# Water Availability Study for the Twelve Mile Creek Watershed Plan Area Niagara Peninsula Source Protection Area

Prepared for
Niagara Peninsula Conservation Authority
250 Thorold Road West, 3rd Floor
Welland, ON L3C 3W2

**Prepared by**

AquaResource Inc.
Integrity . Technology . Solutions

NIAGARA PENINSULA CONSERVATION AUTHORITY

**January 27, 2009**

Acknowledgements

The Niagara Peninsula Conservation Authority (NPCA) wishes to acknowledge the support of those who helped to prepare this Water Availability Study for the Source Water Protection Tier 1 Water Budget.

| | |
|---|---|
| Niagara Peninsula Conservation Authority | Jayme Campbell, SP Hydrogeologist<br>Jeff Lee, GIS Technician<br>Guangli Zhang, Engineering Technician<br>Geoff Verkade, GIS Specialist<br>Brian Wright, SP Coordinator |
| AquaResource Inc. | David Van Vliet, P.Eng.<br>Sam Bellamy, P.Eng.<br>Shaina Collin, E.I.T. |
| Dillon Consulting Limited | Robert Muir, P.Eng., Associate |
| United States Army Corps Of Engineers, Institute of Water Resources, Hydrologic Engineering Centre | Matthew J. Fleming |

Schroeter & Associates

Weather Innovations Inc.

The Regional Municipality of Niagara

Table of Contents

## List of Tables



## List of Figures

## Appendices

# 1. INTRODUCTION

## *1.1 Background and Objectives*

The Niagara Peninsula Conservation Authority (NPCA) and AquaResource Inc. have completed this Water Availability Study (WAS) of the Twelve Mile Creek Watershed Plan Area (Twelve Mile Creek) as part of the Niagara Peninsula Source Protection Area (NPSP Area) Source Water Protection (SWP) Tier 1 Water Budget.

The NPSP Area Tier 1 Water Budget is funded by the province of Ontario. The study methodology was developed by NPCA in consultation with the Ministry of Natural Resources (MNR), based upon the March 2007 Draft Guidance Module – Water Budget and Water Quantity Risk Assessment.

The purpose of the WAS was to determine the water available for surface water flow, groundwater recharge and evapotranspiration on a monthly basis for the time period 1991 to 2005. This time period was chosen to best suit available datasets (e.g. Statistics Canada) and meet the minimum World Meteorological Organization climate normal criterion of fifteen (15) years.

This report documents the WAS for Twelve Mile Creek (TWEL) watershed or Watershed Planning Area (WSPA). The study area is located in the Town of Pelham, Town of Thorold, the City of St.Catharines and a small portion of the Town of Lincoln all located in the Regional Municipality of Niagara (Figure 1.1).

## *1.2 Study Team and Approach*

AquaResource Inc. was awarded the contract to complete the Water Availability Study and has previously worked with NPCA on the Conceptual Water Budget Report (Franz Environmental Inc. et al., 2007). In late 2007 they also completed a technical memo on NPCA Water Survey of Canada stations regarding Baseflow Separation and Streamflow Recession. AquaResource Inc. is involved in the Source Water Protection Water Budget process at a number of levels, including the development of the Water Budget Guidance Module, ongoing technical support for the Ministry of Natural Resources and completing Tier 1, 2 and 3 Water Budget projects for conservation authorities and municipalities.

Peer review of the WAS project was provided primarily by Robert Muir of Dillon Consulting Limited. Mr. Muir previously assisted NPCA in development of the Tier 1 Water Budget work program. He is a Water Resources Engineer with almost two decades of experience and has provided peer review for the Lake Simcoe Region Conservation Authority Water Budget as well as surface water vulnerability studies for a number of conservation authorities.

NPCA staff from three (3) departments were involved throughout the study. These included Jeff Lee and Geoff Verkade from the Geographic Information Systems (GIS) group, Guangli Zhang from Engineering and Jayme Campbell and Brian Wright from Source Water Protection.

The project approach was designed to take advantage of NPCA's GIS expertise and datasets (e.g. soils, land use and digital elevation model) and NPCA's Engineering Department's experience with HEC-HMS. HEC-HMS is the U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center Hydrologic Modelling System. This is the current software package utilized by the NPCA Engineering Department for its in-house floodplain mapping. HEC-GeoHMS was used by NPCA GIS specialists throughout the project to develop the hydrologic modelling inputs for HEC-HMS.

This report describes the work completed as part of the WAS of Twelve Mile Creek.

## 1.3 Project Tasks

The principal objectives of the Water Availability Study are to derive monthly estimates of (i) evapotranspiration, (ii) groundwater recharge and (iii) water available for surface water flow for the time period 1991 to 2005.

The project tasks are:

- Initial parameterization of the numerical models to simulate watershed conditions;
- Calibration of the models to observed surface water flow data (where available) with an emphasis on volumes as opposed to peak flow rates; and
- Continuous model HEC-HMS hourly simulation runs for 1991-2005.

Reporting was completed on the model development, calibration uncertainty and outputs and recommendations for future work.

## 1.4 Relevant Reference Documents

A variety of previous studies provide details regarding the hydrologic conceptual model; these include, most notably:

- Water Budget Conceptual Understanding for the Niagara Peninsula Source Protection Area (Franz et al, 2007);
- Hydrogeologic Assessment of the Fonthill Kame-Delta Complex (Blackport et al, 2005);
- Twelve Mile Creek Watershed Plan (Durley, J., 2006); and
- Baseflow Separation and Streamflow Recession (AquaResource Inc., 2007)

These studies are referenced throughout this report.

## 1.5 Document Organization

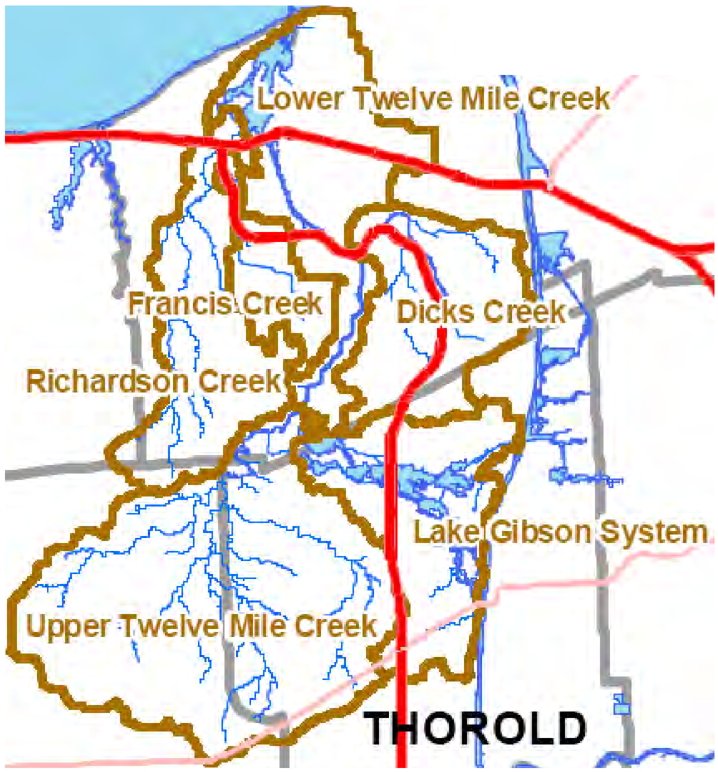
The sections within the report are organized as follows:

- Chapter 2 – Watershed Characteristics;
- Chapter 3 – Watershed Modelling; and
- Chapter 4 – References.

# 2. WATERSHED CHARACTERISTICS

## 2.1 General Description of the Watershed (Durley, 2006)

Twelve Mile Creek contains six (6) main subwatersheds as shown below; Upper Twelve Mile Creek, Lake Gibson system, Richardson Creek, Francis Creek, Dicks Creek and Lower Twelve Mile Creek. The total drainage area of the watershed is 132 $km^2$.




Located in the Town of Pelham and the City of Thorold, the Upper Twelve Mile Creek subwatershed contains the headwaters of Twelve Mile Creek. The Twelve Mile Creek headwaters form a complex incised series of valleys in the Fonthill Kame-Delta Complex. This Short Hills area contains the St. John's and Effingham branches, which originate within the headwaters of the creek. They are the only identified cold water streams within the Niagara Region, and they contain naturally reproducing brook and brown trout populations..

Owned by Ontario Power Generation, the Lake Gibson System (system) is a human-made arrangement of reservoirs located primarily in the City of Thorold. This system was originally created in 1898-1904 for the DeCew Power Station to divert water from Lake Erie via the Welland Canal. The system was expanded in 1947, to enlarge Lakes Moodie and Gibson, and excavate three major channels; an intake channel from the Third Welland Canal north of Allanburg, an equalization channel between the 2 arms of Lake Gibson, and an outflow channel from Lake Moodie to the new penstocks.

Richardson Creek is located primarily in the City of St. Catharines and flows south to north through rural and agricultural areas meandering north through a wooded and well defined valley before emptying into Martindale Pond.

Francis Creek, located in the City of St. Catharines, flows south to north through residential areas and valley corridors before meeting Richardson Creek just south of the Queen Elizabeth Way. The lower portion above Highway 406 is within a large storm channel.

The Dicks Creek subwatershed flows through primarily urban areas of St.Catharines and the St. Catharines Golf and Country Club before meeting up with the Old Welland Canal. It is then diverted underground twice (Welland Canal and Highway 406) before emptying into Twelve Mile Creek.

The Lower Twelve Mile Creek subwatershed has been totally reconstructed. It was originally modified as part of the Welland Canal in the 19$^{th}$ Century and then enlarged to accommodate the tailwater flow from the DeCew Generating Station.

## 2.2 Climate Setting

The climate of Southern Ontario is characterized as having warm summers, mild winters, a long growing season, and usually reliable rainfall. The climate within southern Ontario differs somewhat from one location to another and from one year to the next. Spatial variations are caused by the topography and varying exposure to the prevailing winds in relation to the Great Lakes (Schroeter et al, 1998).

According to Brown et al. (1980), Twelve Mile Creek is located in the Niagara Fruit Belt climatic region. Using the stations shown on Figure 2.1, Figures 2.2 and 2.3 show the 1991-2005 mean monthly precipitation and mean monthly temperature for the TWEL HEC-HMS model (Schroeter and Associates, 2007). Mean monthly precipitation ranged from a low of 44 mm at the St.Catharines Power Glen Environment Canada station 6137306 in February to a high of 89 mm at Ridgeville Environment Canada station 6137161 in September. The mean annual range in temperature was 26.5 degrees Celsius ($^{o}$C).

Spatial variations in mean annual snowfall, air temperature and mean annual precipitation across Twenty Mile Creek in relation to the entire NPCA jurisdiction are illustrated in Figures 2.4, 2.5 and 2.6 and tabulated in Table 2.1. Annual precipitation and snow in Twelve Mile Creek appear to range from 880 to 930 mm per year and 120 to 140 mm, respectively, on average across the watershed. Mean annual temperatures range from 9.1 to 9.5 $^{o}$C.

Figures 2.7, 2.8 and 2.9 show the annual precipitation, annual snow water equivalent and mean annual temperature for the 1991-2005 period respectively for the Ridgeville, St.Catharines Power Glen and Port Dalhousie stations. The annual precipitation ranged from a 1998 low of 676mm to a high of 1191 mm in 1996. On average the annual precipitation was 901 mm (1991-2005). The amount of snow water equivalent ranged from a low of 78 mm in 1998 to a high in 2005 of 215 mm. Overall 130 mm (14%) of precipitation is delivered as snowfall. The mean annual temperature was lowest in 1992 at 7.9$^{o}$C and highest in 1998 at 10.9$^{o}$C.

Brown et al. (1980) previously estimated the regional mean annual actual evapotranspiration between 533-559 mm and mean annual water surplus as about 279 mm.

### 2.2.1 Net Solar Radiation

Six (6) solar radiation and two (2) sunshine station locations were located in and near NPCA ranging from Buffalo, New York to the Hamilton Royal Botanical Gardens (RBG), shown in Figure 2.1. Annual values of net radiation ranged from 26.29 KW/m$^2$ at Niagara Falls, New York in 2004 to 33.89 KW/m$^2$ at Hamilton RBG in 1991 (Figure 2.10). Overall all stations had their lowest annual net radiation results in 2004, for the period 1991-2005. A review of the results however indicates sunshine station results tend to be slightly higher than those measuring incoming radiation directly. The greatest monthly variation between station measurements occurs during the summer period (Figure 2.11) and shows an increase in net solar radiation going to the northwest from Buffalo to Hamilton RBG in the July means.

## *2.3 Topography and Physiography*

The upper portion of the Twelve Mile Creek watershed is characterized by deeply eroded gullies due to the multi-branched pattern of the headwaters. These headwaters are situated at the Fonthill Kame-Delta Complex (Figure 2.13), the highest point of land within the Niagara Peninsula (Durley, 2006). The lower portion below the Niagara Escarpment is generally flat and typical of valleys found within the Niagara Peninsula.

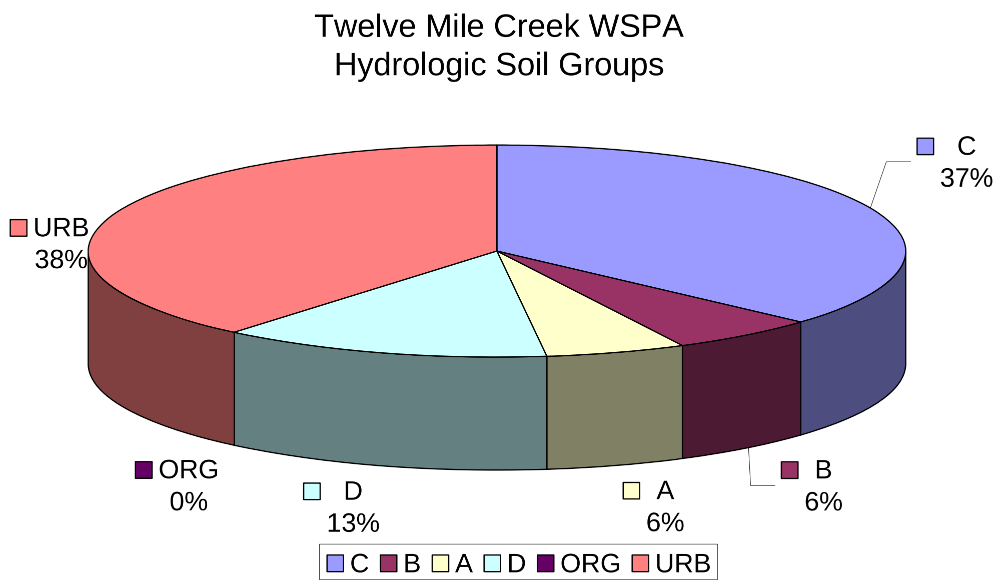
Twelve Mile Creek outlets to Lake Ontario through Martindale Pond in Port Dalhousie. The channel profiles for the six (6) subwatersheds are shown in Figure 2.12.

## *2.4 Soils*

The mapped soils information were provided by the Ontario Ministry of Agriculture and Food from the Niagara Region soil survey. The mapped soils (Figure 2.14) are classified into four hydrologic soil groups (A, B, C and D) or other. The grouping is according to the soil's minimum infiltration rate, obtained for bare soil after prolonged wetting. According to the United States Department of Agriculture the Hydrologic Soil Groups (HSG) are as follows:

- Group A: sand, loamy sand or sandy loam;
- Group B: silt loam or loam;
- Group C: sandy clay loam; and
- Group D: clay loam, silty clay loam, sandy clay, silty clay or clay.

The dominant soil groups are Urban and C. These amount to 39 and 37 percent of the area of the watershed respectively (as presented below). The remaining portion of the watershed is mapped as 13% D, 6% B and 6% A. The hydrologic soil group data inputs for the model are summarized on Table 2.2. Urban soil polygons were not assigned HSG values.




## 2.5 Surficial geology

Above the Niagara Escarpment, the watershed is comprised of stratified clay, silt and sand associated with the Fonthill Kame-Delta Complex (Figure 2.15). Below the escarpment, the watershed is dominated by Halton Till deposits made up of silt and clay. (Durley, 2006) The Fonthill Kame-Delta Complex is a thick deposit consisting mainly of permeable sand and gravel which provides a significant groundwater flow system within the surrounding clay plain. (Blackport and Waterloo Hydrogeologic, 2005) The complex rises roughly 40 to 75 m above the surrounding plain and consists of three large ridges. (Feenstra, 1981)

## 2.6 Land Cover

The Town of Pelham occupies approximately 20 percent of the watershed. Thirty-three percent of the watershed lies within the City of Thorold. Approximately 46 percent of the watershed lies in the City of St. Catharines, and only a small portion (less than 1 percent) of the watershed lies in the Town of Lincoln.

In general, the upper portions of the Twelve Mile Creek watershed have largely forested slopes and ridges in steep valleys and as a result of this rugged landscape many natural areas remain in this portion of the watershed. Some small residential areas in the Town of Pelham, including a portion of the Fonthill urban area, are also located in the upper portion of the Twelve Mile Creek watershed.

For the most part, the lower portion of the watershed has been developed and includes the western portion of the City of St. Catharines urban area. In addition, the areas along Lake Ontario are significantly developed for non-agricultural uses.

Agriculture is also a prominent land use in the Twelve Mile Creek watershed and consists mostly of fruit, grain and oilseed, and miscellaneous specialty crops including sheep and lamb, horse and pony, greenhouse, nursery product, and sod. The majority of fruit crops are concentrated in St. Catharines and Pelham. Above the Escarpment agriculture is predominately grain and oilseed production with some cattle and greenhouse productions. Vineyards and orchards are also located in this portion of the watershed. Greenhouse production, nursery, and fruit crops are the main agricultural commodities located in the lower portion of the watershed below the Escarpment primarily in the Richardson Creek and Francis Creek subwatersheds. (Durley, 2006)

Land cover information was provided by the Ministry of Natural Resources as part of its Southern Ontario Land Resource Information System (SOLRIS). Twenty-two (22) categories were provided as shown on Table 2.3 and simplified on Figure 2.16. The largest land use categories making up 76% of Twelve Mile Creek were (i) built-up impervious 19%, (ii) mixed crop 17%, (iii) idle land 11%, (iv) transportation 10%, (v) deciduous forest 9%, (vi) vineyards 5% and (vii) built-up pervious 5%.

## 2.7 Streamflow

AquaResource Inc. completed an analysis of baseflow separation and streamflow recession for NPCA in November 2007. One (1) station was available for analysis within Twelve Mile Creek as shown below in Table 2.4 and Figure 2.1. The short period of record (see Table 2.6) presents a limitation of the streamflow data which may affect the results.

***Table 2.4 - Current Stream Gauges***

| WSC ID | Description | Drainage Area ($km^2$) | Data Start Date | Data End Date |
|---|---|---|---|---|
| 02HA031 | Twelve Mile Creek Near Power Glen | 47 | 4/1/2006 | 10/2/2007 |

**Table 2.6 – Number of days with observed streamflow per month at the Twelve Mile Creek near Power Glen gauge**

| Month | No. Streamflow Records |
|---|---|
| Jan | 31 |
| Feb | 28 |
| Mar | 31 |
| Apr | 60 |
| May | 62 |
| Jun | 53 |
| Jul | 51 |
| Aug | 36 |
| Sep | 50 |
| Oct | 33 |
| Nov | 29 |
| Dec | 30 |

Flows were statistically analyzed to visualize how flows vary seasonally (Figures 2.17 and Table 2.5). The median, $10^{th}$ and $90^{th}$ percentile flows were calculated for each month from the limited available data. Median flows are representative of the flows most often observed within each month. The $10^{th}$ percentile represents flows that are exceeded 10% of the time, and thus are considered high flows. The $90^{th}$ percentile represents flows that are exceeded 90% of the time, and thus are considered low flows. By plotting the flow distribution in such a manner, it is possible to gain valuable insight on how the system responds due to precipitation events or seasonal shifts, as well as determine the significance of hydrologic processes, such as groundwater discharge within the upstream drainage area.

**Table 2.5 - Streamflow Distribution ($m^3/s$) 2006-2007**

| Station | 02HA031 | | | | |
|---|---|---|---|---|---|
| Parameter | 90th% | Median | Mean | Mean Baseflow | 10th % |
| Jan | 0.260 | 0.490 | 1.15 | 0.34 | 1.722 |
| Feb | 0.220 | 0.295 | 0.32 | 0.23 | 0.450 |
| Mar | 0.519 | 0.732 | 1.72 | 0.43 | 3.126 |
| Apr | 0.301 | 0.412 | 0.53 | 0.27 | 0.888 |
| May | 0.249 | 0.291 | 0.30 | 0.25 | 0.354 |
| Jun | 0.218 | 0.235 | 0.26 | 0.22 | 0.286 |
| Jul | 0.216 | 0.232 | 0.24 | 0.21 | 0.263 |
| Aug | 0.210 | 0.218 | 0.23 | 0.21 | 0.250 |
| Sep | 0.217 | 0.244 | 0.30 | 0.22 | 0.413 |
| Oct | 0.296 | 0.493 | 1.16 | 0.31 | 3.312 |
| Nov | 0.309 | 0.359 | 0.47 | 0.32 | 0.601 |
| Dec | 0.373 | 0.490 | 0.78 | 0.36 | 1.230 |

The overall flow regime observed is not typical of Southern Ontario. While peak flows were observed during the March spring freshet and did decline through April and May, flows were relatively constant through June, July and August. The extremely constant rate of flow throughout the year is most often seen in watersheds with some form of reservoir regulation, or significant groundwater discharge. Due to the lack of any reservoirs or significant control structures on Twelve Mile Creek, the steady flow is most likely caused by a very significant groundwater discharge.

There was some difference between median flows and $10^{th}$ percentile flows during the spring months. The $10^{th}$ percentile flows are on average approximately four times the median flow for the month of March. This suggests the spring flow regime was flashy, as the peak flows were not sustained for a large period of time.

Summer low flows are relatively constant indicating significant groundwater discharge within the gauged catchment.

### 2.7.1 Baseflow Characterization

A baseflow separation exercise was also carried out using the Baseflow Separation Program, included with the Soil and Water Assessment Tool (SWAT) hydrologic model.

This routine employs a digital filtering technique meant to replicate by-hand hydrograph separation. This program has previously been known as BFLOW, and has been selected as the optimum baseflow separation technique for a variety of Conservation Authorities in Southern Ontario, including Ausable Bayfield, Maitland Valley and the Grand River. A review of common baseflow separation techniques was carried out by the GRCA, and found BFLOW to be the most appropriate (Bellamy et al., 2003).

In this analysis, all daily streamflow for each of the gauging stations was inputted into BFLOW to perform the baseflow separation. The program outputs three different daily baseflow estimates, based on successive passes of the digital filter technique employed by BFLOW. Following the methodology employed in the Water Budget Conceptual Understanding (Franz et al, 2007), the third estimate was used in this analysis.

It is important to keep in mind that while baseflow separation routines may separate quick stream response from slow stream response, the association of baseflow to groundwater discharge is not absolute. Baseflow is the release of water from storage contained within the upstream drainage area that drains to a particular gauge. This water released from storage could originate in aquifers, and hence be termed groundwater discharge, but also could originate from wetlands or reservoirs. Other anthropogenic impacts such as sewage treatment plant discharges or water diversions may constitute a portion of baseflow as well. In Southern Ontario however, where regional wetland complexes and significant lakes are not prevalent, it is valid to assume that baseflow is predominately groundwater discharge, provided anthropogenic impacts are accounted for.

The monthly mean estimates of streamflow and baseflow are shown in Figures 2.15 and Table 2.5. These estimates are using data only within a portion of 2006 and 2007. Power Glen shows almost identical streamflow and baseflow mean monthly estimates for low flow periods (summer months) indicating a reliable source of baseflow from the Fonthill Kame; however this may be affected by the lack of long term data.

BFI is the ratio of total annual baseflow volume to total annual streamflow volume. It is used to characterize the proportion of total streamflow that is baseflow. The mean annual values were 0.53 and 0.45 for 2006 and 2007, substantially higher than most NPCA jursidiction gauges, and is likely due to a significant groundwater discharge associated with the Fonthill Kame. Table 2.7 lists estimated BFI values for simplified surficial material to provide context for the expected range of BFI values with the Power Glen results indicating significant surfacewater/groundwater interactions.

**Table 2.7 - BFI Ratios for Various Geologic Materials**

| Surficial-Geologic Material | BFI |
|---|---|
| Coarse-textured sediments | 0.89 |
| Bedrock | 0.78 |
| Till | 0.52 |
| Fine-textured sediments | 0.25 |
| Organic sediments | 0.09 |

Source: Neff, et al. (2005)

# 3. WATERSHED MODELLING

The following sections describe the construction, calibration/verification of the Twelve Mile Creek (TWEL) HEC-HMS model, and present the water balance estimates as well as the Water Quantity Stress Assessment components.

## *3.1 Model Description*

As outlined in the NPCA WAS Terms of Reference, HEC-HMS was chosen to model the hydrology of the fourteen (14) Watershed Protection Areas (WSPAs) within the NPCA official boundary. HEC-HMS is a numerical simulation model, supported by the U.S. Army Corps of Engineers, and is designed to simulate the precipitation-runoff processes of a watershed. The program is an integrated work environment, including a database management system, data entry utilities, a computation engine, results reporting tools, and a graphical user interface. A companion product, HEC-GeoHMS, is a software package for use with ArcGIS, and was employed to develop a significant portion of the required HEC-HMS geospatial inputs.

HEC-HMS can be run at a variety of time steps, from 1 minute to 1 day. For the Twelve Mile Creek WSPA, and other models created for this study, HEC-HMS was run on the hourly time step.

For complete documentation of the HEC-HMS program, as well as individual hydrologic processes included in HEC-HMS, please refer to the HEC-HMS User Manual and/or Technical Reference Manual (USACE, 2006, 2000).

### 3.1.1 HEC-HMS Hydrologic Processes

HEC-HMS includes a variety of algorithms for representing the dominant hydrologic processes. This allows the modelling approach to be tailored both to the available data and the overall goals of the study.

The modeller can specify the appropriate algorithm for the following processes:

- Evapotranspiration;
- Snowmelt;
- Loss (infiltration method);
- Baseflow Routing;
- Catchment Hydrograph Transform; and
- Channel Routing.

The algorithms used in the NPCA WAS (specified by the NPCA Water Availability Study Terms of Reference) for each of the six major hydrologic processes are described in the following sections. A conceptualization of the hydrologic processes simulated by HEC-HMS is included in Figure 3.1.

### 3.1.1.1 Evapotranspiration

The Priestly-Taylor evapotranspiration routine was specified for use in this project. The Priestly-Taylor method relies upon solar radiation and temperature to generate estimates of potential evapotranspiration (PET).

The Priestley-Taylor equation is as follows:

$$PET = \alpha \frac{s(T_a)}{s(T_a) + \gamma}(K_n + L_n) \cdot \frac{1}{\rho_w \lambda_v}$$

Where;

$K_n$ = Short wave radiation
$L_n$ = Long wave radiation
$s(T_a)$ = Slope of the saturation-vapour pressure vs. temperature curve
$\alpha$ = Dryness coefficient
$\rho_w$ = Mass density of water
$\gamma$ = Psychrometric constant (ratio of the heat capacity of the air to the latent heat of vaporization)
$\lambda_v$ = Latent head of vaporization

Once the Priestley-Taylor PET estimate is generated, HEC-HMS applies crop coefficients to reflect cropping practices or vegetative cover. The crop coefficients are applied as multipliers to scale the Priestley-Taylor PET estimate for that time step.

Evapotranspiration rates are generated by applying the estimated potential evapotranspiration rates to the soil-water reservoir represented within HEC-HMS. Actual evapotranspiration is limited by the amount of water within the soil-water reservoir. When the soil-water reservoir is saturated, actual evapotranspiration is equal to potential evapotranspiration. When the soil-water reservoir is empty (water content is zero), evapotranspiration can no longer be supported bringing the actual evapotranspiration to zero. It remains at zero, until a precipitation event replenishes the soil-water reservoir.

### 3.1.1.2 Snowmelt

The ability to simulate snow processes is critical to represent the hydrology of cold climate watersheds. The spring snowmelt period (March/April in Southern Ontario) is the season with the highest typical streamflow, and is also responsible for the majority of streamflow volume. This is also the period of time where saturated soil conditions are common producing groundwater recharge.

HEC-HMS considers snow processes by tracking changes to the snowpack. A snowpack is formed when precipitation occurs and the air temperature is below $0^oC$. HEC-HMS tracks the accumulation and melt of the snowpack through use of the Temperature Index Method. This method utilizes precipitation and temperature to simulate snow accumulation and melt processes. Water content of the snowpack can be increased by snow or rain falling on the snowpack.

Snowmelt is generated when temperatures rise to the point where there is sufficient energy to transform frozen water into liquid water. The amount of melt experienced by the snowpack is dependent for each degree above the freezing point. Snowmelt is held within the snowpack until the snowpack's point of saturation is reached. When the snowpack becomes saturated (specified by the water capacity of the snowpack), liquid water is then provided to the soil surface as water available for infiltration or runoff.

Sublimation is the direct loss of water from the snowpack to the atmosphere. It is not represented within HEC-HMS. Over the winter season, sublimation can result in a significant loss of water content from the snowpack. Schroeter and Associates have estimated this loss to be 0.33 mm/day (Schroeter and Associates, 2004). This is considered a limitation of the HEC-HMS model, and may lead to an over-estimation of water content held within the snowpack.

For a detailed discussion on the snowmelt processes included in HEC-HMS, please refer to Appendix A for an unpublished presentation provided by the USACE.

#### 3.1.1.3 Loss Method (Infiltration)

The infiltration method, or as HEC-HMS terms it, the "loss method", is responsible for partitioning liquid precipitation into direct overland runoff, evapotranspiration, or percolation. The Deficit and Constant Loss method is utilized for this project, and is carried out on a catchment by catchment basis.

Liquid precipitation that falls as rainfall or snowmelt is input into a storage reservoir. This storage reservoir represents all storage elements within each catchment. This includes, but is not limited to, soil water storage, depression storage, and interception storage. The depth of water held within this element is specified by the user.

Water held within the storage reservoir can be removed by evaporation or by percolation. Evaporation, at the rate estimated by the Priestly-Taylor equation, can remove water held within the storage reservoir. If the storage reservoir is empty, actual evapotranspiration is zero for that time step. Water can also leave the reservoir via percolation, which is determined by the Constant Rate. Percolation can only occur when the storage reservoir is completely saturated, and ceases when the storage reservoir drops below the point of saturation. At this point, evapotranspiration is the sole process that is able to reduce the amount of water held in the storage reservoir. Direct overland runoff is only generated when the storage reservoir is full, and liquid precipitation falls at a rate faster than the Constant Rate.

A limitation of this method is the unlimited acceptance of precipitation into the storage element. Provided there is sufficient storage, the reservoir can accept all precipitation, and produce no runoff or recharge, regardless of the intensity of the event. This can result in an under-prediction of flow, particularly when the reservoir is near empty. The impact of this limitation would be most significant when comparing simulated and observed hydrographs for a particular event. Due to the modelling focus being on regional water budgeting, and not flood flow estimation, it is anticipated that this limitation will be not be a major factor for the purposes of this exercise.

#### 3.1.1.4 Baseflow Method

Once the loss method generates estimates of percolation, this water is passed onto the Baseflow Method for a representation of the subsurface processes (see Figure 3.1). The Baseflow Method selected for this study is the Linear Reservoir Method.

Routing flows through a linear storage element is calculated by the following equations: (Schroeter and Watt, 1980)

$$Q_t = C \times Q_{t-1} + (1 - C) \times I_{t-1}$$
$$C = e^{(\frac{-dt}{KR})}$$

Where:

$Q_{t-1}$, $Q_t$ = Outflow
dt = time step
KR = recession constant (hr)
I = Inflow

The Linear Reservoir method uses two linear reservoirs to model the recession of baseflow after a precipitation event. The first linear reservoir is meant to represent a rapidly responding system, often termed “interflow”. Interflow is commonly understood to be subsurface stormflow moving through a shallow unsaturated soil horizon, towards a watercourse (Bedient and Huber, 2002).

The second linear reservoir is meant to represent a slower responding groundwater system, in comparison to the first reservoir. This is the system most commonly associated with baseflow and groundwater recharge.

Previous interpretations of the hydrologic/hydrogeologic system within the NPCA, carried out as part of the Conceptual Water Budget, have indicated that there is very little evidence of a regional groundwater flow system with strong interactions with the surface water system (Franz et al., 2007). The Conceptual Water Budget also stated there was minimal recharge to a deeper regional groundwater system, and that any groundwater discharge that did occur was “fed by localized groundwater recharge, which does not enter the regional aquifer system”. This localized groundwater discharge was termed, perhaps mistakenly, “interflow”. The term interflow, as it was used in the Conceptual Water Budget, meant to indicate discharge that was not sourced from a larger regional system, but rather from localized, near surface, aquifers. It was not meant to describe the shallow stormflow as described by Bedient and Huber (2002).

This broad conceptualization of the NPCA recognized that there were likely local areas which had significant interaction between the deeper groundwater flow systems and the surface water network. The Fonthill Kame area was explicitly identified as an area where there was probable interaction between the deep groundwater system and surface water network.

For the purposes of this study, flow from the first linear reservoir (interflow) will be considered to be part of the storm response, which travels laterally through the unsaturated soil horizon, before discharging into a watercourse. Flow that enters the second reservoir, and is discharged as baseflow, will represent the amount of water that percolates and reaches the saturated soil layer as groundwater recharge.

The percolation computed from the Deficit and Constant Loss method, is split evenly between both reservoirs. The proportion of water supplied to each reservoir, is specified by the program itself, and can not be modified.

Discharges from both of the linear reservoirs are added with any direct runoff, which create the catchment outflow hydrograph. As this method conserves mass within the catchment, there is no ability to route a portion of baseflow to a downstream catchment, or to remove water from the entirety of the watershed representing “deep recharge”. There are two sources of error associated with this limitation. The first source of error is that outflows of groundwater to downstream catchments cannot be represented. This may result in headwater catchments having too much groundwater discharge, with downstream catchments having too little. The error associated with this limitation is inversely proportional to the watershed area. This is due to net groundwater inflows/outflows becoming negligible as the area of interest increases.

The second source of error is that the loss of water to regional groundwater flow systems (removal of water from the watershed) is not able to be represented. By neglecting this loss, other water balance parameters could be over-estimated (ET, runoff, baseflow). It is anticipated this will not be a significant source of error as the regional groundwater system adds water to the surface water system as described in Section 3.3.2.

#### 3.1.1.5 Catchment Hydrograph Transform

Whereas the Baseflow Method is responsible for the routing of percolated water, the Transform Method is responsible for the routing of overland runoff. For this study, the SCS Unit Hydrograph Method was specified for the transform method.

The SCS Unit Hydrograph Method was originally developed from observed data collected in small, agricultural watersheds. The observed data has been generalized as dimensionless hydrographs, and a best-approximate hydrograph was developed for general application. The SCS method scales the generalized hydrograph by a user specified time lag to produce the unit hydrograph. The time lag is approximated by taking 60% of the time of concentration.

#### 3.1.1.6 Channel Routing

As catchment outflow hydrographs are generated and added to the main channel, the resulting hydrographs must be routed downstream. While HEC-HMS has a number of methods available for routing, the Muskingum-Cunge method has been specified for this study. The Muskingum-Cunge routing method is based on the combination of the conservation of mass and the diffusion representation of the conservation of momentum. It represents the attenuation of flood waves and can be used in river reaches with a small slope.

The attenuation of hydrographs is calculated by specifying the characteristics of the channel. These characteristics include length, slope, Manning’s n, and channel geometry (cross section).

#### 3.1.1.7 Flow Diversions

There are a number of transfers of water into Twelve Mile Creek from outside the watershed boundary. The most significant transfer is the discharge from OPG Decew hydroelectric power plant. The Decew hydroelectric plant is supplied by water from Lake Gibson, with discharges reaching 220 $m^3/s$. These discharges are supplied by inflows to Lake Gibson primarily from the Welland Canal, but also Beaverdam Creek, and local inflows to the reservoir. The contribution from the Welland Canal overwhelms the contribution of the local Lake Gibson drainage and Beaverdam Creek, thus 100% of the discharge from Decew is assumed to be sourced from outside the Twelve Mile Creek watershed. To simulate this, a source, with the Decew discharges specified as the flow rate, is included in the model.

A secondary, and relatively minor diversion (in comparison to the Decew discharge), is outflow to supply the Decew WTP with raw water. The Decew WTP only requires a portion of this flow, with the remainder, estimated to be an average of 0.955 $m^3/s$, flowing to Twelve Mile Creek. To simulate this within the model, a constant source of 0.955$m^3/s$ has been specified in the model, as an input into Twelve Mile Creek.

The water balance results (Section 3.5.1) do not include flow diversion amounts. However the surface water supply for the stress assessment (Section 3.5.2.1) will include these flow diversion amounts as the sources are considered reliable and the water available for use downstream.

## *3.2 Model Set-up*

HEC-HMS requires a number of datasets to represent the hydrology of a watershed. A large portion of the model set-up was completed by NPCA, utilizing both GIS and HEC-GeoHMS processing. The following sections summarize the methodology for the initial parameterization of the HEC-HMS model. For the detailed description on the implementation of HEC-GeoHMS, please refer to Appendix B.

### 3.2.1 Meteorological information

To properly represent streamflow and significant hydrologic processes, climate and climate variability must be represented within the hydrologic model.

Climate data from three meteorological stations were considered when constructing the TWEL HEC-HMS model (refer to Figure 2.1 and Table 2.1). All three of the stations, Ridgeville, St Catharines Power Glen and Port Dalhousie, are owned and operated by Environment Canada. As such, they are operated to a national standard, and undergo significant quality assurance/quality control procedures to ensure accurate data collection.

The Ridgeville station is located near the headwaters of Twelve Mile Creek, just outside the watershed divide. The St Catharines Power Glen station is located in the central portion of the watershed, just above the Niagara Escarpment, and the Port Dalhousie station is located below the Escarpment, near the outlet of Twelve Mile Creek. Catchments located in the upper portion of Twelve Mile Creek were assigned climate data from the Ridgeville station, catchments in the central portion of the watershed and located above the Escarpment were assigned data from the St Catharines Power Glen station, and catchments located below the Escarpment were assigned climate data collected at the Port Dalhousie station.

To ensure each climate station had a complete period of record, each dataset was cleaned up and filled-in by Schroeter and Associates (2007). The in-fill procedure was carried out on both the daily datasets (max/min temperatures, rainfall/snowfall totals), and the hourly rainfall datasets.

With the hourly modelling time interval, hourly data inputs were required. To produce hourly precipitation, daily snowfall depths were evenly distributed throughout the day and added to the hourly rainfall dataset. While it is unlikely that the reported daily snowfall depths are evenly distributed throughout a day, the fact that snowfall does not generate an immediate streamflow response means the impact of this assumption is negligible.

Synthetic hourly temperatures were generated using the maximum and minimum daily temperatures and a generalized synoptic curve (Schroeter and Associates, 2004).

A single hourly net solar radiation station was created for Twelve Mile Creek using three datasets; Environment Canada sunshine station St.Catharines 6137287 (1990 to 1994), Weather Innovations Incorporated stations (Vineland -1995,2006 and Jordan-1996, 1998-2000, 2003-2005) and Northeast Regional Climate Centre station Niagara Falls (1997, 2001, 2002). The incoming solar radiation at the St.Catharines station was calculated using the methodology of Selirio et al. (1971) from sunshine data. The overall hourly net radiation was calculated using the methodology of Allen et al. (2005). The same solar radiation data was used for the Niagara-On-The-Lake and 15, 16, 18 Mile Creeks WSPA models.

### 3.2.2 Streamflow Information

Streamflow information was obtained from the federally operated stream gauge on Twelve Mile Creek, as indicated in Section 2.8. Flow data for Twelve Mile Creek near Power Glen (Power Glen) were imported into HEC-HMS and were used as a combination calibration/verification target for the TWEL model.

Care should be taken when relying on observed streamflow estimates for calibration/verification purposes. This is particularly relevant for the Power Glen gauge data due to its short period of record. For a well-functioning gauge, with minimal backwater effects, observed streamflow estimates are commonly given a ±5-15% range of uncertainty (Winter, 1981). Flow estimates at high or low extremes are often more uncertain due to a lack of gauging points on the stage-discharge relationship for that range of discharges, especially for newly established gauges such as Power Glen. Measurement of very low flows is particularly problematic, due to the inability to quantify the portion of flow that is flowing through the channel substrate. With less than 1.5 years of observed data available, these uncertainties are amplified. Due to streamflow estimates being the primary calibration/verification target, these uncertainties are transferred to the simulation model.

### 3.2.3 Catchment boundaries and characteristics

General catchment parameters and specifically parameters for the transform and loss methods are shown on Table 3.1. Catchments were delineated by NPCA GIS specialists and AquaResource Inc., using the NPCA 2 metre DEM. The catchments ranged in size from 3 to 12 $km^2$. Smaller catchments were explored but were not considered possible without the reduction of the model time steps to less than one hour. This constraint is a modelling limitation related to the size of catchment and the model time step within the Transform algorithm (see Section 3.2.8). The model schematic and catchment boundaries are included in Figure 3.2.

### 3.2.4 Initial Parameterization – Loss Method

The Loss Method relies on three parameters to determine the amount of water that infiltrates, or is available to become overland runoff. These parameters are the constant rate, the catchment storage capacity, and the percentage of impervious cover.

The Deficit and Constant Loss Method assumes that the soil has a constant infiltration rate approximated by the saturated soil hydraulic conductivity. Using the soil and water holding capacity information in Appendix C, average maximum infiltration rates were assigned to each polygon in the soil layer based on their soil type. The catchment average constant rate was determined by area weighting each of the soil polygons in the specific catchment.

HEC-HMS assumes that the soil has a fixed water holding capacity, based on the active rooting depth of vegetation and soil type. The soil water holding capacity layer was built by intersecting the SOLRIS land cover and the OMAF soils layers and by assigning soil water holding capacity values from Appendix C to each unique combination of land cover class and soil type. Like the methodology employed for the constant rate, the area weighted average for each polygon within the catchment, was used to calculate the catchment average.

HEC-HMS considers an impervious surface as an area in a watershed for which all contributing precipitation runs off, with no infiltration, no evaporation, and no other volume losses. This surface was built by assuming SOLRIS built-up impervious and transportation polygons were 100% impervious, with built-up pervious polygons being 50% impervious. All other polygons were assumed to have zero impervious cover.

### 3.2.5 Initial Parameterization – Evapotranspiration

In the Deficit and Constant Loss Method, water is removed from the soil to simulate evapotranspiration. Potential evapotranspiration is calculated through use of the Priestly-Taylor method. This method uses a crop coefficient, $K_c$, indicating the ratio of crop potential and short grass reference evapotranspiration. Daily land use layers were created and assigned crop coefficients from Appendix D.

Combined with the solar radiation and temperature datasets, outlined in Section 3.2.1, and the crop coefficients, HEC-HMS calculates the potential evapotranspiration for each time step. This potential evapotranspiration value is then applied to the catchment storage reservoir to generate actual evapotranspiration.

### 3.2.6 Initial Parameterization – Snowmelt

The following parameters are required to represent snowmelt. These generalized parameters are referenced from the HEC-HMS User Manual (version 3.1.0).

- Temperature at which precipitation falls as snow;
- Temperature at which the snowpack begins to melt;
- Water capacity of the snowpack;
- Amount of melt that occurs due to heat transfer from the underlying ground;
- Rate at which snow melts when rain occurs;
- Rate at which snow melts during rainfall-free periods.

### 3.2.7 Initial Parameterization – Baseflow

Once water percolates through the soil column, HEC-HMS routes this water back to the stream as interflow or baseflow. The Linear Reservoir Method, specified for use by the WAS TOR, approximates the discharge by use of a linear reservoir. Groundwater recession constants, estimated via streamflow analysis, represent the reservoir response time and are used as the reservoir constant (also called the time constant) for the linear reservoir in each layer. There are two linear reservoirs that can be represented within HEC-HMS.

For most of the catchments, the first linear reservoir was parameterized with the intent to represent interflow. A groundwater coefficient of 18 hours was initially assigned to this reservoir.

The 2$^{nd}$ linear reservoir, meant to represent groundwater discharge to the watercourse, was parameterized based on streamflow recession analysis completed by AquaResource Inc. (2007). The streamflow recession analysis estimated the reservoir constant for nine streamflow gauges located within the NPCA. Statistics from two of these stations, Twelve Mile Creek near Power Glen and Four Mile Creek near Virgil, were used within the TWEL model. The median reservoir constant from the 1991-2005 period was assigned to the 2$^{nd}$ linear reservoir for each catchment located upstream of the Twelve Mile Creek near Power Glen gauge (708 hours). Catchments located downstream of the Power Glen gauge were assigned the reservoir constant estimated from the Four Mile Creek near Virgil gauge (437 hours), which encompasses similar geologic conditions.

For the catchments that represented the Fonthill Kame, the 1$^{st}$ linear reservoir was parameterized similarly to the 2$^{nd}$ linear reservoir. This effectively removes the interflow component from these catchments, and causes all percolated water to return to the watercourse as baseflow. Due to the thickness and pervious nature of the Fonthill Kame, which would more lend itself to vertical, rather than horizontal, flow of groundwater, it is not appropriate to assign half of the percolated water to interflow. This also has an implication on estimated groundwater recharge rates, where in previous models recharge was half of percolated water due to the inclusion of the interflow component. For catchments within the Fonthill Kame, groundwater recharge will be equal to the total percolated.

### 3.2.8 Initial Parameterization – Transform

The lag time associated with the SCS transform method is a function of the Soil Conservation Service Curve Number (Figure 3.3), the hydraulic length, and the catchment slope. This time lag is used to produce the unit hydrograph that allows precipitation excess (precipitation-infiltration) to be transformed into an overland runoff hydrograph. For adequate definition of the unit hydrograph ordinates, a modelling time step that is less than 29% of the time lag must be used. This constraint effectively places a minimum size requirement on the catchments represented within the model.

Curve Number (CN) values are used in the calculation of CN lag time for the SCS Unit Transform Method. The factors influencing CN values are land cover type, soil type and Antecedent Soil Moisture Condition (AMC). AMC is an estimate of soil water content prior to the beginning of the simulation period, and has 3 levels:

- AMC I reflects soils that are dry but with water content not below the wilting point;
- AMC II reflects soils having average soil water content; and
- AMC III reflects soils that have experienced rainfall in the five days previous to the simulation period.

CN values in the study area were assumed to reflect average soil water content (AMC II). The CN layer was built by intersecting the SOLRIS land cover and OMAF soil layer and by assigning CN values from Appendix C to each unique combination of land use class and soil type. Built-up impervious, built-up pervious and transportation SOLRIS polygons were considered under the impervious surface data field and not assigned CN values.

### 3.2.9 Initial Parameterization – Routing

To simulate the effects of channel geometry on hydrograph shape, the traditional Muskingum-Cunge Routing Method was used assuming trapezoidal channel geometry. The following inputs are required:

- Channel Bottom Width. The channel width for each of the routing reaches was estimated by digitizing cross sections. This channel width estimation assumed that the water surface width on digital air photos approximated the width of the channel bed.
- Channel Side Slope. The channel side slope was approximated by digitizing two points at the end of each digitized channel width cross sections using a 2m resolution DEM as a guide. Slope values were extracted at the location where the points intersected a slope grid.

- Channel Manning's Roughness Coefficient. Appropriate Manning's roughness coefficients were assigned (Appendix C) to channel routing reaches based on a visual stream bed condition assessment of 10-20cm resolution digital air photos.

## 3.3 Model Calibration/Verification

### 3.3.1 Overview of Procedures

Due to the limited observed streamflow data (see Table 2.6), the following methodology was employed for the TWEL model:

- Model Adjustment for 1991-2007: Model parameters were first modified using the parameter adjustments carried out for the Upper Welland River and Twenty Mile Creek models to best replicate regional hydrologic processes and observed flows.

- Calibration/Verification for Apr 2006 – Oct 2007: The model adjustments were tested with observed streamflow data from the Twelve Mile Creek near Power Glen gauge, and further adjustments were made where needed.

- Model Results for 1991-2005: The calibrated TWEL model was then run for the study period (1991-2005) to obtain water budget and stress assessment results.

This methodology assumes that adjustments to model parameters that resulted in an acceptable calibration are transferable between WSPAs. This assumption is validated by the fact that the adjustments required for both Upper Welland and Twenty Mile Creek were extremely similar, which suggests that these adjustments were regional in nature. Given the geologic homogeneity of the NPCA, this is to be expected.

The methodology also allows for the primary model adjustments to be based on more than only 18 months of observed data. Strictly calibrating a model to such a short time period, while possibly increasing the model performance during that time period, may cause the model to be unrepresentative of the longer time period for which the water balance results are being calculated. Additionally, the uncertainty that is associated with observed flow values, generated from a relatively new rating curve, is much greater than from a gauge with a well established rating curve. As such, the observed data will be used largely as a verification check, with model adjustments focused on rectifying significant issues that are identified.

The calibration/verification portion of the modelling focuses on metrics to gauge the appropriateness of the model. This approach recognizes that no single metric is adequate to describe the model's ability to replicate observed flows.

The calibration metrics presented are as follows:

- Annual Streamflow;
- Monthly Streamflow;
- Monthly Calibration Statistics (Standard Error, Nash-Sutcliffe and $R^2$ Coefficients);

- Mean Monthly Streamflow;
- Median Monthly Streamflow; and
- Ranked Duration Daily Streamflow.

Calibration metrics for continuous models are often focused on monthly statistics comparing simulated and observed streamflow, with limited consideration for daily comparisons. This is due to differences in how meteorological data are applied in continuous and event-based modelling. Event-based modelling focuses on understanding rainfall, initial snowpack conditions, and air temperature, specific to a particular event. Climate related information, supplemental to published information gathered at a climate station, may be used to better represent the event-specific distribution (both spatial and temporal) of precipitation. With this level of effort, one can achieve a better match of streamflow, particularly in terms of hydrograph timing, than only relying on published meteorological data for a station alone (which is done in continuous model). Due a lack of information, and limited scope, a modeller is unable to adjust published meteorological data for every event in the continuous record. Due to this limitation, the timing and/or magnitude of the simulated hydrograph may differ from the observed hydrograph. These differences are not due to an issue with the model itself, but rather a limitation of the input data not being able to accurately represent the event's characteristics. For this reason, calibration metrics for continuous models are often primarily focused on monthly statistics, with limited consideration for daily statistics.

To reduce the reliance on the user specified initial conditions, and allow the model to "self-initialize", the modelling period was extended to 1990. No data from the 1990 extension was used for calibration/verification purposes, or included in the final results.

### 3.3.2 Calibrated Model Parameters

As described above, a calibration/verification exercise was conducted from April 2006 to October 2007. Given the limited data for observed flow that was available, the focus of this exercise was on significant processes that were not being accurately represented (i.e. summer baseflows). It should be noted that only flow data from April 2006 to October 2007 data was available. Not having two complete spring, fall and winter seasons in which to test the model was a significant limitation in determining the performance of the models in these seasons. Thus, a high amount of reliance was given to the parameter adjustments utilized for the Twenty Mile and Upper Welland WSPA models.

Limited attention was paid to parameters associated with the channel routing, which may result in hydrograph characteristics (e.g. rise, peak flow, recession) not being representative. With the primary goal of this study being to support a Tier 1 Water Quantity Stress Assessment, particular attention was paid to low flow months.

The Constant Rate and Maximum Storage values in the Deficit and Constant Loss method were adjusted. These values affected the amount of overland runoff, baseflow and interflow, and the amount of evapotranspiration. The modelled values of the Maximum Storage and the Constant Rate for each catchment are shown in Table 3.2. These values provided the base case for the sensitivity analysis which is documented in Section 3.4.

**Table 3.2 - Modelled Deficit and Constant Loss Parameters**

| Catchment TWEL ID | Constant Rate (mm/h) | Max Storage (mm) |
|---|---|---|
| DC_W100 | 0.025 | 125 |
| DC_W110 | 0.046 | 125 |
| FR_W300 | 0.162 | 125 |
| LGS_W100 | 0.010 | 400 |
| LGS_W200 | 0.010 | 400 |
| LTWM_W100 | 0.025 | 125 |
| LTWM_W200 | 0.025 | 125 |
| LTWM_W300 | 0.074 | 125 |
| RI_W100 | 0.232 | 125 |
| RI_W200 | 0.260 | 149 |
| UTWM_W100 | 0.272 | 133 |
| UTWM_W200 | 0.271 | 207 |
| UTWM_W210 | 0.276 | 162 |
| UTWM_W220 | 0.285 | 159 |
| UTWM_W300 | 0.843 | 199 |
| UTWM_W310 | 0.790 | 183 |
| UTWM_W320 | 1.243 | 171 |
| UTWM_W400 | 1.077 | 157 |

As part of the calibration/verification process, the Nash-Sutcliffe coefficient was utilized to quantify the difference between simulated and observed data. A Nash-Sutcliffe coefficient:

- Greater than 0.6 is considered reasonable,
- Greater than 0.8 is considered good, and
- Equal to 1 is a perfect fit (Chiew and McMahon, 1993; Nash and Sutcliffe, 1970).

A coefficient less than zero occurs when the observed mean is a better predictor than the model. In addition to calculating the normal Nash-Sutcliffe coefficient, which is heavily weighted towards higher flows, the log Nash-Sutcliffe coefficient was calculated. The log Nash-Sutcliffe coefficient removes the bias of the higher flows and provides a more accurate assessment of the overall performance of the model.

As per previous models, crop coefficients were modified to adjust the intensity of evapotranspiration applied to the storage element within the Deficit and Constant Loss Method. These modifications are a means to adjust evapotranspiration to account for issues with temperature data, solar radiation, the potential evapotranspiration method itself, or the lack of a sublimation process. They are not due to the crop coefficients being non-representative of their respective catchments. All month's crop coefficients were increased, with the exception of October, which was slightly lowered from the original estimate. As the crop coefficients are direct multipliers to the potential evapotranspiration estimated by Priestley-Taylor Evapotranspiration Method, increasing the crop coefficients resulted in an increase in evapotranspiration, with a corresponding decrease in streamflow (runoff, interflow and baseflow). Table 3.3 displays the final adjustments applied to the original crop coefficients.

**Table 3.3 – Monthly Crop Coefficient Adjustments**

| Month | Crop Coefficient Adjustment |
|---|---|
| January | 12.42 |
| February | 7.45 |
| March | 2.48 |
| April | 1.38 |
| May | 1.38 |
| June | 1.21 |
| July | 1.38 |
| August | 1.38 |
| September | 1.38 |
| October | 0.92 |
| November | 4.97 |
| December | 6.21 |

The groundwater coefficients with the Linear Reservoir Baseflow Method were also adjusted. While these are simply routing parameters, and are not used in partitioning precipitation, they are important to properly represent how infiltrated water is returning to the watercourse. As described in Section 3.2.7, for catchments on or near the Fonthill Kame, the groundwater coefficients for the 1st linear reservoir were set equal to the 2nd linear reservoir. This was done to remove the interflow component from these catchments, and direct all percolated water to the baseflow reservoir. Additionally, the groundwater coefficient for these catchments was increased to 1200 hours, from the original 708 hours. For other catchments draining to the Power Glen gauge that were not associated with the Fonthill Kame, the groundwater coefficient associated with baseflow (GW 2) was increased to 1000 hours from the initial 708 hours. Coefficients for catchments downstream of the gauge remained the same as originally specified (437 hours). Table 3.4 includes the final groundwater coefficients used for the TWEL model.

**Table 3.4 - Groundwater Coefficients in Linear Reservoir Baseflow Model**

| Location Description | Catchment ID | GW 1 Coefficient (hr) | GW 2 Coefficient (hr) |
|---|---|---|---|
| Fonthill Kame | UTWM_W300 | 1200 | 1200 |
| | UTWM_W310 | | |
| | UTWM_W320 | | |
| | UTWM_W400 | | |
| Upstream of Power Glen Gauge and not part of Kame | UTWM_W200 | 18 | 1000 |
| | UTWM_W210 | | |
| | UTWM_W220 | | |
| Downstream of Power Glen Gauge | All others | 18 | 437 |

Initial model simulations significantly under-predicted summer flows, by up to an order of magnitude. To match summer flows, it was determined that ET and direct overland runoff had to be reduced, with a corresponding increase in baseflow, to a point which was not realistic (~300 mm of ET, ~50 of Runoff, ~550 mm of Baseflow). This suggested that there was water entering Twelve Mile Creek that was sourced outside the TWEL WSPA.

A previous study, the Hydrogeologic Assessment of the Fonthill Kame-Delta Complex (Blackport and Waterloo Hydrogeologic Inc. (WHI), 2005), attempted to quantify the portion of baseflow to Twelve Mile Creek that was discharged from bedrock aquifers. The field component of the study included detailed summer baseflow measurements to quantify discharge reaches, as well as chemistry data to identify bedrock sourced water. Two major reaches with bedrock-derived discharge were identified, with the total discharge estimated to be $0.09m^3/s$.

Bedrock groundwater flow systems are typically regional in nature, and frequently do not respect surface water boundaries. Given the relatively small size of the Twelve Mile Creek watershed, it is likely that the bedrock flow system, responsible for this $0.09\ m^3/s$ of discharge, receives the majority of its water from recharge areas outside of the boundaries of Twelve Mile Creek. This was confirmed within the modelling component of the Blackport/WHI study, which estimated the bedrock potentiometric high to be significantly further south than the topographic high of the Fonthill Kame. This suggests bedrock groundwater flow travels from south to north, into the TWEL WSPA. This results in a significant inflow of groundwater into TWEL from beyond the watershed boundaries, which ultimately enters Twelve Mile Creek.

To replicate this process, a source was added into the Twelve Mile Creek model, with a constant discharge of $0.09\ m^3/s$ added to the Creek. While it is unlikely this expression of bedrock flow is constant throughout the year, there is currently insufficient information to vary this rate with season. This limitation may cause simulated streamflow to be lower during the fall, winter and spring periods, as one would expect groundwater discharge to be higher during these seasons.

Following the inclusion of this source of water, simulated streamflows matched very well, particularly for the summer months, as seen in Figures 3.4 to 3.9. This groundwater discharge source does not become part of the Section 3.5.1 water balance but is added to the surface water supply component in Section 3.5.2.1.

Included in Figures 3.4 to 3.9 are a number of calibration/verification plots for Twelve Mile Creek near Power Glen. Figure 3.4 compares the simulated and observed annual flow volumes at Power Glen. Correspondence is very good, with a difference of approximately 45 mm. The simulated total monthly flow volumes at Power Glen align well with the observed flows, as shown in Figure 3.5. The Nash-Sutcliffe coefficient, the log Nash-Sutcliffe coefficient, the standard error, and the $R^2$ value shown in Figure 3.6 and Table 3.5, also demonstrate good agreement between simulated and observed streamflow.

**Table 3.5 – Standard Error, Nash-Sutcliffe and $R^2$ for Apr 2006 – Oct 2007 (Monthly Mean Flow mm/month)**

| Period | Gauge | $R^2$ | Standard Error | Nash-Sutcliffe | Log Nash-Sutcliffe |
|---|---|---|---|---|---|
| April 2006 - October 2007 | Twelve Mile Creek near Power Glen | 0.73 | 10.8 | 0.73 | 0.78 |

Included in Table 3.6 are the observed and simulated flows for Power Glen, with the difference expressed in mm.

**Table 3.6 – Comparison of Mean Streamflow Volume for Apr 2006 – Oct 2007**

| Month | Simulated (mm) | Observed (mm) | Difference (mm) |
|---|---|---|---|
| **Jan** | 55 | 65 | 10 |
| **Feb** | 22 | 18 | 4 |
| **Mar** | 56 | 97 | 41 |
| **Apr** | 44 | 29 | 14 |
| **May** | 20 | 17 | 3 |
| **Jun** | 14 | 14 | 0 |
| **Jul** | 13 | 14 | 1 |
| **Aug** | 10 | 13 | 3 |
| **Sep** | 12 | 17 | 5 |
| **Oct** | 64 | 65 | 2 |
| **Nov** | 43 | 25 | 18 |
| **Dec** | 57 | 44 | 13 |

The mean and median monthly simulated and observed flows at Power Glen are shown in Figures 3.7 and 3.8, respectively. As mentioned earlier, only flow data from April 1, 2006 to October 2, 2007 were available. This causes the observed values for the mean and median graphs to be based on only 30 days of record for the months October-March and 60 days for the months April-September. When viewing Figures 3.7 and 3.8, the reader is cautioned to keep the extremely small dataset in mind, and consider how unrepresentative of the long term average this may be. That being said, the comparison of mean monthly flows shows a very good match in flow volumes between simulated and observed flows. The comparison of median monthly flows shows the distribution of daily flows throughout each month is reasonable. The largest differences are shown to be in the fall or spring period, a time which there is very little observed data available.

The ranked duration curve, shown in Figure 3.9, also demonstrates very close agreement between simulated flows and observed flows. To illustrate the significance of the estimated bedrock discharge into Twelve Mile Creek, a second ranked duration curve is included in Figure 3.10. This ranked duration curve has had the bedrock discharge source removed, and therefore represents the simulated flow regime without this added water. Comparison of Figures 3.9 and 3.10 illustrate that this bedrock discharge is a dominant hydrologic process within Twelve Mile Creek, and that any simulation of the watershed must consider this discharge to properly represent the hydrology.

Considering the short period of observed flow data that is available, and the provisional status of the data, Figures 3.4-3.9, as well as the Nash-Sutcliffe (log and normal) coefficients, indicate that the TWEL model is reasonably replicating the significant hydrologic functions within Twelve Mile Creek.

Additionally, the successful calibration/verification exercise for TWEL has further validated the parameter adjustments initially made for the TWEN and UWR models, and which were subsequently applied to other WSPAs. The fact that no significant modifications to the Loss Method, beyond the initial adjustments, were required to obtain a reasonable calibration/verification match (once the bedrock discharge was considered) confirms those initial adjustments.

### 3.3.3 Hydrograph Separation Comparison

As described in Section 2, a hydrograph separation exercise has been carried out for all streamgauges within NPCA. The Baseflow Separation Program was used and is part of the Soil and Water Assessment Tool (SWAT) hydrologic model. It is traditionally known as BFLOW (AquaResource, 2007). The program employs a digital filter technique that produces estimates of quick response (runoff) and slow response (baseflow) based on the shape of the total flow hydrograph. The program applies the digital filter to the streamflow hydrograph three times in a successive fashion. With each successive pass, separated baseflow becomes a smaller portion of total flow and less responsive to a particular flow event. The user can select the output from any of the three passes as representative of baseflow for the particular watershed. Figure 3.11 includes sample output from each pass.

As a method to test the performance of HEC-HMS in simulating the differing portions of the hydrograph, both the simulated and observed hydrographs were analyzed using BFLOW. By calculating the BFI (proportion of separated flow to total flow) for each BFLOW pass, and comparing the simulated and observed BFIs, insight can be gained into how well the model is representing a specific portion of the hydrograph. Included in Table 3.7 are the calculated BFIs for all three BFLOW passes, for the simulated and observed flows at the Twelve Mile Creek near Power Glen gauge.

**Table 3.7 – Comparison of BFLOW BFIs**

| Streamgauge | BFLOW Pass | Simulated BFI | Observed BFI |
|---|---|---|---|
| Twelve Mile Creek Near Power Glen | Pass 1 | 61% | 62% |
| | Pass 2 | 51% | 53% |
| | Pass 3 | 47% | 49% |

For all three passes, HEC-HMS predicted very similar, but slightly lower BFIs than observed. This indicates that the model is predicting a slightly higher proportion of total flow being direct runoff, than is suggested by the observed streamflow record; however the difference is minimal. The presence of a significant and very steady groundwater discharge is likely a factor in the high level of correlation between the simulated and observed BFIs.

When comparing these values, it is important to recognize that BFLOW results are based on the shape of the hydrograph. The shape of the hydrograph is predominantly determined by the event rainfall pattern, and the routing characteristics of the upstream watercourse. With a single climate station used to represent the hourly pattern, and limited attention paid to the routing characteristics, there is likely significant error associated with the shape of the simulated hydrographs.

With the primary objective of the model being low flows simulation, under-representation of routing within the model is less of an issue than processes relating to the partitioning of precipitation into runoff, infiltration, and evapotranspiration.

## 3.4 Model Sensitivity

A sensitivity analysis was carried out to determine the model sensitivity to variations in hydrologic parameters.

Previous HEC-HMS studies have shown that simulated streamflow is most sensitive to two parameters. They are 1) the maximum infiltration rate (equivalent to the Constant Loss in the Deficit and Constant Loss Method), and 2) the water content available for evapotranspiration (Deficit term in the Deficit and Constant Loss Method) (Fleming and Neary, 2004).

Based on this finding from Fleming and Neary, four scenarios were tested to judge the sensitivity of model output to variations in the Constant Rate and Maximum Storage terms, included in the Deficit and Constant Loss Method. It is recognized that many other parameters and inputs can have an impact on simulated streamflow (snowmelt parameters, temperature, crop coefficients, precipitation, baseflow recession constants, etc.); however, due to the constraints in the scope of this project, only a limited sensitivity analysis was possible.

Both the Constant Rate and the Maximum Storage were varied by ±25% independently, resulting in the four scenarios. Sensitivity analyses for previous WSPAs were carried out at the outlet of each WSPA; however, the very large OPG diversions into the Lower Twelve Mile Creek would mask any variations in locally generated flow. As a result, the sensitivity analysis was conducted utilizing flows at the Twelve Mile Creek at Power Glen gauge, which is upstream of the diversions. Changes in outflow, mean evapotranspiration, runoff and recharge were calculated and tabulated in the following tables.

- Table 3.8 lists the percent change in total outflow at the Power Glen gauge for each scenario, over the base case.
- Table 3.9 displays the percent change in total outflow, evapotranspiration, runoff and recharge for each scenario, over the base case.

**Table 3.8 - Sensitivity Analysis Results – Change in Outflow**

| Month | Constant Rate +25% | Constant Rate -25% | Max Storage +25% | Max Storage -25% |
|---|---|---|---|---|
| Jan | -0.4% | 0.6% | -16.8% | 13.9% |
| Feb | -0.4% | 0.5% | -12.1% | 11.2% |
| Mar | -1.3% | 1.9% | -6.5% | 4.0% |
| Apr | 0.1% | -0.2% | -3.5% | 2.2% |
| May | 2.5% | -3.3% | -2.4% | 1.6% |
| Jun | 3.3% | -4.4% | -2.2% | 1.4% |
| Jul | 3.9% | -4.9% | -1.8% | 1.2% |
| Aug | 2.5% | -3.3% | -1.2% | 0.8% |
| Sep | 1.4% | -1.8% | -0.7% | 8.5% |
| Oct | -0.2% | 0.2% | -15.9% | 33.2% |
| Nov | -2.2% | 2.5% | -32.9% | 52.6% |
| Dec | -1.4% | 1.8% | -24.9% | 27.8% |

**Table 3.9- Sensitivity Analysis Results – Change in Water Balance Estimates**

| Scenario | ET | Baseflow | Interflow | Runoff |
|---|---|---|---|---|
| 1: Constant Rate +25% | 0.0% | 13.1% | 13.1% | -2.8% |
| 2: Constant Rate -25% | 0.0% | -15.5% | -15.5% | 3.3% |
| 3: Max Storage +25% | 4.0% | -10.1% | -10.1% | -3.0% |
| 4: Max Storage -25% | -5.0% | 11.3% | 11.3% | 3.8% |

As is shown by Table 3.8 and 3.9, variations in the Constant Rate did not significantly affect overall streamflow volume, but did cause significant changes in water balance estimates. Given that the Constant Rate controls the drainage of the storage reservoir (when fully saturated) to the groundwater reservoirs, increasing the Constant Rate results in an increase in both baseflow and interflow, with a corresponding decrease in runoff. Alternatively, decreasing the Constant Rate has the effect of increasing runoff, and decreasing baseflow and interflow. Due to the Constant Rate not impacting the amount of water that can be held in storage, evapotranspiration is not affected. Figure 3.12 illustrates the percent change in the mean monthly outflow of the model with a 25% increase and decrease in the Constant Rate. The dotted line at ±10% represents the uncertainty associated with streamflow estimates (Winter, 1981). Despite the percent change being higher than other WSPAs, for both variations in the Constant Rate the percent change is well within the ±10% boundaries, as shown in Figure 3.12. This suggests that estimated streamflow is insensitive to changes in the Constant Rate.

Since percolation and runoff only occur when the storage reservoir is full (i.e. when the soil is saturated), increasing the Maximum Storage results in decreases in baseflow, interflow, and runoff. Actual evapotranspiration increases due to a higher volume of water being held in the storage element. A decrease in the Maximum Storage has the reverse effect: increasing baseflow, interflow and runoff and decreasing evapotranspiration, as less water is required to reach the storage reservoir's point of saturation (refer to Table 3.9). As illustrated in Figure 3.13 and Table 3.8, the model outflow is highly sensitive to variations in Maximum Storage in the fall and early winter months, but insensitive to these variations in the spring and summer. This is due to the storage element either being completely empty (summer) or completely full (spring) during these seasons, regardless of the size of the storage element. Very large variations in Maximum Storage would be required to change streamflow during these seasons. Flows during the fall season do exhibit sensitivity to variations in the Maximum Storage term. This is due to the storage reservoir being filled during these months. A smaller storage reservoir would cause the storage reservoir to be filled quicker, resulting in more volume directed to percolation and direct overland runoff. Increases in the storage reservoir will yield the opposite effect: lowered flows, runoff, and percolation.

It is important to note that variations in the Constant Rate and Maximum Storage term, do not impact flows during the summer months. This suggests that uncertainty with these terms will not likely add significant levels of uncertainty to the Tier 1 Surface Water Stress Assessment.

The results of the sensitivity analysis suggest that the model solution for Twelve Mile Creek is non-unique, particularly with respect to the Constant Rate. In a non-unique solution, it is possible to calibrate the model to streamflow volumes and obtain a good fit with a number of differing sets of parameters. Frequently with non-unique solutions it is likely that compensating errors are present; whereby the model is simulating the correct streamflow, but incorrectly replicating the underlying physical processes.

In the case of Twelve Mile Creek, the Constant Rate can vary by as much as 25%, with a negligible change in streamflow volume. While streamflow is not sensitive to the Constant Rate variation, there is a significant impact on the water balance parameters estimated by the model (±15% baseflow). Water balance estimates (runoff, baseflow) therefore have a greater degree of uncertainty than the streamflow estimates.

To reduce the level of uncertainty, it is recommended that a more detailed Loss Method, such as the Soil Moisture Accounting Method, be tested on a WSPA to validate the water balance estimates made via the Deficit and Constant Loss Method. Such a test would preferably be carried out within a WSPA with a full period of observed streamflow data. The modular approach of HEC-HMS would easily facilitate replacing the Deficit and Constant Loss method with the Soil Moisture Accounting method. Should the more detailed Soil Moisture Accounting Method generate water balance estimates similar to the Deficit and Constant Loss, a higher level of certainty could be attached to estimates generated for other WSPAs. Additionally, the Soil Moisture Accounting Loss method allows the modeller to account for the proportion of percolated water that is lost from the surface water system as "deep recharge", a key limitation of the Deficit and Constant Loss method identified in Section 3.1.1.4.

## 3.5 Results and Discussion

### 3.5.1 Water Balance Results

HEC-HMS outputs a number of water balance parameters at the catchment level. These include, but are not limited to: total flow, runoff, percolated water, evapotranspiration, snow water equivalent, and hydrographs at catchment or reach junctions. These values are output to a HEC DSS file at an hourly time step.

Output from HEC-HMS is summarized in Table 3.10, presenting the mean annual water balance on a catchment basis and an overall WSPA basis for the 1991-2005 time period. The water balance terms are defined below:

- Precipitation – Climate data used to represent the precipitation over each of the catchments is summarized by HEC-HMS and is presented here.
- ET – Estimated actual evapotranspiration.
- Interflow – Outflow from 1st linear reservoir (half of percolated water, except for select UTWM catchments); percolated water which moves laterally through the unsaturated soil horizon.
- Baseflow – Outflow from 2nd linear reservoir (half of percolated water, except for select UTWM catchments); slow responding groundwater system. Consists of water which reaches the saturated soil zone.
- Overland Runoff – Depth of water that does not infiltrate, and reaches the surface water system via overland runoff.
- Total Outflow – Total annual outflow from the catchment; is the sum of Baseflow, Interflow and Runoff.

**Table 3.10 - Summary of Water Balance Model Results**

| Catchment TWEL ID | Precipitation (mm) | ET (mm) | Interflow (mm) | Baseflow (mm) | Runoff (mm) | Outflow (mm) |
|---|---|---|---|---|---|---|
| DC_W100 | 881 | 121 | 8 | 8 | 743 | 758 |
| DC_W110 | 881 | 236 | 13 | 13 | 617 | 643 |
| FR_W300 | 890 | 284 | 41 | 41 | 523 | 605 |
| LGS_W100 | 881 | 634 | 2 | 2 | 238 | 242 |
| LGS_W200 | 881 | 680 | 2 | 2 | 192 | 195 |
| LTWM_W100 | 890 | 211 | 8 | 8 | 663 | 678 |
| LTWM_W200 | 890 | 97 | 8 | 8 | 776 | 792 |
| LTWM_W300 | 881 | 419 | 20 | 20 | 420 | 460 |
| RI_W100 | 890 | 434 | 60 | 60 | 334 | 455 |
| RI_W200 | 890 | 539 | 61 | 61 | 228 | 350 |
| UTWM_W100 | 881 | 562 | 52 | 52 | 213 | 317 |
| UTWM_W200 | 881 | 651 | 41 | 41 | 146 | 228 |
| UTWM_W210 | 916 | 571 | 55 | 55 | 234 | 344 |
| UTWM_W220 | 881 | 573 | 55 | 55 | 196 | 306 |
| UTWM_W300 | 881 | 641 | 0 | 142 | 96 | 238 |
| UTWM_W310 | 916 | 636 | 0 | 151 | 129 | 279 |
| UTWM_W320 | 916 | 604 | 0 | 201 | 110 | 311 |
| UTWM_W400 | 916 | 523 | 0 | 196 | 196 | 392 |
| **Overall WSPA** | **891** | **446** | **26** | **53** | **363** | **442** |

As described in Section 3.3.2, the interflow component has been removed from catchments in the vicinity of the Fonthill Kame, with all percolated water directed into the reservoir responsible for baseflow. As such, for these catchments (UTWM_W300, W310, W320 and W400) the percolated water was not divided equally into baseflow and interflow, but solely to baseflow and there is no modelled interflow for these catchments, as shown in Table 3.10.

The estimated values of evapotranspiration, direct runoff, baseflow and interflow for TWEL, display higher rates of variance than other WSPAs. The standard deviation for the range of baseflow estimates is 64 mm, which is equal to 7% of mean annual precipitation; while the interflow estimates have a standard deviation of 24 mm, which equals 3% of annual precipitation. The standard deviation for the range of direct overland runoff and evapotranspiration estimates are much higher at 223 mm and 485 mm, which is equal to 25% and 55% of mean annual precipitation, respectively. This level of variability is due to the wide range of surficial geologic materials (sands associated with the Fonthill Kame vs. heavy clays), as well as the range of land cover (catchments with significant urban areas vs. open water of Lake Gibson vs. agricultural lands).

Due to the coarse-grained soils associated with the Fonthill Kame, catchments UTWM_320 and W400 have the highest baseflow estimates predicted. Catchments LGS_W100 and W200 have higher than average estimates of evapotranspiration due to the open water of Lake Gibson. Catchments with impervious percentages of 40-50% (DC_W100 and W110 and LTWM_W100 and W200) have very high runoff rates, with correspondingly low baseflow and interflow estimates. Evapotranspiration for these urban catchments is lower than the mean due to a smaller proportion of the catchment supplying water to the storage reservoir in which evapotranspired water is sourced.

### 3.5.2 Stress Assessment

As discussed in Section 1.0, the primary objective of this modelling is to determine water supply and reserve flows for use in the Tier 1 Water Quantity Stress Assessment. The Stress Assessment will be completed both for groundwater and surface water systems, and identifies those subwatersheds where there may be a potential for water taking related stress.

Following the methodology in Guidance Module 7, a subwatershed's stress is estimated by comparing the amount of water consumed with the amount of available water. This comparison is made by calculating "Percent Water Demand" as follows, with the terms defined in Table 3.11:

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

**Table 3.11 – Percent Water Demand Components**

| Term | Definition | Calculation |
|---|---|---|
| $Q_{DEMAND}$ | Consumptive Demand | Mean annual or monthly consumptive demand is calculated as the estimated rate of locally consumptive takings. Water demands are grouped into surface and groundwater takings.<br>Estimates of consumptive demand will be made from PTTW analysis, agricultural water use coefficients and private well usage. This portion of the Stress Assessment is outside the scope of the Water Availability Study, and will be completed by NPCA staff. |
| $Q_{SUPPLY}$ | Water Supply | For surface water, the supply is calculated as the monthly median outflow for the area to be assessed. |

| | | |
|---|---|---|
| | | Groundwater supply is calculated as the estimated annual recharge rate plus the estimated groundwater inflow into a subwatershed. |
| $Q_{RESERVE}$ | Water Reserve | Water Reserve is a specified amount of water that is not considered as part of the available water supply.<br>For surface water supplies, water reserve is estimated using the 90th percentile monthly outflow, at a minimum. The 90th percentile flow is defined as the flow that is equaled or exceeded 90% of the time.<br>Groundwater reserve is calculated as 10% of the total estimated groundwater discharge within a subwatershed. |

It is noted that baseflow is considered in both the surface water supply (baseflow within the outflow hydrograph) and groundwater supply (recharge, which sustains baseflow) terms of the Water Quantity Stress Assessment. While this may seem to "double count" baseflow, one should keep in mind the original purpose of the Stress Assessment, which is only to identify areas that have a high proportion of consumptive water taking, in comparison to the water flowing through the system. Identified areas, particularly at the Tier 1 scale, may not necessarily be experiencing hydrologic or ecologic stress, but rather are identified as requiring additional study to better understand the cumulative impacts of water use. The Stress Assessment methodology should not be utilized as a design/allocation tool, in an attempt to determine the total amount of water available to be withdrawn, as double counting of the baseflow term would then be a consideration.

For surface water systems, the Percent Water Demand equation is based on a mean monthly basis. The maximum percent water demand for all months is then used to estimate the Potential for Surface Water Stress as shown on Table 3.12.

**Table 3.12– Potential for Surface Water Stress Thresholds**

| Surface Water Potential Stress Level Assignment | Maximum Monthly % Water Demand |
|---|---|
| Significant | > 50% |
| Moderate | 20% - 50% |
| Low | <20 % |

For groundwater systems, the stress assessment calculation is based on mean annual demand conditions, as well as for monthly maximum demand conditions. The stress level for groundwater systems is calculated according to the thresholds shown on Table 3.13.

**Table 3.13 – Potential for Groundwater Stress Thresholds**

| Groundwater Potential Stress Level Assignment | Mean Annual | Monthly Maximum |
|---|---|---|
| Significant | > 25% | > 50% |
| Moderate | > 10% | > 25% |
| Low | 0 – 10% | 0 – 25% |

Due to the sheer volume of the OPG discharges (>200 $m^3$/s) to Twelve Mile Creek, it is certain that any possible water quantity issues in the upper reaches of Twelve Mile would be masked when comparing total consumptive demand to total outflow for the WSPA. As such, it is recommended, that for the purposes of the Stress Assessment, the TWEL

WSPA be split into two areas, one being upstream of the OPG diversion and one being downstream. A logical division point would be the Twelve Mile Creek at Power Glen streamgauge. The following sections, which summarize the Stress Assessment water supply components, follow this division of TWEL.

#### 3.5.2.1 Surface Water Supply Components

The monthly median and 90$^{th}$ percentile flows, as estimated by HEC-HMS for the Twelve Mile Creek outlet and the Twelve Mile Creek near Power Glen gauge, are included in Table 3.14. These flow estimates include the direct overland runoff calculated from the upstream drainage area, and the interflow and baseflow components.

**Table 3.14 – Surface Water Percent Water Demand Components**

| | TWELVE MILE CREEK @ OUTLET | | TWELVE MILE CREEK @ GAUGE | |
|---|---|---|---|---|
| **Month** | **Water Supply (Median Flow) ($m^3/s$)** | **Water Reserve (90$^{th}$ % Flow) ($m^3/s$)** | **Water Supply (Median Flow) ($m^3/s$)** | **Water Reserve (90$^{th}$ % Flow) ($m^3/s$)** |
| **Jan** | 214 | 163 | 0.359 | 0.108 |
| **Feb** | 206 | 164 | 0.411 | 0.160 |
| **Mar** | 240 | 195 | 0.585 | 0.327 |
| **Apr** | 245 | 182 | 0.637 | 0.338 |
| **May** | 237 | 218 | 0.472 | 0.244 |
| **Jun** | 237 | 179 | 0.312 | 0.187 |
| **Jul** | 236 | 219 | 0.221 | 0.151 |
| **Aug** | 232 | 126 | 0.165 | 0.120 |
| **Sep** | 234 | 125 | 0.138 | 0.109 |
| **Oct** | 228 | 125 | 0.122 | 0.100 |
| **Nov** | 205 | 163 | 0.167 | 0.098 |
| **Dec** | 225 | 146 | 0.268 | 0.099 |

There is a greater amount of uncertainty with respect to the 90$^{th}$ percentile flows than with the median flows. The 90$^{th}$ percentile flow, being observed at the extreme low end of flows, may be affected by processes not considered by HEC-HMS. These processes may include, but are not limited to: water takings, evaporation from the stream channel, online ponds, and regional groundwater discharge. Due to the magnitude of these processes not being well known, the net effect of these processes (additional or less flow) is not able to be determined, but does introduce a level of uncertainty into the 90$^{th}$ percentile flows.

#### 3.5.2.2 Groundwater Supply Components

The determination of the groundwater supply term is slightly more complex, due to HEC-HMS producing estimates of both interflow and baseflow. As described in Section 3.1.1.4, interflow is the portion of stormflow that moves through a shallow, unsaturated soil horizon towards a watercourse. Based on this description, the portion of percolated water that is directed into the interflow array will not be considered as part of the available groundwater supply.

The portion of percolated water that is directed to the baseflow array within HEC-HMS, and is meant to represent a slower, deeper groundwater system (only relative to the interflow component), will be used to infer groundwater recharge. It is recognized that within the Haldimand Clay Plain, there is very little evidence of a regional aquifer that has strong interconnections with the surface water system (Franz et al., 2007). The presence of the Fonthill Kame within TWEL seems to be the exception to this generalization. Previous studies (Blackport, WHI, 2005) have quantified the amount of discharge to Twelve Mile Creek from the bedrock flow system, and are assumed to be originally sourced from outside the WSPA. Whereas HEC-HMS recharge estimates for the majority of TWEL (and other WSPA) represent recharge to shallow, localized aquifers, this is not the case for catchments which comprise the Fonthill Kame. According to previous studies (Blackport, WHI, 2005), there are bedrock, deep overburden, and shallow overburden aquifers present in and around the Fonthill Kame. A portion of the HEC-HMS recharge estimate would supply all three aquifers; however, the division of total recharge between the three aquifers is not able to be determined within the scope of the current study.

At the scale of a Tier 1 Water Quantity Stress Assessment, no distinction is made for recharge that supplies a specific aquifer unit; rather the stress assessment is carried out on the groundwater system as a whole. This may result in percent water demand being under-estimated for a confined water source whose primary source of water is lateral groundwater inflow.

It is recognized that there is uncertainty associated with HEC-HMS's arbitrary proportioning of percolated water to half baseflow and half interflow. Actually this division would shift from year to year, and season to season, with possibly some periods experiencing all percolated water returning to the watercourse as either interflow or baseflow. Determining the exact proportion of percolated water that reaches the uppermost water table (groundwater recharge) is not an obtainable goal for the scope of this project. By considering half of percolated water that is directed to the baseflow array as available for groundwater taking, the Stress Assessment will be conservative in nature.

Included in Table 3.15 is the estimated 1991-2005 annual mean groundwater recharge rate for the two recommended Stress Assessment areas of Twelve Mile Creek. Also included is the groundwater reserve value, which is equal to 10% of estimated groundwater discharge (baseflow).

**Table 3.15 – Groundwater Percent Water Demand Components**

| Location | Water Supply (Groundwater Recharge) (mm) | Water Reserve (10% Discharge) (mm) |
|---|---|---|
| Area Upstream of Gauge | 105 | 10.5 |
| Area Downstream of Gauge | 24 | 2.4 |

To complete the groundwater Stress Assessment, groundwater inflow to Twelve Mile Creek must be quantified. It is anticipated that NPCA staff will complete this portion of the Stress Assessment as part of a separate project. The bedrock discharge input into the HEC-HMS model as a source of water, would be included in this groundwater inflow term.

## 3.6 Uncertainty

Any model of a natural system is a simplification of reality, and as such, is inherently uncertain. Although the calibration and verification processes are performed in an attempt to reduce uncertainty, the model results and water budgets reflect the uncertainty in the input parameters.

The certainty of the water balance estimates is inexorably tied to the ability of the climate stations used in the model to accurately represent the average climatic conditions over the watershed. The current density of climate stations with long term datasets is likely not sufficient to fully reflect spatial climate variability, particularly during the summer months where extremely localized precipitation events are common (thunderstorms).

Further climate-related uncertainty is introduced into the process by the measurement error in climate observations. Uncertainty with the precipitation measurement has been estimated by Cumming Coburn Limited (2000) to be approximately ±10%, with uncertainty during winter months reaching ±20%, due to the difficulty of measuring snowfall.

Snow accumulation, ablation, redistribution and melt are significant hydrologic processes in Canadian watersheds. The rates of these processes are determined by the inter-relation of many factors, including: land cover, albedo, solar radiation, wind speed/direction, cloud cover, temperature fluctuations, rainfall amount/temperature, and new snow density. Lack of available data and a complete understanding on the interrelations and implications of these factors introduces a level of uncertainty into hydrologic modelling. The simplified snow processes within HEC-HMS reflects this level of uncertainty.

Streamflow measurements have varying degrees of uncertainty which must be considered when calibrating a model. Manual flow measurements that are used to generate rating curves (allowing the translation of river stage to river flow) may contain errors of approximately ±5% to 15% (Winter, 1981). Measurement error for extreme events (very low or very high flow) can be significantly higher. Additionally, changes in river channel geometry may alter the accuracy of the rating curve over time. These changes in river channel geometry may be over the scale of years (riverbed erosion), or over months (aquatic plant growth or river ice conditions causing backwater).

Care should also be taken when interpreting results from extreme events, such as the 1998-1999 drought. During extreme events certain processes that may be insignificant under “average” conditions, and therefore not considered in regional scale modelling, may become dominant and affect the hydrologic response of a watershed. This can lead to model estimates deviating from observed conditions for such periods.

Having minimal observed data to assess the calibration and performance of the TWEL HEC-HMS model is a significant source of uncertainty. Due to the short period of record available, there was not sufficient information to fully assess the model’s performance, particularly during the fall, winter and early spring periods. The model’s ability to be representative of the long term average is largely reliant on the previous calibration/verification exercise carried out for Twenty Mile Creek and Upper Welland River WSPAs.

All modelling algorithms are simplified and are unable to accurately reflect the host of processes that can affect the hydrologic response of a catchment to a precipitation event. These limitations are not solely specific to HEC-HMS, nor the algorithms contained within HEC-HMS, but are rather a limitation of hydrologic science. With an insufficient ability to conceptualize and replicate all hydrologic processes, hydrologic model algorithms group or average, many processes into one. This averaging has the ability to introduce error into water balance estimates, and often the solution reached by an averaged approach results in a non-unique solution (as is shown to be the case in Twelve Mile Creek). This limitation should be kept in mind for utilizing water balance estimates generated as part of this study.

The climate of southwestern Ontario significantly varies from season to season. As a result of these changing seasons, hydrologic parameters (e.g. infiltration, depression storage, overland runoff routing) also vary. In the case of the freezing and thawing of soils, this can have a significant impact on the ability of soil to infiltrate water. HEC-HMS does not have the ability to vary parameters with season, and as such, is a source of uncertainty. Due to the dominance of the Haldimand Clay Plain in the area, and its limited ability to infiltrate water, even under warm conditions, it is expected that the uncertainty associated with this limitation is less significant than for highly pervious watersheds.

The representation of the bedrock discharge into Twelve Mile Creek is a source of uncertainty. It is currently modelled as a steady input, where in reality this discharge would vary seasonally, as well as year to year. The quantity of discharge input into the model was calculated based on measured baseflows for one summer, and therefore may not be representative of the long term average. Additionally, there is the possibility that a portion of the water within the bedrock aquifer, which is assumed to be recharged from outside the WSPA, is in fact, recharged within the TWEL WSPA. Given the information that is available on the hydrology/hydrogeology of the Fonthill Kame, it is felt that uncertainty has been minimized wherever possible.

While any modelling exercise contains inherent uncertainties, it should be noted that the model is acting as an excellent predictor of streamflow, as is shown in Sections 3.3 and 3.4. Based the exhibited performance, the constructed HEC-HMS model produces estimates of streamflow and water balance values that far exceed the level of accuracy expected for a Tier 1 Water Quantity Stress Assessment.

# 4. CONCLUSIONS AND RECOMMENDATIONS

A HEC-HMS continuous hydrologic model has been constructed for Twelve Mile Creek. It has been successfully adjusted for the April 2006 to October 2007 period. Model performance in predicting streamflow is very reasonable. The model replicates the seasonal response of streamflow very well, and produces realistic estimates of direct overland runoff, interflow and baseflow.

The generated water balance and streamflow estimates reflect the most complete understanding of the hydrologic system that is available, and represent the best available estimates. Significant uncertainties do remain; however, there is insufficient information to quantify the net impact of these uncertainties on the water balance and streamflow estimates. These estimates will form the foundation of a future Tier 1 Stress Assessment.

To advance the Tier 1 Water Quantity Stress Assessment as well as the basic understanding of the significant hydrologic processes, the following recommendations are made:

1. That for the purposes of the Water Quantity Stress Assessment, the TWEL WSPA be split into two assessment areas. This will allow the NPCA to isolate possible issues in the headwaters of the watershed, from the overwhelming impact of the OPG discharges to the lower reaches.

2. That the field monitoring program, implemented by Blackport and WHI (2005), which quantifies discharge supplied by shallow overburden, deep overburden and bedrock aquifers be continued. This would assist in determining the seasonal and annual variability of discharge.

3. That additional hydrogeologic conceptualization and analysis be carried out in the vicinity of the Fonthill Kame. The goal of this exercise would be to identify the dominant recharge areas responsible for groundwater discharge into Twelve Mile Creek. Ideally, this analysis would be in the form of a three-dimensional numerical model, employing reverse pathlines to link discharge and recharge areas.

4. That groundwater inflow volumes to Twelve Mile Creek be approximated by use of regional groundwater mapping products. Groundwater inflows are required to fully quantify the water supply term of the Groundwater Stress Assessment.

5. That monthly consumptive surface and groundwater demand (non-Great Lakes sources only) be approximated from Permits To Take Water, Census of Agriculture, and Census of Population. These consumptive demands are required to complete the Water Quantity Stress Assessment.

6. Utilizing the estimated consumptive demands, the groundwater inflow volumes, and values presented in Section 3.5.2, that the Tier 1 Water Quantity Stress Assessment be carried out. This will identify WSPAs that have a potential for hydrologic stress related to water takings.

7. That the water balance estimates generated from the Deficit and Constant Loss Method be validated against estimates generated from a more detailed loss Method (Soil Moisture Accounting Method). This validation exercise would preferably be carried out on a WSPA with a full period of observed streamflow data. Should the more detailed Soil Moisture Accounting Method generate water balance estimates similar to the Deficit and Constant Loss, a higher level of certainty could be attached to water balance estimates generated for other WSPAs. The need for further model refinement could be re-evaluated following the subsequent stress assessment.

Despite the uncertainties inherent with any modelling exercise, the Twelve Mile Creek HEC-HMS model is an excellent tool for estimating the water supply components of a Tier 1 Water Quantity Stress Assessment. In addition to exceeding the expectations of a Tier 1 Stress Assessment, it will greatly assist NPCA staff in characterizing and understanding the fundamental hydrologic processes occurring within Twelve Mile Creek.

# 5. REFERENCES

Allen, R.G., Walter, I.A., Elliot, R.L., Howell, T.A., Itenfisu, D., Jensen, M.E. and Snyder, R.L., 2005.
*The ASCE Standardized Reference Evapotranspiration Equation. American Society of Civil Engineers.*

AquaResource Inc., 2008a
*Long Point Region, Catfish Creek and Kettle Creek Water Budget and Water Quantity Stress Assessment.* Interim Report. Report to Grand River Conservation Authority

AquaResource Inc., 2008b.
*Integrated Water Budget Report – Grand River Watershed.* Report to Grand River Conservation Authority

AquaResource Inc., 2007.
*Baseflow Separation*. Report to Niagara Peninsula Conservation Authority.

Bedient, P.B., Huber, W.C., 2002
*Hydrology and Floodplain Analysis. Third Edition.* Prentice Hall.

Bellamy, S, Boyd, D., Whiteley, H., 2003.
*Baseflow Separation Techniques.* Grand River Conservation Authority.

Blackport & Associates and Waterloo Hydrogeologic Inc., 2005.
*Hydrogeologic Assessment of the Fonthill Kame-Delta Complex. Technical Appendix to the NPCA Groundwater Study.*

Brown, D.M., McKay, G.A. and Chapman, L.J., 1980.
*The Climate of Southern Ontario. Climatological Studies number 5, Environment Canada, Atmospheric Environment Service.*

Chiew, F.H.S. and McMahon, T.A. 1993.
*Assessing the adequacy of catchment streamflow yield estimates*, Australian Journal of Soil Research, 31:65-680.

Cumming Coburn Limited, 2000.
*Water Budget Analysis on a Watershed Basis*. The Watershed Management Committee. Queen’s Printer for Ontario.

Durley, J., 2006.
*Twelve Mile Creek Watershed Plan, Niagara Peninsula Conservation Authority*

Feenstra, B.H., 1981.
*Quaternary Geology and Industrial Minerals of the Niagara-Welland Area, Southern Ontario. Ontario Geological Survey OFR 5361, 260pp.*

Fleming, M. and Neary, V., 2004.
*Continuous Hydrologic Modelling Study with the Hydrologic Modelling System*, Journal of Hydrologic Engineering Vol. 9, No. 3.

Franz Environmental Inc., HydroGeologic, Inc., AquaResource Inc. and Blackport and Associates, ltd., 2007.
*Water Budget Conceptual Understanding for the Niagara Peninsula Source Protection Area.*

Haan, C.T., Johnson, H.P. and Brakensiek, D.L., 1982.
*Hydrologic Modelling of Small Watersheds.*

Ministry of the Environment, 2007.
*Assessment Report: Guidance Module 7 – Water Budget and Water Quantity Risk Assessment.*

Ministry of the Environment, 2003.
*Stormwater Management Planning and Design Manual.*

Nash, J. E., and Sutcliffe, J. V. 1970.
*'River forecasting through conceptual models. Part 1: A discussion of principles*. J. Hydrol., 10:282–290.

Ontario Geological Survey, 2003.
*Surficial geology of southern Ontario. Miscellaneous Release Data – 128. Project Summary and Technical Document, 53 pp.*

Ontario Geological Survey, 1997.
*Quaternary Geology, seamless coverage of the province of Ontario: Ontario Geological Survey, Data Set 14*.

Schroeter & Associates. 2004.
*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.

Schroeter & Associates, 2007.
*Meteorological Data Missing-Value Fill-in Study for Ontario.* Memo to the Grand River Conservation Authority

Schroeter, H., and Boyd, D., 1998.
*Eramosa Watershed Study Hydrology Technical Appendix, Eramosa River Watershed Hydrology Study, prepared for the Grand River Conservation Authority*.

Schroeter, H. and Watt, W., 1980.
*Practical Simulation of Sediment Transport in Urban Runoff. Canadian Journal of Civil Engineering. Vol. 16, No. 5, pp. 704-711*

Selirio, I.S., Brown, D.M. and King, K.M., 1971.
*Estimation of Net and Solar Radiation, Canadian Journal of Plant Science, volume 51, p. 35-39.*

United States Army Corps of Engineers, 2006.
*Hydrologic Modelling System HEC-HMS. User's Manual. Version 3.1.0. http://www.hec.usace.army.mil/software/hec-hms/documentation.html*

United States Army Corps of Engineers, 2000.
*Hydrologic Modelling System HEC-HMS. Technical Reference Manual. http://www.hec.usace.army.mil/software/hec-hms/documentation.html*

Weather Innovations Incorporation, 2007.
*Land Use Evapotranspiration Coefficient Study, prepared for the Niagara Peninsula Conservation Authority.*

Winter, T.C. 1981.
*Uncertainties in estimating the water balance of lakes*. Water Resources Bulletin 17: 82-115

# TABLES

**TABLE 2.1**
**MEAN ANNUAL CLIMATE STATION VALUES**
**WATER AVAILABILITY STUDY**

| MSC ID | NAME | AVERAGE ANNUAL (1991-2005) | | |
|---|---|---|---|---|
| | | PRECIPITATION (mm) | SNOW WATER EQUIVALENT (mm) | TEMPERATURE ($^oC$) |
| 6132148 | DUNNVILLE PUMPING STN | 948 | 91.1 | 8.6 |
| 6132470 | FORT ERIE | 1053 | 193 | 8.7 |
| 6133055 | GRIMSBY MOUNTAIN | 923 | 184 | 9.3 |
| 6133120 | HAGERSVILLE | 947 | 102 | 8.4 |
| 6153194 | HAMILTON A | 898 | 160 | 8.0 |
| 6153298 | HAMILTON PSYCH HOSPITAL | 850 | 108 | 8.8 |
| 6153290 | HAMILTON MUNICIPAL LAB | 793 | 101 | 9.5 |
| 6135657 | NIAGARA FALLS NPCSH | 948 | 160 | 9.4 |
| 6155097 | MIDDLEPORT TS | 896 | 110 | 8.5 |
| 6135FF4 | NIAGARA ON THE LAKE | 838 | 110 | 9.3 |
| 6136606 | PORT COLBORNE | 971 | 147 | 9.3 |
| 6136626 | PORT DALHOUSIE | 895 | 140 | 9.5 |
| 6137161 | RIDGEVILLE | 918 | 117 | 9.1 |
| 6137287 | ST CATHARINES A | 897 | 145 | 9.3 |
| 6139141 | VINELAND | 875 | 137 | 9.5 |
| 6139143 | VINELAND RITTENHOUSE | 850 | 115 | 9.4 |
| 6137306 | ST CATHARINES POWER GLEN | 890 | 135 | 9.2 |
| 6139445 | WELLAND | 969 | 148 | 9.0 |
| 6139148 | VINELAND STATION RCS | 840 | 146 | 9.1 |
| 6131165 | CANBORO | 894 | 120 | 8.4 |

Table Notes:
MSC - Meteorological Survey of Canada

NIAGARA PENINSULA CONSERVATION AUTHORITY

AquaResource Inc.
Integrity . Technology . Solutions

**TABLE 2.2**
**HYDROLOGIC SOIL GROUPS BY CATCHMENT**
**TWELVE MILE CREEK WATERSHED PLANNING AREA**
**WATER AVAILABILITY STUDY**

| Catchment TWEL ID | Area ($km^2$) | Hydrologic Soil Groups (%) A | B | C | D | ORG | URB |
|---|---|---|---|---|---|---|---|
| DC_W100 | 9.1 | | | | 1.9 | | 98.1 |
| DC_W110 | 11.3 | 2.8 | 0.1 | 4.9 | 1.6 | | 90.6 |
| FR_W300 | 6.8 | 2.4 | 0.7 | 31.6 | 28.1 | | 37.1 |
| LGS_W100 | 8.3 | 0.1 | 0.0 | 50.4 | 18.9 | | 30.6 |
| LGS_W200 | 7.7 | | | 19.0 | 28.0 | | 53.0 |
| LTWM_W100 | 7.3 | | 1.3 | 3.0 | | | 95.3 |
| LTWM_W200 | 8.2 | 1.1 | | 3.5 | 0.6 | 1.0 | 93.8 |
| LTWM_W300 | 3.4 | 3.8 | 2.2 | 2.6 | 7.7 | | 83.7 |
| RI_W100 | 11.9 | 4.3 | 2.1 | 51.5 | 25.6 | | 16.4 |
| RI_W200 | 7.0 | 3.3 | 1.0 | 73.2 | 17.9 | | 4.6 |
| UTWM_W100 | 3.2 | 9.5 | 1.8 | 57.8 | 7.4 | | 23.7 |
| UTWM_W200 | 4.5 | | 5.7 | 87.5 | 3.0 | | 3.8 |
| UTWM_W210 | 10.7 | 1.6 | 7.2 | 59.2 | 30.8 | | 1.2 |
| UTWM_W220 | 11.4 | 0.0 | 18.3 | 56.3 | 21.4 | | 3.9 |
| UTWM_W300 | 5.1 | 6.7 | 35.3 | 57.9 | 0.2 | | |
| UTWM_W310 | 5.0 | 11.5 | 20.5 | 55.2 | 0.8 | | 12.1 |
| UTWM_W320 | 5.3 | 37.5 | 16.5 | 41.4 | 3.6 | | 1.0 |
| UTWM_W400 | 5.3 | 49.2 | 3.0 | 30.9 | 1.6 | | 15.2 |
| Average % | | 9.6 | 7.7 | 40.4 | 11.7 | 1.0 | 39.1 |
| % of TWEL model | | 5.6% | 5.8% | 36.8% | 13.0% | 0.1% | 38.8% |
| Area ($km^2$) | | 7.42 | 7.59 | 48.37 | 17.07 | 0.08 | 51.07 |

Table Notes:
ORG - Organic, URB - Urban, TWEL - Twelve Mile Creek
FR - Francis Creek, DC - Dicks Creek, LTWM - Lower Twelve Mile Creek
UTWM - Upper Twelve Mile Creek, LGS - Lake Gibson System, RI - Richardson Creek

**TABLE 2.3**
**LAND COVER BY CATCHMENT**
**TWELVE MILE CREEK WATERSHED PLANNING AREA**
**WATER AVAILABILITY STUDY**



| Catchment TWEL ID | Annual Crop | Mixed Agriculture | Mixed Crop | Monoculture | Orchards | Perennial Crop | Plantations | Vineyards | Coniferous Forest | Deciduous Forest | Forest | Hedge Rows | Mixed Forest | Built Up Pervious | Idle Land | Rural Land Use | Marsh | Swamp | Bog | Open Water | Built Up Impervious | Extraction | Transportation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TWEL_DC_W100 | | | | | | | | | 1.2 | 4.7 | 0.3 | | 0.4 | 13.7 | 1.8 | | | 0.4 | | 0.2 | 53.5 | | 23.9 |
| TWEL_DC_W110 | | | 0.0 | | | 1.9 | | | 2.6 | 11.2 | 1.1 | | 0.5 | 11.1 | 7.9 | | | 1.1 | | 0.5 | 40.7 | 3.0 | 18.3 |
| TWEL_FR_W300 | 5.0 | | 13.5 | | 0.7 | | | 2.9 | | 1.4 | 0.8 | 0.1 | 0.2 | 8.5 | 12.8 | | | 2.1 | | | 36.1 | | 15.8 |
| TWEL_LGS_W100 | 5.3 | 0.2 | 25.0 | 1.8 | | 2.3 | 0.1 | 2.3 | 1.7 | 2.8 | 0.8 | 0.2 | 2.2 | 1.8 | 9.3 | 5.5 | 1.6 | 3.4 | | 16.9 | 8.3 | | 8.7 |
| TWEL_LGS_W200 | 0.6 | 1.6 | 0.6 | 14.9 | | | 1.8 | | 0.2 | 3.2 | 1.1 | 0.7 | 0.1 | 5.5 | 16.6 | 17.4 | 3.1 | 6.5 | | 11.1 | 7.4 | | 7.6 |
| TWEL_LTWM_W100 | | | | | | | | | 2.4 | 0.4 | 1.8 | | 0.5 | 8.0 | 2.3 | | 0.9 | 0.2 | | 18.7 | 48.4 | | 16.4 |
| TWEL_LTWM_W200 | 0.7 | | 0.0 | | | | | | 2.9 | 1.0 | 0.6 | | 1.1 | 6.2 | 3.4 | | 1.6 | 1.0 | | 2.6 | 52.7 | | 26.2 |
| TWEL_LTWM_W300 | | | 0.4 | | | | 0.1 | | 2.2 | 14.2 | 2.3 | 0.3 | 12.3 | 1.2 | 20.4 | | 0.0 | 3.9 | | 7.7 | 24.8 | | 10.1 |
| TWEL_RI_W100 | 5.2 | | 19.3 | | 2.5 | 5.2 | 0.0 | 28.0 | 0.4 | 3.5 | 1.1 | | 0.1 | 1.4 | 9.3 | | 0.6 | 2.0 | | 0.0 | 13.5 | | 7.8 |
| TWEL_RI_W200 | 0.6 | | 36.9 | | 0.6 | 2.1 | | 22.8 | 1.4 | 8.1 | 0.8 | 0.3 | 1.3 | 0.4 | 15.6 | | 0.2 | 1.1 | | 0.1 | 4.0 | | 3.8 |
| TWEL_UTWM_W100 | 3.3 | | 31.0 | | | 0.5 | 1.4 | 1.9 | 3.6 | 6.4 | 1.5 | 0.5 | 9.9 | 4.0 | 14.9 | | | 6.0 | | 6.6 | 4.2 | | 4.2 |
| TWEL_UTWM_W200 | 6.5 | | 24.4 | | 0.0 | 1.9 | | 3.2 | 0.9 | 24.3 | 0.8 | 0.3 | 11.0 | 1.8 | 12.3 | | 0.3 | 8.9 | | 0.0 | 1.0 | | 2.4 |
| TWEL_UTWM_W210 | 2.8 | | 47.1 | | 0.6 | 4.9 | 0.7 | 5.5 | 1.7 | 11.8 | 0.9 | 0.1 | 3.9 | 1.4 | 12.3 | | 0.1 | 1.1 | | 0.0 | 1.0 | | 4.1 |
| TWEL_UTWM_W220 | 7.8 | 1.4 | 32.9 | 5.7 | 1.4 | 0.5 | 0.4 | 3.7 | 0.6 | 9.8 | 0.9 | 0.4 | 2.2 | 1.3 | 14.2 | 6.8 | | 3.8 | | | 2.2 | | 4.0 |
| TWEL_UTWM_W300 | 4.4 | | 17.4 | | 1.2 | 6.6 | 1.4 | 0.7 | 1.1 | 16.1 | 1.1 | 13.6 | 13.1 | | 16.3 | | 0.2 | 2.7 | | | 1.4 | | 3.1 |
| TWEL_UTWM_W310 | 4.2 | | 11.9 | | 4.9 | 1.0 | 1.2 | 2.3 | 1.0 | 31.1 | 1.1 | 0.2 | 12.7 | 10.4 | 11.0 | | 0.1 | 1.5 | | 0.2 | 1.0 | | 4.1 |
| TWEL_UTWM_W320 | 3.8 | | 22.0 | | 4.3 | 0.0 | 1.2 | 0.4 | 1.4 | 29.1 | 0.9 | 0.3 | 9.4 | 1.5 | 16.4 | | 0.4 | 3.3 | | 0.2 | 2.1 | | 3.4 |
| TWEL_UTWM_W400 | 4.3 | | 5.7 | | 3.5 | | 2.0 | 1.5 | 0.5 | 15.5 | 1.1 | 24.9 | 5.7 | 0.7 | 12.6 | | 0.2 | 3.1 | | 0.2 | 12.4 | | 6.2 |
| Average % | 3.9 | 1.1 | 18.0 | 7.5 | 2.0 | 2.5 | 0.9 | 6.3 | 1.5 | 10.8 | 1.0 | 3.2 | 4.8 | 4.6 | 11.6 | 9.9 | 0.7 | 2.9 | NA | 4.3 | 17.5 | 3.0 | 9.4 |
| % of TWEL model | 3.0% | 0.2% | 16.6% | 1.5% | 1.0% | 1.7% | 0.5% | 5.2% | 1.4% | 9.3% | 1.0% | 1.7% | 3.4% | 4.7% | 10.8% | 2.0% | 0.6% | 2.5% | | 3.4% | 19.1% | 0.3% | 10.3% |
| Area/Land Cover ($km^2$) | 4.0 | 0.3 | 21.8 | 1.9 | 1.3 | 2.3 | 0.6 | 6.8 | 1.8 | 12.3 | 1.3 | 2.2 | 4.5 | 6.1 | 14.2 | 2.6 | 0.7 | 3.3 | | 4.4 | 25.2 | 0.3 | 13.5 |

Table Notes:
TWEL - Twelve Mile Creek, FR - Francis Creek, DC - Dicks Creek, LTWM - Lower Twelve Mile Creek, UTWM - Upper Twelve Mile Creek, LGS - Lake Gibson System, RI - Richardson Creek

**TABLE 3.1**
**CATCHMENT PARAMETERS**
**TWELVE MILE CREEK WATERSHED PLANNING AREA**
**WATER AVAILABILITY STUDY**

| Catchment TWEL ID | Area ($km^2$) | Slope (%) | Impervious Area (%) | Curve Number (CN) | Basin Time Lag (hours) | Maximum storage (mm) | Infiltation Rate (mm/hour) |
|---|---|---|---|---|---|---|---|
| FR_W300 | 6.80 | 3.1 | 33.8 | 83 | 2.4 | 82.5 | 1.5 |
| DC_W100 | 9.14 | 4.9 | 50.6 | 89 | 1.8 | 0.7 | 0.0 |
| DC_W110 | 11.29 | 7.7 | 38.7 | 83 | 1.5 | 19.5 | 0.4 |
| LTWM_W300 | 3.39 | 12.7 | 22.5 | 78 | 1.0 | 33.6 | 0.7 |
| UTWM_W100 | 3.24 | 9.5 | 6.4 | 79 | 1.4 | 177.0 | 2.5 |
| LGS_W100 | 8.33 | 3.4 | 12.8 | 86 | 2.2 | 132.8 | 1.5 |
| UTWM_W220 | 11.38 | 5.9 | 5.0 | 80 | 2.3 | 212.7 | 2.6 |
| UTWM_W310 | 4.98 | 13.8 | 4.6 | 72 | 1.3 | 244.3 | 3.6 |
| UTWM_W300 | 5.14 | 16.7 | 3.8 | 71 | 1.4 | 265.7 | 3.8 |
| UTWM_W210 | 10.73 | 5.6 | 4.6 | 80 | 2.4 | 216.6 | 2.5 |
| RI_W200 | 7.02 | 5.0 | 5.8 | 81 | 1.5 | 198.5 | 2.4 |
| UTWM_W400 | 5.25 | 15.7 | 12.4 | 62 | 1.4 | 209.3 | 4.9 |
| UTWM_W320 | 5.29 | 14.3 | 4.4 | 66 | 1.1 | 228.2 | 5.7 |
| LGS_W200 | 7.70 | 3.9 | 11.3 | 85 | 1.8 | 98.3 | 0.9 |
| UTWM_W200 | 4.52 | 11.4 | 2.9 | 77 | 1.4 | 275.7 | 2.5 |
| LTWM_W100 | 7.31 | 3.6 | 40.6 | 93 | 1.0 | 3.7 | 0.2 |
| RI_W100 | 11.94 | 3.6 | 14.5 | 82 | 3.0 | 154.4 | 2.1 |
| LTWM_W200 | 8.18 | 4.5 | 52.6 | 86 | 1.3 | 7.8 | 0.2 |
| Minimum | 3.24 | 3.1 | 2.9 | 61.6 | 1.0 | 0.7 | 0.0 |
| Maximum | 11.94 | 16.7 | 52.6 | 93.5 | 3.0 | 275.7 | 5.7 |
| Average | 7.31 | 8.1 | 18.2 | 79.7 | 1.7 | 142.3 | 2.1 |

Table Notes:
TWEL - Twelve Mile Watershed Planning Area
FR - Francis Creek, DC - Dicks Creek, LTWM - Lower Twelve Mile Creek
UTWM - Upper Twelve Mile Creek, LGS - Lake Gibson System, RI - Richardson Creek

# FIGURES

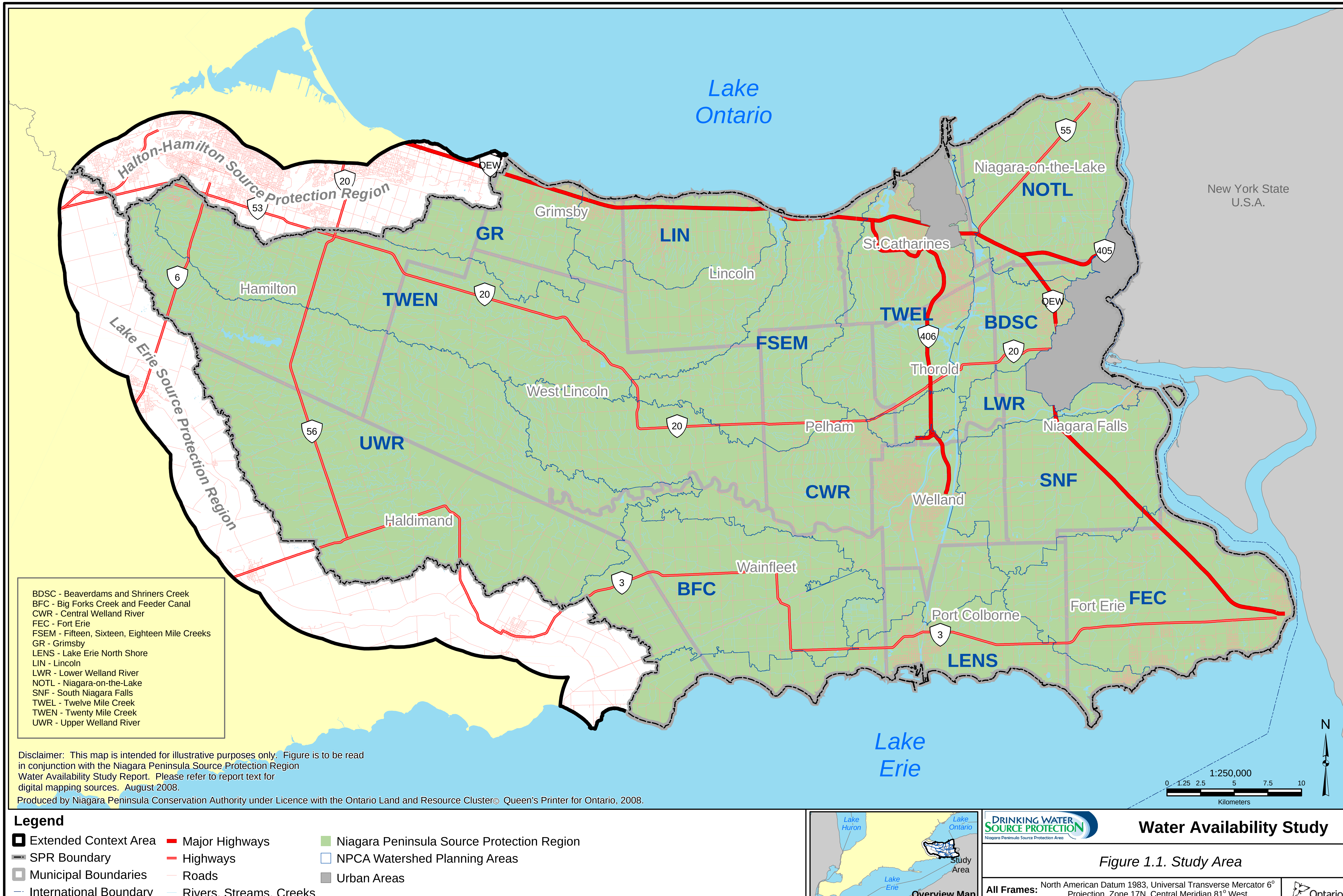
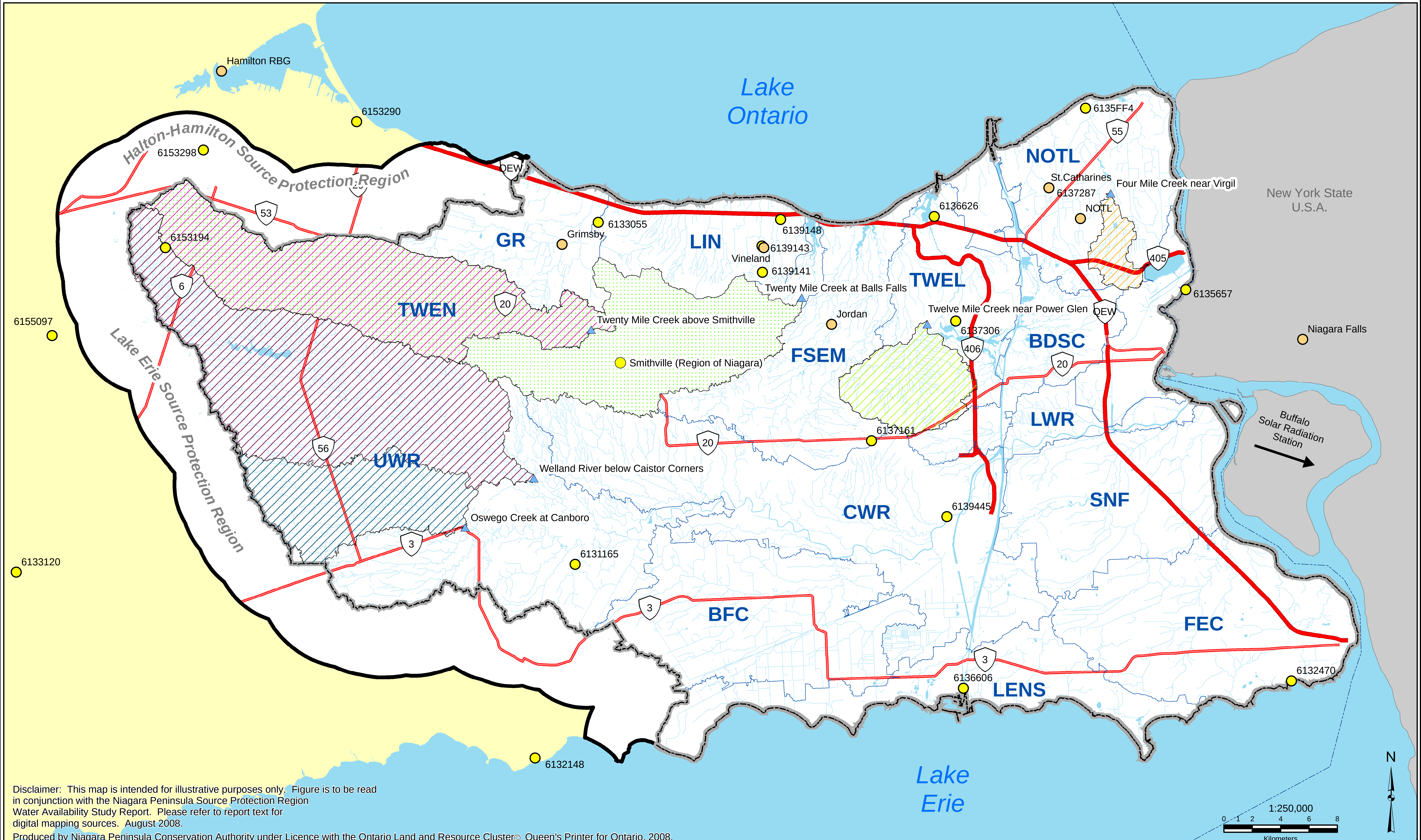



*Figure 1.1. Study Area*




**Legend**

- Extended Context Area
- SPR Boundary
- Municipal Boundaries
- International Boundary
- Major Highways
- Highways
- Rivers, Streams, Creeks
- NPCA Watershed Planning Area
- MSC Climate Station
- WSC Stream Gage Station
- Solar Radiation Stations

Water Survey Canada Stream Gage Drainage Area

- Four Mile Near Virgil
- Twelve Mile Creek
- Twenty Mile Creek (Smithville)
- Twenty Mile Creek (Balls Falls)
- Welland River (Caistor Corners)
- Oswego Creek


DRINKING WATER SOURCE PROTECTION
Niagara Peninsula Source Protection Area

**Water Availability Study**

*Figure 2.1. Study Meterological Stations and Stream Gauges*

**All Frames:** North American Datum 1983, Universal Transverse Mercator 6° Projection, Zone 17N, Central Meridian 81° West.

Ontario

**FIGURE 2.2**
**MEAN (1991-2005) MONTHLY PRECIPITATION**
**TWELVE MILE CREEK WATERSHED PLANNING AREA**

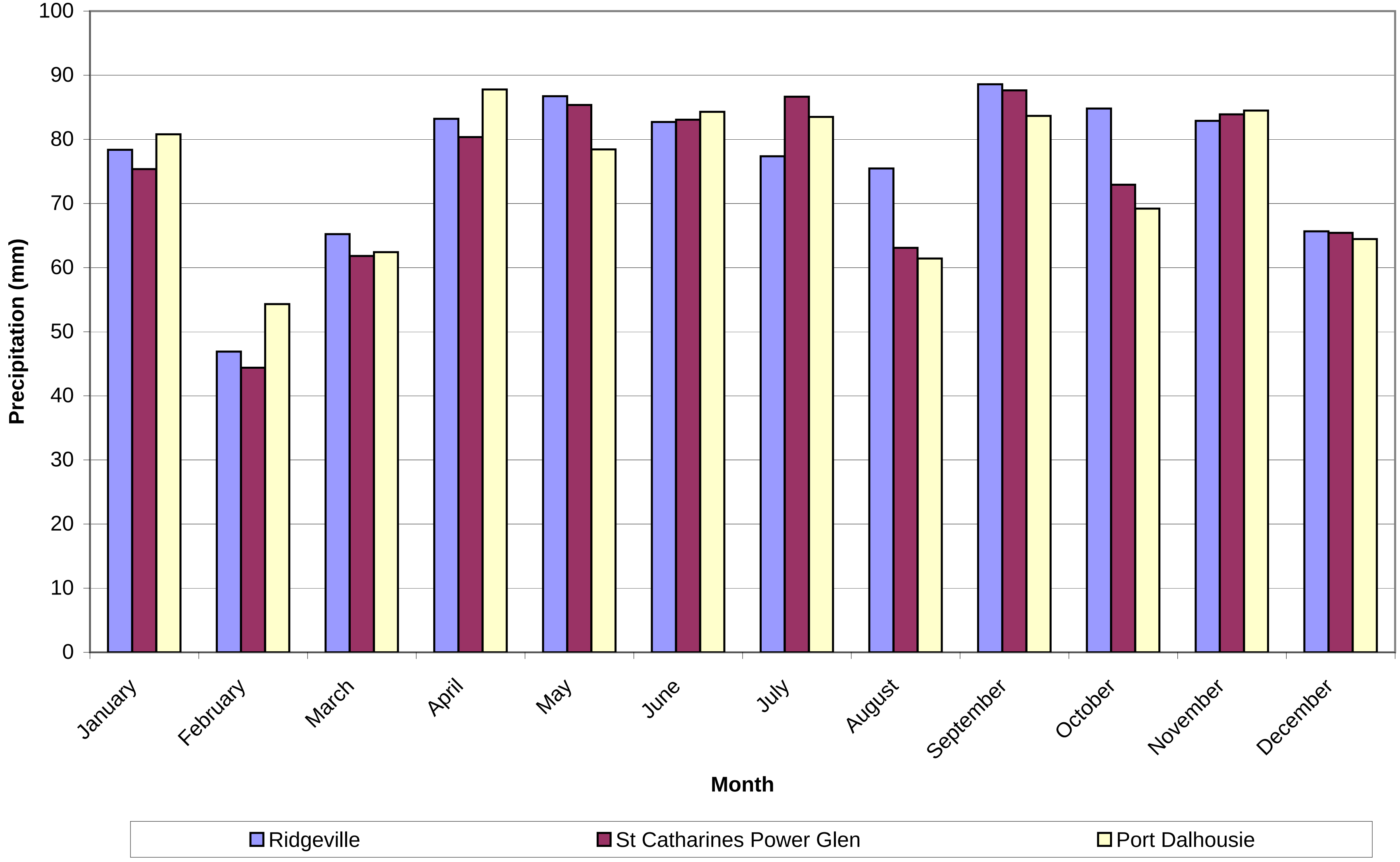
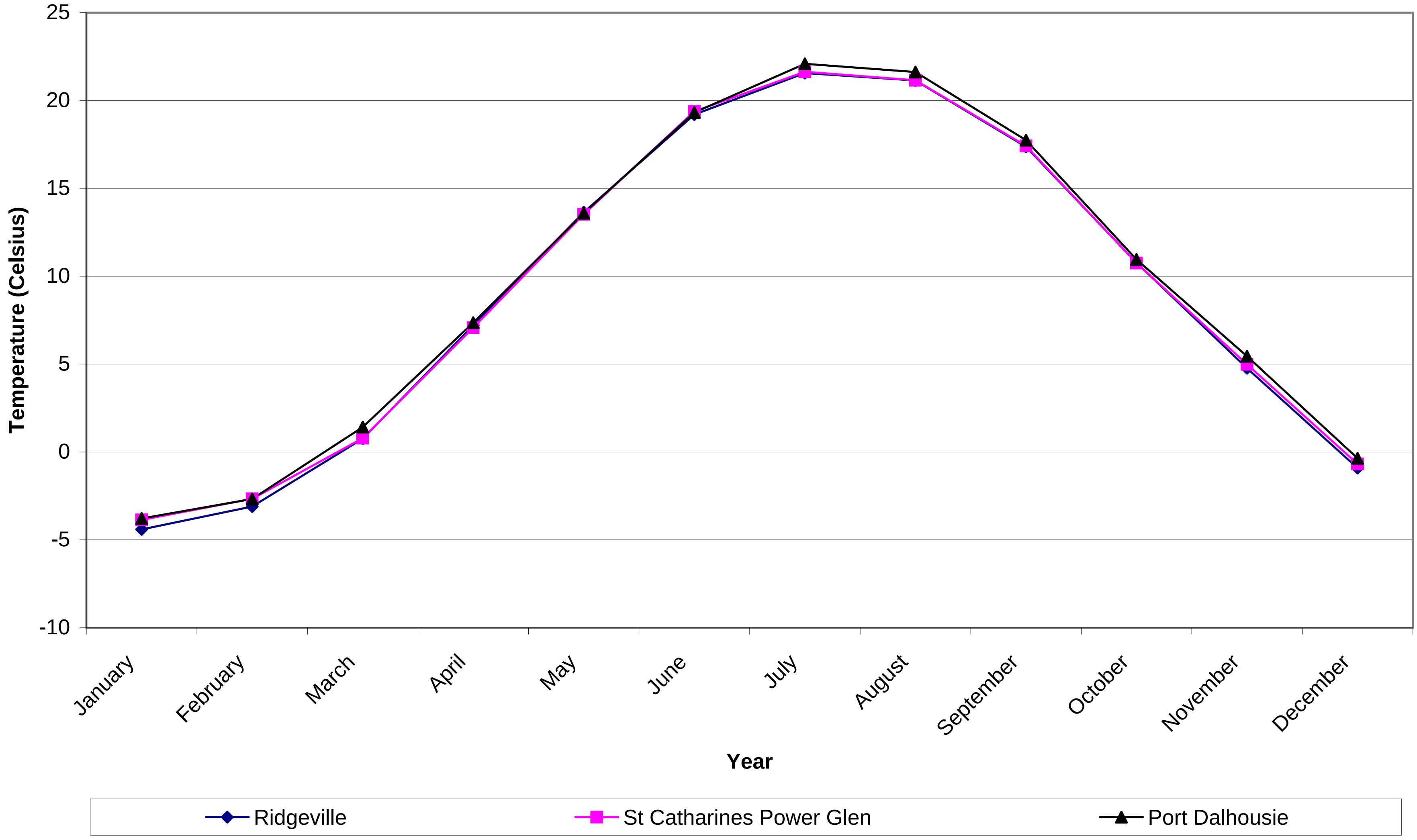
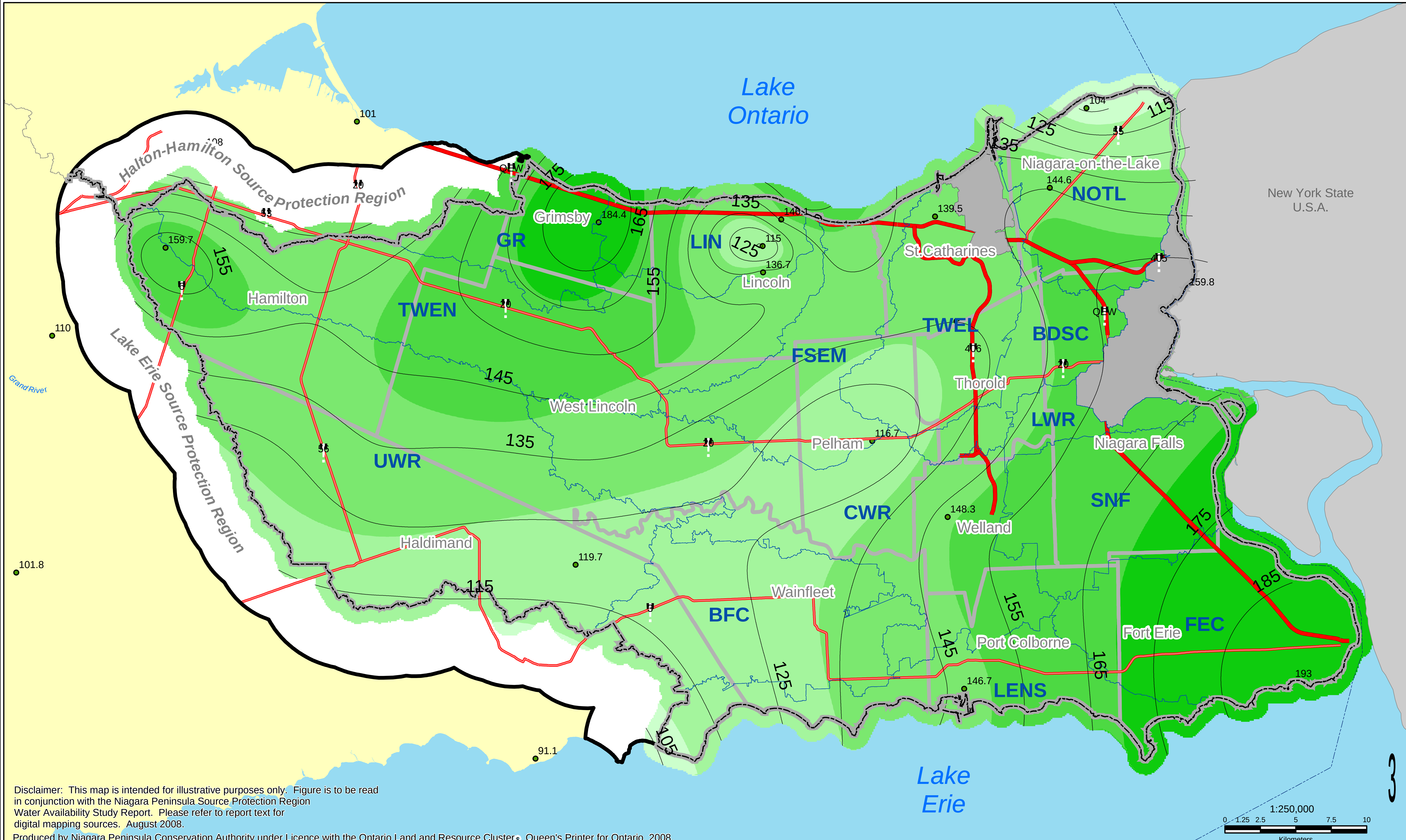


**FIGURE 2.3**
**MEAN (1991-2005) MONTHLY TEMPERATURE**
**TWELVE MILE CREEK WATERSHED PLAN AREA**






Disclaimer: This map is intended for illustrative purposes only. Figure is to be read in conjunction with the Niagara Peninsula Source Protection Region Water Availability Study Report. Please refer to report text for digital mapping sources. August 2008.

Produced by Niagara Peninsula Conservation Authority under Licence with the Ontario Land and Resource Clusters Queen's Printer for Ontario, 2008.

**Legend**

- Extended Context Area
- SPR Boundary
- Municipal Boundaries
- International Boundary
- Major Highways
- Highways
- Roads
- Rivers, Streams, Creeks
- Ponds, Reservoirs, Lakes
- Niagara Peninsula Source Protection Region
- NPCA Watershed Planning Areas
- Urban Areas
- MSC Snow Data

**1991 - 2005 (mm)**

- 90 - 110
- 110 - 130
- 130 - 150
- 150 - 170
- 170 - 190

Lake Huron · Lake Ontario · Lake Erie · Study Area · **Overview Map**

Drinking Water Source Protection — Niagara Peninsula Source Protection Region

## Water Availability Study

*Figure 2.4. Mean Annual Snowfall Water Equivalent*

**All Frames:** North American Datum 1983, Universal Transverse Mercator 6° Projection, Zone 17N, Central Meridian 81° West.

Ontario

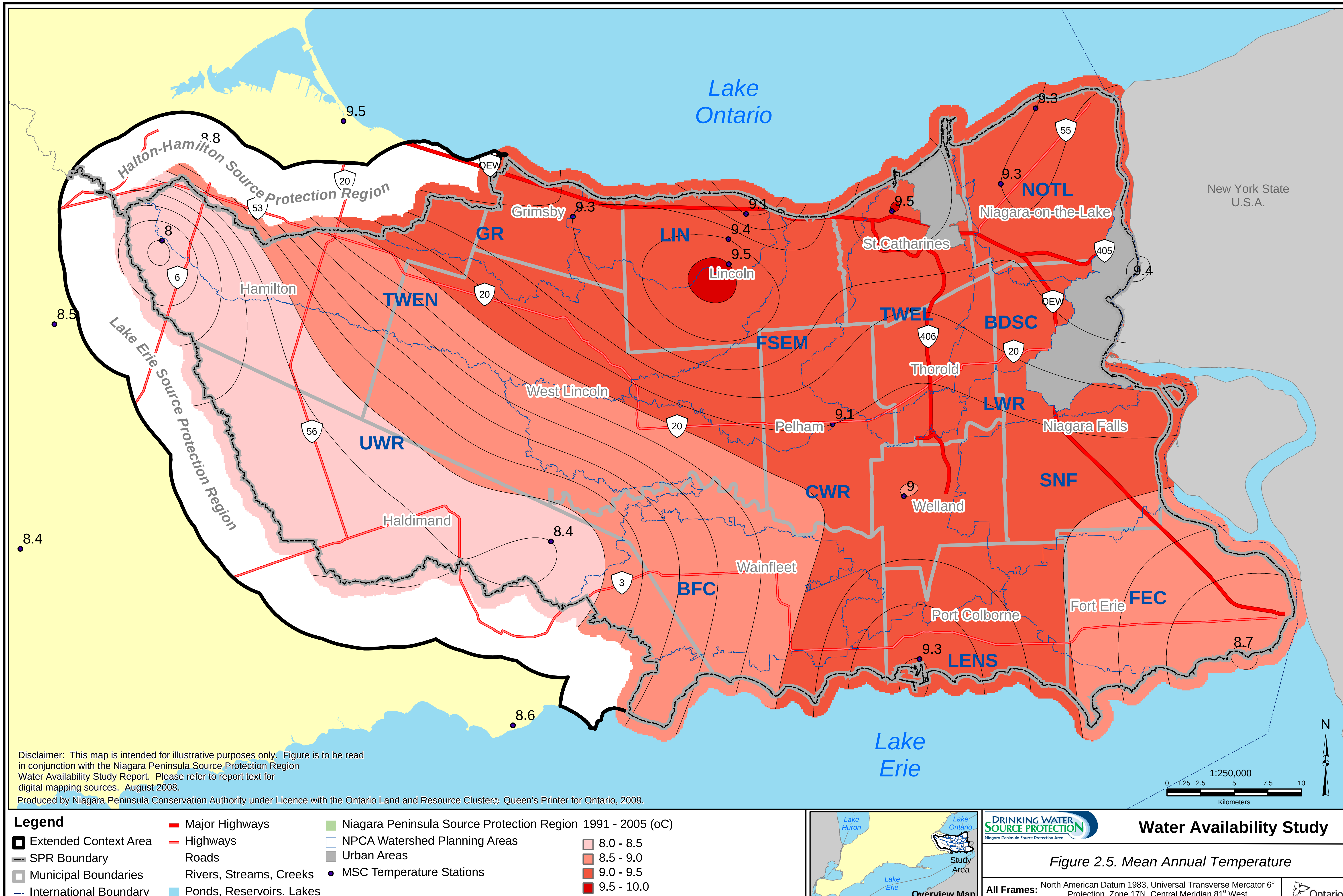



*Figure 2.5. Mean Annual Temperature*

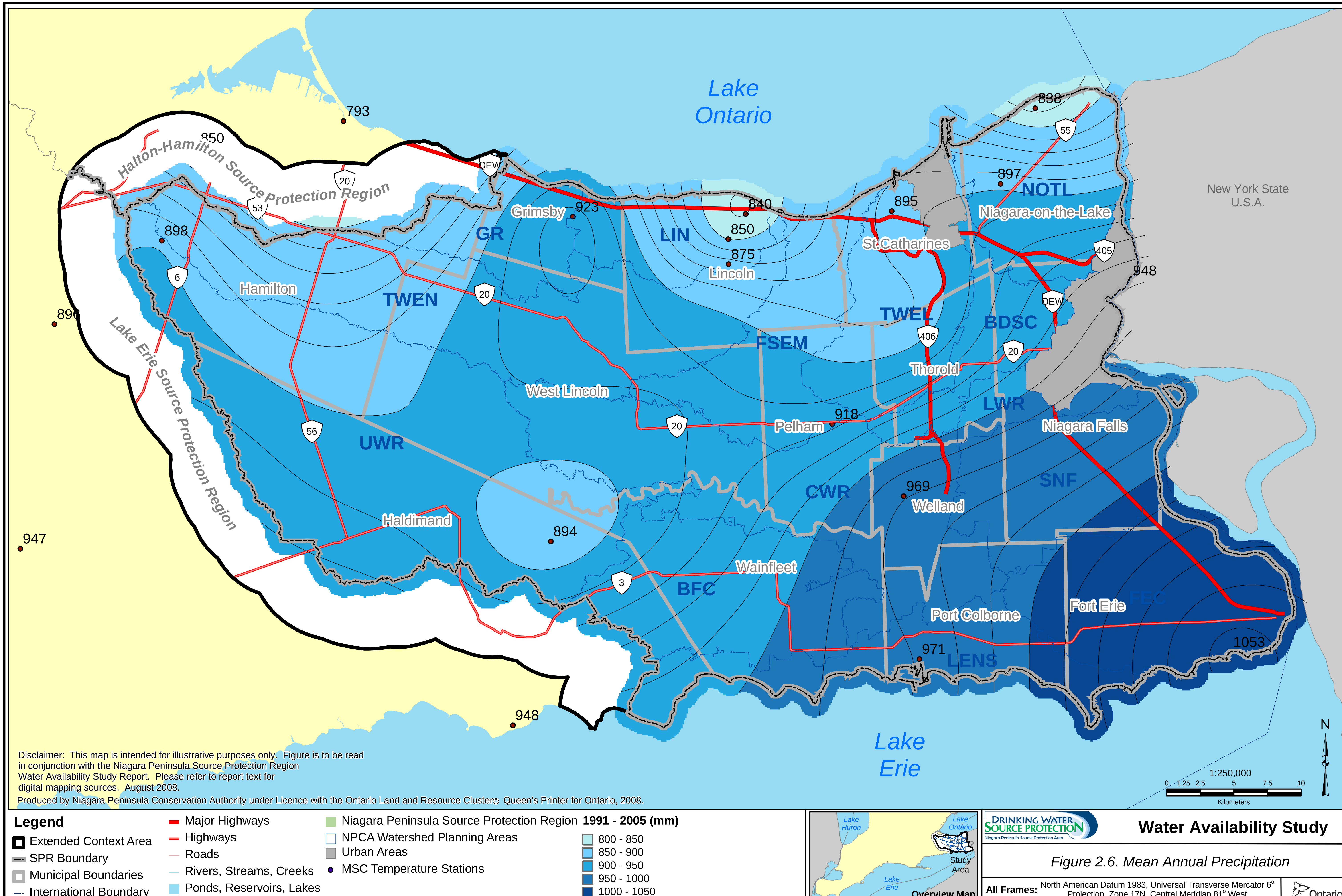



*Figure 2.6. Mean Annual Precipitation*

**FIGURE 2.7**
**ANNUAL PRECIPITATION**
**TWELVE MILE CREEK WATERSHED PLANNING AREA**

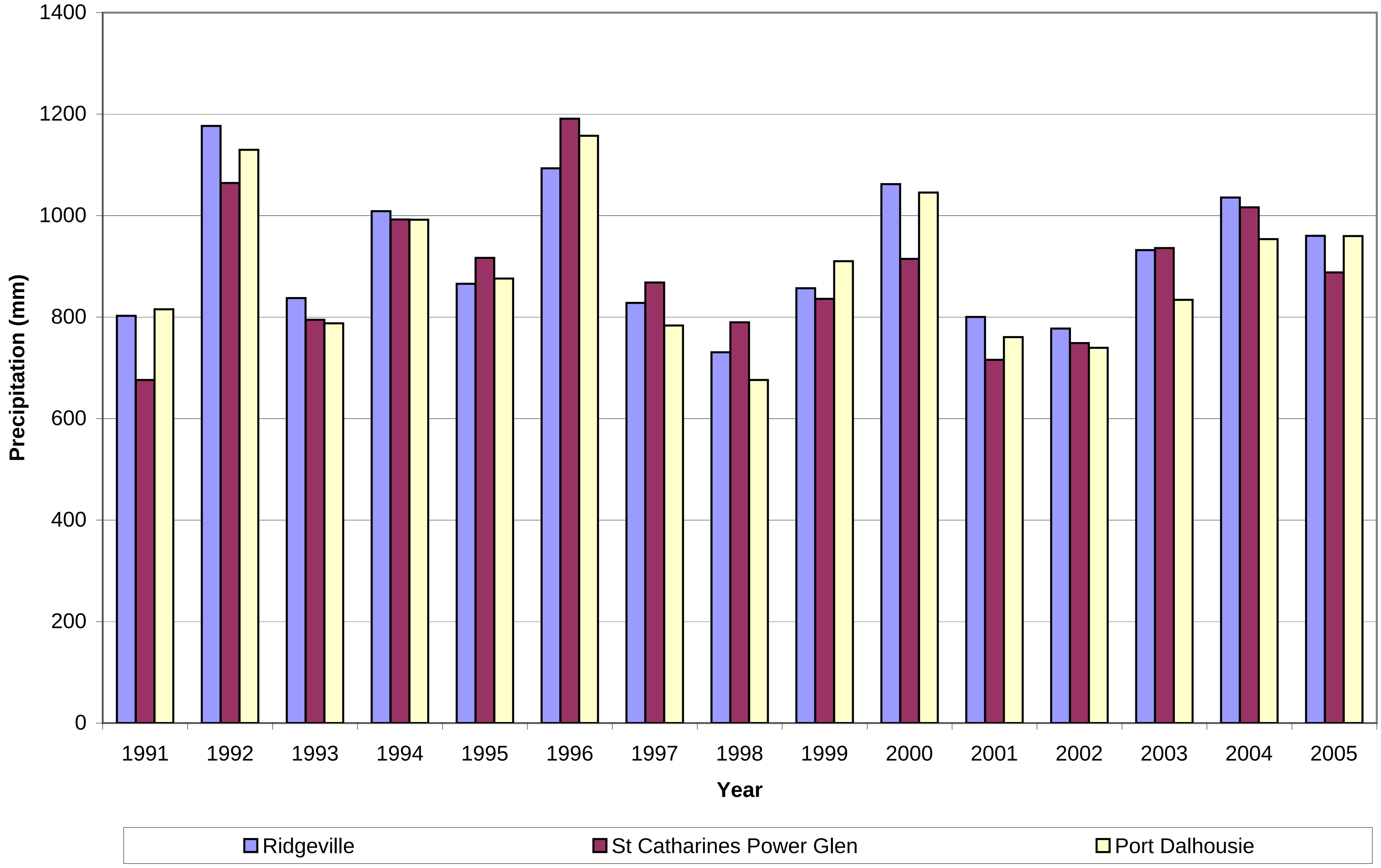
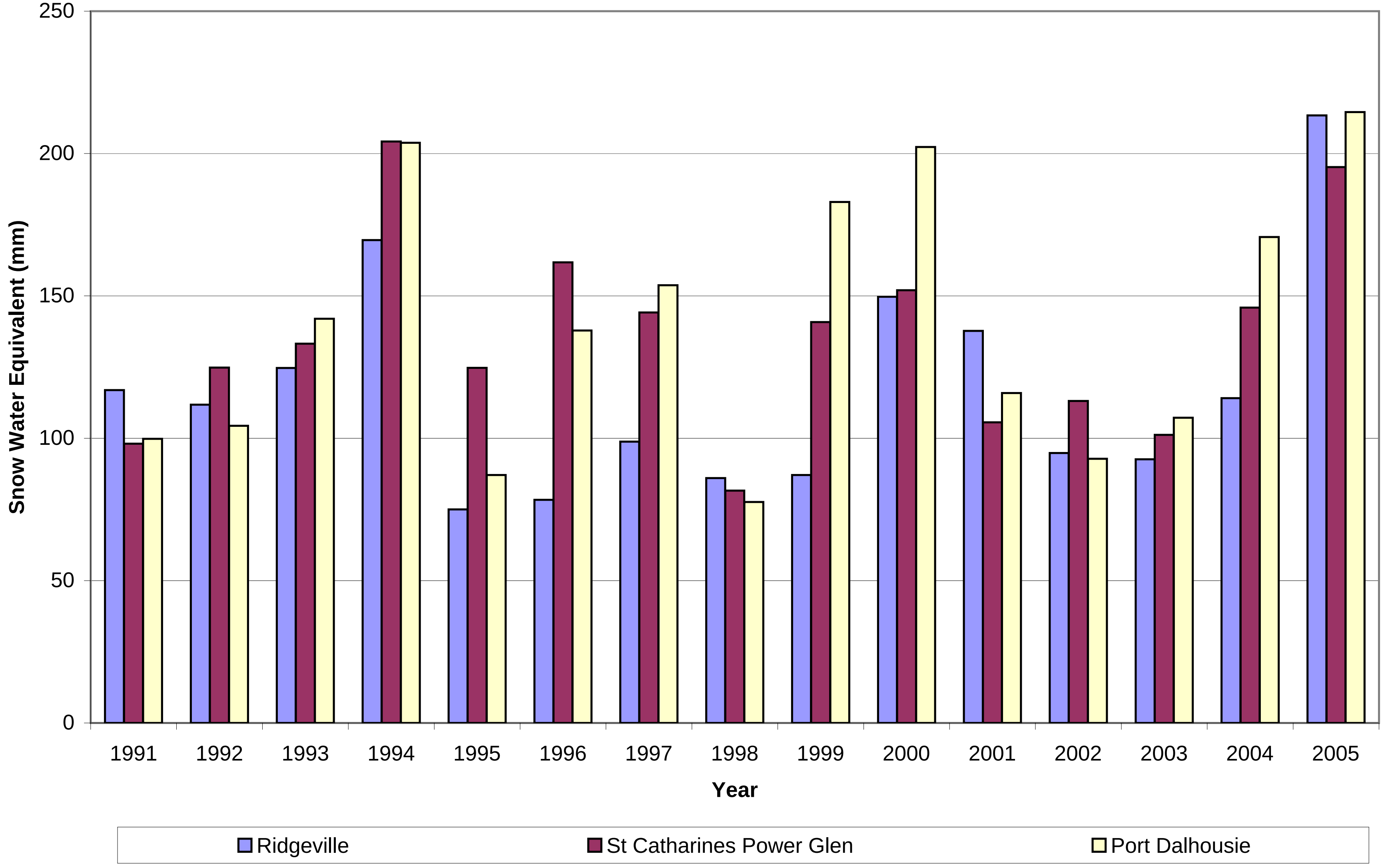


**FIGURE 2.8**
**ANNUAL SNOW WATER EQUIVALENT**
**TWELVE MILE CREEK WATERSHED PLANNING AREA**



## FIGURE 2.9
## MEAN (1991-2005) ANNUAL TEMPERATURE
## TWELVE MILE CREEK WATERSHED PLAN AREA

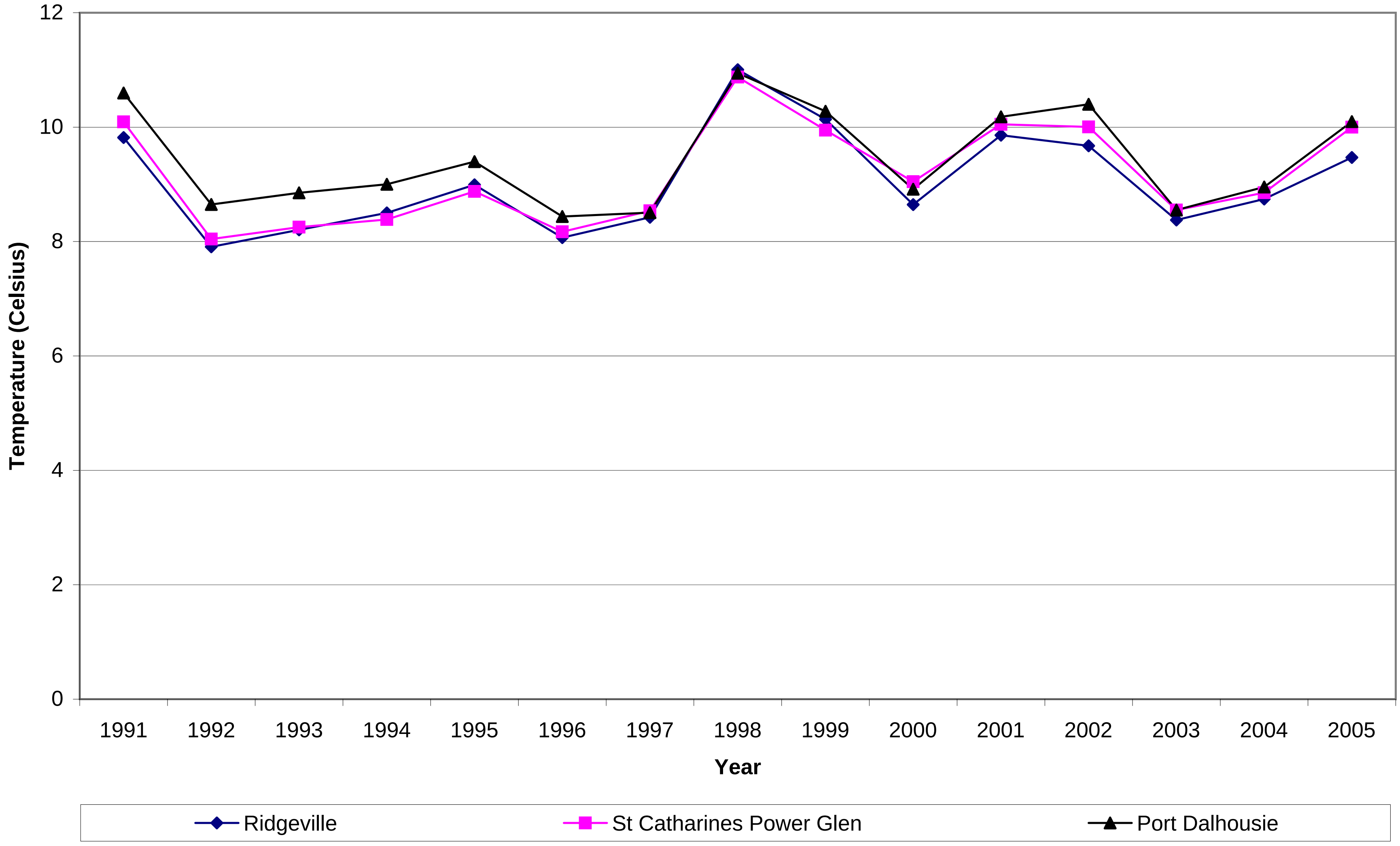


**Figure 2.10**
**ANNUAL NET SOLAR RADIATION**

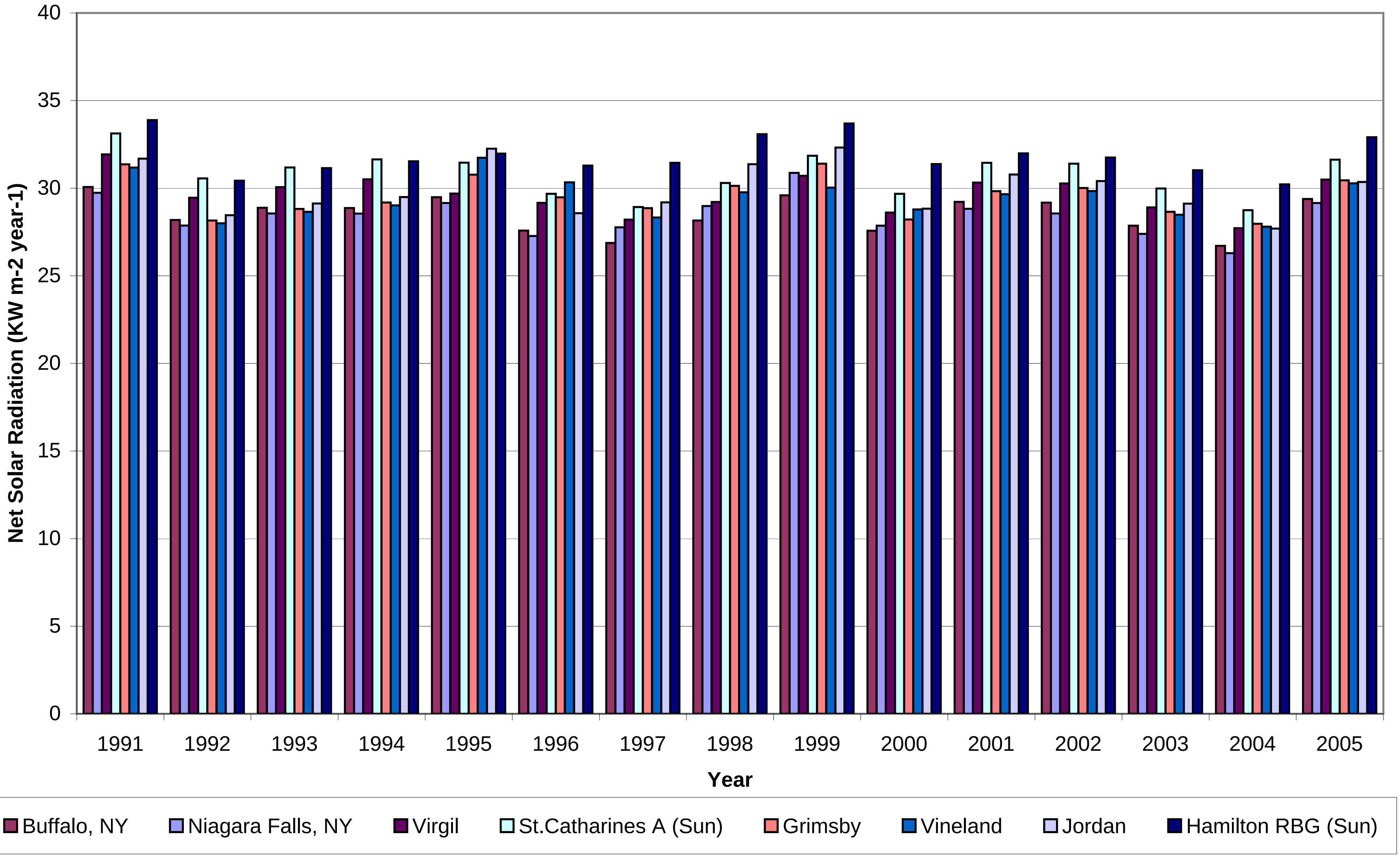


**Figure 2.11**
**MEAN (1991-2005) MONTHLY NET SOLAR RADIATION**

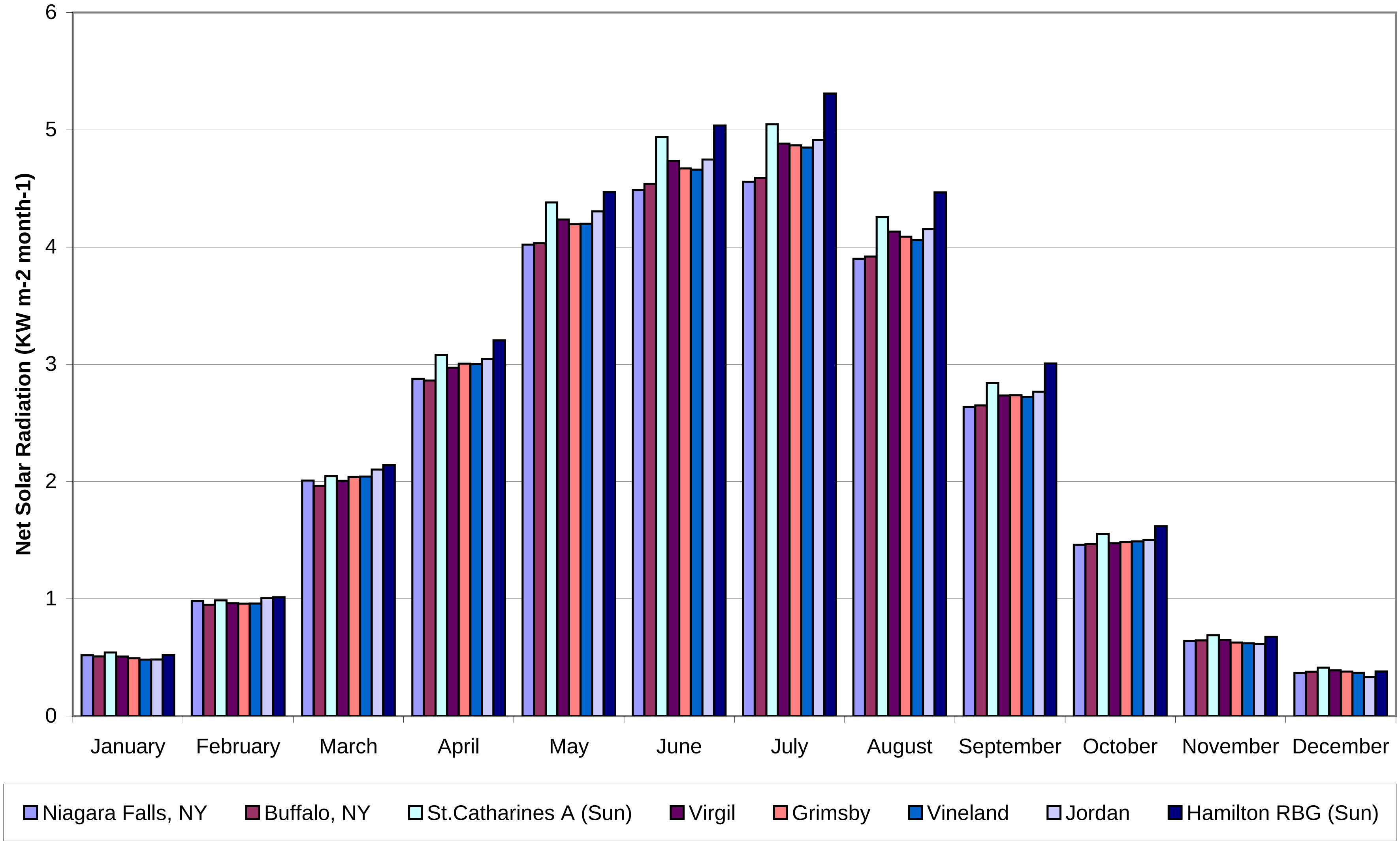
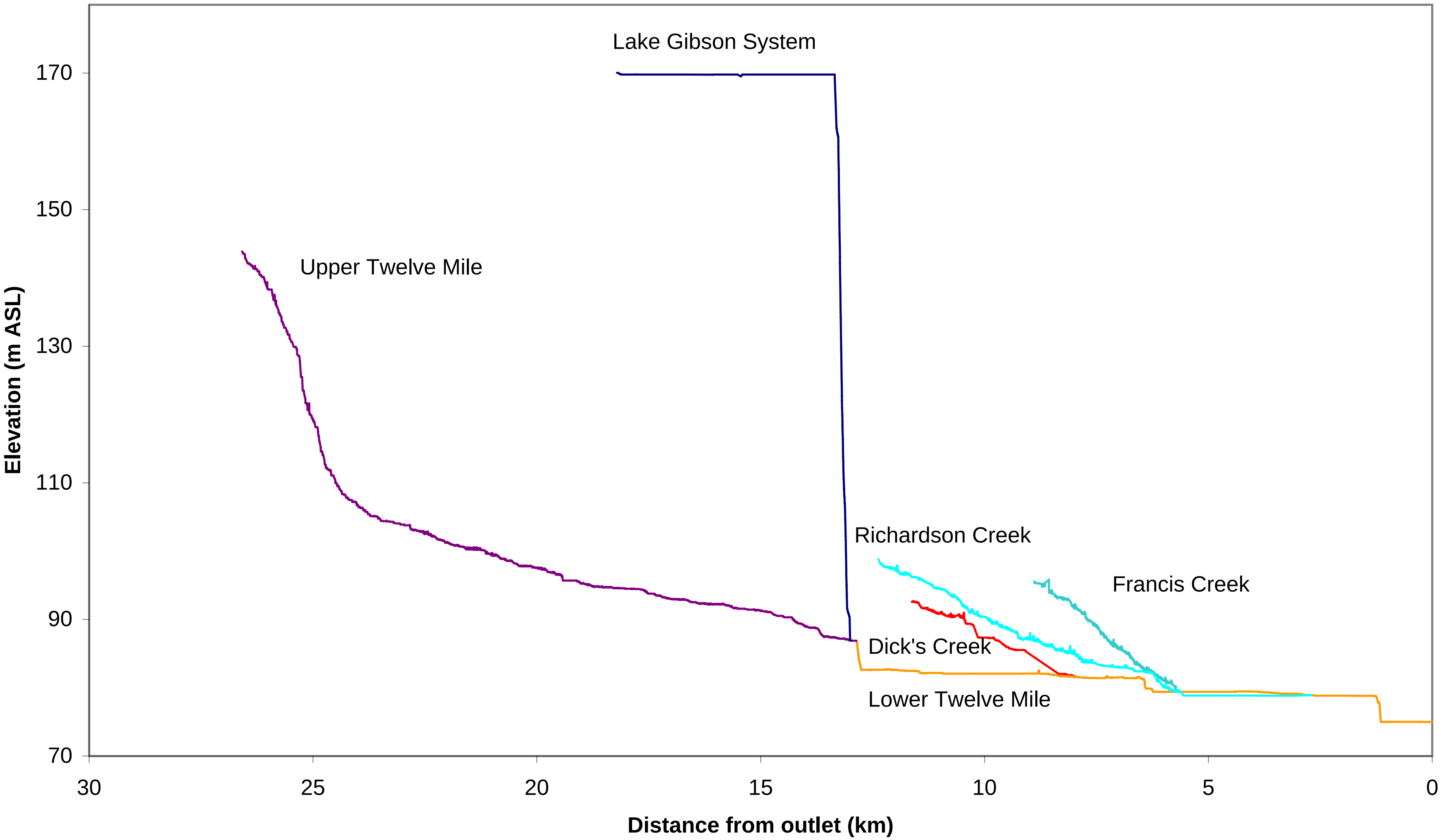


**Figure 2.12**
**Channel Profiles for Twelve Mile Watershed Planning Area**



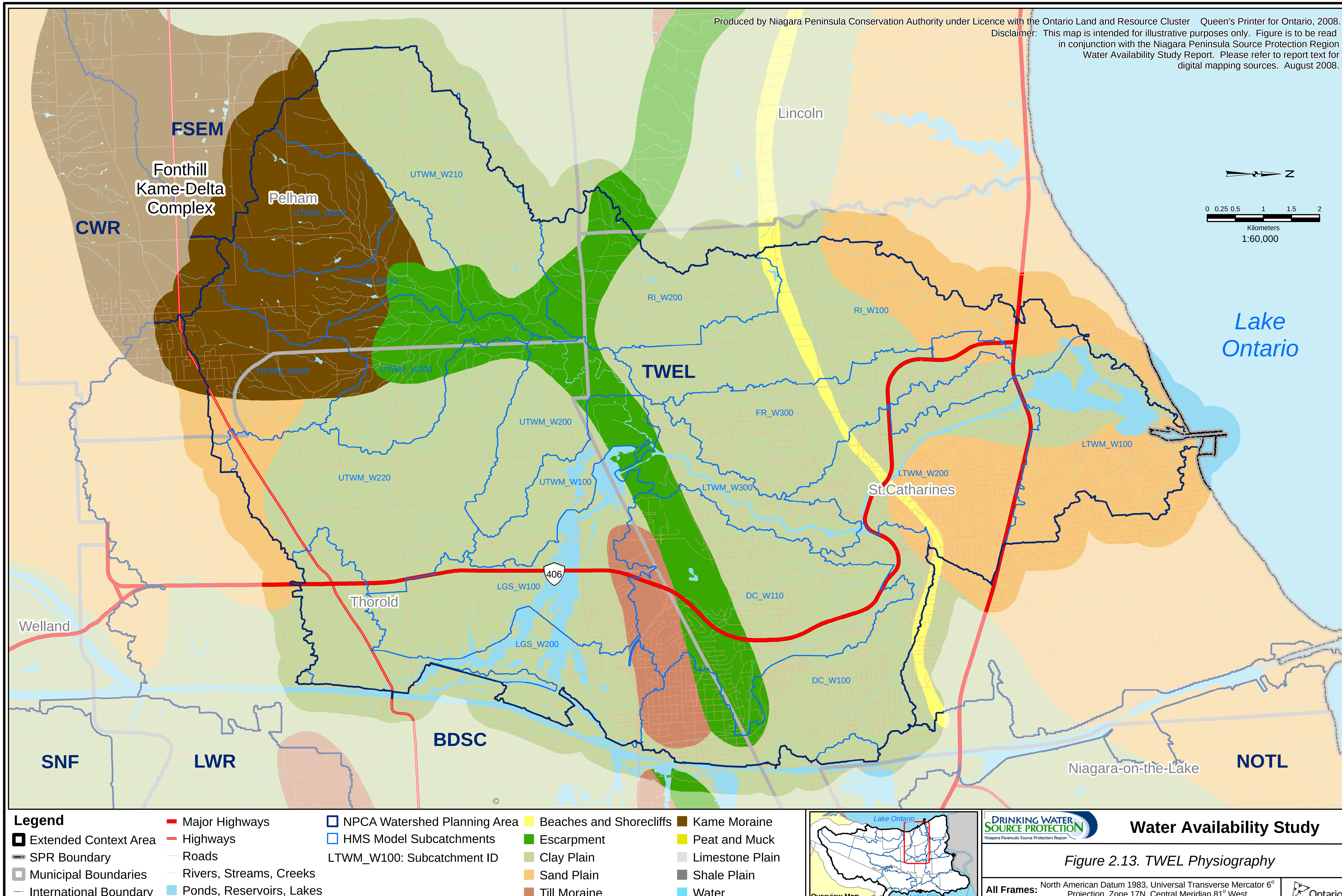
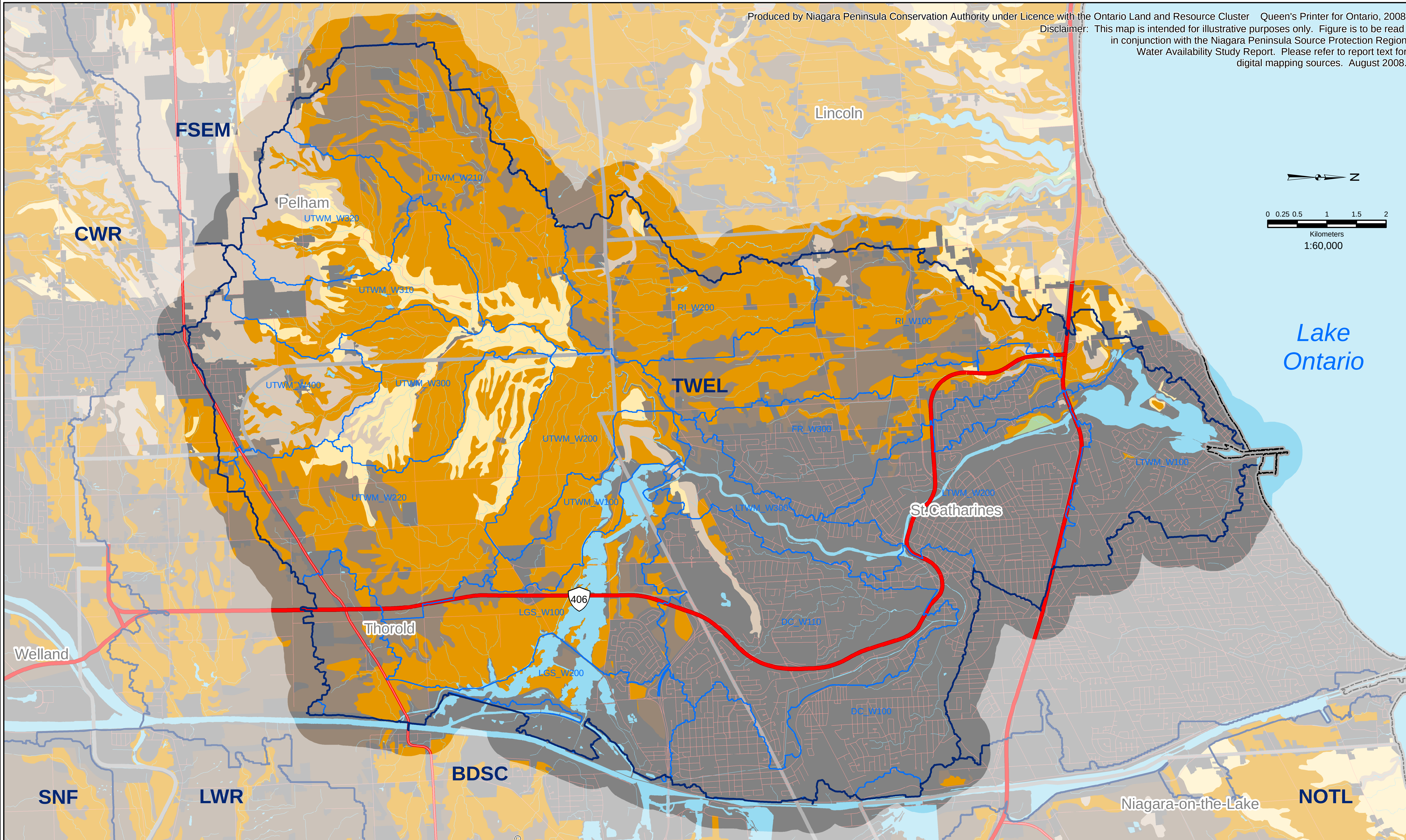



*Figure 2.13. TWEL Physiography*




## Legend

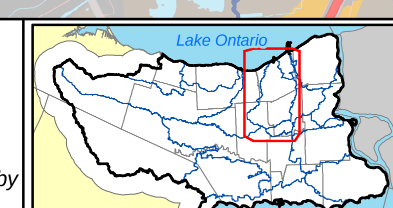
- Extended Context Area
- SPR Boundary
- Municipal Boundaries
- International Boundary
- Major Highways
- Highways
- Roads
- Rivers, Streams, Creeks
- Ponds, Reservoirs, Lakes

Soil HSG

- A
- D
- B
- Organic Soils
- C
- Urbanized

- NPCA Watershed Planning Area
- HMS Model Subcatchments
- LTMC_W100: Subcatchment ID

*Please note that soils mapping in this figure is represented by the combination of three different former county soil surveys.*




DRINKING WATER SOURCE PROTECTION
Niagara Peninsula Source Protection Region

## Water Availability Study

*Figure 2.14. TWEL Soils*

**All Frames:** North American Datum 1983, Universal Transverse Mercator 6° Projection, Zone 17N, Central Meridian 81° West.

Ontario

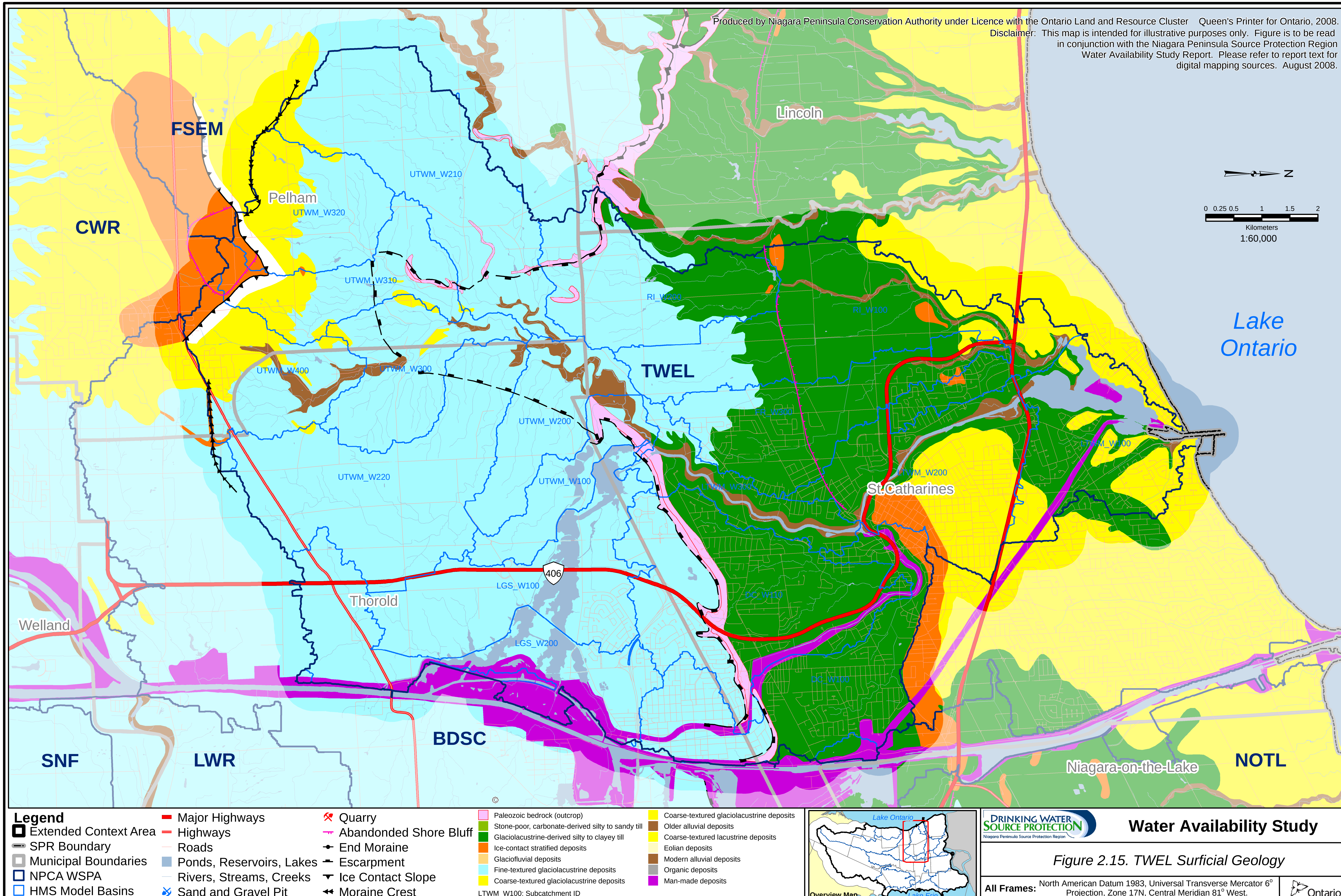



*Figure 2.15. TWEL Surficial Geology*

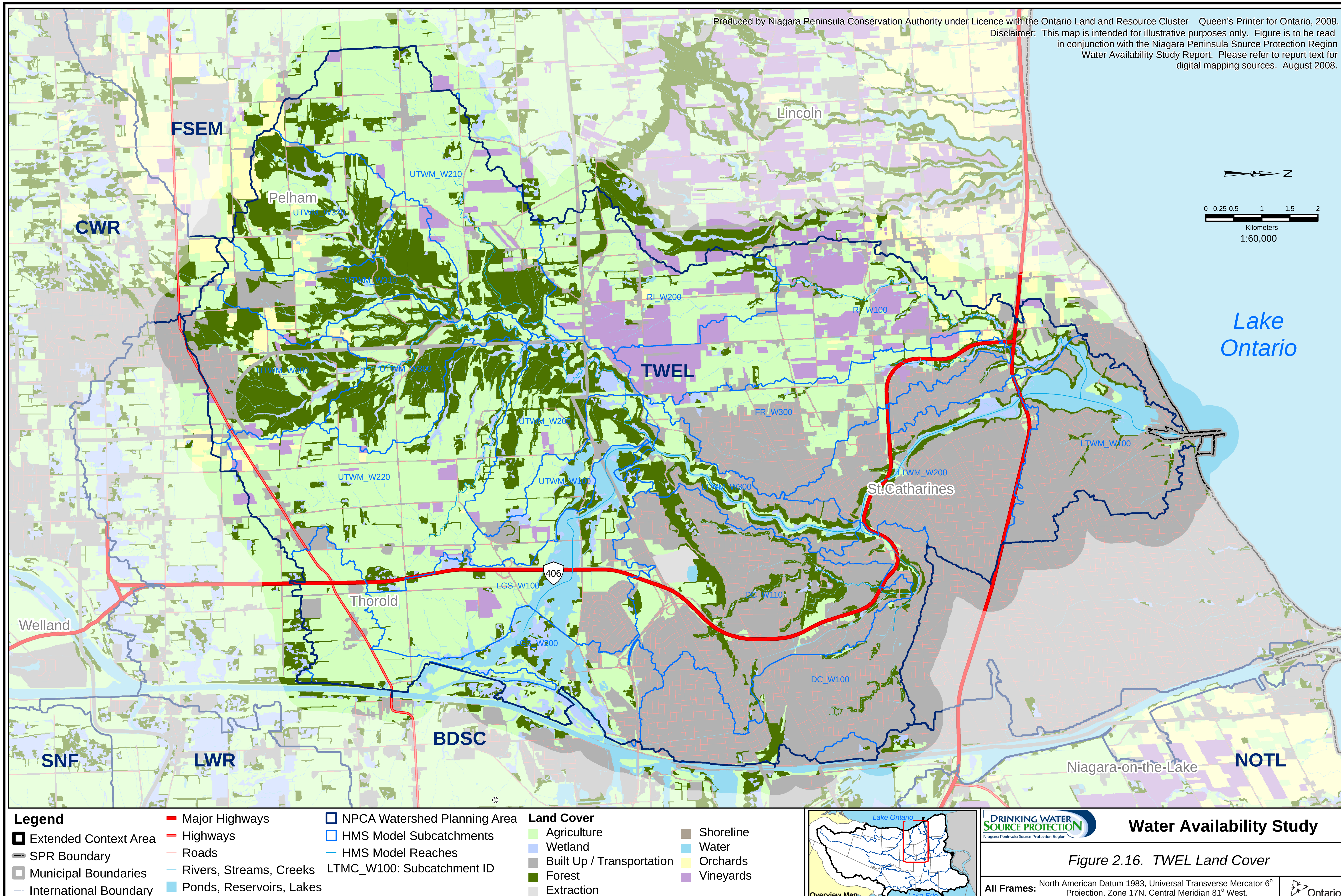
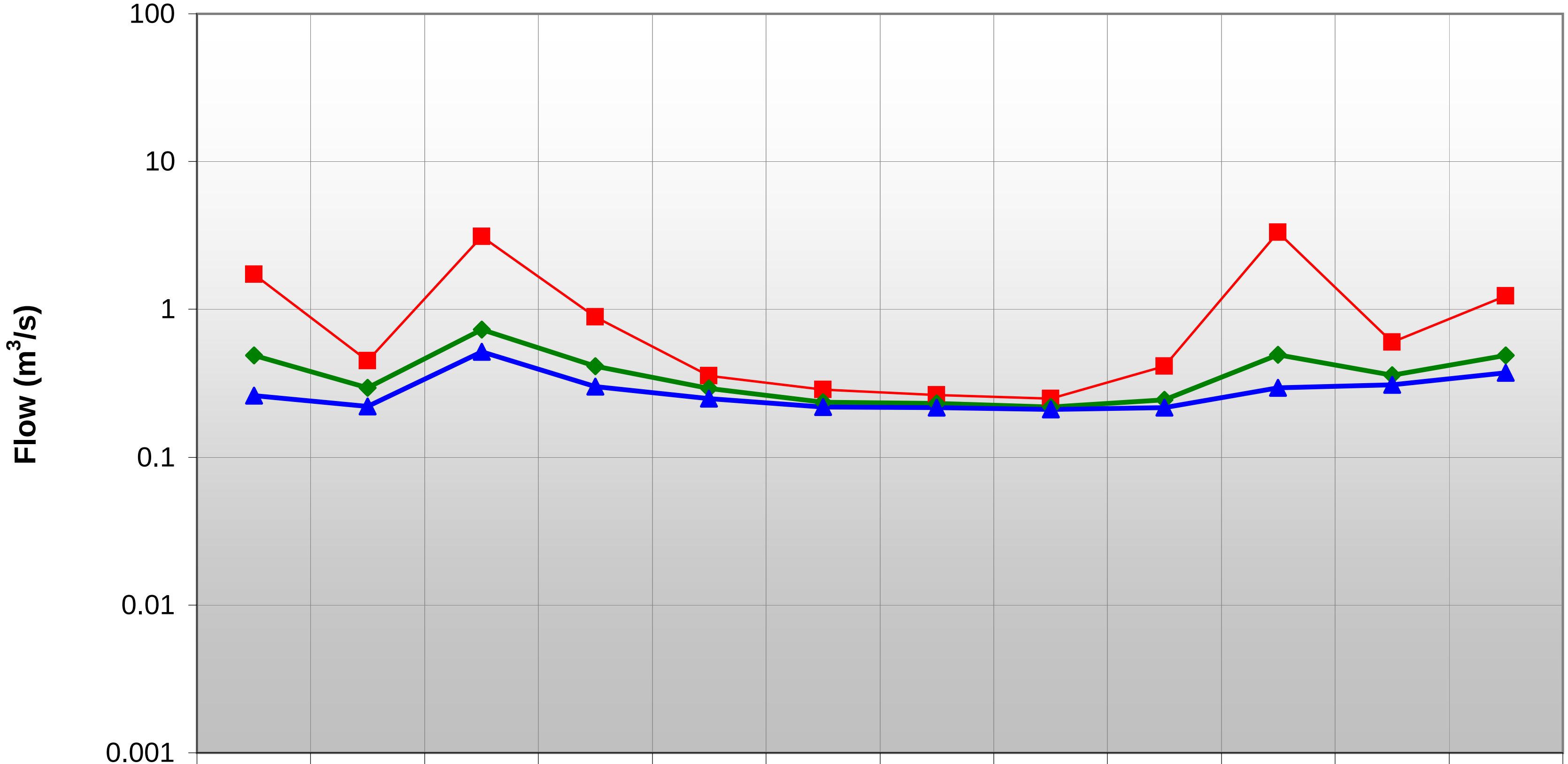



*Figure 2.16. TWEL Land Cover*

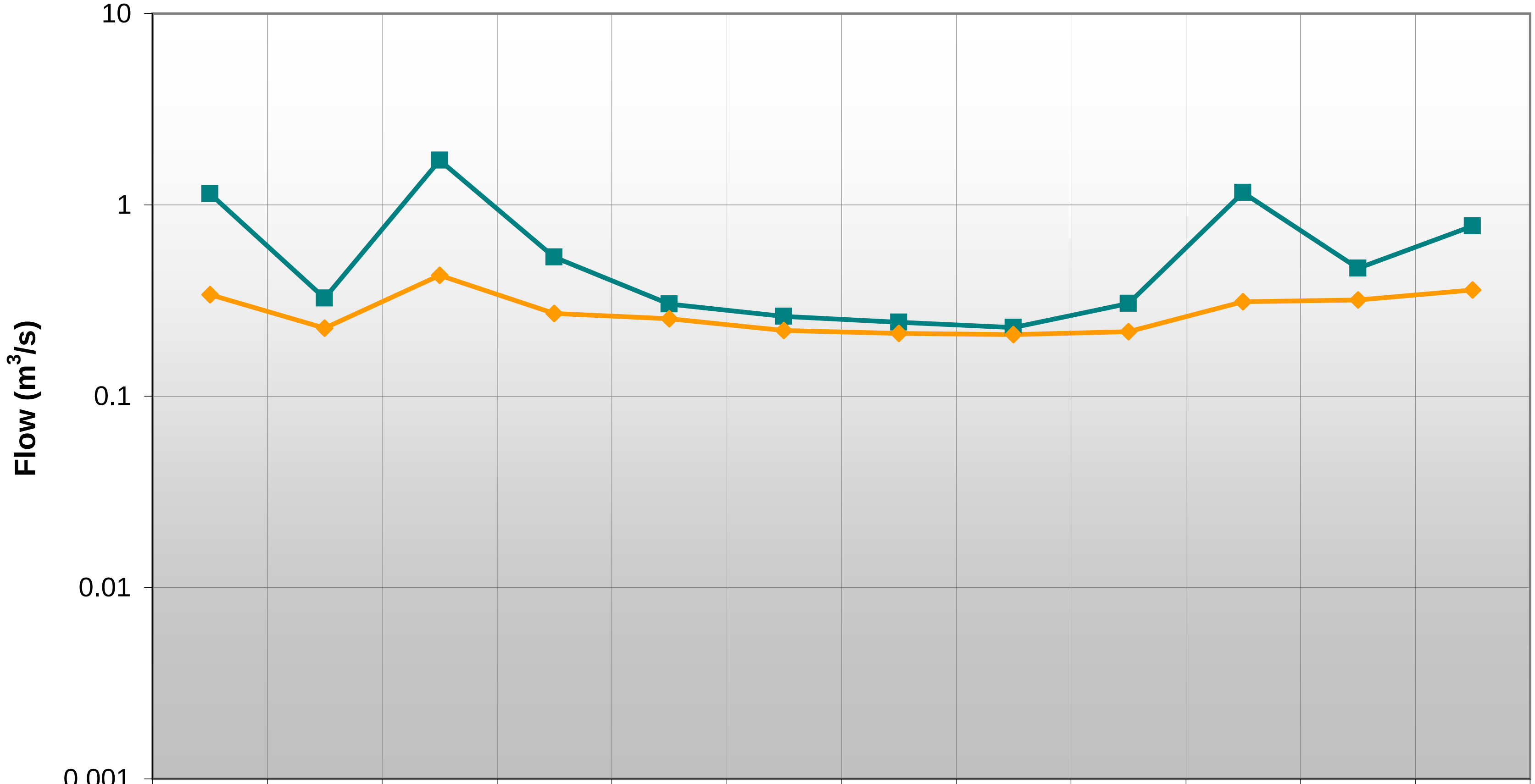
## Figure 2.17 - Monthly Flow Distribution (2006-2007) for 02HA031 - TWELVE MILE CREEK NEAR POWER GLEN




| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10th Percentile | 1.722 | 0.45 | 3.126 | 0.888 | 0.354 | 0.286 | 0.263 | 0.25 | 0.413 | 3.312 | 0.601 | 1.23 |
| Median | 0.49 | 0.295 | 0.732 | 0.412 | 0.291 | 0.235 | 0.232 | 0.218 | 0.244 | 0.493 | 0.359 | 0.49 |
| 90th Percentile | 0.26 | 0.22 | 0.519 | 0.301 | 0.249 | 0.218 | 0.216 | 0.21 | 0.217 | 0.296 | 0.309 | 0.373 |

Month

**Figure 2.18 - Monthly Mean Streamflow and Baseflow (2006-2007) for 02HA031 - TWELVE MILE CREEK NEAR POWER GLEN**




| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Streamflow | 1.146355 | 0.324464 | 1.715839 | 0.534567 | 0.302274 | 0.260434 | 0.243922 | 0.228611 | 0.30452 | 1.159212 | 0.465793 | 0.775533 |
| Baseflow | 0.340433 | 0.227356 | 0.428186 | 0.270125 | 0.254013 | 0.220985 | 0.21331 | 0.210595 | 0.21783 | 0.31151 | 0.317867 | 0.358911 |

**Month**

# Conceptualization of Hydrologic Processes in HEC-HMS

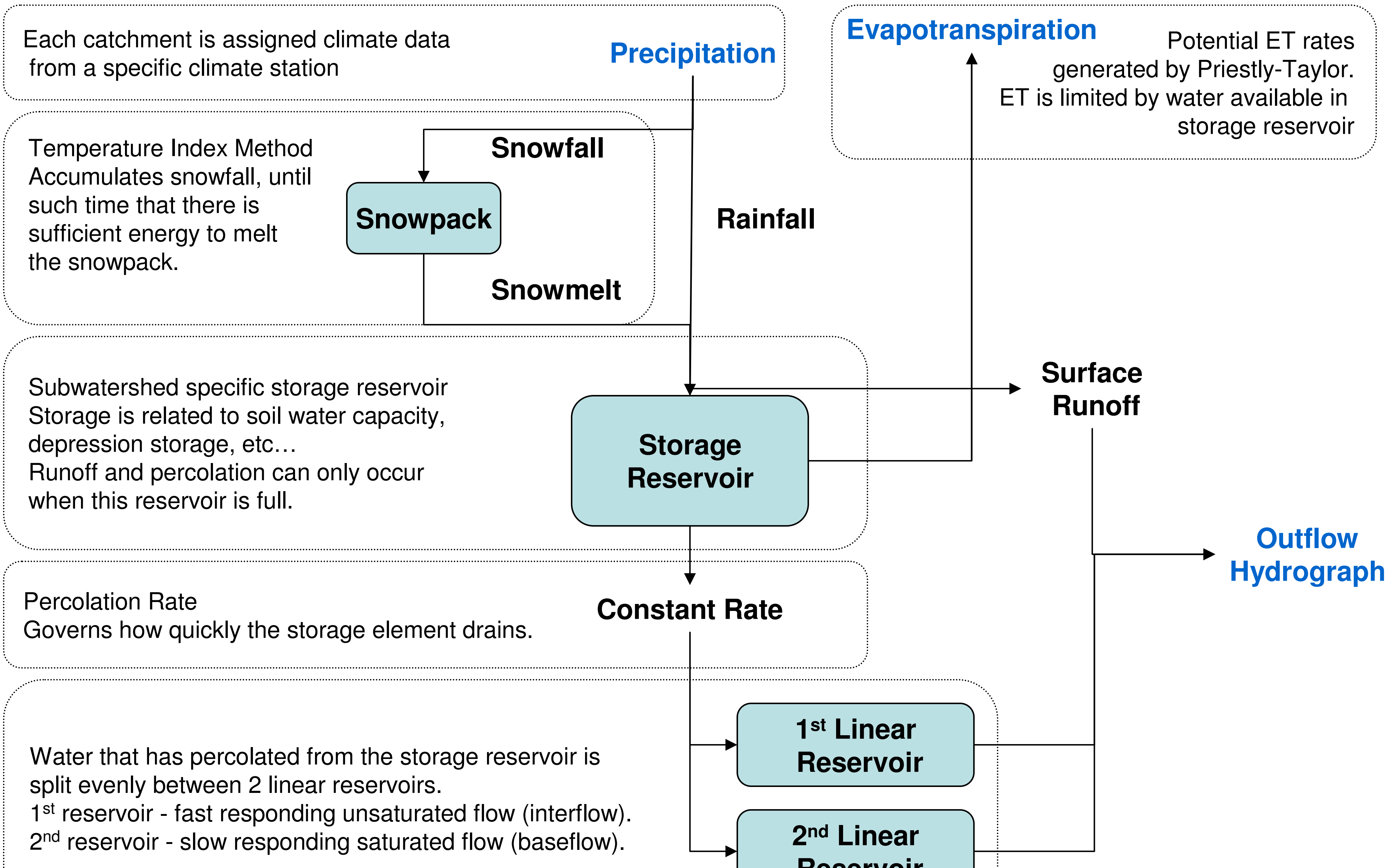



Figure 3.1

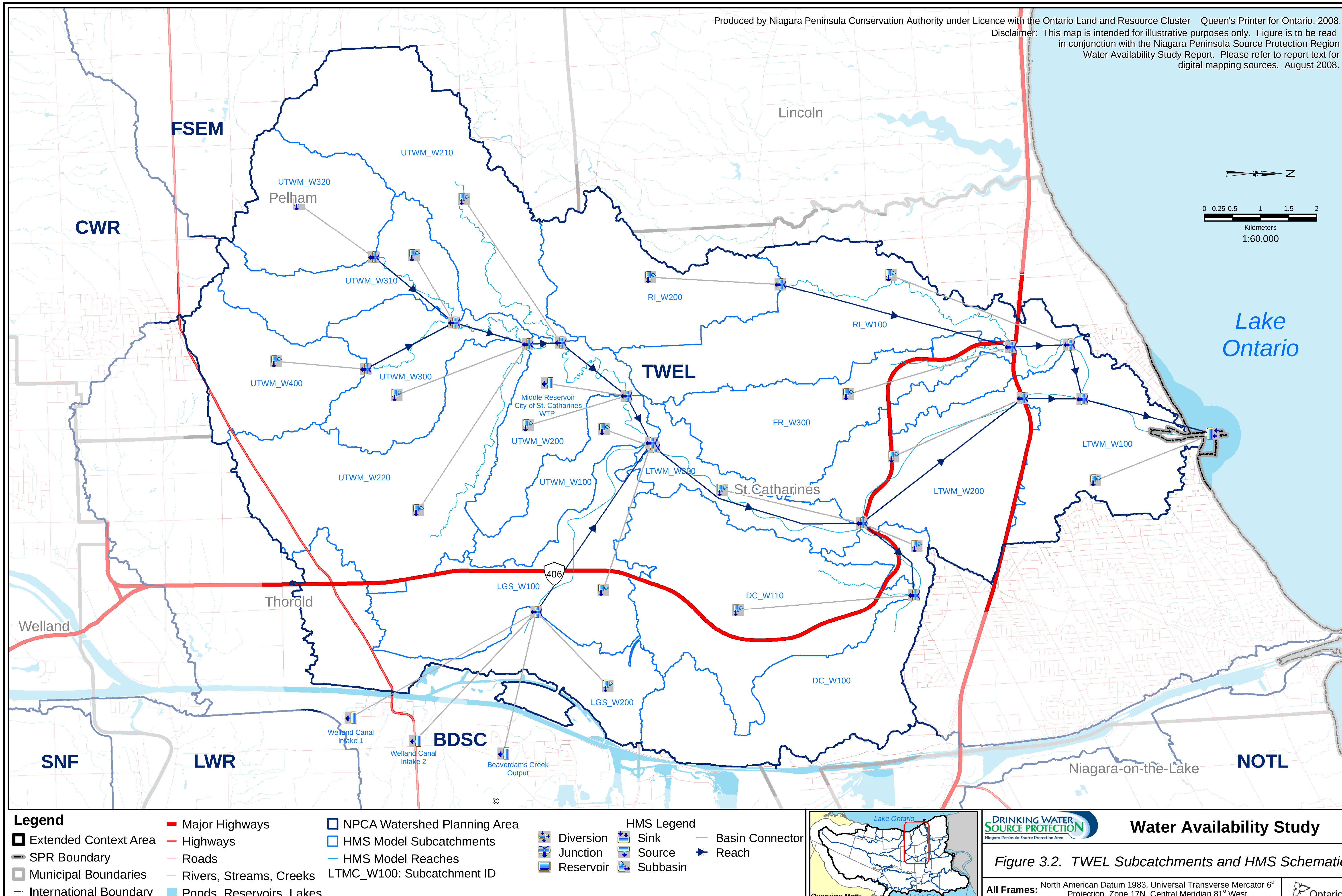
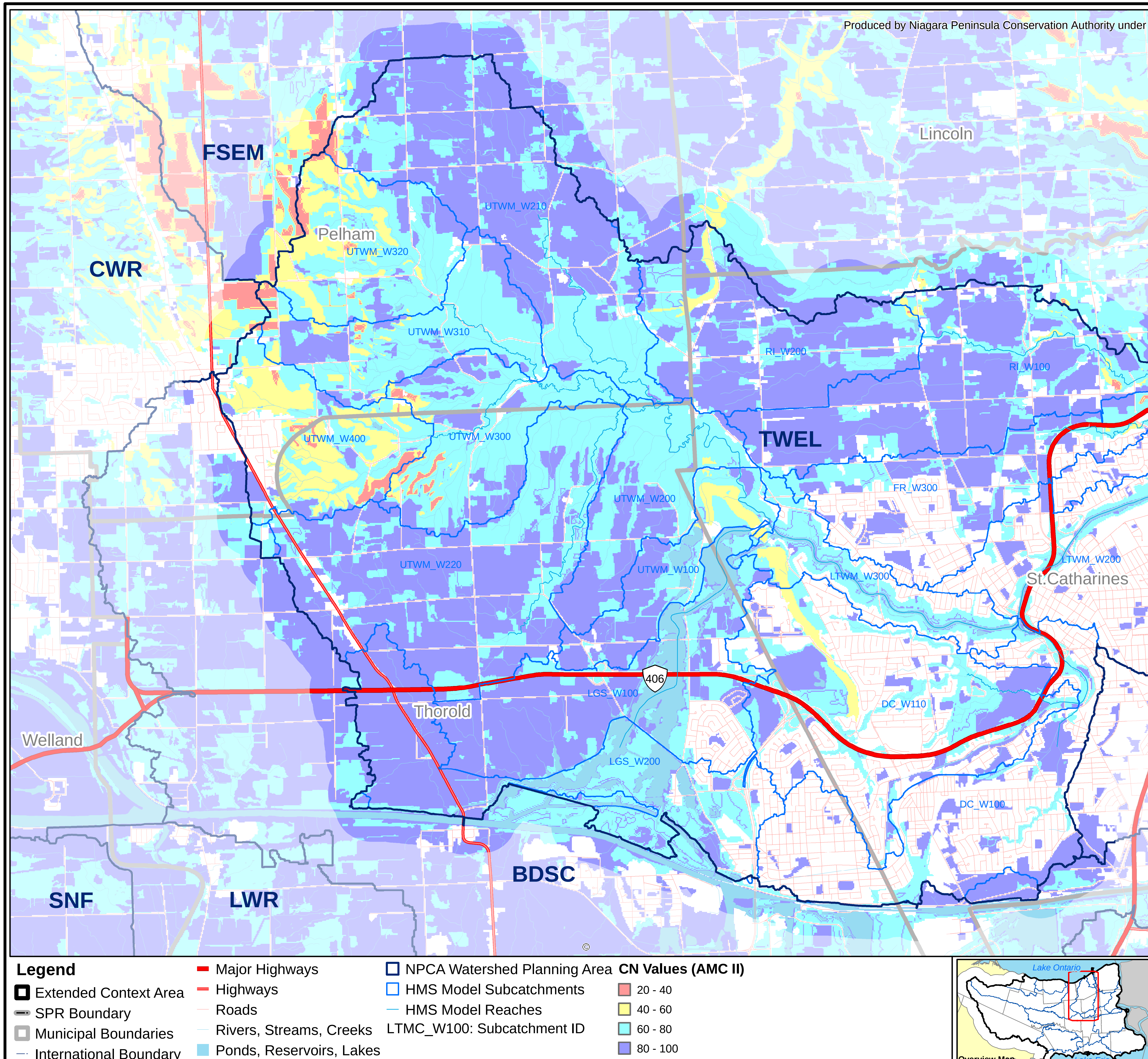


*Figure 3.2. TWEL Subcatchments and HMS Schematic*




DRINKING WATER SOURCE PROTECTION
Niagara Peninsula Source Protection Region

**Water Availability Study**

*Figure 3.3. TWEL Curve Number Values*

**All Frames:** North American Datum 1983, Universal Transverse Mercator 6° Projection, Zone 17N, Central Meridian 81° West.

Ontario

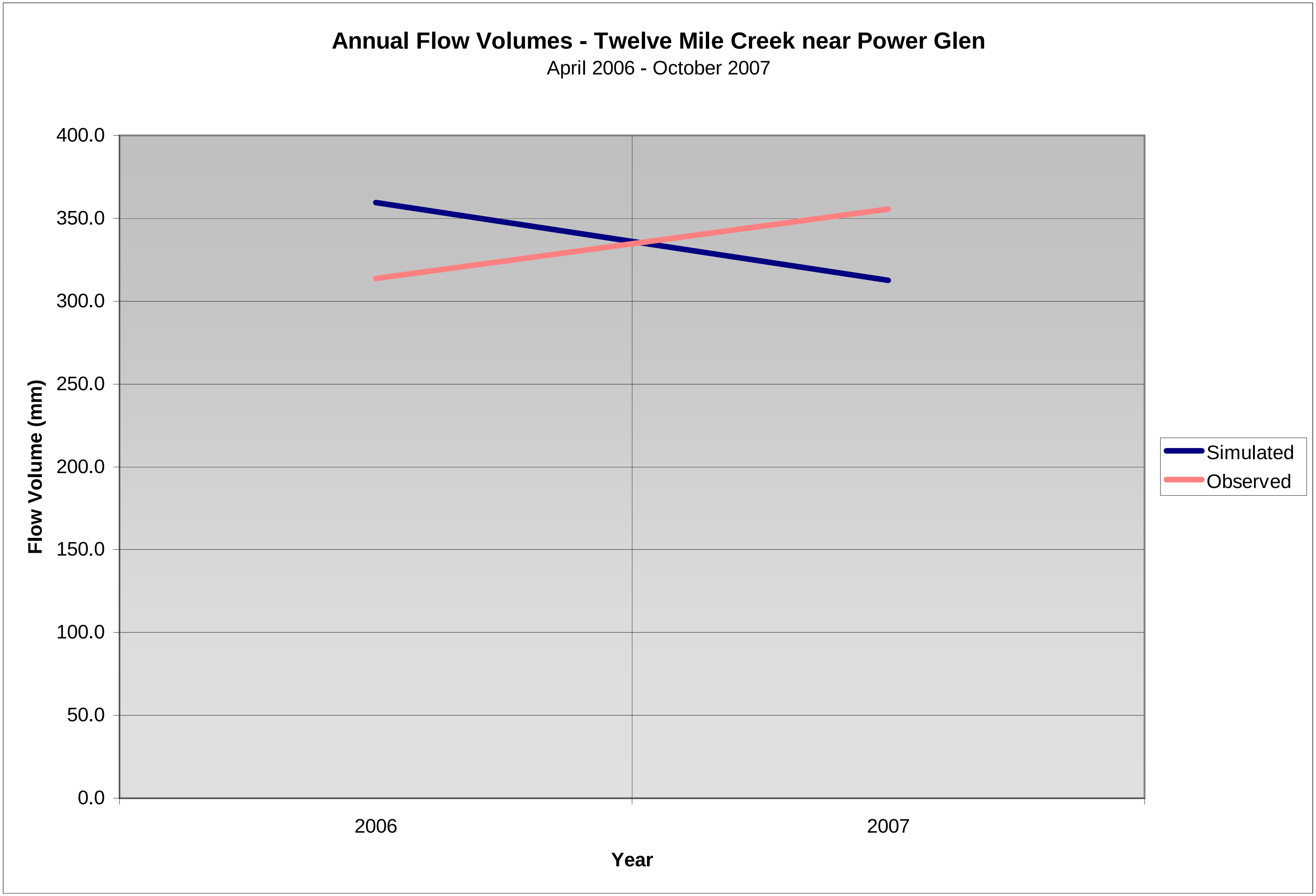
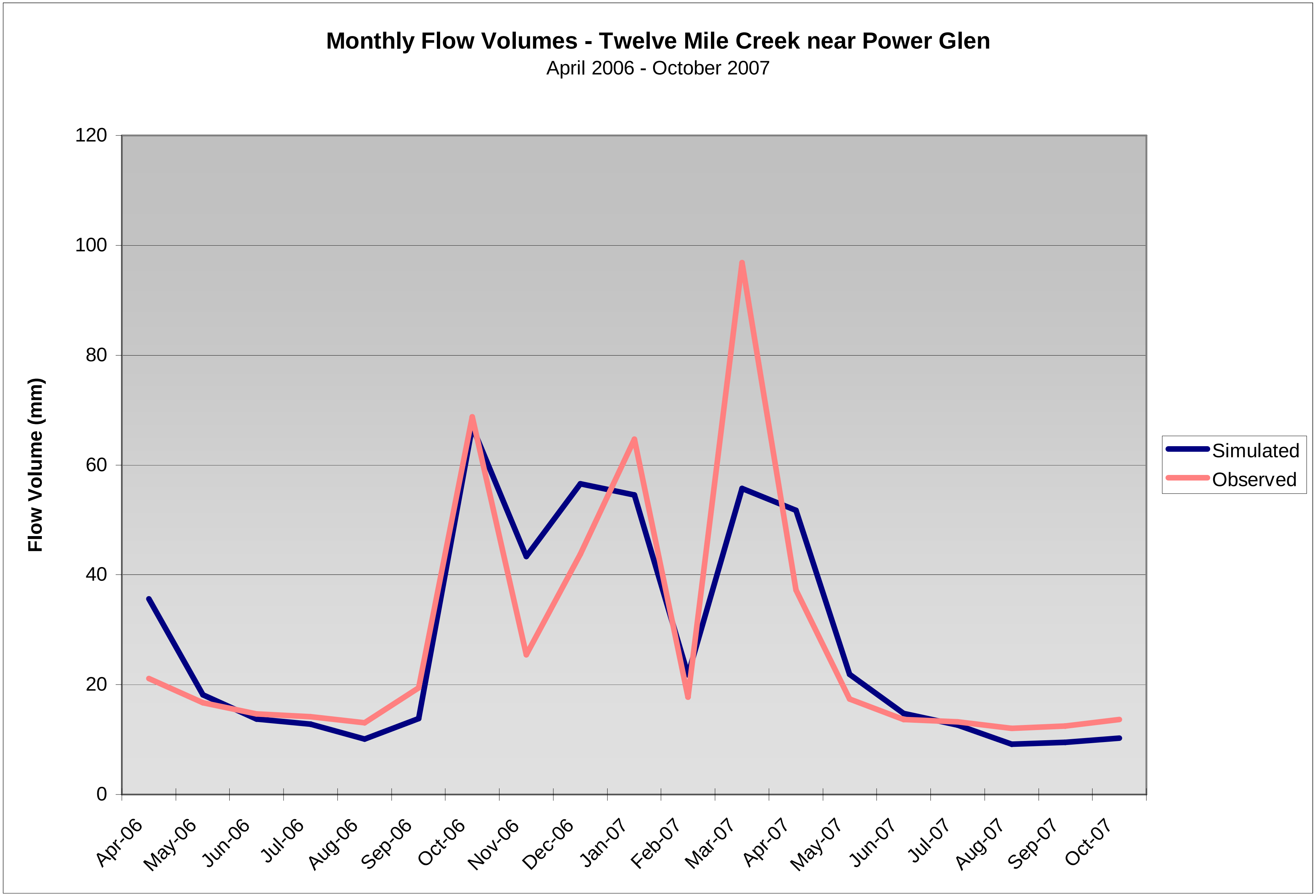

Annual Flow Volumes - Twelve Mile Creek near Power Glen
April 2006 - October 2007
400.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
Flow Volume (mm)
2006
2007
Year
Simulated
Observed

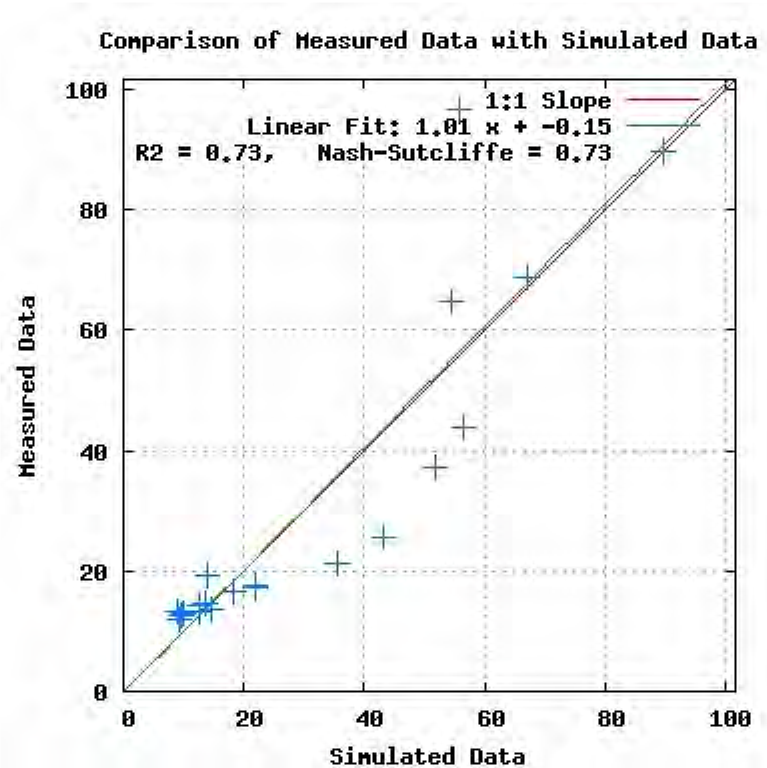
Figure 3.4



Monthly Flow Volumes - Twelve Mile Creek near Power Glen
April 2006 - October 2007
Flow Volume (mm)
0
20
40
60
80
100
120
Apr-06
May-06
Jun-06
Jul-06
Aug-06
Sep-06
Oct-06
Nov-06
Dec-06
Jan-07
Feb-07
Mar-07
Apr-07
May-07
Jun-07
Jul-07
Aug-07
Sep-07
Oct-07
Simulated
Observed


Figure 3.5

Streamflow




Log Streamflow

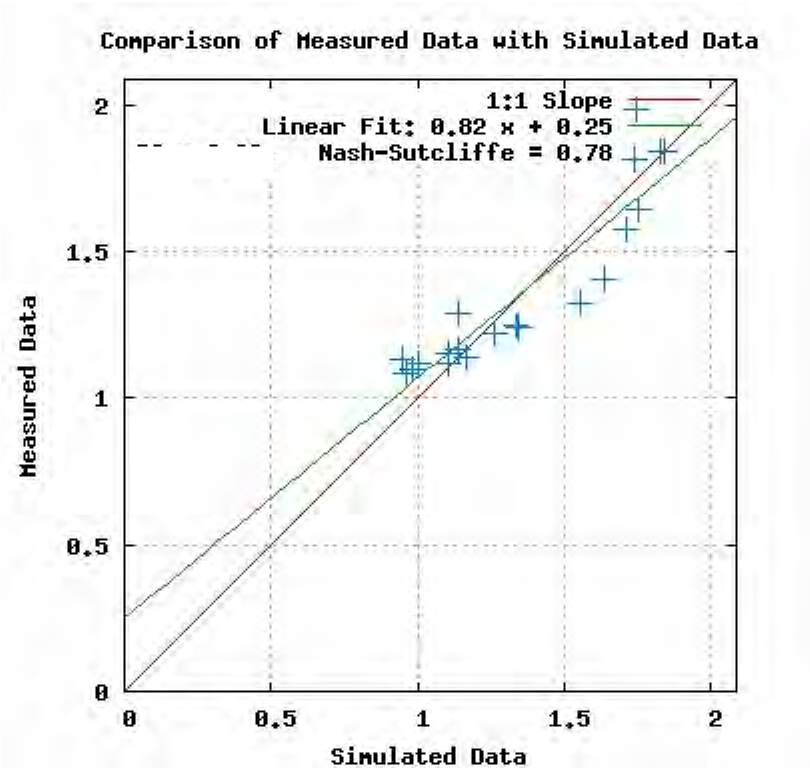



Figure 3.6 - Monthly Calibration Statistics,
Twelve Mile Creek near Power Glen,
April 2006 to October 2007

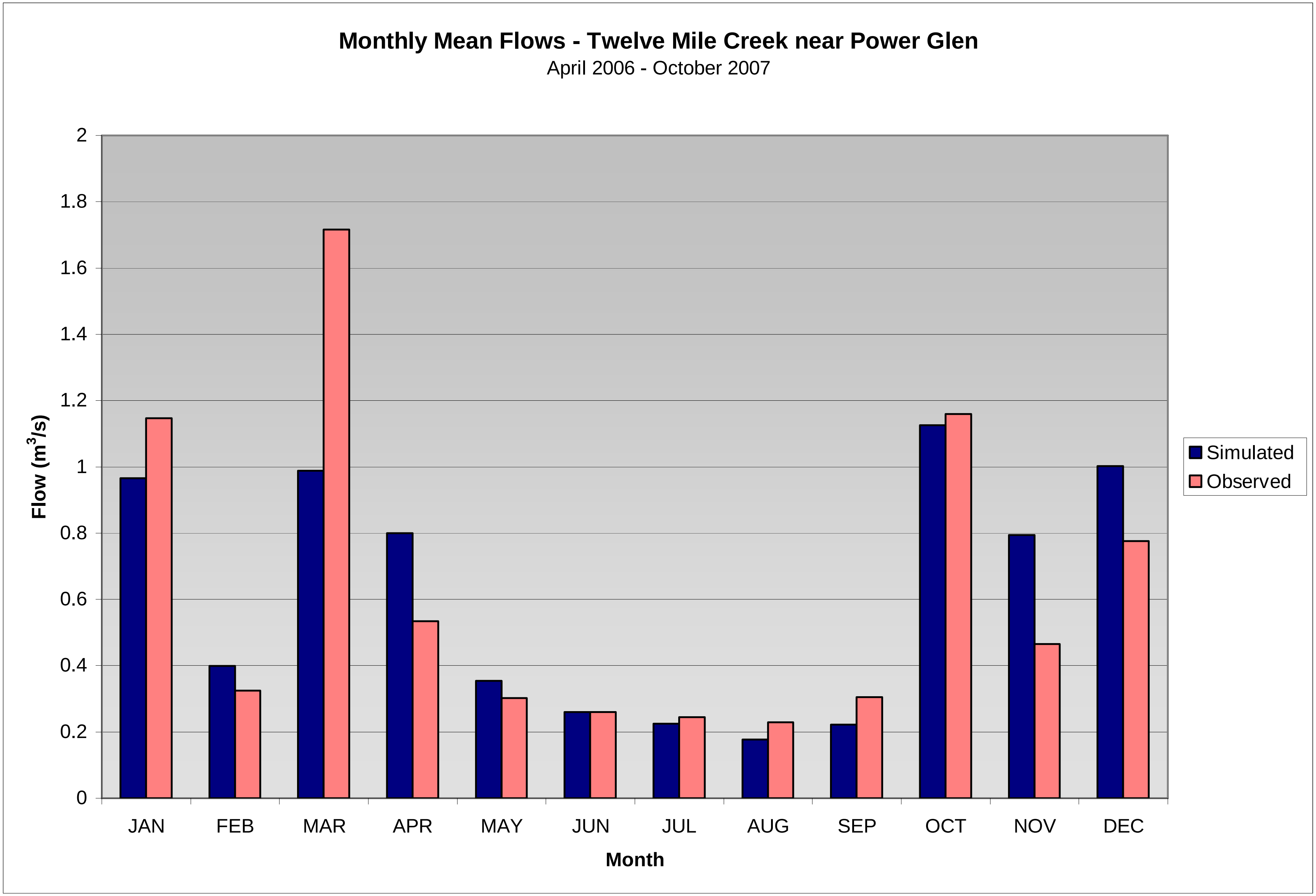

Monthly Mean Flows - Twelve Mile Creek near Power Glen
April 2006 - October 2007
Flow (m3/s)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
Month
Simulated
Observed

Figure 3.7

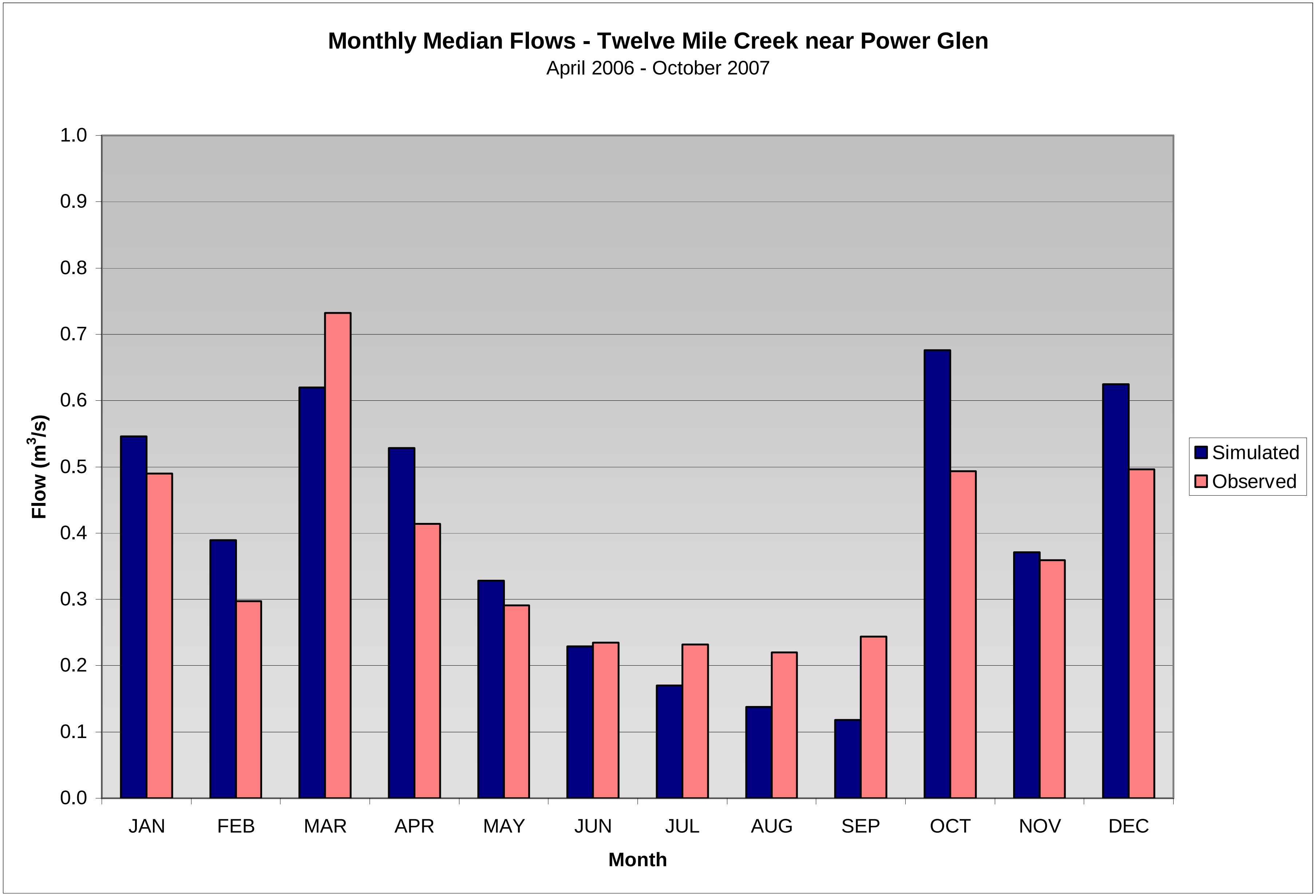
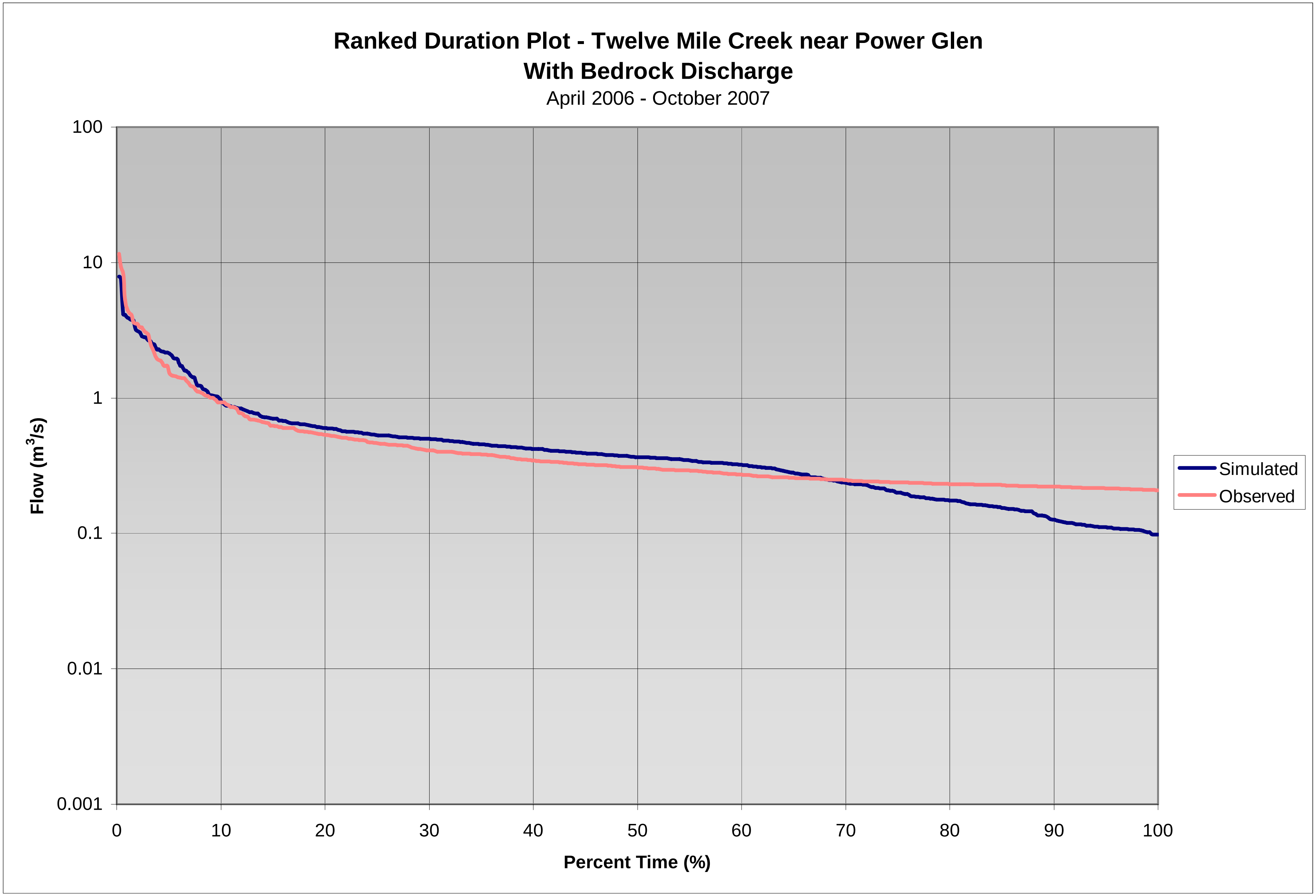

Monthly Median Flows - Twelve Mile Creek near Power Glen
April 2006 - October 2007
Flow (m3/s)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
Month
Simulated
Observed

Figure 3.8



Ranked Duration Plot - Twelve Mile Creek near Power Glen
With Bedrock Discharge
April 2006 - October 2007
100
10
1
0.1
0.01
0.001
Flow (m3/s)
0
10
20
30
40
50
60
70
80
90
100
Percent Time (%)
Simulated
Observed


Figure 3.9

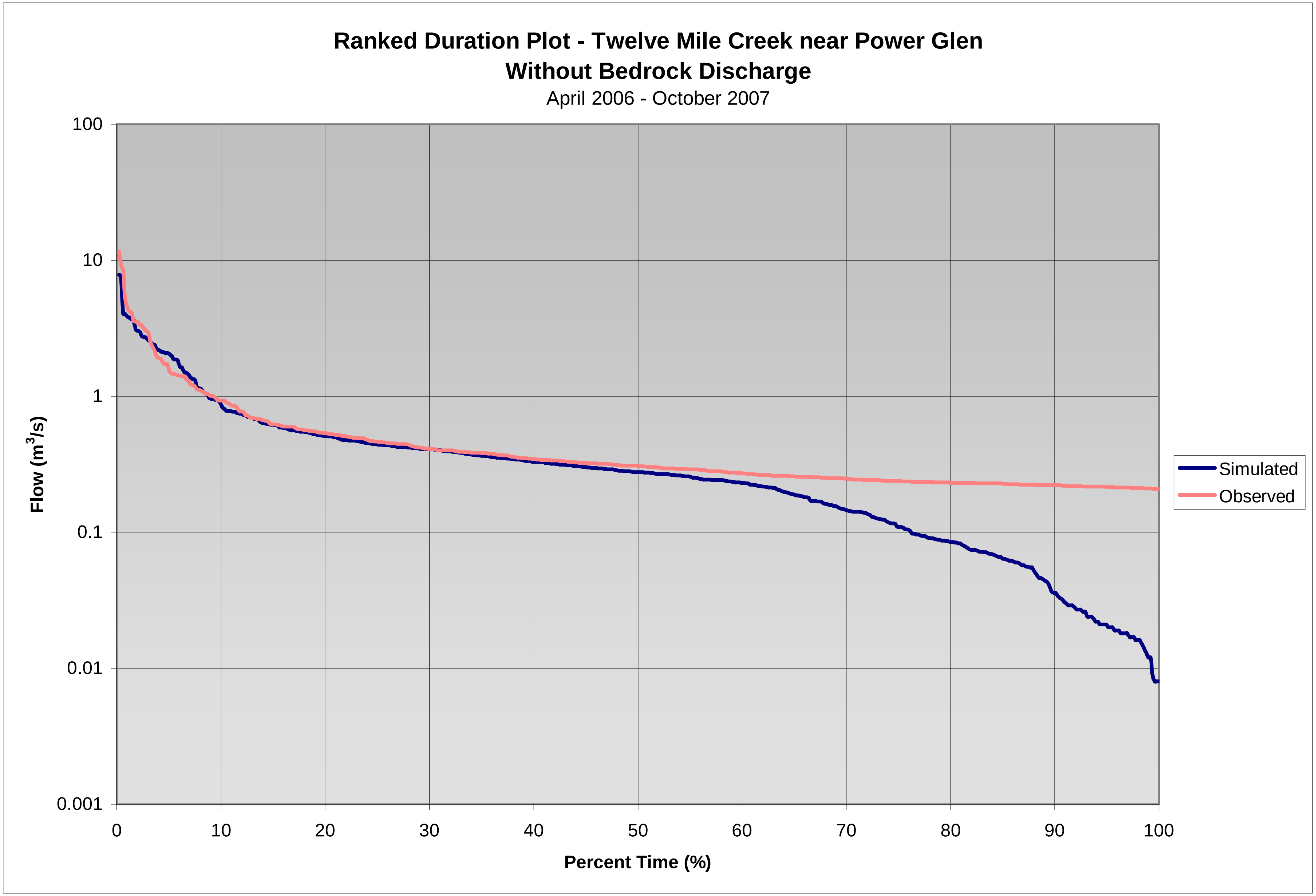

Ranked Duration Plot - Twelve Mile Creek near Power Glen
Without Bedrock Discharge
April 2006 - October 2007
100
10
1
0.1
0.01
0.001
Flow (m3/s)
0
10
20
30
40
50
60
70
80
90
100
Percent Time (%)
Simulated
Observed

Figure 3.10

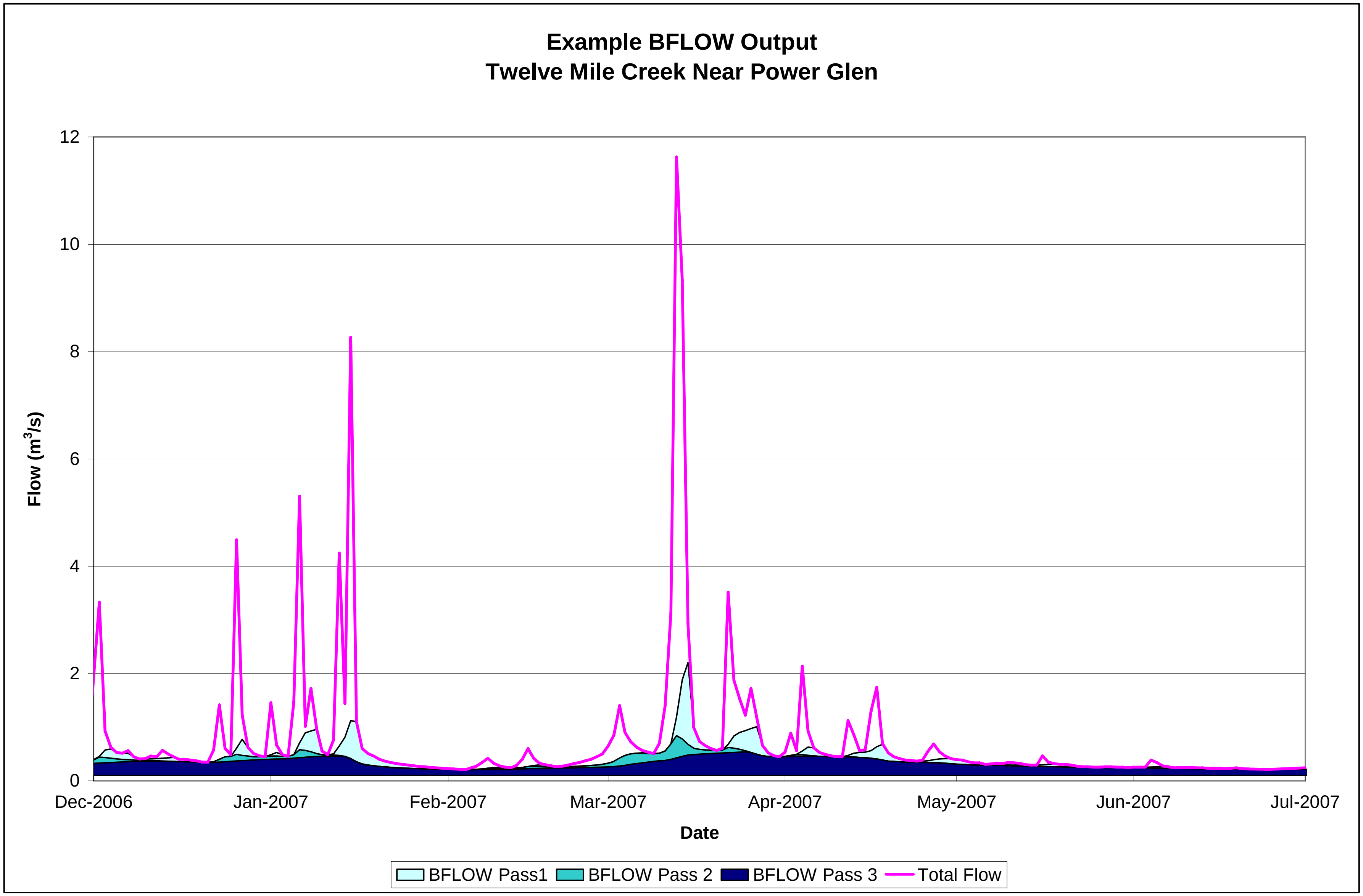
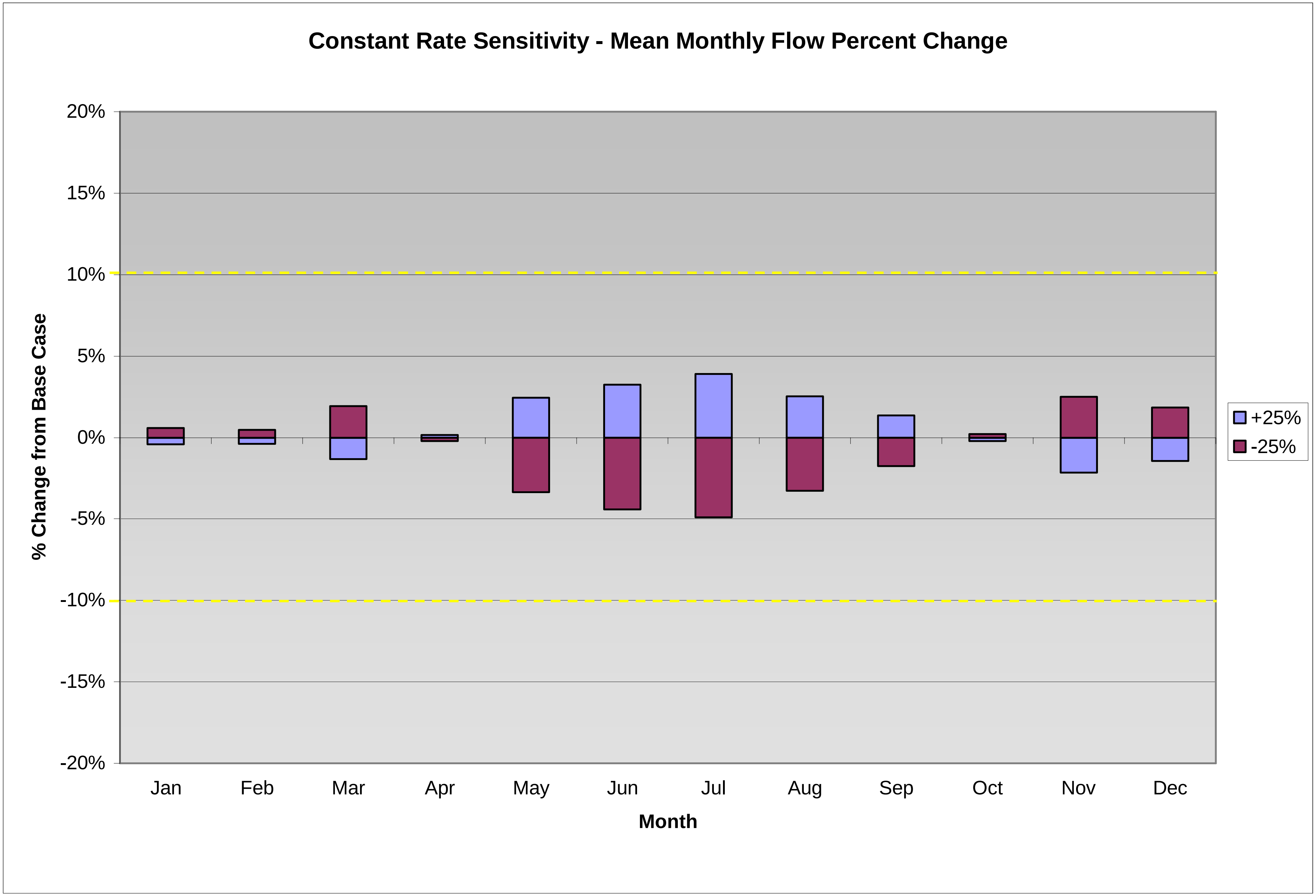
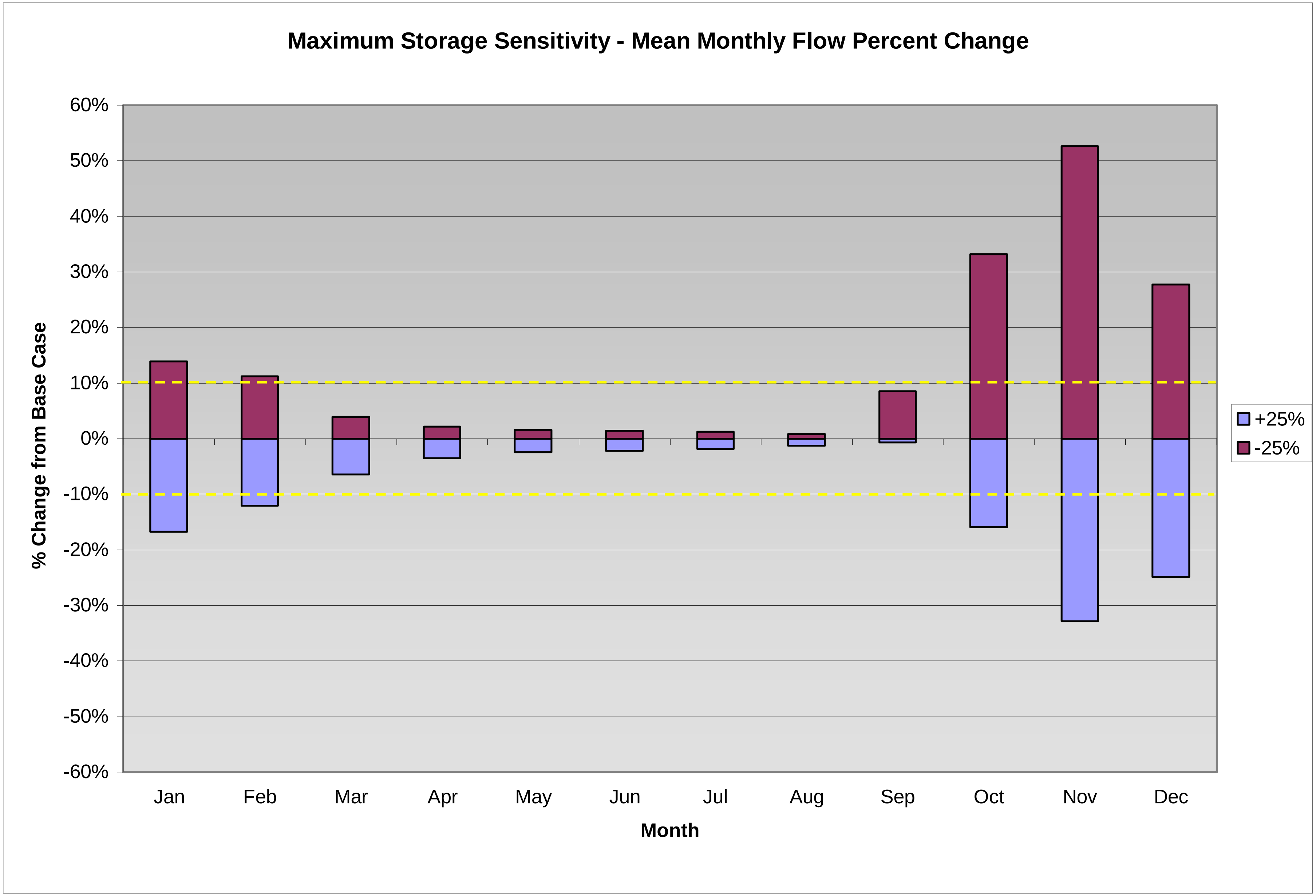



Figure 3.11
BFLOW Hydrograph Separation Example



Constant Rate Sensitivity - Mean Monthly Flow Percent Change
20%
15%
10%
5%
0%
-5%
-10%
-15%
-20%
% Change from Base Case
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
+25%
-25%


Figure 3.12



Maximum Storage Sensitivity - Mean Monthly Flow Percent Change
60%
50%
40%
30%
20%
10%
0%
-10%
-20%
-30%
-40%
-50%
-60%
% Change from Base Case
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
+25%
-25%


Figure 3.13

# Appendix A


# Snow Modeling can support our Snow Hydrology Goals

- Snow Accumulation
  - Estimation of the distribution of watershed snow water equivalent (SWE)
- Snow melt (Ablation)
  - Timing and magnitude of snowmelt

US Army Corps of Engineers

Engineer Research and Development Center

## Snow Modeling Approaches

- Regression – Relate final reservoir volume with observed index of SWE volume
  - Based on historical record
  - Large uncertainty
  - Susceptible to climate change impacts
- Numerical models of snowpack physics – simple to complex



## Numerical Snow Models
## Heat transfer from snowpack to environment

- Simulate each heat transfer mode (Complete energy balance)
  - Data intensive
  - Varies widely due to slope, aspect, vegetation , elevation, etc.
- Simplify heat transfer by considering only key meteorological parameters (temperature index)
  - Air temperature
  - precipitation

## Numerical Snow Models Representing snowpack physical properties

- Multi-layer snow packs
  - Each layer with separate properties
    - Temperature, Density, Liquid water
- Single Snow Layer
  - Average snow properties
    - SWE, Cold Content, Liquid Water, etc



## Temperature Index Snow model

- Often, complete energy budgets are difficult or impossible to estimate. A simpler method, based only on the air temperature, called the Temperature Index (degree-day) method has been developed. It has been widely used with good results.

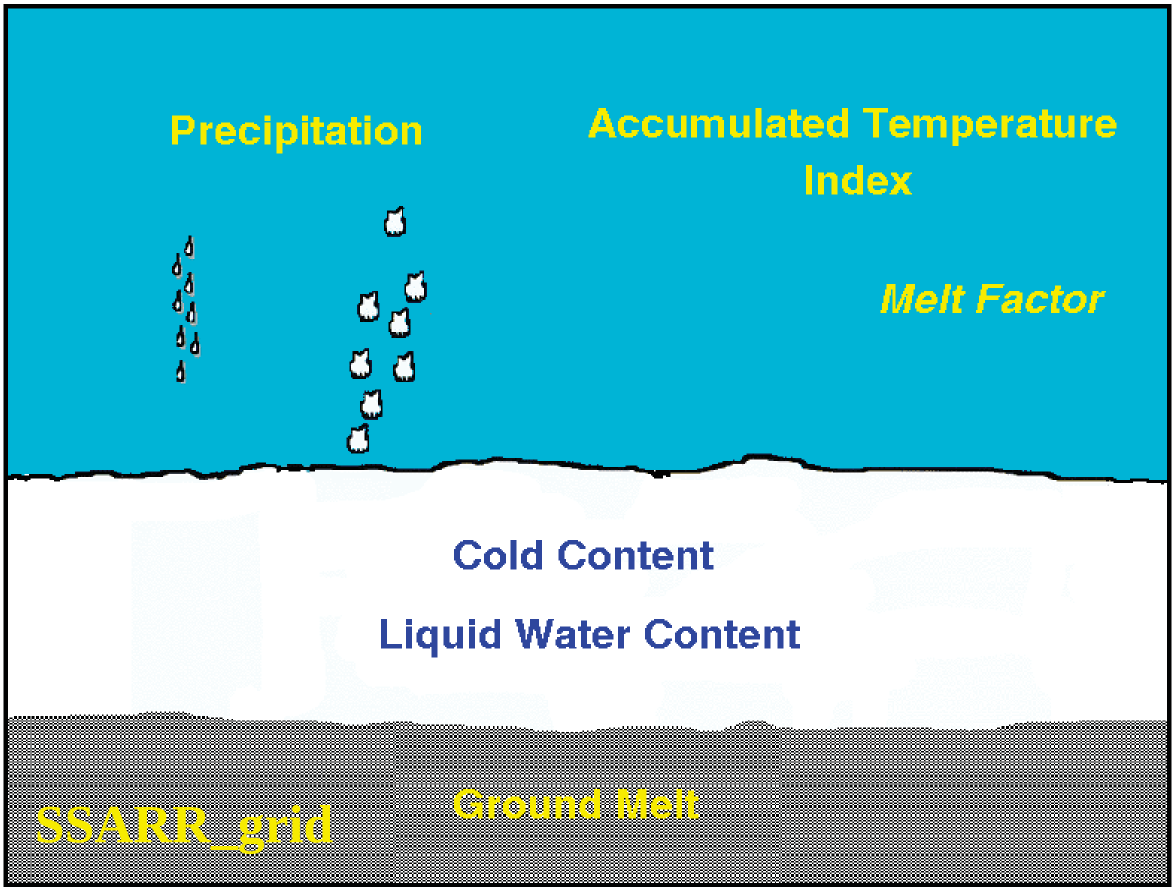
# Numerical Snow Models

- Energy Balance
  - Wind
  - Temperature
  - Water Vapor
  - Radiation (Net)
  - Precipitation
  - Advection (rain)
  - Ground
- Detailed (layered) snow pack
- Temperature Index
  - Temperature
  - Precipitation
- Single layer snow
  - SWE
  - Cold Content
  - Liquid water
- Calibration required



# Snowmelt Modeling in HMS

- Streamflow Synthesis And Reservoir Regulation – SSARR – North Pacific Division – NWD
  - Snow model, hydrology model, reservoir model for Pacific NW
- HEC-1 simple snow model
- SSARR snow model was made stand alone SSARR_grid
- SSARR_grid made into a distributed model Distributed Snow Process Model – DSPM
- SSARR_grid added to HEC-HMS




# Snowmelt Modeling in HMS

- Temperature Index
- Single snow Layer
  - Cold Content
  - Liquid water content
  - Ground melt

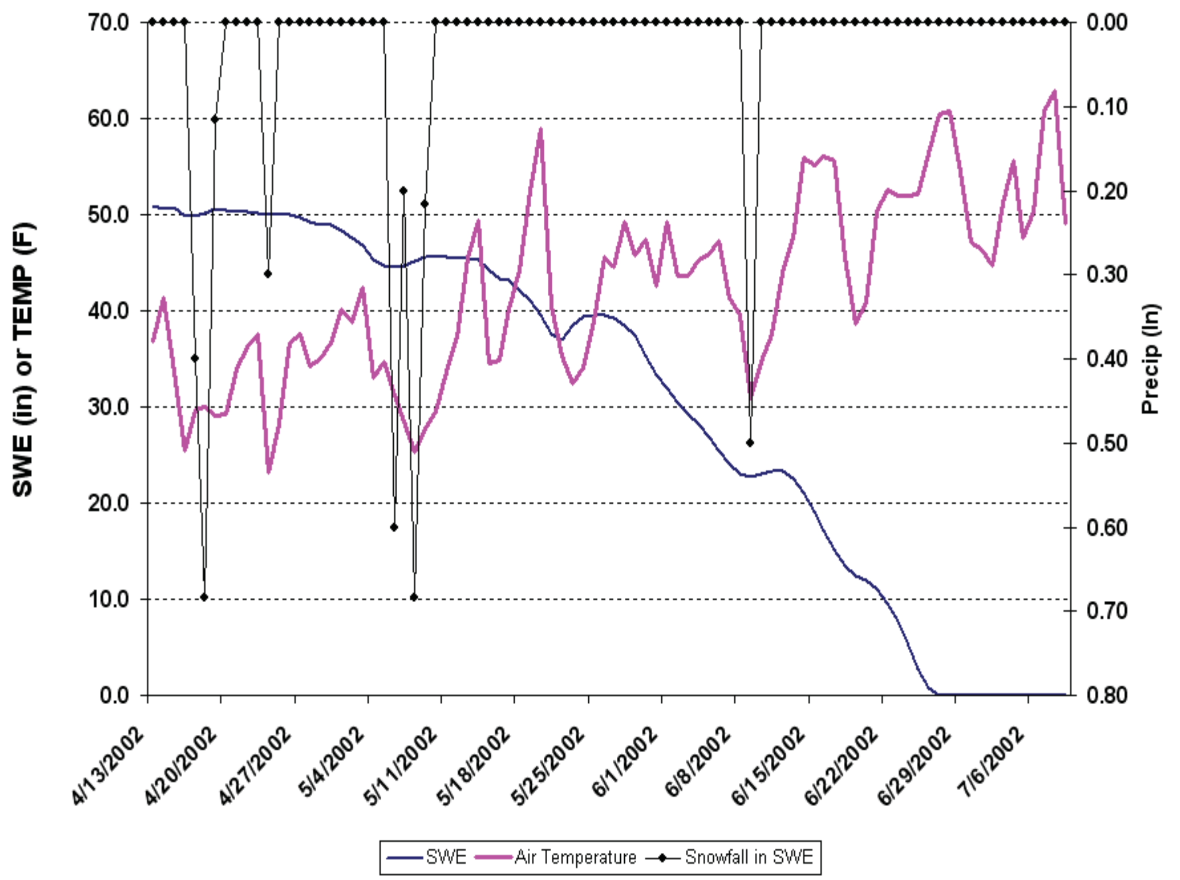
# Snowmelt Modeling in HMS

- Watershed
  - Uniform snow cover
    - Watershed temperature & precipitation
  - Elevation bands
    - Initial SWE
    - Temperature
- Distributed
  - Standard Hydrologic Grid 10m – 100km
  - Distributed air temperature & Precipitation

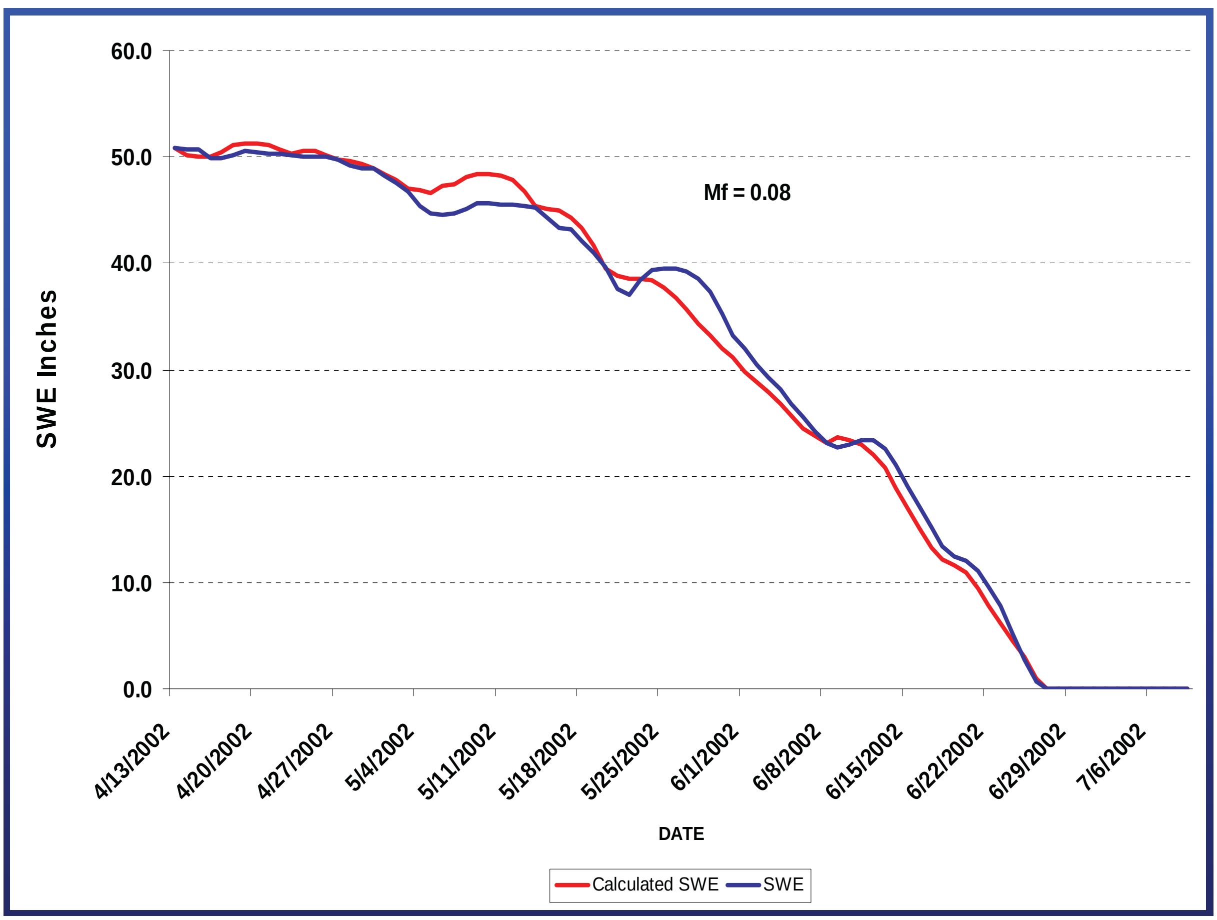


# Temperature Index Snow Model

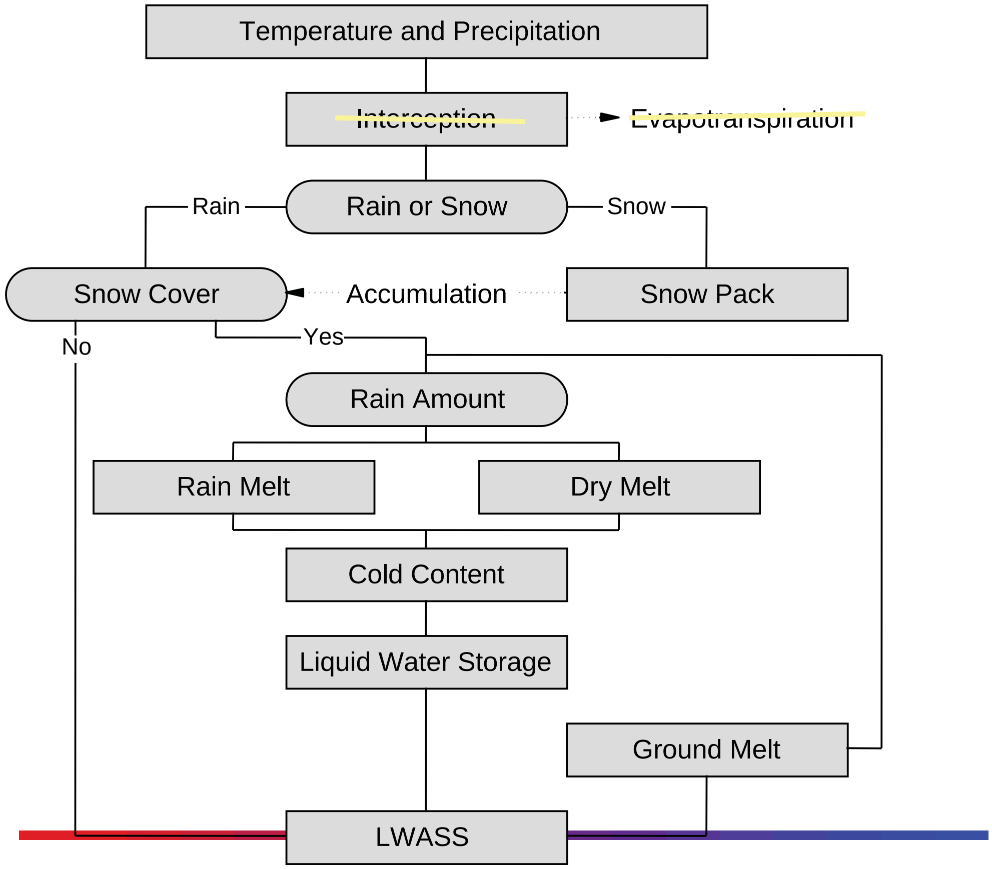
- Snow Melt is estimated as
  - $L_S = M_f (Ta - T_{base})$
  - Mf serves as an index of the total heat transfer at the snow surface which includes long wave, short wave, latent heat, and sensible heat transfer. Also strongly influenced by the wind speed, aspect, slope, vegetation, etc.
  - Mf can be a constant, or set as a function of the accumulated thawing days or set as a function of the month of year.



SWE (in) or TEMP (F)
Precip (In)
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
4/13/2002
4/20/2002
4/27/2002
5/4/2002
5/11/2002
5/18/2002
5/25/2002
6/1/2002
6/8/2002
6/15/2002
6/22/2002
6/29/2002
7/6/2002
SWE
Air Temperature
Snowfall in SWE

SWE Inches
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Mf = 0.08
4/13/2002
4/20/2002
4/27/2002
5/4/2002
5/11/2002
5/18/2002
5/25/2002
6/1/2002
6/8/2002
6/15/2002
6/22/2002
6/29/2002
7/6/2002
DATE
Calculated SWE
SWE




Daly-011

# Given precipitation and air temperature for time step

## Discriminate between rain and snow using PX temperature

- PX The discrimination temperature between precipitation falling as rain or snow. When the air temperature is less than the specified PX temperature, any precipitation is assumed to be snow. When the air temperature is above the specified PX temperature, any precipitation is assumed to be rain. This discrimination temperature is usually one to two degrees above freezing.

## Given precipitation and air temperature for time step

**Discriminate between melt and non-melt using Base temperature**

- **Base Temperature**. The difference between the base temperature and the air temperature defines the temperature index used in calculating snowmelt. The meltrate is multiplied by the difference between the air temperature and the base temperature to estimate the snowmelt amount. If the air temperature is less than the base temperature, then the amount of melt is assumed to be zero. Typically, the base temperature should be 32F (0C) or close to it.



## Given precipitation and air temperature for time step

**Discriminate between melt and non-melt using Base temperature**

- $T < T_{base}$ - No Melt
  - SWE accumulates $T < PX$; $P > 0$
- $T > T_{base}$ - Melt

# $T > T_{base}$ - Melt

**Discriminate between rain melt and dry-melt using rain rate limit**

- ***The rain rate limit***. The discrimination rain rate in inches/day between dry melt and wet melt. The wet meltrate is applied as the meltrate when it is raining at rates greater than the rain rate limit. If the rain rate is less than the rain rate limit, the meltrate is computed as if there were no precipitation.



# Meltfactor

$$L_S = M_f\,(Ta - T_{base})$$

- **Meltfactor** can be constant or variable with time. A variable **meltfactor** recognizes that as snowpack matures the heat transfer rates change AND/OR different components of heat transfer change in importance.

# Meltfactor

- ATIMR The seasonal variation of melt rate is indexed by an antecedent temperature function (ATIMR). The initial melt ATI should be thought of as similar to "the accumulated thawing degree days." This antecedent temperature function allows the melt rate to change as the snowpack matures and ages.
- ATIMR_Die_away Coefficient for updating the antecedent temperature indexATI_MeltRate_out. Typical value is .98



# ATIMR Algorithm

- ATIMR_out = (ATIMR_in * (ATIMR_Die_away ** days) ) + ((Temperature - $T_{base}$) * days)
- IF(ATIMR_out .LT. 0.) THEN ATIMR_out = 0.
- Essentially, ATIMR accumulates as long as T> $T_{base}$

# Melt Factor

- ATI-melt function. Meltrates associated with ATIMR values in inches per degree-day. Typical range of values is 0.015-0.055. The pattern must be entered in the Paired Data Manager.
- Melt pattern. An alternate method of entering the meltrates as a function of the month of year. The pattern must be entered in the Paired Data Manager.



# Typical Melt Factors

- 0.04-0.08 inches/F-day
- 1.8-3.7 mm/C-day
  - Average daily temperature
  - No rain
  - Not heavily forested
  - No extreme conditions – high winds, etc
- Thin ephemeral snowpacks that melt out in a very short time may have a constant melt factor

# Temperature Index Snow Model

- Rain melt
  - Snow melt that occurs when the air temperature is above the snow/rain temperature and the precipitation rate is significant. Rain is assumed to fall at the air temperature
  - Melt from rain and condensation of water vapor in the snowpack.



# $T > T_{base}$ - Melt

- **SWE > 0**
- **Potential melt is estimated using temperature index and melt factor**
- **Melt is first applied to Cold Content. When Cold Content is zero…….**
- **Melt is then applied to liquid water storage. When maximum liquid water storage is reached ……**
- **LWASS is generated. SWE is reduced.**

## Cold Content

- Cold Content
  - Heat required per unit area to raise temperature of snowpack to 32°F (0°C)
    - Snow Depth x Snow Density x Heat Capacity of Snow x (Temperature below freezing)
  - Usually expressed in as a negative number equivalent to inches of frozen water
    - Cold content /( Density of water x latent heat of water)



## Cold Content -Parameters

- *ATICC*. The ATICC is an index to the snow temperature near the surface. It is calculated assuming an approximation to the transient heat flow equations. This value is used to estimate the cold content of the snow. It should be set to the approximate snowpack temperature if known. If not known, it can be set to 32F (0C).
- ATICC_die_away. Coefficient for updating the antecedent temperature index ATI_ColdContent_out. Typical value .84

# ATICC Algorithm

- ATICC_out = ATICC_in +(ATICC_Die_away ** (24./TimeStepHours) ) *(Temperature - ATICC_in)
- IF(ATICC_out .GT. $T_{base}$) THEN ATICC_out = $T_{base}$



# Cold Content -Parameters

- ATI cold function. Cold rates associated with the ATIMR values, in inches per degree-day. Typical range of values is 0.010-0.025. The pattern must be entered in the Paired Data Manager.
- interval_Cold = (Temperature - ATICC_out) *coldRate / 24.
- ColdContent_out = ColdContent_in + interval_Cold *TimeStepHours

# Cold Content-Parameters

- ATICC_Snow_MAX. Precipitation rate, inches per hour. If the precipitation rate exceeds ATICC_Snow_MAX, the antecedent coldness index ATICC is set to the temperature of the precipitation (or the base temperature, which ever is lower) If the precipitation rate is less than ATICC_Snow_MAX, ATICC is computed as an antecedent index. Typical value is (.8 inches/day)



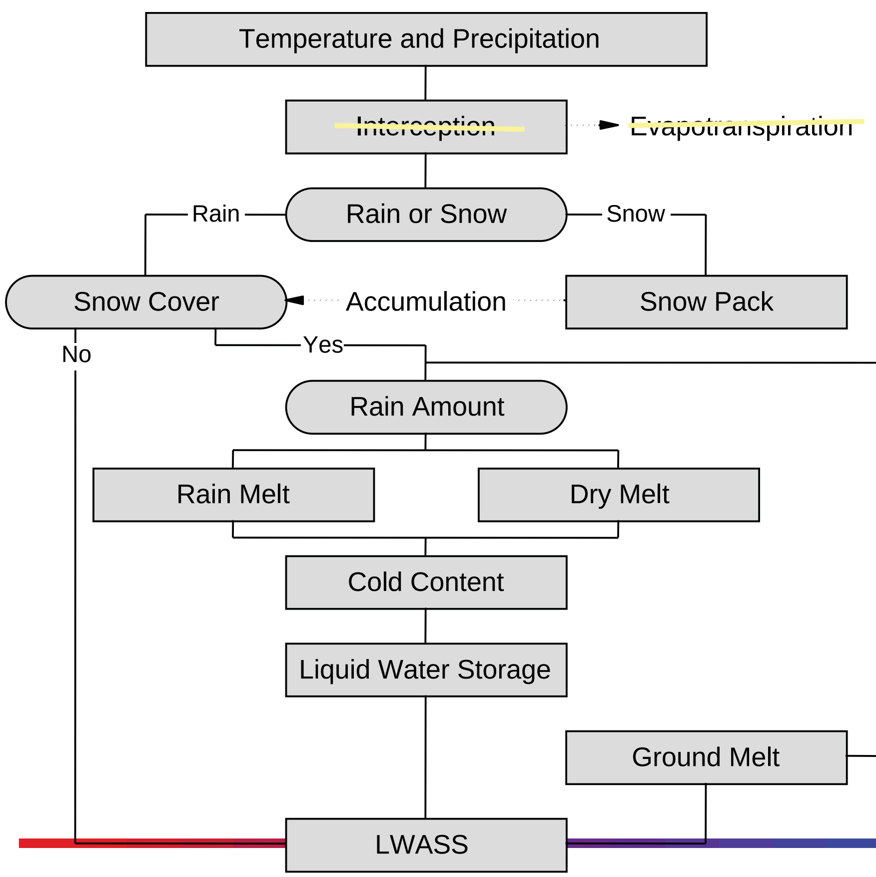
# Liquid Water Storage -Parameters

- Maximum liquid water capacity. The maximum liquid water capacity specifies the amount of melted water that must accumulate in the snowpack before liquid water becomes available at the soil surface for infiltration or runoff. Typically, the maximum liquid water held in the snowpack is on the order of 3%-5% of the SWE, although it can be higher. Liquid water can persist in the snow only if the snowpack temperature is at 32F (0C); at which point the cold content is zero.

# Ground Melt

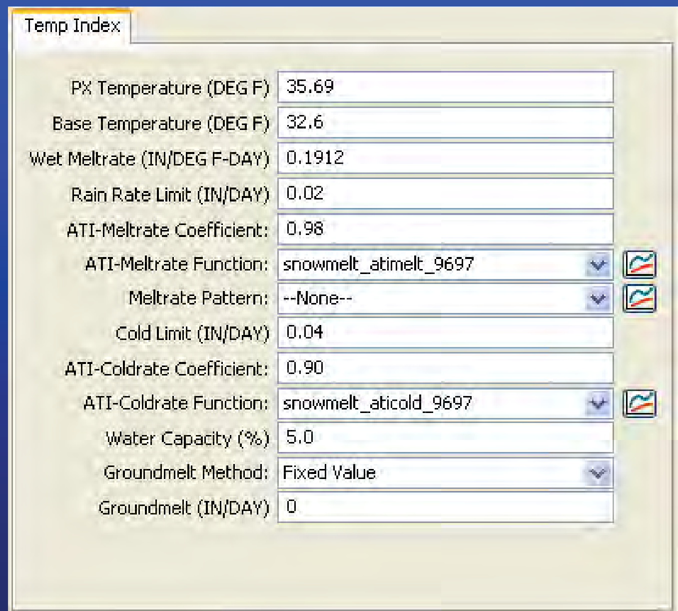
- Snow melt that occurs due to heat from the ground beneath the snowpack. Almost always set to zero, especially for relatively shallow, seasonal snow covers (SWE<12 inches)





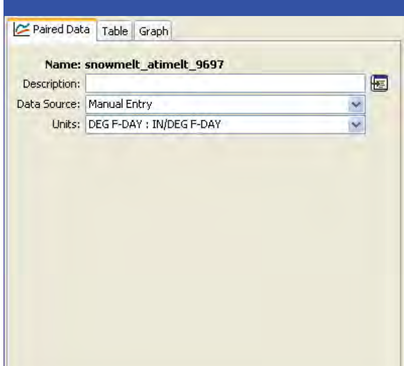

Daly-011

# Entering Snow Parameters in HMS



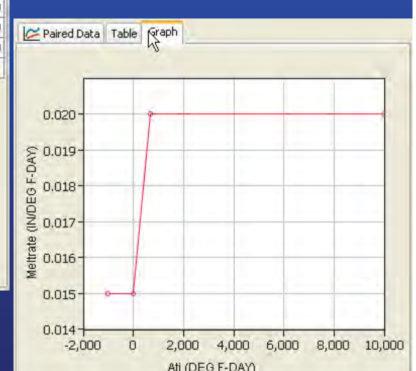


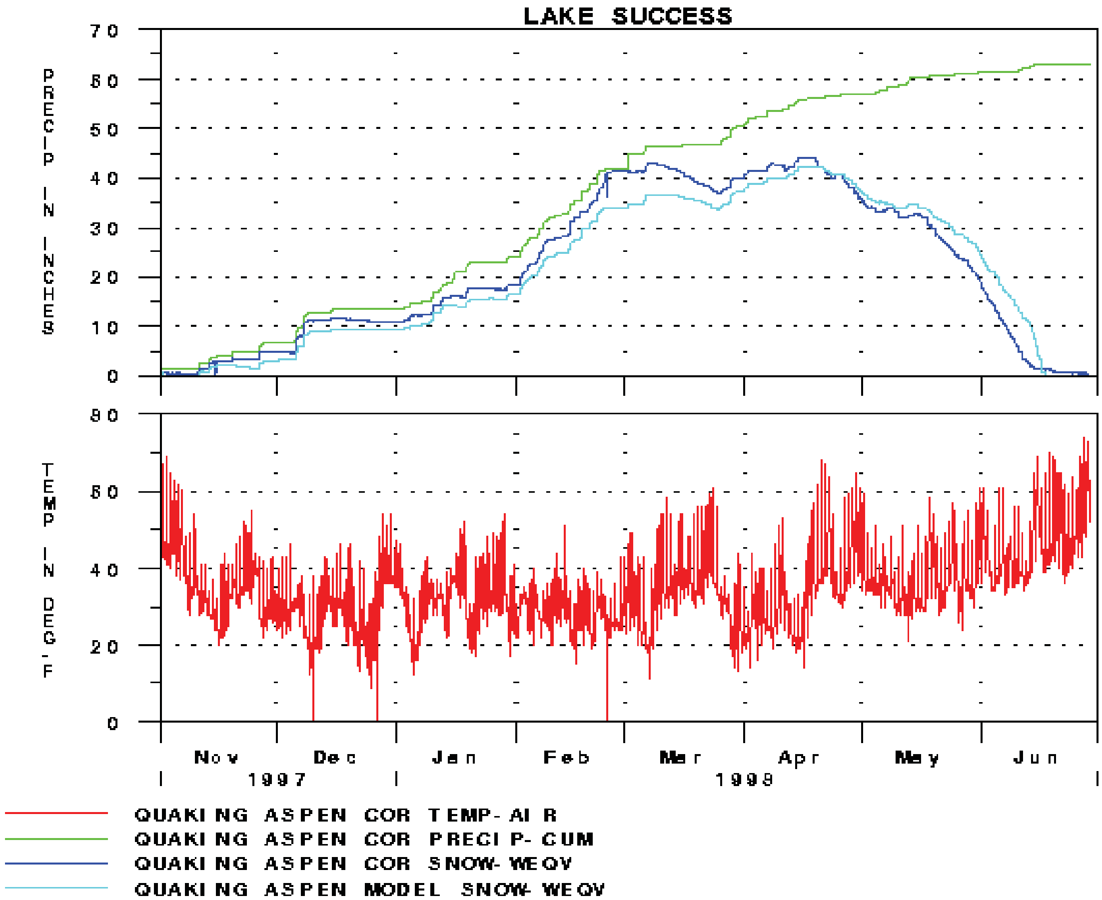

# Entering Paired Data

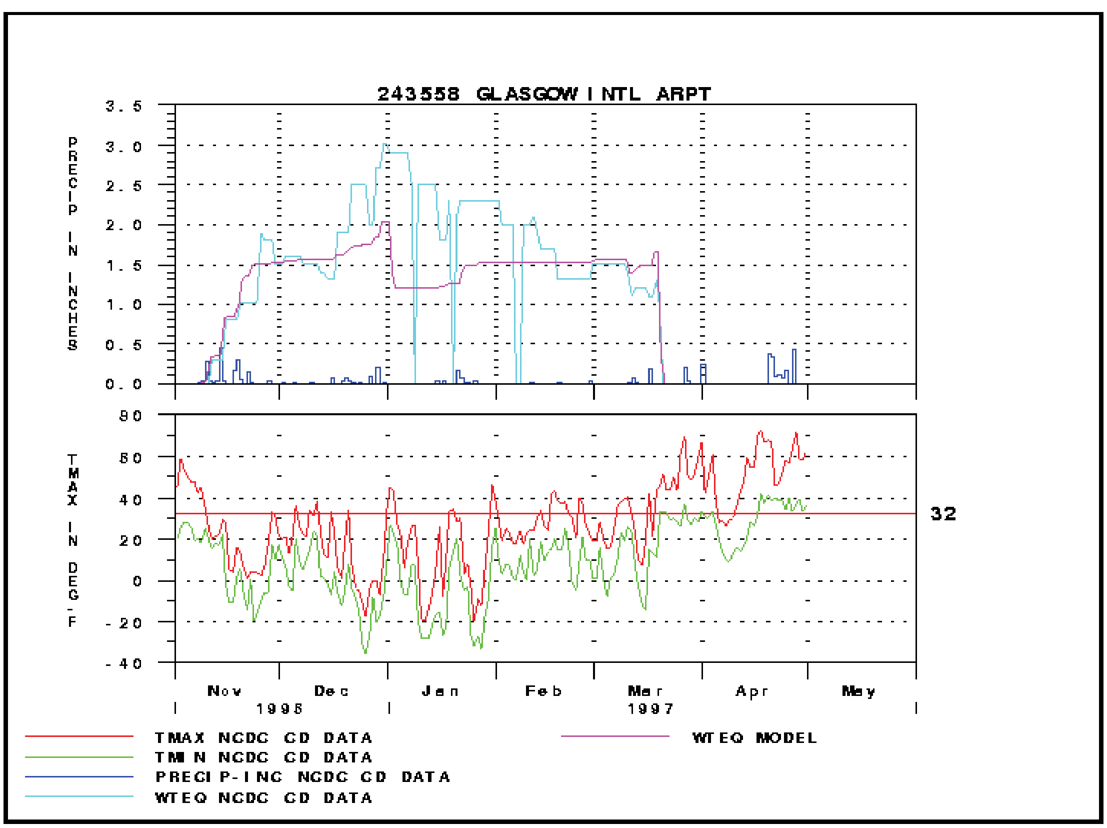




| Ati (DEG F-DAY) | Meltrate (IN/DEG F-DAY) |
|---|---|
| -1000.00 | 0.0150000 |
| 0.00 | 0.0150000 |
| 673.20 | 0.0200000 |
| 9999.00 | 0.0200000 |




LAKE SUCCESS
PRECIP IN INCHES
TEMP IN DEG. F
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
1997
1998
QUAKING ASPEN COR TEMP-AIR
QUAKING ASPEN COR PRECIP-CUM
QUAKING ASPEN COR SNOW-WEQV
QUAKING ASPEN MODEL SNOW-WEQV


243558 GLASGOW INTL ARPT
PRECIP IN INCHES
TMAX IN DEG. F
32
Nov
Dec
Jan
Feb
Mar
Apr
May
1996
1997
TMAX NCDC CD DATA
TMIN NCDC CD DATA
PRECIP-INC NCDC CD DATA
WTEQ NCDC CD DATA
WTEQ MODEL

# Summary -Terms

- Temperature Index Snow Model
- Complete Energy Budget Snow Model
- Snow Water Equivalent (SWE)
- Cold Content
- Snow Liquid Water Storage
- PX
- Base Temperature
- Rain Rate Limit
- Melt factor
- ATIMR
- Rain melt
- LWASS
- ATICC
- Maximum Liquid Water Capacity
- Ground melt

# Appendix B

## GeoHMS Processing

With the wide availability of Geographic Information System (GIS) data layers for the study area, a good proportion of the model set up and parameterization was achieved using ArcHydro, and HEC-GeoHMS, which are publicly available ArcGIS extensions. The primary GIS data sources for the study consisted of a high resolution (3m) Digital Elevation Model (DEM) and stream layer produced by the Niagara Peninsula Conservation Authority; Southern Ontario Land Resource Information System (SOLRIS) land cover layer (Version 2) produced by the Ontario Ministry of Natural Resources (2006) and soils layer obtained from the Ontario Ministry of Agriculture and Food (Niagara Region 1989, Haldimand County 1984, Hamilton-Wentworth 1965). These layers were further processed in a GIS to produce the required HEC HMS model inputs.

## Primary GIS layers processing

The digital soil layer from OMAF aggregates county-based soils maps onto a seamless and standardized product. Included in the product are three tables (soil component, soil name file, soil layer file) that can be relationally linked to the spatial data. The soils component attribute table maintains 17 variables for each soil component, which includes a multifaceted variety of soil and soil-related data. Based on their ability to drain precipitation inputs, soils can be categorized into 4 Hydrologic Soil Groups (HSG) ranging from A to D (Appendix C). HSG A soils have the highest infiltration rates, while HSG D soils have the lowest infiltration rates. Each map unit polygon in the component table can be comprised of up to 2 different (HSG) that contribute to the total area of the map unit. The area occupied by each HSG is represented as a percent of the map unit. However, there is no specific information on the location of the individual HSB within any polygon. For example, a BRADY soil series map unit can be comprised of 70 % HSG (A) and 30 % HSG (B). To avail ourselves with the most detailed information for the study, all HEC-HMS model parameter calculations dependent upon HSG were percent-weighted based on HSG.

SOLRIS is a primary data layer that provides a comprehensive landscape level inventory of land use for the study area. The SOLRIS land use classes for the study area are provided in Appendix II. The version in use in this study groups agricultural crop such as corn, grains, wheat, alfalfa, and soybeans into broad agricultural land use classes such as monoculture and annual crops. The level of detail was insufficient for the application of crop specific coefficients required as input for the evapotranspiration calculations in the Priestly-Taylor method used in HEC-HMS. Statistic Canada field crop data (percent by type) at the census consolidated subdivision level was used as a weight to calculate composite crop coefficient values for the SOLRIS agricultural land use classes.

**Derivative GIS layer processing**

Setting up the model required the user to select methods to simulate infiltration losses, transform excess precipitation into runoff, represent baseflow contribution to subbasin outflow, and simulate flow in open channels. Each method requires one or more parameters that describe the state of each catchment and allow the model to simulate the hydrologic processes. Table 1 shows the simulation methods used and the required GIS derived parameters. With the exception of the crop coefficient, channel bottom width, and channel side slope all vector products were converted to a 15m raster-based product.

Table 1. HEC-HMS simulation methods used

| Category | Method | Required GIS Parameter |
|---|---|---|
| Loss | Deficit and Constant | Soil Water Holding Capacity<br>Soil maximum infiltration rate<br>Crop Coefficient (Priestly Taylor) |
| Transform | SCS Unit Hydrograph | CN, Initial Abstraction, Lag Time |
| Baseflow | Linear Reservoir | N/A |
| Routing | Muskingum-Cunge | Channel Side Slope, Channel Bottom Width |

**Constant infiltration rates**

The deficit and constant loss method assumes that the soil has a set maximum infiltration rate approximated by the saturated soil hydraulic conductivity. Using the information in Appendix C, average maximum infiltration rates were assigned to each polygon in the soil layer based on their HSG.

**Soil water holding capacity**

In the simulation, the soil is also assumed to have a fixed water holding capacity, typically affected by the active rooting depth of vegetation and HSG. The soil water holding capacity layer was built by intersecting the SOLRIS land cover and the OMAF soils layers and by assigning soil water holding capacity values from Appendix C to each unique combination of land cover class and soil HSG. OMAF polygons mapped as urban were not included in the procedure; imperviousness is addressed later.

**Crop Coefficient**

In the deficit constant method, water is removed from the soil to simulate evapotranspiration. In the model, evapotranspiration was calculated through the Priestly-Taylor. This method requires the use of crop coefficient $K_c$, which indicates the ratio of crop potential and grass reference evapotranspiration. Land use layers were created for each day of the year and daily crop coefficients from Appendix D were assigned to the land use classes.

## CN grid

CN values are used in the calculation of CN lag time for the SCS Unit Hydrograph transform method. The factors influencing CN values are land cover type, HSG, and Antecedent Soil Moisture Condition (AMC). AMC is an estimate of soil water content prior to the beginning of the simulation period. AMC I reflect soils that are dry but with water content not below the wilting point. AMC II reflects soils having average soil water content, and AMC III reflects soils that have experienced rainfall in the five days previous to the beginning of the simulation period. CN values in the study area were assumed to reflect average soil water content. The CN layer was built by intersecting the SOLRIS land cover and OMAF soil layer and by assigning CN values from Appendix II to each unique combination of land use class and HSG. CN values were not assigned for built-up impervious, built-up pervious, transportation or open water SOLRIS land cover types.

## Impervious

HEC-HMS considers an impervious surface as an area in a watershed for which all contributing precipitation runs off, with no infiltration, evaporation, or other volume losses. This surface was built by assigning percentages of 100, 100 and 50 to the transportation, built-up impervious and built-up pervious polygons respectively. All other polygons were assigned a value of 0.

## Channel width and side slope

In the model the traditional Muskingum-Cunge routing method was used assuming trapezoidal channel geometry. The method requires the input of channel bottom width, channel side slope, and channel manning roughness coefficient. Channel width for each of the routing reaches was estimated by digitizing cross sections across the channel assuming that the extent (i.e. width) of the water surface on the digital air photos roughly approximates the width of the channel bed. Channel side slope was approximated by digitizing two points at the end of each digitized channel width cross sections using a 2m resolution DEM as a guide. Appropriate channel Manning roughness coefficients from Appendix C were assigned to channel routing reaches following visual channel stream bed condition assessment from 10 and 20 cm resolution digital air photos.

The GIS approach to building a HEC HMS model is generally done in two phases: the terrain processing phase and the model parameterization phase. These are described below.

## Terrain Processing

The terrain processing phase requires a terrain model that is hydrologically correct. The terrain is created by integrating a fully connected dendritic stream network into a DEM. This process can be summarized as follows: 1) rasterization of the vector stream network to the same resolution as the DEM, 2) reclassifying the rasterized stream network by assigning an arbitrary elevation (i.e. 50) value to the cells of the stream network. 3) Subtracting the reclassified grid from the DEM. This has the effect of decreasing the elevation of all DEM cells underlying the stream network by the aforementioned elevation value (50 m). 4) Filling the DEM sinks, thus ensuring that no water is trapped in DEM depressions and that all DEM cells drain to the outlet.

The next steps are the creation of two terrain derivatives from the filled DEM and a series of processing steps to delineate the watershed subbasins. These are performed using the ArcHydro Tools and are briefly outlined below:

1) Flow direction grid: Shows the orientation of the DEM cell's to its neighbour steepest down slope.

2) Flow accumulation grid: Indicates the number of upstream cells draining to each DEM cell.

3) Stream definition: The flow accumulation grid was then used to produce a synthetic stream network by applying a suitable area threshold value. The area threshold value indicates the minimum upstream area required to initiate a synthetic stream network. A 500 ha threshold value was selected so that average catchment size in the study was between 5 and 10 $km^2$ and lag time for most of these catchments greater than 2 hrs.

4) Stream segmentation: The synthetic stream network is divided at the synthetic stream network confluences. All cells belonging to each stream segment are assigned a unique value.

5) Catchment Grid Delineation: This step generates a grid representation of a subbasin for each stream segment. All cells belonging to a subbasin are assigned a unique number.

6) Catchment Polygon Processing: This step converts the grid representation of the subbasin to a vector representation

7) Drainage line processing: This step converts the grid representation of the segmented synthetic stream network into a vector representation.

8) Adjoint catchment processing: This step aggregates the upstream subbasins at every stream confluence. This step has no hydrological significance and is done to increase the performance of the point delineation process.

**Hydrologic Model Creation**

Once the terrain processing is completed, the data required to support model creation and model parameterization can be extracted for the study area using the HEC-GeoHMS tools. The main steps are HEC-HMS model set up, Watershed subbasin boundary refinement and model parameterization. These steps are briefly outlined below.

**HEC-HMS model set up**

An HEC-HMS project is created by specifying the outlet point of the study area. During the project generation, the following datasets are created.

1) Filled DEM: Hydrologically corrected DEM.

2) Raw DEM: Original DEM.

3) Flow direction grid

4) Flow accumulation grid

5) Stream grid: Synthetic stream network in grid representation.

6) Stream link grid : Synthetic stream network segmented at confluences.

7) Catchment grid: Subbasin extents in grid representation.

8) Catchment polygon: Represent the extracted subbasin extent in vector format.

9) Rivers: Represents the synthetic stream network in vector format.

10) Project point: Represent the watershed outlet.

**Watershed subbasin boundary refinement**

Once a HMS project has been set up, the watershed subbasin boundaries can be revised. This was done mainly by combining and by subdividing subbasins. Subbasins larger than the 10 $km^2$ threshold were subdivided at hydrologic control points such as road crossings where changes in flow regime were most likely to occur. Subbasins smaller than the 5 $km^2$ threshold were merged to adjacent subbasins.

**HEC-HMS model parameterization**

Once a satisfactory watershed subbasin layout was defined, the next step was the parameterization of the model. Model parameterization is done in two phases. These are the extraction of the watershed physical parameters and the extraction of the model hydrologic parameters. These steps are outlined below.

**Extraction of the watershed physical parameters**

The HEC-GeoHMS toolbar can compute several topographic related characteristics of streams and subbasins. These include the following:

1) River length: Computes the length of each river features.

2) River slope: Extracts the upstream and downstream elevation of each stream segment and calculates the river slope.

3) Basin slope: Computes the average slope for each subbasin based on an input slope grid that was generated from a 2m DEM.

4) Longest flow path: Computes the longest flow path for each subbasin.

5) Basin centroid: Calculates the centroid as the center of the longest flow path within the subbasin.

6) Centroidal flow path: Calculates the flow path from the projected point of the subbasin centroid on the longest flow path to the subbasin outlet, along the longest flow path route.

**Extraction of the watershed hydrologic parameters**

In addition to extracting watershed physical parameters the HEC-GeoHMS tool can also extract a number of hydrologic inputs for the HEC-HMS model. The steps involved are briefly outlined below:

1) Selection of HMS processes: In this step, the loss, transform, and baseflow type methods for the subbasins and the routing method for the rivers as outlined in Table 1 were selected.

2) Subbasin curve number: Computation of the average subbasin curve number.

3) Muskingum-Cunge parameters: Allows the selection of the Muskingum-Cunge channel shape. A trapezoidal channel shape was selected for this study.

4) CN lag: Computation of the CN lag for each subbasin.

A number of required hydrologic parameters could not be extracted using the HEC-GeoHMS tools. These model parameters were manually calculated or extracted through the development and application of Python scripts. These parameters are listed below:

5) Basin imperviousness: Computation of the average subbasin imperviousness (%).

6) Basin maximum infiltration rate: Computation of the average subbasin maximum infiltration rate (mm/hr).

7) Basin water holding capacity: Computation of the average subbasin maximum water holding capacity (mm).

8) Basin Initial Abstraction: The initial abstraction defines the amount of precipitation that must fall before runoff is observed. This was calculated using the following formula:

   I = 0.2*((25400/ [CN])-254)

   Where:

   I = initial abstraction (mm)
   CN = Subbasin curve number

9) Initial Deficit: Initial Deficit represents the empty storage depth (mm) at the beginning of the simulation period. This quantity was set at half of the basin water holding capacity implying average soil moisture content in the soil at the beginning of the simulation period.

10) Routing channel bottom width: Computation of the average channel bottom width (m) for each routing reach.

11) Routing channel side slope: Computation of the average channel side slope (dimensionless).

12) Crop coefficient: Composite crop coefficient values were calculated for each day of the simulation period by calculating an area-weighted value for each catchment.

**Export Model to HMS**

Before exporting the developed hydrological modelling inputs to an HEC-HMS model input file, the HEC-GeoHMS tools were used to check the GIS layers for stream and basin connectivity, generate HMS schematic, legend, and a background map file.

# Appendix C

Average soil infiltration rates based on Hydrologic Soil Group (Haan et al., 1982)

| **Hydrologic Soil Group** | **Description** | **Average Infiltration Rate (mm/hr)** |
|---|---|---|
| A | Soils having high infiltration rates even when thoroughly wet. These soils consist mainly of deep, well-drained to excessively drained sands or gravels. These soils have a high rate of water transmission and therefore a low runoff potential. | 9.51 |
| B | Soils having moderate infiltration rates when thoroughly wet, consisting mainly of moderately deep to deep, moderately well to well-drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission. | 5.72 |
| C | Soils having slow infiltration rates when thoroughly wet, consisting mainly of either soils with a layer that impedes the downward movement of water or soils with moderately fine or fine textures and slow infiltration rates. These soils have a slow rate of water transmission. | 2.54 |
| D | Soils having very slow infiltration rates when thoroughly wet. These are mainly comprised of either clayey soil with high swelling capacity or potential, soils with a high permanent water table, soils with a clay layer at or near the surface, and/or shallow soils over nearly impervious materials. These soils have a very slow rate of water transmission and therefore a high runoff potential. | 0.64 |

Runoff CN number for SOLRIS land use classes and HSG groups.

| | Hydrologic Soil Group | | | |
|---|---|---|---|---|
| **Land use class** | **A** | **B** | **C** | **D** |
| Annual Crop | 67 | 78 | 85 | 89 |
| Bog | 72 | 72 | 72 | 72 |
| Coniferous Forest | 48 | 58 | 70 | 77 |
| Deciduous Forest | 48 | 58 | 70 | 77 |
| Extraction | 98 | 98 | 98 | 98 |
| Forest | 48 | 58 | 70 | 77 |
| Hedge Rows | 48 | 58 | 70 | 77 |
| Idle Land | 50 | 61 | 74 | 80 |
| Marsh | 85 | 85 | 85 | 85 |
| Mixed Agriculture | 64 | 74 | 80 | 85 |
| Mixed Crop | 67 | 78 | 85 | 89 |
| Mixed Forest | 48 | 58 | 70 | 77 |
| Monoculture | 40 | 62 | 76 | 81 |
| Open Shoreline | 72 | 72 | 72 | 72 |
| Open Water | 100 | 100 | 100 | 100 |
| Orchards | 40 | 62 | 76 | 81 |
| Perennial Crop | 59 | 74 | 83 | 86 |
| Plantations | 38 | 60 | 74 | 80 |
| Rural Land Use | 56 | 70 | 80 | 82 |
| Shoreline | 72 | 72 | 72 | 72 |
| Swamp | 72 | 72 | 72 | 72 |

Soil water holding capacity (mm) for SOLRIS land use classes and HSG groups.

| | Hydrologic Soil Group | | | |
|---|---|---|---|---|
| **Land use class** | **A** | **B** | **C** | **D** |
| Annual Crop | 75 | 150 | 200 | 150 |
| Bog | 250 | 300 | 400 | 350 |
| Built Up Impervious | 0 | 0 | 0 | 0 |
| Built Up Pervious | 50 | 75 | 113 | 75 |
| Coniferous Forest | 250 | 300 | 400 | 350 |
| Deciduous Forest | 250 | 300 | 400 | 350 |
| Extraction | 0 | 0 | 0 | 0 |
| Forest | 250 | 300 | 400 | 350 |
| Hedge Rows | 250 | 300 | 400 | 350 |
| Idle Land | 100 | 150 | 250 | 200 |
| Marsh | 0 | 0 | 0 | 0 |
| Mixed Agriculture | 75 | 150 | 200 | 150 |
| Mixed Crop | 75 | 150 | 200 | 150 |
| Mixed Forest | 250 | 300 | 400 | 350 |
| Monoculture | 75 | 150 | 200 | 150 |
| Open Shoreline | 0 | 0 | 0 | 0 |
| Open Water | 0 | 0 | 0 | 0 |
| Orchards | 250 | 300 | 400 | 350 |
| Perennial Crop | 100 | 150 | 250 | 200 |
| Plantations | 100 | 150 | 250 | 100 |
| Rural Land Use | 100 | 150 | 250 | 200 |
| Shoreline | 0 | 0 | 0 | 0 |
| Swamp | 250 | 300 | 400 | 350 |
| Transportation | 0 | 0 | 0 | 0 |

Channel manning n coefficients under various channel stream bed conditions.

| **Channel Stream bed condition** | **Minimum** | **Average** | **Maximum** |
|---|---|---|---|
| a. Clean, straight, full, no rifts or deep pools | 0.025 | 0.030 | 0.033 |
| b. Same as above, but more stones and weeds | 0.030 | 0.035 | 0.040 |
| c. Clean, winding, some pools and shoals | 0.033 | 0.040 | 0.045 |
| d. Same as above, but some stones and weeds. | 0.035 | 0.045 | 0.050 |
| e. Same as above, lower stages, more ineffective slopes and sections | 0.040 | 0.048 | 0.050 |
| f. Same as “d” but more stones | 0.045 | 0.050 | 0.060 |
| g. Sluggish reaches, weedy, deep pools | 0.050 | 0.070 | 0.080 |
| h. Very weedy reaches, deep pools, or floodways with heavy stands of timber and brush. | 0.070 | 0.100 | 0.150 |
| | | | |

# Appendix D

Weather INnovations Incorporated 7159 Queen's Line RR 5, Chatham, ON N7M 5J5 Ph:(519)352-5334
Fax:(519)352-7630

**Land-Use Evapotranspiration Coefficient Study**

Weather INnovations Incorporated (WIN) was contracted by the Niagara Peninsula Conservation Authority (NPCA) to determine coefficients relating evapotranspiration rates to a reference potential evapotranspiration for the highest density land uses in the Niagara Peninsula.
The land uses of greatest interest, the majority of which were identified to be agricultural, were outlined by the NPCA. The crops of greatest density were used to further define the agricultural land use.

**Table 1**: Identified Land Use

| |
|---|
| **Agricultural Land** |
| - Soybeans |
| - Hay |
| - Grain Corn |
| - Winter Wheat |
| - Vineyards |
| - Peach |
| - Pear/Apple/Cherry/Plum |
| - Grazing Land |
| **Non-Agricultural Land Use** |
| - Idle Land (more than 10 years out of agricultural production) |
| - Deciduous Forest |
| - Swamp |
| - Built-Up Pervious land (sod/grass) |
| **Smaller Coverage Land Uses** |
| -Open/Shallow Water |
| - Marsh |
| - Coniferous Forest |
| - Tallgrass |
| - Fen |
| - Bog |

The results of many researchers have been used to develop the evapotranspiration coefficients suggested by the Food and Agricultural Organization of the United Nations (FAO), and are accepted internationally. Due to the complexity of measuring evapotranspiration and the variability in the values year to year, there are very few (if any) results indicating a daily estimate for evapotranspiration values. WIN has determined, where possible, the growth stages for the various agricultural crops listed, based on suggestions by the FAO and other researchers. The step-wise values have been determined where a linear progression occurs from one coefficient to another.

Very few crop coefficients for Ontario are available, and a majority of the land uses identified by the NPCA could not be found in Ontario documentation. As a result, values from the FAO were substituted, except in the situation of grapes and deciduous fruit trees. These values, although based on FAO findings, were more refined by the OMAFRA Best Management - Irrigation Management guide, and the British Columbia Ministry of Agriculture, Food and Fisheries. These two sources were used in combination, to determine the evapotranspiration coefficient for grapes and deciduous fruit trees.

The FAO suggests modifying the mid-growth stage values depending on the minimum daily relative humidity value, and the wind speed (at 2m) based on the region of interest, and the crop height. They suggest this adjustment to both $Kc_{mid}$ and $Kc_{end}$. The equation indicated is identified for $Kc_{mid}$, however the equation for $Kc_{end}$ is the same, just with the table value for $Kc_{end}$ substituted in place of $Kc_{mid(tab)}$.

$$Kc_{mid} = Kc_{mid(tab)} + [0.04(u_2-2)-0.004[RH_{min}-45]](h/3)^{0.3},$$

where $Kc_{mid(tab)}$ is the published FAO crop coefficient, $u_2$ is the wind speed at 2m (in m/s), $RH_{min}$ is the minimum daily RH value (%), and h is the crop height (m).

In order to conduct this calculation, wind speed and RH data from a station in the Niagara Peninsula was used for 2006. It is important to note that these values will change yearly depending on the season. A yearly average of the 'adjusted' Kc value will be used for the purpose of this project.

The following changes to $Kc_{mid}$ and $Kc_{end}$ were made to the following crops.

**Table 2**: Adjusted $Kc_{mid}$ and $Kc_{end}$ values

| Crop | Crop Height (m) | $Kc_{mid(tab)}$ | Adjusted $Kc_{mid}$ | $Kc_{end(tab)}$ | Adjusted $Kc_{end}$ |
|---|---|---|---|---|---|
| Soybeans | 0.7 | 1.15 | 1.15 | 0.50 | 0.51 |
| Winter Wheat | 1.0 | 1.15 | 1.17 | 0.32 | 0.34 |
| Maize | 2.0 | 1.20 | 1.25 | 0.48 | 0.65 |
| Rye Grass Hay | 0.3 | 1.05 | 1.05 | 1.00 | 1.00 |
| Clover Hay | 0.6 | 0.90 | 0.90 | 0.85 | 0.85 |
| Pasture | 0.4 | 0.95 | 0.95 | 0.85 | 0.85 |
| Wetlands | 1.5 | 1.20 | 1.27 | 0.30 | 0.37 |

FAO provides estimated duration for each crop coefficient. These were taken into consideration when determining the change from one coefficient to another. However, in some instances, alterations were made to better suit the Ontario growing season. Many of the planting dates set for crops are close to the earliest planting date for the crop. These values should be adjusted, if required, to reflect a variety of situations based on planting dates.

The evapotranspiration coefficients for boreal deciduous and coniferous forests were determined from a study by Komastsu (2005). The results, from various research projects around the world, were examined for a comparison of coefficients for the Priestly-Taylor model. In order to determine the values for this study, the average of the findings for both the boreal deciduous and the boreal coniferous forests were used. The values for boreal coniferous forest range from 0.38 to 0.69, with an average of 0.55. Values estimating the winter evapotranspiration coefficients for conifer trees could not be determined in the time allotted for this project. As such, evaporative losses of 0.2 were substituted, the value which is currently used for deciduous trees.

The determination for a coefficient for idle land becomes more complex. As the land has been out of agricultural production for 10 or more years, it is assumed that grasses, weeds and native vegetation are now established. The FAO indicates the use of the following equations to determine the mid-season evaporation rates. Due to the lack of information regarding leaf area index (LAI) values, it was indicated by the FAO that full coverage vegetation would have an LAI value of 3. For the scenario of tallgrass, a similar methodology was used. However, a study by Verma and Berry (1997) indicates that the LAI from a tallgrass prairie was 0.2 from mid-March to early May, and ranged from 0.3 to 1.8 in the later part of May (average of 1.05 will be used for this study). At the peak of the season, the range was 2.5 to 2.8 (average of 2.65 used for this study).

$K_{cb,\,h} = 1.0 + 0.1h$, for $h \leq 2m$

$K_{cb\ full} = K_{cb}, h + [0.04(u_2-2)-(0.004(RH_{min}-45)](h/3)^{0.3}$

$K_{cbmid} = K_{cmin} + (K_{cfull} - K_{cmin})(1-\exp[-0.7LAI])$,

where $Kc_{min}$ is the minimum Kc value for bare soil (ranging from 0.15-0.2). OMAFRA indicates a bare soil coefficient of 0.2. This value was used.

Due to a lack of information regarding evapotranspiration values for swamps, bogs, marshes and fens individually, the value for wetlands was used in all four situations.

Many models used to calculate potential evapotranspiration (ETo) utilize a well-watered turf surface as the reference point. The coefficient for the built-up pervious area (e.g. sod/grass) will be 1.

Open water, especially water at a depth greater than 5m, creates a complex situation. The FAO indicates that deep bodies of water experience fluctuating temperatures, but this may not be true of frozen surfaces. During periods of peak evapotranspirative losses, radiation is being absorbed into the water. Therefore, the evaporative losses are less than ETo. During cooler temperature periods, the energy exchange is reversed. This causes the evaporation rates to be higher than those for grass, during the same period.

The following tables are daily evapotranspiration coefficients for the identified land use classes.

**Table 3**: Annual evapotranspiration coefficients for soybeans, winter wheat and grain corn.

| | Soybeans | Kc | Winter Wheat | Kc | Grain Corn | Kc |
|---|---|---|---|---|---|---|
| Jan. 1 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Jan. 2 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Jan. 3 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Jan. 4 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Jan. 5 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Jan. 6 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Jan. 7 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Jan. 8 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Jan. 9 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Jan. 10 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Jan. 11 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Jan. 12 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Jan. 13 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Jan. 14 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Jan. 15 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Jan. 16 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Jan. 17 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Jan. 18 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Jan. 19 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Jan. 20 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Jan. 21 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Jan. 22 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Jan. 23 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Jan. 24 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Jan. 25 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Jan. 26 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Jan. 27 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Jan. 28 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Jan. 29 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Jan. 30 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Jan. 31 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Feb. 1 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Feb. 2 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Feb. 3 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Feb. 4 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Feb. 5 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Feb. 6 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Feb. 7 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Feb. 8 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Feb. 9 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Feb. 10 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Feb. 11 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Feb. 12 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Feb. 13 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Feb. 14 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Feb. 15 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Feb. 16 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Feb. 17 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Feb. 18 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Feb. 19 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Feb. 20 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Feb. 21 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Feb. 22 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Feb. 23 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Feb. 24 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Feb. 25 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Feb. 26 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Feb. 27 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Feb. 28 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Mar. 1 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Mar. 2 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Mar. 3 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Mar. 4 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Mar. 5 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Mar. 6 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Mar. 7 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Mar. 8 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Mar. 9 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Mar. 10 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Mar. 11 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Mar. 12 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Mar. 13 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Mar. 14 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Mar. 15 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Mar. 16 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Mar. 17 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Mar. 18 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Mar. 19 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Mar. 20 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Mar. 21 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Mar. 22 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Mar. 23 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Mar. 24 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Mar. 25 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Mar. 26 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Mar. 27 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Mar. 28 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Mar. 29 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Mar. 30 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Mar. 31 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Apr. 1 | Bare Soil | 0.20 | Kdev | 0.42 | Bare Soil | 0.20 |
| Apr. 2 | Bare Soil | 0.20 | Kdev | 0.43 | Bare Soil | 0.20 |
| Apr. 3 | Bare Soil | 0.20 | Kdev | 0.45 | Bare Soil | 0.20 |
| Apr. 4 | Bare Soil | 0.20 | Kdev | 0.47 | Bare Soil | 0.20 |
| Apr. 5 | Bare Soil | 0.20 | Kdev | 0.48 | Bare Soil | 0.20 |
| Apr. 6 | Bare Soil | 0.20 | Kdev | 0.50 | Bare Soil | 0.20 |
| Apr. 7 | Bare Soil | 0.20 | Kdev | 0.52 | Bare Soil | 0.20 |
| Apr. 8 | Bare Soil | 0.20 | Kdev | 0.53 | Bare Soil | 0.20 |
| Apr. 9 | Bare Soil | 0.20 | Kdev | 0.55 | Bare Soil | 0.20 |
| Apr. 10 | Bare Soil | 0.20 | Kdev | 0.57 | Bare Soil | 0.20 |
| Apr. 11 | Bare Soil | 0.20 | Kdev | 0.58 | Bare Soil | 0.20 |
| Apr. 12 | Bare Soil | 0.20 | Kdev | 0.60 | Bare Soil | 0.20 |
| Apr. 13 | Bare Soil | 0.20 | Kdev | 0.62 | Bare Soil | 0.20 |
| Apr. 14 | Bare Soil | 0.20 | Kdev | 0.63 | Bare Soil | 0.20 |
| Apr. 15 | Bare Soil | 0.20 | Kdev | 0.65 | Kini | 0.30 |
| Apr. 16 | Bare Soil | 0.20 | Kdev | 0.67 | Kini | 0.30 |
| Apr. 17 | Bare Soil | 0.20 | Kdev | 0.68 | Kini | 0.30 |
| Apr. 18 | Bare Soil | 0.20 | Kdev | 0.70 | Kini | 0.30 |
| Apr. 19 | Bare Soil | 0.20 | Kdev | 0.72 | Kini | 0.30 |
| Apr. 20 | Bare Soil | 0.20 | Kdev | 0.73 | Kini | 0.30 |
| Apr. 21 | Bare Soil | 0.20 | Kdev | 0.75 | Kini | 0.30 |
| Apr. 22 | Bare Soil | 0.20 | Kdev | 0.77 | Kini | 0.30 |
| Apr. 23 | Bare Soil | 0.20 | Kdev | 0.78 | Kini | 0.30 |
| Apr. 24 | Bare Soil | 0.20 | Kdev | 0.80 | Kini | 0.30 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Apr. 25 | Bare Soil | 0.20 | Kdev | 0.82 | Kini | 0.30 |
| Apr. 26 | Bare Soil | 0.20 | Kdev | 0.84 | Kini | 0.30 |
| Apr. 27 | Bare Soil | 0.20 | Kdev | 0.85 | Kini | 0.30 |
| Apr. 28 | Bare Soil | 0.20 | Kdev | 0.87 | Kini | 0.30 |
| Apr. 29 | Bare Soil | 0.20 | Kdev | 0.89 | Kini | 0.30 |
| Apr. 30 | Bare Soil | 0.20 | Kdev | 0.90 | Kini | 0.30 |
| May 1 | Bare Soil | 0.20 | Kdev | 0.92 | Kini | 0.30 |
| May 2 | Bare Soil | 0.20 | Kdev | 0.94 | Kini | 0.30 |
| May 3 | Bare Soil | 0.20 | Kdev | 0.95 | Kini | 0.30 |
| May 4 | Bare Soil | 0.20 | Kdev | 0.97 | Kini | 0.30 |
| May 5 | Bare Soil | 0.20 | Kdev | 0.99 | Kini | 0.30 |
| May 6 | Bare Soil | 0.20 | Kdev | 1.00 | Kini | 0.30 |
| May 7 | Bare Soil | 0.20 | Kdev | 1.02 | Kini | 0.30 |
| May 8 | Bare Soil | 0.20 | Kdev | 1.04 | Kini | 0.30 |
| May 9 | Bare Soil | 0.20 | Kdev | 1.05 | Kini | 0.30 |
| May 10 | Bare Soil | 0.20 | Kdev | 1.07 | Kini | 0.30 |
| May 11 | Bare Soil | 0.20 | Kdev | 1.09 | Kini | 0.30 |
| May 12 | Bare Soil | 0.20 | Kdev | 1.10 | Kini | 0.30 |
| May 13 | Bare Soil | 0.20 | Kdev | 1.12 | Kini | 0.30 |
| May 14 | Bare Soil | 0.20 | Kdev | 1.14 | Kini | 0.30 |
| May 15 | Kini | 0.40 | Kdev | 1.15 | Kini | 0.30 |
| May 16 | Kini | 0.40 | Kmid | 1.17 | Kdev | 0.32 |
| May 17 | Kini | 0.40 | Kmid | 1.17 | Kdev | 0.35 |
| May 18 | Kini | 0.40 | Kmid | 1.17 | Kdev | 0.37 |
| May 19 | Kini | 0.40 | Kmid | 1.17 | Kdev | 0.39 |
| May 20 | Kini | 0.40 | Kmid | 1.17 | Kdev | 0.42 |
| May 21 | Kini | 0.40 | Kmid | 1.17 | Kdev | 0.44 |
| May 22 | Kini | 0.40 | Kmid | 1.17 | Kdev | 0.46 |
| May 23 | Kini | 0.40 | Kmid | 1.17 | Kdev | 0.49 |
| May 24 | Kini | 0.40 | Kmid | 1.17 | Kdev | 0.51 |
| May 25 | Kini | 0.40 | Kmid | 1.17 | Kdev | 0.53 |
| May 26 | Kini | 0.40 | Kmid | 1.17 | Kdev | 0.55 |
| May 27 | Kini | 0.40 | Kmid | 1.17 | Kdev | 0.58 |
| May 28 | Kini | 0.40 | Kmid | 1.17 | Kdev | 0.60 |
| May 29 | Kini | 0.40 | Kmid | 1.17 | Kdev | 0.62 |
| May 30 | Kini | 0.40 | Kmid | 1.17 | Kdev | 0.65 |
| May 31 | Kini | 0.40 | Kmid | 1.17 | Kdev | 0.67 |
| June 1 | Kini | 0.40 | Kmid | 1.17 | Kdev | 0.69 |
| June 2 | Kini | 0.40 | Kmid | 1.17 | Kdev | 0.72 |
| June 3 | Kini | 0.40 | Kmid | 1.17 | Kdev | 0.74 |
| June 4 | Kdev | 0.42 | Kmid | 1.17 | Kdev | 0.76 |
| June 5 | Kdev | 0.45 | Kmid | 1.17 | Kdev | 0.79 |
| June 6 | Kdev | 0.47 | Kmid | 1.17 | Kdev | 0.81 |
| June 7 | Kdev | 0.49 | Kmid | 1.17 | Kdev | 0.83 |
| June 8 | Kdev | 0.51 | Kmid | 1.17 | Kdev | 0.86 |
| June 9 | Kdev | 0.54 | Kmid | 1.17 | Kdev | 0.88 |
| June 10 | Kdev | 0.56 | Kmid | 1.17 | Kdev | 0.90 |
| June 11 | Kdev | 0.58 | Kmid | 1.17 | Kdev | 0.93 |
| June 12 | Kdev | 0.60 | Kmid | 1.17 | Kdev | 0.95 |
| June 13 | Kdev | 0.63 | Kmid | 1.17 | Kdev | 0.97 |
| June 14 | Kdev | 0.65 | Kmid | 1.17 | Kdev | 1.00 |
| June 15 | Kdev | 0.67 | Kmid | 1.17 | Kdev | 1.02 |
| June 16 | Kdev | 0.70 | Kmid | 1.17 | Kdev | 1.04 |
| June 17 | Kdev | 0.72 | Kmid | 1.17 | Kdev | 1.06 |
| June 18 | Kdev | 0.74 | Kmid | 1.17 | Kdev | 1.09 |
| June 19 | Kdev | 0.76 | Kmid | 1.17 | Kdev | 1.11 |
| June 20 | Kdev | 0.79 | Kmid | 1.17 | Kdev | 1.13 |
| June 21 | Kdev | 0.81 | Kmid | 1.17 | Kdev | 1.16 |
| June 22 | Kdev | 0.83 | Kmid | 1.17 | Kdev | 1.18 |

| | | | | | | |
|---|---|---|---|---|---|---|
| June 23 | Kdev | 0.85 | Kmid | 1.17 | Kdev | 1.20 |
| June 24 | Kdev | 0.88 | Kmid | 1.17 | Kdev | 1.23 |
| June 25 | Kdev | 0.90 | Kmid | 1.17 | Kmid | 1.25 |
| June 26 | Kdev | 0.92 | Kmid | 1.17 | Kmid | 1.25 |
| June 27 | Kdev | 0.95 | Kmid | 1.17 | Kmid | 1.25 |
| June 28 | Kdev | 0.97 | Kmid | 1.17 | Kmid | 1.25 |
| June 29 | Kdev | 0.99 | Kmid | 1.17 | Kmid | 1.25 |
| June 30 | Kdev | 1.01 | Kmid | 1.17 | Kmid | 1.25 |
| July 1 | Kdev | 1.04 | Kmid | 1.17 | Kmid | 1.25 |
| July 2 | Kdev | 1.06 | Kmid | 1.17 | Kmid | 1.25 |
| July 3 | Kdev | 1.08 | Kmid | 1.17 | Kmid | 1.25 |
| July 4 | Kdev | 1.10 | Kmid | 1.17 | Kmid | 1.25 |
| July 5 | Kdev | 1.13 | Kmid | 1.17 | Kmid | 1.25 |
| July 6 | Kmid | 1.15 | Kmid | 1.17 | Kmid | 1.25 |
| July 7 | Kmid | 1.15 | Kmid | 1.17 | Kmid | 1.25 |
| July 8 | Kmid | 1.15 | Kmid | 1.17 | Kmid | 1.25 |
| July 9 | Kmid | 1.15 | Kmid | 1.17 | Kmid | 1.25 |
| July 10 | Kmid | 1.15 | Kmid | 1.17 | Kmid | 1.25 |
| July 11 | Kmid | 1.15 | Klate | 1.14 | Kmid | 1.25 |
| July 12 | Kmid | 1.15 | Klate | 1.12 | Kmid | 1.25 |
| July 13 | Kmid | 1.15 | Klate | 1.09 | Kmid | 1.25 |
| July 14 | Kmid | 1.15 | Klate | 1.06 | Kmid | 1.25 |
| July 15 | Kmid | 1.15 | Klate | 1.03 | Kmid | 1.25 |
| July 16 | Kmid | 1.15 | Klate | 1.01 | Kmid | 1.25 |
| July 17 | Kmid | 1.15 | Klate | 0.98 | Kmid | 1.25 |
| July 18 | Kmid | 1.15 | Klate | 0.95 | Kmid | 1.25 |
| July 19 | Kmid | 1.15 | Klate | 0.92 | Kmid | 1.25 |
| July 20 | Kmid | 1.15 | Klate | 0.90 | Kmid | 1.25 |
| July 21 | Kmid | 1.15 | Klate | 0.87 | Kmid | 1.25 |
| July 22 | Kmid | 1.15 | Klate | 0.84 | Kmid | 1.25 |
| July 23 | Kmid | 1.15 | Klate | 0.82 | Kmid | 1.25 |
| July 24 | Kmid | 1.15 | Klate | 0.79 | Kmid | 1.25 |
| July 25 | Kmid | 1.15 | Klate | 0.76 | Kmid | 1.25 |
| July 26 | Kmid | 1.15 | Klate | 0.73 | Kmid | 1.25 |
| July 27 | Kmid | 1.15 | Klate | 0.71 | Kmid | 1.25 |
| July 28 | Kmid | 1.15 | Klate | 0.68 | Kmid | 1.25 |
| July 29 | Kmid | 1.15 | Klate | 0.65 | Kmid | 1.25 |
| July 30 | Kmid | 1.15 | Klate | 0.62 | Kmid | 1.25 |
| July 31 | Kmid | 1.15 | Klate | 0.60 | Kmid | 1.25 |
| Aug. 1 | Kmid | 1.15 | Klate | 0.57 | Kmid | 1.25 |
| Aug. 2 | Kmid | 1.15 | Klate | 0.54 | Kmid | 1.25 |
| Aug. 3 | Kmid | 1.15 | Klate | 0.52 | Kmid | 1.25 |
| Aug. 4 | Kmid | 1.15 | Klate | 0.49 | Kmid | 1.25 |
| Aug. 5 | Kmid | 1.15 | Klate | 0.46 | Kmid | 1.25 |
| Aug. 6 | Kmid | 1.15 | Klate | 0.43 | Kmid | 1.25 |
| Aug. 7 | Kmid | 1.15 | Klate | 0.41 | Kmid | 1.25 |
| Aug. 8 | Kmid | 1.15 | Klate | 0.38 | Kmid | 1.25 |
| Aug. 9 | Kmid | 1.15 | Klate | 0.35 | Kmid | 1.25 |
| Aug. 10 | Kmid | 1.15 | Klate | 0.33 | Kmid | 1.25 |
| Aug. 11 | Kmid | 1.15 | Bare Soil | 0.20 | Kmid | 1.25 |
| Aug. 12 | Kmid | 1.15 | Bare Soil | 0.20 | Kmid | 1.25 |
| Aug. 13 | Kmid | 1.15 | Bare Soil | 0.20 | Kmid | 1.25 |
| Aug. 14 | Kmid | 1.15 | Bare Soil | 0.20 | Klate | 1.23 |
| Aug. 15 | Kmid | 1.15 | Bare Soil | 0.20 | Klate | 1.22 |
| Aug. 16 | Kmid | 1.15 | Bare Soil | 0.20 | Klate | 1.20 |
| Aug. 17 | Kmid | 1.15 | Bare Soil | 0.20 | Klate | 1.19 |
| Aug. 18 | Kmid | 1.15 | Bare Soil | 0.20 | Klate | 1.17 |
| Aug. 19 | Kmid | 1.15 | Bare Soil | 0.20 | Klate | 1.16 |
| Aug. 20 | Kmid | 1.15 | Bare Soil | 0.20 | Klate | 1.14 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Aug. 21 | Kmid | 1.15 | Bare Soil | 0.20 | Klate | 1.13 |
| Aug. 22 | Kmid | 1.15 | Bare Soil | 0.20 | Klate | 1.11 |
| Aug. 23 | Kmid | 1.15 | Bare Soil | 0.20 | Klate | 1.10 |
| Aug. 24 | Kmid | 1.15 | Bare Soil | 0.20 | Klate | 1.08 |
| Aug. 25 | Kmid | 1.15 | Bare Soil | 0.20 | Klate | 1.07 |
| Aug. 26 | Kmid | 1.15 | Bare Soil | 0.20 | Klate | 1.05 |
| Aug. 27 | Kmid | 1.15 | Bare Soil | 0.20 | Klate | 1.04 |
| Aug. 28 | Kmid | 1.15 | Bare Soil | 0.20 | Klate | 1.02 |
| Aug. 29 | Kmid | 1.15 | Bare Soil | 0.20 | Klate | 1.01 |
| Aug. 30 | Kmid | 1.15 | Bare Soil | 0.20 | Klate | 0.99 |
| Aug. 31 | Kmid | 1.15 | Bare Soil | 0.20 | Klate | 0.98 |
| Sept. 1 | Kmid | 1.15 | Bare Soil | 0.20 | Klate | 0.96 |
| Sept. 2 | Kmid | 1.15 | Bare Soil | 0.20 | Klate | 0.95 |
| Sept. 3 | Kmid | 1.15 | Bare Soil | 0.20 | Klate | 0.93 |
| Sept. 4 | Klate | 1.13 | Bare Soil | 0.20 | Klate | 0.92 |
| Sept. 5 | Klate | 1.10 | Bare Soil | 0.20 | Klate | 0.90 |
| Sept. 6 | Klate | 1.08 | Bare Soil | 0.20 | Klate | 0.89 |
| Sept. 7 | Klate | 1.05 | Bare Soil | 0.20 | Klate | 0.87 |
| Sept. 8 | Klate | 1.03 | Bare Soil | 0.20 | Klate | 0.85 |
| Sept. 9 | Klate | 1.01 | Bare Soil | 0.20 | Klate | 0.84 |
| Sept. 10 | Klate | 0.98 | Bare Soil | 0.20 | Klate | 0.82 |
| Sept. 11 | Klate | 0.96 | Bare Soil | 0.20 | Klate | 0.81 |
| Sept. 12 | Klate | 0.93 | Bare Soil | 0.20 | Klate | 0.79 |
| Sept. 13 | Klate | 0.91 | Bare Soil | 0.20 | Klate | 0.78 |
| Sept. 14 | Klate | 0.89 | Bare Soil | 0.20 | Klate | 0.76 |
| Sept. 15 | Klate | 0.86 | Kini | 0.40 | Klate | 0.75 |
| Sept. 16 | Klate | 0.84 | Kini | 0.40 | Klate | 0.73 |
| Sept. 17 | Klate | 0.81 | Kini | 0.40 | Klate | 0.72 |
| Sept. 18 | Klate | 0.79 | Kini | 0.40 | Klate | 0.70 |
| Sept. 19 | Klate | 0.76 | Kini | 0.40 | Klate | 0.69 |
| Sept. 20 | Klate | 0.74 | Kini | 0.40 | Klate | 0.67 |
| Sept. 21 | Klate | 0.72 | Kini | 0.40 | Klate | 0.66 |
| Sept. 22 | Klate | 0.69 | Kini | 0.40 | Klate | 0.64 |
| Sept. 23 | Klate | 0.67 | Kini | 0.40 | Klate | 0.63 |
| Sept. 24 | Klate | 0.64 | Kini | 0.40 | Klate | 0.61 |
| Sept. 25 | Klate | 0.62 | Kini | 0.40 | Klate | 0.60 |
| Sept. 26 | Klate | 0.60 | Kini | 0.40 | Klate | 0.58 |
| Sept. 27 | Klate | 0.57 | Kini | 0.40 | Klate | 0.57 |
| Sept. 28 | Klate | 0.55 | Kini | 0.40 | Klate | 0.55 |
| Sept. 29 | Klate | 0.52 | Kini | 0.40 | Klate | 0.54 |
| Sept. 30 | Klate | 0.50 | Kini | 0.40 | Klate | 0.52 |
| Oct. 1 | Bare Soil | 0.20 | Kini | 0.40 | Klate | 0.51 |
| Oct. 2 | Bare Soil | 0.20 | Kini | 0.40 | Klate | 0.48 |
| Oct. 3 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Oct. 4 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Oct. 5 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Oct. 6 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Oct. 7 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Oct. 8 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Oct. 9 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Oct. 10 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Oct. 11 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Oct. 12 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Oct. 13 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Oct. 14 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Oct. 15 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Oct. 16 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Oct. 17 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Oct. 18 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Oct. 19 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Oct. 20 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Oct. 21 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Oct. 22 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Oct. 23 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Oct. 24 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Oct. 25 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Oct. 26 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Oct. 27 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Oct. 28 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Oct. 29 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Oct. 30 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Oct. 31 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Nov. 1 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Nov. 2 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Nov. 3 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Nov. 4 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Nov. 5 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Nov. 6 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Nov. 7 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Nov. 8 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Nov. 9 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Nov. 10 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Nov. 11 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Nov. 12 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Nov. 13 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Nov. 14 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Nov. 15 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Nov. 16 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Nov. 17 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Nov. 18 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Nov. 19 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Nov. 20 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Nov. 21 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Nov. 22 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Nov. 23 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Nov. 24 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Nov. 25 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Nov. 26 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Nov. 27 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Nov. 28 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Nov. 29 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Nov. 30 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Dec. 1 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Dec. 2 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Dec. 3 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Dec. 4 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Dec. 5 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Dec. 6 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Dec. 7 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Dec. 8 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Dec. 9 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Dec. 10 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Dec. 11 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Dec. 12 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Dec. 13 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Dec. 14 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Dec. 15 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Dec. 16 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Dec. 17 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Dec. 18 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Dec. 19 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Dec. 20 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Dec. 21 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Dec. 22 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Dec. 23 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Dec. 24 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Dec. 25 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Dec. 26 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Dec. 27 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Dec. 28 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Dec. 29 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Dec. 30 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |
| Dec. 31 | Bare Soil | 0.20 | Kini | 0.40 | Bare Soil | 0.20 |

**Table 4**: Annual evapotranspiration coefficients for hay, pasture, and wetlands.

| | Hay[+] | Kc | Pasture | Kc | Wetlands | Kc |
|---|---|---|---|---|---|---|
| Jan. 1 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Jan. 2 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Jan. 3 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Jan. 4 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Jan. 5 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Jan. 6 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Jan. 7 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Jan. 8 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Jan. 9 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Jan. 10 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Jan. 11 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Jan. 12 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Jan. 13 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Jan. 14 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Jan. 15 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Jan. 16 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Jan. 17 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Jan. 18 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Jan. 19 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Jan. 20 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Jan. 21 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Jan. 22 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Jan. 23 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Jan. 24 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Jan. 25 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Jan. 26 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Jan. 27 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Jan. 28 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Jan. 29 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Jan. 30 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Jan. 31 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Feb. 1 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Feb. 2 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Feb. 3 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Feb. 4 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Feb. 5 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Feb. 6 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Feb. 7 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Feb. 8 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Feb. 9 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Feb. 10 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Feb. 11 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Feb. 12 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Feb. 13 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Feb. 14 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Feb. 15 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Feb. 16 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Feb. 17 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Feb. 18 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Feb. 19 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Feb. 20 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Feb. 21 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Feb. 22 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Feb. 23 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Feb. 24 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Feb. 25 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Feb. 26 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Feb. 27 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Feb. 28 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Mar. 1 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Mar. 2 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Mar. 3 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Mar. 4 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Mar. 5 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Mar. 6 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Mar. 7 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Mar. 8 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Mar. 9 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Mar. 10 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Mar. 11 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Mar. 12 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Mar. 13 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Mar. 14 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Mar. 15 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Mar. 16 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Mar. 17 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Mar. 18 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Mar. 19 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Mar. 20 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Mar. 21 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Mar. 22 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Mar. 23 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Mar. 24 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Mar. 25 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Mar. 26 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Mar. 27 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Mar. 28 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Mar. 29 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Mar. 30 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Mar. 31 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Apr. 1 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Apr. 2 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Apr. 3 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Apr. 4 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Apr. 5 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Apr. 6 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Apr. 7 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Apr. 8 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Apr. 9 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Apr. 10 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Apr. 11 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Apr. 12 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Apr. 13 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Apr. 14 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Apr. 15 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Apr. 16 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Apr. 17 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Apr. 18 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Apr. 19 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Apr. 20 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Apr. 21 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Apr. 22 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Apr. 23 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Apr. 24 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Apr. 25 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Apr. 26 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Apr. 27 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Apr. 28 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Apr. 29 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Apr. 30 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| May 1 | Kini | 0.95 | Kini | 0.40 | Dormant | 0.37 |
| May 2 | Kini | 0.95 | Kini | 0.40 | Dormant | 0.37 |
| May 3 | Kini | 0.95 | Kini | 0.40 | Dormant | 0.37 |
| May 4 | Kini | 0.95 | Kini | 0.40 | Dormant | 0.37 |
| May 5 | Kini | 0.95 | Kini | 0.40 | Dormant | 0.37 |
| May 6 | Kini | 0.95 | Kini | 0.40 | Dormant | 0.37 |
| May 7 | Kini | 0.95 | Kini | 0.40 | Dormant | 0.37 |
| May 8 | Kini | 0.95 | Kini | 0.40 | Dormant | 0.37 |
| May 9 | Kini | 0.95 | Kini | 0.40 | Dormant | 0.37 |
| May 10 | Kini | 0.95 | Kini | 0.40 | Dormant | 0.37 |
| May 11 | Kini | 0.95 | Kdev | 0.43 | Dormant | 0.37 |
| May 12 | Kini | 0.95 | Kdev | 0.45 | Dormant | 0.37 |
| May 13 | Kini | 0.95 | Kdev | 0.48 | Dormant | 0.37 |
| May 14 | Kini | 0.95 | Kdev | 0.50 | Dormant | 0.37 |
| May 15 | Kini | 0.95 | Kdev | 0.53 | Kini | 0.30 |
| May 16 | Kini | 0.95 | Kdev | 0.56 | Kini | 0.30 |
| May 17 | Kini | 0.95 | Kdev | 0.58 | Kini | 0.30 |
| May 18 | Kini | 0.95 | Kdev | 0.61 | Kini | 0.30 |
| May 19 | Kini | 0.95 | Kdev | 0.64 | Kini | 0.30 |
| May 20 | Kini | 0.95 | Kdev | 0.66 | Kini | 0.30 |
| May 21 | Kdev | 0.95 | Kdev | 0.69 | Kini | 0.30 |
| May 22 | Kdev | 0.96 | Kdev | 0.71 | Kini | 0.30 |
| May 23 | Kdev | 0.96 | Kdev | 0.74 | Kini | 0.30 |
| May 24 | Kdev | 0.97 | Kdev | 0.77 | Kini | 0.30 |
| May 25 | Kdev | 0.97 | Kdev | 0.79 | Kdev | 0.33 |
| May 26 | Kdev | 0.98 | Kdev | 0.82 | Kdev | 0.36 |
| May 27 | Kdev | 0.98 | Kdev | 0.85 | Kdev | 0.39 |
| May 28 | Kdev | 0.98 | Kdev | 0.87 | Kdev | 0.43 |
| May 29 | Kdev | 0.99 | Kdev | 0.90 | Kdev | 0.46 |
| May 30 | Kdev | 0.99 | Kdev | 0.92 | Kdev | 0.49 |
| May 31 | Kdev | 1.00 | Kmid | 0.95 | Kdev | 0.52 |
| June 1 | Kdev | 1.00 | Kmid | 0.95 | Kdev | 0.55 |
| June 2 | Kdev | 1.00 | Kmid | 0.95 | Kdev | 0.58 |
| June 3 | Kdev | 1.01 | Kmid | 0.95 | Kdev | 0.61 |
| June 4 | Kdev | 1.01 | Kmid | 0.95 | Kdev | 0.64 |
| June 5 | Kdev | 1.02 | Kmid | 0.95 | Kdev | 0.68 |
| June 6 | Kdev | 1.02 | Kmid | 0.95 | Kdev | 0.71 |

| | | | | | | |
|---|---|---|---|---|---|---|
| June 7 | Kdev | 1.03 | Kmid | 0.95 | Kdev | 0.74 |
| June 8 | Kdev | 1.03 | Kmid | 0.95 | Kdev | 0.77 |
| June 9 | Kdev | 1.03 | Kmid | 0.95 | Kdev | 0.80 |
| June 10 | Kdev | 1.04 | Kmid | 0.95 | Kdev | 0.83 |
| June 11 | Kdev | 1.04 | Kmid | 0.95 | Kdev | 0.86 |
| June 12 | Kdev | 1.05 | Kmid | 0.95 | Kdev | 0.89 |
| June 13 | Kdev | 1.05 | Kmid | 0.95 | Kdev | 0.93 |
| June 14 | Kdev | 1.06 | Kmid | 0.95 | Kdev | 0.96 |
| June 15 | Kmid | 1.06 | Kmid | 0.95 | Kdev | 0.99 |
| June 16 | Kmid | 1.06 | Kmid | 0.95 | Kdev | 1.02 |
| June 17 | Kmid | 1.06 | Kmid | 0.95 | Kdev | 1.05 |
| June 18 | Kmid | 1.06 | Kmid | 0.95 | Kdev | 1.08 |
| June 19 | Kmid | 1.06 | Kmid | 0.95 | Kdev | 1.11 |
| June 20 | Kmid | 1.06 | Kmid | 0.95 | Kdev | 1.14 |
| June 21 | Kmid | 1.06 | Kmid | 0.95 | Kdev | 1.18 |
| June 22 | Kmid | 1.06 | Kmid | 0.95 | Kdev | 1.21 |
| June 23 | Kmid | 1.06 | Kmid | 0.95 | Kdev | 1.24 |
| June 24 | Kmid | 1.06 | Kmid | 0.95 | Kdev | 1.27 |
| June 25 | Kmid | 1.06 | Kmid | 0.95 | Kmid | 1.27 |
| June 26 | Kmid | 1.06 | Kmid | 0.95 | Kmid | 1.27 |
| June 27 | Kmid | 1.06 | Kmid | 0.95 | Kmid | 1.27 |
| June 28 | Kmid | 1.06 | Kmid | 0.95 | Kmid | 1.27 |
| June 29 | Kmid | 1.06 | Kmid | 0.95 | Kmid | 1.27 |
| June 30 | Kmid | 1.06 | Kmid | 0.95 | Kmid | 1.27 |
| July 1 | Kmid | 1.06 | Kmid | 0.95 | Kmid | 1.27 |
| July 2 | Kmid | 1.06 | Kmid | 0.95 | Kmid | 1.27 |
| July 3 | Kmid | 1.06 | Kmid | 0.95 | Kmid | 1.27 |
| July 4 | Kmid | 1.06 | Kmid | 0.95 | Kmid | 1.27 |
| July 5 | Kmid | 1.06 | Kmid | 0.95 | Kmid | 1.27 |
| July 6 | Kmid | 1.06 | Kmid | 0.95 | Kmid | 1.27 |
| July 7 | Kmid | 1.06 | Kmid | 0.95 | Kmid | 1.27 |
| July 8 | Kmid | 1.06 | Kmid | 0.95 | Kmid | 1.27 |
| July 9 | Kmid | 1.06 | Kmid | 0.95 | Kmid | 1.27 |
| July 10 | Kmid | 1.06 | Kmid | 0.95 | Kmid | 1.27 |
| July 11 | Kmid | 1.06 | Kmid | 0.95 | Kmid | 1.27 |
| July 12 | Kmid | 1.06 | Kmid | 0.95 | Kmid | 1.27 |
| July 13 | Kmid | 1.06 | Kmid | 0.95 | Kmid | 1.27 |
| July 14 | Kmid | 1.06 | Kmid | 0.95 | Kmid | 1.27 |
| July 15 | Klate | 1.05 | Kmid | 0.95 | Kmid | 1.27 |
| July 16 | Klate | 1.04 | Kmid | 0.95 | Kmid | 1.27 |
| July 17 | Klate | 1.02 | Kmid | 0.95 | Kmid | 1.27 |
| July 18 | Klate | 1.01 | Kmid | 0.95 | Kmid | 1.27 |
| July 19 | Klate | 1.00 | Kmid | 0.95 | Kmid | 1.27 |
| July 20 | Kini | 0.95 | Kmid | 0.95 | Kmid | 1.27 |
| July 21 | Kini | 0.95 | Kmid | 0.95 | Kmid | 1.27 |
| July 22 | Kini | 0.95 | Kmid | 0.95 | Kmid | 1.27 |
| July 23 | Kini | 0.95 | Kmid | 0.95 | Kmid | 1.27 |
| July 24 | Kini | 0.95 | Kmid | 0.95 | Kmid | 1.27 |
| July 25 | Kini | 0.95 | Kmid | 0.95 | Kmid | 1.27 |
| July 26 | Kdev | 0.96 | Kmid | 0.95 | Kmid | 1.27 |
| July 27 | Kdev | 0.96 | Kmid | 0.95 | Kmid | 1.27 |
| July 28 | Kdev | 0.97 | Kmid | 0.95 | Kmid | 1.27 |
| July 29 | Kdev | 0.98 | Kmid | 0.95 | Kmid | 1.27 |
| July 30 | Kdev | 0.98 | Kmid | 0.95 | Kmid | 1.27 |
| July 31 | Kdev | 0.99 | Kmid | 0.95 | Kmid | 1.27 |
| Aug. 1 | Kdev | 1.00 | Kmid | 0.95 | Kmid | 1.27 |
| Aug. 2 | Kdev | 1.01 | Kmid | 0.95 | Kmid | 1.27 |
| Aug. 3 | Kdev | 1.01 | Kmid | 0.95 | Kmid | 1.27 |
| Aug. 4 | Kdev | 1.02 | Kmid | 0.95 | Kmid | 1.27 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Aug. 5 | Kdev | 1.03 | Kmid | 0.95 | Kmid | 1.27 |
| Aug. 6 | Kdev | 1.03 | Kmid | 0.95 | Kmid | 1.27 |
| Aug. 7 | Kdev | 1.04 | Kmid | 0.95 | Kmid | 1.27 |
| Aug. 8 | Kdev | 1.05 | Kmid | 0.95 | Kmid | 1.27 |
| Aug. 9 | Kdev | 1.05 | Kmid | 0.95 | Kmid | 1.27 |
| Aug. 10 | Kmid | 1.06 | Kmid | 0.95 | Kmid | 1.27 |
| Aug. 11 | Kmid | 1.06 | Kmid | 0.95 | Kmid | 1.27 |
| Aug. 12 | Kmid | 1.06 | Kmid | 0.95 | Kmid | 1.27 |
| Aug. 13 | Kmid | 1.06 | Kmid | 0.95 | Kmid | 1.27 |
| Aug. 14 | Kmid | 1.06 | Kmid | 0.95 | Kmid | 1.27 |
| Aug. 15 | Kmid | 1.06 | Kmid | 0.95 | Kmid | 1.27 |
| Aug. 16 | Kmid | 1.06 | Kmid | 0.95 | Kmid | 1.27 |
| Aug. 17 | Kmid | 1.06 | Kmid | 0.95 | Kmid | 1.27 |
| Aug. 18 | Kmid | 1.06 | Kmid | 0.95 | Kmid | 1.27 |
| Aug. 19 | Kmid | 1.06 | Kmid | 0.95 | Kmid | 1.27 |
| Aug. 20 | Kmid | 1.06 | Kmid | 0.95 | Kmid | 1.27 |
| Aug. 21 | Kmid | 1.06 | Kmid | 0.95 | Kmid | 1.27 |
| Aug. 22 | Kmid | 1.06 | Kmid | 0.95 | Kmid | 1.27 |
| Aug. 23 | Kmid | 1.06 | Kmid | 0.95 | Kmid | 1.27 |
| Aug. 24 | Kmid | 1.06 | Kmid | 0.95 | Kmid | 1.27 |
| Aug. 25 | Klate | 1.07 | Kmid | 0.95 | Kmid | 1.27 |
| Aug. 26 | Klate | 1.08 | Kmid | 0.95 | Kmid | 1.27 |
| Aug. 27 | Klate | 1.10 | Kmid | 0.95 | Kmid | 1.27 |
| Aug. 28 | Klate | 1.11 | Kmid | 0.95 | Kmid | 1.27 |
| Aug. 29 | Klate | 1.00 | Kmid | 0.95 | Kmid | 1.27 |
| Aug. 30 | Kini | 0.95 | Kmid | 0.95 | Kmid | 1.27 |
| Aug. 31 | Kini | 0.95 | Kmid | 0.95 | Kmid | 1.27 |
| Sept. 1 | Kini | 0.95 | Kmid | 0.95 | Kmid | 1.27 |
| Sept. 2 | Kini | 0.95 | Kmid | 0.95 | Kmid | 1.27 |
| Sept. 3 | Kini | 0.95 | Kmid | 0.95 | Kmid | 1.27 |
| Sept. 4 | Kini | 0.95 | Kmid | 0.95 | Kmid | 1.27 |
| Sept. 5 | Kini | 0.95 | Kmid | 0.95 | Kmid | 1.27 |
| Sept. 6 | Kdev | 0.96 | Kmid | 0.95 | Kmid | 1.27 |
| Sept. 7 | Kdev | 0.96 | Kmid | 0.95 | Kmid | 1.27 |
| Sept. 8 | Kdev | 0.97 | Kmid | 0.95 | Kmid | 1.27 |
| Sept. 9 | Kdev | 0.98 | Kmid | 0.95 | Kmid | 1.27 |
| Sept. 10 | Kdev | 0.98 | Kmid | 0.95 | Kmid | 1.27 |
| Sept. 11 | Kdev | 0.99 | Kmid | 0.95 | Kmid | 1.27 |
| Sept. 12 | Kdev | 1.00 | Kmid | 0.95 | Kmid | 1.27 |
| Sept. 13 | Kdev | 1.01 | Kmid | 0.95 | Kmid | 1.27 |
| Sept. 14 | Kdev | 1.01 | Kmid | 0.95 | Kmid | 1.27 |
| Sept. 15 | Kdev | 1.02 | Kmid | 0.95 | Kmid | 1.27 |
| Sept. 16 | Kdev | 1.03 | Kmid | 0.95 | Kmid | 1.27 |
| Sept. 17 | Kdev | 1.03 | Kmid | 0.95 | Kmid | 1.27 |
| Sept. 18 | Kdev | 1.04 | Kmid | 0.95 | Kmid | 1.27 |
| Sept. 19 | Kdev | 1.05 | Kmid | 0.95 | Kmid | 1.27 |
| Sept. 20 | Kdev | 1.05 | Kmid | 0.95 | Klate | 1.23 |
| Sept. 21 | Kmid | 1.06 | Kmid | 0.95 | Klate | 1.20 |
| Sept. 22 | Kmid | 1.06 | Kmid | 0.95 | Klate | 1.16 |
| Sept. 23 | Kmid | 1.06 | Kmid | 0.95 | Klate | 1.12 |
| Sept. 24 | Kmid | 1.06 | Kmid | 0.95 | Klate | 1.08 |
| Sept. 25 | Kmid | 1.06 | Kmid | 0.95 | Klate | 1.05 |
| Sept. 26 | Kmid | 1.06 | Kmid | 0.95 | Klate | 1.01 |
| Sept. 27 | Kmid | 1.06 | Kmid | 0.95 | Klate | 0.97 |
| Sept. 28 | Kmid | 1.06 | Kmid | 0.95 | Klate | 0.93 |
| Sept. 29 | Kmid | 1.06 | Kmid | 0.95 | Klate | 0.90 |
| Sept. 30 | Kmid | 1.06 | Kmid | 0.95 | Klate | 0.86 |
| Oct. 1 | Kmid | 1.06 | Kmid | 0.95 | Klate | 0.82 |
| Oct. 2 | Kmid | 1.06 | Klate | 0.94 | Klate | 0.79 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Oct. 3 | Kmid | 1.06 | Klate | 0.94 | Klate | 0.75 |
| Oct. 4 | Kmid | 1.06 | Klate | 0.93 | Klate | 0.71 |
| Oct. 5 | Kmid | 1.06 | Klate | 0.92 | Klate | 0.67 |
| Oct. 6 | Klate | 1.05 | Klate | 0.92 | Klate | 0.64 |
| Oct. 7 | Klate | 1.05 | Klate | 0.91 | Klate | 0.60 |
| Oct. 8 | Klate | 1.04 | Klate | 0.90 | Klate | 0.56 |
| Oct. 9 | Klate | 1.04 | Klate | 0.90 | Klate | 0.52 |
| Oct. 10 | Klate | 1.03 | Klate | 0.89 | Klate | 0.49 |
| Oct. 11 | Klate | 1.02 | Klate | 0.88 | Klate | 0.45 |
| Oct. 12 | Klate | 1.02 | Klate | 0.88 | Klate | 0.41 |
| Oct. 13 | Klate | 1.01 | Klate | 0.87 | Klate | 0.37 |
| Oct. 14 | Klate | 1.01 | Klate | 0.86 | Klate | 0.34 |
| Oct. 15 | Klate | 1.00 | Klate | 0.86 | Klate | 0.30 |
| Oct. 16 | Bare Soil | 0.20 | Klate | 0.85 | Dormant | 0.37 |
| Oct. 17 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Oct. 18 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Oct. 19 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Oct. 20 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Oct. 21 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Oct. 22 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Oct. 23 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Oct. 24 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Oct. 25 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Oct. 26 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Oct. 27 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Oct. 28 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Oct. 29 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Oct. 30 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Oct. 31 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Nov. 1 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Nov. 2 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Nov. 3 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Nov. 4 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Nov. 5 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Nov. 6 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Nov. 7 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Nov. 8 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Nov. 9 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Nov. 10 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Nov. 11 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Nov. 12 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Nov. 13 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Nov. 14 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Nov. 15 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Nov. 16 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Nov. 17 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Nov. 18 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Nov. 19 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Nov. 20 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Nov. 21 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Nov. 22 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Nov. 23 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Nov. 24 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Nov. 25 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Nov. 26 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Nov. 27 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Nov. 28 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Nov. 29 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Nov. 30 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Dec. 1 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Dec. 2 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Dec. 3 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Dec. 4 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Dec. 5 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Dec. 6 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Dec. 7 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Dec. 8 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Dec. 9 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Dec. 10 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Dec. 11 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Dec. 12 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Dec. 13 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Dec. 14 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Dec. 15 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Dec. 16 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Dec. 17 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Dec. 18 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Dec. 19 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Dec. 20 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Dec. 21 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Dec. 22 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Dec. 23 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Dec. 24 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Dec. 25 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Dec. 26 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Dec. 27 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Dec. 28 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Dec. 29 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Dec. 30 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |
| Dec. 31 | Bare Soil | 0.20 | Dormant | 0.40 | Dormant | 0.37 |

[+]3 cuttings were assumed for Hay

**Table 5**: Annual evapotranspiration coefficients for peaches, apples, cherries, pears, and grapes.

| | Peaches* | Apples, Cherries, Pears[‡] | Grapes[a] |
|---|---|---|---|
| Jan. 1 | 0.2 | 0.2 | 0.2 |
| Jan. 2 | 0.2 | 0.2 | 0.2 |
| Jan. 3 | 0.2 | 0.2 | 0.2 |
| Jan. 4 | 0.2 | 0.2 | 0.2 |
| Jan. 5 | 0.2 | 0.2 | 0.2 |
| Jan. 6 | 0.2 | 0.2 | 0.2 |
| Jan. 7 | 0.2 | 0.2 | 0.2 |
| Jan. 8 | 0.2 | 0.2 | 0.2 |
| Jan. 9 | 0.2 | 0.2 | 0.2 |
| Jan. 10 | 0.2 | 0.2 | 0.2 |
| Jan. 11 | 0.2 | 0.2 | 0.2 |
| Jan. 12 | 0.2 | 0.2 | 0.2 |
| Jan. 13 | 0.2 | 0.2 | 0.2 |
| Jan. 14 | 0.2 | 0.2 | 0.2 |
| Jan. 15 | 0.2 | 0.2 | 0.2 |
| Jan. 16 | 0.2 | 0.2 | 0.2 |
| Jan. 17 | 0.2 | 0.2 | 0.2 |
| Jan. 18 | 0.2 | 0.2 | 0.2 |
| Jan. 19 | 0.2 | 0.2 | 0.2 |
| Jan. 20 | 0.2 | 0.2 | 0.2 |

| | | | |
|---|---|---|---|
| Jan. 21 | 0.2 | 0.2 | 0.2 |
| Jan. 22 | 0.2 | 0.2 | 0.2 |
| Jan. 23 | 0.2 | 0.2 | 0.2 |
| Jan. 24 | 0.2 | 0.2 | 0.2 |
| Jan. 25 | 0.2 | 0.2 | 0.2 |
| Jan. 26 | 0.2 | 0.2 | 0.2 |
| Jan. 27 | 0.2 | 0.2 | 0.2 |
| Jan. 28 | 0.2 | 0.2 | 0.2 |
| Jan. 29 | 0.2 | 0.2 | 0.2 |
| Jan. 30 | 0.2 | 0.2 | 0.2 |
| Jan. 31 | 0.2 | 0.2 | 0.2 |
| Feb. 1 | 0.2 | 0.2 | 0.2 |
| Feb. 2 | 0.2 | 0.2 | 0.2 |
| Feb. 3 | 0.2 | 0.2 | 0.2 |
| Feb. 4 | 0.2 | 0.2 | 0.2 |
| Feb. 5 | 0.2 | 0.2 | 0.2 |
| Feb. 6 | 0.2 | 0.2 | 0.2 |
| Feb. 7 | 0.2 | 0.2 | 0.2 |
| Feb. 8 | 0.2 | 0.2 | 0.2 |
| Feb. 9 | 0.2 | 0.2 | 0.2 |
| Feb. 10 | 0.2 | 0.2 | 0.2 |
| Feb. 11 | 0.2 | 0.2 | 0.2 |
| Feb. 12 | 0.2 | 0.2 | 0.2 |
| Feb. 13 | 0.2 | 0.2 | 0.2 |
| Feb. 14 | 0.2 | 0.2 | 0.2 |
| Feb. 15 | 0.2 | 0.2 | 0.2 |
| Feb. 16 | 0.2 | 0.2 | 0.2 |
| Feb. 17 | 0.2 | 0.2 | 0.2 |
| Feb. 18 | 0.2 | 0.2 | 0.2 |
| Feb. 19 | 0.2 | 0.2 | 0.2 |
| Feb. 20 | 0.2 | 0.2 | 0.2 |
| Feb. 21 | 0.2 | 0.2 | 0.2 |
| Feb. 22 | 0.2 | 0.2 | 0.2 |
| Feb. 23 | 0.2 | 0.2 | 0.2 |
| Feb. 24 | 0.2 | 0.2 | 0.2 |
| Feb. 25 | 0.2 | 0.2 | 0.2 |
| Feb. 26 | 0.2 | 0.2 | 0.2 |
| Feb. 27 | 0.2 | 0.2 | 0.2 |
| Feb. 28 | 0.2 | 0.2 | 0.2 |
| Mar. 1 | 0.2 | 0.2 | 0.2 |
| Mar. 2 | 0.2 | 0.2 | 0.2 |
| Mar. 3 | 0.2 | 0.2 | 0.2 |
| Mar. 4 | 0.2 | 0.2 | 0.2 |
| Mar. 5 | 0.2 | 0.2 | 0.2 |
| Mar. 6 | 0.2 | 0.2 | 0.2 |
| Mar. 7 | 0.2 | 0.2 | 0.2 |
| Mar. 8 | 0.2 | 0.2 | 0.2 |
| Mar. 9 | 0.2 | 0.2 | 0.2 |
| Mar. 10 | 0.2 | 0.2 | 0.2 |
| Mar. 11 | 0.2 | 0.2 | 0.2 |
| Mar. 12 | 0.2 | 0.2 | 0.2 |
| Mar. 13 | 0.2 | 0.2 | 0.2 |
| Mar. 14 | 0.2 | 0.2 | 0.2 |
| Mar. 15 | 0.2 | 0.2 | 0.2 |
| Mar. 16 | 0.2 | 0.2 | 0.2 |
| Mar. 17 | 0.2 | 0.2 | 0.2 |
| Mar. 18 | 0.2 | 0.2 | 0.2 |
| Mar. 19 | 0.2 | 0.2 | 0.2 |
| Mar. 20 | 0.2 | 0.2 | 0.2 |

| | | | |
|---|---|---|---|
| Mar. 21 | 0.2 | 0.2 | 0.2 |
| Mar. 22 | 0.2 | 0.2 | 0.2 |
| Mar. 23 | 0.2 | 0.2 | 0.2 |
| Mar. 24 | 0.2 | 0.2 | 0.2 |
| Mar. 25 | 0.2 | 0.2 | 0.2 |
| Mar. 26 | 0.2 | 0.2 | 0.2 |
| Mar. 27 | 0.2 | 0.2 | 0.2 |
| Mar. 28 | 0.2 | 0.2 | 0.2 |
| Mar. 29 | 0.2 | 0.2 | 0.2 |
| Mar. 30 | 0.2 | 0.2 | 0.2 |
| Mar. 31 | 0.2 | 0.2 | 0.2 |
| Apr. 1 | 0.2 | 0.2 | 0.2 |
| Apr. 2 | 0.2 | 0.2 | 0.2 |
| Apr. 3 | 0.2 | 0.2 | 0.2 |
| Apr. 4 | 0.2 | 0.2 | 0.2 |
| Apr. 5 | 0.2 | 0.2 | 0.2 |
| Apr. 6 | 0.2 | 0.2 | 0.2 |
| Apr. 7 | 0.2 | 0.2 | 0.2 |
| Apr. 8 | 0.2 | 0.2 | 0.2 |
| Apr. 9 | 0.2 | 0.2 | 0.2 |
| Apr. 10 | 0.2 | 0.2 | 0.2 |
| Apr. 11 | 0.2 | 0.2 | 0.2 |
| Apr. 12 | 0.2 | 0.2 | 0.2 |
| Apr. 13 | 0.2 | 0.2 | 0.2 |
| Apr. 14 | 0.2 | 0.2 | 0.2 |
| Apr. 15 | 0.2 | 0.2 | 0.2 |
| Apr. 16 | 0.2 | 0.2 | 0.2 |
| Apr. 17 | 0.2 | 0.2 | 0.2 |
| Apr. 18 | 0.2 | 0.2 | 0.2 |
| Apr. 19 | 0.2 | 0.2 | 0.2 |
| Apr. 20 | 0.2 | 0.2 | 0.2 |
| Apr. 21 | 0.2 | 0.2 | 0.2 |
| Apr. 22 | 0.2 | 0.2 | 0.2 |
| Apr. 23 | 0.2 | 0.2 | 0.2 |
| Apr. 24 | 0.2 | 0.2 | 0.2 |
| Apr. 25 | 0.2 | 0.2 | 0.2 |
| Apr. 26 | 0.2 | 0.2 | 0.2 |
| Apr. 27 | 0.2 | 0.2 | 0.2 |
| Apr. 28 | 0.2 | 0.2 | 0.2 |
| Apr. 29 | 0.2 | 0.2 | 0.2 |
| Apr. 30 | 0.2 | 0.2 | 0.2 |
| May 1 | 0.3 | 0.3 | 0.5 |
| May 2 | 0.3 | 0.3 | 0.5 |
| May 3 | 0.3 | 0.3 | 0.5 |
| May 4 | 0.3 | 0.3 | 0.5 |
| May 5 | 0.3 | 0.3 | 0.5 |
| May 6 | 0.3 | 0.3 | 0.5 |
| May 7 | 0.3 | 0.3 | 0.5 |
| May 8 | 0.3 | 0.3 | 0.5 |
| May 9 | 0.3 | 0.3 | 0.5 |
| May 10 | 0.3 | 0.3 | 0.5 |
| May 11 | 0.3 | 0.3 | 0.5 |
| May 12 | 0.3 | 0.3 | 0.5 |
| May 13 | 0.3 | 0.3 | 0.5 |
| May 14 | 0.3 | 0.3 | 0.5 |
| May 15 | 0.3 | 0.3 | 0.5 |
| May 16 | 0.3 | 0.3 | 0.5 |
| May 17 | 0.3 | 0.3 | 0.5 |
| May 18 | 0.3 | 0.3 | 0.5 |

| | | | |
|---|---|---|---|
| May 19 | 0.3 | 0.3 | 0.5 |
| May 20 | 0.3 | 0.3 | 0.5 |
| May 21 | 0.3 | 0.3 | 0.5 |
| May 22 | 0.3 | 0.3 | 0.5 |
| May 23 | 0.3 | 0.3 | 0.5 |
| May 24 | 0.3 | 0.3 | 0.5 |
| May 25 | 0.3 | 0.3 | 0.5 |
| May 26 | 0.3 | 0.3 | 0.5 |
| May 27 | 0.3 | 0.3 | 0.5 |
| May 28 | 0.3 | 0.3 | 0.5 |
| May 29 | 0.3 | 0.3 | 0.5 |
| May 30 | 0.3 | 0.3 | 0.5 |
| May 31 | 0.3 | 0.3 | 0.5 |
| June 1 | 0.4 | 0.4 | 0.68 |
| June 2 | 0.4 | 0.4 | 0.68 |
| June 3 | 0.4 | 0.4 | 0.68 |
| June 4 | 0.4 | 0.4 | 0.68 |
| June 5 | 0.4 | 0.4 | 0.68 |
| June 6 | 0.4 | 0.4 | 0.68 |
| June 7 | 0.4 | 0.4 | 0.68 |
| June 8 | 0.4 | 0.4 | 0.68 |
| June 9 | 0.4 | 0.4 | 0.68 |
| June 10 | 0.4 | 0.4 | 0.68 |
| June 11 | 0.4 | 0.4 | 0.68 |
| June 12 | 0.4 | 0.4 | 0.68 |
| June 13 | 0.4 | 0.4 | 0.68 |
| June 14 | 0.4 | 0.4 | 0.68 |
| June 15 | 0.4 | 0.4 | 0.68 |
| June 16 | 0.6 | 0.6 | 0.68 |
| June 17 | 0.6 | 0.6 | 0.68 |
| June 18 | 0.6 | 0.6 | 0.68 |
| June 19 | 0.6 | 0.6 | 0.68 |
| June 20 | 0.6 | 0.6 | 0.68 |
| June 21 | 0.6 | 0.6 | 0.68 |
| June 22 | 0.6 | 0.6 | 0.68 |
| June 23 | 0.6 | 0.6 | 0.68 |
| June 24 | 0.6 | 0.6 | 0.68 |
| June 25 | 0.6 | 0.6 | 0.68 |
| June 26 | 0.6 | 0.6 | 0.68 |
| June 27 | 0.6 | 0.6 | 0.68 |
| June 28 | 0.6 | 0.6 | 0.68 |
| June 29 | 0.6 | 0.6 | 0.68 |
| June 30 | 0.6 | 0.6 | 0.68 |
| July 1 | 1.0 | 1.0 | 0.77 |
| July 2 | 1.0 | 1.0 | 0.77 |
| July 3 | 1.0 | 1.0 | 0.77 |
| July 4 | 1.0 | 1.0 | 0.77 |
| July 5 | 1.0 | 1.0 | 0.77 |
| July 6 | 1.0 | 1.0 | 0.77 |
| July 7 | 1.0 | 1.0 | 0.77 |
| July 8 | 1.0 | 1.0 | 0.77 |
| July 9 | 1.0 | 1.0 | 0.77 |
| July 10 | 1.0 | 1.0 | 0.77 |
| July 11 | 1.0 | 1.0 | 0.77 |
| July 12 | 1.0 | 1.0 | 0.77 |
| July 13 | 1.0 | 1.0 | 0.77 |
| July 14 | 1.0 | 1.0 | 0.77 |
| July 15 | 1.0 | 1.0 | 0.77 |
| July 16 | 1.0 | 1.0 | 0.77 |

| | | | |
|---|---|---|---|
| July 17 | 1.0 | 1.0 | 0.77 |
| July 18 | 1.0 | 1.0 | 0.77 |
| July 19 | 1.0 | 1.0 | 0.77 |
| July 20 | 1.0 | 1.0 | 0.77 |
| July 21 | 1.0 | 1.0 | 0.77 |
| July 22 | 1.0 | 1.0 | 0.77 |
| July 23 | 1.0 | 1.0 | 0.77 |
| July 24 | 1.0 | 1.0 | 0.77 |
| July 25 | 1.0 | 1.0 | 0.77 |
| July 26 | 1.0 | 1.0 | 0.77 |
| July 27 | 1.0 | 1.0 | 0.77 |
| July 28 | 1.0 | 1.0 | 0.77 |
| July 29 | 1.0 | 1.0 | 0.77 |
| July 30 | 1.0 | 1.0 | 0.77 |
| July 31 | 1.0 | 1.0 | 0.77 |
| Aug. 1 | 1.0 | 1.0 | 0.80 |
| Aug. 2 | 1.0 | 1.0 | 0.80 |
| Aug. 3 | 1.0 | 1.0 | 0.80 |
| Aug. 4 | 1.0 | 1.0 | 0.80 |
| Aug. 5 | 1.0 | 1.0 | 0.80 |
| Aug. 6 | 1.0 | 1.0 | 0.80 |
| Aug. 7 | 1.0 | 1.0 | 0.80 |
| Aug. 8 | 1.0 | 1.0 | 0.80 |
| Aug. 9 | 1.0 | 1.0 | 0.80 |
| Aug. 10 | 1.0 | 1.0 | 0.80 |
| Aug. 11 | 1.0 | 1.0 | 0.80 |
| Aug. 12 | 1.0 | 1.0 | 0.80 |
| Aug. 13 | 1.0 | 1.0 | 0.80 |
| Aug. 14 | 1.0 | 1.0 | 0.80 |
| Aug. 15 | 1.0 | 1.0 | 0.80 |
| Aug. 16 | 1.0 | 1.0 | 0.80 |
| Aug. 17 | 1.0 | 1.0 | 0.80 |
| Aug. 18 | 1.0 | 1.0 | 0.80 |
| Aug. 19 | 1.0 | 1.0 | 0.80 |
| Aug. 20 | 1.0 | 1.0 | 0.80 |
| Aug. 21 | 1.0 | 1.0 | 0.80 |
| Aug. 22 | 1.0 | 1.0 | 0.80 |
| Aug. 23 | 1.0 | 1.0 | 0.80 |
| Aug. 24 | 1.0 | 1.0 | 0.80 |
| Aug. 25 | 1.0 | 1.0 | 0.80 |
| Aug. 26 | 1.0 | 1.0 | 0.80 |
| Aug. 27 | 1.0 | 1.0 | 0.80 |
| Aug. 28 | 1.0 | 1.0 | 0.80 |
| Aug. 29 | 1.0 | 1.0 | 0.80 |
| Aug. 30 | 1.0 | 1.0 | 0.80 |
| Aug. 31 | 1.0 | 1.0 | 0.80 |
| Sept. 1 | 0.95 | 0.95 | 0.75 |
| Sept. 2 | 0.95 | 0.95 | 0.75 |
| Sept. 3 | 0.95 | 0.95 | 0.75 |
| Sept. 4 | 0.95 | 0.95 | 0.75 |
| Sept. 5 | 0.95 | 0.95 | 0.75 |
| Sept. 6 | 0.95 | 0.95 | 0.75 |
| Sept. 7 | 0.95 | 0.95 | 0.75 |
| Sept. 8 | 0.95 | 0.95 | 0.75 |
| Sept. 9 | 0.95 | 0.95 | 0.75 |
| Sept. 10 | 0.95 | 0.95 | 0.75 |
| Sept. 11 | 0.95 | 0.95 | 0.75 |
| Sept. 12 | 0.95 | 0.95 | 0.75 |
| Sept. 13 | 0.95 | 0.95 | 0.75 |

| | | | |
|---|---|---|---|
| Sept. 14 | 0.95 | 0.95 | 0.75 |
| Sept. 15 | 0.95 | 0.95 | 0.75 |
| Sept. 16 | 0.95 | 0.95 | 0.75 |
| Sept. 17 | 0.95 | 0.95 | 0.75 |
| Sept. 18 | 0.95 | 0.95 | 0.75 |
| Sept. 19 | 0.95 | 0.95 | 0.75 |
| Sept. 20 | 0.95 | 0.95 | 0.75 |
| Sept. 21 | 0.95 | 0.95 | 0.75 |
| Sept. 22 | 0.95 | 0.95 | 0.75 |
| Sept. 23 | 0.95 | 0.95 | 0.75 |
| Sept. 24 | 0.95 | 0.95 | 0.75 |
| Sept. 25 | 0.95 | 0.95 | 0.75 |
| Sept. 26 | 0.95 | 0.95 | 0.75 |
| Sept. 27 | 0.95 | 0.95 | 0.75 |
| Sept. 28 | 0.95 | 0.95 | 0.75 |
| Sept. 29 | 0.95 | 0.95 | 0.75 |
| Sept. 30 | 0.95 | 0.95 | 0.75 |
| Oct. 1 | 0.83 | 0.80 | 0.63 |
| Oct. 2 | 0.83 | 0.80 | 0.63 |
| Oct. 3 | 0.83 | 0.80 | 0.63 |
| Oct. 4 | 0.83 | 0.80 | 0.63 |
| Oct. 5 | 0.83 | 0.80 | 0.63 |
| Oct. 6 | 0.83 | 0.80 | 0.63 |
| Oct. 7 | 0.83 | 0.80 | 0.63 |
| Oct. 8 | 0.83 | 0.80 | 0.63 |
| Oct. 9 | 0.83 | 0.80 | 0.63 |
| Oct. 10 | 0.83 | 0.80 | 0.63 |
| Oct. 11 | 0.83 | 0.80 | 0.63 |
| Oct. 12 | 0.83 | 0.80 | 0.63 |
| Oct. 13 | 0.83 | 0.80 | 0.63 |
| Oct. 14 | 0.83 | 0.80 | 0.63 |
| Oct. 15 | 0.83 | 0.80 | 0.63 |
| Oct. 16 | 0.83 | 0.80 | 0.63 |
| Oct. 17 | 0.83 | 0.80 | 0.63 |
| Oct. 18 | 0.83 | 0.80 | 0.63 |
| Oct. 19 | 0.83 | 0.80 | 0.63 |
| Oct. 20 | 0.83 | 0.80 | 0.63 |
| Oct. 21 | 0.83 | 0.80 | 0.63 |
| Oct. 22 | 0.83 | 0.80 | 0.63 |
| Oct. 23 | 0.83 | 0.80 | 0.63 |
| Oct. 24 | 0.83 | 0.80 | 0.63 |
| Oct. 25 | 0.83 | 0.80 | 0.63 |
| Oct. 26 | 0.83 | 0.80 | 0.63 |
| Oct. 27 | 0.83 | 0.80 | 0.63 |
| Oct. 28 | 0.83 | 0.80 | 0.63 |
| Oct. 29 | 0.83 | 0.80 | 0.63 |
| Oct. 30 | 0.83 | 0.80 | 0.63 |
| Oct. 31 | 0.83 | 0.80 | 0.63 |
| Nov. 1 | 0.2 | 0.2 | 0.2 |
| Nov. 2 | 0.2 | 0.2 | 0.2 |
| Nov. 3 | 0.2 | 0.2 | 0.2 |
| Nov. 4 | 0.2 | 0.2 | 0.2 |
| Nov. 5 | 0.2 | 0.2 | 0.2 |
| Nov. 6 | 0.2 | 0.2 | 0.2 |
| Nov. 7 | 0.2 | 0.2 | 0.2 |
| Nov. 8 | 0.2 | 0.2 | 0.2 |
| Nov. 9 | 0.2 | 0.2 | 0.2 |
| Nov. 10 | 0.2 | 0.2 | 0.2 |
| Nov. 11 | 0.2 | 0.2 | 0.2 |

| | | | |
|---|---|---|---|
| Nov. 12 | 0.2 | 0.2 | 0.2 |
| Nov. 13 | 0.2 | 0.2 | 0.2 |
| Nov. 14 | 0.2 | 0.2 | 0.2 |
| Nov. 15 | 0.2 | 0.2 | 0.2 |
| Nov. 16 | 0.2 | 0.2 | 0.2 |
| Nov. 17 | 0.2 | 0.2 | 0.2 |
| Nov. 18 | 0.2 | 0.2 | 0.2 |
| Nov. 19 | 0.2 | 0.2 | 0.2 |
| Nov. 20 | 0.2 | 0.2 | 0.2 |
| Nov. 21 | 0.2 | 0.2 | 0.2 |
| Nov. 22 | 0.2 | 0.2 | 0.2 |
| Nov. 23 | 0.2 | 0.2 | 0.2 |
| Nov. 24 | 0.2 | 0.2 | 0.2 |
| Nov. 25 | 0.2 | 0.2 | 0.2 |
| Nov. 26 | 0.2 | 0.2 | 0.2 |
| Nov. 27 | 0.2 | 0.2 | 0.2 |
| Nov. 28 | 0.2 | 0.2 | 0.2 |
| Nov. 29 | 0.2 | 0.2 | 0.2 |
| Nov. 30 | 0.2 | 0.2 | 0.2 |
| Dec. 1 | 0.2 | 0.2 | 0.2 |
| Dec. 2 | 0.2 | 0.2 | 0.2 |
| Dec. 3 | 0.2 | 0.2 | 0.2 |
| Dec. 4 | 0.2 | 0.2 | 0.2 |
| Dec. 5 | 0.2 | 0.2 | 0.2 |
| Dec. 6 | 0.2 | 0.2 | 0.2 |
| Dec. 7 | 0.2 | 0.2 | 0.2 |
| Dec. 8 | 0.2 | 0.2 | 0.2 |
| Dec. 9 | 0.2 | 0.2 | 0.2 |
| Dec. 10 | 0.2 | 0.2 | 0.2 |
| Dec. 11 | 0.2 | 0.2 | 0.2 |
| Dec. 12 | 0.2 | 0.2 | 0.2 |
| Dec. 13 | 0.2 | 0.2 | 0.2 |
| Dec. 14 | 0.2 | 0.2 | 0.2 |
| Dec. 15 | 0.2 | 0.2 | 0.2 |
| Dec. 16 | 0.2 | 0.2 | 0.2 |
| Dec. 17 | 0.2 | 0.2 | 0.2 |
| Dec. 18 | 0.2 | 0.2 | 0.2 |
| Dec. 19 | 0.2 | 0.2 | 0.2 |
| Dec. 20 | 0.2 | 0.2 | 0.2 |
| Dec. 21 | 0.2 | 0.2 | 0.2 |
| Dec. 22 | 0.2 | 0.2 | 0.2 |
| Dec. 23 | 0.2 | 0.2 | 0.2 |
| Dec. 24 | 0.2 | 0.2 | 0.2 |
| Dec. 25 | 0.2 | 0.2 | 0.2 |
| Dec. 26 | 0.2 | 0.2 | 0.2 |
| Dec. 27 | 0.2 | 0.2 | 0.2 |
| Dec. 28 | 0.2 | 0.2 | 0.2 |
| Dec. 29 | 0.2 | 0.2 | 0.2 |
| Dec. 30 | 0.2 | 0.2 | 0.2 |
| Dec. 31 | 0.2 | 0.2 | 0.2 |

* Values for Peaches were determined using the OMAFRA Best Management Practices - Irrigation Management guide for mature fruit trees with permanent sod and herbicide strip. Values for January to April, and November to December were based on the April coefficient, which is equal to that of bare soil. The values from the British Columbia Ministry of Agriculture, Food and Fisheries were used for October. The values used are an average of the coefficients indicated for the 3 regions in British Columbia.

‡The values for all months, excluding October, were determined from OMAFRA Best Management Practices - Irrigation Management guide for mature fruit trees with

permanent sod and herbicide strip. The values for October were determined based on the average values indicated by the 3 regions in British Columbia by the Ministry of Agriculture, Food and Fisheries.
[a]Ontario does not have published values for grapes. The BC Ministry of Agriculture, Food and Fisheries was used to determine these values from May to the end of October. The values are an average of the 3 identified regions in BC. The coefficient for bare soil was used for the off season months.

**Table 6**: Annual evapotranspiration coefficients for deciduous and coniferous forests, and idle land.

| | Deciduous Forest | Kc[b] | Coniferous Forest | Kc[b] | Idle Land | Kc[b] |
|---|---|---|---|---|---|---|
| Jan. 1 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Jan. 2 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Jan. 3 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Jan. 4 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Jan. 5 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Jan. 6 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Jan. 7 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Jan. 8 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Jan. 9 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Jan. 10 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Jan. 11 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Jan. 12 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Jan. 13 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Jan. 14 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Jan. 15 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Jan. 16 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Jan. 17 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Jan. 18 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Jan. 19 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Jan. 20 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Jan. 21 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Jan. 22 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Jan. 23 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Jan. 24 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Jan. 25 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Jan. 26 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Jan. 27 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Jan. 28 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Jan. 29 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Jan. 30 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Jan. 31 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Feb. 1 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Feb. 2 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Feb. 3 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Feb. 4 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Feb. 5 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Feb. 6 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Feb. 7 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Feb. 8 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Feb. 9 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Feb. 10 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Feb. 11 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Feb. 12 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Feb. 13 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Feb. 14 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Feb. 15 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Feb. 16 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Feb. 17 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Feb. 18 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Feb. 19 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Feb. 20 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Feb. 21 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Feb. 22 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Feb. 23 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Feb. 24 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Feb. 25 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Feb. 26 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Feb. 27 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Feb. 28 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Mar. 1 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Mar. 2 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Mar. 3 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Mar. 4 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Mar. 5 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Mar. 6 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Mar. 7 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Mar. 8 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Mar. 9 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Mar. 10 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Mar. 11 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Mar. 12 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Mar. 13 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Mar. 14 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Mar. 15 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Mar. 16 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Mar. 17 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Mar. 18 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Mar. 19 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Mar. 20 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Mar. 21 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Mar. 22 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Mar. 23 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Mar. 24 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Mar. 25 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Mar. 26 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Mar. 27 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Mar. 28 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Mar. 29 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Mar. 30 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Mar. 31 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Apr. 1 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.00 |
| Apr. 2 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.01 |
| Apr. 3 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.07 |
| Apr. 4 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.06 |
| Apr. 5 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.96 |
| Apr. 6 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.98 |
| Apr. 7 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.93 |
| Apr. 8 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.01 |
| Apr. 9 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.00 |
| Apr. 10 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.03 |
| Apr. 11 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.00 |
| Apr. 12 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.03 |
| Apr. 13 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.02 |
| Apr. 14 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.86 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Apr. 15 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.99 |
| Apr. 16 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.99 |
| Apr. 17 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.99 |
| Apr. 18 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.00 |
| Apr. 19 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.02 |
| Apr. 20 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.00 |
| Apr. 21 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.90 |
| Apr. 22 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.85 |
| Apr. 23 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.94 |
| Apr. 24 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.04 |
| Apr. 25 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.06 |
| Apr. 26 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.03 |
| Apr. 27 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.03 |
| Apr. 28 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.07 |
| Apr. 29 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.08 |
| Apr. 30 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.07 |
| May 1 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.04 |
| May 2 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.04 |
| May 3 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.00 |
| May 4 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.98 |
| May 5 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.03 |
| May 6 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.00 |
| May 7 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.04 |
| May 8 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.03 |
| May 9 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.04 |
| May 10 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.02 |
| May 11 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.97 |
| May 12 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.96 |
| May 13 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.97 |
| May 14 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.94 |
| May 15 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.91 |
| May 16 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.96 |
| May 17 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.94 |
| May 18 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.97 |
| May 19 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.05 |
| May 20 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.04 |
| May 21 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.02 |
| May 22 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.03 |
| May 23 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.03 |
| May 24 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.99 |
| May 25 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.88 |
| May 26 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.98 |
| May 27 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.97 |
| May 28 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.01 |
| May 29 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.99 |
| May 30 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.97 |
| May 31 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.88 |
| June 1 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.91 |
| June 2 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.87 |
| June 3 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.01 |
| June 4 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.01 |
| June 5 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.00 |
| June 6 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.00 |
| June 7 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.99 |
| June 8 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.98 |
| June 9 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.08 |
| June 10 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.00 |
| June 11 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.97 |
| June 12 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.98 |

| | | | | | | |
|---|---|---|---|---|---|---|
| June 13 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.98 |
| June 14 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.03 |
| June 15 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.04 |
| June 16 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.06 |
| June 17 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.03 |
| June 18 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.97 |
| June 19 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.00 |
| June 20 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.97 |
| June 21 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.02 |
| June 22 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.95 |
| June 23 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.93 |
| June 24 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.97 |
| June 25 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.93 |
| June 26 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.89 |
| June 27 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.95 |
| June 28 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.96 |
| June 29 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.98 |
| June 30 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.04 |
| July 1 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.03 |
| July 2 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.97 |
| July 3 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.00 |
| July 4 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.00 |
| July 5 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.98 |
| July 6 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.01 |
| July 7 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.02 |
| July 8 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.03 |
| July 9 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.94 |
| July 10 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.92 |
| July 11 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.88 |
| July 12 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.96 |
| July 13 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.94 |
| July 14 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.97 |
| July 15 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.99 |
| July 16 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.01 |
| July 17 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.01 |
| July 18 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.92 |
| July 19 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.95 |
| July 20 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.92 |
| July 21 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.90 |
| July 22 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.94 |
| July 23 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.01 |
| July 24 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.99 |
| July 25 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.01 |
| July 26 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.96 |
| July 27 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.94 |
| July 28 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.95 |
| July 29 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.91 |
| July 30 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.95 |
| July 31 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.99 |
| Aug. 1 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.01 |
| Aug. 2 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.90 |
| Aug. 3 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.00 |
| Aug. 4 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.95 |
| Aug. 5 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.98 |
| Aug. 6 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.00 |
| Aug. 7 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.02 |
| Aug. 8 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.01 |
| Aug. 9 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.98 |
| Aug. 10 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.01 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Aug. 11 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.01 |
| Aug. 12 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.01 |
| Aug. 13 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.97 |
| Aug. 14 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.02 |
| Aug. 15 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.98 |
| Aug. 16 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.00 |
| Aug. 17 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.96 |
| Aug. 18 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.88 |
| Aug. 19 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.93 |
| Aug. 20 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.00 |
| Aug. 21 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.99 |
| Aug. 22 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.01 |
| Aug. 23 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.95 |
| Aug. 24 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.91 |
| Aug. 25 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.92 |
| Aug. 26 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.92 |
| Aug. 27 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.91 |
| Aug. 28 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.93 |
| Aug. 29 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.98 |
| Aug. 30 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.97 |
| Aug. 31 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.97 |
| Sept. 1 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.93 |
| Sept. 2 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.90 |
| Sept. 3 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.92 |
| Sept. 4 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.88 |
| Sept. 5 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.92 |
| Sept. 6 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.95 |
| Sept. 7 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.99 |
| Sept. 8 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.91 |
| Sept. 9 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.98 |
| Sept. 10 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.98 |
| Sept. 11 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.90 |
| Sept. 12 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.91 |
| Sept. 13 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.88 |
| Sept. 14 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.88 |
| Sept. 15 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.87 |
| Sept. 16 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.94 |
| Sept. 17 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.00 |
| Sept. 18 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.98 |
| Sept. 19 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.00 |
| Sept. 20 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.97 |
| Sept. 21 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.92 |
| Sept. 22 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.93 |
| Sept. 23 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.01 |
| Sept. 24 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.00 |
| Sept. 25 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.96 |
| Sept. 26 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.01 |
| Sept. 27 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.92 |
| Sept. 28 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.94 |
| Sept. 29 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.95 |
| Sept. 30 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.95 |
| Oct. 1 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.95 |
| Oct. 2 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.91 |
| Oct. 3 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.98 |
| Oct. 4 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.98 |
| Oct. 5 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.93 |
| Oct. 6 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.95 |
| Oct. 7 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.92 |
| Oct. 8 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.95 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Oct. 9 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.94 |
| Oct. 10 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.93 |
| Oct. 11 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.98 |
| Oct. 12 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.01 |
| Oct. 13 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.00 |
| Oct. 14 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.01 |
| Oct. 15 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.99 |
| Oct. 16 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.98 |
| Oct. 17 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.94 |
| Oct. 18 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.90 |
| Oct. 19 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.93 |
| Oct. 20 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.91 |
| Oct. 21 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.92 |
| Oct. 22 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.00 |
| Oct. 23 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.97 |
| Oct. 24 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.99 |
| Oct. 25 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.95 |
| Oct. 26 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.92 |
| Oct. 27 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.95 |
| Oct. 28 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.07 |
| Oct. 29 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.01 |
| Oct. 30 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 1.03 |
| Oct. 31 | Kmid | 1.09 | Kmid | 0.55 | Kmid | 0.99 |
| Nov. 1 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Nov. 2 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Nov. 3 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Nov. 4 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Nov. 5 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Nov. 6 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Nov. 7 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Nov. 8 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Nov. 9 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Nov. 10 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Nov. 11 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Nov. 12 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Nov. 13 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Nov. 14 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Nov. 15 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Nov. 16 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Nov. 17 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Nov. 18 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Nov. 19 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Nov. 20 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Nov. 21 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Nov. 22 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Nov. 23 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Nov. 24 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Nov. 25 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Nov. 26 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Nov. 27 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Nov. 28 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Nov. 29 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Nov. 30 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Dec. 1 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Dec. 2 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Dec. 3 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Dec. 4 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Dec. 5 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Dec. 6 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Dec. 7 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Dec. 8 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Dec. 9 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Dec. 10 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Dec. 11 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Dec. 12 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Dec. 13 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Dec. 14 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Dec. 15 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Dec. 16 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Dec. 17 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Dec. 18 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Dec. 19 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Dec. 20 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Dec. 21 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Dec. 22 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Dec. 23 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Dec. 24 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Dec. 25 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Dec. 26 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Dec. 27 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Dec. 28 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Dec. 29 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Dec. 30 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |
| Dec. 31 | Dormant | 0.2 | Off Season | 0.2 | Dormant | 0.2 |

[b]Based on the information available regarding the evapotranspiration of deciduous and coniferous forest, and idle land, step-wise changes in values were used. A growing season of April 1 to Oct. 31 was estimated in order to include bud development as well as killing frost at the end of the season. Should these values not be appropriate for the region of concern or vary seasonally, they should be adjusted accordingly.

**Table 7**: Annual evapotranspiration coefficients for tallgrass, built-up pervious areas, and open water.

| | Tallgrass[c] | Kc[d] | Built-Up Pervious Area | Kc[d] | Open Water (Shallow) | Open Water (>5m depth)[e] |
|---|---|---|---|---|---|---|
| Jan. 1 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Jan. 2 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Jan. 3 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Jan. 4 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Jan. 5 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Jan. 6 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Jan. 7 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Jan. 8 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Jan. 9 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Jan. 10 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Jan. 11 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Jan. 12 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Jan. 13 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Jan. 14 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Jan. 15 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Jan. 16 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Jan. 17 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Jan. 18 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Jan. 19 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Jan. 20 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Jan. 21 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Jan. 22 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Jan. 23 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Jan. 24 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Jan. 25 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Jan. 26 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Jan. 27 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Jan. 28 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Jan. 29 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Jan. 30 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Jan. 31 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Feb. 1 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Feb. 2 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Feb. 3 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Feb. 4 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Feb. 5 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Feb. 6 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Feb. 7 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Feb. 8 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Feb. 9 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Feb. 10 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Feb. 11 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Feb. 12 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Feb. 13 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Feb. 14 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Feb. 15 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Feb. 16 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Feb. 17 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Feb. 18 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Feb. 19 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Feb. 20 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Feb. 21 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Feb. 22 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Feb. 23 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Feb. 24 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Feb. 25 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Feb. 26 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Feb. 27 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Feb. 28 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Mar. 1 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Mar. 2 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Mar. 3 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Mar. 4 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Mar. 5 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Mar. 6 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Mar. 7 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Mar. 8 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Mar. 9 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Mar. 10 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Mar. 11 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Mar. 12 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Mar. 13 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Mar. 14 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Mar. 15 | Kini | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Mar. 16 | Kini | 0.38 | Reference | 1.0 | 1.05 | 1.25 |
| Mar. 17 | Kini | 0.38 | Reference | 1.0 | 1.05 | 1.25 |
| Mar. 18 | Kini | 0.38 | Reference | 1.0 | 1.05 | 1.25 |
| Mar. 19 | Kini | 0.38 | Reference | 1.0 | 1.05 | 1.25 |
| Mar. 20 | Kini | 0.38 | Reference | 1.0 | 1.05 | 1.25 |
| Mar. 21 | Kini | 0.37 | Reference | 1.0 | 1.05 | 1.25 |
| Mar. 22 | Kini | 0.37 | Reference | 1.0 | 1.05 | 1.25 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Mar. 23 | Kini | 0.36 | Reference | 1.0 | 1.05 | 1.25 |
| Mar. 24 | Kini | 0.36 | Reference | 1.0 | 1.05 | 1.25 |
| Mar. 25 | Kini | 0.36 | Reference | 1.0 | 1.05 | 1.25 |
| Mar. 26 | Kini | 0.37 | Reference | 1.0 | 1.05 | 1.25 |
| Mar. 27 | Kini | 0.38 | Reference | 1.0 | 1.05 | 1.25 |
| Mar. 28 | Kini | 0.37 | Reference | 1.0 | 1.05 | 1.25 |
| Mar. 29 | Kini | 0.37 | Reference | 1.0 | 1.05 | 1.25 |
| Mar. 30 | Kini | 0.37 | Reference | 1.0 | 1.05 | 1.25 |
| Mar. 31 | Kini | 0.38 | Reference | 1.0 | 1.05 | 1.25 |
| Apr. 1 | Kini | 0.37 | Reference | 1.0 | 1.05 | 1.25 |
| Apr. 2 | Kini | 0.37 | Reference | 1.0 | 1.05 | 1.25 |
| Apr. 3 | Kini | 0.38 | Reference | 1.0 | 1.05 | 1.25 |
| Apr. 4 | Kini | 0.38 | Reference | 1.0 | 1.05 | 1.25 |
| Apr. 5 | Kini | 0.36 | Reference | 1.0 | 1.05 | 1.25 |
| Apr. 6 | Kini | 0.37 | Reference | 1.0 | 1.05 | 1.25 |
| Apr. 7 | Kini | 0.36 | Reference | 1.0 | 1.05 | 1.25 |
| Apr. 8 | Kini | 0.37 | Reference | 1.0 | 1.05 | 1.25 |
| Apr. 9 | Kini | 0.37 | Reference | 1.0 | 1.05 | 1.25 |
| Apr. 10 | Kini | 0.38 | Reference | 1.0 | 1.05 | 1.25 |
| Apr. 11 | Kini | 0.37 | Reference | 1.0 | 1.05 | 1.25 |
| Apr. 12 | Kini | 0.38 | Reference | 1.0 | 1.05 | 1.25 |
| Apr. 13 | Kini | 0.37 | Reference | 1.0 | 1.05 | 1.25 |
| Apr. 14 | Kini | 0.35 | Reference | 1.0 | 1.05 | 1.25 |
| Apr. 15 | Kini | 0.37 | Reference | 1.0 | 1.05 | 1.25 |
| Apr. 16 | Kini | 0.37 | Reference | 1.0 | 1.05 | 1.25 |
| Apr. 17 | Kini | 0.37 | Reference | 1.0 | 1.05 | 1.25 |
| Apr. 18 | Kini | 0.37 | Reference | 1.0 | 1.05 | 1.25 |
| Apr. 19 | Kini | 0.37 | Reference | 1.0 | 1.05 | 1.25 |
| Apr. 20 | Kini | 0.37 | Reference | 1.0 | 1.05 | 1.25 |
| Apr. 21 | Kini | 0.37 | Reference | 1.0 | 1.05 | 1.25 |
| Apr. 22 | Kini | 0.36 | Reference | 1.0 | 1.05 | 1.25 |
| Apr. 23 | Kini | 0.35 | Reference | 1.0 | 1.05 | 1.25 |
| Apr. 24 | Kini | 0.36 | Reference | 1.0 | 1.05 | 1.25 |
| Apr. 25 | Kini | 0.38 | Reference | 1.0 | 1.05 | 1.25 |
| Apr. 26 | Kini | 0.38 | Reference | 1.0 | 1.05 | 1.25 |
| Apr. 27 | Kini | 0.38 | Reference | 1.0 | 1.05 | 1.25 |
| Apr. 28 | Kini | 0.38 | Reference | 1.0 | 1.05 | 1.25 |
| Apr. 29 | Kini | 0.38 | Reference | 1.0 | 1.05 | 1.25 |
| Apr. 30 | Kini | 0.38 | Reference | 1.0 | 1.05 | 1.25 |
| May 1 | Kini | 0.38 | Reference | 1.0 | 1.05 | 0.65 |
| May 2 | Kini | 0.38 | Reference | 1.0 | 1.05 | 0.65 |
| May 3 | Kini | 0.38 | Reference | 1.0 | 1.05 | 0.65 |
| May 4 | Kini | 0.37 | Reference | 1.0 | 1.05 | 0.65 |
| May 5 | Kini | 0.37 | Reference | 1.0 | 1.05 | 0.65 |
| May 6 | Kini | 0.38 | Reference | 1.0 | 1.05 | 0.65 |
| May 7 | Kini | 0.37 | Reference | 1.0 | 1.05 | 0.65 |
| May 8 | Kini | 0.38 | Reference | 1.0 | 1.05 | 0.65 |
| May 9 | Kini | 0.38 | Reference | 1.0 | 1.05 | 0.65 |
| May 10 | Kini | 0.38 | Reference | 1.0 | 1.05 | 0.65 |
| May 11 | Kini | 0.37 | Reference | 1.0 | 1.05 | 0.65 |
| May 12 | Kini | 0.37 | Reference | 1.0 | 1.05 | 0.65 |
| May 13 | Kini | 0.36 | Reference | 1.0 | 1.05 | 0.65 |
| May 14 | Kini | 0.37 | Reference | 1.0 | 1.05 | 0.65 |
| May 15 | Kdev | 0.85 | Reference | 1.0 | 1.05 | 0.65 |
| May 16 | Kdev | 0.83 | Reference | 1.0 | 1.05 | 0.65 |
| May 17 | Kdev | 0.86 | Reference | 1.0 | 1.05 | 0.65 |
| May 18 | Kdev | 0.85 | Reference | 1.0 | 1.05 | 0.65 |
| May 19 | Kdev | 0.86 | Reference | 1.0 | 1.05 | 0.65 |
| May 20 | Kdev | 0.91 | Reference | 1.0 | 1.05 | 0.65 |

| | | | | | | |
|---|---|---|---|---|---|---|
| May 21 | Kdev | 0.91 | Reference | 1.0 | 1.05 | 0.65 |
| May 22 | Kdev | 0.90 | Reference | 1.0 | 1.05 | 0.65 |
| May 23 | Kdev | 0.90 | Reference | 1.0 | 1.05 | 0.65 |
| May 24 | Kdev | 0.90 | Reference | 1.0 | 1.05 | 0.65 |
| May 25 | Kdev | 0.87 | Reference | 1.0 | 1.05 | 0.65 |
| May 26 | Kdev | 0.81 | Reference | 1.0 | 1.05 | 0.65 |
| May 27 | Kdev | 0.87 | Reference | 1.0 | 1.05 | 0.65 |
| May 28 | Kdev | 0.87 | Reference | 1.0 | 1.05 | 0.65 |
| May 29 | Kdev | 0.89 | Reference | 1.0 | 1.05 | 0.65 |
| May 30 | Kdev | 0.88 | Reference | 1.0 | 1.05 | 0.65 |
| May 31 | Kdev | 0.87 | Reference | 1.0 | 1.05 | 0.65 |
| June 1 | Kmid | 1.19 | Reference | 1.0 | 1.05 | 0.65 |
| June 2 | Kmid | 1.22 | Reference | 1.0 | 1.05 | 0.65 |
| June 3 | Kmid | 1.18 | Reference | 1.0 | 1.05 | 0.65 |
| June 4 | Kmid | 1.32 | Reference | 1.0 | 1.05 | 0.65 |
| June 5 | Kmid | 1.32 | Reference | 1.0 | 1.05 | 0.65 |
| June 6 | Kmid | 1.31 | Reference | 1.0 | 1.05 | 0.65 |
| June 7 | Kmid | 1.31 | Reference | 1.0 | 1.05 | 0.65 |
| June 8 | Kmid | 1.30 | Reference | 1.0 | 1.05 | 0.65 |
| June 9 | Kmid | 1.29 | Reference | 1.0 | 1.05 | 0.65 |
| June 10 | Kmid | 1.38 | Reference | 1.0 | 1.05 | 0.65 |
| June 11 | Kmid | 1.31 | Reference | 1.0 | 1.05 | 0.65 |
| June 12 | Kmid | 1.28 | Reference | 1.0 | 1.05 | 0.65 |
| June 13 | Kmid | 1.29 | Reference | 1.0 | 1.05 | 0.65 |
| June 14 | Kmid | 1.29 | Reference | 1.0 | 1.05 | 0.65 |
| June 15 | Kmid | 1.33 | Reference | 1.0 | 1.05 | 0.65 |
| June 16 | Kmid | 1.34 | Reference | 1.0 | 1.05 | 0.65 |
| June 17 | Kmid | 1.36 | Reference | 1.0 | 1.05 | 0.65 |
| June 18 | Kmid | 1.33 | Reference | 1.0 | 1.05 | 0.65 |
| June 19 | Kmid | 1.28 | Reference | 1.0 | 1.05 | 0.65 |
| June 20 | Kmid | 1.31 | Reference | 1.0 | 1.05 | 0.65 |
| June 21 | Kmid | 1.28 | Reference | 1.0 | 1.05 | 0.65 |
| June 22 | Kmid | 1.33 | Reference | 1.0 | 1.05 | 0.65 |
| June 23 | Kmid | 1.26 | Reference | 1.0 | 1.05 | 0.65 |
| June 24 | Kmid | 1.23 | Reference | 1.0 | 1.05 | 0.65 |
| June 25 | Kmid | 1.27 | Reference | 1.0 | 1.05 | 0.65 |
| June 26 | Kmid | 1.24 | Reference | 1.0 | 1.05 | 0.65 |
| June 27 | Kmid | 1.20 | Reference | 1.0 | 1.05 | 0.65 |
| June 28 | Kmid | 1.26 | Reference | 1.0 | 1.05 | 0.65 |
| June 29 | Kmid | 1.26 | Reference | 1.0 | 1.05 | 0.65 |
| June 30 | Kmid | 1.29 | Reference | 1.0 | 1.05 | 0.65 |
| July 1 | Kmid | 1.34 | Reference | 1.0 | 1.05 | 0.65 |
| July 2 | Kmid | 1.33 | Reference | 1.0 | 1.05 | 0.65 |
| July 3 | Kmid | 1.28 | Reference | 1.0 | 1.05 | 0.65 |
| July 4 | Kmid | 1.30 | Reference | 1.0 | 1.05 | 0.65 |
| July 5 | Kmid | 1.31 | Reference | 1.0 | 1.05 | 0.65 |
| July 6 | Kmid | 1.29 | Reference | 1.0 | 1.05 | 0.65 |
| July 7 | Kmid | 1.32 | Reference | 1.0 | 1.05 | 0.65 |
| July 8 | Kmid | 1.32 | Reference | 1.0 | 1.05 | 0.65 |
| July 9 | Kmid | 1.34 | Reference | 1.0 | 1.05 | 0.65 |
| July 10 | Kmid | 1.25 | Reference | 1.0 | 1.05 | 0.65 |
| July 11 | Kmid | 1.23 | Reference | 1.0 | 1.05 | 0.65 |
| July 12 | Kmid | 1.19 | Reference | 1.0 | 1.05 | 0.65 |
| July 13 | Kmid | 1.26 | Reference | 1.0 | 1.05 | 0.65 |
| July 14 | Kmid | 1.25 | Reference | 1.0 | 1.05 | 0.65 |
| July 15 | Kmid | 1.27 | Reference | 1.0 | 1.05 | 0.65 |
| July 16 | Kmid | 1.29 | Reference | 1.0 | 1.05 | 0.65 |
| July 17 | Kmid | 1.32 | Reference | 1.0 | 1.05 | 0.65 |
| July 18 | Kmid | 1.32 | Reference | 1.0 | 1.05 | 0.65 |

| | | | | | | |
|---|---|---|---|---|---|---|
| July 19 | Kmid | 1.23 | Reference | 1.0 | 1.05 | 0.65 |
| July 20 | Kmid | 1.26 | Reference | 1.0 | 1.05 | 0.65 |
| July 21 | Kmid | 1.23 | Reference | 1.0 | 1.05 | 0.65 |
| July 22 | Kmid | 1.21 | Reference | 1.0 | 1.05 | 0.65 |
| July 23 | Kmid | 1.25 | Reference | 1.0 | 1.05 | 0.65 |
| July 24 | Kmid | 1.32 | Reference | 1.0 | 1.05 | 0.65 |
| July 25 | Kmid | 1.29 | Reference | 1.0 | 1.05 | 0.65 |
| July 26 | Kmid | 1.32 | Reference | 1.0 | 1.05 | 0.65 |
| July 27 | Kmid | 1.27 | Reference | 1.0 | 1.05 | 0.65 |
| July 28 | Kmid | 1.25 | Reference | 1.0 | 1.05 | 0.65 |
| July 29 | Kmid | 1.26 | Reference | 1.0 | 1.05 | 0.65 |
| July 30 | Kmid | 1.22 | Reference | 1.0 | 1.05 | 0.65 |
| July 31 | Kmid | 1.26 | Reference | 1.0 | 1.05 | 0.65 |
| Aug. 1 | Kmid | 1.29 | Reference | 1.0 | 1.05 | 0.65 |
| Aug. 2 | Kmid | 1.32 | Reference | 1.0 | 1.05 | 0.65 |
| Aug. 3 | Kmid | 1.21 | Reference | 1.0 | 1.05 | 0.65 |
| Aug. 4 | Kmid | 1.30 | Reference | 1.0 | 1.05 | 0.65 |
| Aug. 5 | Kmid | 1.26 | Reference | 1.0 | 1.05 | 0.65 |
| Aug. 6 | Kmid | 1.29 | Reference | 1.0 | 1.05 | 0.65 |
| Aug. 7 | Kmid | 1.31 | Reference | 1.0 | 1.05 | 0.65 |
| Aug. 8 | Kmid | 1.33 | Reference | 1.0 | 1.05 | 0.65 |
| Aug. 9 | Kmid | 1.32 | Reference | 1.0 | 1.05 | 0.65 |
| Aug. 10 | Kmid | 1.29 | Reference | 1.0 | 1.05 | 0.65 |
| Aug. 11 | Kmid | 1.31 | Reference | 1.0 | 1.05 | 0.65 |
| Aug. 12 | Kmid | 1.32 | Reference | 1.0 | 1.05 | 0.65 |
| Aug. 13 | Kmid | 1.31 | Reference | 1.0 | 1.05 | 0.65 |
| Aug. 14 | Kmid | 1.27 | Reference | 1.0 | 1.05 | 0.65 |
| Aug. 15 | Kmid | 1.32 | Reference | 1.0 | 1.05 | 0.65 |
| Aug. 16 | Kmid | 1.29 | Reference | 1.0 | 1.05 | 0.65 |
| Aug. 17 | Kmid | 1.30 | Reference | 1.0 | 1.05 | 0.65 |
| Aug. 18 | Kmid | 1.26 | Reference | 1.0 | 1.05 | 0.65 |
| Aug. 19 | Kmid | 1.19 | Reference | 1.0 | 1.05 | 0.65 |
| Aug. 20 | Kmid | 1.24 | Reference | 1.0 | 1.05 | 0.65 |
| Aug. 21 | Kmid | 1.30 | Reference | 1.0 | 1.05 | 0.65 |
| Aug. 22 | Kmid | 1.30 | Reference | 1.0 | 1.05 | 0.65 |
| Aug. 23 | Kmid | 1.31 | Reference | 1.0 | 1.05 | 0.65 |
| Aug. 24 | Kmid | 1.26 | Reference | 1.0 | 1.05 | 0.65 |
| Aug. 25 | Kmid | 1.22 | Reference | 1.0 | 1.05 | 0.65 |
| Aug. 26 | Kmid | 1.23 | Reference | 1.0 | 1.05 | 0.65 |
| Aug. 27 | Kmid | 1.23 | Reference | 1.0 | 1.05 | 0.65 |
| Aug. 28 | Kmid | 1.22 | Reference | 1.0 | 1.05 | 0.65 |
| Aug. 29 | Kmid | 1.24 | Reference | 1.0 | 1.05 | 0.65 |
| Aug. 30 | Kmid | 1.28 | Reference | 1.0 | 1.05 | 0.65 |
| Aug. 31 | Kmid | 1.27 | Reference | 1.0 | 1.05 | 0.65 |
| Sept. 1 | Klate | 0.86 | Reference | 1.0 | 1.05 | 0.65 |
| Sept. 2 | Klate | 0.84 | Reference | 1.0 | 1.05 | 0.65 |
| Sept. 3 | Klate | 0.82 | Reference | 1.0 | 1.05 | 0.65 |
| Sept. 4 | Klate | 0.84 | Reference | 1.0 | 1.05 | 0.65 |
| Sept. 5 | Klate | 0.81 | Reference | 1.0 | 1.05 | 0.65 |
| Sept. 6 | Klate | 0.84 | Reference | 1.0 | 1.05 | 0.65 |
| Sept. 7 | Klate | 0.85 | Reference | 1.0 | 1.05 | 0.65 |
| Sept. 8 | Klate | 0.87 | Reference | 1.0 | 1.05 | 0.65 |
| Sept. 9 | Klate | 0.83 | Reference | 1.0 | 1.05 | 0.65 |
| Sept. 10 | Klate | 0.87 | Reference | 1.0 | 1.05 | 0.65 |
| Sept. 11 | Klate | 0.87 | Reference | 1.0 | 1.05 | 0.65 |
| Sept. 12 | Klate | 0.82 | Reference | 1.0 | 1.05 | 0.65 |
| Sept. 13 | Klate | 0.83 | Reference | 1.0 | 1.05 | 0.65 |
| Sept. 14 | Klate | 0.81 | Reference | 1.0 | 1.05 | 0.65 |
| Sept. 15 | Klate | 0.81 | Reference | 1.0 | 1.05 | 0.65 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Sept. 16 | Klate | 0.80 | Reference | 1.0 | 1.05 | 0.65 |
| Sept. 17 | Klate | 0.85 | Reference | 1.0 | 1.05 | 0.65 |
| Sept. 18 | Klate | 0.88 | Reference | 1.0 | 1.05 | 0.65 |
| Sept. 19 | Klate | 0.87 | Reference | 1.0 | 1.05 | 0.65 |
| Sept. 20 | Klate | 0.88 | Reference | 1.0 | 1.05 | 0.65 |
| Sept. 21 | Klate | 0.87 | Reference | 1.0 | 1.05 | 0.65 |
| Sept. 22 | Klate | 0.84 | Reference | 1.0 | 1.05 | 0.65 |
| Sept. 23 | Klate | 0.84 | Reference | 1.0 | 1.05 | 0.65 |
| Sept. 24 | Klate | 0.89 | Reference | 1.0 | 1.05 | 0.65 |
| Sept. 25 | Klate | 0.88 | Reference | 1.0 | 1.05 | 0.65 |
| Sept. 26 | Klate | 0.86 | Reference | 1.0 | 1.05 | 0.65 |
| Sept. 27 | Klate | 0.89 | Reference | 1.0 | 1.05 | 0.65 |
| Sept. 28 | Klate | 0.83 | Reference | 1.0 | 1.05 | 0.65 |
| Sept. 29 | Klate | 0.85 | Reference | 1.0 | 1.05 | 0.65 |
| Sept. 30 | Klate | 0.85 | Reference | 1.0 | 1.05 | 0.65 |
| Oct. 1 | Klate | 0.36 | Reference | 1.0 | 1.05 | 1.25 |
| Oct. 2 | Klate | 0.36 | Reference | 1.0 | 1.05 | 1.25 |
| Oct. 3 | Klate | 0.36 | Reference | 1.0 | 1.05 | 1.25 |
| Oct. 4 | Klate | 0.37 | Reference | 1.0 | 1.05 | 1.25 |
| Oct. 5 | Klate | 0.37 | Reference | 1.0 | 1.05 | 1.25 |
| Oct. 6 | Klate | 0.36 | Reference | 1.0 | 1.05 | 1.25 |
| Oct. 7 | Klate | 0.36 | Reference | 1.0 | 1.05 | 1.25 |
| Oct. 8 | Klate | 0.36 | Reference | 1.0 | 1.05 | 1.25 |
| Oct. 9 | Klate | 0.36 | Reference | 1.0 | 1.05 | 1.25 |
| Oct. 10 | Klate | 0.36 | Reference | 1.0 | 1.05 | 1.25 |
| Oct. 11 | Klate | 0.36 | Reference | 1.0 | 1.05 | 1.25 |
| Oct. 12 | Klate | 0.37 | Reference | 1.0 | 1.05 | 1.25 |
| Oct. 13 | Klate | 0.37 | Reference | 1.0 | 1.05 | 1.25 |
| Oct. 14 | Klate | 0.37 | Reference | 1.0 | 1.05 | 1.25 |
| Oct. 15 | Klate | 0.37 | Reference | 1.0 | 1.05 | 1.25 |
| Oct. 16 | Klate | 0.37 | Reference | 1.0 | 1.05 | 1.25 |
| Oct. 17 | Klate | 0.37 | Reference | 1.0 | 1.05 | 1.25 |
| Oct. 18 | Klate | 0.36 | Reference | 1.0 | 1.05 | 1.25 |
| Oct. 19 | Klate | 0.36 | Reference | 1.0 | 1.05 | 1.25 |
| Oct. 20 | Klate | 0.36 | Reference | 1.0 | 1.05 | 1.25 |
| Oct. 21 | Klate | 0.36 | Reference | 1.0 | 1.05 | 1.25 |
| Oct. 22 | Klate | 0.36 | Reference | 1.0 | 1.05 | 1.25 |
| Oct. 23 | Klate | 0.37 | Reference | 1.0 | 1.05 | 1.25 |
| Oct. 24 | Klate | 0.37 | Reference | 1.0 | 1.05 | 1.25 |
| Oct. 25 | Klate | 0.37 | Reference | 1.0 | 1.05 | 1.25 |
| Oct. 26 | Klate | 0.36 | Reference | 1.0 | 1.05 | 1.25 |
| Oct. 27 | Klate | 0.36 | Reference | 1.0 | 1.05 | 1.25 |
| Oct. 28 | Klate | 0.36 | Reference | 1.0 | 1.05 | 1.25 |
| Oct. 29 | Klate | 0.38 | Reference | 1.0 | 1.05 | 1.25 |
| Oct. 30 | Klate | 0.37 | Reference | 1.0 | 1.05 | 1.25 |
| Oct. 31 | Klate | 0.38 | Reference | 1.0 | 1.05 | 1.25 |
| Nov. 1 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Nov. 2 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Nov. 3 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Nov. 4 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Nov. 5 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Nov. 6 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Nov. 7 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Nov. 8 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Nov. 9 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Nov. 10 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Nov. 11 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Nov. 12 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Nov. 13 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Nov. 14 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Nov. 15 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Nov. 16 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Nov. 17 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Nov. 18 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Nov. 19 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Nov. 20 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Nov. 21 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Nov. 22 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Nov. 23 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Nov. 24 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Nov. 25 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Nov. 26 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Nov. 27 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Nov. 28 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Nov. 29 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Nov. 30 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Dec. 1 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Dec. 2 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Dec. 3 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Dec. 4 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Dec. 5 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Dec. 6 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Dec. 7 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Dec. 8 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Dec. 9 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Dec. 10 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Dec. 11 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Dec. 12 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Dec. 13 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Dec. 14 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Dec. 15 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Dec. 16 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Dec. 17 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Dec. 18 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Dec. 19 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Dec. 20 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Dec. 21 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Dec. 22 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Dec. 23 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Dec. 24 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Dec. 25 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Dec. 26 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Dec. 27 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Dec. 28 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Dec. 29 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Dec. 30 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |
| Dec. 31 | Dormant | 0.20 | Reference | 1.0 | 1.05 | 1.25 |

[c]A LAI of 0 was used from January 1 to March 14, 0.2 from March 15 to May 15, 1.05 from May 15 to May 31, and 2.65 for June, July and August. An LAI of 1.05 was used from Sept. 1 to Sept. 30, and 0.2 from Oct. 1 to Oct. 31; 0 was used for the remainder of the year. The crop height used was 1.5m.

[d]Based on the information available regarding the evapotranspiration of deciduous and coniferous forest, and idle land, step-wise changes in values were used.

[e]The dates chosen for the change in values for open water >5m are an estimated time as to when the average daily temperature exceeds water temperature (May 1) and when the

average daily temperature is below water temperature (Oct. 1). These values should be adjusted should the conditions vary by the season or by region.

References:

British Columbia Ministry of Agriculture, Food and Fisheries. 2001. Crop coefficients for use in irrigation scheduling. Website: http://www.agf.gov.bc.ca/resmgmt/publist/500series/577100-5.pdf. Accessed: October 2, 2007.

Food and Agricultural Organization of the United Nations. Website: www.fao.org. Accessed: October 2, 2007.

Komatsu, 2005. Forest categorization according to dry-canopy evaporation rates in the growing season: comparison of the Priestly-Taylor coefficient values from various observation sites. Hydrological Processes 19, 3873-3896.

Verma, S and J. Berry, 1997. Net exchange of carbon dioxide in grassland and agricultural ecosystems in the ARM-CART region; modeling and year-round measurement. Website: http://nigec.ucdavis.edu/publications/ar/annual98/greatplains/project1.html. Accessed: October 2, 2007.

Disclaimer: The evapotranspiration coefficients indicated in this report are estimated from published literature produced in various climatic regions. These regions do not necessarily reflect the situations found in the Niagara Peninsula. The reported values are based on “well-watered” soil conditions and dry plant canopies. Information on dormant season (winter) ET is very limited. Any errors in the published literature may be reflected in the values presented in this report. The evapotranspiration coefficients reported are the best estimates available, but they should be used with the full recognition of these limitations.