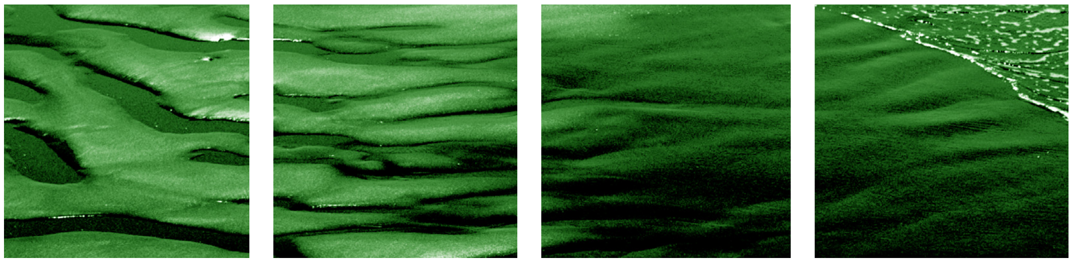

Conceptual Water Budget

Ausable Bayfield
Maitland Valley
Source Protection Region

DRINKING WATER SOURCE PROTECTION
ACT FOR CLEAN WATER

Ausable Bayfield
Maitland Valley
Source Protection
Region

Conservation ONTARIO
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Ausable Bayfield Maitland Valley
FINAL DRAFT
Conceptual Water Budget
October 2007

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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

Conceptual Water Budget

1.0 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 this process and summarize what data exists for the Ausable-Bayfield-Maitland Planning Region as outlined in WC Map 1-1. For an introduction to the region, readers are directed to the draft Watershed Characterization.

1.1 Goals and Anticipated Use of the 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 conceptual understanding 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.

1.2 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 ABCA/MVCA planning region it was noted that similar land and water uses exist throughout, and that differences in physiography were already accounted for in the existing subwatersheds identified for Flood Forecasting purposes. In addition, historical meteorological and flow data exists for these subwatersheds, which facilitated a comparison on the relative responses of each surficial watershed.

Both the ABCA and MVCA have completed hydrology studies which have divided the watersheds into subwatersheds of approximately 25 to 100 km^2. For each of these watersheds, an inventory of pertinent hydrologic parameters (i.e. surface infiltration, deep infiltration, slopes, etc) has been established and a calibrated runoff model has been developed for usage in the existing flood forecasting system. Accordingly, it was felt that these subwatersheds would be an appropriate level of definition for an initial water budget. CWB Map 1 shows the approximate boundaries of these subwatersheds within the Ausable-Bayfield-Maitland Planning Region. A more detailed discussion on the development of these subwatersheds can be found in Section 3.2.2 of this document.

It is acknowledged at this point, that the usage of these uniform areas may be altered upon the gaining of further data, and on the type of numerical model selected for usage in the planning region.

2.0 Characterization of the Ausable-Bayfield-Maitland Surface Water System

2.1 Introduction

Section 1.3 of the Watershed Characterization provides an overview of how physiography, topography and soils generally influence the surface hydrology of the planning region. The overview material presented is organized by major watershed/drainage system present in the study area, specifically:

- Ausable River
- Bayfield River
- Maitland River
- Nine Mile River
- Shore Streams and Gullies (See CWB Map 1)

The Ausable river system drains approximately 21.6% of the Ausable-Bayfield-Maitland planning region. The Bayfield River drains 8.7% of the study area while the Maitland and

Nine mile river systems serve 45.1% and 4.3% of the area's landbase respectively. The series of varied shore streams and gullies drain a significant 20.3% of the study area.

The following sections provide more detailed descriptions of the character of each of these main surface systems by presenting the historical observations and summarizing the findings and outcomes from earlier hydrologic modelling exercises that focused on these surface water systems.

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 Ausable and Maitland 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. Records are available along the Ausable River system far back as 1915. 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.

Development of a conceptual surface water model for the study area began by reviewing the conceptual models developed by earlier hydrology modellers. Major watersheds in the MVCA 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.

Major basins in the ABCA jurisdiction were modelled as part of a 1992 hydrology study using version 6.0 of the GAWSER model (Schroeter and Associates, 1992). This model originated at the University of Guelph as an Ontario adaptation of the USDA-ARS HYMO model. It has also undergone numerous refinements and testing since its initial release in 1977 to arrive at the current version 6.9. ABCA relied on the BRFU system to poll their gauging and meteorological stations and archive the resulting data. A BRFU based model of their main watershed systems was subsequently prepared in 2002.

Figures 1 through 4 present a schematic representation of the Ausable River, Bayfield River, Maitland River and Lucknow River systems respectively as was prepared in developing the BRFU watershed model. CWB Map 1 links this schematic representation to the sub-basins and related surface channel and flow monitoring systems within the study area.

In reviewing Figures 1 through 4, it is important to understand that this is just one modeller's interpretation of the surface flow system in these jurisdictions. For example, the BRFU-based surface watershed model divided the Ausable and Bayfield river systems into 22 and 11 sub-basins respectively while the 1992 GAWSER modeling approach used 58 and 20 sub-basins to describe the same Ausable and Bayfield systems. It is also important to note that neither the BRFU model nor the GAWSER model have been applied to the shore stream and gully region.

Given that the BRFU surface model has been applied in the past to major watersheds in both the ABCA and MVCA jurisdictions, it has been selected as the context within which to describe our existing knowledge of the key features and components that influence the study area's water budget. The following sections outline our current overall understanding of water budget related fluxes in the study area for the purposes of developing a conceptual water budget.

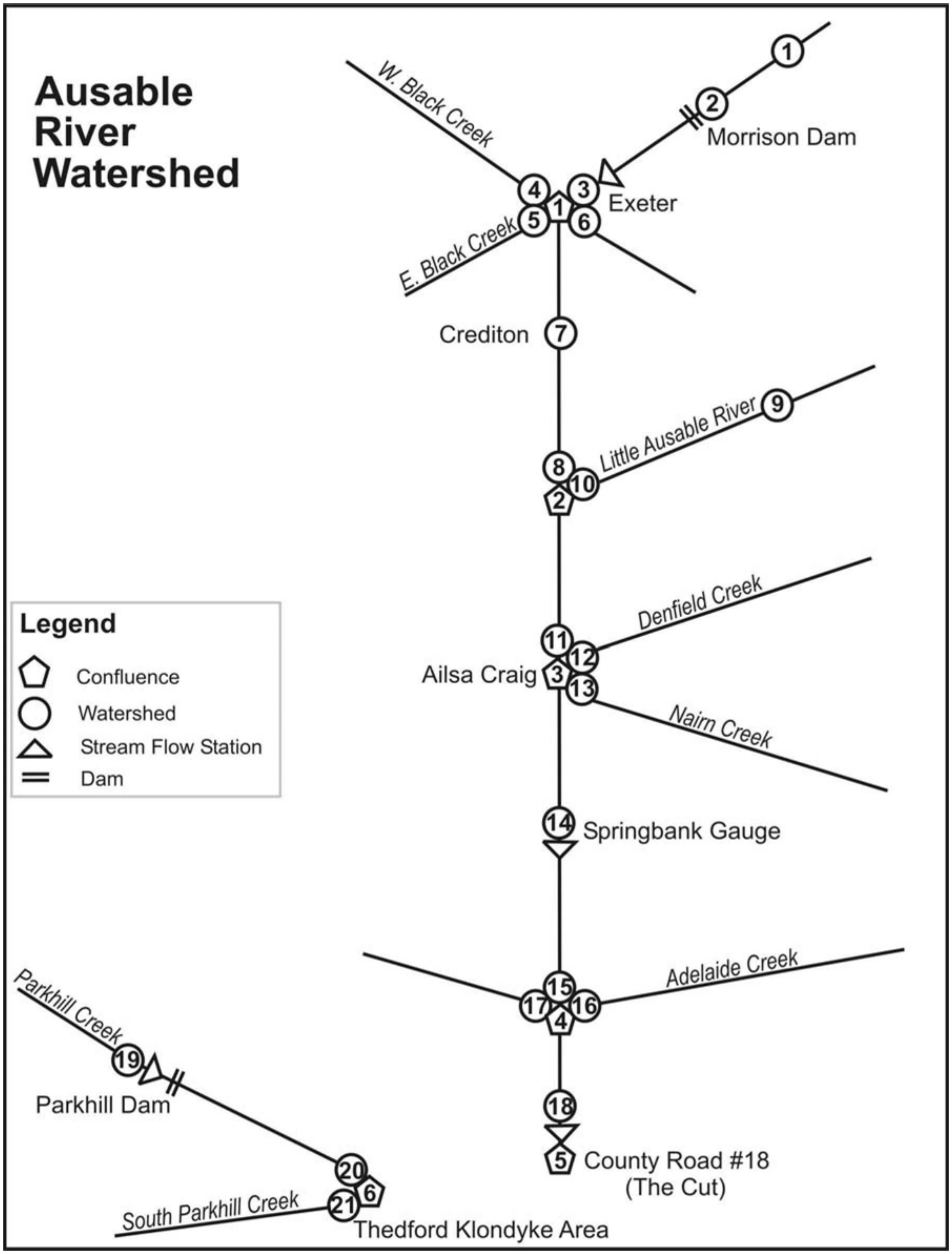

Figure 1. BRFU Model Schematic Representation of the Ausable River System

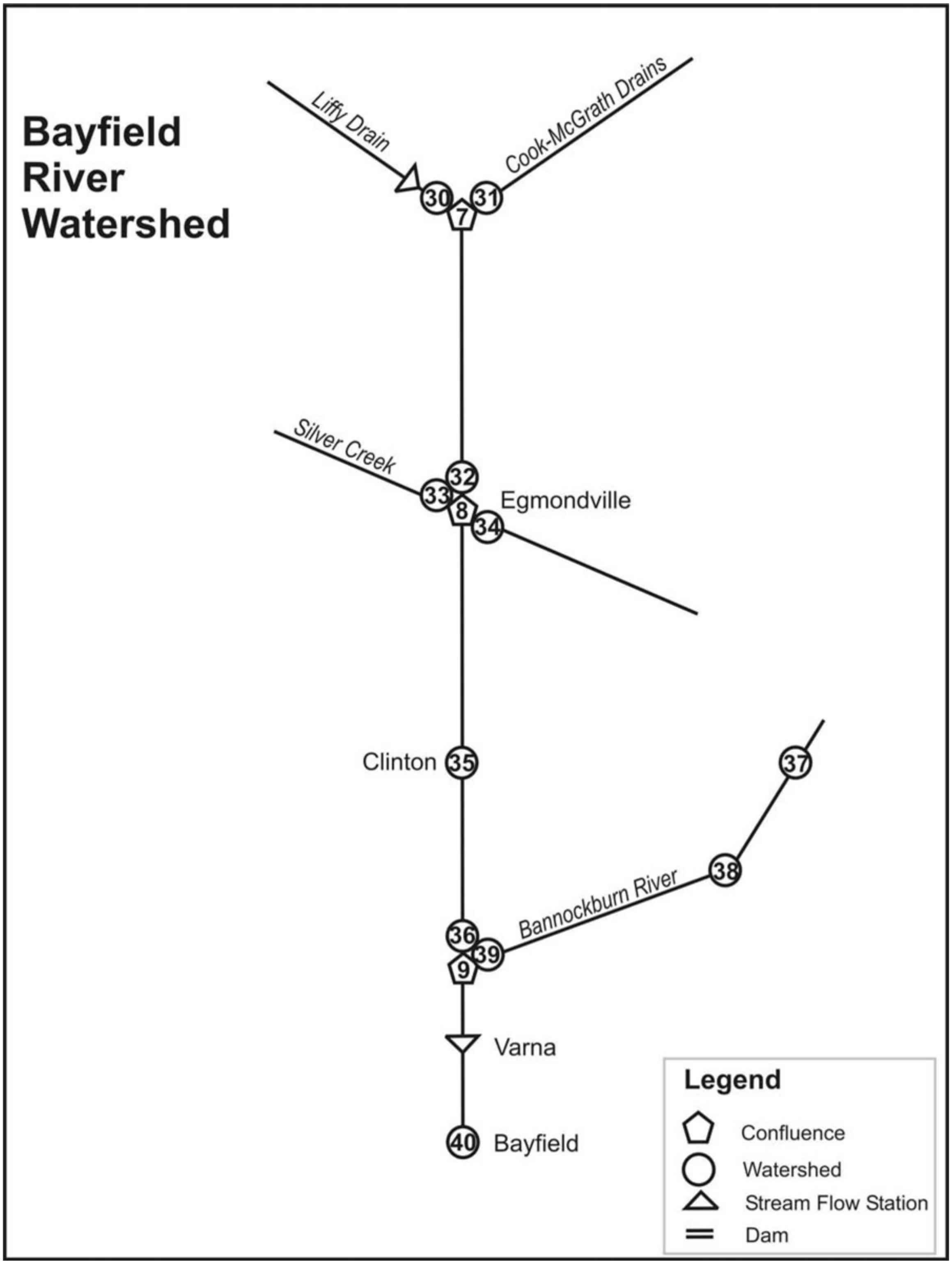

Figure 2. BRFU Model Schematic Representation of the Bayfield River System

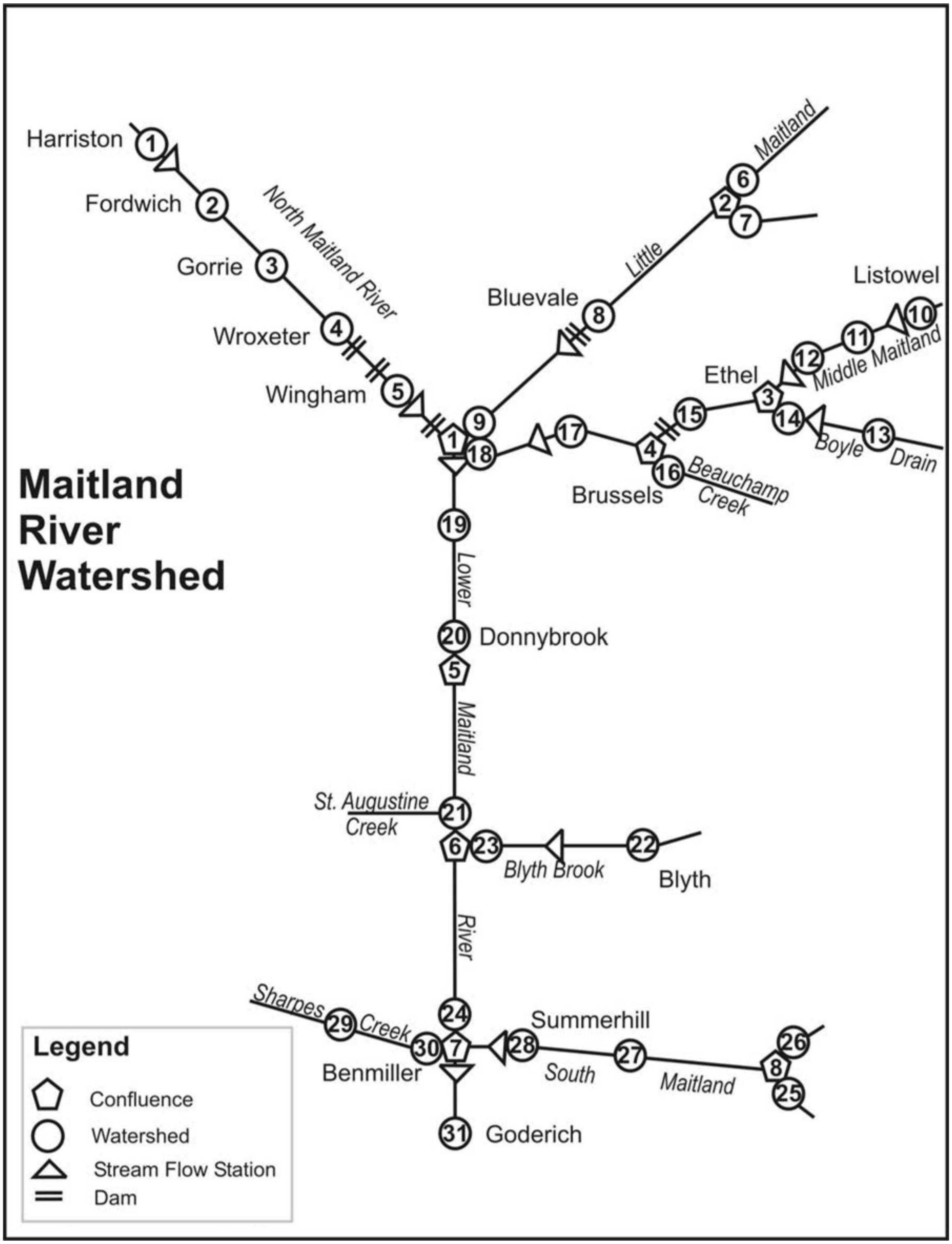

Figure 3. BRFU Model Schematic Representation of the Maitland River System

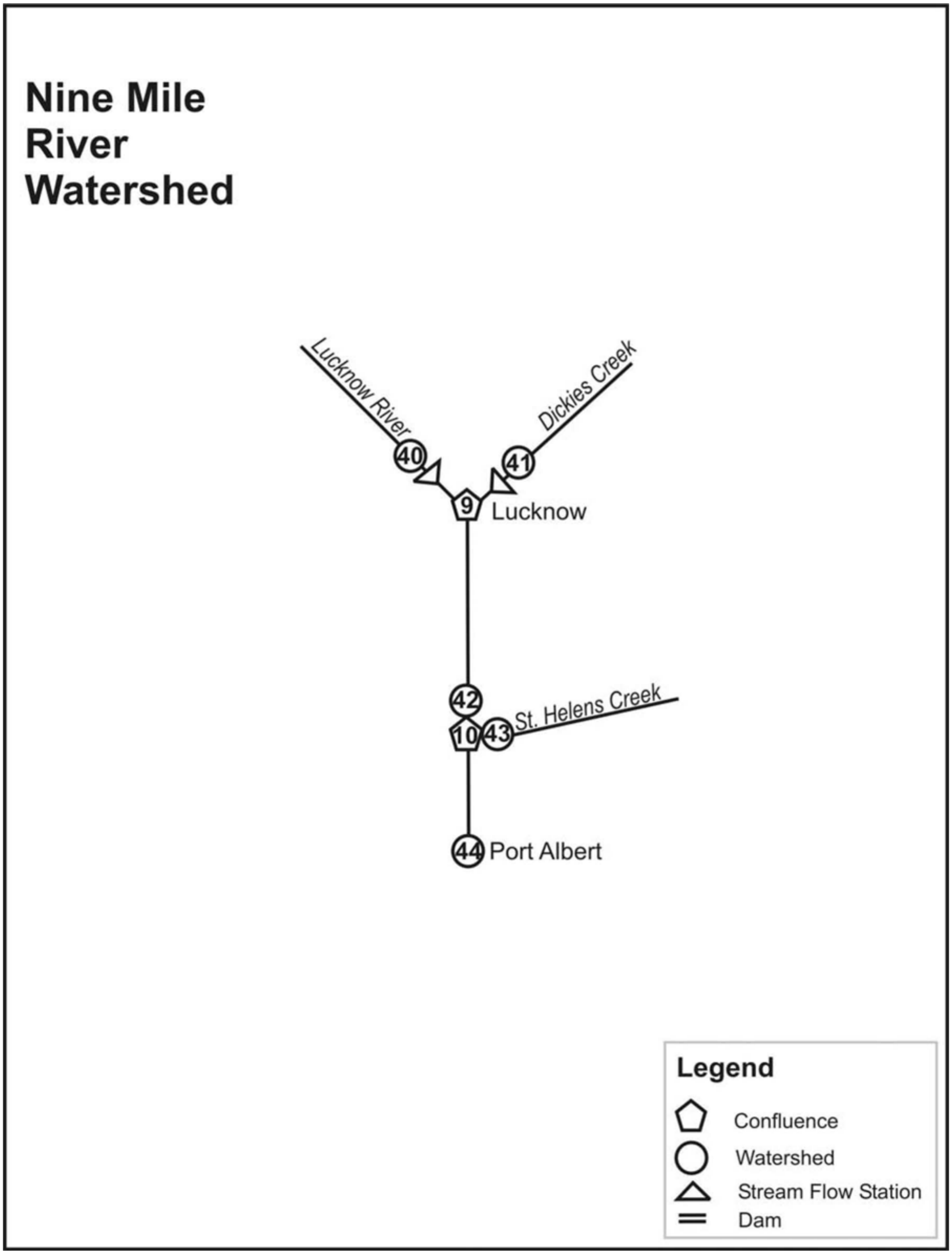

Figure 4. BRFU Model Schematic Representation of the Nine Mile System

2.3 Climate of the Study Area

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

CWB Map 2 shows the location of the main active or recently active Atmospheric Environment Service (AES) climatological stations located within or in close proximity to the Ausable-Bayfield-Maitland planning region. Also shown on CWB Map 2 are the locations of climatological stations that have been developed through the years, typically since the mid-1980's by the local conservation authorities, primarily for flood forecasting purposes. The Table embedded in CWB Map 2 summarizes the types of climatic data collected at these stations and the period of record available.

In addition to the stations shown on CWB Map 2 there are numerous other stations that have been active in the past or for certain periods during the year within the study area. An example of a set of stations that are operational for only part of the year is the set of stations operated by the Ontario Weather Network (OWN) This group, based out of Ridgetown, ON typically focus on operating their network only during the growing season as they provide weather services primarily to agricultural producers for their crop production needs. There are also many AES stations that have been present at various points of time in the past, but have been shut down. Sometimes they were replaced by other nearby gauges. Sometimes they were not.

2.3.1 Precipitation

Appendix A summarizes the AES climate normals (1971 – 2000) for all AES stations within the study area for which these long-term climate normals have been prepared. Long-term data from these stations indicate that annual precipitation in the study area has a weighted range from 975 mm to 1185 mm (see CWB Map 3 and Map 4). In general, the precipitation levels are fairly uniform across the months, although the tendency is for the fall period (September through November) to receive slightly more precipitation than the other months of the year. Snowfall makes up a good portion of the annual precipitation ranging from 17.5% for the Dashwood station to 29.5% for the Blyth Station. A set of snowcourse stations have been established within and near the study area by Conservation Authorities as part of their flood forecasting responsibility. These stations are monitored bi-weekly during the period of snow cover. The location of these snow course stations are shown on CWB Map 2.

Appendix A includes the average annual long-term precipitation values for the 1951 to 1980 period for the same long-term AES weather station. In comparing the same data for the 1971-2000 period, it suggests that the amount of total annual precipitation received within the study area has risen slightly in the last 50 years. The positive change in annual precipitation between the two long-term periods of record ranges from 0.28% to 15.5%. It is important to note that precipitation recorded at the established Conservation Authority stations is liquid precipitation (rainfall or melted snow) only. None of the tipping bucket rain gauges are capable of measuring precipitation in the form of snow. For this reason, historical data collected at these stations is expected to underestimate the total precipitation that occurs at a station site. A comparison of the watershed distributed precipitation determined using the CA rain gauge system with the long term AES station observations verifies this shortcoming. Table 1 shows this comparison for two stations for the years 2000 to 2004. For climatological stations in the Exeter and Blyth areas, it appears that the Conservation Authority network is significantly under-estimating precipitation amounts during the year in large part due to the CA station's inability to measure precipitation as snowfall.

Table 1. Comparison of Annual Precipitation Amounts Recorded by AES and CA stations

Year	Annual Measured Precipitation (mm)				Difference (%)	
	AES Station		CA Station			
	Exeter	Blyth	Exeter	Blyth	Exeter	Blyth
2000	1290.4	1640.5	900.3	922.8	-30.2	-43.7
2001	903.4	1295.5	680	837.5	-24.7	-35.4
2002	815.3	1020.0	514.5	531.5	-36.9	-47.9
2003	1014.4	1375.5	603.3	980.2	-40.5	-28.7
2004	1012.9	-	664.3	724.0	-34.4	-
Average	1007.28	1332.9	672.5	818	-33.2	-38.6

The Ausable-Bayfield-Maitland partnership has initiated a study to address the data concerns associated with the current available precipitation datasets. The study involves comparing historical AES climate (precipitation and air temperature) data with historical CA data. The analysis is being undertaken by Schroeter and Associates using data filling techniques they have developed and described in Schroeter et. al. (2000). The expected outcome of this project will be a minimum 45 year (1960 to 2004) complete set of daily precipitation and air temperature data as well as hourly precipitation data for the CA and AES stations listed previously. These datasets will be valuable for use in more fully characterizing precipitation amounts, form and distribution throughout the study area and will be valuable input files for numerical modeling tools.

2.3.2 Air Temperature

Daily maximum, minimum and average air temperature is a common climatological input for most numerical water budget models. Therefore historical data characterizing this weather measurement from the study area will be valuable. Appendix A summarizes the long-term normals for air temperature as measured at the main AES stations within the study region. CWB Map 2 identifies those AES and CA climate stations that monitor air temperature. The average annual temperature ranges from 6.7 C to 8.0 C. Lake Huron tends to moderate air temperatures, having a decreasing impact as one moves inland. Average daily air temperatures are typically below freezing for the months including December through March in the study area. Comparing the average annual long-term normal temperatures over the past 20 years would suggest perhaps a very slight rise in the average annual temperature. Four of the six stations with data available for comparison show increases ranging from +0.1 C° to +0.7 C°. The other two stations saw a 0.3 C° drop in the same time period. Overall all of the long-term stations, the difference in average temperature is a minimal +0.17 C°.

Air temperature data has not been collected as long at many of the CA climate stations. Many temperature sensors were installed in 2000 or later. Data filling techniques described for precipitation data (See Section 2.3.1) are also being applied to daily maximum, minimum and average air temperature data for the region to acquire a complete set of air temperature data for characterization and numerical modeling purposes (Schroeter et. al., 2000).

2.3.3 Wind, Barometric Pressure and Solar Radiation

Relatively few climatological stations in the study area have measured wind speed and direction, barometric pressure as well as solar radiation in the past. These data are useful as inputs for estimating potential evapotranspiration and may assist in other modeling tasks in the future. Very few of the study area's key AES stations collected such data in the past (see CWB Map 2). A few CA stations have been equipped to record these data, primarily since 2003, although some, such as a few of the Ausable stations and Maitland's Ethel station have been recording some or all of this information since 1990 (see table in CWB Map 2).

Some initial use has been made of this climatological data to assist in estimating actual evapotranspiration rates occurring in the study area. The analysis, described in the Section n to follow, was completed for the 2004 calendar year only as this was the first and only full year of detailed data available. Nevertheless, it does demonstrate how such data may be used in future modeling exercises and will assist in evaluating the importance of collecting and maintaining such data.

2.3.4 Evapotranspiration

A report on the water quantity resources of Ontario (Acres Consulting Services, 1984) estimates that the mean annual evapotranspiration averaged over the province is 415 mm. The provincial average varies from less than 300 mm in the north to over 600 mm in the south. The report estimates that, in the southern areas of the province, approximately 60% of the precipitation that falls is lost to the atmosphere through evapotranspiration. This would suggest the Ausable-Bayfield-Maitland study region should be experiencing evapotranspiration rates in the range of 500 to 575 mm/year. In a separate study, Dickinson and Diiwu (2000) suggested actual evapotranspiration should lie between 500 mm and 550 mm in Ontario's southwest and 450 mm to 500 mm in Central Ontario.

The weather stations that collect data on air temperature, wind speed, barometric pressure and solar radiation are capable of estimating potential evapotranspiration (PET). Such stations have only been operational in the study area since mid 2003. A methodology for estimating actual evapotranspiration (AET) was developed using the PET calculated by the weather station at the Wroxeter station and the existing BRFU hydrology (flood forecasting) model for the study area. Table 2 summarizes the results for each of the study area's gauged watershed units. This methodology used the BRFU model to estimate the water content of the top soil layer. Soil water content decreased the longer the elapsed time since the last precipitation event, reducing the amount of actual evapotranspiration that could occur. Immediately following a significant rainfall event that restored the water in the top soil layer, AET was allowed to rise to the PET for the day and slowly decline based on the modelled soil moisture content until the next rain event. The data in Table 2 estimates actual ET in the study area to fall between 330 mm and 460 mm. This is slightly less than expected and may be a function of the lower precipitation inputs to the estimation approach and possibly the lower temperatures experienced in the 2004 growing season (see Table 1). Only Conservation Authority rain gauges were used in this analysis.

Table 2. Estimation of Actual ET within the Study Area's Gauged Watershed Units

Gauged Watershed Unit	Estimated Actual Evapotranspiration (2004) mm
Ausable	
Parkhill Inflow (02FF008)	418
South Parkhill Creek (02FF004)	402
Exeter (02FF009)	429
Springbank (02FF002)	376
Bayfield	
Silver Creek (02FF011)	375
Varna (02FF007)	451
Maitland	
Harriston (02FE011)	332
Wingham A (02FE005)	358
Bluevale (02FE007)	369
Listowel (02FE003)	385
Boyle Drain (02FE010)	384
Ethel (02FE013)	379
Belgrave (02FE008)	379
Blyth (02FE014)	391
Summerhill (02FE009)	389
Wingham B (02FE002)	374
Benmiller (02FE015)	384
Nine Mile	
Lucknow A (02F002)	392
Lucknow B (CA Station)	387

2.4 Land Cover

CWB Map 5 presents land cover in the Ausable-Bayfield-Maitland planning region. It is based on data published through the Ontario Ministry of Agriculture and Food's (OMAF) agricultural land inventory project undertaken in the late 1970's and early 1980's (OMAF, 1983). As such, the information on this map is dated. Nevertheless, it does give a regional overview of the trends in land cover across the study area. Approximately 82% of the study area is agricultural land under various crops and cropping practices. Approximately 15% of the area is under undisturbed vegetative cover (i.e woodlots, natural areas). Only 3% of the land area has been developed for urban and industrial use.

Based on the 1983 data, agricultural cropping activities which result in less vegetative cover through the year are distributed throughout the study region but are somewhat more concentrated in the south and in the lakeshore gully areas of the region. Areas with higher livestock based agriculture (i.e. dairy or beef) are more likely to see increase areas of pasture and hay production and more land in rotation under grass cover throughout the year. Since this land use survey was completed, some land managers, particularly those operating farms that are non-livestock based, have moved to using conservation tillage practices to reduce production costs and provide improved soil cover, particularly during the non-growing season. This extent of use of conservation tillage practices in the area, however, is not well documented.

The Ausable-Bayfield-Maitland Planning Region was teamed with the Ontario Ministry of Agriculture, Food and Rural Affairs to assess the applicability of the 1983 land cover data relative to current conditions. Land cover information is being collected in the field for the sub-watersheds listed in Table 3. Many of these watersheds correspond with the hydrologic response units identified in this report. Data gathered will be compiled and the results compared with the 1983 mapping. As well, where possible, information is being collected on the tillage practices being used in the area. This will further enhance our understanding of the land cover conditions in the study area. As well, the data has the potential to be used to field truth remotely sensed land cover data when it becomes available and could assist with calibrating remotely sensed images.

Table 3. Areas of Study for Update Land Cover Project

Study Area Drainage System	Sub-basin(s) where 2005 Land Cover is being collected
Ausable	South Parkhill Creek, Exeter
Bayfield	Seaforth
Maitland	Listowel, Blyth Brook
Nine Mile	--
Shore Streams and Gullies	Desjardine Drain, St. Joesph Creek, Kerry's Creek, Eighteen Mile

2.5 Infiltration

The capacity of the landscape to partition falling precipitation as either interception water, runoff or infiltration plays a major role in the pathways for contaminant movement. Therefore some understanding is needed, both spatially and temporally, as to the potential for infiltration versus runoff to occur across the study region. Soils mapping as well as land use mapping were combined to provide a spatial overview of the relative potential for infiltration versus runoff across the study region, while default model input parameters used by the BRFU flood forecasting model were summarized to give some indication of temporal effects on infiltration capacity.

A map presenting soils information classified by hydrologic soil group is shown in CWB Map 6. It is seen from this map that soils with a lower final infiltration rate (soil groups D and C) are more dominant in the southern half of the watershed and in bands inland along the lakeshore, suggesting higher levels of runoff from these lands. It is important to remember, however, that this soil classification approach does not account for "shortcircuit" flow pathways that can develop in these finer-textured soils in dry weather in the form of cracks or macropores. Large cracks have the potential to develop, particularly in the summer months, due to the shrinking of clays forming the soil matrix. The result is an increase in the infiltration capacity of these soils.

CWB Map 7 combines soil and land cover information to arrive at a spatial visualization of the potential variability of infiltration and runoff across the region. Lighter shaded areas show areas where infiltration capacity is expected to be relatively high while the darker shaded areas are likely to have a higher surface runoff potential. Delivery of this runoff to streams is not incorporated into this mapping.

A common landscape feature of this study region that will need to be accounted for in a water budgeting exercise is subsurface tile drainage systems. CWB Map 8 shows the extent of tile drainage in the study region. Mixed opinions exist as to the impact of tile drainage on infiltration and runoff/stream flow. Tile drains encourage more rapid drainage of the soils in spring and late fall and anytime saturated soil profile conditions exist, converting infiltrated soil water to stream flow more rapidly than would be the case without drains. At the same time they contribute to providing increased water storage capacity in the soil profile for subsequent rainfall events possibly delaying or damping runoff peaks. They also encourage deeper root growth, potentially enhancing evapotranspiration rates. Similarly they reduce the risk of soil compaction and therefore reduced infiltration/percolation capacity caused when heavy agricultural equipment is used on wet soils. In the summer they may combine with cracks and macropores (typically in a narrow band over the tile drain) to quickly deliver infiltrated water moving through such large pores into surface streams. Data available still needs to be assessed to understand how best to accommodate this man-made influence on water flow and within a water budget.

Temporally, infiltration capacity varies significantly depending on the soil and cover conditions of the study region at the time of the precipitation event. Attempts have been made in the past to capture this reality in the parameters used to define infiltration in the BRFU flood forecasting models for the major river systems of the study area. Figure 5 shows the recommended adjustment factor to be made to the BRFU's surface infiltration parameter when predicting streamflow for events within each month of the year. The baseline (maximum) infiltration rate is representative of June conditions (ABCA river systems) and July (MVCA river systems). In other months of the year the infiltration rate is adjusted downward by the adjustment factor plotted in Figure 5. Low infiltration values in the winter months are a function of frozen soil conditions that typically are present at that time. Default values for March, October and November are not given for the Maitland watershed systems. Depending on observed watershed conditions for the event the model is to simulate the model user would select the most appropriate value (e.g. January or February if frozen soil conditions, April or September depending on soil cover if unfrozen). Observed historical runoff/streamflow patterns also a similar trend to lower infiltration, higher runoff in the early spring and late fall periods.

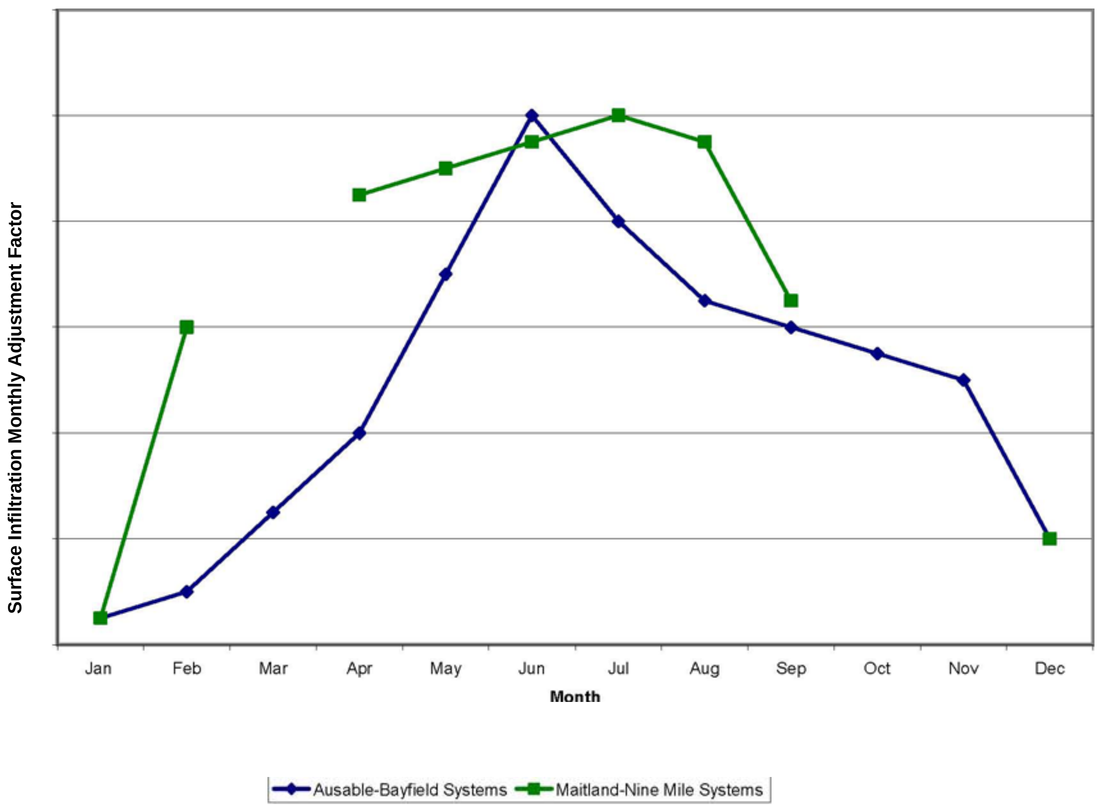

Figure 5. Default Monthly Surface Infiltration Adjustment Factors Used in the BRFU Flood Forecasting Hydrologic Model for River Systems in the Ausable-Bayfield Maitland Valley Planning Region

2.6 Runoff and Streamflow

Streamflow has been monitored for a number of years in the Ausable-Bayfield-Maitland Planning Region and provides the basis for assessing the hydrologic response of the study area's gauged watershed units. CWB Map 1 identifies the current stream gauging stations and their associated gauged watersheds. No long-term data presently exists to assist with characterizing the runoff response of lakeshore streams and gullies. Historical daily and maximum/minimum streamflow data recorded and archived by Water Survey of Canada for stations within the planning region are summarized on a monthly basis in Appendix B. The length of record for each station is identified in the table's first column. Appendix C takes the average historical streamflows and converts it to an estimated depth of runoff over the watershed area for each of the gauged watersheds. Annual streamflow volumes (runoff plus baseflow) from the gauged watersheds range from 370 mm/year to 650 mm/year. CWB Map 9 graphically presents the annual streamflow data given in Appendix B spatially. In general, the southern area of the planning region tends to experience lower total annual runoff volumes. The Silver Creek watershed has only one year of data associated with it, limiting the validity of the mapped result. While Water Survey of Canada streamflow data are not available for the Lucknow B station (A Conservation Authority-managed station), an analysis of historical streamflow data (2000 to 2004) for this station give relatively high annual runoff levels similar to the Lucknow A watershed.

Seasonal variability in runoff across all monitoring stations and associated watershed is worth mentioning. An analysis of the data presented in Table 6 reveals that, on average across the study region, approximately 76% of the total runoff occurs in the months beginning December through to May (i.e. much of the non-growing season). If baseflows were removed from this total streamflow volume, then it is expected that this percentage would increase. Such conditions suggest that an ideal water budget needs to be effective at modeling winter hydrology, snowmelt and early spring hydrologic conditions.

2.7 Baseflow

The baseflow (groundwater discharge) fraction of total streamflow was estimated for the years 2000 through 2004 using a graphical baseflow separation technique applied in a module of the BRFU hydrologic model developed for the study region river systems. Table 4 summarizes the findings of this analysis. Data presented in Table 3.7 for the Silver Creek and Boyle Drain watersheds are for 2004 only. In general, baseflow values lie between 105 mm/year and 420 mm/year. Many of the higher baseflow values observed may be influenced by direct anthropogenic activities. For example, Exeter's baseflow, which in the analysis was shown to have the highest baseflow index (BFI), is likely being augmented to some extent by Morrison Dam and reservoir upstream. Discharge from the town of Exeter's wastewater treatment plant is also expected to be significantly influencing this BFI value. Other locations where wastewater treatment plant discharge is likely contributing significantly to baseflow observations include the Listowel and Harriston stations. These could have residual influences on associated downstream stations as well (e.g. Ethel, Bluevale). Data on wastewater plant outflows will be required to further assess their full impact.

The Blyth and Lucknow gauges as well as the Wingham A station all show relatively high BFI values. This is more likely a result of high levels of natural base flow as suggested by estimates of hydrologic responsiveness of the watersheds associated with these gauges (see CWB Map 7).

Table 4. Estimation of Actual ET within the Study Area's Hydrologic Response Units

Gauged Watershed Unit	Average Annual Estimated Baseflow (mm)	Baseflow Index
Ausable		
Parkhill Inflow (02FF008)	106	0.36
South Parkhill Creek (02FF004)	136	0.33
Exeter (02FF009)	341	0.76
Springbank (02FF002)	130	0.35
Bayfield		
Silver Creek (02FF011)	142 (see note 1)	0.46 (see note 1)
Varna (02FF007)	158	0.33
Maitland		
Harriston (02FE011)	216	0.45
Wingham A (02FE005)	288	0.47
Bluevale (02FE007)	212	0.48
Listowel (02FE003)	191	0.45
Boyle Drain (02FE010)	157 (see note 1)	0.35 (see note 1)
Ethel (02FE013)	159	0.37
Belgrave (02FE008)	208	0.4
Blyth (02FE014)	418	0.63
Summerhill (02FE009)	190	0.33
Wingham B (02FE002)	195	0.41
Benmiller (02FE015)	297	0.44
Nine Mile		
Lucknow A (02F002)	1553 (see note 2)	0.82
Lucknow B (CA Station)	1613 (see note 2)	0.82

Note 1: Data for 2004 only.

Note 2: Errors are known to exist with the rating curve for this gauge station. BFI, however is believed to be reflect the observed ratio of baseflow to total flow from watershed.

3.0 Groundwater System

3.1 Geology

3.1.1 Precambrian Basement Rocks

Underlying all of the study area and a large majority of the North American continent are the metamorphic rock 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 known from oil and gas exploration wells which were terminated in the Precambrian rocks. From these drilling data, the rocks which underlie our 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, these rocks are dominated by metamorphosed plutonic rocks with thin bands of meta-volcanic and meta-sedimentary sequences. 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 which 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) which unsuccessfully began to open approximately 1.1 billion years ago. The basin which 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 which 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 sinkholes 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 spine 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.

3.1.2 Paleozoic Bedrock of Southern Ontario

After a non-conformity spanning approximately 500 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 which 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 likely several points during the deposition of these rocks that they were aerially exposed and eroded. 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. WC Map 1-2 shows the major bedrock units in the study area. For the purposes of this document, only bedrock units which subcrop in the study area will be discussed, from oldest to youngest beginning with the Salina Formation. These formations are used as domestic and municipal sources of drinking water throughout the study area, which will be dealt with in section 3.4 of this report.

Salina Formation
The Salina formation subcrops in only the far northeastern section of the study area but underlies the entire study area. The Salina formation, deposited during the Silurian Era approximately 410 to 440 million years ago, is composed of between 200 and 50 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. Extensive historic mining of these deposits has occurred throughout the study area and continues today 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 Goderich. The effects of this dissolution front on the deposition of younger rocks is unknown, but it is thought to have a relationship to the development of karstic features in overlying formations.

The Salina formation is an important source of drinking water in the study area. 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 northeastern section of the study area due to the relative thin section of rocks it is composed (approximately 30 m true thickness). The Bass Islands Formation is dominated by a brown, oolitic limestone with minor interbeds of relatively resistant dolomitic shales.

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.

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.

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 and their coarse grain size makes the Bass Islands Formation a layer of high permeability which may have a disproportionately important role in the flow of groundwater in the area.

Through the Study area and extending both north and south of the study area right to Lake Huron and Lake Erie, the erodible Bois Blanc Formation has lead to the development of a large bedrock valley which is correlated herein as part of the Dundas Valley. This valley extends from Wingham in the north part of the Study area to Atwood in the east. To the north of the study area this valley is followed by the Saugeen river on its course to Lake Huron and extends southward towards Lake Erie where it has been named the Dundas Valley.

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 which preferentially concentrate flow into the valleys. North of the study area the predominant west-southwest direction of regional groundwater flow is reversed in the Bois Blanc, 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 Bois Blanc Formations' high permeability has also led to its extensive exploitation as a source of groundwater in the study area. Although it is relatively thin and not really an extensive formation, drillers have targeted the Bois Blanc for water supplies due to its 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 metres thick sequence of limestones and dolostones that are 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, is further separated into reefal and non reefal facies. The reefal facies, named the Formosa Reef member, is composed of biohermal reefs which outcrop just north 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 during deposition of the Amherstburg.

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.

Lucas Formation

The Lucas Formation, overlying the Amherstburg Formation, is composed of nonfossiliferous, microcrystalline limestones and dolostones. The Lucas Formation subcrops in a large area within the study area, including an inlier within the overlying

Dundee formation that may be evidence of another bedrock valley in the area which extends from Hensall to Lake Huron at St. Joseph's. The Lucas outcrops within the study area within the Lower Maitland River Valley as well as along the shore of Lake Huron North of Goderich.

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 contact between the Lucas and the overlying Dundee the Lucas has been associated with karst development. Within the study area, several sinkholes (see WC Map 1-4) are developed along the contact between the Lucas and the Dundee. Several studies have been conducted and are continuing which are investigating the relationship between the Lucas and karst development in the Study area (ABCA Sinkhole Study, 2002, 2004)

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 (outside of 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.

Dundee Formation

Overlying the Lucas is the grey brown, highly fossiliferous Dundee Formation. The Dundee formation is characterized by fossiliferous limestones and can be identified by the presence of the fossil zooplankton species *tasmanides*. The Dundee subcrops through a large portion of the study area and outcrops along the shore of Lake Huron between Goderich and Bayfield as well as within the beds of the Ausable and Bayfield Rivers. The contact between the Dundee and the underlying Lucas Formations can be observed in the wall of the Lower Maitland River valley near Goderich.

The relatively competent Dundee formation is a well known aquifer of variable quality and quantity and is exploited widely for domestic drinking water supplies. In an area locate east of the village of Hensall, the Dundee is thought to be host to a relatively shallow, perched aquifer.

Hamilton Group

The Hamilton Group is composed of interbedded shales and limestone horizons of the Bell, Rockport, Arkona, Widder, Hungry Hollow and Ipperwash formations with a total thickness of between 70 and 90 metres. The Hamilton Group subcrops in the southwestern portion of the study area near Grand Bend and outcrops in several locations in the study area, along the shore of Lake Huron, along the Ausable River in Rock Glen, as well as several inland locations. The Uppermost Ipperwash formation forms an erosion resistant cap rock to the Hamilton Group, which has led to the development of a small escarpment which runs from the shore of Lake Huron near Port Franks eastward out of the study area.

Rocks of the Hamilton Group have been exploited historically for the production of bricks and tile. The Hamilton Group, however, is not exploited widely for groundwater as it has been noted to have generally poor water quality due to the presence of petroleum.

Kettle Point Formation
Approximately 30 m thick and extending over only a small portion of the study area is the Kettle Point Formation. The Kettle Point Formation is composed of highly organic, siliciclastic black shales that were deposited during late Devonian-early Mississipian time. These rocks also contain unique, large calcareous concretions commonly referred to as “Kettles” which have led to its’ name. These “kettles” can be seen in outcrop along the shore of Lake Huron at Kettle Point.

The Kettle Point is not considered a reliable aquifer in the area due to its’ low permeability and poor quality.

3.1.3 Pleistocene Glacial Geology

Paleozoic-Pleistocene Non-Conformity
Following deposition of the Paleozoic carbonate rocks, a long non-conformity of approximately 300 million years ensued. 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 which are important hydrogeological features for the study area.

Large bedrock valleys were carved into the bedrock surface by surface waters during this time and these continue to be important features, partially controlling the flow and distribution of groundwater in the region. CWB Map 10 shows the elevation of the top layer of the bedrock units. The bedrock surface slopes generally to the west, crossed by a number of smaller bedrock valleys: the most notable of these being the extension of the Dundas bedrock valley through the village of Atwood and northwest towards the town of Wingham.

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 Insterstades.

The dominant features associated with Port Bruce Stade are the deposition of the Elma, Tavistock, Stratford and Rannoch 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 physiograhic features which dominate the landscape today, such as the Wyoming, Wawanosh and Seaforth moraines as well as many of the glacial outwash features. During the latest retreat of the glaciers during the Twocreeken Insterstade, 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 further Lakes Algonquin and Nippissing.

WC Map 1-3 shows the Physiography of the study area and shows, at a crude scale, the distribution of glacial deposits. The most prominent feature in the area is the prevalence of till deposits which exist through the study area and underlie a significant portion of the watershed. Perched atop these till deposits, and less frequently incised into the till deposits, are numerous moraines, spillways, eskers and syn-glacial and post-glacial lake deposits. These deposits are extremely important features as they tend to include coarser grained gravels and sands, which serve as valuable sources of aggregate, and also tend to host many surficial aquifers. These deposits will be dealt with in more detail in the section 3.4 of this report.

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 which 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 post glacial lakes are documented, in order of development, Lakes Warren (the oldest), Nippissing, Algonquin and present day Lake Huron. 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 and gullies of the study area.

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 Pinery Park area in the very southwestern portion of 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.

3.2 Hydrogeology

Major aquifers in the Maitland –Ausable Bayfield 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. All municipal supplies outside of Goderich, the Lake Huron Water system and the village of Hensall rely 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.

3.2.1 Bedrock Aquifers

The bedrock aquifers are composed of an aggregate of the bedrock formations discussed in section 3.0. 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, the bedrock aquifer is confined by an overlying layer of clay and silt till. The aquifer itself is exposed at the surface in only a few locations and is known to have a piezometric surface well above its' contact with the overlying glacial deposits. CWB Map 11 shows the piezometric surface for the bedrock aquifer for the Maitland –Ausable Bayfield planning region with groundwater flow directions outlined. A major feature of the piezometric surface is the dramatic drop off which occurs on a north-south trend just east of Exeter. This evidence is corroborated by anecdotal accounts of known aquifer elevations from drillers in the area. This drop off corresponds with an increase in permeability within the Lucas Formation which is likely associated with karst development in the area. The dramatic gradient shown on the map may also be partly an artefact of the existence of two bedrock aquifers in the area: the deeper aquifer situated within the Lucas Formation and a shallow, perched aquifer within the overlying, more competent Dundee Formation.

Regional Groundwater Flow

Groundwater flow within the bedrock aquifers radiates away from the Dundalk area and follows a generally west to southwest flow path towards Lake Huron. An important note of discussion for the purposes of this water budgeting exercise is that a significant portion of groundwater inside the study area originates from the north and east outside of the study area. Quantifying this influx of water will be an important boundary condition to be established for the creation of a numerical, three dimensional groundwater flow model.

Groundwater-Surface water interactions

With existing data it is difficult to delineate recharge areas for the study area. Through the majority of the watershed region the bedrock aquifer is not exposed at the surface so any recharge must be transient through the overburden deposits. It is believed that a significant portion of recharge occurs outside of the study area but at this time it is not known to what extent this is the case. As such, a primary goal for the numerical groundwater model is to determine the location of any recharge areas and the interaction between the bedrock aquifers and the overlying overburden aquifers.

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 (particularly the Maitland and Bayfield 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 in the Offshore.

Within the watershed region several sinkholes have been documented. These sinkholes have extensive surface drainage areas which 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.

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. A recent study has been completed by the Ausable Bayfield Conservation Authority for the Pinery Park/North Lambton area (Luinstra, 2004) 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.

In order to discuss these deposits, CWB Map 12 was created in order to approximate the extents of the overburden aquifers. CWB Map 12 shows the physiographic features of the study area which are likely, based on the materials from which they are composed, to be host to aquifers. In addition, it is recognized that there exists a number of overburden aquifers that are not exposed on the ground surface and for which no mapping exists. Where known, these aquifers have been outlined and will be discussed.

3.2.2.1 Surficial Overburden Aquifers

Lake Warren Shoreline Aquifer

Forming a narrow band and extending across, and north and 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 gullies. In addition, several documented private wells are located within this aquifer, in particular in the Goderich area. 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.

North Lambton Aquifer

The North Lambton Aquifer is one of the best understood overburden aquifers in the study area. In 2004 the ABCA undertook a study of the aquifer in partnership with the Ontario Geological Survey in order to investigate the interaction of the aquifer with the bedrock aquifer and Lake Huron. In addition, a water quality study was completed for this area in 2001, as well as two Masters Theses completed at the University of Western Ontario (Steinbach, 1999; HHHH, 2001).

The North Lambton Aquifer is a composite aquifer located within former lakes Nippissing-Algonquin Beach deposits and more recent aeolian dune deposits. The aquifer is unconfined and is recharged in situ. Groundwater flow within the aquifer follows topography with water diverging from two divides, one between Lake Huron and the Old Ausable River Channel and another between the Old Ausable River Channel and the former Lakes Smith and Burwell, located to the east of the aquifer.

The aquifer is separated from the bedrock aquifer by more than 30 metres of clay till and is no connected to the bedrock. The aquifer was extensively used prior to extension of the Lake Huron Water supply into the area.

Holmesville Outwash Aquifer

Located between the Wyoming and Wawanosh moraines, the Holmesville outwash deposit is comprised of an unknown thickness of gravel and sand. This aquifer is host to numerous aggregate extraction operations and is anecdotally well known as a high quantity, high quality aquifer. Several private wells are documented within this aquifer and some smaller developments (i.e. Fernhurst Glen) rely on springs from this aquifer as sources of drinking water.

This aquifer is likely recharged “in situ”, with some contribution from the surrounding, topographically higher moraines. The Holmesville aquifer is an important source of water for a number of surface water bodies, including the coldwater streams Sharpe’s Creek and Trick’s Creek, as well as the Saratoga and Hay swamps. Otherwise, very little is known about this aquifer. The Holmesville aquifer also likely discharges directly into and is an important source of baseflow for the Maitland, Bayfield and Ausable Rivers and the Lakeshore streams and gullies that extend inland far enough to tap into it.

Wawanosh Kame Moraine Aquifer

The Wawanosh moraine 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 Maitland River and Nine Mile River Watersheds 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 Nine Mile River system and portions of the Maitland River where it crosses the moraine. 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 northern part of the study area and is centred on Howick Township. This composite aquifer is situated within a large outwash deposit and glacial spillways which form the rolling topography of this area. In addition, numerous drumlins associated with the Teeswater Drumlin Field and smaller eskers and spillways which are dispersed through Northern Huron and Perth Counties are included in this aquifer.

This aquifer is likely recharge "in situ". It is an important source of water for the North Maitland River, Lakelet Lake, Lakelet creek and Blind Lake Bog. 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.

Seaforth Moraine Aquifer

Located within and on the flanks of the Seaforth moraine and the associated, subparallel outwash deposit is the Seaforth Moraine Aquifer. This aquifer forms a thin, linear band on the eastern flank of the Seaforth Moraine. There exists very little information on this aquifer, but it is thought to be an important source of drinking water for private well supplies in the southern portion of the watershed region, mostly as a result of the general decrease in groundwater quality in the bedrock aquifers in this area.

The Seaforth Moraine Aquifer is an important source of water for the Ausable River and possibly the bedrock aquifer. This aquifer is likely recharge *in situ* with some contribution from the topographically higher Seaforth moraine.

3.2.2.2 Confined Overburden Aquifers

Hensall Aquifer
The Hensall aquifer is centred on the village of Hensall and is situated within the overburden. This aquifer is partially confined and may extend to the Seaforth Moraine aquifer. Recharge for the aquifer is located to the east of the aquifer where the sand deposits are exposed on land surface. Very little geological information exists for this aquifer.

The aquifer is the primary source of drinking water for the village of Hensall as well as a number of documented private wells. As part of the Huron County Groundwater study (2001) a well head protection study was completed for the municipal well which identified a general westward groundwater flow direction and potential recharge areas within a 10 year capture zone for the well. As such this aquifer is considered to be vulnerable to surface water contamination. This is corroborated by the known water quality problems associated with this aquifer. As a result of this, the Municipality of Bluewater has opted to extend a pipeline from the Lake Huron system into the village of Hensall.

Discharge from this aquifer is poorly understood. The deposit is thought to lie directly on bedrock and, accordingly, be a source of inline recharge for the bedrock aquifer.

Atwood/Dundas Bedrock Valley Aquifer
This aquifer is situated within sand and gravel that has infilled the Dundas bedrock valley and has been subsequently covered with clay and silt rich tills. This aquifer is confined and likely both recharges and discharges with the surrounding bedrock aquifers. This aquifer could be considered transient for water flowing within the bedrock aquifer.

The effect of the high permeability materials that comprise this aquifer could funnel water outside of the watershed region but his relationship is poorly understood.

3.2.2.3 Other Overburden aquifers
Numerous other sand and gravel deposits, which cannot be accurately described at the scale of this report, exist throughout the watershed region. These deposits may have local importance as sources of groundwater but are not well documented and poorly understood.

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
WC Map 1-4 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 can not 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.

Hummocky terrain has been identified in the Ausable-Bayfield-Maitland 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.

3.2.4 Groundwater Monitoring

Groundwater monitoring locations were established in the Ausable-Bayfield-Maitland Planning Region in 2003 as part of the Provincial Groundwater Monitoring Network (PGMN). These sites have been equipped with water level and temperature loggers and are recording hourly values for these parameters. Due to the relatively short period of record it is not possible to examine long term trends of groundwater levels throughout the planning region. However, these sites will be valuable for calibrating the three dimensional groundwater flow model, particularly with respect to seasonal variation in groundwater flow.

3.2.5 Hydrostratigraphy

In order to develop a numerical groundwater model, the aquifers and aquitards must be developed into a hydrostratigraphy. As part of a regional scale three dimensional groundwater model being developed for southern Ontario, a hydrostratigraphy has been developed for the watershed region. For this purpose, the geology of the Southern

Ontario has been broken into eight hydrostratigraphic units, of which seven are thought to occur in the Ausable-Bayfield-Maitland Planning Region. Figure 6 shows a schematic representation of this hydrostratigraphy, developed as part of this project. This project is anticipated to be finalized in the fall of 2005, and the base data layers for the Ausable-Bayfield-Maitland Planning Region will be extracted in future versions of this report.

For the purposes of developing a numerical model, each hydrostratigraphic layer will be given a elevation and thickness and representative hydraulic conductivities. These layers will then be incorporated into a groundwater flow model and calibrated to stream flow data for streams with significant groundwater discharge as well as to known groundwater levels from existing monitoring sites and the Water Well Information System.

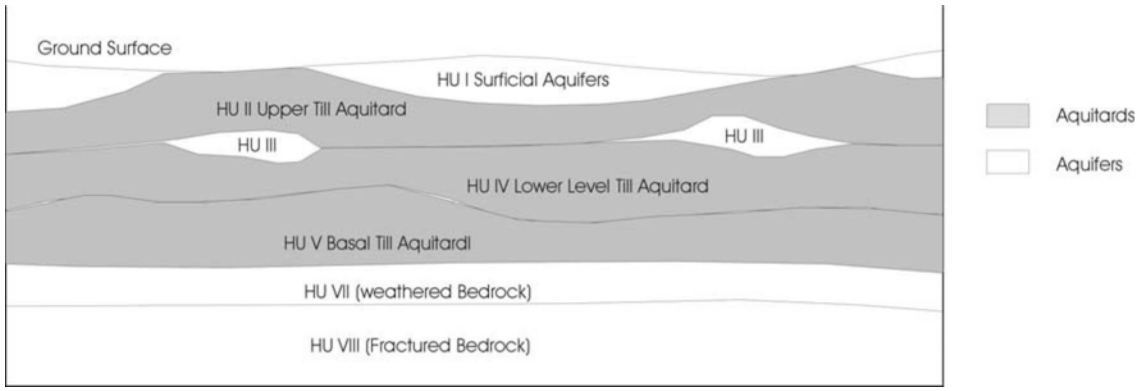

Figure 6. Hydrostratigraphy of Study Area, modified from Abbey et al., 2004

Precipitation will be applied across the entire study area and the model will help to determine the pathways of the water. A major goal of this work will be to determine recharge areas of regional importance.

HU I Upper Unconfined Aquifers

These aquifers located at the ground surface and includes the Howick, the Holmesville, Seaforth Moraine, Wawanosh Moraine, Lake Warren Shoreline, and Lake Huron Shoreline Aquifers.

HU II Upper Till Aquitard

This layer is composed of the various surficial tills in the study area, including the ST. Joseph's, Rannoch and Elma Tills. This aquifer is an effective aquitard in the study area.

HU III Intermediate Sands and gravels Aquifer

This unit includes the Hensall and Atwood/Dundas Bedrock Valley Aquifers.

HU IV Lower level Tills Aquitard

These include the lower stratigraphic Tills including the Tavistock Till.

HU V Basal Sand and Gravel Deposit Aquifer

This unit not present in the study area.

HU VI Basal Tills Aquitard

This unit not present in the study area.

HU VII Weathered and Fractured Bedrock Aquifer

This unit includes the upper 3-5 metres of the bedrock aquifers, which has enhanced permeability as a results of weathering and fracturing.

HU VIII Bedrock Aquifer
This unit includes the remaining bedrock aquifers.

4.0 Water Use

4.1 Data Sources

A number of sources of data for water usage are available for the Ausable-Bayfield-Maitland Planning Region. These data include the Provincial Permit To Take Water (PTTW) database, the Water Well Information System, agricultural water usage studies and census data and Municipal Well annual Reports. These data are useful for approximating the amount of water being extracted in the region.

4.2 Municipal Water Takings

Water takings for municipal drinking water supplies comprise a high volume of water takings within the Ausable-Bayfield-Maitland Planning Region. Most of these takings are exploiting bedrock aquifers with only one supply, for the Village of Hensall, reliant on overburden aquifers.

The Lake Huron Water Supply System, which serves the City of London and numerous other communities, is a major taker within the Ausable-Bayfield-Maitland Planning Region. Of particular interest for the purposes of this water budgeting exercise, a majority of water from this system has outlet in the Thames River system, outside the Ausable-Bayfield-Maitland Planning Region. As such, the Lake Huron Water Supply System represents the largest consumptive water taking in the region.

Several smaller water supply systems exploit Lake Huron as a water source, including Goderich and several smaller systems in the North Lambton. Each of these systems has outlet into Lake Huron directly of via small lakeshore gullies.

Quantifying municipal water takings will be accomplished by examining the water system annual reports as well as any other inflow data which can be provided by municipalities. Although each of these systems has up to date Permits To Take Water, these values are set as daily maximums and could be misleading. Since 2001, municipal and large communal systems have been required to install flow meters and report annual water consumption. These data are in the process of being collected.

4.3 Agricultural Water Takings

Agriculture, including livestock feeding operations and irrigation, represents the largest land use within the Ausable-Bayfield-Maitland 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. Surface water takings associated with agriculture increase to the southern portion of the region, particularly in areas where bedrock water quality is known to be poor in quality.

Quantifying takings from agriculture will be a difficult task. Most livestock facilities are not required to obtain a PTTW, and as such estimations of usage will be made for the different sectors. The University of Guelph completed an Agricultural Water Usage survey which examined takings for different sectors, and this information will be correlated with agricultural census data in order to provide an estimate of overall water takings.

Irrigation facilities often have PTTWs, and as such some information on their water takings may be obtained. However, the PTTW database often lists maximum allowable takings and may not represent actual takings. The newly amended PTTW regulation will require flow monitoring for all permits but this data is not yet available. In order to gain a greater understanding of these takings, contact with operators will have to be made in order to access records (required under existing permits) of takings.

4.4 Private Domestic Consumption

Private consumption within the Ausable-Bayfield-Maitland Planning Region almost exclusively exploits the overburden and bedrock aquifers. The typical scenario involves a drilled, or less commonly, bored wells which are recycled into shallow overburden aquifers via a septic system.

The overall amount of water which 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.

4.5 Industrial and Recreational uses

Several industries within the Ausable-Bayfield-Maitland Planning Region rely on large quantities of water for production. These include aggregate extraction operations, food processing operations, greenhouses, bait harvesters, and golf courses among others. Other recreational uses include constructed wetlands, reservoirs for recreation and flow augmentation.

Most of these operations rely on the bedrock aquifer; however, several takings of surface water are documented in the PTTW database. PTTW information will provide an initial estimate of these takings and contact with operators will have to made in order to access records (required under existing permits) of takings to further constrain actual takings.

5.0 Conceptualization of the Hydrologic System

5.1 Key Components and Processes

For the Ausable-Bayfield-Maitland Planning Region, the key components and processes to be considered for water budgeting are shown in Figure 7. 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. In addition, it is noted that a significant portion of groundwater entering the bedrock aquifer system is derived from extrabasinal sources. 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 7). Evapotranspiration occurs throughout the system whenever water is exposed to the atmosphere or within the root zone of plant life. During dry periods, precipitation is augmented from the river systems, overburden 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. River systems are not heavily exploited as sources of water in the planning region but a significant amount of irrigation is documented, removing water from the river systems and placing it on the ground surface.

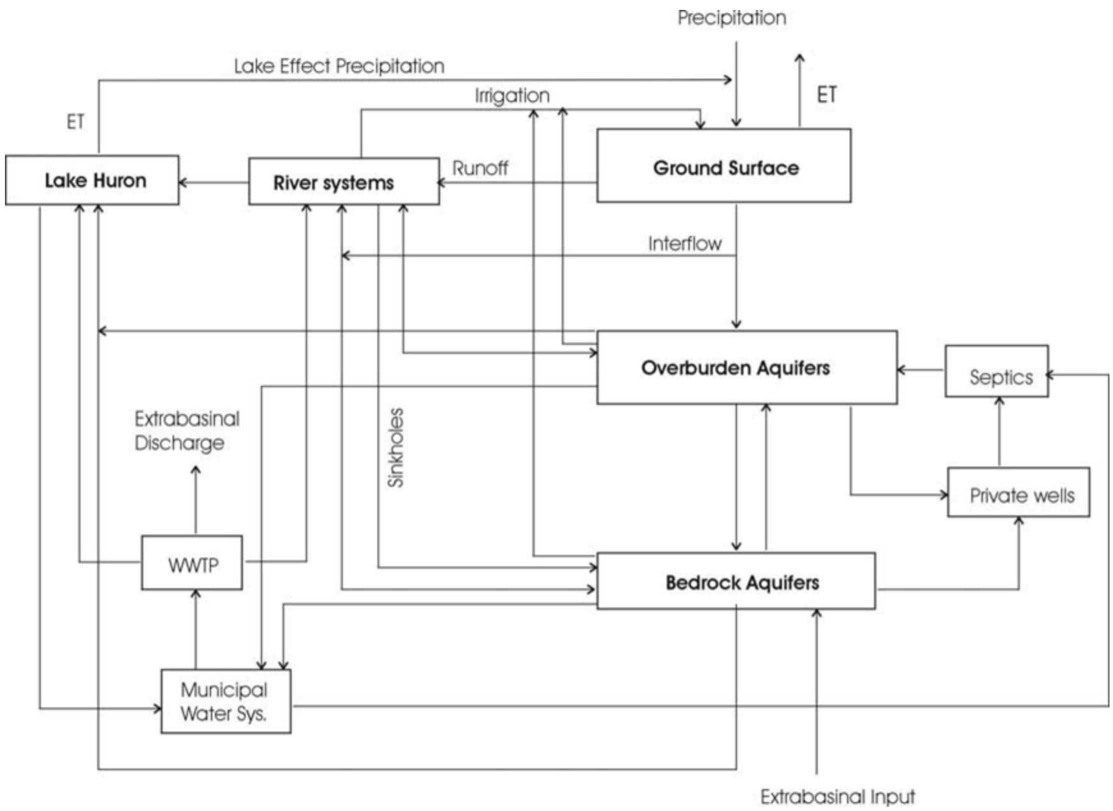

Figure 7. Schematic of the components and fluxes of the Ausable Bayfield Maitland Valley Planning Region Water Budget.

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 which may accelerate interflow throughout the planning region.

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 form the ground surface where the bedrock is exposed, recharge from overlying overburden aquifers, recharge from river systems via losing streams and most notably in the Ausable-Bayfield-Maitland Planning Region, via sinkholes which act as direct conduits for runoff into the bedrock

aquifers. An important input into the bedrock aquifers is derived from extrabasinal sources. Water from the bedrock aquifer naturally discharges into Lake Huron and, in certain areas, into river systems. In addition, large volumes of water are extracted from the bedrock aquifers for industrial and municipal water uses. The majority of this water is treated in municipal waste water treatment facilities (WWTP in Figure3.6) 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.

Lake Huron

Lake Huron is the ultimate destination for water within the system. Lake Huron receives water from **all** the components shown in Figure 7. River systems, overburden and bedrock aquifers all naturally discharge into the Lake. Water from WWTP is also outlet directly into Lake Huron. The key process for Lake Huron is the extraction of water from the Lake for drinking water purposes. The Lake Huron shoreline within the Ausable-Bayfield-Maitland Planning Region is host to two large water systems which are exploiting Lake Huron. The Goderich system forms a closed loop as water from the system is treated and subsequently released back into Lake Huron. The Lake Huron Water Supply is a large system which also exploits Lake Huron in order to provide drinking water for the City of London as well as numerous smaller communities both inside and outside of the Ausable-Bayfield-Maitland Planning Region. Most notably, the vast majority of water that is extracted from this system is treated and released outside of the Lake Huron Basin.

5.2 Data Gaps

In the process of developing a conceptual understanding for the watersheds, a number of data gaps were identified that need to be filled before completion of this work. A number of these data sets are currently being updated, however are not completed at this point. Significant data gaps include:

- Hydrology and flow data for the Lake shore gullies and streams
- Distribution of precipitation on an annual basis, particularly long term snow cover
data, snow fall data and liquid precipitation data
- Long term air temperature trends for the region
- Measured evaporation data
- Actual water usage data from permitted and non-permitted water takers, including
livestock operations and other agricultural operations
- Trends of domestic water usage for the area
- Up to date land use/land cover data
- The location and distribution of hummocky terrain
- Locations and effluent release data for Municipal Waste Water Treatment Plants
- Geological and Hydrogeological information on overburden aquifers, including: usage, water levels, flow directions, recharge areas.
- Development of an influx into the bedrock aquifer as an initial boundary condition for development of a three dimensional groundwater flow model.

6.0 Summary and recommendations for further work

6.1 Summary

Municipal Water Supplies in the Ausable Bayfield Maitland Planning Region
There are two dominant source of municipal drinking water in the study area: Lake Huron 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 Hensall and numerous private wells that are the source of water for the village of Hensall Water Supply system and surrounding area. This system relies heavily on overburden aquifers. These aquifers are more susceptible to the relatively large taking in comparison with the available water in the systems they are exploiting.

Water Quality Issues
Generally, Lake Huron 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.

6.2 Recommendations for Further Work

Major data and knowledge gaps have been identified throughout the report and are listed in section 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 only models available for determination of ET, 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. Detailed model Calculations be evaluated against any known ET data in order to estimate ET with more confidence.

Stream Flow
Although no 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. 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,
2. Incorporation of updated outflow data from dams, reservoirs, municipal STPs and other dischargers.

Development of Simple Surface Water Models in Selected Areas
Surface water models have been developed for the entire Ausable Bayfield Maitland Planning Region. The details of these models, including set-up, calibration, sensitivity analysis and outputs are discussed in the document "Development of a Continuous Long-Term Numerical Water Budget Model for the Ausable Bayfield Maitland Valley Planning Region" (May, 2007) and included as Appendix D to this report. Surface water models will be refined and will be included in Tier I water budget analyses.

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.

6.3 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 ABCA/MVCA study area, this includes the Lake Huron 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 ABCA/MVCA study area, groundwater and surface water models are available for completion of any future work. Given the availability of these models, it would seem appropriate to utilize them for the Tier I water budget. 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 likely not required in order to complete the Tier I water budget for the study area. However, as these models are already completed and available, it is considered appropriate to use them for further water budgeting work.

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 ABCA/MVCA study area. These issues include both naturally occurring as well as introduced contaminants. The regional scale 3D groundwater flow model will assist with resolving some of these issues. Smaller scale, detailed surface water models can also be used to evaluate the relative contributions of specific parameters from land management practices in the future, if required. These models will be an important part of developing vulnerability assessments for municipal supplies, yet fall outside the purview of a water budget exercise.

References

Acres Consulting Services Limited. 1984. Water Quantity Resources of Ontario. G. Lyon's Litho Limited, Fort Erie

Dickinson T. and J. Diiwu. 2000. *Water balance calculations in Ontario* (unpublished). Guelph ON: School of Engineering, University of Guelph.

Environment Canada – Atmospheric Environment Service. 1982. *Canadian Climate Normals – Volume 3 – Precipitation 1951–1980*. Downsview, ON: Environment Canada Atmospheric Environment Service.

Ontario Ministry of Agriculture and Food. 1983. *Agricultural Resource Inventory*. Ontario Ministry of Agriculture and Food, Toronto.

Schroeter, H. O., D. K. Boyd and H. R. Whiteley. 2000. Filling gaps in meteorological data sets used for long-term watershed modelling. In *Proceedings of the Ontario Water Conference 2000*, Richmond Hill, ON.

Appendix A:

AES climate normals (1971 – 2000) for all AES stations within the study area

Appendix A Climate Normals (1971 – 2000) Measured at Long-Term AES Stations in the Ausable-Bayfield-Maitland Planning Region

CLIMATE STATION	DRAINAGE AREA (km2)	CLIMATE STATISTIC	MONTH													
			JAN	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**Annual**	**Annual (1951 - 1981)**
Blyth (6120819) 1971-2000	54.9	**Temperature**														
		Daily Average (°C)	-7.5	-6.7	-1.7	5.5	12.3	17.3	20.2	19.1	15.1	8.8	2.7	-3.6	**6.8**	
		Standard Deviation	3.3	3.5	2.6	2.1	2.2	1.7	1.4	1.8	1.3	1.9	1.9	3.1	**1.3**	
		Daily Maximum (°C)	-4.1	-2.9	2.5	10.1	17.9	22.9	25.9	24.6	20.1	13 4	5.8	-0.6	**11.3**	
		Daily Minimum (°C)	-10.8	-10.5	-5.9	0.8	6.7	11.7	14.5	13.6	10	5	-0.5	-6.5	**2.3**	
		Precipitation														
		Rainfall (mm)	24.9	22.9	39.1	68.4	89.8	85.1	72.7	105.9	115.4	89.2	80.7	40	**834**	
		Snowfall (cm)	102.9	55.9	33.9	13.4	0.4	0	0	0	0	3.6	40.5	99.8	**350.4**	
		Precipitation (mm)	127.8	78.8	73.0	81.8	90.2	85.1	72.7	105.9	115.4	92.8	121.2	139.8	**1184.3**	**1025.5**
Brucefield (6121025) 1971-1993	54.9	**Temperature**														
		Daily Average (°C)	-6.4	-6.3	-1	6.2	12.6	17.2	19.6	19	14.9	9	3.2	-3	**6.8**	
		Standard Deviation	2.8	2.9	2.4	1.9	2	1.5	1.1	1.2	1.1	1.8	1.4	2.6	**1.3**	
		Daily Maximum (°C)	-2.6	-2	3.5	11.4	18.9	23.4	25.8	24.9	20.4	13.6	6.6	0.2	**11.3**	
		Daily Minimum (°C)	-10.1	-10.6	-5.6	1.1	6.4	10.9	13.4	13	9.4	4.3	-0.3	-6.2	**2.3**	
		Precipitation														
		Rainfall (mm)	21.1	23.8	51.1	69.9	76.5	70.5	77	88.6	106.4	93	85.4	41.3	804.6	
		Snowfall (cm)	66	39.4	23.5	4.8	0.1	0	0	0	0	1.3	19.1	47.4	201.6	
		Precipitation (mm)	87	63.2	73.4	74.7	76.6	70.5	77	88.6	106.4	94.3	104.5	88.6	1004.8	**944.7**
Cromarty (6141919) 1971-1991	54.9	**Temperature**														
		Daily Average (°C)	-7.3	-6.9	-1.4	5.9	12.7	17.2	19.8	18.9	14.9	8.5	2.5	-4	6.7	
		Standard Deviation	3	3.2	2.7	2	2.3	1.5	1.2	1.4	1.3	2.1	1.8	2.9	2.1	
		Daily Maximum (°C)	-4	-3.1	2.6	10.6	18.4	22.9	25.8	24.6	20.1	12.9	5.5	-1	11.3	
		Daily Minimum (°C)	-10.7	-10.7	-5.4	1.2	7	11.4	13.8	13.1	9.5	4.1	-0.7	-7	2.1	
		Precipitation														
		Rainfall (mm)	19.6	24	53.8	66	75.4	72.2	77.4	90.1	111.4	90.7	79.2	45.6	**805.5**	
		Snowfall (cm)	84	54	33.8	12.7	0.6	0	0	0	0	3.7	30.3	71.6	**290.8**	
		Precipitation (mm)	103.6	78	87.5	78.8	76	72.2	77.4	90.1	111.4	94.5	109.6	117.2	**1096.3**	**1008.5**
Dashwood 6121969 1976 - 2000	54.9	**Temperature**														
		Daily Average (°C)	-5.6	-4.9	0.1	6.7	13.3	18.3	20.5	19.7	16	9.5	3.5	-2.5	**7.9**	
		Standard Deviation	2.8	3.1	2.4	1.7	2.1	1.6	1.3	1.3	0.9	1.6	1.6	2.8	**1.8**	
		Daily Maximum (°C)	-2.5	-1.4	4	11.1	18.6	23.5	25.7	24.7	20.8	13.6	6.5	0.4	**12.1**	
		Daily Minimum (°C)	-8.7	-8.3	-3.8	2.2	7.9	12.9	15.3	14.6	11.1	5.4	0.4	-5.3	**3.6**	
		Precipitation														
		Rainfall (mm)	23.1	25.3	42.4	75.2	78.5	76.8	85.5	81.9	118.8	84.1	76.4	43	**811.1**	
		Snowfall (cm)	49.4	32.6	19.4	4.6	0	0	0	0	0	1.3	18.3	48.5	**174.1**	
		Precipitation (mm)	72.5	57.9	61.9	79.9	78.5	76.8	85.5	81.9	118.8	85.4	94.6	91.5	**985.2**	--

CLIMATE STATION	DRAINAGE AREA (km2)	CLIMATE STATISTIC	MONTH													
			JAN	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**Annual**	**Annual (1951 - 1981)**
Exeter (6122370) 1971 – 2000	54.9	**Temperature**														
		Daily Average (°C)	-6	-5.7	-0.5	6.2	12.9	18	20.4	19.5	15.3	9.1	3.1	-2.9	**7.5**	
		Standard Deviation	2.7	2.9	2.5	1.8	2.1	1.5	1.2	1.3	1.2	1.7	1.6	2.7	**1**	
		Daily Maximum (°C)	-2.4	-1.8	3.7	11	18.6	23.6	25.8	24.7	20.5	13.6	6.5	0.4	**12**	
		Daily Minimum (°C)	-9.6	-9.7	-4.7	1.3	7.2	12.3	14.9	14.1	10.1	4.6	-0.3	-6.2	**2.8**	
		Precipitation														
		Rainfall (mm)	25.9	20.7	43.4	73.5	77.3	77.7	84.9	85.7	114.5	84.8	74.9	42.8	**805.8**	
		Snowfall (cm)	54.5	32.2	22.5	6	0.1	0	0	0	0	1.8	17.3	48.2	**182.7**	
		Precipitation (mm)	80.4	53	65.9	79.5	77.4	77.7	84.9	85.7	114.5	86.5	92.1	91	**988.5**	**961.5**
Ilderton Bear Creek (6143722) 1971 – 2000	54.9	**Temperature**														
		Daily Average (°C)	-6	-5.1	0.2	7	13.6	18.7	21.1	20	16.1	9.7	3.4	-2.8	**8**	
		Standard Deviation	2.9	2.8	2.3	1.7	2.2	1.4	1.1	1.2	1.1	1.7	1.7	2.8	**2**	
		Daily Maximum (°C)	-2.4	-1.2	4.4	12	19.4	24.6	27	25.7	21.3	14.3	6.8	0.4	**12.7**	
		Daily Minimum (°C)	-9.5	-8.9	-4	1.9	7.6	12.8	15.1	14.3	10.7	5.1	0	-6	**3.3**	
		Precipitation														
		Rainfall (mm)	28.2	27.1	51.5	79.1	87.6	85.4	82.3	96.1	97.5	74.7	76.1	43.8	**829.4**	
		Snowfall (cm)	50.6	34.4	23.4	6.2	0	0	0	0	0	2.2	17.8	51.5	**186.1**	
		Precipitation (mm)	78.8	61.5	74.9	85.3	87.6	85.4	82.3	96.1	97.5	76.9	93.8	95.4	**1015.5**	**923.5**
Lucknow (6124700) 1971 – 2000	54.9	**Temperature**														
		Daily Average (°C)	-6.7	-6.6	-1.7	5.7	12.3	16.8	19.5	18.8	14.6	8.5	2.7	-3.4	**6.7**	
		Standard Deviation	2.5	2.7	2.3	1.9	2	1.5	1.2	1.3	1.1	1.8	1.4	2.4	**1**	
		Daily Maximum (°C)	-2.9	-2.1	3.2	11.2	18.9	23.2	25.7	24.6	20.1	13.2	6.2	0	**11.8**	
		Daily Minimum (°C)	-10.5	-10.9	-6.5	0.2	5.8	10.4	13.2	13	9	3.7	-0.8	-6.7	**1.7**	
		Precipitation														
		Rainfall (mm)	15.9	15.2	38.5	64	79	82.2	69.5	99.4	109.6	94.4	79.9	34.5	**781.9**	
		Snowfall (cm)	111.2	67.6	32.8	11.4	0.3	0	0	0	0	3	26	86.6	**338.9**	
		Precipitation (mm)	127.1	82.8	71.3	75.5	79.3	82.2	69.5	99.4	109.6	97.3	105.9	121.1	**1120.9**	**1058.7**
Wroxeter (6129660) 1971 – 2000	54.9	**Temperature**														
		Daily Average (°C)														
		Standard Deviation														
		Daily Maximum (°C)		Temperature data not collected												
		Daily Minimum (°C)														
		Precipitation														
		Rainfall (mm)	20.4	19	38.9	59.7	86.7	85.3	77.2	99.1	99.3	77.7	68.8	34	**766.1**	
		Snowfall (cm)	64.6	36.8	23.6	6.2	0	0	0	0	0	1.1	23.7	54.8	**210.8**	
		Precipitation (mm)	85	55.8	62.5	65.9	86.7	85.3	77.2	99.1	99.3	78.8	92.4	88.9	**976.9**	**974.2**

Source: Environment Canada’s World Wide Web Site. Url of this page: http//climate.weatheroffice.ec.gc.ca/climate_normals/

Appendix B:

Historical daily and maximum/minimum streamflow within the planning region

Appendix B Long-Term Historical Streamflow Data for Gauged Watershed Units in the Ausable-Bayfield-Maitland Planning Area

PLANNING REGION SUBWATERSHED	DRAINAGE AREA (km^2)	STREAMFLOW STATISTIC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual
NINE MILE RIVER Lucknow A (02F002) (1980 - 1996)	54.9	Day Count (days)	527	481	527	510	527	510	527	523	480	496	480	508	6096
		Average Daily Flow (m^3/s)	1.31	1.56	2.61	2.09	0.862	0.536	0.26	0.298	0.545	0.701	1.34	1.47	1.13
		Maximum Daily Flow (m^3/s)	18.9	16.8	17.4	15.6	10.4	6.99	2.33	6	22.5	7.56	10.7	11.8	22.5
		Minimum Daily Flow (m^3/s)	0.251	0.36	0.322	0.502	0.203	0.107	0.026	0.059	0.086	0.093	0.136	0.355	0.026
NORTH MAITLAND Harriston (02FE011) (1981 - 1998)	112	Day Count (days)	527	480	527	481	496	480	501	527	510	527	510	527	6093
		Average Daily Flow (m^3/s)	1.99	2.15	4.41	3.23	1.08	0.707	0.235	0.268	0.694	0.883	2.15	1.9	1.64
		Maximum Daily Flow (m^3/s)	41.5	40.3	45	40	22.5	20.1	3.85	5.73	31.8	20.4	34.1	34.5	45
		Minimum Daily Flow (m^3/s)	0.12	0.181	0.121	0.477	0.153	0.078	0.014	0.017	0.032	0.031	0.166	0.14	0.014
Wingham A (02FE005) (1953 - 2002)	528	Day Count (days)	1519	1384	1550	1495	1524	1500	1550	1550	1500	1550	1500	1550	18172
		Average Daily Flow (m^3/s)	7.5	9.25	18.6	18	6.85	3.56	1.75	1.7	2.34	4.2	6.98	8.21	7.39
		Maximum Daily Flow (m^3/s)	154	144	243	286	191	108	39.4	53.8	89.9	222	105	117	286
		Minimum Daily Flow (m^3/s)	0.65	0.85	1.16	2.44	0.432	0.34	0.193	0.198	0.17	0.337	0.34	0.685	0.17
LITTLE MAITLAND Bluevale (02FE007) (1967 - 2002)	326	Day Count (days)	961	876	960	931	961	930	961	961	930	992	960	992	11415
		Average Daily Flow (m^3/s)	5.37	5.81	13	11.7	3.96	1.89	0.925	1.26	1.67	2.75	5.11	5.62	4.91
		Maximum Daily Flow (m^3/s)	89	90.3	172	167	83.8	21.4	15.5	94	63.9	48.7	64	81.5	172
		Minimum Daily Flow (m^3/s)	0.623	0.963	0.975	0.991	0.365	0.082	0.088	0.062	0.088	0.059	0.161	0.207	0.059
MIDDLE MAITLAND Listowel (02FE003) (1953 - 2002)	77.7	Day Count (days)	1520	1385	1550	1500	1550	1500	1550	1550	1500	1550	1500	1550	18205
		Average Daily Flow (m^3/s)	0.891	1.15	2.65	2.45	0.78	0.378	0.197	0.205	0.362	0.537	0.986	1.16	0.977
		Maximum Daily Flow (m^3/s)	37.3	33.1	55.8	47.6	27	46	8.16	19.1	39.8	32.8	31.1	21.7	55.8
		Minimum Daily Flow (m^3/s)	0.014	0.014	0.044	0.113	0	0	0	0	0.006	0	0.006	0.014	0
Boyle Drain (02FE010) (1989 - 2002)	197	Day Count (days)	372	339	372	360	341	330	341	353	360	403	390	403	4364
		Average Daily Flow (m^3/s)	1.94	2.27	8.22	8.8	1.67	0.354	0.095	0.432	0.521	0.797	1.96	2.55	2.5
		Maximum Daily Flow (m^3/s)	31.7	29.2	104	71.6	38.8	15.9	2.27	31.1	10.4	27.9	25.8	29.2	104
		Minimum Daily Flow (m^3/s)	0.059	0.1	0.113	0.317	0.017	0	0	0	0	0.003	0.014	0.057	0
Ethel (02FE013) (1983 - 1998)	416	Day Count (days)	465	424	464	421	434	420	434	434	420	440	450	465	5271
		Average Daily Flow (m^3/s)	7.55	8.07	17.2	11.1	3.16	2.14	1.73	1.94	3.61	4.37	9	7.55	6.54
		Maximum Daily Flow (m^3/s)	93.3	124	121	115	49.9	53	49.7	42.4	104	89	79.4	84.7	124
		Minimum Daily Flow (m^3/s)	0.58	0.54	0.48	1.05	0.289	0.06	0.037	0.014	0.03	0.121	0.326	0.49	0.014
Belgrave (02FE008) (1967 - 1998)	648	Day Count (days)	961	876	961	901	930	900	930	930	900	961	930	961	11141
		Average Daily Flow (m^3/s)	9.88	11.4	26	22.8	6.17	2.69	1.61	2.37	3.65	5.37	10.7	11.4	9.53
		Maximum Daily Flow (m^3/s)	138	200	282	237	138	68.8	52.2	135	139	122	118	115	282
		Minimum Daily Flow (m^3/s)	1.26	1.31	1.15	2.08	0.476	0.22	0.116	0.16	0.144	0.161	0.297	0.532	0.116
BLYTH BROOK Blyth (02FE014) (1984 - 2002)	77.7	Day Count (days)	310	282	310	320	341	330	341	341	330	341	333	372	3951
		Average Daily Flow (m^3/s)	1.44	1.21	3.6	2.17	0.655	0.365	0.161	0.208	0.663	0.967	1.69	1.54	1.2
		Maximum Daily Flow (m^3/s)	21.6	23	28.5	26.6	5.32	5.48	2.28	5.56	25.7	9.04	25.1	23.5	28.5
		Minimum Daily Flow (m^3/s)	0.19	0.225	0.26	0.335	0.139	0.038	0.01	0.008	0.012	0.023	0.07	0.124	0.008

(Continued on next page)

Appendix B Long-Term Historical Streamflow Data for Gauged Watershed Units in the Ausable-Bayfield-Maitland Planning Area

PLANNING REGION SUBWATERSHED	DRAINAGE AREA (km^2)	STREAMFLOW STATISTIC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual
SOUTH MAITLAND	376	Day Count (days)	1085	989	1085	1050	1085	1050	1085	1085	1050	1116	1080	1116	12876
Summerhill (02FE009)		Average Daily Flow (m^3/s)	6.96	9.21	15.6	11.1	3.86	1.98	0.97	1.06	1.98	3.68	6.93	7.89	5.91
(1967 - 2002)		Maximum Daily Flow (m^3/s)	115	191	148	113	72.4	61.4	30.2	35.4	89.4	58.4	75	72.4	191
		Minimum Daily Flow (m^3/s)	0.25	0.555	0.71	1.09	0.303	0.109	0.004	0.01	0.004	0.043	0.096	0.219	0.004
MAITLAND (Main Branch)	1630														
Wingham B (02FE002)		Day Count (days)	1333	1215	1364	1350	1395	1350	1395	1391	1320	1364	1320	1364	16161
(1953 - 2002)		Average Daily Flow (m^3/s)	21.4	26.8	61.1	57.4	19.2	8.67	4.4	4.69	6.85	12.8	20.8	25.6	22.4
		Maximum Daily Flow (m^3/s)	372	464	680	626	303	136	115	297	347	464	261	315	680
		Minimum Daily Flow (m^3/s)	1.25	1.44	3.03	6.48	1.3	0.623	0.142	0.142	0.057	0.283	0.396	0.946	0.057
Benmiller (02FE015)	2510	Day Count (days)	434	395	434	420	434	420	434	434	420	434	420	434	5113
(1989 - 2002)		Average Daily Flow (m^3/s)	9.6	60.6	84.8	71.4	34.3	22	10	10.1	12	22.4	48.2	43.6	39.8
		Maximum Daily Flow (m^3/s)	553	523	487	447	406	357	82.9	131	124	185	429	405	553
		Minimum Daily Flow (m^3/s)	8	6.95	8.8	13	3.37	2.67	1.36	0.874	0.774	1.37	1.72	3.2	0.774
BAYFIELD Silver Creek	--	Day Count (days)									20	31	30	31	112
(02FF011)		Average Daily Flow (m^3/s)	0	0	0	0	0	0	0	0		0.009	0.024	0.162	
(2002 - 2002)		Maximum Daily Flow (m^3/s)									0.021	0.027	0.065	1.72	1.72
		Minimum Daily Flow (m^3/s)										0.002	0.008	0.021	
Varna (02FF007)	466														
(1966 - 2002)		Day Count (days)	1116	1017	1116	1080	1116	1080	1116	1116	1080	1147	1110	1147	13241
		Average Daily Flow (m^3/s)	7.18	9.08	17	10.9	4.24	2	1.18	0.864	2.56	3.52	6.89	8.27	6.13
		Maximum Daily Flow (m^3/s)	153	264	280	181	127	74.8	87	32.7	205	85.3	129	148	280
		Minimum Daily Flow (m^3/s)	0.372	0.47	0.7	1.45	0.337	0.09	0.031	0.039	0.041	0.069	0.135	0.362	0.031
AUSABLE Parkhill Inflow	110	Day Count (days)	899	839	930	900	930	900	930	930	900	930	900	930	10918
(02FF008)		Average Daily Flow (m^3/s)	1.62	2.28	3.54	2.05	0.853	0.489	0.322	0.188	0.828	0.828	1.62	1.89	1.37
(1973 - 2002)		Maximum Daily Flow (m^3/s)	30.4	39	32	36.8	26.1	15.6	17.8	14.4	28.5	21.1	28.3	24.4	39
		Minimum Daily Flow (m^3/s)	0.029	0.071	0.055	0.193	0.037	0	0	0	0	0	0	0.034	0
											1110	1178	1140	1178	14179
South Parkhill Creek	41.4	Day Count (days)	1147	1045	1410	1420	1147	1110	1147	1147	0.327	0.371	0.658	0.834	0.586
(02FF004)		Average Daily Flow (m^3/s)	0.658	1.03	1.52	0.662	0.321	0.253	0.111	0.081	29.7 0	15.2 0	18.7 0	16.4	47.8 0
(1955 - 2002)		Maximum Daily Flow (m^3/s)	33.7	47.8	38.1	16	12.2	21.5	9.25	11.5				0.005	
		Minimum Daily Flow (m^3/s)	0.008	0.003	0.001	0	0	0	0	0					
Exeter (02FF009)	113	Day Count (days)	558	508	558	540	558	540	558	562	570	589	570	589	6700
(1984 - 2002)		Average Daily Flow (m^3/s)	2.27	2.56	3.96	2.23	1	0.805	0.588	0.301	1.12	0.954	1.95	1.97	1.63
		Maximum Daily Flow (m^3/s)	40.4	47.8	28.5	29.7	20.5	43	43.3	14.8	43.7	16.4	31.7	22.1	47.8
		Minimum Daily Flow (m^3/s)	0.1	0.16	0.217	0.318	0.069	0.009	0	0	0	0.008	0.015	0.104	0
Springbank (02FF002)	865	Day Count (days)	1705	1554	1749	1710	1767	1710	1767	1767	1710	1798	1740	1798	20775
(1945 - 2002)		Average Daily Flow (m^3/s)	12	16.1	29.4	18.1	7.45	3.94	2.23	1.68	3.55	5.08	9.68	14	10.2
		Maximum Daily Flow (m^3/s)	207	351	317	351	165	120	227	53	205	244	156	250	351
		Minimum Daily Flow (m^3/s)	0.227	0.227	0.906	0.821	0.302	0.142	0.096	0.058	0.113	0.028	0.17	0.283	0.028

Source: Hydat CD - 2002

Appendix C:

Average historical streamflows as estimated depth of runoff

Appendix C Long-Term Average Annual Runoff Volumes from Gauged Watershed Units in the Ausable-Bayfield-Maitland Planning Region

Gauge Station Name	Average Monthly Streamflow Volumes (mm)												
(Station ID)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual
Ausable													
Parkhill Inflow (02FF008)	39.4	50.6	86.2	48.3	20.8	11.5	7.8	4.6	19.5	20.2	38.2	46.0	393.0
South Parkhill Creek (02FF004)	42.6	60.7	98.3	41.4	20.8	15.8	7.2	5.2	20.5	24.0	41.2	54.0	446.7
Exeter (02FF009)	53.8	55.3	93.9	51.2	23.7	18.5	13.9	7.1	25.7	22.6	44.7	46.7	455.2
Springbank (02FF002)	37.2	45.4	91.0	54.2	23.1	11.8	6.9	5.2	10.6	15.7	29.0	43.3	372.1
Bayfield													
Silver Creek (02FF011)													
Varna (02FF007)	41.3	47.6	97.7	60.6	24.4	11.1	6.8	5.0	14.2	20.2	38.3	47.5	415.1
Maitland													
Harriston (02FE011)	47.6	46.9	105.5	74.8	25.8	16.4	5.6	6.4	16.1	21.1	49.8	45.4	462.1
Wingham A (02FE005)	38.0	42.8	94.4	88.4	34.7	17.5	8.9	8.6	11.5	21.3	34.3	41.6	441.7
Bluevale (02FE007)	44.1	43.5	106.8	93.0	32.5	15.0	7.6	10.4	13.3	22.6	40.6	46.2	475.3
Listowel (02FE003)	30.7	36.1	91.3	81.7	26.9	12.6	6.8	7.1	12.1	18.5	32.9	40.0	396.8
Boyle Drain (02FE010)	26.4	28.1	111.8	115.8	22.7	4.7	1.3	5.9	6.9	10.8	25.8	34.7	400.5
Ethel (02FE013)	48.6	47.3	110.7	69.2	20.3	13.3	11.1	12.5	22.5	28.1	56.1	48.6	496.1
Belgrave (02FE008)	40.8	42.9	107.5	91.2	25.5	10.8	6.7	9.8	14.6	22.2	42.8	47.1	464.1
Blyth (02FE014)	49.6	38.0	124.1	72.4	22.6	12.2	5.5	7.2	22.1	33.3	56.4	53.1	487.4
Summerhill (02FE009)	49.6	59.8	111.1	76.5	27.5	13.6	6.9	7.6	13.6	26.2	47.8	56.2	496.0
Wingham B (02FE002)	35.2	40.1	100.4	91.3	31.5	13.8	7.2	7.7	10.9	21.0	33.1	42.1	433.7
Benmiller (02FE015)	63.6	58.9	90.5	73.7	36.6	22.7	10.7	10.8	12.4	23.9	49.8	46.5	500.4
Nine Mile													
Lucknow A (02F002)	63.9	69.4	127.3	98.7	42.1	25.3	12.7	14.5	25.7	34.2	63.3	71.7	649.5
Lucknow B (CA Station)													

Source: Hydat CD - 2002

Appendix D:

Conceptual Water Budget Maps

CWB Map 1: Planning Region Subwatersheds

CWB Map 2: Climatological Monitoring Stations

CWB Map 3: Thiessen Polygon Map for Daily Climate Stations

CWB Map 4: Thiessen Polygon Map for Hourly Climate Stations

CWB Map 5: Landcover

CWB Map 6: Soils

CWB Map 7: Hydrologic Response Units

CWB Map 8: Tile Drainage

CWB Map 9: Runoff in mm/yr for Gauged Watersheds

CWB Map 10: Bedrock Topography

CWB Map 11: Groundwater Flow in Bedrock Aquifer

CWB Map 12: Potential Overburden Aquifers

Appendix E:

Development of a Continuous Long-Term Numerical Water Budget Model for the Ausable Bayfield Maitland Valley Planning Region (May 18, 2007)

Development of a Continuous Long-Term Numerical Water Budget Model for the Ausable Bayfield Maitland Valley Planning Region

Set-up, Performance Evaluation and Selected Model Application to Support Tier 1 Water Budget Analyses

May 18, 2007

Development of a Continuous Long-Term Numerical Water Budget Hydrologic Model for the Ausable Bayfield Maitland Valley Planning Region

Set-up, Performance Evaluation and Selected Model Application to Support Tier 1 Water Budget Analyses

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Summary

The Ausable Bayfield Maitland Valley Source Water Protection technical team undertook selecting and setting up a continuous numeric hydrologic model for river systems within the Ausable Bayfield Maitland Valley Drinking Water Source Protection Planning Region. This document describes the steps that were taken in completing this work. Model selection and development were guided by the findings and recommendations of the conceptual water budget report prepared earlier for the same planning area. The first iteration model setup described herein simulates long-term evapotranspiration, streamflow, and aquifer recharge for all the major river systems located within the Planning Region including the Lucknow (Nine Mile) River, the Maitland River, the Bayfield River, the Parkhill River and the Ausable River. It also models the extensive set of lakeshore gullies and streams situated along the Planning Region's Lake Huron shoreline. In total, 5727 km^2 of land along the east shore of Lake Huron were modelled using a continuous surface water numerical modelling approach.

Two hydrologic models were initially considered and "test driven" as part of this study. The modeling tool called SWAT (Soil and Water Assessment Tool) was identified in the Region's conceptual water budget report as being the numerical model of choice, particularly if watershed-scale non-point source water quality modeling or climate change modeling was required in any future phases of source water planning. SWAT was also found to interface well with existing GIS tools and related databases, allowing the model to be easily updated and improved as new GIS-based datasets for the Region became available in the future.

The GAWSER (Guelph All-Weather Storm-Event Runoff) model was identified in the Region's conceptual water budget report as the second model of choice. Its strength lies with its ability to represent winter hydrologic conditions, particularly snowmelt/runoff events. It also has the flexibility to be run in both long-term continuous mode as well as in an event mode using sub-daily time steps, giving it an advantage if a single model had to be chosen that could also double as a flood forecasting tool. An objective evaluation of these two models in the context of the ABMV Planning Region and anticipated modlling needs under source water protection is presented in this report.

The same schematic representation of the major river systems of the Region was used for both models. The Lucknow, Maitland, Bayfield, Ausable, Parkhill and Shoreline systems were modelled by defining 8, 63, 37, 47, 75 and 242 subcatchments respectively.

Streamflow data from 16 different long-term historical stream gauges along the river systems within the ABMV Planning Region were used to calibrate and validate the two models. Both graphical and statistical approaches were used to assess the ability of the models to represent annual, monthly and daily streamflows. Graphs comparing measured and modelled annual stream volumes over a 20 year period were prepared as were graphs comparing measured and modelled mean monthly volumes. Both models gave very good to excellent simulations of long-term monthly streamflows following calibration of selected global input variables. The Nash-Sutcliffe statistical test of model performance gave SWAT a slightly higher score than GAWSER for representing long-term monthly streamflows (0.81 vs. 0.76). The R^2 statistical

test of model performance also gave SWAT a slightly higher monthly streamflow simulation score than it gave to GAWSER (0.82 vs. 0.78). For daily estimates of streamflow, both models performed poorly, although GAWSER output produced higher statistical scores than did SWAT's daily output. (0.4 for SWAT vs. 0.54 for GAWSER for the Nash-Sutcliffe test and 0.45 for SWAT vs. 0.56 for GAWSER for the R^2 statistical test). It is thought that the better performance by GAWSER when the models were operated in daily mode can be attributed primarily to the fact that GAWSER requires hourly precipitation input. It's stronger winter hydrology routine could also be a factor. At a monthly time-scale, however, the benefit of sub-daily precipitation input did not carry through. Given that source water protection programs and decision-making is more likely to be made on long-term trends, that there will be a greater chance of a need to model water quality as opposed to water quantity in the MVCA Planning Region, and that currently there exists a higher degree of software development and user support momentum behind the SWAT model, it was decided to proceed with preparing initial Tier 1 numerical water budget estimates for the ABMV Planning Region with the aid of SWAT.

Long-term monthly and seasonal water balance quantities, 7-day low flows and flow duration curves were computed for the ABMV Planning Region's main river and shoreline systems by applying the SWAT model in continuous simulation mode for a 20 year period (1985 to 2004). Preliminary determinations of the 7-day low flows estimated for this 20 year period were compared with values derived from similar analyses completed on available streamflow records for the area.

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Daily streamflow data for the 16 long-term historical stream gauges mentioned in this report were obtained from the Water Survey of Canada, Environment Canada, Burlington, Ontario. Historical climate information (daily maximum and minimum air temperature, rainfall and snowfall depths, and hourly rainfall depths) were obained from Environment Canada's Atmospheric Environment Service as well as from Maitland Valley's and Ausable-Bayfield's climate stations that are associated with their local flood forcasting system. Data filling work, as described in a memo report prepared for the ABMV Planning Region by Schroeter and Associates (2005) was used to integrate these two sources of climate information for its ultimate use as daily and hourly input to the continuous hydrologic models applied in this study.

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1.0 Introduction

1.1 Background

In October 2006, the Ontario government passed legislation referred to as the "Clean Water Act". The government's intent with this legislation is to help ensure protection of drinking water at its source as part of its overall commitment to human health and the environment. Regulations established under the authority of the Clean Water Act have identified the combined areas under the jurisdiction of the Ausable Bayfield Conservation Authority and Maitland Valley Conservation Authority as one of the province's nineteen (19) source protection regions. This area is referred herein as the Ausable Bayfield Maitland Valley (ABMV) Source Protection Planning Region.

A key requirement of the Clean Water Act legislation is the completion of a locally-developed, science-based regional assessment of the status of source water in the protection region. Findings from this regional assessment will subsequently assist in developing the same region's source water protection plan. A significant component of the science-based regional assessment is referred to as the water budget where water sinks and sources, water supply and demand are quantified and the movement of water within the planning region is described.

The province has established guidance to assist local source protection planning technical teams in navigating the steps involved in preparing a water budget for their planning region. The publically-available full version of these guidance documents, available at the time this report was prepared, was released October, 2006. It describes the preparation of a water budget as an iterative, tiered process in which greater complexity is incorporated into the water budget as data are gathered and areas are eliminated as needing increasingly complex water budgetting descriptions and approaches. A more recent draft version of the technical guidance's water budget module, distributed to Conservation Authorities in March, 2007, continues to promote a similar tiered approach when preparing a water budget for a source protection region.

In accordance with the technical guidance, water budgetting begins with the preparation of a peer-reviewed conceptual water budget. The conceptual water budget for the ABMV Planning region was prepared by following earlier (October, 2005) guidance materials prepared by the Source Water Implementation Group. The hydrologic modelling tool selected and described in this report, as a follow-up response to recommendations given in the conceptual water budget report, provides the additional technical and science-based information needed to effectively prepare the ABMV Planning Region's Tier 1 water budget report. The Tier 1 report is being prepared under a separte report cover in accordance with Module 7 of the draft (March, 2007) Technical Guidance.

The conceptual water budget report presented a set of criteria to use when selecting an appropriate numeric hydrologic model for source water protection purposes. The model selection approach, originally developed by Von Euw (1990), includes both subjective and objective criteria with which to evaluate a short list of candidate models. The subjetive rating, presented in the ABMV's conceptual water budget report, identified GAWSER and SWAT as being the most suitable modelling packages for watershed modelling purposes in the ABMV

Planning Region. Completing the objective evaluation of the two models, however, required actually applying the two preferred models, and assessing each model's performance in relation to actual field observations. By "test-driving" the two preferred models to determine their strengths and weaknesses, they could then be more fully and practically evaluated. Following this "hands-on" assessment a single model could then be selected and further applied to produce quantitative estimates of water budget components needed for Tier 1 level water budget calculations for the Planning Region.

1.2 Purpose and Scope of the Work

The specific tasks related to the selection and development of a continuous long-term hydrologic model capable of generating Tier 1-related hydrologic data that characterizes the major river systems within the ABMV Planning Region, were as follows:

1. Become familiar with, assemble the input data and prepare the input code necessary to operate the SWAT (Soil and Water Assessment Tool) hydrologic model for key subwatersheds and the major river systems of the ABMV Planning Region.

2. Become familiar with, assemble the input data and prepare the input code necessary to operate the GAWSER (Guelph All-Weather Sequential Events Runoff) hydrologic model for key subwatersheds and the major river systems of the ABMV Planning Region.

3. Assess the relative sensitivity of selected input variables for the SWAT and GAWSER models that influence each model's simulation of a river system's hydrologic response.

4. Using the results of the sensitivity analysis, undertake a preliminary calibration of both the SWAT and GAWSER hydrologic models using available historical stream discharge measurements for selected historical stream gauged subwatersheds within the ABMV Planning Region.

5. Using the findings from the calibration exercise, validate the model by comparing and assessing the output of the two models (SWAT and GAWSER) for gauged subwatersheds in the Planning Region not used in the calibration step.

6. Use the findings from both the calibration and validation steps to complete the objective analysis in the model selection process.

7. Further refine and apply the selected model to each of the ABMV Planning Region's main river systems as well as to its Lake Huron shoreline area, to arrive at monthly and annual estimates of the following water budget components:

    - Precipitation
    - Actual evapotranspiration
    - Surface runoff
    - Drainage tile flow (if possible)
    - Baseflow
    - Shallow aquifer and deep aquifer recharge

8. Using the selected model's estimate of twenty plus years of daily streamflow, complete a Tier 1 level approximation of the monthly 50th percentile flows (Q_{p50}) and 10th percentile flows(Q_{p10}) for the main river systems and shoreline area of the ABMV Planning Region.

9. Complete a preliminary estimate the 7Q20 low flows for selected locations within the ABMV Planning Region

10. Identify any additional input data, field measurements or changes to the selected model's code that could be made to possibly improve the accuracy, reliability, applicability and acceptance of this hydrologic model for use in water budgetting/source water protection purposes within the Ausable Bayfield Maitland Valley Planning Region.

1.3 Previous and Related Concurrent Studies

Work has been completed in the past to numerically model the surface hydrology of the ABMV Planning Region. The main objectives of developing these past models has been for flood forcasting and floodplain mapping along key reaches of interest. Less modelling effort has focussed on long-term hydrologic modelling and tracking of the area's water budget.

The Basins Runoff Forecast Unit model (BRFU) has been applied to all of the main river systems located within the jurisdictional boundaries of the Maitland Valley Conservation Authority (MVCA) and the Ausable-Bayfield Conservation Authority (ABCA). It has also been used to generally characterize the hydology of regions of the Maitland Valley CA shoreline (BM Ross and Associates, 1994). While the BRFU hydrologic model is essentially an event-based model, the idea of modifying it to operate in a continuous mode has been explored. Through the source water protection initiative, a contract was issued to developers of the BRFU model in the spring of 2005 to investigate this possibility. It was shown that, while the potential exists, a significant amount of work is still required to develop the BRFU model into a user-friendly continuous hydrologic model for the study area.

The GAWSER (Guelph All Weather Sequential Events Runoff) model, has also been applied as an event model and as a flood forecasting tool on the Planning Region's Ausable, Bayfield and Parkhill river systems (Schroeter and Associates, 1992; Schroeter and Associates, 1995). Since this initial (1992) application of GAWSER in the Ausable-Bayfield portion of the Planning Region, the GAWSER model has been further developed and enhanced, enabling it to operate in continuous mode for long-term water budgetting purposes. These modifications to the GAWSER code unfortunately, meant that the earlier GAWSER input data files developed for the ABCA river systems, also required modification in order to use them as input files for the continuous version of GAWSER. As well, GAWSER, has yet to be applied on a continuous basis on the numerous shore streams, and gullies that drain much of the land within a zone that extends 5 to 10 km east of the Lake Huron shoreline. Presently, this is the area that also tends to generate a significant number of water and resource-related anthropogenic issues and concerns within the ABMV Planning Region, particularly with respect to water quality.

The ABMV Planning Region's conceptual water budget report (ABMV, 2006) provided a general summary of the area's observed hydrologic character including a summary of measured spatial variability of rainfall, snowfall, observed streamflow and estimates of surface runoff, baseflow, and anthropogenic (agricultural) water use. A second separate report prepared by Luinstra Earth Sciences (2006) looked at the record of permits to take water throughout the ABMV Planning Region to further help characterize anthropogenic water taking in the Region. Other relevant spatial databases including land use, soils, geology, topography, subsurface tile drainage and stream network details were also assembled as part of preparing the conceptual water budget. These datasets formed the basis for preparing the input files and calibrating the numeric models described in this study.

In 2005, the Ontario Ministry of the Environment funded a separate but related Shoreline Hydrology Project. This project had the dual objective of developing a better understanding of both the hydrologic nature of the streams and gullies along the Lake Huron shoreline as well as understanding the effect their discharges have on the quality of shoreline water. Through time, this project will accumulate streamflow data for selected representative shoreline streams and gullies to assist with calibrating and validating a numeric model for shorline subcatchments. In the interim, a hydrologic model, set-up for the shoreline which uses values for model input variables developed for neighbouring stream gauged river basins within the area, will provide a first approximation of the hydrologic response of this shoreline zone, suitable for a Tier 1 level of assessment.

2.0 Watershed Modelling

2.1 Background on Numeric Model Selection Process

As mentioned in Section 1.3, some work was completed in 2005 to explore the potential of converting the existing BRFU event model already set-up for the study region into a continuous model (MacPherson, May 2005). While the BRFU modifications worked, and work continues by BRFU model developers to improve BRFU's function in this regard, input data needed to drive the model for long periods of record were often incomplete and often based on interim datasets. For example, the revised BRFU model requirs measured hourly potential ET data as input. These data have only been collected in the study area since 2004. This limits using the BRFU model on a continuous basis to the period for which real-time potential ET data have been collected in the Region (i.e. post 2004). As well, actual ET values estimated by the modified BRFU model were found to be significantly lower than actual ET estimates derived for other source protection regions in southern Ontario (see Table 1).

Table 1. Comparison of Actual ET Estimates for the ABMV Planning Region with Estimates from other Southern Ontario Source Protection Regions.

Planning Region	Actual ET Estimation Method	Actual ET Range
ABMV	Modified BRFU	330 – 460 (2004 only)
ABMV	Acres Consulting Services (1984)	561 - 693
ABMV	Dickinson and Diiwu (2000)	450 - 550
Thames Sydenham[1]	Thornwaite and Mather	537 - 570
Essex Region[2]	Thornwaite and Mather	545 - 585

[1] Thames Sydenham and Region Source Water Protection (2006)
[2] Essex Region (2007)

The ABMV Planning Region's conceptual water budget report (ABMV, 2006) includes a table outlining the comparison criteria that were used to undertake the evaluation of the surface water models considered for numerical water budgetting purposes. Following an initial screening (Phase I), four (4) models, GAWSER, HSP-F, SWAT and AGNPS were considered to be best suited to the numerical modelling task at hand. These models then proceeded to a Phase II evaluation step that involved scoring each of these short-listed models using a common set of subjective and objective evaluation criteria. GAWSER and SWAT received the highest subjective scores of 36.5 and 42.9 (out of 60) respectively. This then warranted further testing and evaluation of these two models within the context of the ABMV Planning Region to complete an objective evaluation of the two models. Combining the subjective and objective scores would eventually lead to the selection of a preferred model for use. The report sections that follow describe the data preparation, model set-up and output analyses undertaken to complete an objective analysis of the preferred models. This document also presents data resulting from the application of the final selected model needed to undertake a Tier 1 level water budget analysis for the ABMV Planning Region.

2.2 SHORT-Listed Model Descriptions

2.2.1 The Soil and Water Assessment Tool (SWAT) Model

SWAT (Soil and Water Assessment Tool) was developed and is actively supported by researchers at the USDA-ARS (United States Department of Agriculture- Agriculture Research Service). Their objective in developing the model was to be able to predict the effect of land management decisions on water, sediment, nutrient and pesticide yields with reasonable accuracy on large, ungauged river basins (SWAT, 2007). In recent years it has become a key modelling tool for estimating runoff volumes and total maximum daily loadings (TMDLs) of non-point and point source pollutants to waterbodies listed as threatened or impaired in the United States. It has also been applied in many other regions of the world. A full description of the SWAT model and the range of applications and the support that is available for this model can be found on the SWAT Home website (SWAT, 2007). Complete manuals and supporting documentation can be accessed from this website as can a copy of the public domain model itself.

For source protection water budgetting applications, SWAT's hydrologic modelling component and its corresponding ability to predict long-term stream flows is of primary interest. While the model's ability to predict sediment, nutrient and pesticide yields may also be of interest in the future, evaluating this componenet of SWAT was beyond the scope of this initial set-up and application of the SWAT model in the ABMV Planning Region. Nevertheless, if SWAT is shown to be capable of giving reasonably accurate predictions of the water budget component of the study area, this would encourage testing its ability to predict non-point source loadings of pollutants of concern in future phases of source protection planning. The following gives a brief description of SWAT's water budgeting/hydrologic modelling approach.

SWAT is a distributed hydrologic model, allowing a river basin of interest to be divided into a series of subcatchments. These subcatchments are then further divided into areas of common soil and land use characteristics defined as hydrologic response units (HRUs). SWAT considers the hydrology of a watershed to be divided into two major phases – the land phase and the hydrologic routing phase. The land phase controls the amount of water that reaches the main channel in each subcatchment while the hydrologic routing phase determines the movement of water through the channel network to the watershed outlet. The hydrologic cycle for the land phase is simulated separately by SWAT under a daily time step for each HRU using the following water balance equation (Neitsch et al., 2002):

$$SW_t = SW_0 + \sum_{i=1}^{t} (R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw})$$

where SW_t is the final soil water content (mm), t is the time (days), R_{day} is the amount of precipitation on day i (mm), Q_{surf} is the amount of surface runoff on day i (mm), E_a is the amount of evapotranspiration on day i (mm), w_{seep} is the amount of water entering the vadose zone from the soil profile on day i (mm) and Q_{gw} is the amount of return flow on day i (mm).

SWAT allows the user to choose to partition the precipitation that falls on each HRU between runoff and infiltration using either the Green-Ampt infiltration method or a modified version of the Soil Conservation Service (SCS) runoff curve number method. The Green-Ampt method requires that the user provide precipitation input data on a 30-minute time step or smaller. Our preliminary testing of this infiltration modelling approach, however, revealed that it was not yet a fully functional option in SWAT. As well, it resulted in significantly slower run times and unmanageably large output files given the scale of modelling being considered in this study. The curve number method on the other hand operates on a daily time step, allowing the use of more readily available daily precipitation data.

The curve number method does not model infiltration directly. Instead, it estimates runoff and calculates the infiltration to be the difference between the amount of rainfall and the amount of surface runoff. The modified version of the SCS model applied in SWAT adjusts runoff amounts depending on the antecedent moisture content and the runoff curve number associated with the HRU being simulated.

Once runoff is predicted for each HRU in a subcatchment, the runoff from each HRU is summed and this runoff amount is routed from the subcatchment's outlet point to the watershed outlet.

Routing of water along the main channel in SWAT is achieved by using either the variable storage coefficient method developed by Williams (1969) or the Muskingham routing method. As water flows downstream, a portion can be lost due to evaporation or transmission through the bed channel. Surface water takings from the channel for human use can be simulated as can human inputs such as sewage treatement plant discharges to the channel system. (Neitsch et. al., 2002).

Water that does not run off enters the soil. SWAT redistributes the soil water in a manner that attempts to reach a uniform water content throughout the soil profile. The soil water redistribition component of SWAT uses a storage routing technique to predict flow though each soil layer . Downward flow (percolation) occurs when the field capacity of a soil layer is exceeded and the layer below is not already saturated. The flow rate through the upper soil layer is governed by its saturated hydraulic conductivity. When soils are frozen in a particular layer, no redistribution from that layer is allowed.

SWAT gives the user three options for estimating potential evapotranpiration (PET) – Hargreaves, Priestley-Taylor and Penman-Monteith. Actual soil water evaporation is estimated by using exponential functions of soil depth and water content. Plant transpiration is simulated as a linear function of potential evapotranspiration and leaf area index as proposed by Ritchie, (1972) (Neitsch et. al., 2002). SWAT also simulates plant growth, therefore adjusting leaf area index throughout the season. It also considers the availability of soil water on the day of simulation.

Water that percolates past the bottom of the root zone is assumed to act as recharge to either a shallow unconfined aquifer system or a deep confined aquifer system. The shallow aquifer can contribute return flows to streams within the subcatchment, while water in the deep aquifers may contribute to stream flows at points outside the subcatchment. Water stored in the shallow aquifer may replenish water in the soil profile under very dry conditions or be removed by plant roots (Neitsch et al., 2002). Water may be pumped out of either the shallow or deep aquifers.

2.2.2 The Guelph All-Weather Sequential Events Runoff (GAWSER) Model

GAWSER was originally a 1970s University of Guelph adaptation of the popular HYMO hydrologic program created by Williams and Haan of the USDA-ARS and Texas A & M University in the late 1960s. Since the 1970's, GAWSER has undergone a number of revisions in reponse to meeting the demands of the various situations in which it was applied. It has been applied widely in Ontario for planning, design and real-time flood forcasting (Schroeter and Associates, 2006c). In 1987-1988, it was set up to model the entire Grand River Watershed and later formed the basis for the Grand River Conservation Authoritiy's real-time flood forcasting system (Schroeter & Associates, 2006c). A very similar GAWSER-based flood forcasting tool was subsequently applied in the Ausable Bayfield watershed (Schroeter & Associates, 1995).

Watershed studies undertaken in the province initiated the need for GAWSER to operate in continuous mode, so a continuous (sequential events) version was developed and has since been applied in a number of source water protection hydrologic modelling studies (Schroeter & Associates, 1999a and Schroeter and Associates, 2006a,b,c). A GAWSER Training Guide is available (Schroeter and Associates, 1996) as is one-on-one support from the key developer of the model. For detailed information on the operation of GAWSER beyond what is presented below, the reader is referred to the Training Guide as well as the many GAWSER model application reports prepared in the past (e.g. Schroeter and Associates, 2006a,b,c). To summarize, GAWSER has been extensively calibrated, verified and validated in more than 40 Ontario watershed modelling studies within the last 20 years. The continuous version of the model has been compared with long-term streamflow data from more than 40 gauges resulting in some 600 gauge-years of application (Schroeter and Associates, 2006c).

GAWSER simulates nine hydrological processes including snow accumulation and ablation, interception and depression storage, infiltration, evapotranspiration, runoff estimates and overland flow routing, subsurface and baseflow routing, channel routing and reservoir routing. (Schroeter et al., 2000). There is some capability to estimate sediment loads as well. Like SWAT, today's version of GAWSER can also be considered a distributed model that uses the concept of HRUs to determine the hydrologic response of each subcatchment. GAWSER, however, limits the total number of HRUs that can be defined within a subcatchment to nine (one impervious HRU and eight pervious) . This does not mean only nine HRUs can be defined for the entire study area, as the input can be prepared to allow an entirely different set of nine HRUs to be defined for each modelled subcatchment. Typically, however, the model is set-up in a manner that defines a set of nine HRUs for each defined zone of uniform meteorology (ZUM). As well, the model is typically set-up to include two HRUs that define forested areas in the watershed. One of the forested HRUs is typically characterized as forests located on rapidly-draining soils while the second forested HRU is defined as being located on more slowly draining soil types. This leaves six HRUS to be defined in a manner that best represents the predominance of wetland areas and soil and agricultural land cover combinations within the watershed's subcatchments.

Rainfall (or snowmelt) falling on a GAWSER-defined impervious HRU first fills surface depression storage before it is available to contribute to overland runoff. Rainfall (or snowmelt) falling on one of GAWSER's-defined pervious HRUs is partitioned into overland runoff and infiltration using the Green-Ampt infiltration model (Mein and Larson, 1973). As such, GAWSER requires that the rainfall/snowmelt input be provided on a time step. Typically, an hourly time step is used, however, it can accommodate other time steps (1 minute to 24 hours). While this can make input climate data more difficult to assemble and locate, it does allow GAWSER to generate output on a sub-daily basis. This is particularly useful if the desire is to model runoff events (such as for flood forecasting) or if sub-daily model output is needed

When a subcatchment is considered to be partially snow covered, GAWSER assumes that the fraction of landbase that is bare soil receives rainfall only, while the snow covered areas receive rainfall plus snowmelt. The weighted average of these two amounts are added to determine the total runoff amount for the time step.

Each pervious HRU in GAWSER is considered as two layers as shown in Figure 2.1 (Schroeter and Associates, 2006c). The thicknesses of these layers are user-defined, but typically the first layer is set at 200 mm for well drained soils and 100 mm for poorly drained soils. The second layer's depth is generally set at 600 mm for HRUs considered to contribute to subsurface flow (e.g. tile drainage) and 1000 mm for those HRUs thought to be contributing to groundwater storage (Schroeter and Associates, 2006a,b,c). The term *infiltration* is used in GAWSER to describe the rate of water movement downward through the soil surface. *Seepage* in GAWSER indicates the water movement downward from the bottom of the first soil layer into the second layer, whereas *percolation* in GAWSER refers to the downward movement out of the bottom of the second layer of a hydrologic response unit (Schroeter and Associates, 2006a,b,c). Percolated water appears as subsurface flow (e.g. tile drainage) in HRUs assumed to contribute to this storm flow component, or to groundwater storage in all other response units. The rate of water movement into each soil layer (either from rainfall, snowmelt, or soil-water flow) depends on the user-defined drainage characteristics of each soil layer associated with the HRU.

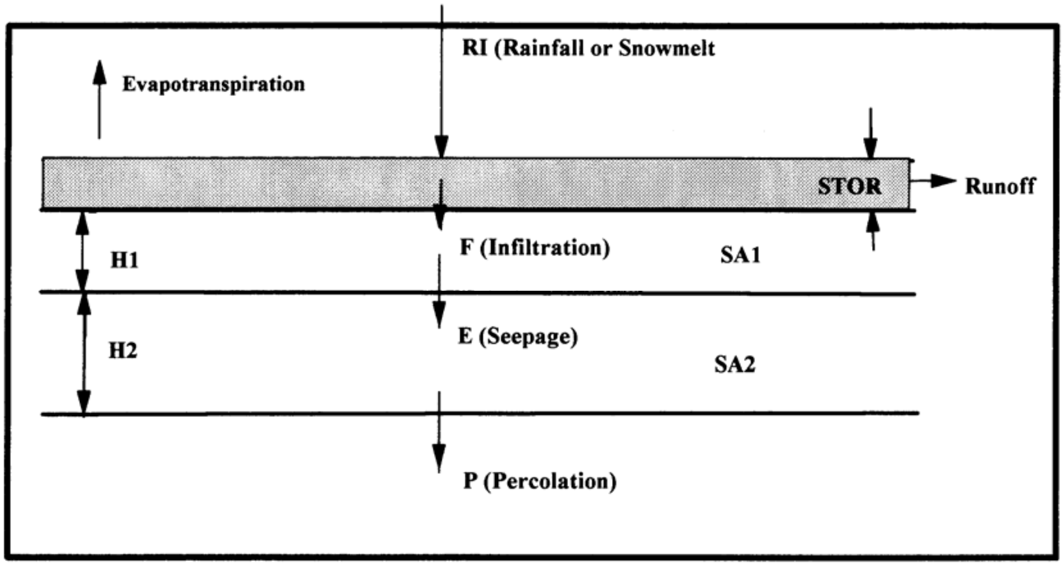

Figure 1. The Two-layer Soil Concept used in GAWSER's Runoff Generation Model.

Initially, some soil parameters (e.g. saturated soil-water content, field capacity soil-water content) were believed to have different values for each soil layer within a response unit type. GAWSER has been structured to allow independent specification of such parameters for each response unit and soil layer, but as a first approximation (except when obvious differences are identified, e.g. hydraulic conductivity for clay over sandy soils), the same parameter values are used for all soil layers in a given response unit (Schroeter and Associates, 2006c).

When operating in continuous mode, GAWSER typically applies a modified version of the Linacre (1977) formula to estimate potential ET. This formula uses daily mean air temperatures, subcatchment elevation and latitude to compute daily potential evapotranspiration rates. Experience in applying the model in the neighbouring Grand River watershed found that the Linacre model, as published, greatly overestimated potential ET. An adjustment factor of 0.6 was applied as was an upper limit for the potential ET amount for each month of the year to bring values to a level that were more typical of published values for the province (Schroeter and Associates, 2006c). Table 2 presents the upper bound of daily potential ET allowed by GAWSER in each month.

Table 2. Upper Boundary Potential ET Rates for Each Month Applied to the Liacre ET Estimation Method Used by GAWSER

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1.98	2.50	3.36	4.97	5.74	6.37	6.16	5.25	3.92	2.80	1.96	1.83

(Source: Schroeter and Associates, 2006c) (Units: mm/day)

Through their experience in calibrating and running the GAWSER model in event mode, GAWSER authors have identified the most sensitive input parameters and developed some general techniques and seasonal adjustment tables that the model automatically applies when operating in continuous mode. Table 3 gives an example of the monthly parameter adjustment factors that were used in when applying the continuous version of GAWSER to southern Ontario's Kettle Creek watershed. These adjustment factors combined with the model's snow pack routines, help GAWSER to better represent seasonal changes in the hydrologic response associated with each HRU.

Water takings and sewage treatment plant (STP) discharges can be represented in GAWSER. STPs are considered as direct contributions to the baseflow totals for a stream at the point of STP discharge (Schroeter and Associates, 2006c). Surface water taking from within a subcatchment is subtracted from the model's estimate of total subcatchment flow at the time the withdrawal is defined to occur.

Table 3. Example Monthly Parameter Adjustment Factor Table Used by GAWSER

Symbol	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
FDS	0.75	1.00	0.50	1.00	1.20	1.15	1.15	1.50	1.50	1.00	0.75	0.75
FKEFF	0.02	0.02	0.02	0.10	0.40	0.65	0.75	0.90	0.65	0.25	0.10	0.02
FCS	0.03	0.02	0.02	0.09	0.40	0.50	0.60	0.75	0.35	0.30	0.13	0.06
FD	0.06	0.04	0.04	0.05	0.05	0.06	0.09	0.10	0.10	0.10	0.08	0.06
FKO	2.25	1.75	2.25	2.25	1.35	1.75	2.67	2.00	3.25	1.75	2.50	2.25
FKSS	2.00	2.00	2.13	2.25	2.37	2.50	2.75	2.75	2.67	2.50	2.40	2.25
FKMF	0.25	0.33	1.10	1.40	1.60	1.00	1.00	1.00	1.00	1.00	0.25	0.15
FNEW	1.00	1.00	1.10	1.15	1.20	1.00	1.00	1.00	1.00	1.00	1.10	1.10
FEVAP	0.00	0.00	0.00	2.90	4.00	4.45	5.00	4.45	2.84	1.16	1.13	0.00
FINS	0.20	0.20	0.20	.50	0.70	1.20	1.50	1.50	1.20	0.70	0.20	0.20

(Source: Schroeter and Associates, 2006c) (Units: unitless)

2.3 Preparing Model Input Datasets

T The input datasets for both models were prepared using as much readily-available existing watershed information as possible. This information was gleaned from the data files prepared for the previous flood forecasting model set-up studies where applicable and from the data sources assembled as part of preparing the conceptual water budget and watershed characterization reports for the ABMV Planning Region. The GIS-based tools associated with AVSWAT-X (an ArcView extension designed to build datasets for the SWAT model) were used when appropriate to derive input parameters for both models. The following sections briefly describe the steps followed in setting up both the SWAT and GAWSER models.

2.3.1 Climate Data

Climate data drive hydrologic models. It is therefore critical that complete and representative climate data be available for any hydrologic modelling exercise. Earlier work associated with completing the conceptual water budget identified a data gap in the availability of complete long-term datasets of climate data for the ABMV Planning Region. To fill this data gap, Schroeter and Associates were commissioned to apply their data filling techniques (see Schroeter et al., 2000a and Schroeter, 2005). The result was a 45 year (1960 – 2004) complete dataset of daily precipitation (rain, snow and snow water equivalent) as well as daily maximum and minimum air temperature data for 20 stations across the study region. These data formed the basis for preparing the ".pcp" and ".tmp" climate files needed to drive the SWAT model (see Di Luzio et al., 2002). CWB Map E-1 shows the location of these daily climate stations used to drive the SWAT model relative to major river and shoreline systems modelled in the ABMV Planning Region.

GAWSER commonly uses daily maximum/minimum air temperature data and hourly rainfall input data. Sixteen (16) of the 20 stations had sufficient historical tipping bucket rainfall data available at the station or at a nearby station to enable hourly rainfall data files to be prepared as part of the data-filling contract (Schroeter and Associates, 2005). Given that Schroeter and Associates completed this data filling work, they were also familiar with the input data formats needed by GAWSER and prepared the temperature and hourly rainfall input files for these 16 stations in a GAWSER-readable format as part of the climate data-filling study. CWB Map E-2 shows the location of the hourly climate stations used to drive the GAWSER model.

Both GAWSER and SWAT can operate with temperature and precipitation as the only climate input provided. SWAT, however, also allows users to input other less commonly measured climate data if available, including daily solar radiation, daily average wind speeds and daily maximum and minimum relative humidity/dewpoint. These inputs are used primarily to drive some of the potential ET models included with SWAT (i.e. Penman-Monteith model). Only limited data were available for these climate measurements in the ABMV Planning Region, so it was not possible to prepare complete historical datasets of these climate observations for each of the 20 daily precipitation and temperature stations shown in CWB Map E-1.

To aid in preparing climate input files, SWAT includes a "Weather Generator". This tool, described in detail in Chapter 4 of Neitsch et al., (2002), assists the user in generating climatic data if none are available or if future (e.g. climate change) scenarios want to be considered. It also can be used to fill in data for the less frequent weather observations listed above, provided monthly average values of the particular observation for a station of interest are provided. For example, wind speed had not been collected on a routine basis for most of the 20 stations shown in CWB Maps E-1 and E-2. Environment Canada's Atmospheric Environment Service (AES), however, has published average annual windspeed data for a few stations near or within the ABMV Planning Region including Goderich, London, Sarnia and Waterloo-Wellington (Environment Canada, Canadian Climate Centre, 1981). The long-term average monthly values from these AES stations were then used as input to SWAT's embedded weather generator allowing it to produce continuous daily estimates of these parameters in accordance with the methods described in Neitsch et al., (2002). Table 4 lists the 20 data-filled daily stations and the corresponding (nearest) station used as the source of the long-term data needed to generate estimates of solar radiation, dewpoint and wind speed for these daily stations.

Note that long-term observations of solar radiation and dewpoint were limited even from Atmospheric Envronment Service (AES) stations. It was therefore decided to also use the solar radiation and dew point data, currently being collected by the Conservation Authority, as the basis for populating SWAT's weather generator. It is important to point out, however, that the averages provided by these datasets are based only on 2 to 3 years of observations because these more comprehensive weather stations were set up by the conservaton authorities just recently in 2004 or 2005. The weather generator developers recommend a minimum of 20 to 25 years of historical data be used to produce representative weather generation datasets. Unfortunately, this was not possible for these weather observations.

Statistical analyses were completed as needed to provide the weather generator with the necessary values for operation. Table 5 gives an example of the resulting dataset that was prepared for each of the daily stations listed in Table 4. For similar tables for the other 19 daily stations, the reader is referred to electronic weather datasets included with the SWAT model input that is housed on computers at each of the Conservation Authority offices within the ABMV Planning Region (see Schedule A).

Table 4. Stations Used in Providing Climate Data for th SWAT and GAWSER[1] Models

Daily Data-Filled Climate Station Name[2]	Station Source for Long-Term Monthly Climate Data Not Measured at the Data-Filled Climate Station		
	Solar Radiation	Dewpoint	Wind Speed[3]
Belgrave	Wroxeter	Wroxeter	Goderich
Blyth	Wroxeter	Wroxeter	Goderich
Brucefield	Exeter	Exeter	Goderich
Cromarty	Exeter	Exeter	London
Dashwood	Exeter	Exeter	Goderich
Ethel	Wroxeter	Wroxeter	Waterloo-Wellington
Exeter	Exeter	Exeter	London
Goderich	Falls Reserve	Falls Reserve	Goderich
Harriston	Wroxeter	Wroxeter	Mount Forest
Ilderton – Bear Creek	Exeter	Exeter	London
Listowel	Wroxeter	Wroxeter	Waterloo-Wellington
Lucknow	Falls Reserve	Falls Reserve	Goderich
Mitchell	Exeter	Exeter	London
Nairn	Exeter	Exeter	London
Parkhill	Exeter	Exeter	Goderich
Plover Mills	Exeter	Exeter	London
Strathroy	Exeter	Exeter	London
Summerhill	Falls Reserve	Falls Reserve	Goderich
Thedford	Exeter	Exeter	Sarnia
Wroxeter	Wroxeter	Wroxeter	Mount Forest

[1] Stations shaded had hourly rainfall data available and were used to drive the GAWSER model.
[2] Stations listed in this column had precipitation and air temperature observations data-filled by Schroeter and Associates (2005). Statistical analyses of the data-filled data was then completed to derive the statistical parameters for both precipitation and air temperature needed for SWAT's weather generator.
[3] Long term wind speed data for all stations listed was acquired from published AES data (Environment Canada, Canadian Climate Program, 1981)

2.3.1.1 Distribution of Meteorological Inputs

It is well established that meteorological inputs can vary significantly across a watershed or region. Annual precipitation amounts alone for instance vary from north to south over the ABMV Planning Region. Even more variability across a region could be seen if rainfall observations from individual summer thunderstorm events were mapped. For this reason, hydrologic models including SWAT and GAWSER accept inputs simultaneously from more than one meteorological station. While both SWAT and GAWSER handle this situation in a slightly different manner, the net effect is the same. SWAT allows users to enter the geographic coordinates of each station for which data are available and subcatchments that fall closest to the station are assumed to experience the same meteorological conditions as were observed at that station. GAWSER uses the concept of a ZUM (zone of uniform meteorology), defined as follows (Schroeter et al., 2006c):

A portion of a watershed throughout which one set of meteorological measurements can be used to calculate snowmelt and runoff.

Table 5. Example Dataset Prepared to Drive SWAT's Weather Generator - Blyth Station

Monthly Parameters	Unit	Month											
		JA	FE	MR	AP	MA	JN	JL	AU	SE	OC	NO	DE
TMPMX	˚C	-2.68	-1.65	3.51	11.14	18.24	23.55	25.82	24.81	20.90	13.96	6.85	0.36
TMPMN	˚C	-10.87	-10.74	-6.09	0.84	6.42	11.48	14.15	13.44	10.03	4.44	-0.33	-6.82
TMPSTDMX	˚C	6.14	6.12	6.51	6.80	6.23	5.01	3.89	3.85	5.11	5.68	5.40	5.64
TMPSTDMN	˚C	6.63	6.83	6.50	5.29	5.07	4.60	3.92	3.98	4.92	4.55	4.62	6.07
PCPMM	mm	81.09	60.63	67.43	78.97	90.80	81.42	74.45	99.22	105.6	99.12	115.01	109.4
PCPSTD	mm	4.33	4.62	4.26	5.61	6.74	7.03	6.01	8.88	8.46	6.28	6.83	5.70
PCPSKW	-	3.00	4.92	2.75	0.12	4.03	0.14	3.76	5.11	0.12	3.04	0.15	2.80
PR_W1	-	0.42	0.33	0.31	0.30	0.27	0.27	0.24	0.28	0.29	0.32	0.40	0.43
PR_W2	-	0.68	0.58	0.50	0.50	0.49	0.46	0.41	0.36	0.53	0.53	0.58	0.66
PCPD	-	17.53	12.51	11.82	11.13	10.76	10.00	8.84	9.47	11.44	12.62	14.73	17.27
RAINHHMX	mm	7.70	10.30	9.90	20.90	33.00	24.20	40.90	43.90	45.10	9.60	35.90	12.10
SOLARAV	MJ/m^2-day	4.69	7.74	11.42	15.37	16.76	21.24	19.40	17.06	12.56	7.33	4.18	3.41
DEWPT	˚C	-9.33	-8.38	-5.06	0.29	6.48	12.55	15.91	15.08	11.75	5.34	1.20	-5.14
WINDAV	m/s	5.75	4.64	5.00	4.44	3.58	3.36	2.83	2.94	3.94	4.75	5.50	5.75

The result of both approaches is a set of subcatchments, all receiving the same meteorological input. CWB Map E-3 shows the "ZUMs" as applied by the SWAT Model following its assessment of the proximity of various subcatchments to the available set of daily climate stations. CWB Map E-4 shows the ZUMs defined for GAWSER for the hourly meteorological stations used by GAWSER. The ZUM boundaries for both of these models align with the subcatchment boundaries determined through GIS-based delineation procedures discussed in Section 2.3.2 below.

2.3.2 Delineation of Subcatchment Boundaries and Modelling Elements

CWB Map E-5 shows the five (5) major river systems as well as the shoreline area associated with the ABMV Planning Region. The watershed areas associated with each of these major systems are as follows:

- Ausable River (1172 km^2).
- Parkhill River (466 km^2).
- Bayfield River (502 km^2).
- Maitland River (2572 km^2).
- Lucknow (Nine Mile) River (245 km^2).
- Shoreline streams and gullies (770 km^2).

TThe shoreline area is divided into the north shoreline, located exclusively in the MVCA region, the middle shoreline area located between Goderich and Bayfield (MVCA and ABCA), and the south shoreline area including Mud Creek (ABCA only).

For hydrologic modelling purposes, each of these major systems were further divided into a set of subcatchment elements. Maps detailing the subcatchment delineation of each major river system and shoreline area are provided in Schedule B.

Both the main river system and the subcatchment boundary delineations were completed in a GIS environment using the ArcView (version 3.3) extension and graphical user interface for SWAT version 2005 called AVSWAT-X. A complete description of AVSWAT-X and its operation can be found in the AVSWAT-X user's guide (Di Luzio et al., 2002). In summary, however, AVSWAT-X was developed by the SWAT model's development team in part to assist with creating the required input data files for the SWAT model from existing GIS-based datasets. AVSWAT-X consists of a series of modules that allow a user to take advantage of ArcView's GIS working environment and Windows-based users interface to complete the following tasks:

- Delineate subcatchments
- Define hydrologic response units (HRUs) (as defined by SWAT)
- Define meteorological stations
- Prepare SWAT databases
- Tabulate SWAT Output
- Calibrate SWAT

O Output from the GIS-based subcatchment delineation module, which includes summaries of each subcatchment's physical characteristics including its drainage area, length of slope, and channel grade, can also be used as the basis for preparing input files for other hydrologic models including GAWSER. Running both the GAWSER and SWAT models evaluated as part of this study with the same set of subcatchments and associated physical descriptions was important in order to make it easier to complete an objective evaluation of the performance of the two models.

A digital elevation model (DEM) as well as a hydrography (stream) layer are required datasets for AVSWAT-X to delineate and determine the characteristics of the subcatchments and stream elements within each modelled river system. For this study, the Ontario Ministry of Natural Resources (2002) DEM was used in combination with the Department of Fisheries and Oceans' (2003) stream network layer available for the ABMV Region. During the course of preparing the watershed delineation input files for the SWAT and GAWSER models, newer versions of both the DEM and stream layer for the ABMV Planning Region were made available to the project. In the interest of time, however, it was decided not to upgrade to these newer layers. Small area checks showed the subcatchment boundaries and features, while they changed slightly with the new DEM did not result in dramatically different input file values when compared with the datasets developed using the older DEM. As well, considerable time had been spent removing problems associated with these original GIS data layers (e.g. circular stream flow situations). It was feared that even the new datasets may still contain such information errors, further delaying progress. Also, while upgrading SWAT watershed datasets is a relatively automated exercise through applying AVSWAT-X, upgrading GAWSER's input files is much more time consuming. To facilitate a better comparision of SWAT and GAWSER output, it was decided to stay consistent and use the older datasets for both models.

AVSWAT-X allows the user to define a threshold catchment size to guide the subcatchment delineation process. Similarly, AVSWAT-X allows users to identify points of interest (e.g. stream gauge stations) where the user would like a subcatchment to outlet. A number of factors were considered when determining how best to sub-divide each of the major river systems for this project. For the Ausable, Parkhill and Bayfield river systems, the subcatchments defined by Schroeter and Associates, (1992) for the purpose of building the GAWSER model were used as the starting point for guiding AVSWAT-X in subdividing these river systems. The earlier GAWSER set-up took into consideration locations of streamgauges and flooding points of interest. New points of interest were added in this study where necessary to accommodate features installed since the 1992 work such as new stream gauging stations. In some cases, the original subcatchments defined by Schroeter and Associates (1992) were further subdivided to better accommodate the automated watershed delineation procedure associated with AVSWAT-X. Table 6 compares the number of subcatchments used as the basis for the 1992 application of GAWSER in the Ausable-Bayfield area (Schroeter and Associates, 1992) with the number used by GAWSER and SWAT in this modelling effort. Note that the shoreline streams and gullies, while they were delineated, were not modelled as part of the 1992 GAWSER work.

Table 6. Comparison of Subcatchment Modelling Detail Between the 1992 GAWSER Event Model and the Source Water Protection GAWSER and SWAT Continuous Models Applied to the ABCA River Systems.

Major River System	Total Area (km²)	Number of Subcatchments	Subcatchment size (km²)	
			Mean	Range
1992 Ausable Bayfield Watershed Hydrology Study (Schroeter and Associates, 1992)				
Ausable	1076	47	23.5	5.31 – 65.9
Parkhill	567	20	28.4	6.9 – 37.1
Bayfield	505	20	25.3	9.1 – 52.6
ShorelineStreams/Gullies	286	49	5.8	0.1 – 51.3
Source Water Protection Continuous Models (GAWSER and SWAT)				
Ausable	1172	75	15.6	5.5 – 31.4
Parkhill	466	47	9.9	2.1 – 17.9
Bayfield	502	37	13.6	3.8 – 21.4
ShorelineStreams/Gullies	325	118	2.8	<0.1 – 31.3

In reviewing the data in Table 6, a discrepency is seen between the total watershed area sizes determined through the 1992 study and the watershed sizes determined in this study through GIS-based hydrographic procedures embedded in AVSWAT-X. The 1992 study delineated watersheds manually from available topographic mapping of the area. The AVSWAT-X output is very similar to the results of a GIS-based watershed delineation completed for the Ausable Bayfield Conservation Authority's watershed report card (ABCA, 2006). It is believed that the watershed report card boundaries are the most representative of the real situation as there was also some field truthing done to finalize the GIS-derived watershed boundaries presented in the watershed report card. Future refinements of the water budget model could include fine tuning this watershed boundary layer to match the ABCA report card boundaries. As well, the more recent version of the DEM for the study area, released for official use after this project was underway could also be used and may give slightly different watershed areas and boundary configurations. For this Tier 1 level and scale of numerical watershed modelling, however, the watershed boundaries as defined solely by the AVSWAT-X procedures and input datasets used here were felt to be quite representative.

For the river systems located within the boundaries of the Maitland Valley Conservation Authority no previous GAWSER modelling study existed to act as a reference point for building a new continuous version of the GAWSER model. The previous BRFU modelling work divided the Maitland system into 31 subcatchments and the Nine Mile river system into 4 subcatchments. The shoreline streams and gullies were represented by a separate set of 5 subcatchment areas resulting in a total of 40 subcatchments for the entire Maitland Valley Conservation Authority region. The source water model developed for this study delineated a total of 63, 8 and 123 subcatchments for the Maitland, Nine Mile and MVCA portion of the shoreline respectively. Where possible the source water model identified a subcatchment outlet at the same point in the new source water model as was identified in the old BRFU model so the original BRFU basins could be defined as a set of smaller subcatchments used in this modelling effort. Main points of interest in the Maitland Valley system, including more recently installed stream gauges and flooding points of interest were also considered when delineating subcatchments for the new source water protection continuous model. Table 7 compares the number of subcatchments used as the basis for the BRFU model of the MVCA river systems with the number used by GAWSER and SWAT in this modelling effort.

Table 7. Comparison of Subcatchment Modelling Detail Between the BRFU Event Model and the Source Water Protection GAWSER and SWAT Continuous Models for the MVCA River Systems.

Major River System	Total Area (km^2)	Number of Subcatchments	Subcatchment size (km^2)	
			Mean	Range
Maitland Valley BRFU Model				
Maitland	2648	31	85.4	31.1 – 169.1
Nine Mile	251	4	62.8	45.0 – 88.7
ShorelineStreams/Gullies	441	5	88.2	61.2 – 120.2
Source Water Protection Continuous Models (GAWSER and SWAT)				
Maitland	2572	63	40.8	9.0 – 88.0
Nine Mile	245	8	30.6	9.7 – 47.4
ShorelineStreams/Gullies	445	124	3.6	<0.1 – 27.4

It is evident from comparing the data in Tables 6 and 7 that the size of the subcatchment elements for river systems modelled in the MVCA region are larger than those in the ABCA region. This was done in part to avoid a significant increase in the number of subcatchments that the Maitland Valley staff are currently accustomed to describing and dealing with. It also gave some opportunity to test the value (if any) of subdividing the river systems into a larger number of smaller subcatchments when comparing the relative performance of the models between the Maitland Valley Conservaton Authority and the Ausable-Bayfield Conservation Authority areas. For example, Solomon et al., (1968) recommended that a minimum of at least 5 sub-catchment or channel elements be used to represent drainage areas upstream of points of interest. Poorer correlations of modelled data with observed data at points where the upstream drainage areas are represented by relatively few modelling elements may indicate a need to further sub-divide the upstream watershed for modelling purposes. With SWAT's AVSWAT-X interface, breaking the river system into additional smaller elements is a relatively simple and automated task if modelling results show that a further breakdown would be worthwhile in future modeling refinements

For the initial set-up of the SWAT and GAWSER models, man-made streamflow obstructions (eg. dams) were ignored and handled simply as flow-through elements. Later, refinements to the final selected model could include representing the Morrison Reservoir and the Parkhill Reservoir and possibly some of the smaller dams (in many cases established for the purpose of enhancing the river edge aesthetics of a local village or town), as reservoir elements in both SWAT and GAWSER. It is recognized that, particularly for these smaller dams and their associated reservoirs, a relatively small amount of water is retained by them and dam boards, which maintain the water levels, are typically removed in the fall and not replaced until the spring runoff season has ended. For this reason, ignoring them, at least in the objective evaluation of the two models, was not thought to be a major issue. It is expected that these smaller dams may have a relatively larger influence on water quality along a reach than on water flow.

Schematic representations of each of the major river and shoreline systems within the ABMV Planning Region are provided in Schedule B. In viewing the schematic drawings in combination with the subwatershed map of the same area (also in Schedule B), a more complete picture can be seen of how the river systems were represented for numerical modelling purposes in both the GAWSER and SWAT models. The schematic drawings also show the inter-relationships between the various subcatchment, channel, reservoir and addition point modelling elements.

2.3.3 Soils Data

The soils within a drainage area have a major influence on the runoff and infiltration characteristics of the region. This is therefore a critical layer of information required by both GAWSER and SWAT. The provincal digital soils layer was obtained from the Ontario Ministry of Agriculture, Food and Rural Affair's Geomatics Service Centre (OMAFRA, 2005). This product is essentially a digitally stiched version of the set of soils maps and associated soil map units that have been prepared over a period of approximately 75 years for each county in the province. A datafile accompanies this GIS soils layer to more fully define each soil map unit.

Because the soils maps were prepared at different times and by different people, the mapping is not consistent from county to county because it reflects the surveying approaches applied at the time of each county soil report's publication. As part of this study, considerable effort was made in rectifying the soil codes and soil property descriptions among counties to produce a more generic and seamless soil coverage for the ABMV Planning Region. The ABMV Planning Region has portions or entire areas of six (6) different counties – Huron, Perth, Middlesex, Lambton, Wellington and Bruce. As such, the base soils map layer for the ABMV Planning Region as clipped from the OMAFRA provincial file is comprised of six different county soils reports. Of the six reports, the Middlesex County soils report provided the most detailed information, and provides a generalized soil profile description of the majority of soil series and soil map units present in the county. The generalized soil profile descriptions include information such as the texture (sand, silt, clay) and organic matter content of each soil horizon as well as the depth of each soil horizon to a 1 m profile depth. Other soil reports (e.g. Huron, Perth and Bruce) only defined the texture of the surface horizon for each mapped unit or soil series name

Often the different soils reports used a different code for the same soil series or soil map unit even though a review of the descriptions of each soil unit would suggest that the soils being mapped are very similar in character. To develop a more unified watershed-based soils coverage for the entire ABMV Region, similar soil map units listed in the various county soils reports were given a common code. In general, soil unit codes from the Huron County soil report were used as the default soil code because this county covers the majority of the landbase within the ABMV Planning Region. When soil unit names present in the ABMV Planning Region were identified that were not listed in the Huron County soils report, then the soil code used by the county soil report the soil type was found in was used. Table 8 summarizes the different soil map units present in the ABMV Planning Region and lists the various soil codes that were combined to be represented by a common code. In some cases, due to the variety of codes used in the various reports, a "new" unique soil code had to be given. These unique soil codes are listed in "bold" in Table 8.

The SWAT model requires that a description of each soil unit present in the study area be included in its common soils database. This meant that the following information be manually entered into the SWAT soils database for each soil type listed in Table 8:

For each soil type:	Name, number of soil layers, hydrologic soil group, total profile depth, universal soil loss equation (USLE) K.
For each layer:	Layer thickness, bulk density, available water holding capacity, saturated hydraulic conductivity K, carbon (O.M.) content, clay content, silt content, sand content, rock content.

For many of the soil units, the textural characteristics of the surface layer was obtained from the relevant soil county report(s). Often there was wide variability in the field-observed textures of the surface soil horizons, even within a soil textural category. In those cases, a generalized surface soil texture was used that fell within the range of the textural category given for the soil layer. For all soil layers below the surface horizon, there was less information available in most of the county soil reports. The Middlesex county soil report provided the most complete information on the lower soil horizons and was therefore relied upon to supply this information for many of the soil units. The nearby Waterloo County soil report, also a relatively recent and detailed report which covers lands just to the east of the ABMV Planning Region, was used when there was no information for a particular soil type in the Middlesex County's soil report.

In many cases there was incomplete information available from the existing county soils reports for soil variables listed above other than soil texture. To fill in this missing data, the Soil Water Characteristics model (version 1.0.103), developed by Saxton (2006) was used. Upon a user entering a soil layer's sand, silt, clay and gravel content, this model then estimates the soil layer's bulk density, water holding capacity and saturated hydraulic conductivity.

The Universal Soil Loss Equation (USLE) K factor was determined from an in-service training manual prepared for the Ontario Ministry of Agriculture and Food by van Vliet (1977). For the hydrologic modelling component of SWAT, however, this soil input characteristic is not used.
Table 9 is a printout of the soils data assembled for the ABMV Planning Region as entered into the SWAT soils database for use in its various hydrologic modelling algorithms. A digital copy is also included with the SWAT input data files located in Schedule A.

Table 8. Soil Map Units and Associated Hydrologic Soil Group (HSG) Within the ABMV Planning Region

Soil Code	Name	County Source	Equivalent Soil Code (Used in Other County Soil Reports)	HSG values in Soils Database	HSG Used for ABMV SWAT/GAWSER[1]
AYRFSL	Ayr fine sandy loam	Middlesex		C	C
ZALSICL	Alluvium	Middlesex		C	
B.L.	Bottomland	Huron, Lambton, Perth, Bruce, Wellington	ZVC (Middlesex), ZERSL (Middlesex)	-	
BRTSIL	Brant silt loam	Middlesex		A - C	B
Brs	Brady sandy loam	Huron	Bsl (Grey, Bruce), **Bysl (Wellington - original Bs)**, Bysl (Lambton), BAYSL (Middlesex)	A - C	B
Bc	Brookston clay loam	Huron, Bruce, Perth		D	D
Bc-st	Brookston clay loam - stoney phase	Lambton		D	D
BCWSIC	Blackwell silty clay	Middelsex		D	D
Blac	Blackwell clay	Lambton		D	D
Bes	Berrien sandy loam	Huron, Bruce	Be (Waterloo), Besl (Lambton), BRRFSL (Middlesex)	A - D	C
BFOSICL	Brantford silty clay loam	Middlesex		C	C
Bg	Burford loam	Huron, Bruce, Wellington, Perth	Bul (Lambton), Bu (Waterloo - Burford cobbly loam)	A	A
BUFGSL	Burford gravelly sandy loam	Middlesex		A - B	A
Brl	Brisbane loam	Huron, Bruce	Bxl (Lambton), Bl (Wellington)	B	B
Bn	Bennington loam	Waterloo		B - C	B
BNGSIL	Bennington silt loam	Middlesex		B	B
Br	Brookston loam	Waterloo	Bnl (Wellington)	B - D	D
Bs	Brookston silt loam	Huron, Bruce, Perth	Bns (Wellington)	D	D
Bos	Bookton sandy loam	Huron, Bruce	Bo (Waterloo), BOOFSL (Middlesex)	A - D	B
Bp	Breypen	Bruce		-	A
BRYSIL	Bryanston silt loam	Middlesex		A - C	B
Bsc	Brookston silty clay loam	Huron, Bruce	BKNSICL (Middlesex)	D	D
Bul-sh	Burford loam - shallow phase	Lambton		A	A
BVYSICL	Beverly silty clay loam	Middlesex		A - D	C
Bxl-sh	Brisbane loam - shallow phase	Lambton		B	B
Bys	Brady sand	Lambton		B	B
CADSL	Caledon sandy loam	Middlesex		A - C	A
CWOL	Colwood loam	Middlesex	Cd (Waterloo)	C - D	C
CMBSIL	Crombie silt loam	Middlesex		B - C	C
CMLSL	Camilla sandy loam	Middlesex	CMLFSL(Middlesex)	A - C	B
Cof	Colwood fine sand	Wellington		C	C
Cos	Colwood silt loam	Wellington		C	C
Dos	Donnybrook sandy loam	Huron, Bruce	Db (Wellington), Dsl (Perth)	A	A
Dl	Dumfries loam	Huron	Dl (Wellington), Dl (Bruce)	A	A
Ds	Dumfries sandy loam	Huron		A	A
EBRSIL	Embro silt loam	Middlesex		B - C	C
EKFSIC	Ekfrid silty clay	Middlesex		C - D	D
Esi	Elderslie silt loam	Bruce		C	C
Ets	Eastport sand	Lambton		A	A
FANSIL	Fanshawe silt loam	Middlesex		B - C	B
Fs	Fox sandy loam	Huron, Wellington	Fo (Waterloo), Fsl (Bruce, Grey), Fxsl (Lambton)	A - B	A

Soil Code	Name	County Source	Equivalent Soil Code (Used in Other County Soil Reports)	HSG values in Soils Database	HSG Used for ABMV SWAT/GAWSER[1]
FOXLS	Fox loamy sand	Middlesex		A - C	A
GFDSL	Gilford sandy loam	Middlesex		C	C
Gil	Gilford loam	Huron, Bruce, Wellington, Perth, Lambton		C	C
Gl	Guelph loam	Perth, Lambton		B	B
Gl-sh	Guelph loam - shallow phase	Lambton		B	B
Gs	Granby sandy loam	Huron	Grsl (Lambton), Gsl (Bruce), GNYSL (Middlesex), Grs (Wellington)	B - C	C
GOBCL	Gobles	Middlesex		A - C	C
Gul	Guerin loam	Huron		B	B
Huc	Huron clay loam	Huron, Bruce, Perth, Lambton	Hc (Waterloo)	C	C
Hl	Harriston loam	Huron, Wellington, Bruce		B	B
Hs	Harriston silt loam	Huron, Bruce, Wellington	Hsi (Perth)	B	B
Huronsl	Huron sandy loam	**Waterloo (was Hs)**		B	C
Hul	Huron loam	Wellington	Hu (Waterloo)	B - D	C
Huc-e	Huron clay - eroded	Lambton		C	C
Hus	Huron silt loam	Huron, Perth, Wellington, Bruce	HUOSIL (Middlesex)	B - D	C
HYWSIL	Honeywood silt loam	Middlesex		B	B
Lal	Lambton loam	Lambton		C	C
Lasil	Lambton silt loam	Lambton		C	C
Li	Lisbon sandy loam	Waterloo		A - C	A
Ll	Listowel loam	Huron, Bruce	Lil (Wellington)	B	B
Ls	Listowel silt loam	Huron, Bruce	Lis (Wellington), Lsi (Perth)	B	B
Lonl	London loam	Wellington	**Lonl (Perth - original Ll)**	B	B
Lyl	Lyons loam	Huron		C	C
M	Muck	Huron, Bruce, Wellington, Perth, Lambton	Mc, Md, Mf (Waterloo) vary with underlying materials/depth. Huron, Middlesex counties refer to muck as organic soil	-	-
MPWL	Maplewood loam	Middlesex	Mp (Waterloo)	C	C
MUISIL	Muriel silt loam	Middlesex		B - C	C
NDEFSL	Normandale fine sandy loam	Middlesex		A - B	B
NISSIL	Nissouri silt oam	Middlesex		B - C	C
P	Peat	Wellington	ZORLFS, ZORORG (Middlesex humic and mesic soils)	A - C	-
Pal	Parkhill loam	Huron, Bruce, Wellington,	Pl (Perth)	C	C
Pas	Parkhill silt loam	Huron, Bruce, Wellington		C	C
Pc	Perth clay loam	Huron, Bruce, Perth	**Pcl (Lambton) (one polygon was called a Perth Clay Loam but was named Pc)**	C	C
Pclay	Perth clay	**Lambton (was Pc)**		C	C
Pc-e	Perth clay - eroded phase	Lambton		C	C
PFDFS	Plainfield fine sand	Middlesex	Pds (Lambton)	A - D	A
PTHL	Perth loam	Middlesex	**PTHL (Wellington - original Pl),** Pe (Waterloo)	C - D	C
Psl	Perth sandy loam	**Waterloo (was Ps)**		B - C	C
Ps	Perth silt loam	Huron, Perth, Wellington, Bruce		C	C
Psc	Perth silty clay loam	Huron	PTHSICL (Middlesex)	B - D	C
Sc	St Clements	Waterloo		B - C	C
ZZ	Water	Middlesex, Huron, Waterloo, Bruce, Lambton, Perth	**ZZ (Wellington - original Sc) - stream course, ZZZSL (Middlesex)**	-	-
SLIVFSL	St Williams very fine sandy loam	Middlesex		A - C	B
Sml	Shashawandah loam	Lambton		B	B
Ssil	Saugeen silt loam	**Bruce (was Ss)**		C	C
Sus	Sullivan sand	Bruce		A	A
Ta	Tavistock loam	Waterloo	TVKL (Middlesex)	A - D	C

Soil Code	Name	County Source	Equivalent Soil Code (Used in Other County Soil Reports)	HSG values in Soils Database	HSG Used for ABMV SWAT/GAWSER[1]
Tc	Toledo clay loam	Huron, Grey, Bruce, Wellington	Tocl (Lambton)	D	D
Tes	Teeswater silt loam	Huron, Bruce, Wellington	TEWSIL (Middlesex)	A - B	B
THNSIL	Thorndale silt loam	Middlesex		A - C	B
TLDSICL	Toledo silty clay loam	Middlesex		C - D	D
Toc	Toledo clay	Lambton		D	D
Ts	Toledo silt loam	Huron, Bruce		D	D
TUCL	Tuscola loam	Middlesex	Tu (Waterloo)	A - D	C
UR	Urban area	Bruce, Waterloo	ZNMORG (Middlesex)	-	-
VITFSL	Vittoria fine sandy loam	Middlesex		B - C	C
WAMLFS	Walsingham loamy fine sand	Middlesex		A - C	A
Was	Wauseon sandy loam	Huron, Bruce	WUSFSL (Middlesex)	B - D	C
WATFSL	Watford fine sandy loam	Middlesex		A - D	A
WRNLFS	Waterin loamy fine sand	Middlesex		A - C	C
WSHFSL	Walsher fine sandy loam	Middlesex		B - C	C
Wsl	Waterloo sandy loam	Bruce, Perth		A	A

[1] These codes match the HSG values in the Drainage Guide for Ontario - Publication 29 (OMAFRA, 1997)

Table 9. SWAT Soils Database Prepared for the ABMV Planning Region

Soil Code	No. of Layers	HSG	Profile Depth (mm)	Texture	Soil_Z1	Soil_BD1	Soil_AWC1	Soil_K1	Soil_CBN1	Clay1	Silt1	Sand1	Rock1	USLE_K1	Soil_Z2	Soil_BD2	Soil_AWC2	Soil_K2
AYR	5	C	1000.00	SaL SaL SaL SaL SaL	150.00	1.24	0.22	508.90	3.10	8.00	42.00	50.00	0.00	0.14	230.00	1.45	0.14	63.30
AYRFSL	5	C	1000.00	SaL SaL SaL SaL SaL	150.00	1.24	0.22	508.90	3.10	10.00	35.00	55.00	0.00	0.14	230.00	1.54	0.12	26.40
B.L.	2	B	1000.00	LSa, SaL	250.00	1.78	0.08	58.60	1.20	4.00	16.00	80.00	15.00	0.10	1000.00	1.77	0.10	50.20
BAY	4	B	1000.00		180.00	1.22	0.19	243.50	3.10	12.00	27.00	61.00	0.00	0.14	280.00	1.44	0.12	36.60
Bc	3	D	1000.00	CL, SiCL, SiCL	240.00	1.31	0.15	3.50	2.90	33.00	42.00	25.00	1.00	0.24	530.00	1.27	0.15	2.60
Bc-st	3	D	1000.00	CL, SiCL, SiCL	240.00	1.34	0.15	3.50	2.90	33.00	42.00	25.00	5.00	0.24	530.00	1.30	0.15	2.60
BCWSIC	3	D	1000.00	SiC HC SiCL	330.00	1.20	0.15	2.60	6.15	53.00	40.00	7.00	0.00	0.15	660.00	1.18	0.15	2.70
Bes	4	C	1000.00	SaL, SaL, LSa, SiCL	240.00	1.57	0.10	27.20	2.20	10.00	19.00	71.00	1.00	0.24	550.00	1.61	0.09	32.50
BFOSICL	4	C	1000.00	SiCL, SiCL, SiC, SiCL	220.00	1.30	0.17	5.00	2.73	31.00	55.00	14.00	1.00	0.29	470.00	1.27	0.16	2.90
Bg	3	A	1000.00	L, LSa(gr), SaL(gr)	200.00	1.51	0.12	10.50	1.86	17.00	37.00	46.00	14.00	0.21	380.00	1.78	0.08	50.00
BKN	6	C	1000.00		100.00	1.23	0.31	1928.90	6.30	4.00	88.00	8.00	0.00	0.37	200.00	1.17	0.16	7.70
BL	2	B	1000.00	LSa, SaL	250.00	1.78	0.08	58.60	1.20	4.00	16.00	80.00	15.00	0.10	1000.00	1.77	0.10	50.20
Blac	3	D	1000.00	L HC SiCL	330.00	1.36	0.16	7.60	7.22	23.00	49.00	28.00	0.00	0.15	660.00	1.18	0.15	2.70
blank	2	B	1000.00	LSa, SaL	250.00	1.78	0.08	58.60	1.20	4.00	16.00	80.00	15.00	0.10	1000.00	1.77	0.10	50.20
BNG	4	A	1000.00	SiL L C SiCL	180.00	1.25	0.19	89.80	1.70	18.00	53.00	29.00	0.00	0.37	250.00	1.53	0.13	7.70
BNGSIL	4	B	1000.00	SiL, SiL, SiL, SiC	230.00	1.38	0.17	10.60	2.55	20.00	56.00	24.00	1.00	0.36	470.00	1.39	0.17	13.50
BOO	5	A	1000.00	SaL SaL SaL CL CL	200.00	1.32	0.14	82.30	1.90	14.00	21.00	65.00	0.00	0.14	330.00	1.44	0.11	25.40
Bos	3	B	1000.00	SaL, SaL, SiC	240.00	1.59	0.10	26.50	2.20	10.00	21.00	69.00	4.00	0.14	500.00	1.34	0.09	36.70
Br	3	D	1000.00	L, SiCL, SiCL	240.00	1.36	0.15	3.10	2.90	25.00	45.00	30.00	1.00	0.28	530.00	1.27	0.15	2.60
Brl	3	B	1000.00	L, L, L	280.00	1.47	0.13	14.50	0.80	15.00	40.00	45.00	2.00	0.21	535.00	1.49	0.13	14.30
BRR	5	B	1000.00	SaL LSa SaL C C	180.00	1.44	0.08	115.00	1.20	10.00	21.00	69.00	0.00	0.14	230.00	1.61	0.09	100.00
Brs	4	B	1000.00	SaL, LSa, SaL, LSa	280.00	1.59	0.10	26.70	1.97	10.00	20.00	70.00	3.00	0.17	480.00	1.66	0.09	44.50
BRT	6	A	1000.00	L L SiL C L L	125.00	1.19	0.22	351.70	3.20	13.00	46.00	41.00	0.00	0.31	255.00	1.37	0.18	92.70
BRTSIL	4	B	1000.00	SiL SiL SiL SiL	280.00	1.41	0.16	12.20	2.20	18.00	53.00	29.00	1.00	0.38	610.00	1.46	0.15	17.70
BRYSIL	3	B	1000.00	SiL, SiL, L	210.00	1.38	0.16	7.70	2.32	23.00	51.00	26.00	3.00	0.31	520.00	1.35	0.17	8.70
Bs	3	D	1000.00	SiL, SiCL, SiCL	240.00	1.34	0.16	6.50	2.51	26.00	53.00	21.00	1.00	0.31	530.00	1.27	0.15	2.60
BSB	4	A	1000.00	L Lgr SaCLgr Sagr	150.00	1.20	0.16	315.00	2.40	16.00	52.00	32.00	0.00	0.31	200.00	1.66	0.13	50.00
Bsc	3	D	1000.00	SiCL, SiCL, SiCL	240.00	1.30	0.16	3.70	2.90	34.00	46.00	20.00	1.00	0.24	530.00	1.27	0.15	2.60
BUF	4	A	1000.00	L Lgr SaCLgr Sagr	180.00	1.20	0.16	315.00	2.40	16.00	52.00	32.00	0.00	0.31	250.00	1.66	0.13	50.00
BUFGSL	3	A	1000.00	L, LSa(gr), SaL(gr)	200.00	1.59	0.10	14.20	1.90	14.00	29.00	57.00	14.00	0.16	380.00	1.78	0.08	50.00
Bul-sh	3	A	600.00	L, LSa(gr), SaL(gr)	200.00	1.51	0.12	10.50	1.86	17.00	37.00	46.00	14.00	0.21	380.00	1.78	0.08	50.00
BVYSICL	4	C	1000.00	SiCL, SiC, SiCL, SiC	220.00	1.30	0.17	4.40	2.55	32.00	51.00	17.00	1.00	0.27	490.00	1.23	0.16	2.90
Bxl-sh	4	B	1500.00	L, L, L, C	280.00	1.47	0.13	14.50	0.80	15.00	40.00	45.00	2.00	0.21	535.00	1.49	0.13	14.30
Bys	4	B	1000.00	Sa, LSa, SaL, LSa	280.00	1.67	0.07	52.50	1.97	7.00	4.00	89.00	3.00	0.17	480.00	1.66	0.09	44.50
CAD	6	A	1000.00	SaL SaL SaL SaL Sa LSa	200.00	1.41	0.15	92.20	1.40	10.00	30.00	60.00	0.00	0.14	355.00	1.68	0.12	35.80
CADSL	4	A	1000.00	SaL LSa SaL GLSa	240.00	1.64	0.10	35.60	1.74	8.00	21.00	71.00	6.00	0.16	520.00	1.69	0.09	53.10
CMBSIL	3	C	1000.00	SiL SiL SiL	290.00	1.33	0.17	6.80	3.19	26.00	56.00	18.00	1.00	0.30	600.00	1.40	0.17	12.80
CMLSL	4	B	1000.00	SaL SaL SaL LSa	230.00	1.56	0.10	19.70	1.91	12.00	23.00	65.00	4.00	0.17	520.00	1.61	0.10	30.70
Cof	3	C	1000.00	S, SaL, SiL	150.00	1.69	0.07	65.10	3.83	6.00	4.00	90.00	1.00	0.40	510.00	1.50	0.11	15.40
Cos	3	C	1000.00	SiL, SaL, SiL	150.00	1.51	0.16	27.60	3.83	10.00	55.00	35.00	1.00	0.36	510.00	1.50	0.11	15.40
CTG	5	B	1000.00	SiL L SiL SiL L	130.00	1.12	0.19	490.00	3.30	20.00	65.00	15.00	0.00	0.37	230.00	1.34	0.15	10.00
CWO	5	C	1000.00	LFS-LFS-SCL	180.00	1.20	0.21	330.80	4.40	12.00	41.00	47.00	0.00	0.31	330.00	1.31	0.19	199.70
CWOL	3	C	1000.00	L, L, SiL	250.00	1.42	0.14	9.90	3.83	19.00	43.00	38.00	1.00	0.32	740.00	1.37	0.16	8.30
Dl	3	A	1000.00	L, L, SaL	250.00	1.52	0.14	23.60	1.70	11.00	47.00	42.00	3.00	0.26	460.00	1.51	0.14	20.70
Dos	3	A	1000.00	SaL, SaL, Sa	610.00	1.58	0.10	16.60	1.00	13.00	27.00	60.00	10.00	0.16	785.00	1.57	0.10	12.60
Ds	3	A	1000.00	SaL, L, SaL	300.00	1.51	0.50	13.60	2.00	15.00	30.00	55.00	3.00	0.20	460.00	1.51	0.14	20.70
DYK	5	A	1000.00	Sl Sl Ls Sl G	90.00	1.80	0.10	150.00	0.05	19.00	50.00	31.00	0.00	0.01	200.00	1.70	0.13	111.00
EBRSIL	3	C	1000.00	SiL, SiL, SiL	250.00	1.38	0.17	10.60	2.55	20.00	56.00	24.00	1.00	0.35	620.00	1.39	0.16	11.40
EKFSIC	4	D	1000.00	SiC, C, C, SiC	210.00	1.25	0.16	2.90	2.84	41.00	45.00	14.00	0.00	0.20	460.00	1.19	0.15	2.60
EMI	4	B	1000.00	L L L L	200.00	1.17	0.22	310.70	3.00	15.00	49.00	36.00	0.00	0.31	300.00	1.42	0.16	65.00
Esi	3	C	1000.00	SiL, C, C	150.00	1.35	0.16	7.50	3.42	24.00	53.00	23.00	0.00	0.28	300.00	1.27	0.15	2.40
Ets	2	A	1000.00	S, S	150.00	1.68	0.07	65.50	1.50	6.00	4.00	90.00	0.00	0.10	1000.00	1.68	0.07	65.50
FAD	5	B	1000.00		130.00	1.24	0.24	509.60	2.60	9.00	58.00	33.00	0.00	0.37	360.00	1.22	0.23	350.50
FANSIL	4	B	1000.00	SiL, SiL, L, SaL	320.00	1.37	0.17	9.30	3.05	22.00	58.00	20.00	2.00	0.32	560.00	1.36	0.18	10.90
FEP	6	A	1000.00	SaL SaL SaL SaL SaL L	180.00	1.35	0.16	141.60	1.90	10.00	28.00	62.00	0.00	0.14	250.00	1.66	0.11	34.70
FOXLS	4	A	1000.00	LSa, LSa, SaL, Sa	230.00	1.65	0.09	44.80	1.87	7.00	16.00	77.00	3.00	0.11	410.00	1.72	0.08	68.30
Fs	4	A	1000.00	SaL, LSa, SaL, Sa	230.00	1.65	0.09	44.30	1.80	7.00	17.00	76.00	3.00	0.20	410.00	1.72	0.08	68.30
GFDSL	4	C	1000.00	SaL, L, L, SaL(gr)	180.00	1.48	0.12	13.80	4.60	15.00	30.00	55.00	0.00	0.17	360.00	1.48	0.13	6.30
Gil	4	C	1000.00	L, L, L, SaL(gr)	180.00	1.56	0.12	11.60	4.58	16.00	36.00	48.00	0.00	0.23	360.00	1.48	0.13	6.30
Gl	3	B	1000.00	L, CL, L	250.00	1.40	0.15	9.50	1.50	20.00	48.00	32.00	1.00	0.33	360.00	1.36	0.13	3.60
Gl-sh	2	B	500.00	L, L, L	250.00	1.40	0.15	9.50	1.50	20.00	48.00	32.00	1.00	0.33	500.00	1.38	0.14	5.10
GNY	4	A	1000.00	LSa LSa LSa LSa Sa	210.00	1.54	0.06	130.00	1.00	7.00	15.00	78.00	0.00	0.05	360.00	1.70	0.09	90.00
GOBCL	4	C	1000.00	CL, CL, SiC, SiCL	250.00	1.34	0.15	4.70	1.91	29.00	46.00	25.00	2.00	0.27	470.00	1.32	0.14	2.90
GRD	5	B	1000.00	L L L-SiL L SL	200.00	1.78	0.12	41.40	3.00	4.00	40.00	56.00	0.00	0.31	440.00	1.78	0.12	41.40
Gs	4	C	1000.00	SaL, SaL, LSa, Sa	150.00	1.63	0.09	44.60	3.60	7.00	18.00	75.00	0.00	0.13	300.00	1.60	0.09	33.40
Gul	3	B	1000.00	L, L, L	230.00	1.42	0.14	8.60	1.00	20.00	40.00	40.00	2.00	0.26	430.00	1.44	0.13	8.50
GUP	4	A	1000.00	SiL L CL L	130.00	1.31	0.15	180.00	1.50	13.00	59.00	28.00	0.00	0.37	250.00	1.58	0.15	40.00
HIG	6	B	1000.00	SaL SaL LSa SaL SaL SaL	180.00	1.26	0.21	398.30	2.80	8.00	34.00	58.00	0.00	0.14	280.00	1.43	0.16	212.80
Hl	5	B	1000.00	L, L, L, L, L	130.00	1.40	0.14	8.30	2.32	21.00	44.00	35.00	1.00	0.27	280.00	1.46	0.15	17.10
Hltest1	1	B	1000.00	L, L, L, L, L	130.00	1.40	0.14	8.30	2.32	21.00	44.00	35.00	1.00	0.27	0.00	0.00	0.00	0.00
Hltest2	2	B	1000.00	L, L, L, L, L	500.00	1.40	0.20	10.00	2.32	21.00	44.00	35.00	1.00	0.27	1000.00	1.40	0.20	17.10
HRR	5	A	1000.00	L L L L L	130.00	1.23	0.16	440.00	2.60	12.00	46.00	42.00	0.00	0.31	280.00	1.30	0.19	170.00
Hs	5	B	1000.00	SiL, SiL, SiL, SiL, SiL	130.00	1.40	0.16	12.30	3.00	18.00	53.00	29.00	0.00	0.32	280.00	1.40	0.16	12.30
Huc	4	C	1000.00	CL, SiCL, SiCL, SiCL	250.00	1.16	0.15	4.40	2.78	29.00	41.00	30.00	0.00	0.25	350.00	1.29	0.17	4.50
Huc-e	2	C	1000.00	CL(er), C, C	280.00	1.27	0.15	2.20	0.50	32.00	44.00	24.00	0.00	0.20	1000.00	1.26	0.15	2.40
Hul	5	C	1000.00	L, L, CL, C, CL	125.00	1.46	0.15	17.10	2.32	14.00	46.00	40.00	0.00	0.29	305.00	1.37	0.15	6.70
Hus	4	C	1000.00	SiL, SiCL, SiCL, SiCL	250.00	1.35	0.16	6.90	2.78	25.00	53.00	22.00	2.00	0.35	350.00	1.29	0.17	4.50
HWV	5	C	1000.00	SiL SaL SaL SaL SaL	360.00	1.31	0.20	142.70	1.70	12.00	52.00	36.00	0.00	0.37	460.00	1.45	0.13	18.00
HWW	5	C	1000.00	SiL SaL SaL SaL SaL	360.00	1.31	0.20	142.70	1.70	12.00	52.00	36.00	0.00	0.37	460.00	1.45	0.13	18.00
HYWSIL	3	B	1000.00	SiL, SiL, L	230.00	1.39	0.17	13.40	3.13	18.00	60.00	22.00	1.00	0.38	590.00	1.39	0.17	13.70
KSU	4	B	1000.00	SL SL SL GSL	200.00	1.17	0.22	310.70	3.00	15.00	49.00	36.00	0.00	0.31	300.00	1.42	0.16	65.00
Lal	3	C	1000.00	L, SiCL, C	300.00	1.34	0.16	6.00	3.00	26.00	48.00	26.00	0.00	0.27	550.00	1.27	0.16	2.90
Lasil	3	C	1000.00	SiL, SiCL, C	300.00	1.37	0.17	10.00	2.61	22.00	57.00	21.00	0.00	0.27	550.00	1.27	0.16	2.90
Ll	4	B	1000.00	L, L, SiL, L	120.00	1.41	0.15	9.10	2.30	20.00	45.00	35.00	2.00	0.28	330.00	1.37	0.15	6.00
LOD	4	B	1000.00	L L L L	200.00	1.17	0.22	310.70	3.00	15.00	49.00	36.00	0.00	0.31	300.00	1.42	0.16	65.00
Lonl	4	B	1000.00	L, L, L, L	150.00	1.45	0.15	15.60	3.02	15.00	49.00	36.00	2.00	0.25	280.00	1.52	0.13	23.20
LTW	4	B	1000.00	SiL SiL SiL L	150.00	1.16	0.22	309.50	3.50	16.00	52.00	32.00	0.00	0.37	300.00	1.42	0.16	18.70
Lyl	3	C	1000.00	L, SaL, SaL	150.00	1.56	0.12	13.30	1.75	15.00	40.00	45.00	15.00	0.28	510.00	1.58	0.11	12.50
M	2	A	1000.00	SiC, SiC (organic soil)	300.00	1.10	0.18	92.40	10.00	40.00	50.00	10.00	0.00	0.24	1000.00	1.10	0.17	87.00
MCT	6	C	1000.00		300.00	1.17	0.16	84.00	2.80	22.00	22.00	56.00	0.00	0.22	610.00	1.27	0.16	9.10
MPW	6	C	1000.00	L SiL SiL SiL SiC SiCL	100.00	1.10	0.15	210.00	3.30	27.00	49.00	24.00	0.00	0.31	200.00	1.36	0.16	15.00
MPWL	3	C	1000.00	L, L, SiCL	250.00	1.42	0.12	7.20	2.44	21.00	31.00	48.00	0.00	0.31	580.00	1.37	0.12	4.20
MTI	2	A	1000.00	LSa SaL	250.00	1.62	0.11	132.90	1.20	4.00	16.00	80.00	0.00	0.05	1000.00	2.12	0.06	37.60
MUISIL	5	C	1000.00	SiL SiL SiCL SiCL SiCL	220.00	1.35	0.17	8.70	1.97	23.00	58.00	19.00	1.00	0.30	280.00	1.36	0.17	9.60
MYL	4	C	1000.00		150.00	1.10	0.19	112.10	3.30	30.00	46.00	24.00	0.00	0.31	360.00	1.24	0.17	25.50
NDEFSL	4	B	1000.00	SL, LS, SL, SL	220.00	1.56	0.11	26.80	2.26	10.00	24.00	66.00	0.00	0.29	610.00	1.66	0.09	53.00
NISSIL	3	C	1000.00	SiL, L, L	280.00	1.34	0.16	6.30	2.78	26.00	52.00	22.00	1.00	0.28	610.00	1.37	0.14	5.10
P	2	A	2000.00	SiC, SiC (organic soil)	300.00	1.10	0.18	92.40	10.00	40.00	50.00	10.00	0.00	0.24	2000.00	1.10	0.17	87.00
Pal	4	C	1000.00	L, SiL, SiL, SiL	180.00	1.41	0.15	10.40	3.10	19.00	48.00	33.00	1.00	0.25	360.00	1.44	0.15	14.30
Pas	4	C	1000.00	SiL, SiL, SiL, SiL	180.00	1.41	0.16	13.50	3.10	17.00	53.00	30.00	0.00	0.32	360.00	1.43	0.15	14.40
Pc	4	C	1000.00	CL, CL, SiC, SiCL	250.00	1.32	0.16	4.40	2.55	31.00	48.00	21.00	2.00	0.25	440.00	1.31	0.15	3.10
Pc-e	4	C	1000.00	CL, CL, C, C	50.00	1.32	0.16	4.40	2.55	31.00	48.00	21.00	2.00	0.22	240.00	1.31	0.15	3.10
Pclay	4	C	1000.00	CL, CL, C, C	250.00	1.32	0.16	4.40	2.55	31.00	48.00	21.00	2.00	0.22	440.00	1.31	0.15	3.10
PFDFS	4	A	1000.00	LSa, Sa, Sa, Sa	230.00	1.67	0.08	57.90	1.91	6.00	11.00	83.00	1.00	0.17	420.00	1.70	0.08	75.90
Porg	2	A	2000.00	SiC, SiC (organic soil)	300.00	1.10	0.18	92.40	10.00	40.00	50.00	10.00	0.00	0.24	2000.00	1.10	0.17	87.00
Ps	4	C	1000.00	SiL, CL, SiC, SiCL	250.00	1.36	0.16	6.80	2.55	25.00	52.00	23.00	2.00	0.34	440.00	1.31	0.15	3.10
Psc	4	C	1000.00	SiCL, CL, SiC, SiCL	250.00	1.31	0.16	4.00	2.55	33.00	48.00	19.00	2.00	0.32	440.00	1.31	0.15	3.10
PTH	5	B	1000.00	L L CL CL CL	130.00	1.12	0.15	240.00	3.50	24.00	48.00	28.00	0.00	0.31	180.00	1.30	0.16	40.00
PTHL	4	C	1000.00	L, CL, SiC, SiCL	250.00	1.40	0.13	6.20	2.55	23.00	35.00	42.00	2.00	0.20	440.00	1.31	0.15	3.10
SCM	5	B	1000.00	SiL SiL SiC SiC SiCL	100.00	1.10	0.16	270.00	4.60	26.00	56.00	18.00	0.00	0.37	200.00	1.26	0.19	50.00
SJB	5	A	1000.00	SiL SiL L SaLgr LSagr	130.00	1.21	0.18	520.00	2.60	23.00	49.00	28.00	0.00	0.37	230.00	1.37	0.19	202.00
SLIVFSL	4	B	1000.00	SaL, LSa, LSa, LSa	290.00	1.52	0.10	17.40	5.16	13.00	22.00	65.00	1.00	0.26	510.00	1.69	0.09	62.60
Sml	2	B	380.00	L, L	250.00	1.60	0.12	12.90	3.00	15.00	40.00	45.00	20.00	0.15	380.00	1.69	0.11	11.80
Ssil	4	C	1000.00	SiL, SiCL, C, C	100.00	1.34	0.17	7.20	3.64	25.00	55.00	20.00	0.00	0.32	230.00	1.31	0.17	5.30
Sus	3	A	1000.00	Sa, Sa, Sa	75.00	1.66	0.07	54.30	3.00	7.00	3.00	90.00	0.00	0.12	250.00	1.66	0.07	54.30
Ta	4	C	1000.00	L, L, SiCL, SiCL	230.00	1.40	0.14	9.10	2.32	20.00	44.00	36.00	0.00	0.34	530.00	1.41	0.14	10.00
Tc	4	D	1000.00	CL, CL, SiC, C	230.00	1.31	0.15	3.40	3.13	33.00	39.00	28.00	0.00	0.26	630.00	1.30	0.15	3.10
Tes	4	B	1000.00	SiL, SiL, SiCL, Gr	380.00	1.41	0.16	13.50	2.70	17.00	53.00	30.00	0.00	0.32	460.00	1.36	0.16	8.70
THNSIL	4	B	1000.00	SiL, SiL, CL, L	360.00	1.38	0.16	8.70	2.05	22.00	54.00	24.00	2.00	0.32	530.00	1.36	0.16	7.40
TLDSICL	4	D	1000.00	SiCL SiCL SiC SiC	230.00	1.27	0.16	3.30	3.13	37.00	46.00	17.00	0.00	0.22	630.00	1.26	0.16	3.00
Toc	4	D	1000.00	C, CL, SiC, C	230.00	1.21	0.14	2.00	4.19	56.00	28.00	16.00	0.00	0.22	630.00	1.30	0.15	3.10
Ts	4	D	1000.00	SiL SiCL SiC SiC	230.00	1.35	0.16	7.20	3.13	24.00	51.00	25.00	0.00	0.24	630.00	1.26	0.16	3.00
TUC	5	B	1000.00	L SaL SaL SaL SiL	180.00	1.18	0.21	285.20	3.00	30.00	55.00	15.00	0.00	0.31	250.00	1.52	0.14	54.60
TUCL	3	C	1000.00	L, L, SiL	280.00	1.42	0.15	11.50	3.00	18.00	48.00	34.00	1.00	0.35	640.00	1.44	0.15	13.70
TVK	6	B	1000.00	SiL SiL SiL SiC C SiL	100.00	1.11	0.18	390.00	6.00	22.00	61.00	17.00	0.00	0.14	150.00	1.11	0.22	300.00
ULD	5	B	1000.00	SiL L SiL SiL L	130.00	1.22	0.17	90.40	3.30	20.00	65.00	15.00	0.00	0.37	230.00	1.46	0.14	0.40
VITFSL	5	C	1000.00	SaL LSa LSa SaL SiL	250.00	1.60	0.10	31.60	1.97	9.00	19.00	72.00	2.00	0.21	450.00	1.67	0.09	52.70
WAMLFS	4	A	1000.00	LSa Sa Sa Sa	210.00	1.70	0.08	69.70	2.03	5.00	11.00	84.00	1.00	0.14	550.00	1.70	0.08	77.50
Was	4	C	1000.00	SaL, SaL, LSa, SiCL	250.00	1.48	0.10	11.70	3.30	16.00	21.00	63.00	0.00	0.18	460.00	1.53	0.09	15.00
WATFSL	4	A	1000.00	SaL, LSa, SaL, SaL	230.00	1.60	0.10	30.70	2.09	9.00	23.00	68.00	3.00	0.25	600.00	1.71	0.08	70.60
WEY	5	A	1000.00	SiC SiC SiC SiC SiCL	150.00	1.10	0.15	74.40	7.40	56.00	40.00	4.00	0.00	0.24	200.00	1.10	0.15	22.80
WOW	5	A	1000.00	SiL SaL SaL SiCL L	180.00	1.30	0.14	200.00	1.70	13.00	51.00	36.00	0.00	0.37	380.00	1.51	0.16	120.00
WRNLFS	4	A	1000.00	LSa, Sa, Sa, Sa	250.00	1.62	0.09	39.80	2.49	8.00	12.00	80.00	1.00	0.18	620.00	1.70	0.08	74.40
WSHFSL	3	C	1000.00	SaL, SaL, L	300.00	1.61	0.09	27.40	1.51	10.00	13.00	77.00	5.00	0.14	550.00	1.58	0.09	19.80
Wsl	6	A	1000.00	SaL SaL LSa LSa SaL Sa	100.00	1.53	0.12	23.10	3.60	11.00	30.00	59.00	0.00	0.13	230.00	1.66	0.11	53.60
WTO	6	A	1000.00	SaL SaL LSa LSa SaL Sa	100.00	1.23	0.14	420.00	3.60	11.00	30.00	59.00	0.00	0.14	230.00	1.53	0.14	225.00
WUS	6	C	1000.00	SaCL SaCL SaL SaL L L	180.00	1.21	0.13	29.40	2.00	27.00	18.00	55.00	0.00	0.22	300.00	1.44	0.10	6.30
ZALSICL	2	C	1000.00	LSa, SiL	250.00	1.78	0.08	58.60	1.20	4.00	16.00	80.00	15.00	0.10	1000.00	1.56	0.16	26.80
ZZ	5	C	1000.00	SaL SaL SaL SaL SaL	150.00	1.24	0.22	508.90	3.10	8.00	42.00	50.00	0.00	0.14	230.00	1.45	0.14	63.30

Soil Code	Soil_CBN2	Clay2	Silt2	Sand2	Rock2	Soil_Z3	Soil_BD3	Soil_AWC3	Soil_K3	Soil_CBN3	Clay3	Silt3	Sand3	Rock3	Soil_Z4	Soil_BD4	Soil_AWC4	Soil_K4
AYR	1.00	10.00	35.00	55.00	0.00	380.00	1.56	0.11	37.40	0.50	9.00	26.00	65.00	0.00	560.00	1.78	0.08	31.00
AYRFSL	1.00	10.00	35.00	55.00	0.00	380.00	1.57	0.11	30.90	0.50	9.00	26.00	65.00	0.00	560.00	1.62	0.09	31.20
B.L.	0.30	3.00	27.00	70.00	15.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BAY	1.00	14.00	23.00	63.00	0.00	405.00	1.42	0.12	33.80	1.10	15.00	20.00	65.00	0.00	1000.00	1.52	0.11	22.80
Bc	1.16	40.00	40.00	20.00	1.00	1000.00	1.27	0.16	3.20	0.05	39.00	47.00	14.00	2.00	460.00	1.22	0.15	2.30
Bc-st	1.16	40.00	40.00	20.00	5.00	1000.00	1.33	0.16	3.00	0.05	39.00	47.00	14.00	10.00	0.00	0.00	0.00	0.00
BCWSIC	2.73	61.00	37.00	2.00	0.00	1000.00	1.25	0.17	4.20	1.00	37.00	57.00	6.00	0.00	0.00	0.00	0.00	0.00
Bes	0.52	9.00	15.00	76.00	2.00	790.00	1.74	0.08	70.00	0.06	5.00	9.00	86.00	6.00	1000.00	1.25	0.17	3.60
BFOSICL	0.70	40.00	45.00	15.00	2.00	570.00	1.22	0.17	3.20	0.64	44.00	51.00	5.00	0.00	1000.00	1.24	0.17	3.70
Bg	0.64	6.00	13.00	81.00	17.00	1000.00	1.85	0.07	20.30	0.05	10.00	19.00	71.00	37.00	0.00	0.00	0.00	0.00
BKN	1.00	47.00	43.00	10.00	0.00	300.00	1.16	0.15	6.60	1.00	52.00	39.00	9.00	0.00	460.00	1.22	0.15	2.30
BL	0.30	3.00	27.00	70.00	15.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Blac	2.73	61.00	37.00	2.00	0.00	1000.00	1.25	0.17	4.20	1.00	37.00	57.00	6.00	0.00	0.00	0.00	0.00	0.00
blank	0.30	3.00	27.00	70.00	15.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BNG	0.20	17.00	43.00	40.00	0.00	430.00	1.23	0.14	3.00	0.60	52.00	31.00	17.00	0.00	1000.00	1.31	0.16	3.60
BNGSIL	1.33	18.00	61.00	21.00	1.00	570.00	1.35	0.15	5.80	0.58	26.00	46.00	28.00	0.00	1000.00	1.23	0.17	3.10
BOO	0.90	15.00	17.00	68.00	0.00	380.00	1.52	0.11	8.10	0.40	13.00	25.00	62.00	0.00	505.00	1.28	0.15	8.00
Bos	0.41	8.00	18.00	74.00	5.00	1000.00	1.25	0.17	3.20	0.05	41.00	50.00	9.00	1.00	0.00	0.00	0.00	0.00
Br	1.16	40.00	40.00	20.00	1.00	1000.00	1.27	0.16	3.20	0.05	39.00	47.00	14.00	2.00	0.00	0.00	0.00	0.00
Brl	0.25	15.00	40.00	45.00	4.00	1000.00	1.48	0.13	8.20	0.20	20.00	40.00	40.00	10.00	0.00	0.00	0.00	0.00
BRR	0.60	7.00	7.00	86.00	0.00	330.00	1.69	0.09	60.00	0.20	6.00	21.00	73.00	0.00	480.00	1.27	0.14	5.00
Brs	0.52	7.00	16.00	77.00	5.00	660.00	1.59	0.10	26.70	0.81	10.00	20.00	70.00	3.00	1000.00	1.74	0.08	68.20
BRT	1.40	12.00	47.00	41.00	0.00	355.00	1.44	0.16	25.50	0.50	13.00	51.00	36.00	0.00	660.00	1.25	0.12	0.11
BRTSIL	0.52	14.00	51.00	35.00	1.00	840.00	1.41	0.17	15.70	0.46	16.00	58.00	26.00	0.00	1000.00	1.43	0.16	13.40
BRYSIL	0.58	23.00	58.00	19.00	1.00	1000.00	1.41	0.15	5.10	0.05	27.00	46.00	27.00	10.00	0.00	0.00	0.00	0.00
Bs	1.16	40.00	40.00	20.00	1.00	1000.00	1.27	0.16	3.20	0.05	39.00	47.00	14.00	2.00	0.00	0.00	0.00	0.00
BSB	0.60	11.00	47.00	42.00	0.00	500.00	1.87	0.07	15.00	1.20	27.00	20.00	53.00	0.00	1000.00	2.16	0.04	75.00
Bsc	1.16	40.00	40.00	20.00	1.00	1000.00	1.27	0.16	3.20	0.05	39.00	47.00	14.00	2.00	0.00	0.00	0.00	0.00
BUF	0.60	11.00	47.00	42.00	0.00	380.00	1.87	0.07	15.00	1.20	27.00	20.00	53.00	0.00	1000.00	2.16	0.04	75.00
BUFGSL	0.64	6.00	13.00	81.00	17.00	1000.00	1.85	0.07	20.30	0.05	10.00	19.00	71.00	37.00	0.00	0.00	0.00	0.00
Bul-sh	0.64	6.00	13.00	81.00	17.00	600.00	1.85	0.07	20.30	0.05	10.00	19.00	71.00	37.00	0.00	0.00	0.00	0.00
BVYSICL	0.70	44.00	47.00	9.00	0.00	560.00	1.27	0.17	3.50	0.64	37.00	49.00	14.00	0.00	1000.00	1.24	0.17	3.70
Bxl-sh	0.25	15.00	40.00	45.00	4.00	1200.00	1.48	0.13	8.20	0.20	20.00	40.00	40.00	10.00	1500.00	1.24	0.15	2.00
Bys	0.52	7.00	16.00	77.00	5.00	660.00	1.59	0.10	26.70	0.81	10.00	20.00	70.00	3.00	1000.00	1.74	0.08	68.20
CAD	0.20	5.00	36.00	59.00	0.00	480.00	1.75	0.09	26.30	0.05	5.00	27.00	68.00	0.00	660.00	1.68	0.08	10.30
CADSL	0.58	6.00	15.00	79.00	5.00	690.00	1.53	0.09	8.40	0.41	18.00	14.00	68.00	8.00	1000.00	1.84	0.07	38.60
CMBSIL	0.81	18.00	57.00	25.00	1.00	1000.00	1.45	0.14	9.10	0.05	20.00	47.00	33.00	8.00	0.00	0.00	0.00	0.00
CMLSL	0.52	9.00	22.00	69.00	4.00	560.00	1.56	0.09	10.90	0.52	16.00	20.00	64.00	11.00	1000.00	1.81	0.07	48.70
Cof	0.75	14.00	26.00	60.00	0.00	1000.00	1.40	0.17	12.80	0.05	18.00	57.00	25.00	1.00	0.00	0.00	0.00	0.00
Cos	0.75	14.00	26.00	60.00	0.00	1000.00	1.40	0.17	12.80	0.05	18.00	57.00	25.00	1.00	0.00	0.00	0.00	0.00
CTG	0.40	30.00	40.00	30.00	0.00	380.00	1.34	0.18	15.00	0.50	23.00	64.00	13.00	0.00	480.00	1.43	0.15	15.00
CWO	2.00	10.00	40.00	50.00	0.00	510.00	1.35	0.18	151.60	1.70	10.00	41.00	49.00	0.00	860.00	1.47	0.15	33.70
CWOL	0.75	22.00	50.00	28.00	0.00	1000.00	1.40	0.17	12.80	0.05	18.00	57.00	25.00	1.00	0.00	0.00	0.00	0.00
Dl	0.80	12.00	43.00	45.00	3.00	1000.00	1.56	0.10	12.70	0.50	15.00	25.00	60.00	10.00	0.00	0.00	0.00	0.00
Dos	0.50	15.00	27.00	58.00	12.00	1000.00	1.75	0.07	48.20	0.05	7.00	4.00	89.00	15.00	750.00	1.45	0.16	10.00
Ds	0.80	12.00	43.00	45.00	3.00	1000.00	1.56	0.10	12.70	0.50	15.00	25.00	60.00	10.00	0.00	0.00	0.00	0.00
DYK	0.05	15.00	55.00	30.00	0.00	300.00	1.70	0.30	105.00	0.05	25.00	50.00	25.00	0.00	750.00	1.65	0.06	111.00
EBRSIL	0.58	19.00	55.00	26.00	1.00	1000.00	1.47	0.14	9.70	0.05	19.00	46.00	35.00	9.00	0.00	0.00	0.00	0.00
EKFSIC	0.93	55.00	39.00	6.00	0.00	510.00	1.18	0.15	2.70	0.70	58.00	37.00	5.00	0.00	1000.00	1.20	0.16	2.70
EMI	1.10	11.00	41.00	48.00	0.00	355.00	1.54	0.13	72.80	0.80	7.00	29.00	64.00	0.00	1000.00	1.78	0.12	41.40
Esi	1.50	41.00	36.00	23.00	0.00	1000.00	1.25	0.15	2.10	0.05	45.00	34.00	21.00	0.00	0.00	0.00	0.00	0.00
Ets	0.05	6.00	4.00	90.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FAD	0.60	12.00	54.00	34.00	0.00	480.00	1.49	0.15	15.20	0.40	15.00	49.00	36.00	0.00	660.00	2.06	0.05	40.30
FANSIL	0.46	21.00	63.00	16.00	1.00	660.00	1.50	0.13	7.00	0.05	22.00	45.00	33.00	17.00	1000.00	1.76	0.09	15.90
FEP	0.20	6.00	30.00	64.00	0.00	410.00	1.63	0.11	34.40	0.30	7.00	28.00	65.00	0.00	560.00	1.59	0.10	20.30
FOXLS	0.46	5.00	11.00	84.00	4.00	620.00	1.59	0.09	16.70	0.29	13.00	14.00	73.00	8.00	1000.00	1.73	0.07	75.40
Fs	0.46	5.00	11.00	84.00	4.00	620.00	1.59	0.09	16.70	0.29	13.00	14.00	73.00	8.00	1000.00	1.73	0.07	75.40
GFDSL	2.67	23.00	43.00	34.00	15.00	660.00	1.48	0.13	3.40	1.28	23.00	44.00	33.00	15.00	1000.00	1.76	0.10	48.90
Gil	2.67	23.00	43.00	34.00	15.00	660.00	1.48	0.13	3.40	1.28	23.00	44.00	33.00	15.00	1000.00	1.76	0.10	48.90
Gl	0.16	30.00	35.00	35.00	3.00	1000.00	1.64	0.12	18.30	0.05	12.00	42.00	46.00	20.00	0.00	0.00	0.00	0.00
Gl-sh	0.16	26.00	39.00	35.00	3.00	1000.00	1.64	0.12	18.30	0.05	12.00	42.00	46.00	20.00	0.00	0.00	0.00	0.00
GNY	0.30	5.00	15.00	80.00	0.00	630.00	1.70	0.09	80.00	0.30	4.00	18.00	78.00	0.00	1000.00	1.78	0.06	150.00
GOBCL	0.75	34.00	33.00	33.00	1.00	600.00	1.26	0.16	2.70	0.52	42.00	43.00	15.00	2.00	1000.00	1.28	0.16	3.30
GRD	1.10	4.00	40.00	56.00	0.00	590.00	1.42	0.16	65.00	1.10	11.00	41.00	48.00	0.00	950.00	1.78	0.12	41.40
Gs	0.99	9.00	13.00	78.00	0.00	380.00	1.63	0.08	42.30	1.17	8.00	7.00	85.00	0.00	1000.00	1.66	0.07	54.30
Gul	0.20	20.00	40.00	40.00	5.00	1000.00	1.48	0.13	8.20	0.10	20.00	40.00	40.00	10.00	1000.00	1.69	0.11	25.00
GUP	0.20	8.00	50.00	42.00	0.00	360.00	1.39	0.13	5.00	0.20	30.00	35.00	35.00	0.00	1000.00	1.69	0.11	25.00
HIG	1.70	6.00	30.00	64.00	0.00	355.00	1.72	0.09	39.80	0.20	3.00	25.00	72.00	0.00	460.00	1.47	0.10	6.30
Hl	1.70	14.00	47.00	39.00	1.00	480.00	1.45	0.15	13.90	0.50	16.00	48.00	36.00	2.00	635.00	1.46	0.15	15.40
Hltest1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hltest2	2.32	21.00	44.00	35.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HRR	1.70	14.00	47.00	39.00	0.00	480.00	1.42	0.15	25.00	0.50	16.00	48.00	36.00	0.00	635.00	1.47	0.15	20.00
Hs	3.00	18.00	53.00	29.00	0.00	480.00	1.42	0.16	15.00	0.50	16.00	54.00	30.00	0.00	635.00	1.44	0.16	16.00
Huc	0.87	32.00	52.00	16.00	0.00	500.00	1.27	0.16	3.20	0.81	39.00	47.00	14.00	2.00	1000.00	1.32	0.15	3.00
Huc-e	0.05	40.00	39.00	21.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hul	1.00	24.00	47.00	29.00	2.00	430.00	1.34	0.15	4.70	0.30	29.00	46.00	25.00	2.00	635.00	1.30	0.15	2.40
Hus	0.87	32.00	52.00	16.00	0.00	500.00	1.27	0.16	3.20	0.81	39.00	47.00	14.00	2.00	1000.00	1.32	0.15	3.00
HWV	0.60	15.00	33.00	52.00	0.00	510.00	1.60	0.11	46.40	0.50	6.00	26.00	68.00	0.00	560.00	1.57	0.13	31.60
HWW	0.60	15.00	33.00	52.00	0.00	510.00	1.60	0.11	46.40	0.50	6.00	26.00	68.00	0.00	560.00	1.57	0.13	31.60
HYWSIL	1.45	18.00	62.00	20.00	1.00	1000.00	1.49	0.14	11.90	0.05	17.00	47.00	36.00	10.00	0.00	0.00	0.00	0.00
KSU	1.10	11.00	41.00	48.00	0.00	355.00	1.54	0.13	72.80	0.80	7.00	29.00	64.00	0.00	1000.00	1.78	0.12	41.40
Lal	0.87	39.00	42.00	19.00	0.00	1000.00	1.25	0.15	2.30	0.05	44.00	36.00	20.00	0.00	0.00	0.00	0.00	0.00
Lasil	0.87	39.00	42.00	19.00	0.00	1000.00	1.25	0.15	2.30	0.05	44.00	36.00	20.00	0.00	0.00	0.00	0.00	0.00
Ll	0.50	25.00	44.00	31.00	2.00	450.00	1.48	0.15	17.60	0.30	14.00	53.00	33.00	5.00	1000.00	1.54	0.14	18.20
LOD	1.10	11.00	41.00	48.00	0.00	355.00	1.54	0.13	72.80	0.80	7.00	29.00	64.00	0.00	1000.00	1.78	0.12	41.40
Lonl	1.10	11.00	41.00	48.00	2.00	405.00	1.50	0.13	17.90	0.81	13.00	36.00	51.00	2.00	1000.00	1.50	0.12	9.40
LTW	0.50	15.00	54.00	31.00	0.00	600.00	1.45	0.16	16.70	0.30	14.00	53.00	33.00	0.00	1000.00	1.50	0.14	13.40
Lyl	0.30	15.00	30.00	55.00	15.00	1000.00	1.64	0.09	11.60	0.10	15.00	20.00	65.00	0.00	0.00	0.00	0.00	0.00
M	8.70	42.00	49.00	9.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MCT	0.90	30.00	42.00	28.00	0.00	710.00	1.28	0.15	9.30	0.90	29.00	40.00	31.00	0.00	810.00	1.56	0.08	14.90
MPW	0.40	25.00	52.00	23.00	0.00	380.00	1.35	0.16	15.00	0.50	25.00	51.00	24.00	0.00	640.00	1.39	0.16	10.00
MPWL	1.22	27.00	30.00	43.00	0.00	1000.00	1.27	0.17	4.00	0.05	36.00	54.00	10.00	0.00	0.00	0.00	0.00	0.00
MTI	0.60	3.00	27.00	70.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MUISIL	0.46	22.00	60.00	18.00	2.00	380.00	1.26	0.17	3.60	0.35	38.00	52.00	10.00	1.00	710.00	1.26	0.17	3.40
MYL	1.50	27.00	44.00	29.00	0.00	480.00	1.40	0.14	5.90	0.60	23.00	41.00	36.00	0.00	1000.00	1.51	0.12	3.00
NDEFSL	0.52	6.00	17.00	77.00	1.00	740.00	1.51	0.09	13.20	0.23	15.00	15.00	70.00	0.00	1000.00	1.65	0.10	50.40
NISSIL	0.87	27.00	42.00	31.00	3.00	1000.00	1.45	0.14	6.80	0.05	23.00	46.00	31.00	11.00	0.00	0.00	0.00	0.00
P	8.70	42.00	49.00	9.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pal	1.20	16.00	51.00	33.00	2.00	580.00	1.43	0.15	11.80	0.20	18.00	51.00	31.00	3.00	1000.00	1.44	0.15	11.50
Pas	1.20	16.00	51.00	33.00	1.00	580.00	1.41	0.16	11.90	0.20	18.00	51.00	31.00	1.00	1000.00	1.42	0.15	11.70
Pc	0.81	35.00	40.00	25.00	2.00	500.00	1.26	0.16	2.50	0.70	42.00	40.00	18.00	1.00	1000.00	1.30	0.16	3.40
Pc-e	0.81	35.00	40.00	25.00	2.00	300.00	1.25	0.15	2.30	0.70	45.00	37.00	18.00	1.00	1000.00	1.26	0.15	2.20
Pclay	0.81	35.00	40.00	25.00	2.00	500.00	1.25	0.15	2.30	0.70	45.00	37.00	18.00	1.00	1000.00	1.26	0.15	2.20
PFDFS	0.81	3.00	9.00	88.00	0.00	770.00	1.71	0.07	80.80	0.35	2.00	7.00	91.00	0.00	1000.00	1.70	0.08	75.90
Porg	8.70	42.00	49.00	9.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ps	0.81	35.00	40.00	25.00	2.00	500.00	1.26	0.16	2.50	0.70	42.00	40.00	18.00	1.00	1000.00	1.30	0.16	3.40
Psc	0.81	35.00	40.00	25.00	2.00	500.00	1.26	0.16	2.50	0.70	42.00	40.00	18.00	1.00	1000.00	1.30	0.16	3.40
PTH	1.70	21.00	45.00	34.00	0.00	250.00	1.27	0.15	20.00	1.20	30.00	35.00	35.00	0.00	510.00	1.32	0.14	10.00
PTHL	0.81	35.00	40.00	25.00	2.00	500.00	1.26	0.16	2.50	0.70	42.00	40.00	18.00	1.00	1000.00	1.30	0.16	3.40
SCM	1.30	25.00	58.00	17.00	0.00	430.00	1.12	0.15	20.00	1.30	56.00	39.00	5.00	0.00	690.00	1.14	0.15	20.00
SJB	1.70	12.00	53.00	35.00	0.00	300.00	1.52	0.17	225.00	1.50	7.00	44.00	49.00	0.00	580.00	1.69	0.09	30.00
SLIVFSL	0.58	5.00	17.00	78.00	1.00	710.00	1.72	0.08	71.00	0.05	4.00	10.00	86.00	4.00	1000.00	1.70	0.08	67.20
Sml	0.05	15.00	40.00	45.00	30.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ssil	1.50	29.00	52.00	19.00	0.00	405.00	1.25	0.15	2.40	0.10	44.00	38.00	18.00	0.00	1000.00	1.25	0.15	2.20
Sus	0.10	7.00	3.00	90.00	0.00	1000.00	1.66	0.07	54.30	0.05	7.00	3.00	90.00	0.00	0.00	0.00	0.00	0.00
Ta	0.58	19.00	44.00	37.00	0.00	850.00	1.25	0.17	3.30	0.41	40.00	50.00	10.00	0.00	1000.00	1.24	0.17	3.70
Tc	1.10	35.00	39.00	26.00	0.00	920.00	1.25	0.16	3.00	0.64	41.00	47.00	12.00	0.00	1000.00	1.25	0.15	2.40
Tes	1.00	22.00	53.00	25.00	0.00	735.00	1.42	0.15	5.30	0.50	28.00	53.00	19.00	15.00	1000.00	1.89	0.10	3.50
THNSIL	0.64	24.00	53.00	23.00	2.00	580.00	1.35	0.15	4.40	0.58	29.00	42.00	29.00	3.00	1000.00	1.42	0.15	7.10
TLDSICL	1.10	40.00	46.00	14.00	0.00	920.00	1.25	0.16	3.00	0.64	41.00	47.00	12.00	0.00	1000.00	1.24	0.17	3.30
Toc	1.10	35.00	39.00	26.00	0.00	920.00	1.25	0.16	3.00	0.64	41.00	47.00	12.00	0.00	1000.00	1.25	0.15	2.40
Ts	1.10	40.00	46.00	14.00	0.00	920.00	1.25	0.16	3.00	0.64	41.00	47.00	12.00	0.00	1000.00	1.24	0.17	3.30
TUC	0.70	8.00	39.00	53.00	0.00	380.00	1.55	0.12	25.70	0.30	10.00	35.00	55.00	0.00	510.00	1.58	0.11	18.40
TUCL	0.87	16.00	46.00	38.00	1.00	1000.00	1.43	0.17	16.90	0.05	15.00	57.00	28.00	1.00	0.00	0.00	0.00	0.00
TVK	3.70	25.00	58.00	17.00	0.00	330.00	1.31	0.19	75.00	1.20	19.00	62.00	19.00	0.00	530.00	1.24	0.15	10.00
ULD	0.40	30.00	40.00	30.00	0.00	380.00	1.46	0.17	1.00	0.50	23.00	64.00	13.00	0.00	480.00	1.56	0.14	1.00
VITFSL	0.64	6.00	17.00	77.00	2.00	520.00	1.67	0.09	56.10	0.58	6.00	13.00	81.00	1.00	600.00	1.56	0.09	17.30
WAMLFS	0.70	3.00	8.00	89.00	0.00	810.00	1.71	0.07	80.80	0.23	3.00	6.00	91.00	0.00	1000.00	1.71	0.07	82.60
Was	0.70	14.00	16.00	70.00	2.00	660.00	1.72	0.08	64.20	0.10	5.00	14.00	81.00	5.00	1000.00	1.26	0.17	3.40
WATFSL	0.41	4.00	11.00	85.00	2.00	870.00	1.66	0.09	54.10	0.12	6.00	16.00	78.00	0.00	1000.00	1.66	0.10	49.10
WEY	3.10	55.00	42.00	3.00	0.00	410.00	1.18	0.16	4.00	0.60	52.00	45.00	3.00	0.00	580.00	1.17	0.17	11.40
WOW	0.80	7.00	43.00	50.00	0.00	610.00	1.60	0.14	70.00	0.30	6.00	45.00	49.00	0.00	810.00	1.29	0.18	15.00
WRNLFS	0.70	5.00	8.00	87.00	0.00	840.00	1.71	0.07	82.60	0.29	4.00	4.00	92.00	0.00	1000.00	1.71	0.07	86.40
WSHFSL	0.87	12.00	15.00	73.00	5.00	1000.00	1.43	0.14	9.60	0.05	19.00	42.00	39.00	3.00	0.00	0.00	0.00	0.00
Wsl	1.22	4.00	29.00	67.00	0.00	380.00	1.69	0.08	68.80	0.52	2.00	15.00	83.00	0.00	530.00	1.68	0.09	62.00
WTO	1.20	4.00	29.00	67.00	0.00	380.00	1.67	0.09	120.00	0.50	2.00	15.00	83.00	0.00	530.00	1.74	0.08	75.00
WUS	0.30	21.00	16.00	63.00	0.00	400.00	1.51	0.09	9.10	0.20	16.00	19.00	65.00	0.00	480.00	1.54	0.10	13.70
ZALSICL	0.30	10.00	60.00	30.00	10.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ZZ	1.00	10.00	35.00	55.00	0.00	380.00	1.56	0.11	37.40	0.50	9.00	26.00	65.00	0.00	560.00	1.78	0.08	31.00

Soil Code	Soil_CBN4	Clay4	Silt4	Sand4	Rock4	Soil_Z5	Soil_BD5	Soil_AWC5	Soil_K5	Soil_CBN5	Clay5	Silt5	Sand5	Rock5	Soil_Z6	Soil_BD6	Soil_AWC6	Soil_K6	Soil_CBN6	Clay6	Silt6	Sand6	Rock6
AYR	0.50	9.00	18.00	73.00	0.00	1000.00	1.78	0.09	19.50	0.10	8.00	28.00	64.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AYRFSL	0.50	9.00	18.00	73.00	5.00	1000.00	1.62	0.11	34.30	0.10	8.00	28.00	64.00	5.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B.L.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BAY	0.60	13.00	25.00	62.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bc	0.52	38.00	42.00	20.00	0.00	610.00	1.29	0.16	1.90	0.35	46.00	40.00	14.00	0.00	1000.00	1.30	0.16	1.90	0.23	36.00	45.00	19.00	0.00
Bc-st	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BCWSIC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bes	0.05	39.00	53.00	8.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BFOSICL	0.05	40.00	54.00	6.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BKN	0.30	51.00	39.00	10.00	0.00	610.00	1.29	0.16	1.90	0.20	43.00	46.00	11.00	0.00	1000.00	1.30	0.16	1.90	0.20	40.00	44.00	16.00	0.00
BL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Blac	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
blank	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BNG	0.50	38.00	46.00	16.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BNGSIL	0.05	45.00	52.00	3.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BOO	0.50	39.00	36.00	25.00	0.00	1000.00	1.37	0.14	2.00	0.10	33.00	39.00	28.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bos	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Br	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Brl	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BRR	0.30	45.00	32.00	23.00	0.00	1000.00	1.38	0.14	5.00	0.40	43.00	36.00	21.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Brs	0.05	4.00	11.00	85.00	7.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BRT	0.20	56.00	14.00	30.00	0.00	860.00	1.50	0.12	9.10	0.10	15.00	38.00	47.00	0.00	1000.00	1.58	0.14	18.40	0.10	9.00	48.00	43.00	0.00
BRTSIL	0.05	17.00	54.00	29.00	3.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BRYSIL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BSB	0.50	4.00	4.00	92.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bsc	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BUF	0.50	4.00	4.00	92.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BUFGSL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bul-sh	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BVYSICL	0.05	40.00	54.00	6.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bxl-sh	0.05	48.00	32.00	20.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bys	0.05	4.00	11.00	85.00	7.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CAD	0.20	14.00	13.00	73.00	0.00	810.00	2.18	0.03	30.90	0.10	2.00	6.00	92.00	0.00	1000.00	2.13	0.04	27.20	0.10	4.00	11.00	85.00	0.00
CADSL	0.05	7.00	12.00	81.00	28.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CMBSIL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CMLSL	0.05	6.00	12.00	82.00	22.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cof	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cos	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CTG	0.30	18.00	51.00	31.00	0.00	1000.00	1.63	0.11	10.00	0.05	16.00	40.00	44.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CWO	0.60	10.00	47.00	43.00	0.00	1000.00	1.51	0.14	41.70	0.60	9.00	40.00	51.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CWOL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dl	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dos	0.05	20.00	55.00	25.00	10.00	1000.00	1.52	0.14	14.30	0.05	15.00	45.00	40.00	10.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ds	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DYK	0.05	20.00	55.00	25.00	0.00	1000.00	1.80	0.00	90.00	0.05	15.00	45.00	40.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
EBRSIL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
EKFSIC	0.05	52.00	45.00	3.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
EMI	0.40	4.00	40.00	56.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Esi	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ets	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FAD	0.30	3.00	14.00	83.00	0.00	1000.00	2.06	0.05	40.30	0.30	3.00	14.00	83.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FANSIL	0.05	12.00	30.00	58.00	32.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FEP	0.20	10.00	25.00	65.00	0.00	660.00	1.48	0.11	7.10	0.30	18.00	28.00	54.00	0.00	1000.00	1.80	0.10	11.00	0.05	9.00	41.00	50.00	0.00
FOXLS	0.05	4.00	7.00	89.00	4.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fs	0.05	4.00	7.00	89.00	4.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
GFDSL	0.23	5.00	27.00	68.00	15.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gil	0.23	5.00	27.00	68.00	15.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gl	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gl-sh	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
GNY	0.05	1.00	5.00	94.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
GOBCL	0.05	38.00	48.00	14.00	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
GRD	0.40	4.00	40.00	56.00	0.00	1000.00	1.54	0.06	130.00	1.00	7.00	15.00	78.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gs	0.23	7.00	3.00	90.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gul	0.10	12.00	42.00	46.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
GUP	0.10	12.00	42.00	46.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HIG	0.30	19.00	21.00	60.00	0.00	610.00	1.58	0.10	21.20	0.20	10.00	25.00	65.00	0.00	1000.00	1.70	0.10	26.00	0.10	6.00	28.00	66.00	0.00
Hl	0.20	15.00	48.00	37.00	2.00	1000.00	1.45	0.15	15.60	0.10	15.00	49.00	36.00	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hltest1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hltest2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HRR	0.20	15.00	48.00	37.00	0.00	1000.00	1.48	0.14	15.00	0.10	15.00	49.00	36.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hs	0.20	15.00	51.00	34.00	0.00	1000.00	1.46	0.16	15.00	0.10	13.00	51.00	36.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Huc	0.05	37.00	44.00	19.00	0.00	580.00	1.28	0.15	5.00	0.20	30.00	35.00	35.00	0.00	1000.00	1.37	0.13	22.00	0.10	35.00	30.00	35.00	0.00
Huc-e	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hul	0.05	41.00	38.00	21.00	5.00	1000.00	1.36	0.15	2.90	0.05	36.00	41.00	23.00	10.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hus	0.05	37.00	44.00	19.00	7.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HWV	0.30	8.00	40.00	52.00	0.00	1000.00	2.08	0.06	22.00	0.20	5.00	28.00	67.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HWW	0.30	8.00	40.00	52.00	0.00	1000.00	2.08	0.06	22.00	0.20	5.00	28.00	67.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HYWSIL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
KSU	0.40	4.00	40.00	56.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lasil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ll	0.20	13.00	48.00	39.00	10.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LOD	0.40	4.00	40.00	56.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lonl	0.05	18.00	32.00	50.00	8.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LTW	0.20	13.00	48.00	39.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lyl	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MCT	0.30	13.00	9.00	78.00	0.00	940.00	1.54	0.10	19.00	0.30	12.00	20.00	68.00	0.00	1000.00	1.40	0.12	6.10	0.50	23.00	30.00	47.00	0.00
MPW	0.10	24.00	55.00	21.00	0.00	830.00	1.28	0.15	5.00	0.30	46.00	40.00	14.00	0.00	1000.00	1.28	0.16	10.00	0.50	36.00	46.00	18.00	0.00
MPWL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MTI	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MUISIL	0.23	39.00	50.00	11.00	1.00	1000.00	1.31	0.18	6.40	0.05	29.00	62.00	9.00	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MYL	0.10	23.00	39.00	38.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NDEFSL	0.50	6.00	21.00	73.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NISSIL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
P	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pal	0.30	18.00	50.00	32.00	5.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pas	0.30	18.00	50.00	32.00	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pc	0.05	37.00	48.00	15.00	5.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pc-e	0.05	48.00	37.00	15.00	5.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pclay	0.05	48.00	37.00	15.00	5.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PFDFS	0.05	4.00	8.00	88.00	5.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Porg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ps	0.05	37.00	48.00	15.00	5.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Psc	0.05	37.00	48.00	15.00	5.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PTH	0.60	31.00	33.00	36.00	0.00	1000.00	1.32	0.13	10.00	0.50	32.00	30.00	38.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PTHL	0.05	37.00	48.00	15.00	5.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SCM	1.10	54.00	42.00	4.00	0.00	1000.00	1.19	0.18	45.00	1.50	34.00	65.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SJB	1.30	19.00	24.00	57.00	0.00	1000.00	2.16	0.04	60.00	0.50	4.00	13.00	83.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SLIVFSL	0.05	3.00	15.00	82.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sml	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ssil	0.05	45.00	36.00	19.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ta	0.05	40.00	54.00	6.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tc	0.05	44.00	38.00	18.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tes	0.05	27.00	54.00	19.00	60.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
THNSIL	0.05	23.00	48.00	29.00	8.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TLDSICL	0.05	41.00	50.00	9.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Toc	0.05	44.00	38.00	18.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ts	0.05	41.00	50.00	9.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TUC	0.20	10.00	33.00	57.00	0.00	1000.00	1.58	0.17	23.80	0.20	7.00	62.00	31.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TUCL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TVK	0.60	44.00	39.00	17.00	0.00	635.00	1.29	0.11	10.00	0.05	62.00	9.00	29.00	0.00	1000.00	1.38	0.16	10.00	0.20	28.00	57.00	15.00	0.00
ULD	0.30	18.00	51.00	31.00	0.00	1000.00	1.75	0.10	0.50	0.05	16.00	40.00	44.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
VITFSL	0.23	13.00	13.00	74.00	3.00	1000.00	1.46	0.18	2.20	0.05	12.00	64.00	24.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WAMLFS	0.05	3.00	5.00	92.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Was	0.05	39.00	50.00	11.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WATFSL	0.05	6.00	22.00	72.00	3.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WEY	1.00	41.00	49.00	10.00	0.00	1000.00	1.28	0.18	8.00	0.40	29.00	67.00	4.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WOW	0.50	28.00	58.00	14.00	0.00	1000.00	1.58	0.14	30.00	0.30	11.00	47.00	42.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WRNLFS	0.05	2.00	4.00	94.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WSHFSL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wsl	0.12	3.00	20.00	77.00	0.00	610.00	1.52	0.09	15.20	0.17	14.00	12.00	74.00	0.00	1000.00	1.70	0.08	75.90	0.12	2.00	10.00	88.00	0.00
WTO	0.10	3.00	20.00	77.00	0.00	610.00	1.56	0.08	20.00	0.20	14.00	12.00	74.00	0.00	1000.00	1.76	0.07	85.00	0.10	2.00	10.00	88.00	0.00
WUS	0.20	13.00	22.00	65.00	0.00	580.00	1.47	0.13	13.50	0.30	15.00	39.00	46.00	0.00	1000.00	1.43	0.12	2.90	0.20	29.00	30.00	41.00	0.00
ZALSICL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ZZ	0.50	9.00	18.00	73.00	0.00	1000.00	1.78	0.09	19.50	0.10	8.00	28.00	64.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

GAWSER users in the past have typically used the provincial-wide quaternary geology maps as the substitute for a digital soils coverage. There are limitations associated with representing surface soil characteristics with a quaternary geology map. However, given that GAWSER necessarily establishes rather broad soil descriptive categories due to the fact that it uses a mximum of 9 HRUs per subcatchment, the detail available from a soils report would not be realized anyway. For this study, mineral soils in the Region were classified for GAWSER as falling into one of 4 hydrologic soil groups (HSG), A, B, C or D as identified in Table 9. To be consistent with past use of GAWSER, however, values defining the drainage characteristics (e.g. hydraulic conductivity soil water content, depression storage depth) for each HSG were determined after reviewing published information (e.g. WATT et al., 1989) and other recent studies in which GAWSER was applied (e.g. Schroeter and Associates, 2006 a,b,c). These values formed the basis for characterizing GAWSER's HRUs, described further in Section 2.3.5.

2.3.4 Land Cover Data

The land cover GIS layer used for defining HRUs was the digital version of the OMAFRA (1983) agricultural resource inventory (ARI) mapping. This mapping is unique in that it identifies the cropping systems or rotational systems present on the landscape at the time the mapping was completed as opposed to specific crops present at the time of mapping. While more work needs to be done to confirm that these general cropping systems identified by the ARI mapping remain descriptive of the land cover in the study area, a very general comparison of the 1983 mapped systems with the current field crops suggested that cropping patterns have remained relatively stable across the study area over the past 20 years. Some limited field truthing was completed to help confirm this. Figure 2.2 shows the Ausable River basin above the Exeter streamgauge, as described by the 1983 land use mapping. Figure 2.3 shows the findings of a 2005 windshield survey of the same watershed. Both maps continue to show a good proportion of the land in a row crop or mixed type cropping system. While not readily apparent from Figures 2.2 and 2.3, a review of the data collected in the 2005 field survey revealed that, if anything, there has been a trend to less corn production and more soybean and edible bean production in this particular subcatchment. Approximately 1/3 of the land was observed to be under some form of conservation tillage practice as well.

To develop a map that more closely represents the same information that was presented in the 1983 ARI mapping would require collecting a minimum of 3 years of field data and combining it with property ownership/management information. Combining this information would allow trends to be seen in crop rotations being followed in the area along with an idea of the relative proportion of various crops grown by the farm managers. To-date, however, insufficient data have been collected.

In the GAWSER model, given the fact that only nine (9) HRUs can be defined per subcatchment, such a subtle shift in cropping cannot be readily modelled. As with past applications of the GAWSER model, the major landcover distinctions used in this evaluation of the GAWSER continuous model were: impervious/urban, wetlands, forest (high vegetative) cover, and agricultural (low vegetative) cover.

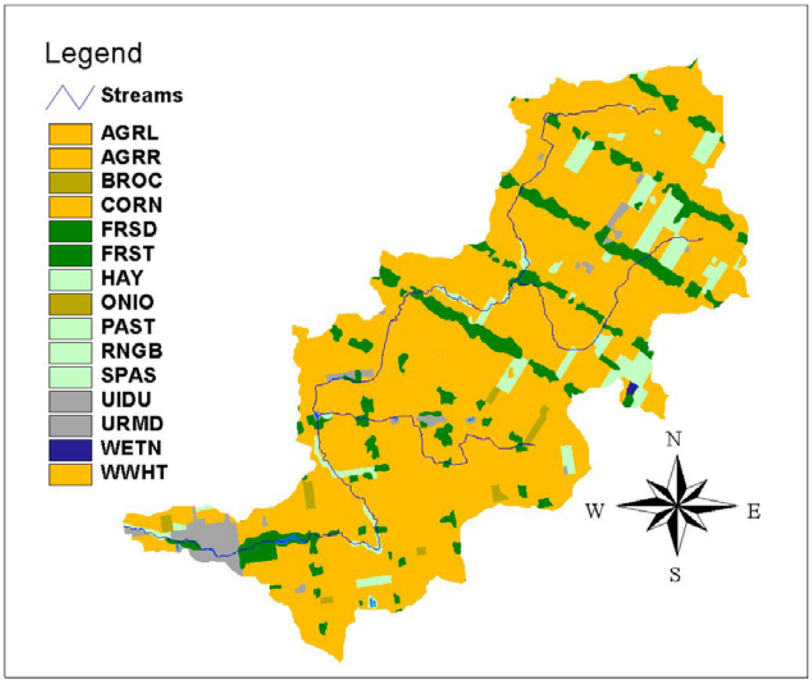

Figure 2. 1983 ARI Land Use Systems Mapping - Ausable River Above Exeter Gauge

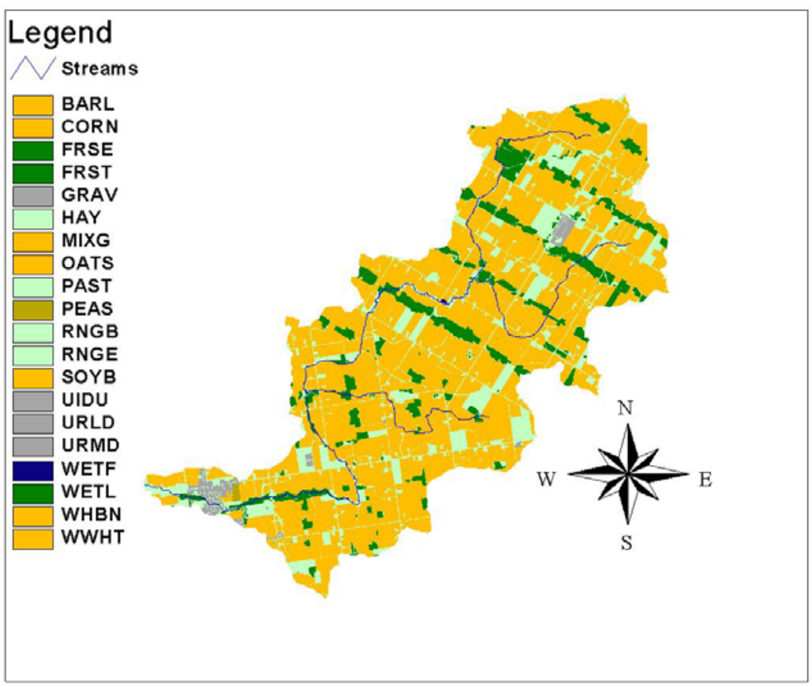

Figure 3. 2005 Land Cover Mapping - Ausable River Above Exeter Gauge

SWAT can distinguish between different crops in a growing season. However, a much more detailed year-by-year knowledge of the cropping practices is needed than is readily available in existing datasets to fully utilize this capability of SWAT. Such a detailed database simply does not exist for the entire ABMV study area. In completing a sensitivity analysis of the model inputs, (See Section 3.0), it was learned that hydrologic reponse of the SWAT model was not strongly influenced by the type of land cover provided the general classification of land was identified (e.g. forest versus agricultural land). Land cover would likely become a much more sensitive data input layer if the model was used to estimate water quality as well as water quantity.

Similar to the soils database, SWAT requests that a common database be prepared that contains the characteristics of all of the land covers present in the modelled area. Table 10 lists all the land systems that were identified within the ABMV Planning Region from the 1983 agricultural resource inventory and matches them to a 4 digit code that was pre-defined in the SWAT "crops" or "urban" land cover database supplied with the SWAT model.

Information required to describe each landcover in SWAT's "crop" and "urban" definition databases includes, but is not limited to the following:

- SCS runoff curve number for moisture condition II (for all 4 hydrologic soil groups);
- Manning's n for overland flow (OV_N);
- Land cover/plant classification (IDC);
- Biomass/energy ratio (BIO_E);
- Harvest Index (HVSTI);
- Maximum leaf area index (BLAI);
- Maximum canopy height (CHTMX);
- Maximum root depth (RDMX);
- Optimal temperatiure for plant growth (T_OPT);
- Minimum Temperature for Plant Growth (T_Base);
- Fraction of N in seed (CNYLD);
- Fraction of phosphorus in seed ((CPYLD);
- Lower limit of harvest index (WSYF);
- Minimum value of USLE_C applicable to the land cover/plant (USLE_C)
- Maximum stomatal conductance (in drought condition) (GSI)
- Vapour pressure deficit corresponding to the fraction of maximum stomatal conductance defined by FRGMAX (VPDFR)
- Fraction of maximum stomatal conductance that is achieved at a high vapour pressure deficit (FRGMAX)
- Rate of decline in radiation use efficiency per unit increase in vapour pressure deficit (WAVP)

Not all of the above inputs are relevant for the urban land uses. As well, only a few of these variables (e.g. SCS runoff curve number and Manning's n) were found to have a strong influence on the model's hydrology component (see Section 3.0 – Sensitivity Analysis).

Table 10. ARI Land Systems Categories in the ABMV Planning Region and their Corresponding SWAT Landcover Database Code

ARI Code	SWAT Landcover Code	Description
P	AGRR	Continuous Row Crop
ZZ, W	WATR	Water
Zr, ZR	FRSE	Reforestation
Zm	FRST	Mixed Woodlots/Woodlands
Zd	FRSD	Deciduous Woodlot/Woodlands
Ze	FRSE	Evergreen Woodlot/Woodlands
X	WETN	Swamp/Marsh/Bog
T	BLUG	Sod
R	FRSD or PAST	Recreation
PE	ORCD	Peaches
PC	ORCD	Peaches/Cherries
OV	ORCD	Orchard/Vineyard
OR	APPL	Orchard
NM	--	Not Mapped
MG	WWHT or BARL	Grain System
M	AGRC	Mixed System
KT	TOBC	Tobacco System
KN	PINE or AGRR	Nursery
KM	BROC	Market Garden/Truck Farm
KF	POTA or ONIO	Extensive Field Vegetables
IR	--	Indian Reserve
HG	PAST	Pasture System
H	HAY	Hay System
G	SPAS	Grazing System
E2	UIDU	Extraction/Topsoil Removal
E1	UIDU	Extraction/Pits and Quarries
Ch	ORCD	Cherries
C	AGRL or Corn	Corn System
BE, BG, B	URMD	Built-up Urban Lands
A2	RNGB	Idle Ag Land > 10 years
A1	RNGE	Idle Ag Land 5 - 10 years

2.3.5 Hydrologic Response Units

The soil and land cover data assembled for the study area were used as the basis for defining the "hydrologic response units" (HRUs) within each subcatchment. While both SWAT and GAWSER use the concept of HRUs to help define the runoff response of model subcatchments, the two models differ in terms of how they identify and delineate HRUs. SWAT identifies a unique HRU whenever a unique combination of landuse and soil type exist. For example, if a subcatchment has 10 different landuses identified and 10 different soil types present within the subcatchment a potential for 100 different HRUs could be defined by SWAT. As outlined in Section 2.2.2, GAWSER allows a maximum of 9 HRUs per subcatchment. Of these, 1 has to be an impervious HRU and typically two more HRUs are required to represent forested areas in the subcatchment. Therefore, remaining soil/crop combinations necessarily have to be grouped to fit into the defintions of the remaining 6 available HRUs.

The digital soils data and land cover data (described in Sections 2.3.3 and 2.3.4 above) were overlaid using the tools provided in AVSWAT-X. A full description of AVSWAT-X's overlaying process can be found in Di Luzio et al., (2002). In summary, however, AVSWAT-X automates the process of identifying and tabulating the set of unique landcover/soil combinations present within the subcatchment. AVSWAT-X provides the option of limiting HRU definitions for a watershed to the domininat soil/land cover domination or restricting the number of HRUs generated to only those soils and land covers that meet a certain user-defined threshold of area within the subcatchment. For example, if a user specifies that soil type representing <10% of the total subcatchment area not be considered, then soils covering <10% of the subcatchment are ignored when defining HRUs). For the initial set-up/comparison of both GAWSER and SWAT, no thresholds were defined, so all possible HRUs were identified using AVSWAT-X. The sensitivity of restricting soil and land cover combinations to certain thresholds was assessed as part of the sensitivity analysis (See Section 3.0).

HRU output from AVSWAT-X is in the format required for use as SWAT model input. Summary tables of HRUs for each of the major river systems in the ABMV study area as well as the shoreline used by SWAT in this study are provided on CD in Schedule C1. These same SWAT databases were then taken and used as the basis for preparing the HRU definitions for each of the subcatchments for the GAWSER model. The tables in Schedule C1 were placed in an excel spreadsheet and the results further analysed to identify and define the nine dominant combinations of soil and land cover for each subcatchment. For GAWSER, the soils were categorized by hydrologic soil group (HSG) so that all soils fell into one of 5 different soil categories (A, B, C, D or organic(wetland)). Land cover categories were also simplified. Non-pervious (urban, road) areas were identified as a separate HRU, regardless of the soil type associated with this land use. Forests located on the more rapidly draining soils (HSG "A" and "B") were considered to represent the rapidly draining forested HRU while forests on HSG "C" and "D" soils were considered to be the more slowly draining forested HRU. If there was a significant amout of organic soils in an area, then a separate HRU was established for wetland areas. The remaining five HRUs were then typically defined by the dominant HSG and agricultural cover combinations present.

Sensitivity analysis of the GAWSER model found that changes in soil group category had a much larger impact on model hydrologic output than did a change in landcover on the same soil class (See Section 3.0). For this reason, HRUs defined for agricultural lands typically considered the 5 different categories of soil types (A,B, C, D, organic). In some cases, however, if one or more soil types were not present, or if a particular soil type covered a very small fraction of the entire subcatchment, then this soil category was ignored and a more dominant soil group present in the subcatchment was further divided into two different HRUs on the basis of the type of agricultural land cover present. Perennial crops such as hays and pastures were considered to be one category of agricultural land cover while annual crops such as small grains, corn and beans were considered as another broad category of agricultural land cover. Table 11 summarizes the combinations of HSG and land cover that could possibly form the set of nine (9) GAWSER HRUs defined for a subcatchment The HRU entries shaded in grey were typically present in all of GAWSER's subcatchment HRU definitions.

Using the Lucknow (Nine Mile) river system, Table 12 gives an example, of how GAWSER HRUs were defined and distributed within this river basin's subcatchments. The GAWSER model was set-up such that subcatchments falling within a ZUM had the same HRU definitions. In general each zone of uniform meteorology (ZUM) within a modelled river system was assigned a unique set of 9 hydrologic response units. For the example shown in Table 12, however, the same set of HRUs happened to be used for both ZUMS covering the Lucknow river basin. Similar tables for each of the other river and shoreline systems in the ABMV Planning Region can be found in Schedule C2.

Table 11. HRUs Categoris Defined for GAWSER

Hydrologic Response Unit Code	Code Description (soil classification/vegetation)
Imp.	Impervious surfaces
Org.	Wetlands/Organic Soils – all cover types
Org-F	Wetlands/Organic Soils – forested
A-AG	HSG A soils with all forms of agricultural land cover
A-R	HSG A soils with predominantly annual agricultural crop cover.
A-P	HSG A soils with predominantly perennial agricultural crop cover
B-AG	HSG B soils with all forms of agricultural land cover
B-R	HSG B soils with predominantly annual agricultural crop cover.
B-P	HSG B soils with predominantly perennial agricultural crop cover
C-AG	HSG C soils with all forms of agricultural land cover
C-R	HSG C soils with predominantly annual agricultural crop cover.
C-P	HSG C soils with predominantly perennial agricultural crop cover
D-AG	HSG D soils with all forms of agricultural land cover
D-R	HSG D soils with predominantly annual agricultural crop cover
D-P	HSG D soils with predominantly perennial agricultural crop cover
CD-R	HSG C and D with predominantly annual agricultural crop cover
CD-P	HSG C and D with predominantly perennial agricultural crop cover
Org.-Ag	Organic soils with all forms of agricultural land cover
Org.-F	Organic soils with a natural/forest land cover.
AB-F	HSG A and B soils with forest cover
CD-F	HSG C and D soils with forest cover

Table 12. GAWSER's HRU Distribution for the Lucknow (Nine Mile) River System

ZUM	Sub-Catchment ID	Proportion of Hydrologic Response Unit (Percent)								
		Imp.	Org.	A-AG	B-AG	C-R	C-P	D-AG	AB-F	CD-F
1	501	1.04	11.36	6.32	7.55	38.12	20.66	4.75	1.07	9.13
1	502	0.24	17.25	31.56	28.6	2.32	0.85	0.73	16.69	1.76
1	503	7.16	0.00	26.58	3.20	22.37	24.03	0.00	12.32	4.34
1	504	1.30	11.86	40.88	15.89	3.82	0.58	0.34	23.00	2.33
1	505	1.35	12.93	25.62	41.32	1.36	0.16	0.00	16.64	0.62
1	506	2.57	3.81	10.68	32.41	23.65	5.42	1.66	13.18	6.62
1	507	0.33	7.88	6.19	41.73	18.68	2.58	2.41	15.13	5.07
2	508	2.81	0.07	10.14	7.63	38.82	0.77	14.55	12.93	12.28

2.3.6 HRU Drainage Characteristics

SWAT model input tables defining the drainage characteristics of the various subcatchment HRUs are prepared automaticlly by AVSWAT-X through its soil/land cover overlay procedure. For example, if an HRU was identified as consisting of a Huron clay loam soil having a land use of continuous row crops (AGRR), AVSWAT-X combines information from both the soils database (see Section 2.3.3) and the land cover database (see Section 2.3.4) to arrive at the drainage character of this particular HRU. Characteristics such as soil layer (horizon) depths, available water holding capacity of each layer, and hydraulic conductivity of each layer are pulled directly from the soils database description of the Huron soil profile (see Table 9). Key hydrologic inputs such as the runoff curve number (moisture condition II) for continuous row crop production on a Huron clay loam (HSG C) are obtained from the land cover database. .

The drainage characteristics including layer depth, hydraulic conductivity, soil-water content and depression storage depths for the various hydrologic response units defined for GAWSER were not derived from the base soil and crop datasets prepared for SWAT. Instead, values used in recent other successful applications of GAWSER within southern Ontario (Schroeter and Boyd, 1998; Schroeter and Associates, 1992, 1999a, 1999b, 2006a,b,c; CH2M-Hill, 1996; Totten Sims Hubicki, 1998; Schroeter et al., 2000a), as well as from other published information (Watt et al., 1989), were used to identify suitable initial values. The following italicized paragraphs are an excerpt from a recent GAWSER report (Schroeter and Associates., 2006a) which suggests a starting point for estimating values for selected GAWSER HRU drainage characteristics:

<u>Soil Layer Thickness, HI and HII (mm)</u>: *Generally, the first soil layer is set at 200 mm for well-drained soils, and 100 mm for poorly drained soils. The second soil layer is generally set at 600 mm for response units that contribute to subsurface flow and 1000 mm for those that contribute to groundwater storage. These soil layer thicknesses listed were selected based on information given on quaternary geology maps, soil type maps, soils reports and previous modelling experience.*

<u>Maximum depth of interception storage, INC (mm)</u>: *This represents the depth of water that is intercepted and held on the surface of vegetative growth (e.g. leaves), and gradually depleted by evapotranspiration only. It depends on the type of vegetative surfaces, with forest cover having the largest values (about 5 mm). Typical values were initially determined by Schroeter and Boyd*

(1998), and have been amazingly consistent in most applications since then (see Schroeter & Associates, 2006 b and c).

<u>Maximum depth of depression storage, DS (mm)</u>: This parameter represents the maximum depth that water can pond temporarily on the surface of a response unit, and is gradually depleted by evaporation or infiltration. It depends on surface topography (e.g. potholes, slope) and vegetative cover. (Note: These depressions do not include the large ones in hummocky areas.) For example, a relatively smooth surface (no potholes) on grade so that water does not remain ponded after a heavy rainfall would have a depressional storage depth of 1 to 5 mm. The values selected were taken from a review of Table 8.1 in the Hydrology of Floods in Canada (Watt et al., 1989).

<u>Effective hydraulic conductivity, KEFF (mm/h) at the soil surface</u>: In some publications, this parameter is referred to as the 'net infiltration capacity' of a soil or the 'final infiltration rate', and is a function of soil type and vegetative cover. For instance, in Table 8.4 of Watt et al. (1989), KEFF=1.3 mm/h for a fine textured clay with bare ground cover. This same table suggests KEFF for the same soil with "good pasture" cover is 5.0 mm/h and 6.4 mm/h with forest cover.

<u>Maximum seepage rate, CS (mm/h) and maximum percolation rate, D (mm/h)</u>: These control soil-water movement out of the first and second soil layers. They are a function of the soil hydraulic conductivity in each layer, which generally, decreases with depth in the unsaturated zone (the area above the water table). This happens because the macro pores (caused by roots, worm holes, cracks, bugs) are larger near the surface, yielding a higher hydraulic conductivity. With depth, the macropores decrease, and so the hydraulic conductivity is reduced.

Because there is no detailed information about the hydraulic conductivity of the soils in each response unit just a few metres from the surface, these parameters are estimated from the KEFF values. In earlier applications of GAWSER (see Ecologistics, 1988; Schroeter & Associates, 1996), the percolation rate (D) was estimated as half of KEFF, with CS being set at some value between D and KEFF, or CS=0.5(KEFF+D). Recent applications in moraine areas (see Schroeter et al.., 2000a, 2003), suggest percolation rates (D) should be set much less than KEFF/2, more like KEFF/10 or KEFF/20. In this study, D=KEFF/10, and CS=0.75*KEFF.*

<u>Average suction at the wetting front, SAV (mm)</u>: This is a parameter in the Green and Ampt infiltration formula (see Eq. [A.18], GAWSER Training Guide and Reference Manual). It can be estimated from soil-water characteristic curves, a plot of volumetric water content versus pressure head, which can be measured in a laboratory using soil samples taken in the field. In the absence of detailed information, previously published estimates of SAV will suffice. Mein and Larsen (1973) and Skaggs (1982) give representative values of SAV for several different soil types. The values selected in Table 2.2.3 were taken from a review of these documents, and previous applications.

<u>Soil-water contents; saturated, SMC; field capacity, FCAP; and Wilting point, WILT</u>: They are important for defining the amount of water stored in each soil layer of a response unit. Each variable is defined separately below.

The <u>saturated soil-water content, SMC</u> (vol/vol) is the condition of the soil when all the void space is filled with water and no storage is available. Any infiltration into a saturated top soil layer must *equal the seepage, the rate at which soil-water leaves the bottom of the first soil layer. Any seepage to a saturated second layer must equal the percolation rate to subsurface or groundwater storage. Generally, the saturated soil-water content is estimated by the porosity of the soil.*

Field capacity soil-water content, FCAP (vol/vol) is the condition whereby the soil void space contains the maximum residual water that can be held by capillary forces after gravity drainage. When soil-water characteristics are available, FCAP is estimated at a pressure head of 0.33 bar.

The wilting point soil-water content, WILT (vol/vol) is the amount of water contained in the void spaces that cannot be removed by evaporation, and is held by capillary forces. WILT is estimated from soil-water characteristic curves, and defined at a pressure head of 15 bar.

Typical values of SMC, FCAP and WILT for various soil types are listed in Table 8.2 of Watt et al., (1989).

Although it is possible in GAWSER to specify separate values of SMC, FCAP and WILT for each soil layer, they are generally set equal as first estimates. This means, for instance, that the SMC used for layer 1 (e.g. SMCI) was also used for layer 2 (SMCII).

Initial soil-water content, IMC (vol/vol): This variable specifies how much soil-water is present in a soil layer at the start of the simulation. In most GAWSER applications over the past 18 years, IMC has been set equal to FCAP for that layer.

These initial values were further modified in a later calibration step (see Section 4.0) in order to obtain a better match between continuous observed streamflow and modelled streamflow across the ABMV Planning Region. The result was Table 13, an optimized set of response unit drainage characteristic values for each of the HRUs defined for the ABMV Region.

2.3.7 Subcatchment Characteristics

To complete runoff hydrograph (overland and channel flow) calculations, both the GAWSER and SWAT models need input beyond just the HRU descriptions to characterize each subcatchment. This additional data includes the subcatchment's drainage area, a representative length (L) and width (W) of the subcatchment, as well as the slopes of the overland flowpaths and main and tributary channels. SWAT again relies on the AVSWAT-X extension of ArcView (v.3.3) to automatically calculate the values needed from the DEM file for the area. Schedule D contains the AVSWAT-X summary of subcatchment characterisitics of each subcatchment modelled in the ABMV area. These values are then used by SWAT as inputs to estimate the peak runoff rate using a modified rational method as well as the time of concentration for both overland and channel flow.

Table 13. Drainage Characteristics of HRUs Defined for the GAWSER Model in the ABMV Planning Region

Symbol	*Description*	*Units*	Hydrologic Response Unit Option						
			Imperv.	*Org. (Mait.)*	*Org. (other)*	*Org.-F (Mait.)*	*A-AG (Mait.)*	*A-AG (other)*	*B-P (Mait.)*
DS	Maximum depth of depression Storage	(mm)	1	5	5	5	5	5	5
KEFF	Infiltration into 1st soil layer	(mm/h)	0	1	2	1	6	12	4
CS	Infiltration into 2nd soil layer	(mm/h)	0	0.01	0.2	0.01	0.06	1.2	0.04
D	Infiltration out of 2nd layer	(mm/h)	0	0.02	0.8	0.04	0.24	4.8	0.16
SAV	Average suction at the wetting front	(mm)	0	100	100	200	200	250	200
X	Groundwater Contribution Indicator: 1=SS, 0=GW		1	1	1	1	0	0	1
FATR	Groundwater Fraction (not used in this model, set=1)		1	1	1	1	1	1	1
INC	Maximum depth of interception storage	(mm)	0	1	1	1	1	1	1
	First Soil Layer								
HI	Soil layer thickness	(mm)	0	100	100	100	200	200	200
SMCI	Saturated soil-water content (porosity)	(vol/vol)	0	0.6	0.6	0.60	0.50	0.5	0.52
IMCI	Initial soil-water content	(vol/vol)	0	0.45	0.45	0.45	0.1	0.1	0.25
FCAPI	Field capacity soil-water content	(vol/vol)	0	0.45	0.45	0.45	0.1	0.1	0.25
WILTI	Wilting point soil-water content	(vol/vol)	0	0.2	0.2	0.2	0.04	0.04	0.12
	Second Soil Layer								
HII	Soil layer thickness	(mm)	0	300	300	300	500	500	600
SMCII	Saturated soil-water content (porosity)	(vol/vol)	0	0.6	0.6	0.6	0.5	0.5	0.52
IMCII	Initial soil-water content	(vol/vol)	0	0.45	0.45	0.45	0.1	0.1	0.25
FACPII	Field capacity soil-water content	(vol/vol)	0	0.45	0.45	0.45	0.1	0.1	0.25
WILTII	Wilting point soil-water content	(vol/vol)	0	0.2	0.2	0.2	0.04	0.04	0.12

Notes: HRU Codes used are as follows: A = HSG A B = HSG B C = HSG C D = HSG D AG = All agricultural land covers
P = permanent ag crops R = annual (row) crops F = high vegetation forest cover
Mait. - refers to values used for HRUs in the Maitland river system only. *other* - refers values used for HRUs in all other river systems

Table 13 (continued).Drainage Characteristics of HRUs Defined for the GAWSER Model in the ABMV Planning Region

Symbol	*Description*	*Units*	**Hydrologic Response Unit Option**						
			B-P (other)	***B-R (Mait.)***	***B-R (other)***	***B-AG***	***C-P (Mait.)***	***C-P (other)***	***C-R (Mait.)***
DS	Maximum depth of depression Storage	(mm)	5	5	5	5	5	5	5
KEFF	Infiltration into 1st soil layer	(mm/h)	8	4	8	8	2	4	2
CS	Infiltration into 2nd soil layer	(mm/h)	0.8	0.04	0.8	0.8	0.04	0.4	0.04
D	Infiltration out of 2nd layer	(mm/h)	3.2	0.16	3.2	3.2	0.08	1.6	0.08
SAV	Average suction at the wetting front	(mm)	200	200	200	200	200	150	200
X	Groundwater Contribution Indicator: 1=SS, 0=GW		1	1	1	1	1	1	1
FATR	Groundwater Fraction (not used in this model, set=1)		1	1	1	1	1	1	1
INC	Maximum depth of interception storage	(mm)	1	1	1	1	1	1	1
	First Soil Layer								
HI	Soil layer thickness	(mm)	200	200	200	200	150	150	150
SMCI	Saturated soil-water content (porosity)	(vol/vol)	0.52	0.52	0.52	0.52	0.56	0.56	0.56
IMCI	Initial soil-water content	(vol/vol)	0.25	0.25	0.25	0.25	0.4	0.38	0.4
FCAPI	Field capacity soil-water content	(vol/vol)	0.25	0.25	0.25	0.25	0.4	0.38	0.4
WILTI	Wilting point soil-water content	(vol/vol)	0.12	0.12	0.12	0.12	0.18	0.17	0.18
	Second Soil Layer								
HII	Soil layer thickness	(mm)	600	600	600	600	800	800	800
SMCII	Saturated soil-water content (porosity)	(vol/vol)	0.52	0.52	0.52	0.52	0.58	0.56	0.58
IMCII	Initial soil-water content	(vol/vol)	0.25	0.25	0.25	0.25	0.4	0.38	0.4
FACPII	Field capacity soil-water content	(vol/vol)	0.25	0.25	0.25	0.25	0.4	0.38	0.4
WILTII	Wilting point soil-water content	(vol/vol)	0.12	0.12	0.12	0.12	0.18	0.17	0.18

Note: HRU Codes used are as follows: A = HSG A B = HSG B C = HSG C D = HSG D AG = All agricultural land covers
P = permanent ag crops R = annual (row) crops F = high vegetation forest cover
Mait. - refers to values used for HRUs in the Maitland river system only. o*ther* - refers values used for HRUs in all other river systems

Table 13 (continued).Drainage Characteristics of HRUs Defined for the GAWSER Model in the ABMV Planning Region

Symbol	*Description*	*Units*	**Hydrologic Response Unit Option**						
			C-R (other)	***CD-AG***	***CD-P***	***CD-R***	***D-AG (Mait.)***	***D-AG (other.)***	***D-P***
DS	Maximum depth of depression Storage	(mm)	5	5	5	5	5	5	5
KEFF	Infiltration into 1st soil layer	(mm/h)	4	2	2	2	1	2	2
CS	Infiltration into 2nd soil layer	(mm/h)	0.4	0.02	0.02	0.02	0.02	0.2	0.2
D	Infiltration out of 2nd layer	(mm/h)	1.6	0.08	0.08	0.08	0.04	0.8	0.8
SAV	Average suction at the wetting front	(mm)	150	150	150	150	200	100	150
X	Groundwater Contribution Indicator: 1=SS, 0=GW		1	1	1	1	1	1	1
FATR	Groundwater Fraction (not used in this model, set=1)		1	1	1	1	1	1	1
INC	Maximum depth of interception storage	(mm)	1	1	1	1	1	1	1
	First Soil Layer								
HI	Soil layer thickness	(mm)	150	150	150	150	100	100	100
SMCI	Saturated soil-water content (porosity)	(vol/vol)	0.56	0.56	0.56	0.56	0.60	0.6	0.6
IMCI	Initial soil-water content	(vol/vol)	0.38	0.4	0.4	0.4	0.45	0.45	0.45
FCAPI	Field capacity soil-water content	(vol/vol)	0.38	0.4	0.4	0.4	0.45	0.45	0.45
WILTI	Wilting point soil-water content	(vol/vol)	0.17	0.18	0.18	0.18	0.2	0.20	0.20
	Second Soil Layer								
HII	Soil layer thickness	(mm)	800	800	800	800	1000	1000	1000
SMCII	Saturated soil-water content (porosity)	(vol/vol)	0.56	0.58	0.58	0.58	0.60	0.60	0.6
IMCII	Initial soil-water content	(vol/vol)	0.38	0.4	0.4	0.4	0.45	0.45	0.45
FACPII	Field capacity soil-water content	(vol/vol)	0.38	0.4	0.4	0.4	0.45	0.45	0.45
WILTII	Wilting point soil-water content	(vol/vol)	0.17	0.18	0.18	0.18	0.2	0.20	0.2

Note: HRU Codes used are as follows: A = HSG A B = HSG B C = HSG C D = HSG D AG = All agricultural land covers
P = permanent ag crops R = annual (row) crops F = high vegetation forest cover.
Mait. - refers to values used for HRUs in the Maitland river system only. *other* - refers values used for HRUs in all other river systems

Table 13 (continued).Drainage Characteristics of HRUs Defined for the GAWSER Model in the ABMV Planning Region

Symbol	*Description*	*Units*	Hydrologic Response Unit Option		
			D-R	*AB-F*	*CD-F*
DS	Maximum depth of depression Storage	(mm)	5	15	8
KEFF	Infiltration into 1st soil layer	(mm/h)	2	10	3
CS	Infiltration into 2nd soil layer	(mm/h)	0.2	7.5	1
D	Infiltration out of 2nd layer	(mm/h)	0.8	5	15
SAV	Average suction at the wetting front	(mm)	150	200	100
X	Groundwater Contribution Indicator: 1=SS, 0=GW		1	0	1
FATR	Groundwater Fraction (not used in this model, set=1)		1	1	1
INC	Maximum depth of interception storage	(mm)	1	5	5
	First Soil Layer				
HI	Soil layer thickness	(mm)	100	200	100
SMCI	Saturated soil-water content (porosity)	(vol/vol)	0.6	0.5	0.56
IMCI	Initial soil-water content	(vol/vol)	0.45	0.1	0.38
FCAPI	Field capacity soil-water content	(vol/vol)	0.45	0.1	0.38
WILTI	Wilting point soil-water content	(vol/vol)	0.20	0.04	0.17
	Second Soil Layer				
HII	Soil layer thickness	(mm)	1000	700	1000
SMCII	Saturated soil-water content (porosity)	(vol/vol)	0.6	0.5	0.56
IMCII	Initial soil-water content	(vol/vol)	0.45	0.1	0.38
FACPII	Field capacity soil-water content	(vol/vol)	0.45	0.1	0.38
WILTII	Wilting point soil-water content	(vol/vol)	0.2	0.04	0.17

Note: HRU Codes used are as follows: A = HSG A B = HSG B C = HSG C D = HSG D AG = All agricultural land covers
P = permanent ag crops R = annual (row) crops F = high vegetation forest cover
Mait. - refers to values used for HRUs in the Maitland river system only. *other* - refers values used for HRUs in all other river systems.

The information derived through AVSWAT-X and provided in Schedule D was used as the source for values such as subcatchment area (A), flowpath length (L) and slope (S) for the GAWSER model as well. GAWSER also requires an estimate of subcatchment width to determine overland routing parameters required in the area/time versus time method of overland flow estimation.. It estimates this using one of the following ways:

$W_1 = A/L$ (first estimate)

or

$W_2 = A/L_T$ (second estimate)

where A is the subcatchment area, L is the representative length of the watershed, and L_T is the total length of all the "measurable" tributaries within the subcatchment.

The actual subcatchment width is taken as the larger of W_1 or W_2. If a subcatchment is regarded as having a lot of lateral inflow into the main channel, then W is taken as the larger of the following values:

$W_1 = L/1.5$

or

$W_2 = A/(L_c + L)$

where L_c is the length of the channel routing reach that traverses the lateral inflow subcatchment.

Other factors which GAWSER needs to characterize subcatchments include the overland flow basetime factor (FTB), the groundwater factor (GWFACT), and recession constants needed to define outflows from subsurface and groundwater storage from the subcatchment (KGW and KSS). These were obtained from values used in previous studies (Schroeter et al., 2006a,b,c).

2.3.8 Stream Channel Data

Stream channel data are needed to route the runoff water overland and through the watershed channels. Model users are asked to enter a value for Manning's n for both overland and channel flow. In channel flow, water storage and its influence on flow rate is also considered, making it necessary to supply channel cross-section information. SWAT simplifies this model input requirement by assuming all channels to be trapezoidal in cross-section with 2:1 side slopes. Estimates of the channel depth and top width are provided through the AVSWAT-X analysis of the DEM and upstream watershed area. These estimated values were used in setting up SWAT for this initial model evaluation and Tier 1 modelling task. SWAT, however does allow a user to enter in actual depth and width values if more detailed data are available or more detailed modeling of the area needs to be undertaken in the future. The trapezoidal cross-section assumption however is maintained.

GAWSER allows the user to enter in representative cross-sections for use in channel routing procedures. For river systems within the jurisdiction of the Ausable-Bayfield Conservation Authority, channel cross-sections used in the GAWSER event model set-up by Schroeter and Associates, (1992) were used where available. Some cross-sections were also obtained from reviewing the BRFU model set-up in both the MVCA and ABCA jurisdictions. In the end, it was not possible to obtain-field-measured or detailed cross-section data for main channels in each subcatchment or channel routing element. Therefore, some of the observed sections were also used to represent sections at other points in the watershed if those sections were believed to be representative of channel at the point being described. When no measured data were available at all, representative sections were derived from previously applied geomorphical relationships. A fuller description of the development and use of these relationships can be found in Annable, (1996) and in Schroeter and Associates, (2006a,b,c).

2.3.9 Dam and Reservoir Data

CEB Map E-6 shows the location of the main in-channel water control structures present in the ABMV Planning Region. In SWAT the water balance for reservoirs includes inflow, outflow, precipitation on the surface, evaporation, seepage from the reservoir bottom and diversions. Three alternatives for estimating outflow from a reservoir are offered in SWAT. Option 1 allows the user to input detailed measured outflow. For small, uncontrolled reservoirs, a second option that allows users to simply specify a water release rate is offered. When the reservoir volume exceeds the principle storage, the extra water is released at the specified rate. Volumes exceeding the emergency spillway are released within one day. The third option is more for larger, managed reservoirs and asks that the user specify monthly target outflow volumes for the reservoir.

In GAWSER, storage-outflow information for reservoirs (as well as ponds, lakes and wetlands) can be entered as tables computed by other means (e.g. HEC-2, HEC-RAS), as standard equations representing flow through different parts of the control structure (e.g. weir, gates, valves or turbines) and the storage in the reservoir as a function of water level, or as a combination of tables (e.g. elevation-storage) and discharge equations. These procedures are fully described in Schroeter and Associates, (1996).

As mentioned in Section 2.3.2, limited effort was spent representing the main reservoirs in the ABMV Planning Region during the initial set-up and evaluation of both GAWSER and SWAT. When the final model for long-term modeling use was selected, more time was spent representing these features in the model input code. Stage-storage-discharge relationships used in the original GAWSER model set-up for the Ausable and Parkhill River systems were used as the basis for describing the Morrison Reservoir and Dam and Parkhill Reservoir and Dam. The other smaller dams were set-up, even in the final model for this Tier 1 evaluation as flow through elements.

2.3.10 Sewage Treatment Plant (STP) Data

A review of the Ministry of Environment's database identified 22 STP discharge points in the ABMV Planning Region. Two (2) other significant STP discharge points, not included in the MOE database, were also identified by local CA staff members familiar with the Region. CWB CWB Map E-7 shows the distribution of these STP's across the major river and shoreline systems in the ABMV Planning Region

SWAT can identify these STP discharges as point source loadings. Annual, monthly, or daily values of STP discharge water, sediment and nutrient/pollutant loadings may be provided as input to the SWAT model. The constant daily, monthly average daily or measured actual daily data can be read directly by SWAT provided they match the required input data format. The location of each point of STP discharge is specified during the model's set-up through the AVSWAT-X interface tool. When SWAT detects a point discharge within a subcatchment, the daily discharge volume is added to the estimate of natural stream flow along the section of reach where the STP water is discharged and subsequently routed through downstream reaches.

Sewage treatment plant (STP) discharge is treated in GAWSER as part of the subcatchment outflow calculations, and is considered as a direct contribution to the baseflow totals. STP effluents can be specified as a table of mean monthly discharges, or can be read directly from a disk file.

For the initial objective evaluation of the GAWSER and SWAT models, sewage treatment plant discharges were not included in the model set-up. They were, however, added when refining input datasets of the model selected to prepare the Tier 1 model estimates.

In many cases the wastewater treatment facilities present in the ABMV Planning Region incorporate wastewater lagoons which may discharge to the local watercourse for short durations. This most often occurs at wetter times of the year when stormwater runoff or other conditions overburden the treatment system. Neither GAWSER or SWAT currently have a convenient capability of modelling these short duration, high volume releases of lagoon water, (although it may be possible to represent it as an intermittent daily value in SWAT) . As such, they were not modelled and could be considered a modelling capability gap. On the other hand, from a hydrology perspective, the water associated with these discharges is likely associated with higher runoff volumes generated just prior to the time the water had to be discharged. In a sense, then this runoff water is already accounted for in the model's estimate of runoff.

2.3.11 Consideration of Water Takings

Both the GAWSER and SWAT models can represent water takings for various human uses. SWAT allows water to be removed from the shallow aquifer, the deep aquifer, the reach or the pond defined within any subcatchment in the river system. Water may also be removed from reservoirs for consumptive use. Water removed for consumptive use (defined by SWAT as water used for irrigation outside the watershed or removal of water for urban/industrial use) is considered to be lost from the system. Consumptive water use input files required by SWAT ask the user to specify where the water is being removed from the system and the average daily water removal on a month-by-month basis from the supply. Irrigation water use within the watershed is identified through SWAT's ".mgt" input file. Water is applied to one or more defined HRUs at a frequency and depth (volume amount) defined by the model user. Additioal details on defining irrigation events are provided in Chapter 20 of Neitsch et al., (2002).

GAWSER allows modellers to represent surface water takings only. Surface water taking amounts are withdrawn from the total subcatchment outflow at a given time in the simulation in the following manner as described in Schroeter and Associates (2006c):

$$Q_{TAKE} = \min(Q_{TI}\ ,\ FSPUMP * ISEAS * Q_{PUMP}) \text{ and } Q_{TI} \geq 0$$

$$Q_{TF} = \max(0\ ,\ Q_{TI} - Q_{TAKE}),$$

where Q_{PUMP} is the total withdrawal rate (in L/s) for all surface water takers within a given subcatchment element, ISEAS is a seasonal on/off switch code (either 1 or 0), FSPUMP is a global adjustment factor applied to all the surface takers within the watershed, Q_{TAKE} is the actual water taking amount, and Q_{TI}, and Q_{TF} are the total subcatchment outflows (in L/s) before and after the surface water taking amounts are removed, respectively.

Obtaining comprehensive datasets to provide these hydrologic models with the information needed to represent water takings is difficult and time consuming. GAWSER users in the past have specified values for Q_{PUMP} in each subcatchment element to be the maximum permitted amounts noted in the respective PTTWs (Permits To Take Water) as this is the only information that is readily available that even begins to assess how much water is actually being taken. (Schroeter and Associates, 2006a,b,c). It is recognized, however, that the actual water taking amounts would be less than this. The global adjustment factor FSPUMP is used to conveniently adjust permitted amounts to values that are closer to the actual amounts.

There are relatively few water takings in the study area compared to other parts of the province. Luinstra Earth Sciences (2006) prepared a report for the ABMV Planning Region summarizing their findings from a survey conducted of PTTWs in the area. They found that there were 146 permit holders in the MOE PTTW database that fell within the Planning Region. Of these, 19 were excluded as temporary permits, 37 were expired permits and 4 permits did not identify a permit holder/contact person. This left 86 valid permits in the Planning Region. Of these, 44 permits were for municipal water supply and the remaining 42 permit holders were for other uses. These other uses were primarily irrigation for golf courses/turf and vegetable and fruit production in the area. Other uses included aggregate washing, private/institutional water supply, aquaculture, and commercial bait farming. Luinstra Earth Sciences (2006) estimated the non-municipal permitted water takings to be between 28 million and 31 million litres per year. This translates into an equivalent depth of 0.006 mm of water over the entire Planning Region – a relatively insignificant amount. Certainly, in localized areas where water taking may be influencing local water supplies, the amounts may not be insignificant, however at this initial regional scale (Tier 1 level) of modelling and analysis, it was decided not to incorporate this level of detail into the models. If the Tier 1 water budget assessment identified areas of moderate stream or groundwater stress, then a more detailed accounting of water use in the watershed could be undertaken with the selected numerical model.

CWB Map E-8 shows the distribution of the water taking permits across the ABMV Planning Region. Permits are classified on this map as follows:

Municipal (e.g. town water supply)

- Agricultural Related (e.g. irrigation of fruit, vegetable or field crops)
- Aquacultural Related (e.g. fish farm)
- Private drinking Water Supply (>50,000 L/day)
- Industrial, Commercial , Institutional related (e.g. gravel pits)
- Recreational Related (e.g. golf courses)

CWB Map E-8 shows that the greatest concentration of PTTWs that are not for municipal applications occurs in the south central and south-western portion of the ABMV Planning Region. It is important to note that surface water supplies in the south0western area are generally influenced by Lake Huron water levels. Therefore, the water supply available in that area extends beyond the stream water to lake water, further reducing the need to be concerned with surface water supply in this area.

3.0 Sensitivity Analysis

Prior to simulating the hydrology of the river systems in the ABMV Planning Region, an investigation was made to determine which input variables cause the greatest unit change in both the SWAT and GAWSER model output. Knowing the sensitivity of a model's output to changes in various input variables can speed up the model calibration process by focussing attention on the most sensitive input varaiables. For this investigation, only input variables expected to affect the hydrology component of the models evaluated were considered. Annual streamflow (water yield) was the focus of this sensitivity analysis, although with some input variables, their influence on spring runoff, annual shallow groundwater aquifer recharge, total annual surface runoff and annual tile drainage flow were also considered.

Given the size of the study area, it was decided to conduct the sensitivity analysis on a set of sub-watersheds that were more or less representative of the range of watershed conditions present in the Planning Region. By working on sub-watersheds as opposed to entire river systems, the models could be more efficiently set-up and run several times to assess the impact of input variable adjustments on the output of interest. The three subwatersheds considered were the Ausable River subwatershed above the Exeter stream gauge, the Blyth Brook subwatershed above the Blyth stream gauge and the Kerry's Creek shoreline subwatershed. The Exeter subwatershed (113 km^2), is representative of much of the agricultural practices and heavier, tile drained soils in the Planning Region. An urban centre also exists within the bounds of this subwatershed. The Blyth Brook watershed (73.4 km^2), is also representative of the rural flavour of the Planning Region, but includes a higher percentage of high infiltration soils and lands with forest cover. Baseflow also makes up a higher proportion of the total streamflow in the Blyth subwatershed than it does in the Exeter subwatershed. Kerry's Creek (27.9 km^2) was selected as a representative shoreline subwatershed. While larger than many of the shoreline stream and gullies, it was a better match with the other inland test subwatersheds. Permanent streamgauge data were not available for the Kerry's Creek subwatershed, although some manual streamgauging began in the fall of 2005 through a separate study. Long-term streamgauge data were available for the Exeter and Blyth subwatersheds. The following sections outline the findings of the sensitivity analyses for SWAT and GAWSER.

3.1 SWAT Model

The SWAT model was set-up for the three test subwatersheds (Exeter, Blyth and Kerry's Creek) using the datasets described in Section 2 and largely default values provided with the model for any other outstanding inputs. The SWAT model includes an automated sensitivity analysis routine as part of its package. This routine was run on each of the three subwatersheds with the sensitivity of the input variables evaluated in terms of their sensitivity on streamflow only. A

total of 280 model runs were completed on each of the test subwatersheds. The result was a ranking of the input variables for each of the subwatersheds as shown in Table 14. From this, an average sensitivity ranking of the 26 most sensitive input variables was also calculated (see Table 14). For a detailed description of each of these input variables, the reader is referred to Neitsch et al., 2002). A brief discussion around the more sensitive variables, however, follows.
Runoff curve number (CN2) was clearly identified as SWAT's most sensitive input variable affecting streamflow. Researchers at the University of Guelph have also confirmed this to be the case and have spent a considerable amount of time identifying reasonable values for CN2 for different land cover conditions (personal communication, Amanjot Singh, 2006).

SWAT's second most sensitive variable affecting streamflow was found to be RCHRG_DP (Fraction of total aquifer recharge moving from the shallow aquifer to the deep aquifer). Without very detailed hydrogeological investigation, this value is impossible to determine. This value could therefore be set in the calibration step at a value that gives the best model result.

SOL_Z (Depth from the soil surfac to the bottom of the layer) was also found to be a very sensitive parameter. For this initial set-up the soil depths provided by soil report descriptions of generic soil profiles were assumed to be valid. This input was therefore not adjusted in the calibration process and was generally set as 1 metre.

GWQMN (threshold depth of water in the shallow aquifer required for return flow to occur) is the fourth most sensitive parameter. It could be adjusted as needed to optimize model output in the calibration step.

Inputs characterizing snow processes (SMFMN, SMTMP, SMFMX, SFTMP) were also found to be rather sensitive input parameters for the SWAT model. Again adjusting these values within the limits of the varibles expected range could help in the calibration step.

ESCO (soil evaporation compensation factor) is a coefficient that allows the SWAT user to adjust the soil's evaporative demand to account for capillary action, crusting and cracks. It fell in SWAT's ten list of most senstive input parameters. This variable can be adjusted globally or within each HRU.

SOL_AWC (soil available water holding capacity) and GW_REVAP (the groundwater revaporation coefficient) were also identified as being in the top ten. Like SOL_Z, the SOL_AWC determined for each soil type using the soil water characteristics model, (see Section 2.3.3), was assumed to be valid and was therefore not adjusted in later calibration efforts.

GW_REVAP, which refers to the movement of water from the shallow aquifer back into the overlying unsaturated zone can be significant, particularly if the water table is shallow or if deep rooted plants are present.

A more detailed investigation of input variable sensitivity than what was completed using SWAT's automated routine was completed on the Blyth and Exeter subwatersheds in an effort to more fully understand the relative impact of altering some of SWAT's inputs. Table 15 presents the findings of this more detailed sensitivity analysis as completed on the Blyth subwatershed.

Results show that certain parameters had a strong influence on the specific components of the water budget while essentially no influence on other factors. For example, adjusting the curve number (CN) dramatically affects the partioning of surface runoff and infiltration but has a much smaller influence on the overall net streamflow (water yield) of a subcatchment. Similarly inputs describing snow pack and snow melt, while quite sensitive, primarily influence the spring runoff predictions. Groundwater related variables had little to no effect on surface flow, but could be used to adjust the baseflow component of water yield.

Table 14. Results from SWAT's Automated Sensitivity Analysis Routine for Selected Subwatershed - Hydrology Only

Input Variable	Sensitivity Ranking			
	Blyth	Exeter	Kerry's Creek	Average Rank
ALPHA_BF	23	22	23	23
BIOMIX	12	10	12	12/13
BLAI	27	27	27	27
CANMX	13	14	14	14
CH_K2	21	21	20	21
CH_N	25	24	25	24/25
CN2	1	1	1	1
EPCO	24	26	24	24/25
ESCO	4	9	8	7
GW_DELAY	20	23	22	22
GWQMN	3	7	3	4
GW_REVAP	6	13	9	10
RCHRG_DP	2	4	2	2
REVAPMN	15	20	21	19/20
SFTMP	8	11	13	11
SLOPE	16	17	17	16
SLSUBBSN	18	19	18	18
SMFMN	7	3	4	5
SMFMX	10	6	7	8
SMTMP	8	5	6	6
SOL_ALB	19	18	19	19/20
SOL_AWC	9	8	10	9
SOL_K	22	15	15	17
SOL_Z	5	2	5	3
SURLAG	17	16	16	15
TIMP	11	12	11	12/13
TLAPS	26	25	26	26

Note: units shown where appropriate.

It is interesting to note the influence tile drain parameters had on hydrologic response. They had relatively little if any effect. Tests were run which compared modelling the entire watershed with tile drainage to modelling the same watershed with no tile drainage simulated. A minimal (2-5 mm water depth) difference resulted in model output with these two extremes. To make SWAT's tile drainage component more responsive would require defining a more restrictive soil

horizon below the defined tile drain depth. In this round of modelling, it was assumed that the soil profile descriptions provided in the various referenced soils reports were accurate, so edits to soil horizon characteristics were not made.
Table 15 also shows the findings of a set of runs that tested the sensitivity of the model's HRU definition set-up. Reducing the number of HRUs in SWAT could reduce run times and file size. It was found that ignoring soil and landuse combinations that represent less than 5% of the subwatershed area resulted in only a 2% change in key hydrologic output values. Similarly ignoring soil and landuse combinations that represent less than 10% of the subwatershed area resulted in less than a 3% difference in hydrologic response. Therefore simplifying the model in this way would not likely result in a significant change in SWAT's hydrologic output response but could reduce run times.

In order to confirm the effects of some of the more critical inputs, additional sensitivity runs were completed using the Exeter watershed as the base model. Would the model respond in the same way in this model setting as it did in the Blyth set-up? The sensitivity of other aspects of SWAT were also tested. The outcome of these tests are presented in Table 16. In general, it is clear from the data presented in Table 16 that, while the selected variables did not behave exactly as they did in the Blyth watershed set-up, the general trends were the same.

The Exeter watershed was also used to test the influence of choice of potential ET model on model output. The choice was found to have a very significant influence. The Priestly –Taylor model gives the lowest estimate of daily PET while Hargraeves method gives the highest estimate.

Table 15. Sensitivity Analysis of Selected SWAT Input Variable on Selected Hydologic Output - Blyth Waterhed

Input Variable	Lower Range	Upper Range	Reference Value[1]	Input Variable Value and Corresponding Change in Output Relative to Output using the Reference Value (%)						Output Response Considered
SFTMP	-5	5	**1.0**	-5	-2	-1	0	2	5	
				-27.2	-14.8	-10.9	-8.9	+6.7	+12.7	March SurQ
SMTMP	-5	5	**0.5**	-5	-2	-1	0	2	5	
				-55.8	-32.7	-23.3	-7.4	+11.7	-8.1	March SurQ
SMFMX	1.4	6.9	**4.5**	1.5	3	3.5	4	5	6.5	
				-3.4	-1.4	-0.8	-0.4	+0.1	-1.8	March SurQ
SMFMN	1.4	6.9	**4.5**	1.5	3	3.5	4	5	6.5	
				+30.9	+8.5	+5.6	+2.6	-2.8	-10.2	March SurQ
TIMP	0.01	1.0	**1.0**	0.1	0.4	0.5	0.6	0.7	0.9	
				+32.3	+22.8	+17.5	+13.5	+9.4	+3.0	March SurQ
SNOCOVMX	0	1.0	**1.0**	0.2	0.4	0.5	0.6	0.75	0.8	
				0.0	0.0	0.0	0.0	0.0	0.0	March SurQ
SNO50COV	0	1.0	**0.5**	0.2	0.4	0.55	0.6	0.7	0.8	
				0.0	0.0	0.0	0.0	0.0	0.0	March SurQ
ESCO	0.01	1	**0.95**	0.2	0.4	0.8	0.85	0.90	1.0	
				-6.6	-6.0	-2.9	-2.1	-1.1	+1.1	Annual SurQ
				-28.6	-27.2	-17.6	-13.9	-8.4	+12.6	Annual GW_Q
				-15.2	-14.3	-8.7	-6.7	-4.0	+5.7	Annual WYLD
EPCO	0.01	1	**1.0**	0.2	0.4	0.5	0.6	0.8		
				+0.7	+0.4	+0.3	+0.2	+0.1		Annual SurQ
				+2.3	+1.0	+0.7	+0.5	+0.2		Annual GW_Q
				+1.3	+0.6	+0.4	+0.3	+0.1		Annual WYLD
CANMX	0	10	2	0	1	3	4	5	8	
				+1.0	+0.4	-0.3	-0.6	-0.9	-1.6	Annual SurQ
				+0.4	-0.1	+0.2	+0.3	+0.4	+0.3	Annual GW_Q
				+0.7	+0.2	-0.1	-0.3	-0.4	-0.9	Annual WYLD

Table 15. (Cont'd): Sensitivity Analysis of Selected SWAT Input Variables on Selected Hydrologic Output – Blyth Watershed

Input Variable	Lower Range	Upper Range	Reference Value[1]	Input Variable Value and Corresponding Change in Output Relative to Output for this Variable's Default Value (%)						Output Response Considered
SOL_ALB (Soil type Hl) (HSG: B)	0	0.5	0.15	0.0	0.05	0.1	0.2	0.25		
				0.0	0.0	0.0	0.0	0.0		Annual SurQ
				0.0	0.0	0.0	0.0	0.0		Annual GW_Q
				0.0	0.0	0.0	0.0	0.0		Annual WYLD
SURLAG	1	12	2	1	3	4	5	6	12	
				-0.1	0.0	+0.1	+0.1	+0.1	+0.1	Annual SurQ
				0.8	-0.5	-0.8	-1.0	-1.3	-2.0	Annual GW_Q
				-0.1	0.1	+0.1	+0.1	+0.2	+0.2	Annual WYLD
CN2 (B HSG)	55	90	75	55	60	70	80	85	90	
				-62.1	-50.4	-20.3	+23.2	+49.1	+84.9	Annual SurQ
				+32.4	+26.5	+10.9	-12.5	-26.9	-46.3	Annual GW_Q
				-3.2	-2.7	-1.2	+1.6	+3.4	+6.8	Annual WYLD
CH_N (1&2)	0.016	0.14	0.10	0.016	0.02	0.05	0.08	0.12	0.14	
				0.0	0.0	0.0	0.0	0.0	0.0	Annual SurQ
				-2.7	-2.5	-1.4	-0.5	+0.5	+1.0	Annual GW_Q
				+0.2	+0.2	+0.2	+0.1	-0.1	-0.1	Annual WYLD
OV_N	0.008	0.5	0.35	0.008	0.1	0.2	0.3	0.4	0.5	
				+0.1	0.0	0.0	0.0	0.0	0.0	Annual SurQ
				-3.7	-2.2	-1.2	-0.4	+0.4	+1.0	Annual GW_Q
				+0.3	+0.2	+0.1	0.0	0.0	-0.1	Annual WYLD
CH_K (1&2)	1	15	5.3	1	2	3	8	10	15	
				0.0	0.0	0.0	0.0	0.0	0.0	Annual SurQ
				-10.7	-8.0	-5.4	+4.3	+7.3	+11.5	Annual GW_Q
				+0.5	+0.4	+0.3	-0.4	-0.7	-1.2	Annual WYLD

Table 15. (Cont'd): Sensitivity Analysis of Selected SWAT Input Variables on Selected Hydrologic Output – Blyth Watershed

Input Variable	Lower Range	Upper Range	Reference Value[1]	Input Variable Value and Corresponding Change in Output Relative to Output for this Variable's Default Value (%)						Output Response Considered
SOL_BD (Soil type: Hl) (1 layer) (HSG: B)	1.1	1.9	1.4	1.2	1.3	1.5	1.6	1.7	1.8	
				-15.0	-4.8	+2.4	+1.7	-1.3	-8.3	Annual SurQ
				+10.6	+3.9	-2.2	-1.9	+0.1	+1.5	Annual GW_Q
				-0.9	-0.3	+0.3	+0.3	+0.1	-1.4	Annual WYLD
SOL_AWC (Soil type: Hl) (1 layer) (HSG: B)	0.05	0.3	0.14	0.1	0.12	0.15	0.16	0.18	0.2	
				-0.9	+0.5	-0.6	-1.2	-3.0	-5.6	Annual SurQ
				+5.8	+2.2	-0.7	-1.5	-1.8	-1.6	Annual GW_Q
				+2.6	+1.2	-0.6	-1.0	-2.1	-3.1	Annual WYLD
SOL_K (Soil type: Hl) (1 layer) (HSG: B)	1	100	10	5	20	25	30	40	50	
				+2.5	-1.3	-1.5	-1.7	-1.8	-1.8	Annual SurQ
				-2.5	+1.2	+1.4	+1.6	+1.8	+1.8	Annual GW_Q
				-0.3	+0.2	+0.3	+0.3	+0.4	+0.4	Annual WYLD
GW_DELAY	1	50	30	10	15	20	25	40	50	
				0.0	0.0	0.0	0.0	0.0	0.0	Annual SurQ
				+4.2	+3.0	+1.8	+0.8	-1.0	-0.9	Annual GW_Q
				+1.5	+1.1	+0.7	+0.3	-0.4	-0.3	Annual WYLD
ALPHA_BF	0.1	1	0.95	0.4	0.6	0.7	0.8	0.9	1.0	
				0.0	0.0	0.0	0.0	0.0	0.0	Annual SurQ
				-0.5	-0.3	-0.2	-0.1	0.0	0.0	Annual GW_Q
				-0.2	-0.1	-0.1	0.0	0.0	0.0	Annual WYLD
GWQMN	10	1000	100	10	50	200	300	500	1000	
				0.0	0.0	0.0	0.0	0.0	0.0	Annual SurQ
				+26.6	+11.0	-2.7	-5.1	-9.8	-21.4	Annual GW_Q
				+9.5	+3.9	-1.0	-1.8	-3.5	-7.7	Annual WYLD

Table 15. (Cont'd): Sensitivity Analysis of Selected SWAT Input Variables on Selected Hydrologic Output – Blyth Watershed

Input Variable	Lower Range	Upper Range	Reference Value[1]	Input Variable Value and Corresponding Change in Output Relative to Output for this Variable's Default Value (%)						Output Response Considered
GW_REVAP	0.02	0.2	0.14	0.02	0.1	0.12	0.16	0.18	0.2	
				+20.2	+8.8	+4.2	-3.4	-6.4	-9.4	Annual GW_Q
				+7.4	+3.2	+1.5	-1.2	-2.3	-3.4	Annual WYLD
REVAPMN	10	1000	50	10	100	200	300	500	1000	
				0.0	0.0	0.0	0.0	0.0	0.0	Annual SurQ
				-2.6	+22.5	+22.5	+22.5	+22.5	+22.5	Annual GW_Q
				-0.9	+8.2	+8.2	+8.2	+8.2	+8.2	Annual WYLD
Landuse Fraction (HRU Def'n)	0	26	0	5	10	15	20			
				+1.1	+0.5	+4.9	+4.9			Annual SurQ
				-1.2	-0.5	-6.7	-7.1			Annual GW_Q
				0.0	0.0	-0.6	-0.9			Annual WYLD
Soil Fraction (HRU Def'n)	1	100	0	5	10	15	20			
				+0.1	+0.8	+1.2	+3.2			Annual SurQ
				-0.6	-2.0	-3.1	-5.1			Annual GW_Q
				-0.2	-0.6	-0.9	-0.8			Annual WYLD
Soil and Landuse (HRU Def'n)	0 + 0	20 + 20	0 + 0	3 + 3	5 + 5	10 + 10		15 + 15		
				+0.3	+1.2	+1.4		+6.3		Annual SurQ
				-0.7	-1.7	-2.6		-10.1		Annual GW_Q
				-0.2	-0.2	-0.5		-1.6		Annual WYLD
RCHRG_DP	0	1	0.1	0	0.2	0.4	0.7	0.9	1	
				-100.0	+100.0	+300.0	+600.0	+800.0	+1200	Deep AQ
				+13.2	-13.2	-39.5	-77.3	-97.3	-100	Annual GW_Q
				+4.8	-4.8	-14.3	-28.0	-35.2	-36.2	Annual WYLD
D_DRAIN	600	1200	900	600	700	800	1000	1100	1200	Annual Tile Drain Flow
				-22.6	-13.2	-7.5	-100	-100	-100	
TDRAIN	6	60	24	6	12	18	36	48	60	Annual Tile Drain Flow
				+9.4	+7.5	+3.8	-9.4	-20.8	-28.3	
GDRAIN	0.5	11	5	0.5	1	3	7	9	11	Annual Tile Drain Flow
				0.0	0.0	0.0	0.0	0.0	0.0	

[1] Values Shown in **bold** font are SWAT recommended values as identified in the SWAT User's Manual. Normal font values are reference values used in the sensitivity analysis for variables where no recommended value was identified by SWAT developers.

Table 16. Sensitivity Analysis of Selected SWAT Input Variables on Selected Hydrologic Output - Exeter Watershed

Input Variable	Lower Range	Upper Range	Reference Value	Input Variable Value and Corresponding Change in Output Relative to Output using the Reference Value (%)						Output Response Considered
SFTMP	-5	5	0.6	-3	-1	0	1	3		
				-19.6	-8.0	-2.8	+4.8	+15.2		March SurQ
SMTMP	-5	5	-0.75	-5	0	1	5			
				-50.4	+13.0	+28.8	+14.8			March SurQ
SMFMX	1.4	6.9	6.5	1.5	2	3.5	4.5	5	6.9	
				-4.4	-1.7	+1.9	+1.5	+1.4	-0.4	March SurQ
SMFMN	1.4	6.9	2.0	1.5	3.5	4	4.5	5	6.5	
				+7.3	-10.8	-13.5	-16.1	-18.9	-24.8	March SurQ
TIMP	0.01	1.0	0.85	0.1	0.3	0.4	0.6	0.7	0.9	
				+21.7	+19.4	+14.6	+6.2	+3.4	-0.9	March SurQ
ESCO	0.01	1	0.85	0.2	0.4	0.8	0.90	1.0		
				-4.2	-3.6	-0.7	+0.8	+2.9		Annual SurQ
				-12.8	-11.5	-3.2	+4.8	+22.1		Annual GW_Q
				-8.2	-7.2	-1.8	+2.5	+11.0		Annual WYLD
PET Calculation Method	--	--	Priestley- Taylor	Penman - Monteith			Hargraeves			
				+27.4			+39.8			Annual PET
				-21.6			-36.1			Annual GW_Q
				-13.7			-21.5			Annual WYLD
GWQMN	10	1000	120	10	300	1000				
				+11.5	-1.7	-8.5				Annual WYLD
GW_REVAP	0.02	0.2	0.14	0.02	0.1	0.12	0.16	0.18	0.2	
				0.0	0.0	0.0	0.0	0.0	0.0	Annual SurQ
				+20.2	+8.8	+4.2	-3.4	-6.4	-9.4	Annual GW_Q
				+7.4	+3.2	+1.5	-1.2	-2.3	-3.4	Annual WYLD
REVAPMN	10	1000	50	10	100	200	300	500		
				-0.1	+10.0	+39.6	+39.6	+39.6		Ann. Shallow GW_Q
				0	2.7	10.6	10.6	10.6		Annual WYLD
RCHRG_DP	0	1	0.1	0	1					
				-100.0	+0					Deep AQ
				+16.0	-100					Ann. Shallow GW_Q
				+4.3	-26.9					Annual WYLD

3.2 GAWSER Model

Evaluating the sensitivity of the GAWSER model to various input values has been completed on a number of watersheds across southern Ontario (See Ecologistics 1988, Schroeter and Boyd, 1998, Schroeter and Associates, 1999a, 2006a, 2006b and 2006c). Traditionally this evaluation has been done using the "event" model version of GAWSER where a rainfall-only event as well as a snowmelt event (often during a rain) is modelled and the effects of various GAWSER input variables considered on the modelled output of interest. Normally past sensitivity analyses of the GAWSER model have focussed on the effect that changing an input variable, or set of variables, has on an event hydrograph's peak flow as well as the event's total runoff volume. These past investigations have led to the identification of a set of key input variables that have the greatest impact on GAWSER model reponse. The most sensitive GAWSER input variables are listed in Table 17.

Table 17. Sensitive Input Variables for GAWSER

Input Variable	Description
DS	Depression storage adjustment
KEFF	Effective hydraulic conductivity (influences runoff amounts as per Green and Ampt equation)
CS	Maximum seepage rate (influences water movement between soil layers 1and 2)
D	Maximum percolation rate (influences water movement out of soil layer 2 and its contribution to subsurface or groundwater storage)
KO	Overland runoff lag (influences peak flowrates)
KSS	Combined subsurface/groundwater (baseflow) recession
HI	Thickness of first soil layer
KMF	Combined snowmelt/freeze (influences snowmelt and refreeze rates)
NEW	New snow relative density (affects water content of snow)
EVAP	Evapotranspiration adjustment
DINS	Maximum interception storage (accounts for plant interception)

It is seen that, while GAWSER and SWAT are two different modelling tools and therefore have different input definitions, the inputs of that primarily affect their hydrologic simulation are quite similar. Input variables that dominate the hydrologic sensitivity of both models include those that describe a hydrologic response unit's (HRU's) drainage characteristics, those that adjust the movement of water through each HRU's soil profile, inputs that characterize a watershed's snow pack and snow melt characteristics, variables that influence groundwater storage amounts, and those variables that influence evapotranspiration rates.

Developers of the GAWSER model have used past findings from parameter sensitvity analyses to develop the concept of a monthly parameter adjustment table which allows users to globally modify GAWSER's known most sensitive parameters on a monthly basis in order to improve model performance. This table is referred to in the GAWSER software as the GAWSPARM.DAT file. Schedule B of GAWSER's Training Guide (Schroeter and Associates, 1996) describes the development of the GAWSPARM.DAT file as follows:

> *The sample GAWSPARM.DAT file has seen wide application in more than 30 watersheds in southern Ontario involving observed and simulated comparisons at more than 100 stream gauges. When applying the program to another watershed in Ontario, we recommend you start with this table and test it against any available streamflow data before making any refinements.*

Table 18 is the GAWSPARM.DAT file as distributed with the GAWSER model. Indirectly, it gives some indication of the relative sensitivity of GAWSER's most sensitive model inputs as identified by past southern Ontario applications of the model. The monthly values for the adjustment factors are used to adjust the input variable they refer to. For example, the depression storage adjustment factor (FDS) would be used to modify the specified values of maximum depth of depression storage (DS) for each hydrologic response unit in the model (see Table 13). A value of FDS=1 tells the program that the 'as specified' values of depression storage (See Table 13) are to be used in the calculations. A value of FDS=0.80 would be mean that 80% of the "as-specified" depression storage is to be used in the computation process for that month. Typically a linear interpolation process is used to smooth out the month-to-month changes in the adjustment factor values.

Input adjustment factors shown in Table 18 whose corresponding input variable is not listed in Table 17 are shown in grey. The adjustment factors FMCR, FOCF and FOCR provide the user with the ability to adjust the Manning's n value used for the main channel the floodplain associated with the main channel and the off channels respectively. Typically this input has not been found to be highly sensitive in past applications although it is included in the GAWSPARM.DAT file. The other greyed out adjustment factors are associated with inputs that affect the water quality /water temperature modelling component of GAWSER and therefore have no effect on its hydrologic simulation.

Table 18. The GAWSPARM.DAT File as Distributed with the Continuous GAWSER Model

Input Variable Adjustment Factor	JA	FE	MR	AP	MA	JU	JL	AU	SE	OC	NO	DE
FDS	0.50	0.50	0.50	0.50	1.20	1.15	1.15	1.50	1.50	1.00	1.00	0.75
FKEFF	0.02	0.02	0.02	0.10	0.40	0.70	0.80	0.90	0.65	0.25	0.20	0.02
FCS	0.03	0.02	0.02	0.09	0.40	0.50	0.60	0.75	0.35	0.30	0.13	0.06
FD	0.04	0.03	0.03	0.05	0.05	0.05	0.05	0.06	0.07	0.06	0.05	0.05
FKO	3.50	4.00	3.50	4.00	3.00	4.50	5.50	6.00	5.00	4.00	3.50	3.00
FKSS	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
FHI	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FKMF	0.25	0.33	1.10	1.40	1.50	1.00	1.00	1.00	1.00	1.00	0.25	0.15
FNEW	1.00	1.00	1.10	1.10	1.00	1.00	1.00	1.00	1.00	1.00	1.10	1.10
FEVAP	0.00	0.00	0.00	2.33	3.23	3.83	4.52	3.61	2.40	1.35	1.00	0.00
FMCR	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FOCF	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FOCR	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FKE	1.00	1.00	1.00	1.00	1.00	2.00	2.00	2.00	2.00	2.00	1.00	1.00
FKD	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FDD	1.00	1.00	1.00	1.00	1.00	2.50	2.50	2.50	2.50	2.50	1.00	1.00
FRCC	1.00	1.00	1.00	1.00	1.00	1.00	1.50	1.50	1.50	1.50	1.00	1.00
FSSC	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FTE	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FTEM	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FDINS	0.20	0.20	0.20	0.50	0.70	1.20	1.50	1.50	1.20	0.70	0.20	0.20

4.0 Model Calibration

4.1 Calibration Approach

With the necessary model input files in place and an understanding of which model input variables appear to have the greatest influence on the model's simulation of hydrologic response, the next step was to calibrate the model. James and Burgess (1982) describe calibration as the process of adjusting model parameters, variables or other inputs in order to reduce the differences between simulated and observed values to levels that are deemed acceptable.

Calibration of both the SWAT and GAWSER models was undertaken on both the Exeter and Blyth subwatersheds of the ABMV Planning Region. These subwatersheds were chosen for calibration purposes because they were the same subwatersheds that were used to help identify the most sensitive input variables for the SWAT model. They also represented areas of higher versus lower baseflow conditions as discussed in Section 3. An earlier version of the GAWSER model had also been set-up on the Exeter subwatershed in the past, so some experience also existed with calibrating GAWSER for flood forecasting purposes to this setting. Both subwatersheds had long-term historical streamgauge data with which to compare model output to. This was not the case with the Kerry's Creek watershed, also used in the SWAT sensitivity analysis.

Because this study was still at the stage of completing an objective evaluation of the preferred models, only variables that resulted in global adjustments were considered. For example, while the SWAT model allows users to adjust runoff curve number (RCN) values within acceptable ranges at the watershed, subcatchment and the HRU level to improve calibration results, this would be a very time-consuming task and was deemed not necessary at this point of the investigation. Only variables that affected all HRUs at once were adjusted. Ideally, the preferred model would only need to undergo a limited amount of calibration in order to generate acceptable results. Acceptable results for calibration were defined at this point as simulated results that produced average annual estimates of streamflow that were within 10% of observed values and monthly estimates of streamflow that were in a similar range. This calibration step also assumed the following inputs/observations to be accurate:

- Climate input data used to drive the models (precipitation, snow and air temperature)
- Soils/landuse databases used to describe the drainage characteristics and soil properties (soil layer depth, etc.)
- Subcatchment characteristics (channel lengths, channel slopes, sub-catchment areas etc.) as derived from AVSWAT-X's watershed delineation approach and the provincial DEM
- Default runoff curve numbers (RCNs) provided by the SWAT model.
- The archived Hydat records of observed streamflow for the Exeter and Blyth stations.

Note that streamflow records existed for the Blyth station beyond what were available through Water Survey of Canada's Hydat station archives because the MVCA flood forecasting system has downloaded and archived the raw data for the Blyth station since its installation in 1984. In 1996, however, Water Survey of Canada discontinued its maintenance and archiving of the station until 2004 when it was once again restored as a Water Survey of Canada station. For the period of record from 1996 through 2004, however, the raw data has not undergone a quality check. As a result, it was decided not to include this period of time for model calibration purposes.

Graphical approaches were the primary techniques used to help calibrate both SWAT and GAWSER's modelled daily streamflow output to the daily observed streamflows. A 21-year simulation (1984-2004) was performed and the daily output was plotted and compared to the observed values. If results showed consistent trends such as persistent underestimation of baseflow, an overestimation of spring thaw runoff, higher than observed peak flows, delayed peaks or rapid declines in the hydrograph's recession curve, then input variables or combinations of input variables, known to affect these aspects of the model's streamflow output were adjusted. The calibration exercise was therefore very much a trial-and-error exercise.

As graphical approaches gradually showed little additional benefit could be gained through making further adjustments to the suite of global input variables considered, a statistical assessment was completed of the relative difference between the observed and modelled monthly streamflows over the 21-year simulation period. The first year in the simulation (1984) was removed from the statistical comparison because it was assumed that this first year would be needed to "initialize" both models, leaving 20 years of data for statistical analyses. The statistical comparison approaches used included the Nash-Sutcliffe model efficiency parameter and the R^2 approach as described in detail in Loague and Green, 1991.

4.2 SWAT Calibration Results

Table 19 lists the values for input variables, known to significantly affect the SWAT model's streamflow simulation, that enabled SWAT to best match observed streamflow recorded at the Exeter and Blyth gauges. All other inputs identified in Section 3.1 as being sensitive (i.e. BIOMX, BLAI, CN2, SLOPE, SLSUBBSN, SOL_K, SOL_AWC, SOL_K, SOL_Z and TLAPS) were left as default values or, for the case of soils input, left as values obtained from available soil reports. It is interesting to note that there really is very little difference in the final set of calibrated values between the Exeter and Blyth subwatersheds. In fact the only changes were with the groundwater input variables GWQMN (threshold depth of water in the shallow aquifer required for return flow (baseflow) to occur) and REVAPMN (threshold depth of water in the shallow aquifer for "revap' or percolation to the deep aquifer to occur). The similarity between the two input sets may be in part due to the fact that the Exeter watershed was calibrated first and Exeter results were then used as a starting point to begin calibrating the Blyth subwatershed. SWAT seemed to perform reasonably well at this initial scale of modelling on the Blyth subwatershed simply using the Exeter-calibrated results. Overall, SWAT's annual average estimate of streamflow was within 1.7% and 3.9% of observed Exeter and Blyth streamflows respectively.

The computed Nash-Sutcliffe efficiency as well as the R^2 values, both of which provide a statistical evaluation of the similarity between SWAT's calibrated streamflow estimates and the Hydat observed results, are summarized in Table 20. A statistical score of 1 indicates perfect agreement between modelled and observed results. The closer the score is to 1, the suggestion is that the model is more effectively simulating actual conditions. This analysis was completed on both daily and monthly data as seen in Table 20.

Table 19. Calibrated Values of Selected Input Variables Determined for the Exeter and Blyth Subwatersheds

Input Variable	Calibrated Value	
	Ausable River System Above Exeter Gauge	Maitland River System Above Blyth Gauge
ALPHA_BF	0.95	0.95
CANMX	2.0	2.0
CH_K2	5.0	5.0
CH_N	0.1	0.1
EPCO	1.0	1.0
ESCO	0.5	0.5
GW_DELAY	27.0	27.0
GWQMN	120.0	70.0
GW_REVAP	0.15	0.15
RCHRG_DP	0.1	0.1
REVAPMN	50.0	40.0
SFTMP	0.6	0.6
SMFMN	2.0	2.0
SMFMX	6.5	6.5
SMTMP	-0.75	-0.75
SURLAG	2.0	2.0
TIMP	0.85	0.85

Table 20. Statistical Measures of the SWAT Model's Performance Following Calibration

Subwatersehd ID	Model Efficiency Score (Monthly)		Model Efficiency Score (Daily)	
	Nash-Sutcliffe	R^2	Nash-Sutcliffe	R^2
Exeter	0.90	0.90	0.37	0.47
Blyth	0.91	0.92	0.31	0.43

Table 21 provides a subjective rating as suggested by Schroeter et al., (2006a,b,c) for the statistical scores presented in Table 20. Comparing the results in Table 4.2 with the subjective ratings given in Table 21 would suggest that the calibrated SWAT model produced a very good to excellent estimation of monthly flows for both the Exeter and Blyth subwatersheds. Looking at the scores when the same statistical analyses were completed on daily data, however, yielded very different and disappointing results. For both calibrated subwatershed settings, the performance scores were considered to be poor. There are a number of possible explanations for this. The main reason is quite likely due to the fact that the SWAT model was operated on a daily time step, with the SCS method of runoff determination used to partition rainfall into runoff and infiltration. By operating on a daily time step, it is not possible to predict the impact of rainfall intensity on runoff timing and infiltration rates. Only breakpoint (sub-daily) rainfall data combined with the Green–Ampt infiltration model (or equivalent) can achieve this.

Table 21. Subjective Ratings for Statistical Model Performance Scores

Subjective Rating	Nash-Sutcliffe Model Efficiency	Coefficient of Determination - R^2
Excellent	>0.90	>0.90
Very Good	>0.80 – 0.90	>0.80 – 0.90
Good	>0.70 – 0.80	>0.70 – 0.80
Fair	>0.60 – 0.70	>0.60 – 0.70
Poor	≤ 0.60	≤ 0.60

As discussed in Section 2.2.1, SWAT does accommodate the option of using sub-daily rainfall data and applying the Green-Ampt infiltration equation. Testing of this option in this study, however, revealed a number of implementation barriers which quickly led to the conclusion that application of sub-daily precipitation data was not feasible at this time or scale of investigation. To begin with, the SWAT model generated huge output datasets when operating in a sub-daily model using the Green–Ampt model. It would be better suited to subwatershed analysis than whole river system analysis. As well, preliminary runs showed the model to give very different results compared to the same watershed set-up using the SCS runoff prediction method. This would force a repeat of the calibration process. Finally, the SWAT model currently does not accept hourly precipitation input. The largest time step allowed is a 30-minute time step. The flood forecasting archival system as well as the datafilling project provided hourly time-step data only (to meet GAWSER's input needs). Significant work would be needed to develop an accurate precipitation dataset that supplied 30-minute or smaller time step information.

4.3 Gaswer Calibration Results

GAWSER was calibrated on the same test subwatersheds as SWAT (Exeter, Blyth). Graphical approaches were used to help calibrate the model's known most sensitive input variables. Table 22 shows the final calibrated values of hydrologic response unit drainage characteristics for the Exeter subwatershed. Table 23 shows the calibrated values of hydrologic response unit drainage characteristics for the Blyth subwatershed. The default GAWSPARM.DAT file, (see Table 18) as provided with the model, was used in this initial calibration to assess model performance. A similar amount of time was spent calibrating GAWSER as was spent calibrating SWAT.

GAWSER's 20 year estimate of average annual streamflow was within 13.9% of Exeter's value and within 7% of Blyth's measured value. Table 24 summarizes the statistical scores resulting from comparing GAWSER monthly and daily streamflow estimates to the observed values for the watershed. GAWSER's monthly streamflow estimates were primarily in the very good range. This is similar to, although slightly lower than SWAT's results. Daily estimates were in the poor to fair range - significantly better than the SWAT model's estimate of daily flows. The fact that GAWSER uses hourly rainfall input data is likely the major reason for these improved daily results.

Table 22. Calibrated Hydrologic Response Unit Drainage Characteristics for the Exeter Subwatershed

Symbol	*Description*	*Units*	Hydrologic Response Unit								
			IMP	*A-AG*	*B-R*	*B-P*	*C-R*	*C-P*	*D-AG*	*AB-F*	*CD-F*
DS	Maximum depth of depression Storage	(mm)	1	5	5	5	5	5	5	5	5
KEFF	Infiltration into 1st soil layer	(mm/h)	0	12	8	8	4	4	2	10	3
CS	Infiltration into 2nd soil layer	(mm/h)	0	1.2	0.8	0.8	0.4	0.4	0.2	7.5	1
D	Infiltration out of 2nd layer	(mm/h)	0	4.8	3.2	3.2	1.6	1.6	0.8	5	1.5
SAV	Average suction at the wetting front	(mm)	0	250	200	200	200	200	200	250	200
X	Groundwater Contribution Indicator: 1=SS, 0=GW		0	0	1	1	1	1	1	0	1
FATR	Groundwater Fraction (not used in this model, set=1)		1	1	1	1	1	1	1	1	1
INC	Maximum depth of interception storage	(mm)	0	1	1	1	1	1	1	5	5
	First Soil Layer										
HI	Soil layer thickness	(mm)	0	200	200	200	150	150	100	200	100
SMCI	Saturated soil-water content (porosity)	(vol/vol)	0	0.5	0.52	0.52	0.56	0.56	0.6	0.5	0.56
IMCI	Initial soil-water content	(vol/vol)	0	0.1	0.25	0.25	0.38	0.38	0.45	0.1	0.38
FCAPI	Field capacity soil-water content	(vol/vol)	0	0.1	0.25	0.25	0.38	0.38	0.45	0.1	0.38
WILTI	Wilting point soil-water content	(vol/vol)	0	0.04	0.12	0.12	0.17	0.17	0.20	0.04	0.17
	Second Soil Layer										
HII	Soil layer thickness	(mm)	0	500	600	600	800	800	1000	700	1000
SMCII	Saturated soil-water content (porosity)	(vol/vol)	0	0.5	0.52	0.52	0.56	0.56	0.60	0.5	0.56
IMCII	Initial soil-water content	(vol/vol)	0	0.1	0.25	0.25	0.38	0.38	0.45	0.1	0.38
FACPII	Field capacity soil-water content	(vol/vol)	0	0.1	0.25	0.25	0.38	0.38	0.45	0.1	0.38
WILTII	Wilting point soil-water content	(vol/vol)	0	0.04	0.12	0.12	0.17	0.17	0.20	0.04	0.17

Notes: HRU Codes used are as follows: A = HSG A B = HSG B C = HSG C D = HSG D AG = All agricultural land covers
P = permanent ag crops R = annual (row) crops Org. = Organic soils F = high vegetation forest cover crops

Table 23. Calibrated Hydrologic Response Unit Drainage Characteristics for the Blyth Subwatershed

Symbol	*Description*	*Units*	Hydrologic Response Unit								
			Imperv	*Org.*	*A-All*	*B-R*	*B-P*	*CD-R*	*CD-P*	*AB-F*	*CD-F*
DS	Maximum depth of depression Storage	(mm)	1	5	5	5	5	5	5	15	8
KEFF	Infiltration into 1st soil layer	(mm/h)	0	1	6	4	4	2	2	10	3
CS	Infiltration into 2nd soil layer	(mm/h)	0	0.01	0.06	0.04	0.04	0.02	0.02	7.5	1
D	Infiltration out of 2nd layer	(mm/h)	0	0.02	0.24	0.16	0.16	0.08	0.08	5	1.5
SAV	Average suction at the wetting front	(mm)	0	200	200	200	200	200	200	250	200
X	Groundwater Contribution Indicator: 1=SS, 0=GW		1	1	0	1	1	1	1	0	1
FATR	Groundwater Fraction (not used in this model, set=1)		1	1	1	1	1	1	1	1	1
INC	Maximum depth of interception storage	(mm)	0	1	1	1	1	1	1	5	5
	First Soil Layer										
HI	Soil layer thickness	(mm)	0	100	200	200	200	150	150	200	100
SMCI	Saturated soil-water content (porosity)	(vol/vol)	0	0.6	0.5	0.52	0.52	0.56	0.56	0.5	0.56
IMCI	Initial soil-water content	(vol/vol)	0	0.45	0.1	0.25	0.25	0.4	0.4	0.1	0.38
FCAPI	Field capacity soil-water content	(vol/vol)	0	0.45	0.1	0.25	0.25	0.4	0.4	0.1	0.38
WILTI	Wilting point soil-water content	(vol/vol)	0	0.2	0.04	0.12	0.17	0.18	0.18	0.04	0.17
	Second Soil Layer										
HII	Soil layer thickness	(mm)	0	300	500	600	600	800	800	700	1000
SMCII	Saturated soil-water content (porosity)	(vol/vol)	0	0.6	0.5	0.52	0.52	0.58	0.58	0.5	0.56
IMCII	Initial soil-water content	(vol/vol)	0	0.45	0.1	0.25	0.25	0.4	0.4	0.1	0.38
FACPII	Field capacity soil-water content	(vol/vol)	0	0.45	0.1	0.25	0.25	0.4	0.4	0.1	0.38
WILTII	Wilting point soil-water content	(vol/vol)	0	0.2	0.04	0.12	0.12	0.18	0.18	0.04	0.17

Notes: HRU Codes used are as follows: A = HSG A B = HSG B C = HSG C D = HSG D AG = All agricultural land covers
P = permanent ag crops R = annual (row) crops Org. = Organic soils F = high vegetation forest cover

Table 24. Statistical Measures of the GAWSER Model's Performance Following Calibration

Subwatersehd ID	Model Efficiency Score (Monthly)		Model Efficiency Score (Daily)	
	Nash-Sutcliffe	R^2	Nash-Sutcliffe	R^2
Exeter	0.86	0.87	0.54	0.54
Blyth	0.87	0.91	0.62	0.62

5.0 Model Validation

Model validation refers to applying the calibration model to a situation (in this case a subwatershed or river system) not used directly in the calibration step and comparing the resulting model output in this new setting with observations (e.g. streamflows) made in that new independent setting. The ABMV Planning Region has historical streamflow records at 23 different points along the river systems in the watershed (See CWB Map E-9). Four of these streamgauge stations have just been installed within the last 5 years (e.g. Silver Creek, Tricks Creek, Little Ausable, and Lakelet) so there is a relatively small dataset available for use. The Boyle Drain streamgauge located on the Maitland river system was operational in the 1970's but discontinued in the early 80's through to 2003 when it was once again brought into service by Water Survey of Canada. Therefore, this station has a relatively small dataset available. The Donnybrook streamgauge was present on the Maitland River system until 1987 when it was discontinued. Given that modelling was simulated for the period, 1985 though 2004, data available from this streamgauge was also limited. On the Lucknow river system, the Conservation Authority maintains the Dickies Creek streamgauge independent of Water Survey of Canada. While useful for flood forecasting purposes, daily data recorded by this gauge is not quality checked to the standards applied by Water Survey of Canada. For this reason, data available from this gauge (Lucknow B) was also excluded. This left data from 16 long-term historical streamgauging stations that could be used to validate the SWAT and GAWSER models.

Both the SWAT and GAWSER models were set-up in a manner that allowed them to output estimates of daily flow at each of the existing gauging stations in the ABMV Planning Region. For validation purposes, the calibrated models were run for a 21 year period (1984 through 2004) and the streamflow estimated by each model was compared against Water Survey of Canada's archived streamflow data for the same station. The 16 stations with long-term (> 5 years) of historical data that fell within the period of simulation were used. Monthly summaries of both the simulated and observed data were plotted for comparison purposes. Statistical evaluations of each model's performance, using the same tools as were applied in the calibration step were also completed.

Schedule E contains the various graphs prepared comparing the measured and modelled results. Graphs in Schedule E are grouped by major river system in the watershed and include the following for each streamgauge station:

- A comparison of measured and modelled <u>annual</u> streamflow volumes (A series)

- A comparison of measured and modelled average monthly streamflow volumes (B series)
- A comparison of measured and modelled monthly streamflow volumes (C series)
- A comparison of the measured and modelled flow duration curves (D series

A review of these various graphed results reveals no strong advantage of one model over the other in terms of modelling monthly and long-term flows. Some weak general trends were seen in model performance. Both models, for example, tended to underestimate monthly streamflow volumes in the month of March. Both models gave estimates in the summer months that were higher at some sites and lower at other sites than the observed values for the summer (low flow) period. Fall (November) streamflows were generally (but not always) overestimated by the models. Refinements in input datasets through a more rigorous calibration effort could perhaps help to address these observations. In general, however, the results showed both models were relatively robust at simulating another area of the watershed using the results of the initial calibration of the models to the test watersheds in the ABMV Region.

Statistical assessments of model performance were also completed for each model at each of the validation sites. Table 25 summarizes the results. Monthly model predictions ranged from poor to excellent, with the average being 82 (very good) and 77 (good) for SWAT and GAWSER respectively. The Harriston subwatershed showed the poorest results. By perhaps further subdividing this subwatershed into more subcatchments better simulation results could be achieved. It is clear that improvements could be made in the performance of both models if calibration was completed at each streamgauge station. The data, however, does indicate that both models can give reasonable results at a monthly and annual time scale with a minimum amount of calibration effort. This would be a starting point for a Tier 1 level water budget investigation.

Statistical measures of each model's ability to represent daily data are also presented in Table 25 and clearly show that the models are poor to very poor at simulating flows observed on any particular day. The GAWSER model is the better of the two models, but even it gives only fair to poor results. These findings again emphasize that neither of these continuous models operated exclusively in continuous mode would be suitable for flood forecasting purposes. Both models need the user to establish and properly represent initial watershed conditions and supply appropriate input variables to help define watershed conditions just prior to a rainfall or rain/snowmelt event being modelled . Of the two models, GAWSER has more potential to be used as both a long-term continuous model as well as an event (flood forecasting) model.

The purpose of developing a continuous numerical water budget model is ultimately to use it to estimate annual and monthly long-term annual water budgets for various points in the source protection region. The ability of the numerical models to produce representative long-term annual estimates of water budget components besides streamflow was therefore also assessed as part of this validation activity. Table 26 summarizes the long-term water balance prepared by SWAT for the main river systems of the ABMV Planning Region. The table includes SWAT's estimate of the amount of precipitation falling on the watershed, the fraction that becomes surface runoff, evapotranspiration losses, the portion that moves beyond the root zone to shallow and deep aquifers and the baseflow (groundwater and lateral flow returning to the river system after it has infiltrated). Similar tables were prepared using output from GAWSER (Table 27) and the information acquired through the conceptual water budget (Table 28) for selected streamgauge stations on each of the major river systems. The shoreline area is not included in these tables because there was no long-term measured streamflow/baseflow/surface runoff for that area which could be used to compare the water budget results against. While the SWAT data tabulated represents the water budget for the entire river system, the other tables show data for a specific upstream gauge station – typically one near the river system's outlet. SWAT provides a convenient output file to retrieve entire basin water budget results, but does not make extracting data at specified points along the stream quite as convenient. Conversely, the GAWSER model was set up in this evaluation run to produce output at each gauge station. Editing the code to request summary data for the entire watershed could have been done, but would require some additional modifications to the input dataset. For this initial model evaluation exercise, it was decided that the effort need to modify either model's input files to obtain water balance estimates for a common point was not warranted. The general trends of model performance can be easily seen when comparing Tables 26, 27 and 28. In terms of long-term annual water budgets, the deviation between the actual and observed average annual streamflow is between -2% and +28% for SWAT and 9% and 30% for GAWSER.

Table 25. Statistical Measures of Model Performance on Validation Sites

Subwatershed ID	Model Efficiency Score (Monthly)				Model Efficiency Score (Daily)			
	Nash-Sutcliffe		R^2		Nash-Sutcliffe		R^2	
	SWAT	GAWSER	SWAT	GAWSER	SWAT	GAWSER	SWAT	GAWSER
Ausable River System								
Exeter	0.90	0.86	0.90	0.87	0.37	0.54	0.47	0.54
Springbank	0.90	0.82	0.90	0.82	0.34	0.55	0.44	0.56
Parkhill River System								
Parkhill Inflow	0.86	0.77	0.86	0.83	0.31	0.49	0.39	0.60
S. Parkhill Cr.	0.68	0.69	0.69	0.70	0.30	0.39	0.30	0.39
Bayfield River System								
Varna	0.87	0.80	0.87	0.81	0.41	0.51	0.48	0.52
Maitland River System								
Belgrave	0.72	0.72	0.72	0.72	0.53	0.62	0.55	0.63
Benmiller	0.78	0.69	0.79	0.7	0.50	0.69	0.54	0.69
Bluevale	0.86	0.57	0.87	0.63	0.53	0.59	0.54	0.60
Blyth	0.91	0.87	0.92	0.91	0.31	0.62	0.43	0.62
Ethel	0.83	0.82	0.83	0.82	0.47	0.61	0.49	0.62
Harriston	0.58	0.65	0.61	0.65	0.42	0.43	0.42	0.43
Listowel	0.78	0.78	0.78	0.79	0.37	0.45	0.40	0.46
Summerhill	0.85	0.65	0.85	0.74	0.48	0.45	0.52	0.52
Wingham A	0.67	0.68	0.72	0.70	0.39	0.58	0.42	0.58
Wingham B	0.88	0.86	0.88	0.86	0.49	0.65	0.52	0.65
Lucknow (Nine Mile) River System								
Lucknow A	0.89	0.83	0.89	0.84	0.40	0.57	0.51	0.63

Note: Shaded entries are calibration subwatersheds.

The biggest factor to note is the difference in the estimate of actual evapotranspiration between the two models. SWAT's actual ET is in the 420 mm to 470 mm range for the study region while GAWSER's results for AET lie in the 500 mm to 600 mm range. This difference has a strong influence on the values estimated for the other water balance components. It is known that actual ET has the biggest controlling factor for hydrologic modelling accuracy (Hauser and Gilmon, 2004). While calibration helped to force the models to be relatively accurate in their estimation of streamflow, the differences in each model's estimation of evapotranspiration resulted in a significant difference in the estimate of water moving beyond the root zone to recharge lower aquifers. This emphasizes the need to look further into determining what a reasonable estimate for actual ET would be for the Region.

Table 26. Long-Term Annual Water Budget as Estimated by SWAT for Major River Systems in the ABMV Planning Region.

River System	Precipitation (mm)	AET (PET) (mm)	Streamflow (mm)	Surface Runoff (mm)	Baseflow (mm)	Net Soil and GW Additions (mm)
Ausable	962.1	421.6 (573.1)	411.91	301.84	110.07	226.91
Parkhill	931.7	419.6 (569.0)	354.04	287.42	66.62	215.05
Bayfield	985.7	428.1 (568.7)	444.44	329.49	114.95	216.63
Maitland	1044.6	467.0 (593.3)	362.24	296.28	165.96	270.18
Lucknow	1117.0	468.9 (625.7)	499.51	275.21	224.3	341.33

Table 27. Long-Term Annual Water Budget as Estimated by GAWSER at Selected Streamgauge Points Along Major river Systems in the ABMV Planning Region.

River System	Precipitation (mm)	AET (PET) (mm)	Streamflow (mm)	Surface Runoff (mm)	Baseflow (mm)	Net Soil and GW Additions (mm)
Ausable (Springbank)	913.3	575.9 (--)	334.0	141.3	192.7	196.1
Parkhill (S. Parkhill Cr.)	907.2	560.2 (--)	345.0	286.8	58.2	60.2
Bayfield (Varna)	827.4	491.2 (--)	374.4	286.9	87.5	49.4
Maitland (Benmiller)	950.9	483.1 (--)	456.2	414.4	41.8	53.4
Lucknow (Lucknow A)	1088.0	602.8 (--)	467.7	280.6	187.1	204.6

Measuring actual ET is an extremely costly and complex endeavour. It is perhaps best accomplished through the use of weighing lysimeters. Even this would only give a plot scale estimate of actual ET. About the best weighing lysimeter site in the "general vicinity" of the study area is located in the North Appalachian Experimental Watershed near Coshocton, Ohio. Historically, this station has typically been used to measure potential ET. Long-term (> 10 years) of data on a well-watered orchard and brome grass plots located on a Coshocton weighing lysimeter has shown potential ET to be between 760 mm and 770 mm/year. Potential ET in the ABMV Planning Region could therefore be assumed to be around or slightly below this value. Actual ET would also be below this value.

Table 28. Long-Term Annual Water Budget as Estimated From Precipitation and Streamflow Observations for Major River Systems in the ABMV Planningn Region.

River System	Precipitation (mm)	AET (PET) (mm)	Streamflow (mm)	Surface Runoff (mm)	Baseflow (mm)	Net Soil and GW Additions (mm)
Lucknow (Lucknow A)	1166.8	--	647.13	344.49	302.64	--
Maitland (Benmiller)	1042.8	--	502.97	312.10	190.87	--
Bayfield (Varna)	988.2	--	435.16	314.98	120.18	--
Parkhill (S. Parkhill Cr.)	940.71	--	494.82	419.36	75.46	--
Ausable (Springbank)	956.64	--	398.83	277.32	121.51	--

Approaches for estimating potential ET include evaporation pans and a weather station/modelling approach. Table 29 summarizes the historical potential ET data that has been recorded using weather stations or pan evaporation sites within the ABMV Planning Region. Only a few years of data exist and, in many cases, a complete dataset for any year was not collected (i.e. equipment malfunctions occurred or equipment was necessarily removed for winter). These data, however would suggest that PET in the area is on average 785 mm/year. This is in close agreement with the Coshocton, Ohio long-term lysimeter data.

The GAWSER model does not print out its estimate of potential ET either when using a set daily potential for each month (the climatology approach) developed from available lake evaporation estimates, or when using the Linacre (1977) formula (See Schroeter and Associates, 2006c). With the Linacre method, which estimates potential ET with the aid of measured daily air temperature, an upper limit for PET is set in GAWSER (see Table 2), as previous applications of GAWSER showed the Linacre method to overestimate potential ET.

F For the water budget estimates presented in Table 26, SWAT used the Priestley-Taylor model to estimate potential ET. Similar to the Linacre model, this approach also estimates potential ET based on daily air temperature. The Priestley-Taylor model estimated potential ET to be in the range of 570 mm to 625 mm, significantly below other estimates of potential ET for the area. Therefore the Priestley-Taylor would appear to be underestimating potential ET. The Hargreaves Model or Penman-Monteith model, alternative potential ET estimation models available in the SWAT model, could be considered in future model applications to see if SWAT's potential ET estimate and ultimately its actual ET estimate would differ using these approaches.

Determining the actual ET from the potential ET is generally left up to a modelling approach. SWAT calculates actual transpiration using an approach similar to that of Ritchie (1972). Sublimation and evaporation from the soil is then added to the transpiration value. A full description of the SWAT methodology is described in Chapter 7 of Neitsch et al., 2002). GAWSER essentially allows the user to calibrate the model to match what has in the past been regarded as a reasonable estimate of actual ET for southern Ontario (Brown et. al., 1974 and OMNR. 1984) (See Table 1).

Tan et al (2002) completed a detailed field-measured investigation of actual ET on a controlled drainage plot on a brookston clay loam soil. They found actual ET on this southern Ontario site to be in the range of 420 mm to 450 mm for free draining plots growing corn and soybeans. They assumed actual ET in the non-growing season to be negligible, making this estimate a slight underestimation of actual ET. Nevertheless, it gives an idea of the range actual ET should fall into on the finer-textured agricultural soils in the study region.

Another way to arrive at an estimation of actual ET is to consider the following water balance equation for a watershed:

Precipitation – Streamflow = Actual ET + Deep Percolation + Consumptive Use/export

Where deep percolation refers to infiltration that does not reappear within the considered watershed.

Subtracting observed precipitation from observed streamflows (see Table 28) for each major river system gives the following value for the sum of actual ET, deep percolation and consumptive use/export:

Ausable	558 mm
Parkhill	446 mm
Bayfield	553 mm
Maitland	540 mm
Lucknow	520 mm

In many cases, GAWSER's estimate of actual ET alone for these river systems is larger than the values above. This strongly suggests that the GAWSER model as set-up in this study is overestimating actual ET. Combining this information with information from Tan et al., (2002) would further suggest actual ET in the Planning Region to be in the range of 440 mm and 480 mm. This is closer to the SWAT model's estimate.

Comparing the data in Tables 26, 27 and 28 reveals that the watershed precipitation amounts output by the GAWSER model were significantly less than in the SWAT model. The SWAT model's values are more realistic, when compared to the observed numbers presented in Table

28. A setting or data input error must be present in the GAWSER model as tested to result in this large a difference because the hourly and daily precipitation input files for the stations used by the models were essentially identical to each other. If the GAWSER model was to be further developed for this study region, this discrepancy between input and output precipitation amounts needs to be investigated to see if GAWSER's water balance numbers presented here could be improved.

Table 29. Summary of Potential Evapotranspiration (PET) Data Collected in the ABMV Planning Region

Month	**Potential Evapotranspiration (mm)**									
	ABCA Office Station (Exeter)			MVCA Office Station (Wroxeter)			Falls Reserve Station (Goderich)			AES Evaporation Pan[1] (Pinery)
	2004	2005	2006	2004	2005	2006	2004	2005	2006	(Avg, 1970-1989)
Jan	--	--	18.87	11.02	12.17	14.84	--	17.58	21.3	--
Feb	--	--	11.23	25.77	19.92	17.63	--	24.28	--	--
Mar	--	--	20.9	32.21	44.23	44.31	--	47.24	--	--
Apr	--	--	95.87	71.36	75.69	78.61	85.25	95.98	--	--
May	--	--	111.04	81.8	99.4	101.6	92.19	120.1	115.94	102.20
Jun	--	--	133.38	111.65	123.4	118.84	129.56	142.08	131.49	122.37
Jul	--	--	116.87	101.43	116.56	117.72	113.85	134.65	131.99	131.73
Aug	--	--	111.34	89.94	93.35	101.69	108.9	110.88	116.39	104.97
Sep	--	--	60.46	80.2	75.9	50.39	97.18	96.05	65.45	72.55
Oct	--	--	74.77	38.4	--	34.27	52.1	--	50.08	45.09
Nov	--	--	23.89	23.04	--	19.84	30.91	--	30.27	--
Dec	--	--	18.35	11.97	--	15.47	19.47	--	25.87	--
Annual Total	--	--	796.97	678.79	--	715.21	--	--	--	--
Annual Estimate			**796.97**	**678.79**	**732.12**	**715.21**	**811.14**	**893.19**	**857.28**	**Overall Average Est. = 785 mm**

[1] Pan evaporation data were collected May through October only. Assumed a Pan Evaporation Coefficient (Kp) of 0.75 to arrive at numbers shown.

6.0 Final Model Selection

With experience gained in applying the two short-listed numerical hydrologic models to the ABMV Planning Region, it was now possible to make a final decision on which model to proceed with in fine-tuning and developing further for water budgeting and possibly future water quality modelling applications as required by source water protection planning in the ABMV Region. The decision tables developed and partially completed as part of the conceptual water budget exercise (see Schedule C of ABMV, (2006)) were revisited and revised as seen in Tables 30 (GAWSER) and 31 (SWAT) below.

Hands-on experience in applying the models through this study emphasized the value of an up-to-date and complete user's manual as well as access to a pool of model experts (user's group) to which questions could be directed when problems arose. For this reason, the weighting of this aspect of the selection criteria was significantly increased. The subjective criteria list was compressed somewhat in this revised matrix. The most significant change was the removal of the model's potential to double as a flood forecasting tool. While this would be a bonus, for drinking water source protection purposes and future work, it was concluded that it would be much more valuable if, for drinking water source protection purposes, the tool could accurately estimate long term monthly flows (low water) concerns rather than flooding concerns. Event models are more adept at flood forecasting than continuous models but source water needs necessarily directs the search for a model towards the long-term continuous models. The level of staff knowledge needed to use and maintain the models was also removed. Continuous models, in general, it would appear need a relatively high level of staff knowledge to operate and maintain. Software cost was also removed as a criterion. Only models that were public domain or low cost were being considered.

Scores for many of the subjective criteria considered actually increased following the "test drive" of the models. Both models provided the output required, although not always in the preferred format. The exception was the tile drainage component. While identified in each model's documentation as being an output, the value of that output was questionable. GAWSER tile drainage output is indirectly represented as lateral flow generated from the first soil layer, leaving the volumes discharges in this manner at the discretion of the modeller. For the SWAT model, input variables that could be adjusted to affect tile drainage were essentially not sensitive and the model's estimate of total annual tile flow seemed insignificant (i.e. < 4 mm/year) and of questionable accuracy given that systematic tile drainage systems are designed to remove water at a rate of 10 to 15 mm/day under saturated field conditions. Adjustments to tiel flow could have been possible by adjusting the soil characteristics database. However, it was assumed that published soil profile descriptions available the relevant county soil reports were correct.

The objective criteria scores came out similar for both models as graphical and statistical comparisons of model output with measured streamflow data showed that both models performed very similarly given a similar level of effort and time taken to learn, set-up and apply the models. There remains room with both models, however, with further effort, to further fine-tune to possibly improve their representation of the area's hydrology.

Table 30. Final Model Selection Criteria Scoring - GAWSER

Model Attribute **GAWSER**	Phase I (Y/N)	Phase II Rating (1–10)	Phase II Weight (%)	Partial Index
Subjective Criteria (60%)				
Documentation and Support (25%)				
- User's Manual	Y	6	5	3.0
- Additional References (past application reports/papers)	Y	8	5	4.0
- User Support (User groups, conferences, training etc.)	Y	6	5	3.0
- Model "momentum" (Ontario, North America, globally)		5	5	2.5
Input and Program Utility (10%)				
- Availability of Input Data (i.e. data requirements to operate)	Y	7	2	1.4
- Ability to interface with GIS for data input (Input format utility)	Y	3	2	0.6
- Ability to accommodate available input data sources	Y	5	2	1.0
- Potential to interface with a groundwater model		8	1	0.8
- Ability to model tile drainage system effects	Y	3	2	0.6
- Potential to address future water quality modelling tasks		3	1	0.3
Model Sensitivity (5%)				
- Overall stability and ease of use	-	6	5	3.0
Model Output (20%)				
- Continuous output	Y	10	4	4.0
- Appropriate temporal scale (daily, monthly, seasonally)	Y	10	4	4.0
- Appropriate spatial scale (Watershed size ranges: Shoreline Gullies <2000 ha vs. River Systems 265,000 ha.)		7	4	2.8
- Appropriate watershed characteristics modelled (e.g agricultural/rural landuses, tile drainage, winter hydrology)	Y	8	4	3.2
-Appropriate output (i.e. full suite of water balance)				
- Streamflow (separating baseflow + runoff)	Y	10	0.75	0.75
- Tile drainage component	y	0	0.50	0.0
- Snowmelt component	Y	10	0.50	0.5
- Deep percolation (beyond root zone components)	y	8	0.75	0.6
- Potential and Actual ET	y	8	0.75	0.6
- Output flexibility (link to spreadsheets, GIS etc.)	y	5	0.75	0.38
Subjective Analysis Total:			60	37.08
Objective Criteria (40%)				
Model Calibration (Results from calibration runs on test watersheds) (20%)				
- Ability to simulate annual stream flows (Graphical and Statistical assessment)	-	8	5	4.0
- Ability to simulate monthly flows	-	7	5	3.5
- Ability to simulate daily flows	-	4	5	2.0
- Ability to simulate actual ET	-	3	5	1.5
Model Testing (Validation Results) (20%)				
- Ability to simulate annual flows (Graphical and Statistical assessment)	-	8	5	4.0
- Ability to simulate monthly flows	-	7	5	3.5
- Ability to simulate daily flows	-	5	5	2.5
- Ability to simulate actual ET	-	3	5	1.5
Objective Analysis Total:			40	22.5
TOTAL PERFORMANCE INDEX			100	**59.6**

Source: Von Euw. 1990. Note: A small "y" in the Phase I qualitative analysis indicates the model has capability, but weak or takes a number of steps to acquire from the output.

Table 31. Final Model Selection Criteria Scoring - AVSWAT

Model Attribute **SWAT/AVSWAT**	Phase I (Y/N)	 II Rating (1–10)	 Weight (%)	Partial Index
Subjective Criteria (60%)				
Documentation and Support (25%)				
- User's Manual	Y	8	5	4.0
- Additional References (past application reports/papers)	Y	8	5	4.0
- User Support (User groups, conferences, training etc.)	Y	9	5	4.5
- Model "momentum" (Ontario, North America, globally)		9	5	4.5
Input and Program Utility (10%)				
- Availability of Input Data (i.e. data requirements to operate)	Y	8	2	1.6
- Ability to interface with GIS for data input (Input format utility)	Y	8	2	1.6
- Ability to accommodate available input data sources	Y	6	2	1.2
- Potential to interface with a groundwater model		8	1	0.8
- Ability to model tile drainage system effects	Y	4	2	0.8
- Potential to address future water quality modelling tasks		8	1	0.8
Model Sensitivity (5%)				
- Overall stability and ease of use	-	7	5	3.5
Model Output (20%)				
- Continuous output	Y	10	4	4.0
- Appropriate temporal scale (daily, monthly, seasonally)	Y	10	4	4.0
- Appropriate spatial scale (Watershed size ranges: Shoreline Gullies <2000 ha vs. River Systems 265,000 ha.)		8	4	3.2
- Appropriate watershed characteristics modelled (e.g agricultural/rural landuses, tile drainage, winter hydrology)	Y	7	4	2.8
-Appropriate output (i.e. full suite of water balance)				
- Streamflow (separating baseflow + runoff)	Y	10	0.75	7.5
- Tile drainage component	y	1	0.50	0.5
- Snowmelt component	Y	7	0.50	0.35
- Deep percolation (beyond root zone components)	y	8	0.75	0.6
- Potential and Actual ET	y	5	0.75	0.38
- Output flexibility (link to spreadsheets, GIS etc.)	y	5	0.75	0.38
Subjective Analysis Total:			60	51.01
Objective Criteria (40%)				
Model Calibration (Results from calibration runs on test watersheds) (20%)				
- Ability to simulate annual stream flows (Graphical and Statistical assessment)	-	8	5	4.0
- Ability to simulate monthly flows		7	5	3.5
- Ability to simulate daily flows	-	1	5	0.5
- Ability to simulate actual ET	-	2	5	1.0
Model Testing (Validation Results) (20%)				
- Ability to simulate annual flows (Graphical and Statistical assessment)	-	8	5	4.0
- Ability to simulate monthly flows	-	7	5	3.5
- Ability to simulate daily flows	-	1	5	0.5
- Ability to simulate actual ET	-	2	5	1.0
Objective Analysis Total:			40	18
TOTAL PERFORMANCE INDEX			100	**69.0**

Source: Von Euw. 1990. Note: A small "y" in the Phase I qualitative analysis indicates the model has capability, but weak or takes a number of steps to acquire from the output.

The final scores arrived at (rated out of 100) were 68.5 and 57.9 for SWAT and GAWSER respectively. SWAT was therefore identified as the model of choice for possible future use, development and modification. The input files developed for the GAWSER model, could be adapted for use in a flood forecasting tool (e.g. ABIFFs) if this became a need for source water protection applications in the ABMV Planning Region. For long-term modeling purposes, however, SWAT was found to be more applicable. Input files for both of the models, as set-up and tested through this study, are provided in Schedule A of this document for possible future use and modification. The input files developed for the GAWSER model for example could be adapted for use in a flood forecasting tool (e.g. ABIFFS) if this became a priority for either of the Conservation Authorities in the ABMV Planning Region at some future date.

7.0 Applying SWAT to Assist With Tier 1 Water Budget Analyses

Preparing a Tier 1 water budget is a requirement of the source water protection area assessment process. Module 7 of the Ministry of the Environment's Technical Guidance Document for drinking water source protection planning (March, 2007) describes the requirements of a Tier 1 water budget and stress assessment. It asks that, at the Tier 1 stage, the drinking water source protection team apply a suitable approach to estimate the various water fluxes for each watershed in the Source Protection Planning Region. These estimates are to be calibrated to observed data. While not an absolute requirement at the Tier 1 level, Module 7 (MOE, March 2007) indicates that the preferred and recommended method for estimating both monthly surface water supply and groundwater recharge rates is long term simulation (20+ years) using a calibrated continuous surface water or groundwater model.

This report section describes some minor adjustments that were made to the SWAT model in an effort to further refine it for use in the ABMV Planning Region. SWAT was then used to continuously simulate the hydrologic component of all of the major river and shoreline systems in the ABMV study area for a 20 year period (1985 to 2004). The key information needed from these long-term simulations were then summarized. These results were then available to be fed into the ABMV Planning Region's Tier 1 water budget and water quantity stress assessment.

7.1 Revisions Made to the SWAT Model

The model calibration and validation steps described previously in this report showed that, when compared to available long-term historical measured continuous streamflow data records for the study area, SWAT was capable of producing reasonable estimations/predictions of annual and monthly streamflow across the Planning Region. This modelling result could be achieved with datasets using default or reference data acquired as part of the conceptual water budgeting exercise. The datasets acquired included daily precipitation, soils and land cover descriptions available through standard soils reports and default values provided by the SWAT model itself. Further improvements could be made through adjustments to key (sensitive) global data input variables that were identified through a sensitivity analysis. These results achieved using baseline data raised confidence in using SWAT to estimate both monthly stream flow (water yield) and baseflow at the points in the Planning Region not permanently monitored. This would be useful for estimating surface water and groundwater supply at any point in the Region.

While the initial SWAT set-up (provided in Schedule A) gave reasonable results, there were a number of weaknesses/simplifications in this initial SWAT model set-up as noted in previous sections of this report. Addressing these weaknesses/simplifications, either with the aid of improved datasets or through refinements to the model could perhaps improve the model's predictive capabilities. Some refinements were therefore made to the SWAT model's application prior to using it in the ABMV Planning Region to prepare input needed for the Tier 1 water budget and stress assessment. These refinements, all of which are included in the model datasets found in Schedule F, were as follows:

- Improve the model's estimate of potential evapotranspiration.
- Define the major reservoir and recreational/aesthetic dams within the model set-up.
- Add the points of sewage treatment plant (STP) discharge and simulate their effect on streamflow

Each of these refinements could have a significant affect on the model's water budget predictions. Perhaps the most significant from this list from a Tier 1 water budgeting perspective is the adjustment in potential ET estimates. This is because an adjustment in this could possibly have a significant affect on the estimate of actual ET occurring across the Region. An increase in actual ET, if streamflow calibration was to be maintained, would necessarily result in a significant decline in the model's estimate of annual groundwater recharge. Improving or gaining confidence in SWAT's estimate of groundwater is important because essentially all of the municipal drinking water supplies source their water from groundwater (The exceptions are the Lake Huron pipeline and the Goderich municipal supply which draw water from Lake Huron). A significant percentage of the permits to take water (PTTW) also use groundwater sources (see CWB Map E-8). Therefore having confidence in the model's estimate of annual groundwater recharge is very important within the ABMV Planning Region.

The location of reservoirs/dams were identified and added to the SWAT input files using the AVSWAT-X interface for each of the study area's river systems. Reservoir input files describing the Morrison and Parkhill reservoirs (i.e. surface area, volume of water needed to fill reservoir to principle spillway, volume of water needed to fill reservoir to the emergency spillway, hydraulic conductivity of reservoir bottom etc.) were prepared.

The location of sewage treatment plant discharge points were also added to the SWAT input files using the AVSWAT-X interface. The mapped data layer used to achieve this (See CWB Map E-7) was verified using aerial photography. Sewage treatment plant (STP) flow volumes from MOE records of STP operation, as provided through Source Water Protection channels, were used where available. These data were then assembled into the monthly point source files in the format required by SWAT as input. Only STP water flow data were added to SWAT's point source input file at this time. Water quality data could be added at a later date if SWAT were used to predict water quality through the Planning Region.

The datasets from MOE did not cover the entire 20 years of model simulation. Typically the dataset covered the period 1987 through 2004. Therefore, in the years data were not available, an average estimate was used of monthly discharge (m^3/day) as calculated from the years for which data were available. Table 32 presents the average STP discharge values that were derived from the available monthly datasets and used to datafill. In general, populations of urban centres in the Planning Area have been relatively static for the years modelled, making this a reasonable approach. Some of the known STPs had no data available in the MOE dataset. Consequently an estimate was made based on population size of the centre and known industrial activity. Urban centres with a similar industrial character were matched with the centre for which STP discharge was not known and then the STP discharge was prorated in accordance with the population difference. These values are shown in italics in Table 32.

Table 32. Average Daily STP Discharges by Month in the ABMV Planning Region

STP Name	River System Location	Population Serviced	Subcatchment Location	Average Daily Discharge (m3/day)											
				Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Arkona	Ausable	500	163	*217*	*236*	*249*	*251*	*253*	*236*	*241*	*247*	*246*	*231*	*246*	*252*
Ailsa Craig	Ausable	838	143	364	344	381	369	337	271	273	265	308	299	347	366
Exeter	Ausable	4264	106	3975	3396	4562	4590	3304	2724	3291	3394	4255	3167	4203	3722
Hensall	Ausable	1228	110	630	588	673	635	593	548	536	568	639	597	625	599
Lucan	Ausable	1673	130	700	668	856	735	700	588	524	497	548	532	703	758
Thedford	Ausable	661	171	287	312	329	332	334	312	319	326	325	306	325	333
Grand Bend	Parkhill	700	243	632	636	719	803	971	948	1210	1171	891	713	653	641
Parkhill	Parkhill	1575	213	723	673	745	753	700	588	592	582	681	617	688	691
Lucknow	Nine Mile	1100	504	*563*	*528*	*747*	*656*	*574*	*478*	*434*	*451*	*434*	*466*	*571*	*570*
Blyth	Maitland	890	445	404	316	486	424	415	367	348	339	361	354	396	398
Brussels	Maitland	1106	437	566	531	751	659	577	481	437	453	437	469	574	573
Harriston	Maitland	1963	402	1690	1499	5565	1998	1398	1180	860	748	1013	1040	1528	1472
Listowel	Maitland	6582	427	5713	5227	7495	7016	5665	5645	4877	4488	4997	5092	6546	5938
Milverton	Maitland	1500	430	627	545	736	768	648	525	499	483	522	521	620	613
Palmerston	Maitland	2273	414	1520	1411	1926	1999	1378	1144	931	1076	978	1004	1432	1329
Wingham	Maitland	2970	440	2883	2553	3482	3513	2736	2258	2007	2007	1976	2016	2502	2635
Goderich	Lake Huron	7400	n/a	8334	7574	9528	9042	8344	6818	6166	5787	6228	6025	7392	7856
Bayfield	Bayfield	700	337	*632*	*636*	*719*	*803*	*971*	*948*	*1210*	*1171*	*891*	*713*	*653*	*641*
Clinton	Bayfield	3000	315	3030	2745	4031	3098	2828	2042	1888	1810	1984	2065	3014	2998
Dublin (Poultry)	Bayfield	*250*	302	*217*	*199*	*285*	*266*	*215*	*214*	*185*	*170*	*190*	*193*	*249*	*226*
Seaforth	Bayfield	2153	312	2083	2166	3055	2677	2287	1651	1272	1572	1738	1581	2226	2320
Vanastra	Bayfield	900	319	734	676	1025	870	576	457	494	519	519	599	874	807
Zurich	Shoreline Gully	920	873	416	400	449	473	435	400	386	404	350	385	420	420
Huron Park	Ausable	1400	120	1564	1473	1774	1780	1472	1175	1079	1040	1150	1012	1436	1472

Note: entries in italics are estimated values

Finally, obtaining a new estimate of potential ET for the Planning Region proved to be a matter of populating SWAT's weather generation tool database and changing the choice of potential ET estimation model to be used by SWAT. The Penman-Monteith approach was selected, which is the same general approach used by the potential ET measuring stations established in the ABMV Planning Region (See Table 29). Test runs on the Exeter and Blyth (calibration) subwatersheds showed SWAT's new annual PET estimates using Penman-Monteith were in the 750mm to 800 mm range - values that more closely matched other data sources for potential ET.

With these changes, the SWAT model was re-run for each river system. The global inputs known to have the greatest influence on SWAT's water yield output were adjusted from the first set of values established through the initial calibration process to help improve model performance. Table 33 summarizes the performance scores for streamflow (as defined in Table

Table 33. Statistical Measures of SWAT's Performance Following Revisions to Input Files

Subwatershed ID	Model Efficiency Score (Monthly) Nash-Sutcliffe	Model Efficiency Score (Monthly) R^2
Ausable River System		
Exeter	0.88	0.88
Springbank	0.88	0.89
Parkhill River System		
Parkhill Inflow	0.85	0.85
S. Parkhill Cr.	0.66	0.71
Bayfield River System		
Varna	0.85	0.85
Maitland River System		
Belgrave	0.85	0.85
Benmiller	0.87	0.88
Bluevale	0.83	0.84
Blyth	0.89	0.89
Ethel	0.82	0.82
Harriston	0.67	0.68
Listowel	0.75	0.75
Summerhill	0.85	0.85
Wingham A	0.79	0.83
Wingham B	0.85	0.85
Lucknow River System		
Lucknow A	0.85	0.86

Note: Scores >90 = excellent; Scores >80 ≤ 90 = very good; Scores >70 ≤ 80 = good.

21) achieved following these refinements. For most of the observation stations, the statistical scores actually dropped 2 or 3 points with the revised model set-up compared to the initial set-up See Table 25). There were exceptions such as the Belgrave, Benmiller, Harriston and Wingham A. These stations had relatively poor scores with the initial set-up. Overall, the revised model increased the average statistical score across all stations by about 1 point to 82.

Schedule G provides a graphical comparison of the revised SWAT model's performance for each long-term streamgauging station in the ABMV Planning Region. These graphs can also be compared against the graphs prepared for the SWAT and GAWSER initial set-up provided in Schedule E. In comparing the graphical results, it is clear that the revised SWAT model was more prone to underestimating spring streamflows and overestimating summer runoff volumes.

7.2 Long Term Water Budget Estimates

Both the initial calibrated SWAT model setup as well as the revised model setup described above were applied to derive long term water budget values needed as input to the Tier 1 water budget and water stress assessment. The Tier 1 assessment was completed at the river system (watershed) scale. Consequently, as a starting point, SWAT was used to estimate a long term water balance at the outlet of each of the main river and shoreline system in the MVCA Planning Region. If this initial assessment revealed a need to provide long-term water budget estimates at a smaller (subwatershed or subcatchment) level, then the SWAT model would be capable of doing so. Typically, detailed HRU and river reach output files generated by SWAT following a 20 year simulation of some of the larger main river systems in the ABMV Planning Region are so large that they cannot be loaded into common spreadsheet packages (e.g. Excel) for further analysis and graphing. However, software developed by Amanjot Singh (University of Guelph – Watershed Research Team, 2006), allows a user to extract detailed water balance data at the point of interest in the watershed from large SWAT output files and place the information into a common spreadsheet. This then gave the ABMV technical team the ability to summarize and present SWAT's long-term water balance estimates for any subcatchment modelled in the ABMV Planning Region (See CWB Map E-10). Through comparing future field observations with SWAT output, (e.g. spot streamflow/baseflow measurements at points of interest), more (or less) confidence will be gained in SWAT's ability to predict long-term water balances at any point in the watershed.

Tables 34 summarizes the long-term water balance estimated by SWAT for the major river and shoreline systems in the ABMV Planning Region as output by the initial SWAT set-up (i.e. the set-up used in the SWAT/GAWSER objective comparison). Table 35 presents the same data (minus the shoreline area) generated by the revised model set-up intended to improve potential ET estimates and that included dam structures, and STP discharges. Given that there were no significant dams on the shoreline gullies, that only one shoreline watershed has a STP associated with it, and that actual ET estimates did not change significantly using the Penman-Monteith model (see Table 36 below), it was concluded that recalculating long-term water balance for the shoreline was not warranted for use as input to Tier 1 level water budget calculations.

Table 34. The Initial SWAT Model's Long-Term Water Budget Estimate for Major River/Shoreline Systems in the ABMV Planning Region.

River/Shoreline System	Month												
Precipitation	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**Annual**
Ausable	69.14	54.30	59.24	78.22	83.69	79.02	87.75	76.01	110.86	91.26	97.06	76.84	963
Parkhill	63.59	55.04	58.24	78.22	80.80	77.15	88.41	81.11	104.16	92.54	96.37	59.78	935
Bayfield	81.85	56.71	58.89	75.42	87.32	78.38	87.96	71.68	119.51	94.95	104.48	74.22	991
Maitland	75.69	61.59	64.00	77.68	97.57	85.64	85.69	93.68	111.32	94.70	115.42	89.13	1052
Lucknow (Nine Mile)	98.29	76.13	75.65	82.01	101.31	91.61	78.92	90.31	118.55	105.55	122.52	114.65	1156
Shoreline - North of Maitland River Outlet	93.43	74.23	76.49	80.63	98.81	89.64	77.01	88.64	116.50	103.54	119.85	112.90	1132
Shoreline - South of Maitland River Outlet to MVCA/ABCA boundary	80.34	70.46	81.66	80.83	93.01	83.64	71.77	85.09	111.65	97.49	114.79	108.47	1079
Shoreline - North of Bayfield River Outlet to ABCA/MVCA boundary	84.25	59.04	62.50	78.31	89.94	78.29	86.15	74.88	119.87	98.44	107.95	80.94	1021
Shoreline - South of Bayfield River Outlet including Mud Creek	66.00	54.23	55.76	78.41	85.29	76.83	88.18	75.79	110.48	93.05	101.18	79.73	965
Streamflow	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**Annual**
Ausable	41.30	43.43	64.52	52.49	28.48	16.26	14.88	9.57	25.14	23.62	47.84	53.54	421
Parkhill	35.11	44.17	49.48	41.52	25.42	16.97	16.44	12.28	23.28	21.03	38.18	39.31	363
Bayfield	38.98	46.80	77.65	56.44	36.39	20.49	17.45	8.83	27.59	26.18	51.55	49.63	458
Maitland	39.14	49.56	81.83	68.97	48.72	23.22	10.12	10.22	15.86	23.29	55.06	51.76	478
Lucknow (Nine Mile)	51.47	70.13	106.39	69.05	51.26	27.21	10.15	10.04	16.48	22.62	53.92	65.02	554
Shoreline - North of Maitland River Outlet	53.79	69.47	104.08	69.78	57.92	41.40	19.60	23.86	33.57	39.09	69.85	71.16	654
Shoreline - South of Maitland River Outlet to MVCA/ABCA boundary	58.17	64.88	87.01	65.52	51.84	33.22	13.29	17.18	26.41	28.80	58.34	68.13	573
Shoreline - North of Bayfield River Outlet to ABCA/MVCA boundary	44.72	54.35	75.36	62.25	47.67	28.42	21.80	13.29	31.97	35.89	61.75	59.69	537
Shoreline - South of Bayfield River Outlet including Mud Creek	51.78	53.83	59.35	50.88	48.76	37.03	32.79	20.19	38.31	37.27	60.40	63.86	554
Surface Runoff	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**Annual**
Ausable	28.17	38.14	51.19	16.42	11.93	13.47	14.19	9.23	24.13	14.09	20.03	24.38	265
Parkhill	25.73	40.30	39.15	15.95	12.07	13.72	15.15	11.54	21.73	13.92	21.47	20.00	251
Bayfield	28.30	42.85	68.55	19.53	12.24	12.84	15.32	8.24	25.29	14.73	22.31	23.71	294
Maitland	27.99	44.39	69.41	25.51	11.74	8.82	5.84	7.99	12.29	8.41	21.51	24.54	268
Lucknow (Nine Mile)	28.16	56.42	84.63	19.99	11.56	9.89	3.58	7.02	12.40	7.34	17.63	26.71	285
Shoreline - North of Maitland River Outlet	37.20	62.42	88.88	25.44	22.11	22.02	11.99	20.41	28.14	17.36	28.31	36.00	400
Shoreline - South of Maitland River Outlet to MVCA/ABCA boundary	40.11	56.65	69.66	23.16	17.62	17.21	8.46	15.33	22.99	13.65	23.75	32.70	341
Shoreline - North of Bayfield River Outlet to ABCA/MVCA boundary	27.83	46.99	62.31	18.80	13.77	13.73	15.84	11.03	25.68	14.12	20.92	23.70	295
Shoreline - South of Bayfield River Outlet including Mud Creek	28.69	42.76	46.04	17.63	17.28	18.07	22.06	14.63	31.26	17.48	23.84	25.05	305
Actual Evapotranspiration	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**Annual**
Ausable	0.42	1.99	17.00	50.46	68.15	76.15	79.37	63.95	40.40	17.01	3.23	0.18	418
Parkhill	0.60	2.64	18.77	50.52	67.10	74.94	78.64	63.58	40.09	16.55	3.19	0.22	417
Bayfield	0.26	1.19	14.96	49.83	70.91	77.45	82.81	65.47	41.01	17.51	3.04	0.16	425
Maitland	0.17	1.35	14.57	47.97	64.13	92.14	89.83	80.16	52.80	18.96	3.11	0.09	465
Lucknow (Nine Mile)	0.21	1.27	16.87	46.80	59.08	89.68	86.14	78.32	54.81	19.32	2.89	0.05	455
Shoreline - North of Maitland River Outlet	0.24	1.51	16.55	37.05	43.59	64.53	67.93	60.34	42.17	16.57	2.74	0.03	353
Shoreline - South of Maitland River Outlet to MVCA/ABCA boundary	0.36	2.05	19.19	42.41	51.15	74.98	73.51	65.38	46.69	17.76	2.88	0.04	396
Shoreline - North of Bayfield River Outlet to ABCA/MVCA boundary	0.35	1.58	16.35	39.86	50.31	66.74	76.66	61.42	38.83	16.13	3.02	0.17	371
Shoreline - South of Bayfield River Outlet including Mud Creek	0.46	2.28	17.15	38.44	48.55	58.92	68.88	53.96	33.57	14.96	3.08	0.15	340
Baseflow	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**Annual**
Ausable	13.14	5.28	13.33	36.07	16.55	2.80	0.70	0.34	1.01	9.54	27.81	29.16	156
Parkhill	9.38	3.87	10.33	25.57	13.35	3.25	1.29	0.74	1.55	7.10	16.71	19.31	112
Bayfield	10.68	3.95	9.09	36.91	24.15	7.64	2.12	0.58	2.30	11.45	29.24	25.92	164
Maitland	11.15	5.17	12.43	43.46	36.97	14.41	4.28	2.23	3.57	14.88	33.55	27.21	209
Lucknow (Nine Mile)	23.31	13.70	21.76	49.06	39.70	17.31	6.57	3.02	4.07	15.28	36.29	38.32	268
Shoreline - North of Maitland River Outlet	16.60	7.05	15.21	44.34	35.82	19.38	7.61	3.45	5.43	21.73	41.54	35.16	253
Shoreline - South of Maitland River Outlet to MVCA/ABCA boundary	18.06	8.23	17.35	42.35	34.23	16.01	4.83	1.85	3.41	15.15	34.59	35.42	231
Shoreline - North of Bayfield River Outlet to ABCA/MVCA boundary	16.90	7.35	13.06	43.45	33.90	14.69	5.96	2.26	6.29	21.77	40.83	35.99	242
Shoreline - South of Bayfield River Outlet including Mud Creek	23.09	11.08	13.32	33.25	31.48	18.96	10.73	5.57	7.05	19.79	36.56	38.81	250
Net Soil/Groundwater Recharge	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**Annual**
Ausable	-10.31	-1.51	28.75	8.09	-5.11	0.96	1.10	2.02	14.26	27.61	26.00	-14.76	77
Parkhill	-6.60	-0.89	30.02	11.94	-3.72	0.12	0.45	2.36	12.00	30.40	36.67	-4.89	108
Bayfield	-8.93	-2.06	25.59	13.18	-10.83	-3.74	-0.65	0.42	13.50	27.61	24.82	-16.59	62
Maitland	-8.60	-0.26	25.56	23.30	-8.73	-6.84	-1.05	2.65	14.03	26.90	22.17	-18.58	71
Lucknow (Nine Mile)	-16.67	-2.48	40.33	25.58	-6.15	-4.13	-2.96	3.51	20.49	37.65	31.73	-19.58	107
Shoreline - North of Maitland River Outlet	-13.03	-2.93	33.20	14.48	-6.25	-5.80	-2.61	4.10	19.61	31.03	18.58	-20.29	67
Shoreline - South of Maitland River Outlet to MVCA/ABCA boundary	-13.67	-3.61	35.15	11.07	-9.49	-8.02	-2.27	2.87	15.78	28.43	27.60	-16.43	67
Shoreline - North of Bayfield River Outlet to ABCA/MVCA boundary	-13.57	-3.49	29.68	21.52	-6.90	-2.90	-0.52	1.94	22.30	29.84	21.82	-21.35	78
Shoreline - South of Bayfield River Outlet including Mud Creek	-19.08	-6.96	32.05	12.66	-10.85	-8.80	-5.39	0.64	17.33	28.49	24.17	-20.14	44

Table 35. The Revised SWAT Model's Long-Term Water Budget Estimate for Major River Systems in the ABMV Planning Region.

River System	Month												
Precipitation	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**Annual**
Ausable	69.14	54.30	59.24	78.22	83.69	79.02	87.75	76.01	110.86	91.26	97.06	76.84	963
Parkhill	63.59	55.04	58.24	78.22	80.80	77.15	88.41	81.11	104.16	92.54	96.37	59.78	935
Bayfield	81.85	56.71	58.89	75.42	87.32	78.38	87.96	71.68	119.51	94.95	104.48	74.22	991
Maitland	75.71	61.61	64.01	77.68	97.57	85.64	85.68	93.68	111.33	94.71	115.43	89.16	1052
Lucknow (Nine Mile)	98.29	76.13	75.65	82.01	101.31	91.61	78.92	90.31	118.55	105.55	122.52	114.65	1156
Streamflow	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**Annual**
Ausable	37.35	44.90	61.31	40.18	30.29	23.51	20.12	13.09	29.59	23.54	39.14	47.76	411
Parkhill	34.16	46.20	49.85	37.71	28.46	22.37	20.60	15.09	26.21	21.76	38.70	41.17	382
Bayfield	36.14	46.97	75.29	40.72	31.27	24.57	22.70	13.82	34.14	26.92	46.78	48.62	448
Maitland	35.06	49.44	73.21	46.76	36.47	26.89	17.81	18.60	26.53	31.16	49.53	45.43	457
Lucknow (Nine Mile)	45.45	68.51	99.98	63.88	48.13	34.66	18.63	18.90	29.72	39.00	61.65	63.08	592
Surface Runoff	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**Annual**
Ausable	29.25	40.36	52.31	17.94	14.96	16.82	17.55	11.29	27.05	15.53	22.23	27.05	292
Parkhill	26.90	42.11	40.55	17.70	15.05	16.95	18.71	13.83	24.29	15.41	23.92	22.45	278
Bayfield	28.78	43.34	70.08	20.67	15.53	16.75	19.62	11.74	30.69	17.02	24.73	26.31	325
Maitland	27.68	45.16	68.01	26.70	13.97	12.11	9.52	12.54	17.69	10.13	22.93	24.69	291
Lucknow (Nine Mile)	29.53	57.93	83.78	21.61	13.32	12.94	6.09	10.58	16.75	8.83	19.50	27.88	309
Actual Evapotranspiration	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**Annual**
Ausable	21.15	5.28	12.59	45.41	51.64	68.62	68.23	66.08	42.31	40.29	13.92	1.97	438
Parkhill	21.87	2.04	14.32	44.60	50.42	67.87	68.69	67.32	43.10	41.48	15.79	2.07	440
Bayfield	22.43	10.75	9.67	43.48	51.00	65.66	65.12	62.18	40.86	39.47	12.14	2.73	425
Maitland	8.81	7.97	24.71	47.32	51.13	65.16	71.09	66.07	44.51	35.78	32.39	8.58	464
Lucknow (Nine Mile)	3.08	5.03	26.39	42.36	48.34	61.44	66.98	65.06	44.06	37.43	15.85	10.77	427
Baseflow	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**Annual**
Ausable	9.96	3.87	8.74	24.06	15.82	6.23	3.19	2.10	3.16	8.74	18.34	21.13	125
Parkhill	8.91	3.67	8.30	21.58	13.74	4.97	2.64	1.78	2.61	6.96	16.18	19.16	110
Bayfield	9.20	2.95	5.51	21.98	16.73	7.98	3.94	2.03	4.12	11.02	24.03	23.00	132
Maitland	9.10	4.28	6.90	22.34	23.86	14.80	8.98	6.71	9.62	22.35	28.16	20.91	178
Lucknow (Nine Mile)	18.07	10.18	19.32	44.89	35.54	21.73	12.73	8.87	12.93	30.99	43.47	35.10	294
Net Soil/Groundwater Recharge	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**Annual**
Ausable	1.59	1.91	31.92	43.11	18.24	8.79	5.73	4.41	17.88	28.03	39.21	12.42	213
Parkhill	1.24	1.12	31.84	38.09	16.69	7.84	5.00	5.48	15.23	26.52	36.43	12.11	198
Bayfield	0.93	0.87	22.56	45.49	22.60	10.03	5.77	3.93	22.44	34.29	42.99	8.23	220
Maitland	1.73	3.32	21.97	53.77	35.56	17.64	11.60	12.92	32.89	43.17	37.64	5.55	278
Lucknow (Nine Mile)	5.55	9.76	50.66	72.97	40.26	25.69	11.62	15.47	42.95	52.80	57.28	15.39	400

Table 36 shows the difference in annual potential ET that was calculated using the Priestley-Taylor model versus the Penman-Monteith model. The Penman-Monteith model brought the potential ET up to values that seem consistent with other sources of potential ET estimates for the study area. It is interesting to note, however, that the actual ET values presented in Tables 34 and 35 were not very different from each other. While these values near the expected range of actual ET (see discussion in Section 5.0), they may be slightly lower than what is actually occurring. Further investigation into actual ET may be warranted because this has a large impact on whether SWAT's groundwater recharge estimates for each river system presented in Tables 34 and 35 are also representative of actual conditions.

For input to the Tier 1 analyses, it was decided that the data presented in Table 7.3 be recommended for use. The values for the various water budget components are very similar in magnitude to the values presented in Table 34 and Table 35 included data for the major shoreline areas of the Planning Region.

Table 36. Average Annual PET and AET as Estimated By SWAT using the Priestley Taylor and the Penman-Monteith PET Models.

River System	Priestley-Taylor		Penman-Monteith	
	Annual PET	Annual AET	Annual PET	Annual AET
Ausable	573	418	834	437
Parkhill	569	417	834	440
Bayfield	569	425	779	425
Maitland	593	465	813	464
Lucknow (Nine Mile)	626	455	775	427

7.3 Water Supply, Water Reserve and Low Flow Analyses

For source protection (Tier 1) applications, estimates of monthly water supply and monthly water reserve need to be determined. Periods of low flow or low aquifer recharge are also of interest as it is in periods of low flow or low aquifer recharge when water users will induce water quantity stress. For Tier 1, the monthly water supply is to be estimated as the monthly 50th percentile flow (Q_{p50}). The monthly water reserve is to be estimated as the monthly 10th percentile flows (Q_{p10}). Some simple low flow analyses were also completed here using both the historical streamgauge streamflow and the 20-year continuous streamflow estimates generated with SWAT.

Graphs presenting the annual estimates of the Q_{p50} and Q_{p10} are given on the "D series of plots in Schedule E and G for each of the gauged subwatersheds in the ABMV Planning Region. Q_{p50} and Q_{p10} have also been tabulated on a monthly basis for each of the major river and shoreline systems as a whole in Table 37 for use as input to Tier 1 calculations. Table 37 was prepared using data generated by the initial SWAT set-up. The shoreline values are estimates only, based on comparing the mean annual flows of the shoreline areas with a nearby main river system and assuming the ratio of Q_{p50} and Q_{p10} to mean annual flow is similar between the two areas.

Table 37. Monthly Water Supply and Water Reserve Estimate for Major River/Shoreline Systems in the SBMV Planning Region

River/Shoreline System	Month												
Monthly Water Supply (Q_{p50}) (mm)	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**Annual**
Ausable	33.80	19.53	53.82	49.93	20.66	5.71	4.09	3.28	4.40	10.05	42.18	50.37	249
Parkhill	16.09	11.85	41.24	34.42	15.27	4.48	3.29	2.39	3.99	9.18	23.39	27.25	155
Bayfield	17.79	9.49	43.33	46.82	27.37	8.71	2.88	1.82	3.12	8.71	41.81	33.53	199
Maitland	19.10	15.72	47.46	56.24	41.08	15.50	5.64	3.40	3.95	13.19	46.08	40.60	264
Lucknow (Nine Mile)	31.40	24.46	60.52	59.71	44.26	17.17	7.22	4.62	3.65	12.36	46.90	48.20	321
Shoreline - North of Maitland River Outlet	29.53	23.14	59.78	58.62	49.43	26.88	12.43	9.45	7.89	21.75	59.61	54.28	370
Shoreline - South of Maitland River Outlet to MVCA/ABCA boundary	31.93	21.61	49.98	55.04	44.24	21.57	8.43	6.80	6.21	16.03	49.79	51.97	325
Shoreline - North of Bayfield River Outlet to ABCA/MVCA boundary	20.45	12.80	52.44	51.63	32.25	9.79	3.97	2.67	4.54	13.81	43.96	40.85	231
Shoreline - South of Bayfield River Outlet including Mud Creek	23.68	12.68	41.30	42.19	32.98	12.75	5.98	4.05	5.45	14.34	43.00	43.70	238
Monthly Water Reserve (Q_{p10}) (mm)	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**Annual**
Ausable	9.51	5.65	15.06	25.08	6.30	1.07	0.51	0.43	0.18	1.32	4.12	17.74	21.44
Parkhill	4.35	3.57	7.31	13.20	5.33	1.34	0.56	0.24	0.18	0.69	5.80	6.88	14.49
Bayfield	4.90	3.22	6.31	23.24	11.43	1.79	0.40	0.17	0.02	0.52	3.61	9.59	13.20
Maitland	7.50	4.72	10.14	28.42	16.52	3.67	1.19	0.46	0.25	0.84	9.29	15.03	24.05
Lucknow (Nine Mile)	15.00	9.53	18.34	35.19	17.64	6.46	1.13	0.41	0.13	1.02	6.26	21.82	32.09
Shoreline - North of Maitland River Outlet	12.99	8.02	15.42	32.16	19.79	8.18	2.24	1.02	0.40	1.58	9.94	22.27	35.39
Shoreline - South of Maitland River Outlet to MVCA/ABCA boundary	14.05	7.49	12.89	30.20	17.71	6.56	1.52	0.74	0.32	1.17	8.31	21.32	31.01
Shoreline - North of Bayfield River Outlet to ABCA/MVCA boundary	5.58	4.07	8.63	22.71	12.48	2.36	0.62	0.26	0.14	0.95	6.85	10.99	18.45
Shoreline - South of Bayfield River Outlet including Mud Creek	6.46	4.03	6.80	18.56	12.77	3.08	0.94	0.40	0.16	0.99	6.70	11.76	19.05

Statistical analyses to determine the 7Q20 flows were not performed at this time as part of this study. This work could be completed, however, on the datasets (or datasets for a new set of runs) generated by the SWAT model. To get some idea of the validity of using the SWAT model's data in such an analysis, a 7-day moving average flow was calculated for the 20 years of simulation to determine a crude 7Q20 estimate. Table 38 presents the findings. In general the model currently appears to be under-estimating the 7Q20 value when estimates using the modelled output are compared against data from sites that have a 20 year daily flow dataset for the same time period. More investigation is needed here

Table 38. Preliminary (Simplified) Estimate of 7Q20 Low Flows for Selected Gauged ABMV Planning Region Watersheds

Subwatershed ID	SWAT Model 7Q20 (m^3/s)	Observed 7Q20 (m^3/s)
Ausable River System	0	--
Exeter	0	0
Springbank	0	0.123
Parkhill River System	0.006	--
Parkhill Inflow	0	0
S. Parkhill Cr.	0	0
Bayfield River System	0	--
Varna	0.029	0.050
Maitland River System	0	--
Belgrave	0	--
Benmiller	0.010	0.906
Bluevale	0.0004	--
Blyth	0	--
Ethel	0.046	--
Harriston	0	--
Listowel	0	0.007
Summerhill	0	0.013
Wingham A	0	0.206
Wingham B	0.054	--
Lucknow River System	0	--
Lucknow A	0	--

Note: Shoreline watersheds were not assessed

A preliminary analysis was completed to determine which subcatchments in the watershed would most likely be experiencing a higher degree of anthropogenic water stress within the Planning Region. This analysis was completed by simply considering the number of water taking permits present in the subcatchment and the proportion of the subcatchment that is impacted by a well head protection area (WHPA). Two year through 25 year WHPAs were all given the same weighting in this analysis. CWB Map E-11 graphically presents the outcome of this preliminary assessment. It suggests that subcatchments that presently may be most vulnerable to water quantity stress include subcatchments, 112, 753, 117, 173, 308 and 764.

It is important to note that the level of stress being experienced is relative to other areas in the study region alone and not relative to other, more highly urbanized areas. Nevertheless, it gives some initial indication of where baseflow or other more detailed investigations may be warranted, particularly if the Tier 1 water budget stress Assessment gives any of these areas a moderate or higher stress rating. Similarly SWAT model output could be acquired for each of these subcatchments and assessed to fine tune Tier 1 calculations if these was needed to reduce the uncertainty score in the assessment.

8.0 Recommendations

From experience gained in undertaking the hydrologic modelling activities presented in this report, the following recommendations are given if the SWAT model is to be applied in the ABMV Region beyond its current level of application:

1. Further testing and investigation needs to be undertaken to confirm the actual ET amounts in the ABMV Planning Region to verify/refute numbers being generated by the SWAT model. Are the SWAT estimates realistic given the vegetative cover over much of the Region?

2. Conduct an independent study to assess the validity of the soil characterisitics developed for this model and entered in the soils database (see Table 9). The defined soil characteristics (e.g. soil depth, available water holding capacity etc.) can have a significant effect on model hydrologic output including ET and tile drainage flow. Other models, such as the McBride desorption release model (McBride, 1983), may give results that are more representative of Ontario soils than the Saxton (2006) soil characteristics model because the McBride model was developed using analysis results from Ontario soil samples. Other pedotransfer functions couls also be assessed.

3. If the model is to be revised and re-run over an entire river system, calibration should be completed on a subwatershed basis, beginning at the uppermost watershed for which calibration data are available and working downstream. This will generate a set of subwatershed-based calibration numbers as opposed to the river system based numbers determined in this study.

4. To make the output from this long-term water budget model more accessable and usable for water protection purposes, key long-term average water budget data could be tabulated in a spreadsheet or database on a subcatchment basis (see Figure 7.1). Data tabulated for each subcatchment could include average annual precipitation (rainfall + snowfall), streamflow, baseflow, groundwater recharge, 50^{th} percentile and 90^{th} percentile flows and 7Q20 estimates (or equivalent). Field observations would be necessary to confirm if the model is giving reasonable estimates of these values at select points in the study area.

5. The Tier 1 water quantity risk assessment may identify subwatersheds or subcatchments under a moderate or high level of water quantity stress. If this is the case and there is a need to move to a Tier 2 level of analysis, the model should be refined to set-up in such a way that it focuses on the smaller area (subcatchment or subwatershed) of concern. This would

allow modellers to describe the area in more detail and take full use of any additional data available without creating excessive model set-up and run times.

6. Further investigation could be made into applying this model to assess its potential to predict water quality (nutrients, bacteria) and subsequently its ability to assess the relative benefits of implementing various beneficial management practices aimed at improving water quality. This modelling should also be undertaken at a subwatershed or subcatchment of concern (i.e. where water quality "issues" are found to be present). This will allow modellers to take full advantage of some available datasets (e.g. detailed land cover data, and land management practice data) and reduce set-up and run times. Examples of subwatersheds where the SWAT model could be tested from a water quality perspetive include: Kerry's Creek or other shoreline gullies of interest from a water quality perspective, Middle Maitland above Listowel, Silver Creek, St Joseph Drain and Zurich Drain.

9.0 References

Acres Consulting Services Limited. 1984. Water Quantity Resources of Ontario. G. Lyons Litho Limited, Fort Erie.

Annable. W.K. 1996a. Morphologic Relationships of Rural Watercourses in Southern Ontario and Selected Field Methods in Fluvial Geomorphology. Prepared for Credit Valley Conservation and the Ontario Ministry of Natural Resources.

Annable. W.K. 1996b. Database of Morphologic Characteristics of Watercourses in Southern Ontario. Prepared for Credit Valley Conservation and the Ontario Ministry of Natural Resources.

Ausable Bayfield Maitland Valley Planning Region. 2006. Conceptual Water Budget. Ausable Bayfield Conservation Authority, Exeter, ON.

B. M. Ross and Associates Limited. 1994. Hydrology Study – Technical Manual. Maitland Valley Conservation Authority, Wroxeter.

Brown, D.M, G.A. McKay and L.J. Chapman. 1974. The Climate of Southern Ontario. Climatological Studies Number 5, Environment Canada, Atmospheric Environment Services, En57-7/5.

CH2M-Hill Ltd. 1996. Mill Creek Subwatershed Planning Study. Submitted to the Grand River Conservation Authority.

Chow, V.T. 1959. Open-Channel Hydraulics. McGraw-Hill Book Company, New York, NY.

Chow. V.T. (Editor). 1964. Handbook of Applied Hydrology. McGraw-Hill Book Company, New York, N.Y.

Department of Fisheries and Oceans. 2003. Ausable Bayfield Maitland Valley Drain Classification. Department of Fisheries and Oceans, Ottawa

Dickinson T., and Diiwu. 2000. Water balance calculations in Ontario (unpublished). Guelph ON: School of Engineering, University of Guelph.

Di Luzio, M., R. Srinivasan, J.G. Arnold, S.L. Neitsch. 2002. ArcView Interface for SWAT2000, User's Guide. TWRI Report TR-193. Texas Water Resources Institute, College Station, TX.

Ecologistics Ltd. 1988. Speed and Eramosa Rivers Floodplain Mapping Study. A study funded under the Canada/Ontario Flood Damage Reduction Program.

Environment Canada. Canadian Climate Program. 1981. Canadian Climate Normals: Wind: 1951–1980, Ontario. Environment Canada Atmospheric Enviroment Service, Downsview.

Essex Region Conservation Authority. 2007. Essex Region Watershed Draft Conceptual Water Budget Report, Essex, Ontario

Haan, C.T., H.P. Johnson and D.L. Brakensiek. 1982. Hydrologic Modeling of Small Watersheds, Mono. No. 5, American Society of Agricultural Engineers.

Hagerty, T.P. and M.S. Kingston. 1992. The Soils of Middlesex County, Volume 1. Report No. 56 of the Ontario Centre for Soil Resource Evaluation. Ontario Ministry of Agriculture and Food and Agriculture Canada Research Branch, Guelph

Hagerty, T.P. and M.S. Kingston. 1992. The Soils of Middlesex County, Volume 2. Report No. 56 of the Ontario Centre for Soil Resource Evaluation. Ontario Ministry of Agriculture and Food and Agriculture Canada Research Branch, Guelph

Hauser, Visctor L. and Dianna M Gimon. 2004. Evaluating Evapotranspiration (ET) Landfill Cover Performance Using Hydrologic Models Air Force Centre for Environmental Excellance, Brooks City-Base, TX.

Hoffman, D.W. , N.R. Richards. 1952 (reprinted, 1989). Soil Survey of Perth County. Report No. 15 of the Ontario Soil Survey. Ontario Ministry of Agriculture and Food and Agriculture Canada Research Branch, Guelph.

Hoffman, D.W. , N.R. Richards and F.F. Morwick. 1952 (reprinted, 1990). Soil Survey of Huron County. Report No. 13 of the Ontario Soil Survey. Ontario Ministry of Agriculture and Food and Agriculture Canada Research Branch, Guelph.

Hoffman, D.W. , N.R. Richards. 1954. Soil Survey of Bruce County. Report No. 16 of the Ontario Soil Survey. Canada Department of Agriculture and the Ontario Agriculture College, Guelph.

Hoffman, D.W. , B.C. Matthews and R.E. Wicklund. 1963. Soil Survey of Wellington County. Report No. 35 of the Ontario Soil Survey. Canada Department of Agriculture and Ontario Department of Agriculture, Guelph.

James, D.L., and S.J. Burges. 1982. Selection, Calibration, and Testing of Hydrologic Models. In Hydrologic Modeling of Small Watersheds, Mono. No. 5, American Society of Agricultural Engineers.

Linacre, E.T. 1977. A simple formula for estimating evaporation rates in various climates, using temperature data alone. Agricultural Meteorology, Vol. 18, pp. 409-424.

Luinstra Earth Sciences. 2006. Permit to Take Water Final Report. Ausable Bayfield Conservation Authority and Maitland Valley Conservation Authority, Exeter, ON

Matthews, B.C., N.R. Richards and R.E. Wicklund. 1957. Soil Survey of Lambton County. Report No. 22 of the Ontario Soil Survey. Ontario Ministry of Agriculture and Food and Agriculture Canada Research Branch, Guelph..

McBride, R.E. 1983. Agronomic and Engineering Interpretations from Water Retention Data. Ph.D thesis. Guelph, ON: University of Guelph.

Mein, R.G. and C.L. Larson. 1973. Modeling infiltration during a steady rain. Water Resources Research, Vol. 9, No. 2, pp. 384-394.

Nash, J.E. and J.V. Sutcliffe. 1970. River flow forecasting through conceptual models: Part I - A discussion of principles. J. of Hydrology, Vol. 10, pp. 282-290.

Neitsch, S.L., J.G. Arnold, J.R. Kiniry, J.R. Williams and K.W. King. 2002. Soil and Water Assessment Tool Theoretical Documentation, version 2000. TWRI Report TR-191. Texas Water Resources Institute, College Station, TX.

Neitsch, S.L., J.G. Arnold, J.R. Kiniry, R. Srinivasan and J.R. Williams. 2002. Soil and Water Assessment Tool Users Manual, version 2000. TWRI Report TR-192. Texas Water Resources Institute, College Station, TX.

Ontario Ministry of Agriculture, Food and Rural Affairs. 2005. Digital Soils Coverage, Southern Ontario, ver. 1. Ontario Ministry of Agriculture, Food and Rural Affairs, Guelph.

Ontario Ministry of Natural Resources. 2002. Digital Elevation Model – Provincial Tiled Data Set (DEM) Ver 1. Ontario Ministry of Natural Resources, Peterborough.

Ontario Ministry of the Environment (MOE). March 2007. Water Budget and Water Quantity Risk Assessment. Assessment Report Guidance Module 7. Source Water Protection Branch, Toronto.

Ontario Ministry of Natural Resources (OMNR). 1984. Water Quantity Resources of Ontario. OMNR Publication No. 5932, Queen's Park, Toronto, Ontario.

Presant, E.W. and R.E. Wicklund. 1971. The Soils of Waterloo County. Report No. 44 of the Ontario Soil Survey. Canada Department of Agriculture and the Ontario Department of Agriculture and Food, Guelph.

Ritchie, J.T. 1972. Model for Predicting Evaporation from a Row Crop with Incomplete Cover. Water Resources Research. 8:1204-1213.

Saxton, K. E. accessed Feb 2006. Soil Water Characteristics, version 1.0.103. http://www.bsyse.wsu.edu/saxton/

Schroeter, H.O. 2005. Meteorological Data Missing Value Fill-in Study. Memo report submitted to Mr. Kevin McKague, P.Eng., Ausable Bayfield Maitland Valley Planning Region, Exeter, Ontario.

Schroeter, H.O., D.K. Boyd, and H.R. Whiteley. 2000a. Filling gaps in meteorological data sets used for long-term watershed modelling. Proceedings of the Ontario Water Conference 2000, April 26-27, 2000, Richmond Hill, Ontario.

Schroeter, H.O. and D.K. Boyd. 1998. Eramosa River Watershed Hydrology Study. Final report submitted to the Grand River Conservation Authority, Cambridge, Ontario.

Schroeter, H.O., D.K. Boyd, and H.R. Whiteley. 2000. GAWSER: A versatile tool for water management planning. Proceedings of the Ontario Water Conference 2000, April 26-27, 2000, Richmond Hill, Ontario.

Schroeter, H.O., D.K. Boyd, and H.R. Whiteley. 2003. Achieving water balance: some case studies using GAWSER. Proceedings of the 16th Canadian Hydrotechnical Conference, October 22-24, 2003, Burlington, Ontario, sponsored by the Canadian Society for Civil Engineering (CSCE).

Schroeter, H.O., D.K. Boyd, and H.R. Whiteley. 2000a. Filling gaps in meteorological data sets used for long-term watershed modelling. Proceedings of the Ontario Water Conference 2000, April 26-27, 2000, Richmond Hill, Ontario.

Schroeter and Associates. 1992. Ausable-Bayfield Watershed Hydrology Study. Final Technical Report. Ausable Bayfield Conservation Authority, Exeter.

Schroeter and Associates. 1995. Ausable Bayfield Integrated Flood Forecast System (ABIFFS): Model Parameter Study. Ausable Bayfield Conservation Authority, Exeter.

Schroeter and Associates. 2006a. Long Point Region Watershed Hydrology Model: Set-up, Validation and Application. Submitted to Long Point Region Conservation Authority and Norfolk County, Simcoe, ON

Schroeter and Associates. 2006b. Catfish Creek Watershed Hydrology Model: Set-up, Validation and Application. Submitted to Catfish Creek Conservation Authority and the Lake Erie Source Water Protection Working Group, Cambridge, ON

Schroeter and Associates. 2006c. Kettle Creek Watershed Hydrology Model: Set-up, Validation and Application. Kettle Creek Conservation Authority, St. Thomas, ON

Schroeter and Associates. 1994. Upper Conestogo River Hydrologic Model: Revisions. Final summary report submitted to the Grand River Conservation Authority, Cambridge, Ontario.

Schroeter and Associates. 1996. GAWSER: Guelph All-Weather Sequential-Events Runoff Model, Version 6.5, Training Guide and Reference Manual. Submitted to the Ontario Ministry of Natural Resources and the Grand River Conservation Authority. (Appendix A and B updated for Version 6.9.6, October 2004)

Schroeter & Associates. 1999a. Caledon Creek & Credit River Subwatershed Study (Subwatersheds 16 and 18): Technical Appendix – Hydrology. Submitted to Credit Valley Conservation, Meadowvale, Ontario.

Schroeter and Associates. 1999b. Appendix K: Stormwater Management Analysis-Continuous Simulations (GAWSER). Submitted to Cosburn Patterson Mather, Markham, Ontario, as part of the Master Environmental Servicing Plan: Yonge Street Secondary Plan Area, Town of Richmond Hill.

Schroeter & Associates. 2003. Appendix G: Hydrology Impact Assessment Model, Silver Creek Subwatershed Study (Subwatershed 11) Impact Assessment Report, Phase II. Submitted to the Town of Halton Hills, and Credit Valley Conservation.

Soil and Water Management Branch. 1983. Agricultural Resource Inventory. Ontario Ministry of Agriculture and Food, Guelph.

SWAT. 2007. Official SWAT Website http://www.brc.tamus.edu/swat/

Tan, C.S., C.F. Drury, J.D. Gaynor, T.W. Welacky and W.D. Reynolds. 2002. Effect of tillage and water table control on evapotransiration, surface runoff, tile drainage and soil water content under maize on a clay loam soil. Agricultural Water Management 54 pp 173-188.

Thames, Sydenham and Region Source Water Protection. 2006. Conceptual Water Budget (Draft). Upper Thames River Conservation Authority, London, ON.

Totten Sims Hubicki (lead consultant). 1998. Torrance Creek Subwatershed Management Strategy; Technical Appendix 5 - Hydrology/Hydraulics. Final report submitted to the Grand River Conservation Authority and the City of Guelph.

Van Vliet, L. (ed.). 1977. Soil Erosion – In-Service Training Seminar for Ontario Ministry of Agriculture and Food. Ontario Ministry of Agriculture and Food, Guelph.

Watt, W.E. et al. 1989. Hydrology of Floods in Canada: A Guide to Planning and Design., National Research Council Canada, Associate Committee on Hydrology, Ottawa, Ontario.

Williams, J.R. 1969. Flood Routing with variable travel time or variable storage coefficients. Trans. of the ASAE 12(1):100-103.

Williams, J. R. and R. W Haan Jr. 1973. HYMO: Problem-Oriented Computer Language for Hydrologic Modelling – User's Manual. USDA –ARS and Texas A & M University College Station, TX.