaver River is located in the GSCA and is monitored by the Beaver River near 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, which 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 on the draining to Georgian Bay at 435 mm. This may have to do with the increased distance from Lake Huron, and therefore not as much lake effect precipitation. There is also the potential for a significant amount of groundwater flow directly info 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 2nd highest BFI of all gauges analyzed, which is 0.61. It also has the 2nd 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.

Saugeen River

The Saugeen River Watershed represents a total drainage area of approximately 3900 km^2 which discharges into Lake Huron in the Town of Saugeen Shores. The watershed is comprised of a number of large tributaries that are grouped into a number of different areas for this assessment as shown on Map 11. These areas include:

- Lower Saugeen. The Lower Saugeen area includes the North Saugeen River, and the Saugeen River downstream of Walkerton.

- Upper Saugeen. The Upper Saugeen area includes the Saugeen River upstream of Walkerton in addition to the Beatty Saugeen and Rocky Saugeen subwatersheds.

- South Saugeen. The South Saugeen River is included with the Carrick Creek subwatershed along the boundary of the Grand River Watershed.

- Teeswater. The Teeswater River is a large tributary that joins the Saugeen in Paisley.

There are a relatively large number of dams located throughout the Saugeen Watershed that may have an impact on hydrological response. There are currently 52 dams in the watershed that are greater than 3 metres in height. The majority of these structures are former mill dams that supplied power to mill operations.

Today, eight of these structures produce hydroelectric power while others provide recreational and transportation benefits. None of the 52 dams were designed to prevent or control flooding; however a small number of dams in the watershed do provide minimal assistance in preventing floods by breaking up ice or by controlling ice movement and thereby prevent the formation of ice jams (Smith, 1980). Since these dams are not actively controlled, it can be assumed that baseflow along major tributaries can be generally attributed to natural conditions, but that some buffering effects from the dams are expected. Baseflow calculations in smaller tributaries containing higher proportions of wetlands and larger dams and inline ponds may be affected to a greater extent by those features.

In addition to HYDAT gauges, SVCA maintains a separate set of 11 stream gauges at various locations throughout the watershed. Although these gauges may provide suitable records for flood events, they have not been corrected for damming due to ice conditions, and therefore the gauges are not used to support this generic hydrologic characterization.

The hydrological characterization for each of the above four areas is summarized in the following sections.

Lower Saugeen

The Lower Saugeen includes a drainage area of approximately 930 km^2 downstream of the Saugeen River at Walkerton, and excludes the Teeswater River. Three gauges are included in this area, including; Saugeen River at Port Elgin (02FC001) and two SVCA gauges; North Saugeen River Above Chesley (SVCA_12) and Saugeen River Above Paisley (SVCA_9).

The surficial materials in the drainage area contributing to the Port Elgin gauge are primarily silty tills, and also include extensive deposits of sand/gravel, which account for approximately 30-35% of the area. Hummocky topography makes up approximately 10% of the drainage area, which may provide precipitation additional time to infiltrate. Note that these distributions of surficial materials are aggregated over the entire upstream catchment area.

There are no significantly large wetland complexes in the Lower Saugeen area that would have a significant effect on flows within the Saugeen River.
The Port Elgin gauge indicates approximately 480 mm/yr of streamflow from the upstream catchment. Baseflow is estimated to be 259 mm/hr resulting in a BFI of 0.54. Because of the very large drainage area associated with the lower reaches of the Saugeen River, the flow regime is very buffered and constant. Flashiness is low, as indicated by the low 10:90 ratio of 9. The two SVCA gauges in this area also exhibit a low 10:90 ratio, however it is unknown how impacted this metric is, due to inaccurate winter flows.

Upper Saugeen

The Upper Saugeen area includes the area upstream of the Walkerton gauge, with the exception of the South Saugeen and Carrick Creek tributaries. This area includes a number of smaller tributaries such as the Rocky Saugeen, and Beatty Saugeen Rivers. There are 8 gauges within this area, and are as follows:

- Beatty Saugeen River Near Holstein (WSC)
- Beatty Saugeen River Near Hanover (SVCA)
- Saugeen River Near Hanover (SVCA)
- Saugeen River Above Priceville (SVCA)
- Rocky Saugeen River at Aberdeen (SVCA)
- Saugeen River Above Durham (WSC)
- Saugeen River Near Walkerton (WSC)

Silty tills predominate the surficial geology, with some catchments having deposits of sand and gravel in excess of 30%. Much of this area has approximately 30% or more forest cover. Hummocky topography has been extensively mapped over this area, with typical catchments having between 10% and 20% hummocky topography, and up to 47% for the Beatty Saugeen River Near Holstein.

Although there are wetlands located throughout the Upper Saugeen area, some of the wetland complexes that may have the most hydrological effect include;

- The Welbech Wetland and Dornoch Swamp in the headwaters of the Saugeen River near Hanover;
- Topcliff, Yoevil, and Dromore Swamp wetland complexes in the headwaters of the Beatty Saugeen River (note that this is also an area of significant hummocky topography); and
- Turner-Gillies-Wilcox Lake, Maxwell Swamp, Hatherton Wetland, and Proton Station wetland in the Saugeen River Above Priceville headwaters catchment.

The HYDAT stations report average annual streamflow ranging from 370 to 480 mm/yr. The relatively low annual streamflow in the Beatty Saugeen River Near

Holstein (370 mm/yr) may be due to higher evapotranspiration rates associated with the swamp wetland complexes and hummocky topography in the area. The BFI values for smaller catchments including the Beatty Saugeen River Near Holstein and the Saugeen River Above Durham are 0.46 and 0.43, respectively, indicating that baseflow is a smaller component of total flow in these headwaters catchments. This is expected, given that some of the groundwater recharged in the headwaters areas is expected to discharge in downstream reaches. The estimated baseflows at the Saugeen River near Walkerton is 244 mm/year, which results in a BFI of 0.54. This value is higher than those for the headwaters areas, and is equal to the BFI for the Saugeen River at Port Elgin. BFI for other catchments in the Upper Saugeen area cannot be reliability calculated due to the potential errors associated with the SVCA gauges.

The 10:90 ratio also shows a similar comparison between the hydrological response in the headwaters versus the main river. The smaller drainage areas having WSC gauges each have 10:90 ratios of 15, signifying a moderate level of flashiness. Primarily because of the size of the Walkerton drainage area, this gauge exhibits a less variable flow rate with a 10:90 ratio of 8. Monthly hydrologic trends at all HYDAT gauges show expected results, with peaks during the snowmelt period and low flows in August and September..

South Saugeen

The South Saugeen drains an area of approximately 618 km^2, and abuts the Grand River watershed. The Carrick Creek catchment area is included with the South Saugeen catchment area due to geographic proximity. There are two HYDAT gauges located in the area including South Saugeen River Near Neustadt (02FC012) and Carrick Creek Near Carlsruhe (02FC011). There are two SVCA gauges located in this area including; South Saugeen River Below Mount Forest (SVCA_6) and South Saugeen River at Cedarville (SVCA_13). Much like other areas in the Saugeen River watershed, the surficial materials is mainly comprised of silty tills (60-70%) and deposits of sand and gravel (20-30%). Forest cover throughout the Saugeen watershed is relatively consistent at approximately 30%. Hummocky topography is not as in the Upper Saugeen area.

Wetland complexes with a larger hydrologic significance include;

- North Lakelet complex in the headwaters of Carrick Creek;
- Clifford-Harriston wetland complex in the headwaters of Carrick Creek and the adjoining South Saugeen River;
- South Saugeen River complex; and
- Gildale Wetland, Ventry Swamp, and Keldon Swamp wetlands in the South Saugeen River headwaters.

The South Saugeen Near Neustadt HYDAT gauge indicates that the mean annual streamflow for the Saugeen River is approximately 480 mm/yr. Baseflow is estimated to be 180 mm/yr, which results in a BFI equal to 0.38. Although the SVCA gauges are less reliable and would tend to over-estimate BFI, they are also indicative of low BFI values for the South Saugeen River. Given that the estimated groundwater recharge into the South Saugeen Catchment is approximately 280 mm/year, approximately 100 mm/year, or 36% of this recharge is not being seen as baseflow to the river.

The 10:90 flow ratios calculated for Carrick Creek and South Saugeen Rivers are 15 and 19, respectively. The South Saugeen River is relatively flashy when compared to other rivers with similar catchment areas. The flashiness may be due, in part, to the relatively low baseflow.

It is noted that the catchments with SVCA gauges also exhibit high 90:10 ratios, which would support the South Saugeen being a runoff driven system. However, due to the ice effect on the flow data, this cannot be accurately confirmed.
As with the other SVCA stream gauges, both the Mount Forest and Cedarville gauges exhibit evidence of ice-influenced flows. For both gauges, monthly median and high decile winter flows are very similar to spring flows.

Teeswater

The Teeswater River drains an area of 669 km^2 adjacent to the Maitland River watershed. The Teeswater River joins with the Saugeen River near Paisley. The catchment area is primarily comprised of silty tills with sand/gravel deposits, however a higher proportion clay/clayey tills also start to appear in this area. Hummocky topography makes up approximately 15% of the area, and forest cover is just under 30%.

The Greenock Swamp is a very significant wetland complex covering a large portion of the catchment area. In addition, the Teeswater Complex is a significant wetland feature in the headwaters of the Teeswater river.
There are two gauges within this area; Teeswater River at Bruce Rd. 20 (SVCA_10); and Teeswater River Near Paisley (02FC015). The Paisley gauge reports an estimate of 515 mm/yr of streamflow. Estimated baseflow is 260 mm/yr, which results in a BFI of 0.50 that is similar to the average for all analyzed stream gauges.

The 10:90 ratio of 15 indicates a moderate level of flashiness that is consistent with other similarly sized catchments in this area. Low flows appear to be relatively stable, with the low deciles for summer months being relatively stable. The Greenock Swamp wetland complex present in this basin also may be moderating the flow regime.

Pine

The Pine River is a catchment that is 156 km^2, and drains directly to Lake Huron. This catchment is primarily comprised of silty tills, with some clay/clayey tills, and little sand/gravel deposits. There is no mapped hummocky topography, or karst, and forest cover is the lowest of all analyzed catchments at 18%.
The gauge investigated for this area is the Pine River at Lurgan Beach (02FD001).

Mean annual streamflow is estimated to be 463 mm/yr. Baseflow is estimated to be 107 mm/yr, which results in very low BFI of 0.28. This low baseflow an likely be explained by the fact that a component of groundwater that recharges into the catchment will discharge directly into Lake Huron, as opposed to the Pine river. The 10:90 ratio is calculated to be 177, which is the highest of all analyzed catchments. This is an extremely flashy watercourse, which quickly responds to precipitation events, and quickly returns to dry weather conditions. Low decile flows for summer months shows that flows can drop to as low as 0.001 m^3/s for the month of August.

1.3 GROUNDWATER SYSTEM

1.3.1 Geology

1.3.1.1 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 these 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 (a.k.a. the "thumb") of Michigan and is the regional structure that 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 though 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).

1.3.1.2 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 is 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 were 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 for the study area) and as such, the oldest rocks are exposed in the far northeastern portion of the study area. Map 19 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 3.3.2.1 of this report.

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 60m 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 through the study area.

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 form 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.

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, argillaceous shales, generally without any fossils with thickness that varies from 45-335m. 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 tot the fine-grained nature of these shales, they must be considered a regionally significant aquitard, with very low hydraulic conductivities.

Manitoulin Formation

The Manitoulin Formation overlies a very thin layer of quartzose sandstone that has been broken out and named the Whirlpool formation (so named after the famous whirlpools which exist within it in the Niagara Gorge). The Whirlpool Formation overlies the Queenston shales and is the oldest Silurian sequence in the area, yet is only 3m 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.

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.

Amabel Formation

The thick sequence of dolomitic rocks that overly 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.

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.

Salina Formation

The Salina formation subcrops through a northwest oriented band of the central 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.

This bedrock valley is an important bedrock topographical feature that has a profound effect on the regional flow of groundwater. 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 (Grey and Bruce County Groundwater Study, 2001).

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.

Bass Islands Formation

Deposited on top of the Salina formation is the Upper Silurian Bass Islands Formation. This formation forms a relatively thin band of rocks in the southwestern section of the study area due to the relative thin section of rocks it is composed (approximately 30 m true thickness). A brown, oolitic limestone with minor interbeds of relatively resistant dolomitic shales dominates the Bass Islands Formation.

Based on the limited area of subcrop within the study area, the Bass Islands Formation is not considered to be a major source of drinking water. However, several municipal wells penetrate and are drawing water from the Bass Islands Formation as well as numerous private domestic supplies. Where it is encountered, the Bass Islands can be considered a reliable, good quality aquifer.

Bois Blanc Formation

Overlying the Bass Islands Formation is the Bois Blanc Formation. This relatively thin formation (~50 m true thickness) is composed of fossiliferous limestones interbedded with siliceous shales and cherts.

The top of the Bois Blanc Formation is delineated by an unconformity at which time the rocks were exposed subaerially and eroded. The resultant weathering and fracturing of these rocks along its upper and lower contacts makes the Bass Islands Formation's contacts layers of high permeability that may have a disproportionately important role in the flow of groundwater in the area.

The Bois Blanc Formations' high permeability contact zones has also led to its' extensive exploitation as a source of groundwater in the study area. Although it is relatively thin and not an areally extensive formation, drillers have targeted the Bois Blanc for water supplies due to it's high yields (Hydrogeology of Southern Ontario, 1997).

Detroit River Group

Overlying the Bois Blanc Formation is the areally extensive Detroit River Group. The Detroit River Group is a 60 to 90 me thick sequence of limestones and dolostones that are be separated into two distinct Formations in the study area, The Amherstburg and Lucas Formations. Due to the relative importance of the Detroit River Group the two formations will be dealt with independently.

Amherstburg Formation

The Amherstburg Formation is composed of brown limestones, and is further separated into reefal and non-reefal facies. The reefal facies, named the Formosa Reef member, is composed of biohermal reefs that outcrop in the south of the study area in the village of Formosa. These reefal facies are located at all stratigraphic levels suggesting a prolonged period of reef development, coincident with deposition of the less fossiliferous, non-reefal Amherstburg facies.

The Amherstburg is used extensively for municipal and private water supplies and is considered to be a high quality, high yield aquifer for the area. It is not uncommon to encounter high yields and artesian conditions associated with the Amherstburg.

Lucas Formation

The Lucas Formation, overlying the Amherstburg Formation, is composed of non-fossiliferous, microcrystalline limestones and dolostones. The Lucas Formation subcrops in a large area in the southwestern portion of the planning region. The Lucas outcrops within the study area within the along the shore of Lake Huron North of Kincardine as well as within the beds of the Pine and Penetangore Rivers.

The Lucas was deposited in extremely warm waters during a prolonged period of restricted flow within the Michigan Basin. These conditions led to the development of typical Sabkha sequences in the Lucas, which may also be responsible for the characteristic chemistry of the Lucas and groundwater within the Lucas.

Near the upper contact of the Lucas, it has been associated with karst development. Within the study area, at least two sinkholes are developed along this contact, south of Ripley. Several studies have been conducted, and are continuing, which are investigating the relationship between the Lucas and karst development south of the Study area (e.g. ABCA Sinkhole Study, 2002, 2004). Further karst inventory work is also ongoing as part of regional geological mapping efforts (Brunton, et al., 2005)

The Lucas Formation is considered a high quality, high yielding aquifer in the study area and as such is used extensively as a source of drinking water. Numerous Municipal wells have been completed into the Lucas formation for this purpose. The water has notoriously high levels of Fluoride and, in fact, the pioneering study on tooth decay that led to the use of Fluoride in toothpaste was initiated in a community within the study area which was exploiting the Lucas for it's groundwater, and where a dentist noticed a dramatic decrease in the instance of tooth decay.

1.3.1.3 Pleistocene Glacial Deposits

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.

During this period, the regionally significant cuesta, the Niagara Escarpment was formed. This feature, defined by a continuous steep cliff face, up to 300 metres in height, extending from the Niagara Peninsula to the tip of the Bruce peninsula, is a dominant feature throughout southern Ontario. It has a tremendous impact on the hydrogeology of the planning region, acting as an area where many otherwise buried bedrock aquifers are exposed along the cliff face, which is host to numerous springs.

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, reached their furthest extents during the late Wisconsinan 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 Stage, 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 which 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 deposits at the base of the Wyoming moraine. Subsequent melting and recession led to the establishment of Lakes Algonquin and Nippissing.

Map 23 shows the surficial geology of the study area and shows, at a crude scale, the distribution 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. The Bruce Peninsula is an area of very little Pleistocene cover, as glaciers scraped off any existing cover. 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 3.3.2 Hydrogeology.

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), Nippissing, Algonquin and present day Lake Huron (including 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.

1.3.1.4 Holocene Erosion and Deposition

Erosion and deposition of sediment continues today. The major rivers of the watershed region 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 erode the glacial sediments along its shoreline, in the process mining and transporting sediment in cells along the shore. In the Sauble Beach area, as well as numerous other large beaches in the study area, large deposits of this sediment have been and continue to be altered by wind forming large sand dunes which migrate inland from the shore of Lake Huron.

1.3.2 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 Watershed Region. Municipal supplies located away from the shore of Lake Huron and Georgian Bay rely almost exclusively on groundwater from the bedrock aquifer for their drinking water. A large majority of documented private wells also rely on the bedrock aquifers for their water supplies.

1.3.2.1 Bedrock Aquifers

The bedrock aquifers are composed of an aggregate of the bedrock Formations discussed in section 3.3.1.2. Within each specific bedrock Formation, water quality and quantity can differ dramatically, largely a consequence of the chemical and physical characteristics of the rocks themselves.

Throughout the majority of the study area, an overlying layer of clay and silt till confines the bedrock aquifer. The bedrock aquifer itself is exposed at the surface in only in the northern portion of the planning region along the Bruce Peninsula and the Niagara Escarpment, (see Map 22) and is known to have a piezometric surface well above its' contact with the overlying glacial deposits (Map 21). 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.

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, and a significant portion of which flows through and is eventually discharged outside the planning region, particularly to the south into the Maitland Valley Conservation Authority area. Map 21 shows the regional piezometric surface for the bedrock aquifer system.

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 can has been developed using existing water well record data. Map 26 outlines the recharge and discharge areas for the study area, as defined by the Grey Bruce groundwater study (2003).

Karst features, formed by the dissolution of bedrock by infiltrating waters, is well documented within the northern portion of the planning region and is manifested by numerous sinkholes and disappearing streams (WHI, 2005; Brunton, 2005). 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, 2005) have focussed predominantly at locating the known karst features, and 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 extents of such an interaction is unknown. In the lower reaches of the major rivers bedrock is exposed in the river beds and it is assumed that the bedrock aquifers in these areas are discharging directly into the rivers in these areas. Ultimately the bedrock aquifers are thought to discharge directly into Lake Huron and Georgian Bay in the Offshore.

Along the north facing, steep slope of the Niagara escarpment there can be found numerous springs that feed streams and rivers that flow into Georgian Bay. In areas of substantial karst development the existence of springs may be indicative of “reappearing” streams rather than true discharge from bedrock aquifers.

Within the watershed region several sinkholes have been documented. These sinkholes have extensive surface drainage areas that are drained directly into the sinkholes, providing a direct conduit of surface water to the bedrock aquifers themselves. Several studies have been completed investigating the development of the sinkholes and the extent of the resultant interaction between surface water and groundwater. These studies indicate that a high volume of water is recharged into the bedrock aquifer via sinkholes.

A more detailed explanation of recharge and discharge areas, as well as karst development will be dealt with at a later date as part of the vulnerable areas chapter.

1.3.2.2 Overburden Aquifers

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

Unfortunately, there exists very little information 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, very little information exists for these aquifers and flow directions, water quality and quantity are poorly understood.

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.

Thornbury Aquifer

Located south of Thornbury, this aquifer consists of gravel and sand deposits associated with glacial lake deposits and ranges from several meters 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.

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.

Arthur-Mount Forest Aquifer

Located between Arthur and Mount Forest, this aquifer consists of sand and gravel deposits that occur at the surface or are overlain by till or clay deposits up to 47 m in thickness. The thickness of sand and gravel deposits range from 20 – 45 m. Where the deposits are at the surface, the aquifer is unconfined.

This aquifer is considered of good quality and quantity, with some wells yielding up to 130 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.

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.

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.

Durham Aquifer

Located near Durham and consisting mainly of sand and gravel deposits occurring at the surface. This unconfined aquifer ranges in thickness from 13 – 42 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. This aquifer is considered of good quality and quantity, with some wells yielding up to 120 l/min.

Port Elgin – Southampton Aquifer

Located within the lower part of the Saugeen River and in the vicinity of Port Elgin and Southampton. It consists of sand and gravel deposits that range in thickness from 6 to 20 m. In some places it is partially confined, overlain by up to 13 m of clay deposits. Elsewhere, and more typically, it is situated in sand and gravel deposits which 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 120 l/min.

Hanover Aquifer

Located in proximity to Hanover; consists of sand and gravel deposits and thickness ranges from a few metres to 33 m. The aquifer is confined by clay and till deposits of 35 m. At places where the sand and gravel deposits are at the surface, the aquifer is unconfined. This aquifer acts as a source for the municipality, as it discharges into Ruhl Lake, from which water is extracted.

Outside of the Ruhl Lake area, 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.

Holstein Aquifer

Occurs between Durham and Mount Forest and mainly consists of gravel and sand deposits with thickness ranging from 14 – 68 m. It is a predominantly unconfined aquifer. In some places it is overlain by sand and gravel deposits up to 35 m of till and clay deposits.

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.

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 of 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 1800 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.

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 which 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.

Walkerton Aquifer

Occurs at the vicinity of Walkerton and consists of gravel and sand deposits from 1 – 12 m thick. In places it is overlain by clay and till deposits up to 15 m deep.
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 225 l/min.

Lake Warren Shoreline Aquifer

Forming a narrow, north-south oriented band along the south of the entire watershed region is the former Lake Warren shoreline. These former beaches and dunes have formed well-sorted, well-rounded sand deposits which are ideal potential aquifers. This aquifer is an important source of cold water for the numerous lakeshore streams and wetlands. In addition, several documented private wells are located within this aquifer, in particular in the Municipalities of Kincardine and Huron Kinloss. This is an unconfined aquifer, and is likely recharged *in situ*, otherwise, very little is known about this aquifer.

Lake Huron Beach Aquifer

Located within the beach deposits along the present day shoreline of Lake Huron, the Lake Huron Beach 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.

Wawanosh Kame Moraine Aquifer

The Wawanosh moraine, located along the very southern portion of the area, is composed of large kame deposits and is an ideal location for potential surficial aquifers. The Wawanosh moraine forms a distinct topographic high within the southern portion of the Teeswater River Watershed and is often characterized by hummocky terrain. This preponderance for hummocky terrain makes the Wawanosh moraine an area of high infiltration and groundwater recharge for the study area. The extent to which the moraine contributes water to bedrock aquifers is unknown, but it does directly overlie bedrock in a number of locations and may be an important source of “inline” recharge for the bedrock aquifers.

The Wawanosh moraine is the major source of water for the coldwater Teeswater River system and the Nine Mile River system to the south (part of the Maitland River Watershed.) Within this aquifer significant amounts of water are exchanged between the Teeswater and Nine Mile River systems, as shown by groundwater flow directions determined in the Grey Bruce Groundwater Study (WHI, 2003). Usage by private wells is poorly documented in water well records, but the aquifer was used historically for water extensively.

Information about usage, groundwater flow and groundwater quality are lacking for this aquifer.

Howick Aquifer

The Howick aquifer is located in the southern part of the study area and is located within and along the northern boundary of Howick Township. This composite aquifer is situated within a large outwash deposit and glacial spillways that form the rolling topography of this area. In addition, numerous drumlins associated with the Teeswater Drumlin Field and smaller eskers and spillways, which are included in this aquifer.

This aquifer is likely recharge in situ. It is an important source of water for the Teeswater River system as well as the North Maitland River, Lakelet Lake, Lakelet creek and Blind Lake Bog to the south (part of the Maitland River Watershed.) Within this aquifer significant amounts of water are exchanged between the Teeswater and the North Maitland River systems, as shown by groundwater flow directions determined in the Grey Bruce Groundwater Study (WHI, 2003). This aquifer is also likely an important source of “inline” recharge for the bedrock aquifer as it has incised the underlying tills and lies directly on bedrock. The extent of this interaction is poorly understood.

Of particular interest for this aquifer is the concentration of Mennonite and Amish communities in the aquifer. These communities tend to rely on shallow aquifers for drinking water and which are considered to be more vulnerable to contamination than bedrock sources.

This aquifer is poorly understood, with little to no information about groundwater flow, water quantity and quality.

1.3.2.3 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, valuable for specific fisheries. Shallow overburden aquifers, particularly unconfined aquifers, are areas of increased infiltration due to their coarse-grained composition and topography.

Cold Water Fisheries

Map 15 shows the cold-water fisheries throughout the planning region. 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.

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 thus important as it may produce a disproportionately high volume of recharge to underlying aquifers and is shown on Map 15.

Hummocky terrain has been identified in the SVCA/GSCA/MNBP planning region, yet the full extent of its development has not been mapped. This is considered a data gap for the region and several methodologies for mapping Hummocky terrain are being tested.

1.4 Water Use

1.4.1 Data Sources

A number of sources of data for water usage are available for the Saugeen-Grey Sauble-Northern Bruce Peninsula Planning Region. 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 (by subwatershed) in Maps 27 through 30. Takings are represented both by permitted takings at locations as well as expressed as depth of equivalent precipitation over each subwatershed.

1.4.2 Municipal Water Takings

Water takings for municipal drinking water supplies comprise a high volume of water takings within the Saugeen-Grey Sauble-Northern Bruce Peninsula Planning Region. A large portion of these takings are exploiting bedrock aquifers with only no known supplies reliant on overburden aquifers. Surface water is exploited extensively along the Lake Huron and Georgian Bay Shorelines, as well as one inland lake, 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 could, therefore, 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 7 lists these municipal water takings by municipality for Grey and Bruce Counties. According to these data, the amount of water taken from the SVCA and GSCA jurisdictions are 16,176 m^3/day and 1,237 m^3/day, respectively.

Table 7. 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	1660	8769
Chatsworth	170	1128.6	985	32869
West Grey	1463	2065.5	1627	53818
Southgate	660	1578.8	864	1014
Hanover	1753	0	47	0
Grey Highlands	3490	1280.5	1260	9157
Owen Sound	0	0	0	1650
Meaford	0	2083.5	1025	0
Blue Mountains	0	3649.4	760	2781
Arran-Elderslie	1262	1680.9	512	197
S. Bruce Peninsula	198	550.2	858	464
Brockton	5756	1757.6	801	546
Huron-Kinloss	2030	1271.7	137	267
South Bruce	1047	2333.9	676	25911
Kincardine	579	1549.4	667	67534
Saugeen Shores	0	244.6	327	5245
N. Bruce Peninsula	0	478.5	542	0
Native Reserves	0	0	221	0
Total(m^3/day)	**18615**	**22373**	**12696**	**210588**

* This includes some takings that are part of the Ausable Bayfield Maitland Region
** includes industrial, recreational and some communal water system takings, both consumptive and non consumptive

Several municipal water supply systems exploit Lake Huron and Georgian Bay as a water source (see Table 7). Each of these systems has outlet into Lake Huron 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 as part of the Application for Source Protection Grant, CRA (2006).

The Kimberley and Talisman water supplies exploit bedrock springs for their water supply. These springs are related to karst features in the area and are highly susceptible to water quantity stresses.

1.4.3 Agricultural Water Takings

Agriculture, including livestock feeding operations and irrigation, represents the largest land use within the Saugeen-Grey Sauble-Northern Bruce Peninsula Planning Region. 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 SVCA/GSCA/MNBP planning region that 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 7 above. Total consumption for the SVCA and GSCA area is estimated at 12,040 and 8948 m^3/day, respectively.

1.4.4 Consumptive Industrial Water Takings

Consumptive water takings are those takings in which water is directly exported outside of the water shed, 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 form 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 7. Estimated total consumptive groundwater takings for Grey and Bruce County are approximately 84,690 m^3/day.

There are no known consumptive surface water takings in the region.

1.4.5 Non-consumptive Industrial Water Takings

Non-consumptive Industrial 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 SVCA/GSCA/MNBP planning region 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 contaminating 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 above in Table 7. Estimated total non-consumptive takings for Grey and Bruce County are approximately 157,004 m^3/day.

1.4.6 Private Domestic Water Takings

Private consumption within the SVCA/GSCA/MNBP Planning Region almost exclusively exploit overburden and bedrock aquifers. The typical taking utilizes a drilled, or less commonly, bored well which are then redirected into shallow overburden aquifers via a septic system.

Estimates of private usage of groundwater was developed on a municipality 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 7, above. Total estimated usage for the SVCA and GSCA jurisdictions are 6,197 and 6,386 m^3/day, respectively.

The overall amount of water that is transferred from deeper aquifers to shallower aquifers needs to be addressed in order to accurately represent the flow of groundwater in the area numerically. A possible method for estimating this quantity would involve attributing an average consumption per household and attaching them to individual wells in the Water Well Information System.

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

1.4.7 Recreational Water Usage

Recreational water use is a large economic driver within the SVCA/GSCA/MNBP Planning Region. These uses include outdoor recreation, hobby fishing, canoeing and tourism and are focussed on the major river systems, Lake Huron and Georgian Bay. Recreational usage of water within the region tends is 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.

1.5 Conceptualization of the Hydrologic System

1.5.1 Key Components and Processes

For the SVCA/GSCA/MNBP planning region, the key components and processes to be considered for water budgeting are shown in figure 4. 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 modeling.

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 evapo-transpiration (ET on Figure 4). Evapo-transpiration 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 and bedrock aquifers via irrigation.

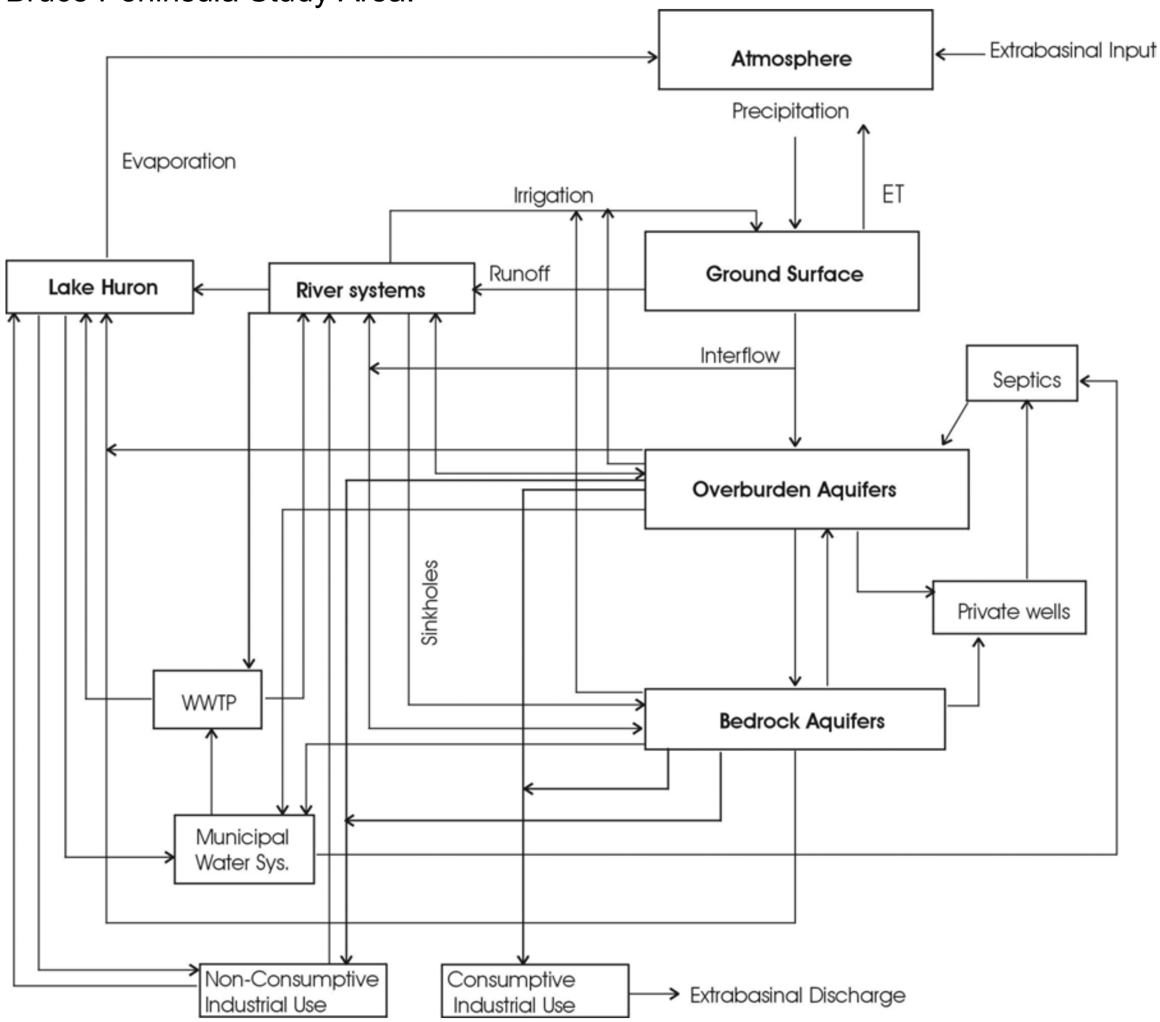
River Systems

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/or 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.

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 7. Components and Flux of water in the Grey Sauble/Saugeen/Northern Bruce Peninsula Study Area.



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 potentially 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.

Bedrock Aquifers

Inputs into the bedrock aquifers include recharge originating from the ground surface where the bedrock is exposed, recharge from overlying overburden aquifers, 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 SVCA/GSCA/MNBP planning region itself. Water from the bedrock aquifer naturally discharges into Lake Huron and/or Georgian Bay, and, in certain areas, into River systems. In addition, large volumes of water are extracted from the bedrock aquifers for industrial and municipal water uses. The majority of this water is treated in municipal waste water treatment facilities (WWTO in Figure 4) 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. There are significant consumptive water takings from the bedrock aquifers in the area in the form of water and beverage bottling operations.

Lake Huron/Georgian Bay

Lake Huron/Georgian Bay is the ultimate destination for water within the system. Lake Huron/Georgian Bay receives water from All the components shown in Figure 4. River systems, Overburden and Bedrock aquifers all naturally discharge towards the Great Lakes. Water from WWTP is also outlet directly into Lake Huron/Georgian Bay. The key process for Lake Huron/Georgian Bay is the extraction of water from the Lake for drinking water purposes. The Lake Huron shoreline within the SVCA/GSCA/MNBP planning region is host to ten large municipal water systems that are exploiting Lake Huron. In addition, the single largest user of water within the area is for the production of electricity at Bruce Nuclear Power Development. These systems form a closed loop as water from them is treated and subsequently released back into Lake Huron/Georgian Bay.

1.5.2 Major Data Gaps

Information gaps can be separated into Data gaps or Knowledge gaps. Data gaps are those, which require the filling of data in order to complete or refine the existing water budget. Knowledge gaps are those that apply to situations or events that are not well understood in the study area.

Data Gaps

Major data gaps for the study area include:

- Stream Flow Data for ungauged catchments
- Quaternary Geology mapping for the northern Bruce Peninsula*
- Accurate flow and operational information for major dams
- Correction of SVCA stream gauge data for winter ice conditions and low flow conditions
- Development of rating curves for all SVCA gauges
- Collection of long-term, reliable wind data
- Determination of actual water takings versus permitted, including an understanding of the consumptive or non-consumptive nature of those takings.
- High quality subsurface data (geophysical surveys, overburden drilling)

* currently being completed by Cowan Minerals Ltd as a partnership between the SVCA/GSCA/MNBP SWP group and the Ontario Geological Survey

Data Density

It is important to acknowledge that the density of certain data sources are important for the purposes of water budgeting. The density of data collection stations are crucial limits on the uncertainty associated with the conceptual understanding of the flow system in the study area. These data density gaps will be identified at the end of the water budgeting exercise in order to produce more reliable estimates in the future.

Knowledge Gaps

Major Knowledge gaps for the study area include:

- The extent and impact of karst development on surface and groundwater flows
- The extent and flow of groundwater within overburden aquifers is poorly understood

Water Budget Analysis

The quantity of water for the components of each gauged catchment is listed below in Table 8. These are estimates compiled for each subwatershed based on the data and methodologies listed in this report.

These quantities allow us to perform some preliminary, crude comparisons between the fluxes for the watersheds. It is important to note that these comparisons include a number of limitations and assumptions. The greatest assumption of these is in understanding that these comparisons are made at the scale of the gauged catchments and may or may not reflect conditions of smaller subwatersheds, rather they represent the aggregate of all smaller subwatersheds within that catchment.

Additionally, these calculations are provided for illustrative purposes only, to further enhance the knowledge and understanding of the study area. A more detailed, and accurate assessment will be carried out as part of a Tier I water budget.

1.6.1 Water Distribution Calculations for Surface water systems

In order to evaluate the flux of water of specific subwatersheds, a comparison was made between the total Streamflow (including both runoff and baseflow) of a sub watershed and the precipitation. Subtracting Streamflow from the precipitation values should leave a value comparable to Evapotranspiration. Map 31 shows these mass balance calculations graphically.

Areas with high values are those in which ET rates should be higher or may represent higher rates of infiltration and recharge to aquifers. The range of results shown in Map 31 are considered to be plausible, although relatively high and are likely a reflection of higher precipitation rates due to lake-effect snow fall.

Overall estimates of streamflow indicate that there is more streamflow than can be accounted for from precipitation and ET. This could be a function of inaccurate ET estimates, the lack of widespread snowfall data or, in the case of the Beaver River, a result of anthropogenic discharge (i.e. Lake Eugenia hydroelectric power plant).

1.6.2 Surface water allocation versus availability

As part of formulating a Tier 1 analysis it is necessary to evaluate the degree of impact of takings within the large-scale areas identified for carrying out this analysis. In evaluating takings, it was necessary to utilize the maximum permitted amounts, as no reliable data exists to correct these amounts to account for actual takings. As a result, the comparison between available water

Catchment Name	Catchment ID	Precipitation (mm/year)	Potential ET (mm/year)	Runoff (mm/year)	Baseflow (mm/year)	Recharge (mm/year)	Surface Water Takings (mm/year)	Groundwater Takings (mm/year)
Sauble River at Sauble Falls	GSCA_1	1135.528	578.908	178.156	315.373	196.405	109.887	1.812
Sauble River at Allenford	GSCA_2	1133.936	613.023	268.405	166.945	258.054	0.233	0.000
Sydenham River Near Owen Sound	GSCA_4	1137.730	613.023	244.596	268.316	240.364	0.000	36.684
Bighead River Near Meaford	GSCA_5	1058.286	613.023	245.149	237.354	247.420	9.499	6.434
Beaver River Near Clarksburg	GSCA_6	746.420	585.275	167.717	267.548	264.307	13.296	12.899
Stokes River Near Ferndale	NBP_1	875.148	546.657	368.107	242.003	0.000	0.000	0.000
Saugeen River Above Durham	SVCA_1	1034.918	569.803	275.713	206.047	326.564	0.000	3.868
Teeswater River at Bruce Rd. 20	SVCA_10	998.010	611.295	260.632	256.301	298.368	2.381	6.216
Rocky Saugeen at Aberdeen	SVCA_11	766.604	577.407	129.385	302.249	283.507	0.025	10.759
North Saugeen River Above Chesley	SVCA_12	989.251	605.649	182.650	237.260	265.866	0.000	1.369
South Saugeen River at Cedarville	SVCA_13	1028.384	569.749	296.600	184.107	252.552	0.000	0.000
Saugeen River Near Port Elgin	SVCA_16	1035.246	614.237	182.650	237.260	252.451	2.378	12.782
Saugeen River Above Priceville	SVCA_18	1019.427	569.749	275.713	206.047	240.016	0.000	2.624
Beatty Saugeen River Near Holstein	SVCA_19	1011.734	569.749	202.467	169.168	328.405	0.000	0.000
Saugeen River Near Hanover	SVCA_2	1030.899	595.338	129.385	302.249	309.378	48.541	3.520
Carrick Creek Near Carlshrue	SVCA_21	965.554	602.714	235.046	194.327	296.412	0.000	14.106
Pine River at Lurgan Beach	SVCA_22	1005.309	627.553	357.929	105.868	238.271	0.000	2.026
South Saugeen River Near Neustadt	SVCA_3	981.611	583.651	296.600	184.107	313.104	0.352	0.603
Saugeen River Near Walkerton	SVCA_5	1014.390	609.401	129.385	302.249	312.225	42.295	28.150
South Saugeen River Below Mount Forest	SVCA_6	961.170	572.541	296.600	184.107	298.630	0.000	18.764
Teeswater River Near Paisley	SVCA_7	1068.952	616.137	260.632	256.301	258.827	0.000	3.979
Beatty Saugeen River Near Hanover	SVCA_8	991.315	578.946	129.385	302.249	310.089	0.000	0.000
Saugeen River Above Paisley	SVCA_9	999.201	611.023	182.650	237.260	292.424	6.627	39.052

and takings are more reflective of the allocation of water than to actual takings. It is also important to recognize that the majority of the takings in the study area, particularly surface takings, are non-consumptive in nature and simply reflect a diversion of water.

Understanding the limitations of both the data available and caused by the scale of analysis, surface water allocations (in the form of maximum permitted values) are presented as a percentage of available streamflow in Map 32.
Surface water takings are generally small throughout the study area; however, significant takings are found within the Sauble and upper Saugeen areas. The significant takings from the Sauble River are a result of diversions for the creation of wetlands. The significant takings from the upper Saugeen between Hanover and Durham are a consequence of high, non-consumptive takings for the purposes of aquaculture. Further study is required in these two areas to determine the impacts of these takings.

Ruhl Lake, a small kettle lake, which is a primary source for the Hanover Water Supply System, is another unique situation. The Lake is fed via a series of springs and a relatively small surface water catchment. As a result, at the scale of the study area and the uniform areas that have been delineated for this report, there is no obvious water quantity issue. However, information from the operator as well as the relatively small area form which it is extracting water suggest that this supply is vulnerable to water quantity issues and warrants further investigation.

1.6.2 **Groundwater Recharge versus allocation**

Similar to the comparison of surface water takings to Streamflow, it was considered important to derive even a simplified comparison of groundwater takings as a function of recharge. This was accomplished on a sub watershed basis and as a result additional limitations to the value of this information must be recognized, specifically that it does not account for movement of groundwater between subwatersheds, which is common in the most commonly exploited bedrock aquifer. Another salient feature of groundwater takings is that most are consumptive with respect to the source in which the water originates. This means that groundwater is rarely returned to the aquifer from which it was extracted.

The evaluation of takings on a specific sub watershed was accomplished by comparing the recharge values with the takings. Map 33 shows the percentage of recharge being extracted through takings (allocation) for each subwatershed, and identifies municipal wells located in those subwatersheds.

In general, groundwater takings are relatively small compared to recharge over the study area. However, there are subwatersheds with higher percentages of takings including the middle Saugeen and Sydenham sub watersheds. The immediate causes of these high takings are not immediately known and will require further investigation. In particular, areas within the Municipality of Grey Highlands, where smaller aquifers have been targeted by water bottling companies warrant more detailed investigation.

1.7 Summary and recommendations for further work

1.7.1 Summary

Municipal Water Supplies in the Saugeen-Grey-Sauble-Northern Bruce Peninsula Planning Region

There are two dominant source of municipal drinking water in the study area: Lake Huron (including Georgian Bay) and the Bedrock Aquifers. These sources can be considered to be large, high quantity sources. In addition, based on this preliminary water budgeting exercise, takings from these sources tend to be small relative to the overall availability of water in the area.

The exception to this is Ruhl Lake and the wells that are the source of water for the Town of Hanover Water Supply system. This system relies heavily on overburden aquifers, which supply water to Ruhl Lake via springs as well as to the wells (Designated GUDI Wells). Similarly, the Town of Walkerton (Municipality of Brockton) has wells that are GUDI and are more susceptible to water quantity issues. These systems are more susceptible to the relatively large taking in comparison with the available water in the systems they are exploiting.

The Kimberley and Talisman supplies are also unique in that they are reliant on bedrock derived springs for their water. These systems are located in areas of known karst, and as a result are inherently susceptible to water quantity issues.

Other Water Quantity Issues

Water bottling facilities in the Municipality of Grey Highlands are highly visible consumptive water takers in the area. Public concern over these takings has been historically and remains high. At this time, there does not exist adequate information on the aquifer that is being exploited in this area to determine if these takings are having an effect on nearby private and municipal water supplies.

Water Quality Issues

Generally, Great Lake (i.e. Lake Huron and Georgian Bay) water systems are the highest quality in the area. The dominant water quality issue for these supplies relates to elevated turbidity associated with runoff and wave action during storm events. The surface water bodies that are in the zone of influence of these intakes are commonly not well understood with little to no water quantity or quality data available and represent a major data gap both for Source Protection Planning Activities.

Municipal water systems that are supplied by groundwater have a wide range of water quality. Natural water quality issues such as (but not limited to) elevated Iron, Hardness, Sulphates and Fluoride are common throughout the area. Nitrate is the most common introduced water quality concern, particularly in GUDI wells and overburden derived groundwater systems.

1.7.2 Recommendations for Further Work

Major data and knowledge gaps have been identified throughout the report and are listed in section 3.5.2. These data gaps have implications not only for this water budgeting exercise but also to the whole Source Water Protection Planning program. The following recommendations are for work or the acquisition of data needed to improve this conceptual understanding of the area as well as provide information needed for development of a Tier I water budget. This is separate from determining the detail and scope of the numeric water budget modeling, which is dealt with below in section 3.7.3.

Evapotranspiration

ET is the largest component of the water budget at the scale of the study area. With no evaporation data available, and no detailed modeling of the area, there is a high degree of uncertainty with the numbers that have been provided. As a result, it is recommended that:

1. An Evaporation Pan be installed in at least one (1) location in the study area to provide calibration data in the future; and,
2. A detailed model/calculation be developed in order to estimate ET with more confidence.

Stream Flow

Although only one municipal supply is reliant on streamflow in the area, it is an important component of the water budget and needs to be fully understood. As a result, it is recommended that:

1. Existing Streamflow data for the SVCA operated gauges be corrected for Ice-Damming effects and have rating curves developed: and,
2. Spot flows be collected in areas of interest (i.e. high baseflow areas) as well as on streams that are presently ungauged. In particular, those smaller streams which may be influencing Great Lakes municipal intakes should be measured; and,

3. Incorporation of updated outflow data from dams, reservoirs, municipal STPs and other dischargers.

Development of Simple Surface Water Models in Selected Areas

As mentioned above, the streams that may be influencing the great lakes intakes are poorly understood. Accordingly, a surface water model for these streams integrating both water quantity and quality would benefit the operation of those systems. In the Ruhl Lake situation, this type of model will be required in order to properly estimate the contribution of surface water to the overall lake fed system.

Development of a Conceptual and Preliminary Numeric Groundwater Model

A conceptual and preliminary groundwater model has been developed for the study area, and is to be included as part of the Tier I water budget analysis. This model will be a useful resource in furthering the understanding of the groundwater flow system in the area. This model can be refined in future water budget (i.e Tier II or further) work if necessary.

Development of a Tier 1 Water Budget for the region

Development of a Tier 1 water budget for the area seems appropriate, given the relatively high population and water usage. The high percentage (~50%) of the population who are reliant on private water supplies also augment any argument for a regional scale, Tier 1 water budget analysis.

A Tier 1 water budget analysis will also include a consumptive water demand estimation, based on the information provided in the latest guidance form the province. This will allow for assessment of the potential water quantity stresses for the study area.

Although difficult to predict until the process has been completed, it is anticipated that as a result of the Tier 1 water budget analysis more detailed investigations will be required for the Ruhl Lake/Town of Hanover System, as well as the Kimberley and Talisman systems. As such, it is recommended that a simple water budget be developed for these systems. Ongoing work aimed at characterising the vulnerability of these systems will provide more detailed geological and hydrological information and will be used to perform this simple water budget.

1.7.3 Screening Decisions

After completion and acceptance of the conceptual water budget report, a number of screening decisions are to be made through the Peer Review Committee developed for the water budget process. These screening decisions are meant to scope the effort required in order to assess the overall risk of water quantity issues within a given area. Listed below are the screening questions (as per provincial guidance) with the salient information and recommendations by the SWP staff.

1. *Is the water supply from an international or inter-provincial waterway or from a large inland water body only?*

In the case of the SVCA/GSCA/MNBP study area, this includes the Lake Huron and Georgian Bay municipal systems. As a result, these systems are not meant to be included in further work but guidance from the provincial government is required before proceeding. As mentioned above, it seems appropriate at this time to begin sampling and flow monitoring of any surface water body that has been demonstrated to impact a great lakes intake for the overall Source Protection Program, but this lies outside the water budgeting exercise.

For the remainder of the study area, the dominant source of potable water is groundwater. As a result the answer to the screening question for these supplies is “No”. According to the guidance, these supplies warrant further examination.

2. *What is the required level of numeric modeling?*

For the SVCA/GSCA/MNBP study area, the focus of any modeling effort should be on groundwater. All the supplies that are not exploiting Lake Huron/Georgian Bay are reliant on groundwater, with the exception of Ruhl Lake, which has some component of surface water input. A regional scale groundwater model has been developed in order to accurately address any water quantity issues for the area. Using this model, it is possible to place the municipal groundwater systems in the context of the overall groundwater regime, and establish boundary conditions for those systems. This will facilitate development of a simple water budget model in order to complete the tier I assessment.

3. *are both groundwater and surface water models needed?*

At this stage, numeric modeling is not required in order to complete the Tier I water budget for the study area. However, it is recommended that the existing groundwater model be calibrated for the entire region. This calibration will allow the groundwater model to be refined in the future for more detailed water budget work. Due to the overall lack of surface water takings for the study area (with the exception of Ruhl Lake), it is recommended that simple surface water models be created in the Ruhl Lake area as well as those streams that may be influencing Great Lakes intakes.

4. *Are there sub-watershed wide water quality threats and issues that require complex modeling it assist with their resolution?*

A number of known water quality issues have been documented for the SVCA/GSCA/MNBP study area. These issues include both naturally occurring as well as introduced contaminants (see section 3.7.1). The development of a regional scale 3D groundwater flow model will assist with resolving some of these issues. Smaller scale, detailed surface water models in the Ruhl Lake area as well as those streams that may be influencing Great Lakes intakes will also help in operation of these systems. These models will be an important part of developing vulnerability assessments for municipal supplies, and fall outside the purview of a water budget exercise.

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