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

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NIAGARA PENINSULA CONSERVATION AUTHORITY

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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 Twenty Mile Creek Watershed Plan Area (Twenty 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was developed by NPCA in consultation with the Ministry of Natural Resources (MNR), based upon the March 2007 Draft Guidance Module – Water Budget and Water Quantity Risk Assessment.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 Twenty Mile Creek (TWEN), the second largest Watershed Plan Area (WSPA) within NPCA at 306 km^2. The study area is located in the City of Hamilton and the Regional Municipality of Niagara including portions of the local municipalities, Town of Lincoln, Township of West Lincoln and the Town of Grimsby (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 Twenty 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);
- Baseflow Separation and Streamflow Recession (AquaResource Inc., 2007); and
- Revised Floodplain Mapping Twenty Mile Creek (NPCA 2007).

These studies are referenced throughout this report. Additional information was also gathered from the Twenty Mile Creek Watershed Plan (Durley, J., 2006) to assist with the Watershed Characteristics section.

1.5 Document Organization

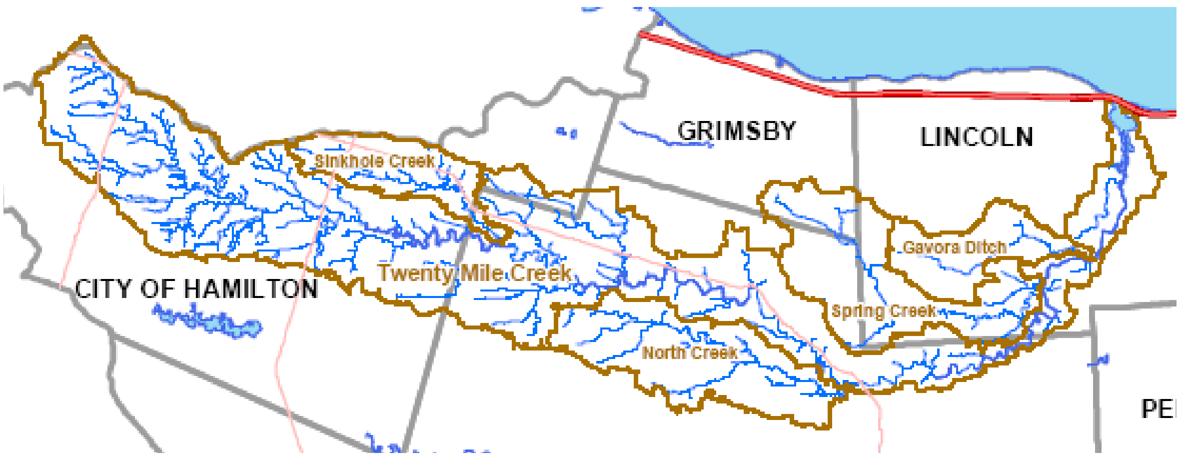
The sections within the report are organized as follows:

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

2. WATERSHED CHARACTERISTICS

2.1 General Description of the Watershed

Twenty Mile Creek contains five (5) main subwatersheds: the main branch of Twenty Mile Creek (TYMC), North Creek (NC), Sinkhole Creek (SHC), Spring Creek (SC) and Gavora Ditch (GD) as shown below. The total drainage area of the watershed is 306 km^2. The headwaters of the main branch of Twenty Mile Creek originate in the former municipality of Glanbrook (City of Hamilton, and eventually the creek outlets to Lake Ontario at Jordan Harbour.



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), Twenty 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 (Schroeter and Associates, 2007). Mean monthly precipitation ranged from a low of 50 mm at the Vineland Environment Canada station 6139141 in February to a high of 87 mm at Hamilton Airport Environment Canada station 6153194 in July. The mean annual range in temperature was 27.9 degrees Celsius (^{o}C). Mean temperatures appear warmer moving downstream from Hamilton Airport to Vineland, likely related to the effect of Lake Ontario and decreasing elevation.

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 Twenty Mile Creek appear to range from 920 to 850 mm per year and 160 to 130 mm, respectively, on mean across the watershed. Mean annual temperatures range from 8 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 Hamilton Airport and Vineland stations. The total annual precipitation ranged from a 1998 low of 668 mm to a high of 1163 mm in 1996, over double the amount. On average the annual precipitation was 886 mm (1991-2005). The amount of snow water equivalent ranged from a low of 72 mm in 1998 to a high in 1994 of 264 mm. Overall 148 mm (17%) of precipitation is delivered as snowfall. The amount of snow received at Hamilton Airport was usually greater than that at Vineland. The mean annual temperature was lowest in 1992 at 7.5^{o}C and highest in 1998 at 10.6^{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

The upper reaches of the watershed are characterized by rolling topography with fairly steep slopes in the headwaters. The middle and lower portions of the watershed have a gently rolling to flat topography before the creek bed drops almost 100 metres at the Niagara Escarpment (Figures 2.12). Most of Twenty Mile Creek flows over bedrock or is controlled by bedrock ridges.

2.4 Physiography

Above the Niagara Escarpment, most of the watershed lies at the northern margin of the Haldimand Clay Plain physiographic region (Figure 2.13). This portion of the watershed is characterized by a broad flat clay plain. Drainage for Twenty Mile Creek originates in Ancaster and flows easterly between the Fort Erie Moraine to the south, and the Niagara Falls Moraine to the north (Figure 2.13). Above the escarpment, the watershed is rarely wider than 5 to 6 kilometers with a dendritic drainage pattern. Below the escarpment the watershed is within the Niagara Fruit Belt portion of the Iroquois Plain.

2.5 Soils

The mapped soils information was provided by the Ontario Ministry of Agriculture and Food and combines two (2) soil surveys, Niagara Region and City of Hamilton (Figure 2.14).

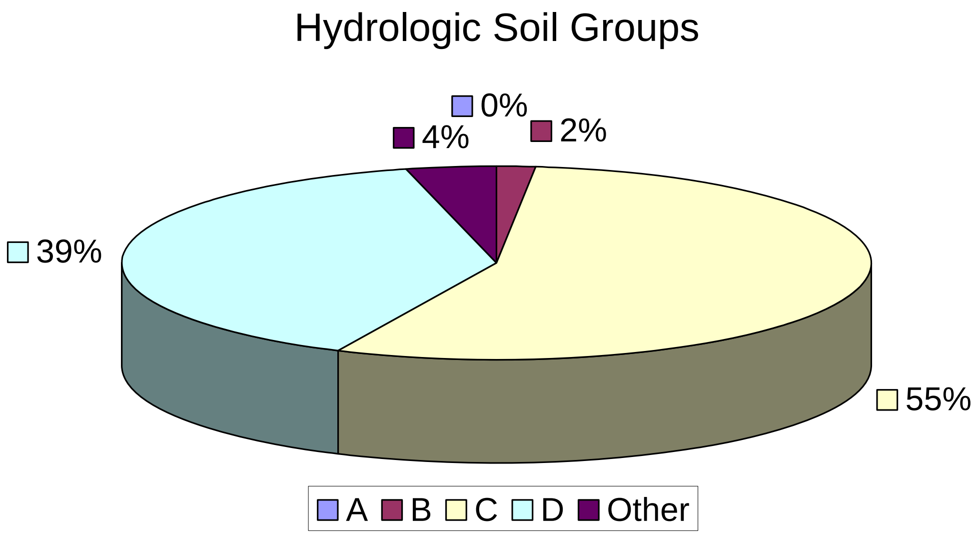
In the upper portion of the watershed, located above the Niagara Escarpment, the soils are generally clay and largely imperfectly drained, with low permeability and medium to high water holding capacity. These soils are suitable for growing common field crops if drainage systems (e.g. tile drains) are used. Between Smithville and Ball's Falls the soils are clay to silty clay, moderately well-drained and moderately to slowly permeable with a relatively high water-holding capacity, surface runoff can be rapid and increases with slope. Below the Niagara Escarpment the fine sandy soil is imperfectly drained and moderately to rapidly permeable with moderately low water holding capacity and slow to moderate surface runoff.

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 category of "other" consists of soils that were not mapped or coincident with an area of high runoff, i.e. urban areas, water bodies, bedrock at surface. These polygons were not assigned HSG values.

The dominant soil groups are C and D. These amount to 55 and 39 percent of the area of the watershed respectively (as presented below). The remaining portion of the watershed is mapped as 4% other, 2% B and less than 1% A. The hydrologic soil group data inputs for the model are summarized on Table 2.2.



2.6 Surficial geology

The surficial geology of Twenty Mile Creek is largely fine-textured glaciolacustrine deposits, matching the overlying clayey soils (Figure 2.15). Portions of bedrock at surface are also mapped within the watershed and are coincident with aggregate operations (i.e. Vineland Quarries). The Sinkhole Creek and Gavora Ditch subwatersheds contain several sites of known karst topography. Below the Escarpment, the surficial geology is largely silty to sandy till before outleting in an area of coarser textured glaciolacustrine deposits associated with the Iroquois shoreline.

2.7 Land Cover

In general, the western portions of the watershed are characterized by urban, estate and strip rural residential development, together with livestock and poultry operations. The mid to eastern reach land uses tend more toward intensive crop and grape operations, some cattle operations and nodal residential development. Golf course and aggregate operations are also located within the watershed. Agriculture is the predominant land use in the watershed. Corn, wheat, cereal hay and livestock are common above the Escarpment and orchards, vineyards and greenhouses dominate agricultural land use below the Escarpment.

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 78% of Twenty Mile Creek were (i) rural land use 19%, (ii) mixed crop 18%, (iii) monoculture 13%, (iv) annual crop 11%, (v) swamp 6%, (vi) mixed agriculture 6% and (vi) deciduous forest 5%.

2.8 Streamflow

Streamflow drops to zero in the summer months in all five (5) subwatersheds of Twenty Mile Creek. Spring Creek, Sinkhole Creek and Gavora Ditch flow only intermittently throughout the year and Gavora Ditch generally only during the spring melt period and following significant precipitation events. The low to non-existent summer flows may be due to a number of land use factors primarily resulting from agricultural expansion. These factors include a loss of water storage resulting from a decrease in the amount of forested areas, soil compaction, soil loss, and tile drainage. There may also be natural surface water losses or gains via bedrock fractures and karst features (Durley, 2006).

AquaResource Inc. completed an analysis of baseflow separation and streamflow recession for NPCA in November 2007. Two (2) stations were available for analysis within Twenty Mile Creek as shown below in Table 2.4 and Figure 2.1.

Table 2.4 - Current Stream Gauges

WSC ID	Description	Drainage Area (km^2)	Data Start Date	Data End Date
02HA006	Twenty Mile Creek At Ball's Falls	293	3/1/1957	12/31/2005
02HA020	Twenty Mile Creek Above Smithville	168	1/1/1987	12/31/2005

Flows were statistically analyzed to visualize how flows vary seasonally (Figures 2.17 and 2.18 and Table 2.5). The median, 10th and 90th percentile flows were calculated for each month during the study period (1991-2005). Median flows are representative of the flows most often observed within each month. The 10th percentile represents flows that are exceeded 10% of the time, and thus are considered high flows. The 90th 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) 1991-2005

Station	02HA006					02HA020				
Parameter	90th%	Median	Mean	Mean Baseflow	10th %	90th%	Median	Mean	Mean Baseflow	10th %
Jan	0.060	1.000	4.56	0.65	10.90	0.023	0.460	2.45	0.29	6.590
Feb	0.125	1.570	5.08	0.79	14.10	0.072	0.529	2.76	0.36	6.820
Mar	0.576	3.590	7.88	1.35	19.60	0.240	1.960	4.25	0.67	9.750
Apr	0.491	2.380	6.43	1.27	16.40	0.275	1.240	3.21	0.66	7.760
May	0.189	0.662	2.24	0.43	4.700	0.082	0.420	1.28	0.24	2.830
Jun	0.039	0.208	1.14	0.20	2.210	0.005	0.104	0.71	0.10	1.560
Jul	0.001	0.068	0.58	0.07	1.010	0.001	0.015	0.42	0.03	0.507
Aug	0.001	0.008	0.20	0.04	0.445	0.001	0.001	0.10	0.02	0.240
Sep	0.001	0.003	0.55	0.06	1.290	0.001	0.001	0.26	0.03	0.902
Oct	0.001	0.089	1.02	0.13	2.220	0.001	0.008	0.68	0.07	1.200
Nov	0.017	0.425	3.12	0.48	9.420	0.001	0.275	1.83	0.27	5.800
Dec	0.220	1.400	3.24	0.56	8.160	0.087	0.612	1.73	0.25	4.820

The flow regime observed is typical of Southern Ontario. Due to spring freshet, annual peak flows are observed during the month of March. The flows quickly decline through the months of April, May and June, reaching summer low flows by July. Low to no flow remains until the mid to the later portion of the fall, where lower evaporation and more regional rainfall allow streamflow to recover.

There is a significant difference between median flows and 10th percentile flows during the spring months. The 10th percentile flows are on average approximately five times the median flow for the month of March. This suggests the flow regime is extremely flashy, as peak flows are not sustained for large periods of time. Soon after a precipitation event, flows quickly return to baseflow conditions. This is indicative of a well-drained watershed dominated by tight surficial materials. There does not seem to be any evidence of significant depression storage on the landscape.

Summer low flows are lower than in many other regions of Southern Ontario. Ball's Falls has monthly median summer flows (July – August) below 0.1 m^3/s indicating that there are no areas with significant groundwater discharge within the gauged catchment.

The 90th percentiles, or low flows, show that Ball's Falls and Smithville have past occurrences of no flow. For a watershed of 293 km^2, such as Ball's Falls, to have zero flow, it provides more evidence there is very little surface/groundwater interactions for catchments located within the Haldimand Clay Plain, a runoff driven system.

2.8.1 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 2.19 and 2.20. These estimates are using data within the study period only (1991-2005). The estimates are consistent with previous results (Franz et al., 2007). In general, baseflow follows the same seasonal trends as streamflow.

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 for Smithville and Ball's Falls were 0.17 and 0.15, respectively for the period 1991 to 2005. Table 2.6 lists estimated BFI values for simplified surficial material to provide context for the expected range of BFI values. The calculated BFI for these gauges is at the extreme lower end, further evidence that the majority of the NPCA is primarily driven by overland runoff, with very little surfacewater/groundwater interaction.

Table 2.6 - 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)

2.8.2 Estimated Water Balance

As part of the Conceptual Water Budget, Franz et. al. (2007) estimated the water balance for the gauged areas of NPCA. This analysis relied on interpretation of climate and streamflow data to arrive at estimates of annual precipitation, evapotranspiration, runoff and baseflow. The estimated values are included in Table 2.7 for Ball's Falls and Smithville.

Table 2.7 –Estimated Water Balance from Streamflow Analysis

Gauged Catchment		Total Flow	Runoff	Baseflow	Precipitation	Evapo-transpiration
		mm/year				
02HA006	Ball's Falls	324	269	55	900	575
02HA020	Smithville	305	258	46	900	595

3. WATERSHED MODELLING

The following sections describe the construction, calibration/verification of the Twenty Mile Creek 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 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 Twenty 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
α = Dryness coefficient
ρ_w = Mass density of water
γ = Psychrometric constant (ratio of the heat capacity of the air to the latent heat of vaporization)
λ_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^{o}C. 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).

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). Due to the conceptualization reported in the Conceptual Water Budget (Franz et al., 2007) of minimal interaction between the regional groundwater system and the surface water system, it is anticipated this will not be a significant source of error.

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).

3.2 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 Twenty Mile Creek HEC-HMS models. Two of the stations, the Hamilton Airport (Station ID 6153194) and the Vineland (Station ID 6139141) 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 third meteorological station located at Smithville is operated by the Region of Niagara (RON).

The Hamilton Airport Station is located near the headwaters of Twenty Mile Creek, just outside the watershed divide. The RON Smithville Station is located in the central portion of the watershed, and the Vineland Climate Station is located below the Escarpment, just outside the watershed divide. Catchments located in the upper portion of Twenty Mile Creek were initially assigned climate data from Hamilton Airport, with the central portion of the watershed being assigned data from the RON Smithville Station. Catchments located below the Niagara Escarpment were assigned climate data collected at the Vineland Climate 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 the Twenty Mile Creek using two datasets, Environment Canada sunshine station Hamilton RBG 6153300 (1990 to 1994) and Weather Innovations Incorporated Grimsby station (1995 to 2005). The incoming solar radiation at the Hamilton RBG station was calculated using the methodology of Selirio et al. (1971). The overall hourly net radiation was calculated using the methodology of Allen et al. (2005).

As a check to determine the applicability of data collected at the climate stations, annual totals from the three locations were compared. Comparisons between the RON Smithville station and the Environment Canada stations displayed significant differences in monthly total precipitation amounts. Particularly for the winter months, the Smithville Climate Station reported precipitation amounts that were up to 40mm lower than both the Vineland and Hamilton Airport Stations. On an annual basis, this difference reached a maximum of 400mm. Due to the magnitude of difference to the two other climate stations, it is suspected that Smithville was under-reporting precipitation. This suspicion was validated, when initial model simulations generated lower than expected water balance estimates, and the absence of a significant snowpack for those catchments that were using Smithville precipitation. As a result, precipitation data from the Hamilton Airport Station was utilized for all catchments above the Escarpment.

As there were no suspicions regarding the temperature data associated with Smithville, no changes were made to the spatial temperature distribution.

3.2.2 Streamflow Information

Streamflow information was obtained from the two federally operated stream gauges on Twenty Mile Creek, as indicated in Section 2.8. Flow data for Twenty Mile Creek at Ball's Falls, and Twenty Mile Creek at Smithville were imported into HEC-HMS and were used as the primary calibration points for Twenty Mile Creek.

Care should be taken when relying on observed streamflow estimates for calibration/verification purposes. Flow estimates can often be affected by backwater effects due to ice and aquatic plant growth and as a result, 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. 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. 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 1.5 to 17 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.

The first linear reservoir was parameterized with the intent to represent interflow. A groundwater coefficient of 6 hours was initially assigned to this reservoir.

The 2nd 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, Twenty Mile Creek at Ball's Falls and Twenty Mile Creek at Smithville, were used within the Twenty Mile Creek model. The median reservoir constant from the 1991-2005 period was assigned to the 2nd linear reservoir for each catchment located upstream of the gauge. Catchments located downstream of the Ball's Falls gauge were assigned the reservoir constant estimated from the Ball's Falls gauge.

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

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.

The model period, from 1991-2005, has been divided into two parts:

- The Calibration Period: 1991-1998. Model parameters are adjusted to best replicate hydrologic processes, and observed flows.
- The Verification Period: 1999-2005.The model parameterization completed during the calibration phase, was tested against a different set of inputs (climate data), and observations (observed flow). A reasonable fit in the verification period will increase the certainty that the model is properly representing hydrologic processes.

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 Period and Parameters

As described above, calibration was completed over the 1991-1998 period. The focus of the exercise was on processes that would affect the seasonal response of the watershed, as well as water balance numbers (evapotranspiration, snowmelt, loss method, baseflow routing). 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 for calibration. 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 TWEN ID	Constant Rate (mm/h)	Max Storage (mm)
TYMC_W100	0.21	112
TYMC_W200	0.17	127
GD_W100	0.17	137
GD_W200	0.16	144
TYMC_W300	0.21	172
SC_W100	0.17	155
SC_W200	0.12	172
SC_W110	0.13	177
SC_W300	0.22	156
SC_W210	0.16	137
SC_W400	0.16	155
TYMC_W400	0.19	169
TYMC_W500	0.15	111
NC_W100	0.16	158
NC_W200	0.19	156
NC_W110	0.15	170
NC_W400	0.15	167
TYMC_W600	0.17	149
TYMC_W700	0.19	168
TYMC_W610	0.18	156
TYMC_W800	0.20	150
TYMC_W710	0.22	171
TYMC_W711	0.16	158
TYMC_W720	0.19	157
TYMC_W900	0.21	150
SHC_W100	0.21	144
SHC_W200	0.23	136
TYMC_W1000	0.21	159
TYMC_W910	0.22	155
TYMC_W1100	0.22	154
TYMC_W1010	0.25	158
TYMC_W1200	0.21	150
TYMC_W1110	0.22	155
TYMC_W1300	0.22	138
TEMC_W100	0.20	112
TYMC_W1400	0.28	96

As part of the calibration and 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.

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. For example, initial simulations indicated excess streamflow in comparison to observed streamflow. Actual evapotranspiration estimates for these initial simulations were 350mm/year. To reduce the annual volume of streamflow to match observed values, the crop coefficients were increased primarily for the late fall, winter and early spring months. 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. Groundwater coefficients for the reservoir associated with baseflow, were initially parameterized based upon recession analysis (AquaResource, 2007) and were not modified during calibration. Groundwater coefficients for the reservoir associated with interflow initially set to 6 hours were increased to 18 hours through calibration. Table 3.4 includes the final coefficients used for Twenty Mile Creek.

Table 3.4 - Groundwater Coefficients in Linear Reservoir Baseflow Model

WSC Gauging Station	GW 1 Coefficient (hr)	GW 2 Coefficient (hr)
Twenty Mile Ck at Ball's Falls	18	344
Twenty Mile Ck at Smithville	18	278

Included in Figures 3.4 to 3.15 are a number of calibration plots for both Twenty Mile Creek at Ball's Falls and Twenty Mile Creek at Smithville. Figure 3.4 compares the simulated and observed annual flow volumes at Ball's Falls for the calibration period. Correspondence is very good, with the exception of 1995, with a difference of approximately 95mm. With other years matching reasonably well, this difference in 1995 is suspected to be climate driven, rather than an issue with the simulated processes. The simulated total monthly flow volumes at Ball's Falls align well with the observed flows, as shown in Figure 3.5. The Nash-Sutcliffe coefficient, the log Nash-Sutcliffe coefficient and the R^2 value are shown in Figure 3.6. Table 3.5 also demonstrates good agreement between simulated and observed streamflow.

Table 3.5 – Standard Error, Nash-Sutcliffe and R^2 for Calibration Period (Monthly Mean Flow mm/month)

	Gauge	R^2	Standard Error	Nash-Sutcliffe	Log Nash-Sutcliffe
Calibration Period 1991-1998	Ball's Falls	0.86	13.0	0.85	0.56
	Smithville	0.89	11.9	0.85	0.68

Included in Table 3.6 is the observed and simulated flow for Ball's Falls, with the difference expressed in mm.

Table 3.6 – Comparison of Mean Streamflow Volume – Ball's Falls Calibration Period

Month	Simulated (mm)	Observed (mm)	Difference (mm)
Jan	66	51	15
Feb	53	44	10
Mar	80	81	-1
Apr	48	50	-2
May	16	16	0
Jun	6	6	-1
Jul	5	8	-4
Aug	3	2	1
Sep	4	7	-4
Oct	9	10	-1
Nov	31	30	1
Dec	33	30	3

The mean and median monthly simulated and observed flows at Ball's Falls are shown in Figures 3.7 and 3.8, respectively. The comparison of mean monthly flows shows a 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 for Ball's Falls. While there is good correlation between simulated and observed streamflow, some discrepancies exist. The most significant is in April, where the observed median flow is higher than simulated. Due to the mean volume in April matching well, the difference in the median flow suggests a possible timing issue. The discrepancies in the winter months are likely due to the omission of a sublimation process in the snowmelt model, and possible errors in the gauged streamflow data due to ice. Discrepancies in summer months can be attributed to difficulties involved when measuring low flows, not considering local water takings or direct evaporation from the watercourse. The ranked duration curve, shown in Figure 3.9, demonstrates very close agreement between simulated flows and observed flows.

The annual streamflow volumes at Smithville are also in reasonable agreement, with the largest discrepancy (145mm) again in 1995 as shown in Figure 3.10. The simulated total monthly flow volumes at Smithville correlate well with the observed flows, as shown in Figure 3.11. The Nash-Sutcliffe coefficient, the log Nash-Sutcliffe coefficient, and the R^2 value show very good model performance, as shown in Figure 3.12 and Table 3.5. Similar to Ball's Falls, omission of a sublimation process from the model may be contributing to the over-prediction of flows in the spring months.

The mean and median monthly simulated and observed flows at Smithville are shown in Figures 3.13 and 3.14 respectively and compared in Table 3.7. The comparison of mean monthly flows demonstrates a good match between simulated and observed flow volumes throughout the year.

Table 3.7 – Comparison of Mean Streamflow Volume – Smithville Calibration Period

Month	Simulated (mm)	Observed (mm)	Difference (mm)
Jan	65	51	14
Feb	52	40	12
Mar	83	75	8
Apr	52	45	7
May	18	16	1
Jun	6	7	-1
Jul	5	9	-4
Aug	3	1	2
Sep	4	5	-1
Oct	10	10	0
Nov	32	29	3
Dec	34	26	7

Similar to Ball's Falls, the median monthly simulated flows show larger deviations than the mean monthly flow. These discrepancies are due to timing issues, and are more difficult to reconcile than volume issues associated with mean monthly flow. The ranked duration curve, included in Figure 3.15, shows that simulated flows are in generally in good agreement with observed flows; however baseflow is being over-predicted. Since low flows at Ball's Falls are in good agreement, this indicates that there is a possibility of groundwater discharging downstream of the Smithville gauge that is sourced from recharge occurring upstream of the Smithville gauge. Since HEC-HMS is mass conservative with respect to each catchment, it is not possible to replicate inter-catchment groundwater movement. It is also important to keep in mind the uncertainties in low flow measurements, and that the actual difference between the simulated and observed low flows at Smithville is on the order of 50L/s during low flow periods.

Comparisons of observed to simulated streamflow indicate that the model has been well calibrated, and is performing admirably as an estimator of streamflow. While discrepancies do exist (winter, spring flows), they are unlikely to impact the results of the Stress Assessment.

3.3.3 Verification

Once calibrated for the 1991-1998 period, the model was subjected to validity testing comparing simulated model results to measured flow rates within the 1999-2005 period. Verification plots are included in Figure 3.16-3.27.

Figure 3.16 shows the simulated and observed annual total flow volumes at Ball's Falls for the verification period. All years compare favourably, with a maximum difference of 120mm in 2003. Much like 1995 in the calibration period, this outlier is likely related to inconsistencies in climate data. Monthly total flow volumes at Ball's Falls are shown in Figure 3.17. As shown in Table 3.8 and Figure 3.18, the Nash-Sutcliffe coefficients and the R^2 value for Ball's Falls are reasonable, however, they are lower than the simulation period.

Table 3.8 - Standard Error, Nash-Sutcliffe and R^2 for Verification Periods (Monthly Mean Flow mm/month)

	Gauge	R^2	Standard Error	Nash-Sutcliffe	Log Nash-Sutcliffe
Verification Period 1999-2005	Ball's Falls	0.72	15.2	0.69	0.40
	Smithville	0.77	14.3	0.73	0.50

The mean and median monthly flows are shown in Figures 3.19 and 3.20, respectively. Mean flows are included in tabular form in Table 3.9. The simulated and observed seasonality of the streamflow are in reasonably good agreement. The ranked duration plot in Figure 3.21 also confirms a reasonable simulation of flows.

Table 3.9 – Comparison of Mean Streamflow Volume – Ball's Falls Verification Period

Month	Simulated (mm)	Observed (mm)	Difference (mm)
Jan	38	24	14
Feb	56	48	8
Mar	63	60	4
Apr	42	60	-18
May	22	24	-2

Jun	13	14	-1
Jul	4	2	2
Aug	3	1	2
Sep	5	3	2
Oct	12	8	5
Nov	38	29	10
Dec	49	30	19

The simulated and observed annual total flow volumes for the Smithville gauge are shown in Figure 3.22; the maximum difference is 124mm in 2004. Estimates of monthly simulated flow correlate well with observed flow at Smithville, as is shown in Figure 3.23. Figure 3.25 and Table 3.8 summarizes the Nash-Sutcliffe and R^2 coefficients as well as the Standard Error for the verification period.

The mean and median monthly flows are shown in Figures 3.25 and 3.26, respectively. The simulated and observed seasonality of the streamflow are in good agreement. The Ranked Duration Plot in Figure 3.27 also confirms a reasonable simulation of flows. Mean flows for the Smithville gauge in the verification period are included in Table 3.10.

Table 3.10 – Comparison of Mean Streamflow Volume – Smithville Verification Period

Month	Simulated (mm)	Observed (mm)	Difference (mm)
Jan	33	23	10
Feb	58	48	10
Mar	68	59	9
Apr	42	55	12
May	25	25	0
Jun	15	16	1
Jul	4	2	2
Aug	4	2	2
Sep	5	2	3
Oct	16	11	4
Nov	42	29	13
Dec	47	29	19

The verification phase of model development is a critical step in testing how accurate the model is, outside the period in which it was calibrated. While it is expected that the comparison of the simulated to the observed flows will be poorer during the verification phase than during the calibration phase; the model should still reasonably replicate observed flow. The results of this verification phase demonstrate this to be the case. As such, it can be concluded that the Twenty Mile Creek HEC-HMS is reasonably replicating the major hydrologic processes.

3.3.4 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 3.28 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 run through BFLOW. By calculating the BFI (proportion of separated flow to total flow) for each BFLOW pass, and comparing the simulated and observed BFI's, insight can be gained into how well the model is representing a specific portion of the hydrograph. Included in Table 3.11 are the calculated BFIs for all three BFLOW passes, for both the simulated and observed flows at the Twenty Mile Creek Above Smithville and Twenty Mile Creek at Ball's Falls.

Table 3.11 – Comparison of BFLOW BFIs

Streamgauge	BFLOW Pass	Simulated BFI	Observed BFI
Smithville	Pass 1	29%	43%
	Pass 2	16%	24%
	Pass 3	11%	16%
Ball's Falls	Pass 1	31%	43%
	Pass 2	17%	24%
	Pass 3	12%	17%

For all passes and both gauges, HEC-HMS predicted a lower BFI than observed. This indicates that the model is predicting a higher proportion of total flow being direct runoff, than is suggested by the observed streamflow record. This difference is largest at the 1^{st} pass, with the smallest difference occurring at the 3^{rd} pass.

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. In this case, it seems the simulated hydrograph is responding to, and receding from, a precipitation event too quickly. This is resulting in BFLOW proportioning a higher amount of streamflow to direct runoff, and is suggesting that there may be insufficient routing represented within the model.

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. It is noted that, with successive passes of the BFLOW filter, the simulated and observed BFIs come into better agreement.

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 the 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 a 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. Changes in total outflow, mean evapotranspiration, runoff and recharge were calculated and tabulated in the following tables.

- Table 3.12 lists the percent change in total outflow for each scenario, over the base case.
- Table 3.13 displays the percent change in total outflow, evapotranspiration, runoff and recharge for each scenario, over the base case.

Table 3.12 - Sensitivity Analysis Results – Change in Outflow

Month	Constant Rate +25%	Constant Rate -25%	Max Storage +25%	Max Storage -25%
Jan	0.1%	-0.2%	-13.5%	2.1%
Feb	0.4%	-0.4%	-3.6%	0.1%
Mar	0.0%	0.0%	-0.1%	0.0%
Apr	1.4%	-1.5%	0.0%	0.0%
May	1.7%	-1.9%	0.0%	0.0%
Jun	1.1%	-1.1%	0.1%	0.0%
Jul	0.5%	-0.4%	-0.5%	3.0%
Aug	0.1%	-0.1%	-0.8%	0.0%
Sep	0.0%	0.1%	-10.8%	31.1%
Oct	-0.5%	0.6%	-41.4%	88.4%
Nov	-0.4%	0.5%	-27.7%	24.0%
Dec	-0.1%	0.2%	-20.5%	35.8%

Table 3.13- Sensitivity Analysis Results – Change in Water Balance Estimates

Scenario	ET	Baseflow	Interflow	Runoff
1: Constant Rate +25%	0.0%	19.7%	19.7%	-5.4%
2: Constant Rate -25%	0.0%	-21.7%	-21.7%	6.0%
3: Max Storage +25%	6.3%	-10.0%	-10.0%	-8.4%
4: Max Storage -25%	-6.4%	9.1%	9.1%	8.7%

As is shown by Table 3.12 and Table 3.13, 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 3.29 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). As shown in the figure, the percent change for both variations in the Constant Rate, is well within these boundaries, which 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 3.13). As illustrated in Figure 3.30 and Table 3.13, 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 Twenty 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 Twenty 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 (+20% 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 to validate the water balance estimates made via the Deficit and Constant Loss Method. 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 3.14, presenting the mean annual water balance on a catchment basis and an overall watershed 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); percolated water which moves laterally through the unsaturated soil horizon.
- Baseflow – Outflow from 2nd linear reservoir (half of percolated water); 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 3.14 - Summary of Water Balance Model Results

Catchment TWEN ID	Precipitation (mm)	ET (mm)	Interflow (mm)	Baseflow (mm)	Runoff (mm)	Outflow (mm)
TYMC_W100	875	496	41	41	299	381
TYMC_W200	875	527	37	37	277	350
GD_W100	875	515	35	35	292	362
GD_W200	898	544	35	35	284	354
TYMC_W300	898	604	40	40	214	294
SC_W100	898	569	37	37	255	329
SC_W200	898	618	24	24	232	280
SC_W110	898	606	26	26	240	292
SC_W300	898	565	46	46	240	333
SC_W210	898	543	37	37	281	355
SC_W400	898	548	35	35	280	350
TYMC_W400	898	597	37	37	226	301
TYMC_W500	898	453	33	33	378	445
NC_W100	898	586	34	34	243	312
NC_W200	898	575	39	39	244	323
NC_W110	898	604	30	30	233	294
NC_W400	898	602	30	30	236	296
TYMC_W600	898	563	36	36	264	335
TYMC_W700	898	605	37	37	219	293
TYMC_W610	898	568	37	37	256	330
TYMC_W800	898	564	41	41	251	334
TYMC_W710	898	611	43	43	200	287
TYMC_W711	898	591	34	34	239	307
TYMC_W720	898	555	41	41	260	342
TYMC_W900	898	538	42	42	275	360
SHC_W100	898	523	46	46	283	374
SHC_W200	898	503	51	51	293	395
TYMC_W1000	898	538	45	45	269	359
TYMC_W910	898	540	47	47	264	357
TYMC_W1100	898	534	46	46	270	363
TYMC_W1010	898	529	50	50	270	369
TYMC_W1200	898	533	45	45	275	365
TYMC_W1110	898	546	46	46	260	352
TYMC_W1300	898	502	46	46	303	396
TEMC_W100	898	517	39	39	302	380
TYMC_W1400	898	364	54	54	425	533
Overall Watershed	**897**	**547**	**39**	**39**	**271**	**350**

The estimated values for evapotranspiration, direct runoff, baseflow and interflow are very similar for most of the catchments. This is to be expected due to the homogeneity of geologic conditions found within the watershed. The standard deviation for the range of baseflow estimates is 8mm, which is equal to 1% of mean annual precipitation. The standard deviation for the range of direct overland runoff estimates is approximately 40 mm, which is equal to 5% of mean annual precipitation. This stability suggests that the current catchment discretization is appropriate, and refining the catchments, smaller than the current mean of 10 km^2, would not result in significant changes in water balance estimates.

The largest differences are shown in catchments W1400 and W500, which contain significant portions of impervious areas (21 and 13% respectively). Evapotranspiration for these catchments are lower than mean because a smaller proportion of the catchment supplies water to the storage reservoir in which evapotranspired water is sourced. Typical with impervious areas, runoff is higher within urbanized catchments.

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:

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

Table 3.15 – 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. 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. For surface water supplies, water reserve is estimated using the 90^{th} percentile monthly outflow, at a minimum. The 90^{th} percentile flow is defined as the flow that is equaled or exceeded 90% of the time. 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 within a subwatershed, 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 3.16.

Table 3.16– 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 3.17.

Table 3.17 – 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%

3.5.2.1 Surface Water Supply Components

The monthly median and 90th percentile flows, as estimated by HEC-HMS for the outlet of Twenty Mile Creek are included in Table 3.18. These flow estimates include the direct overland runoff calculated from the upstream drainage area, and the interflow and baseflow component.

Table 3.18 – Surface Water Percent Water Demand Components

Month	Water Supply (Median Flow) (m^3/s)	Water Reserve (90th % Flow) (m^3/s)
Jan	1.87	0.35
Feb	2.17	0.57
Mar	4.15	0.77
Apr	1.28	0.38
May	0.47	0.09

Jun	0.24	0.01
Jul	0.14	0
Aug	0.11	0
Sep	0.07	0
Oct	0.17	0
Nov	0.61	0.03
Dec	1.67	0.15

There is a greater amount of uncertainty with respect to the 90th percentile flows than with the median flows. The 90th 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 90th 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). Groundwater recharge estimates, inferred from HEC-HMS baseflow estimates, should not be considered recharge to deep, confined aquifers below the Haldimand Clay Plain, but rather recharge to shallow and localized aquifers near surface. 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 3.19 is the estimated 1991-2005 annual mean groundwater recharge rate. Also included is the groundwater reserve value, which is equal to 10% of estimated groundwater discharge (baseflow).

Table 3.19 – Groundwater Percent Water Demand Components

Water Supply (Groundwater Recharge)	Water Reserve (10% Discharge)
(mm)	(mm)
39	3.9

To complete the groundwater Stress Assessment, groundwater inflow to Twenty 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.

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%. Precipitation measurement in winter months has a higher degree of uncertainty 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.

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 Twenty 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.

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 Twenty Mile Creek. It has been successfully calibrated to the 1991-1998 period, and underwent a verification test in the 1999-2005 period. Model performance in predicting streamflow, for both the calibration and verification phase 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 groundwater inflow volumes to Twenty 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.

2. 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.

3. 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.

4. That the water balance estimates generated from the Deficit and Constant Loss Method for Twenty Mile Creek, be validated against estimates generated from a more detailed loss Method (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. The need for further model refinement could be re-evaluated following the subsequent stress assessment.

5. The precipitation from the Smithville RON climate stations was identified as possibly suspect, and subsequently excluded from the modelling exercise. This caused a significant area within the central portion of Twenty Mile Creek, without reliable climate data. It is recommended that the suspected under-reporting of precipitation at the Smithville station be investigated, and an action-plan be made to rectify the issue.

Despite the uncertainties inherent with any modelling exercise, the Twenty 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 Twenty Mile Creek.

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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 (°C)
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

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

Catchment TWEN ID	Area (km^2)	Hydrologic Soil Groups (%) A	B	C	D	Other[1]
TYMC_W100	11.95	1.6	13.7	38.6	17.1	27.9
TYMC_W200	3.12		2.8	62.2	14.0	21.0
GD_W100	7.14			44.8	50.8	4.4
GD_W200	10.00		4.2	32.7	62.9	0.2
TYMC_W300	6.64			79.8	15.0	5.1
SC_W100	13.18		0.6	51.2	45.5	2.7
SC_W200	2.04		0.4	15.3	81.9	2.5
SC_W110	7.62			10.4	88.6	1.0
SC_W300	5.34		14.9	40.5	44.6	0.1
SC_W210	5.76		1.3	41.0	56.0	1.7
SC_W400	9.75		0.9	36.6	61.0	1.4
TYMC_W400	9.61		0.2	66.6	26.8	6.4
TYMC_W500	10.22		0.7	41.5	33.8	24.0
NC_W100	12.02			37.7	59.2	3.2
NC_W200	7.18			56.8	40.5	2.7
NC_W110	8.73			41.6	56.9	1.6
NC_W400	12.40			20.4	77.8	1.8
TYMC_W600	16.98		0.3	38.9	54.4	6.4
TYMC_W700	3.06			57.7	39.1	3.2
TYMC_W610	13.40			49.2	49.0	1.9
TYMC_W800	10.41		1.3	51.9	38.7	8.0
TYMC_W710	1.47			60.7	36.9	2.3
TYMC_W711	7.54			44.5	55.1	0.4
TYMC_W720	10.39			63.4	36.0	0.6
TYMC_W900	6.28		0.2	80.8	15.9	3.1
SHC_W100	11.31		0.2	79.2	19.3	1.3
SHC_W200	7.04			89.7	10.3	
TYMC_W1000	13.07			79.2	20.8	
TYMC_W910	7.31			79.7	20.3	
TYMC_W1100	7.55			80.8	19.2	
TYMC_W1010	5.47			95.9	4.1	
TYMC_W1200	11.10			74.9	25.1	
TYMC_W1110	6.35			80.4	19.6	
TYMC_W1300	8.87			80.8	19.2	
TEMC_W100	7.84			67.1	32.9	
TYMC_W1400	8.16	2.0	19.5	50.7	27.8	
Average %		1.6	3.0	49.4	44.0	5.2
% of TWEN		0.1	1.7	55.1	39.2	4.0
Area (km2)		0.35	5.10	168.71	119.88	12.13

Table Notes:
TYMC - Twenty Mile Creek, GD - Gavora Ditch, SC - Spring Creek, NC - North Creek, SHC - Sinkhole Creek
TEMC - Three Mile Creek
1 - Where soils unmapped or an area of high runoff, i.e. urban areas, water bodies, bedrock at surface

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

Catchment TWEN 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	Open Water	Built Up Impervious	Extraction	Transportation
TYMC_W100	4.1		9.9		5.8	1.5		11.9	2.2	7.8	1.3	0.1	5.0	0.7	8.4		6.3	4.5	9.4	8.3	7.5	5.4
TYMC_W200	6.7	13.8	16.8	15.2	0.2		2.7		1.6	4.8	0.7		1.7		4.6	21.7	1.0	2.7	1.4	0.5		3.8
GD_W100	16.5	0.7	35.2	0.0	0.7	1.8	2.1	8.9		2.5	0.7	1.2	0.2	2.3	9.0	0.2	1.4	7.4		1.1	2.7	5.3
GD_W200	17.3	0.8	31.4	2.4	0.0	0.4		7.7		1.4	0.5	0.4	0.7	1.2	8.9	6.2	2.5	13.1		0.4		4.6
TYMC_W300		14.5		23.7			0.3			13.7	0.3	1.9		0.0	0.0	35.3		4.9	2.5	0.0		2.8
SC_W100	2.5	7.8	6.4	22.7		1.3	0.4		0.0	8.1	0.6	0.5		0.4	1.0	36.3	0.2	3.9	0.1	0.6	3.9	3.3
SC_W200		7.2		20.5		4.3				15.4	1.1	0.7		0.4	0.1	34.1	1.7	11.9	0.0	0.2	1.2	1.3
SC_W110		1.4		33.7						7.1	2.2	0.6		1.0	0.0	28.2	1.0	22.1		0.6		2.1
SC_W300	23.4		34.5	0.8	0.9	0.1		7.6		1.3	0.5	0.6	0.2		7.1	0.1	0.1	20.1		0.3		2.6
SC_W210	12.0	1.8	17.8	41.8		1.0		1.8		2.4	0.4	0.6		0.4	1.0	11.9	0.0	3.4		0.8		2.9
SC_W400	14.3	0.8	32.8	0.8	1.3	2.7	0.1	8.7		2.4	0.4	0.6	0.2		11.6	2.5	0.2	15.0		1.4	0.1	4.2
TYMC_W400		7.1		32.0			0.1			10.2	1.1	1.5		0.1	0.1	34.5	0.1	8.8	1.0	0.9		2.3
TYMC_W500		9.0		31.6			0.1			3.7	1.0	1.5		4.0		20.7	1.8	4.2	1.7	14.7		6.0
NC_W100		18.6		18.9			0.3			7.6	0.4	0.9		0.0		47.3	0.0	2.8	0.1	0.4		2.6
NC_W200		14.7		20.8			0.5			3.4	0.5	0.4		0.0		49.5	2.1	4.1	0.1	0.3		3.7
NC_W110		14.8		19.5			0.0			9.3	1.6	0.4		0.3		40.5	1.4	10.0				2.2
NC_W400		7.1		25.4			0.1			9.7	1.5	0.4		0.2	0.1	43.7	0.8	8.6	0.0	0.3		2.1
TYMC_W600		11.6		29.7			0.2			5.9	0.8	0.6		2.1	0.0	36.8	0.4	5.6	0.3	2.7		3.2
TYMC_W700		13.0		16.1						7.4	0.6	3.0			0.0	54.4		2.9	0.2			2.4
TYMC_W610	3.5	6.2	23.6	21.6		3.5	0.4			4.4	0.7	0.5		1.1	2.4	18.8	0.5	8.7	0.1	0.8		3.1
TYMC_W800	1.7	16.5	1.5	26.1			0.6			4.2	0.9	1.1		1.6	0.1	34.3	0.5	5.5	0.4	2.2		2.8
TYMC_W710		0.2		39.4			0.3			3.1	0.8	2.3		0.0	0.0	48.0		4.2	0.1			1.6
TYMC_W711		16.5		17.0						4.8	0.1	0.3		0.2		57.4		1.1				2.4
TYMC_W720	8.7	4.9	27.0	13.8		4.4	2.8			4.5	0.6	0.9		0.2	2.1	21.1	0.6	4.5		1.6		2.2
TYMC_W900	23.0	3.6	12.8	5.3		6.0	0.3			7.3	0.6	0.8		9.5	4.7	6.0	1.2	9.6	0.1	6.3		2.9
SHC_W100	20.9	2.2	34.9	1.9	0.0	7.7	0.1			3.3	0.6	1.0	0.3	1.7	8.3	1.9	3.6	3.9		4.8		3.0
SHC_W200	43.8		29.2			1.9				0.9	0.1	1.0		1.5	7.2		2.9	2.0	0.2	6.8		2.7
TYMC_W1000	26.1		44.0		3.3	3.4	0.4	0.0	0.1	3.5	0.8	2.2	0.6	0.2	4.4		0.5	4.6		3.4		2.4
TYMC_W910	18.5		60.5		5.3	4.0	0.1	0.1		3.2	0.3	0.8	0.1		2.2			0.8	0.0	2.4		1.6
TYMC_W1100	22.8		49.7		0.8	1.6	0.6			4.2	0.8	1.7	0.1	0.1	5.4		1.5	5.0		3.3		2.4
TYMC_W1010	21.4		41.3		4.8	10.5	0.9			2.3	0.4	2.9		0.4	5.4		0.3	1.0		5.3		3.1
TYMC_W1200	22.4		46.6			8.2	0.2			2.0	0.6	1.6	0.6	0.2	5.7		1.6	4.7		3.5		2.3
TYMC_W1110	17.2		56.0			7.7	0.2			6.1	0.5	1.0	0.1		4.4		1.2	2.0		1.1		2.6
TYMC_W1300	34.7		22.2			2.0			0.1	5.3	0.7	0.5	0.4	3.3	10.4		5.1	3.8		8.3		3.3
TEMC_W100	16.1		12.7			13.0	0.2			2.0	0.6	0.8	0.6	31.2	4.8		3.1	2.0	0.1	9.3		3.5
TYMC_W1400	17.5		13.9			4.3	1.2		0.2	4.2	0.7	0.6	0.1	7.1	12.3		2.4	1.7	0.7	22.3		10.8
Average %	14.2	8.1	22.4	19.2	1.3	2.8	0.6	7.8	1.3	5.8	0.8	0.9	1.2	1.3	3.5	27.7	1.3	7.2	1.0	2.4	3.1	3.1
% of TWEN	10.7	5.6	18.4	13.3	0.7	2.5	0.4	1.4	0.1	5.2	0.7	0.9	0.3	2.0	3.7	18.8	1.4	6.1	0.6	3.4	0.5	3.3
Area/Land Use	32.7	17.2	56.2	40.7	2.1	7.6	1.2	4.2	0.4	16.0	2.3	2.8	1.1	6.0	11.3	57.7	4.2	18.7	1.8	10.4	1.6	10.1

Table Notes:
TYMC - Twenty Mile Creek, GD - Gavora Ditch, SC - Spring Creek, NC - North Creek, SHC - Sinkhole Creek, 'TEMC - Three Mile Creek

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

Catchment TWEN ID	Area (km^2)	Slope (%)	Impervious Area (%)	Curve Number (CN)	Basin Time Lag (hours)	Maximum storage (mm)	Infiltation Rate (mm/hour)
TYMC_W100	11.95	8.3	9.5	81.5	1.9	149.2	2.1
TYMC_W200	3.12	5.4	4.0	83.7	1.2	169.6	1.7
GD_W100	7.14	2.7	5.9	84.4	2.3	182.2	1.7
GD_W200	10.00	2.0	4.7	83.6	2.4	192.5	1.6
TYMC_W300	6.64	4.3	2.8	82.4	2.6	229.4	2.1
SC_W100	13.18	3.5	3.5	84.2	2.9	207.1	1.7
SC_W200	2.04	1.5	0.8	83.0	1.7	229.6	1.2
SC_W110	7.62	1.5	2.3	82.2	3.5	235.3	1.3
SC_W300	5.34	1.8	2.7	81.8	2.1	207.9	2.2
SC_W210	5.76	1.5	3.5	85.7	2.4	183.3	1.6
SC_W400	9.75	2.1	5.0	82.5	2.4	206.3	1.6
TYMC_W400	9.61	4.3	2.8	82.5	2.0	225.6	1.9
TYMC_W500	10.22	3.4	13.3	84.9	2.2	148.3	1.5
NC_W100	12.02	2.8	2.8	84.3	2.4	211.2	1.6
NC_W200	7.18	2.4	4.0	84.0	2.7	207.7	1.9
NC_W110	8.73	2.0	2.1	83.1	3.0	226.3	1.5
NC_W400	12.40	1.5	2.3	83.5	2.8	223.1	1.5
TYMC_W600	16.98	2.2	4.5	84.3	3.0	198.9	1.7
TYMC_W700	3.06	2.3	2.4	83.4	1.6	224.4	1.9
TYMC_W610	13.40	1.8	3.6	83.8	4.0	208.3	1.8
TYMC_W800	10.41	2.3	4.0	83.9	3.2	199.5	2.0
TYMC_W710	1.47	2.7	0.9	83.5	1.4	228.3	2.2
TYMC_W711	7.54	1.8	2.5	84.8	2.0	210.1	1.6
TYMC_W720	10.39	1.8	3.0	83.7	3.1	209.6	1.9
TYMC_W900	6.28	2.7	6.0	82.9	2.7	200.4	2.1
SHC_W100	11.31	2.3	5.3	83.3	3.3	192.2	2.1
SHC_W200	7.04	2.3	6.0	84.1	1.9	181.7	2.3
TYMC_W1000	13.07	2.8	4.1	83.2	3.1	211.7	2.1
TYMC_W910	7.31	2.3	2.8	84.3	2.0	206.1	2.2
TYMC_W1100	7.55	3.5	4.1	83.2	2.0	205.4	2.2
TYMC_W1010	5.47	2.6	5.8	82.8	1.8	211.1	2.5
TYMC_W1200	11.10	3.7	4.0	83.7	2.1	199.4	2.1
TYMC_W1110	6.35	3.4	3.2	83.7	1.7	206.5	2.2
TYMC_W1300	8.87	4.8	7.4	83.0	1.9	183.9	2.2
TEMC_W100	7.84	4.2	8.1	87.1	2.0	149.5	2.0
TYMC_W1400	8.16	4.6	21.9	81.9	1.7	128.3	2.8

Minimum	1.5	1.5	0.8	81.5	1.2	148.3	1.2
Maximum	17.0	8.3	13.3	85.7	4.0	235.3	2.3
Average	8.5	2.7	4.1	83.5	2.5	203.3	1.8

Table Notes:
TYMC - Twenty Mile Creek, GD - Gavora Ditch, SC - Spring Creek, NC - North Creek, SHC - Sinkhole Creek
TEMC - Three Mile Creek

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FIGURES

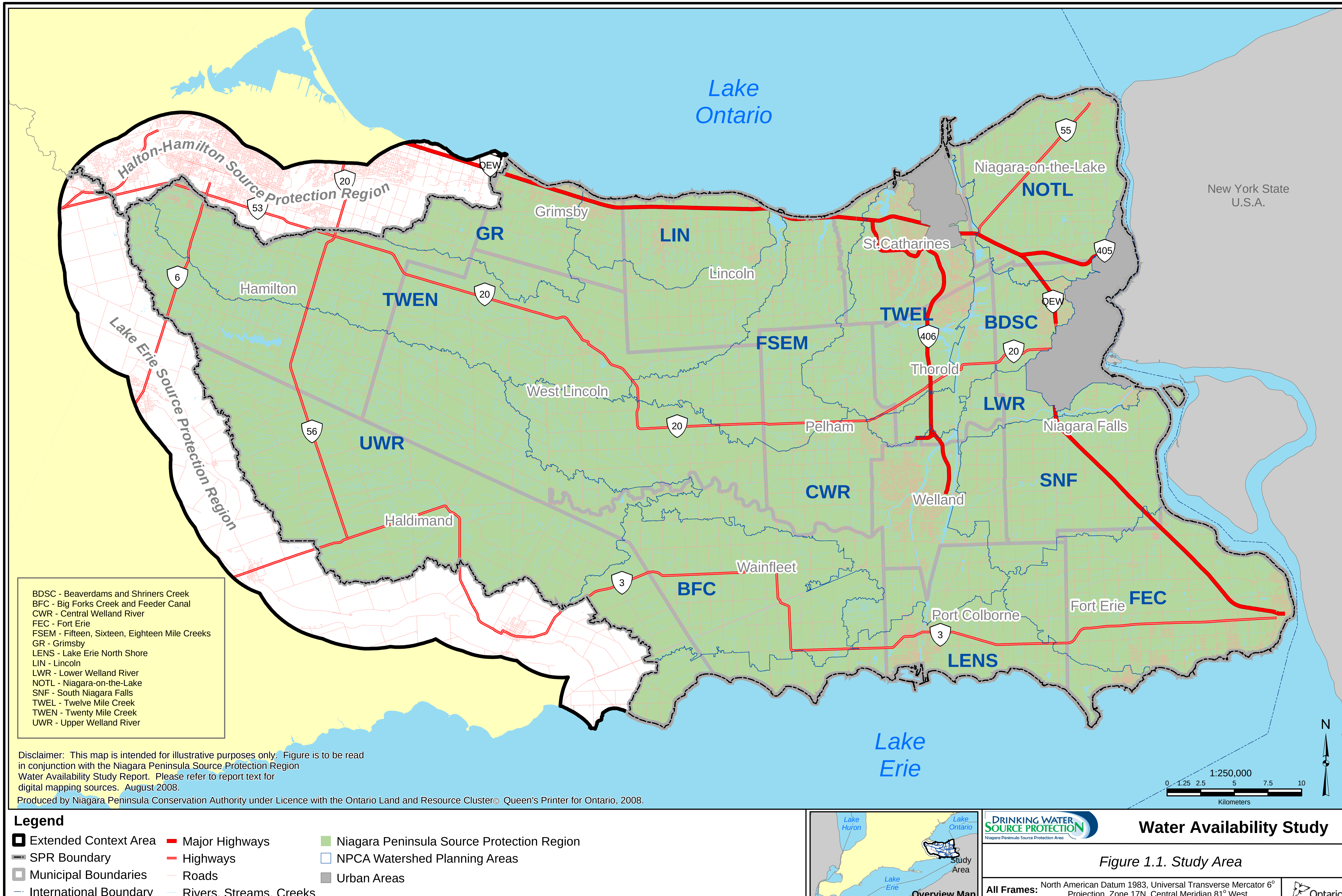


Figure 1.1. Study Area

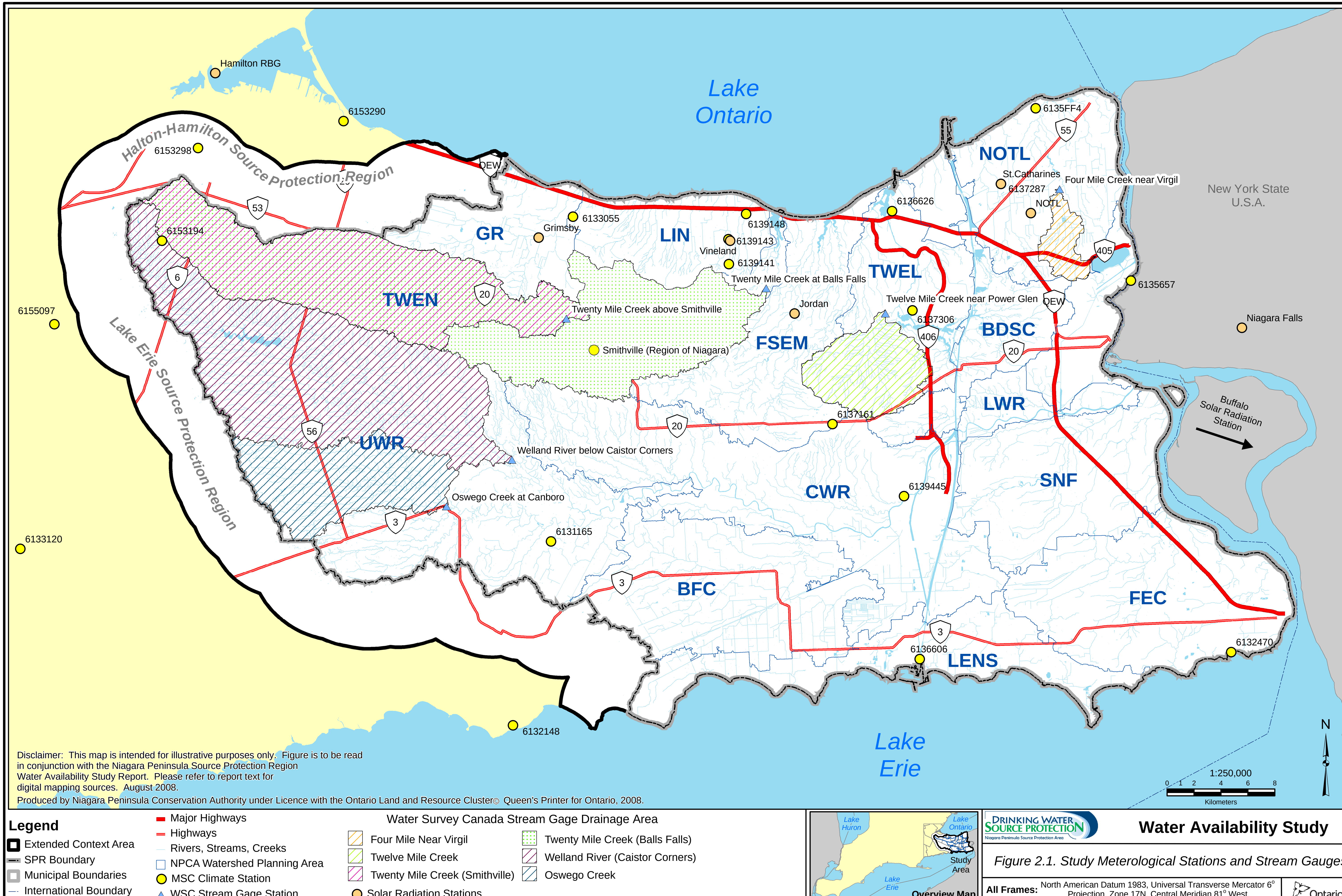


Figure 2.1. Study Meterological Stations and Stream Gauges

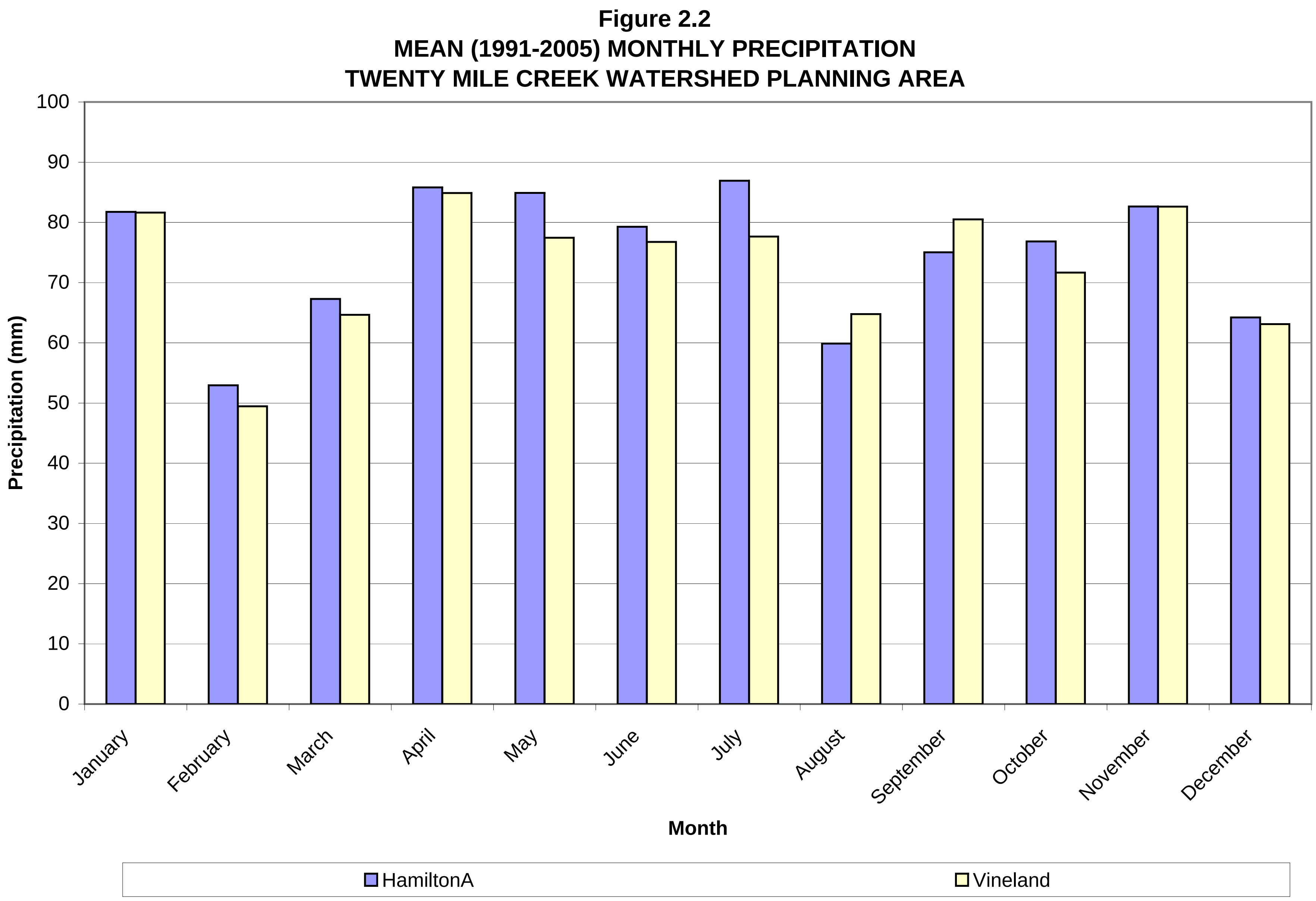
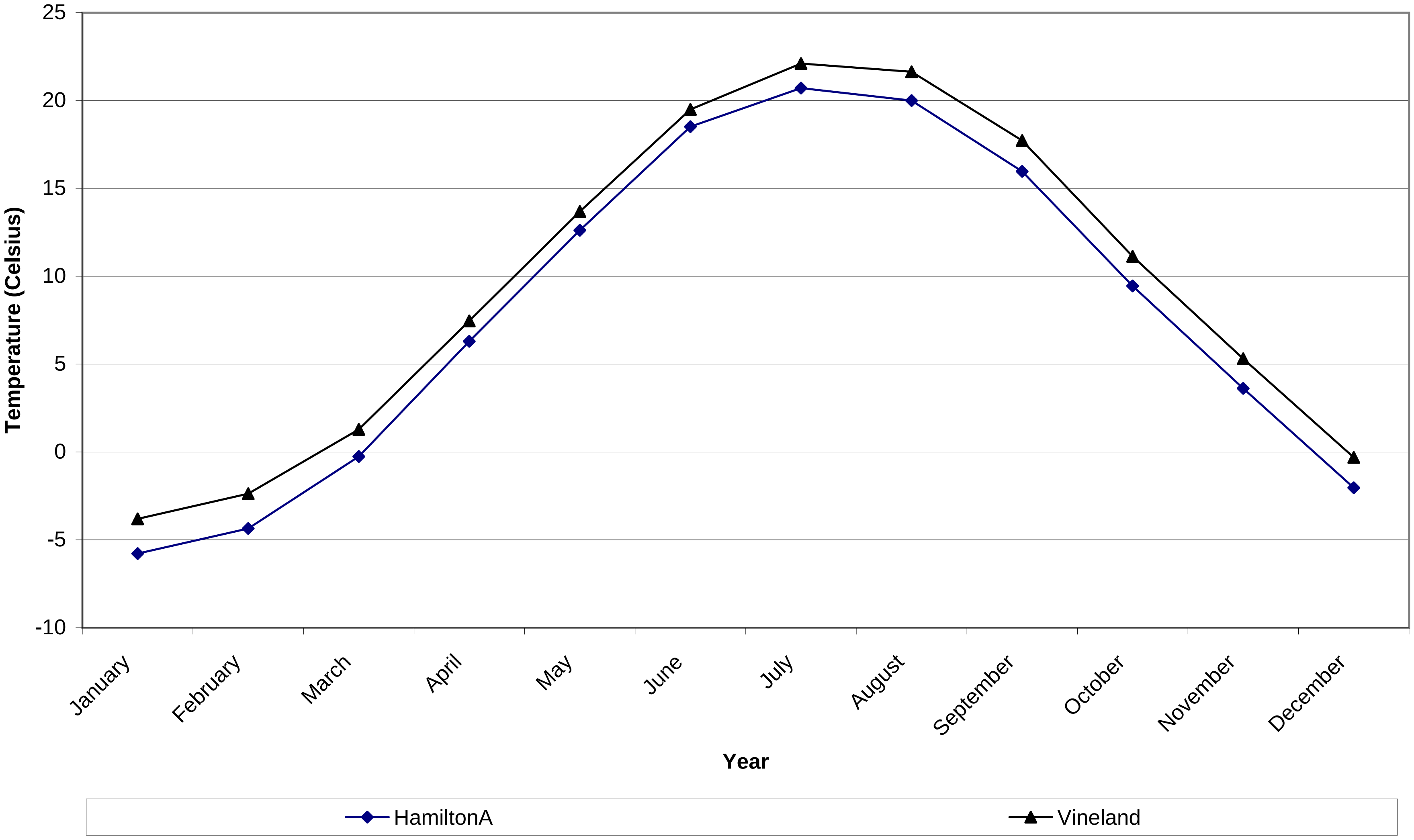
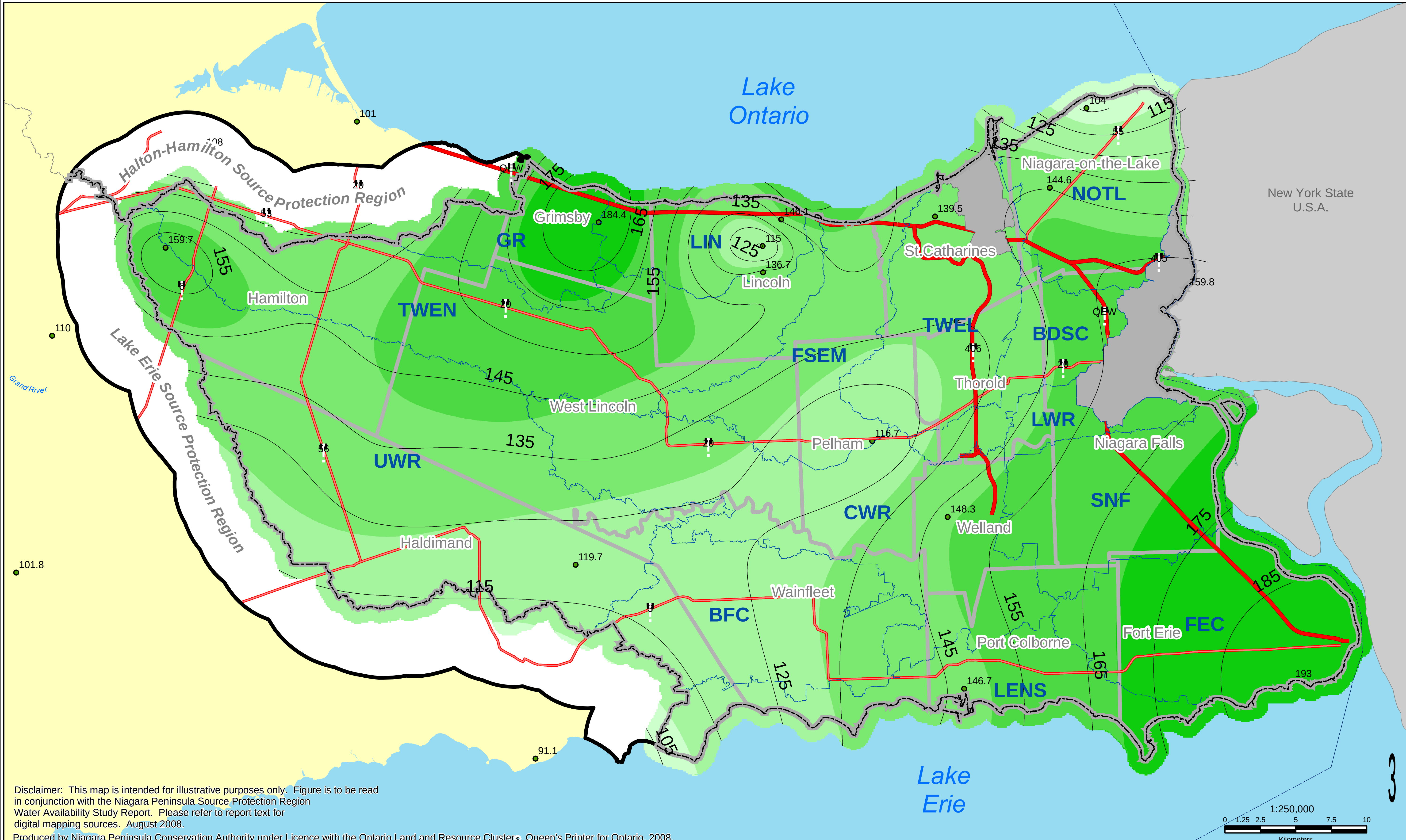


Figure 2.2
MEAN (1991-2005) MONTHLY PRECIPITATION
TWENTY MILE CREEK WATERSHED PLANNING AREA
Precipitation (mm)
100
90
80
70
60
50
40
30
20
10
0
January
February
March
April
May
June
July
August
September
October
November
December
Month
HamiltonA
Vineland

Figure 2.3
MEAN (1991-2005) MONTHLY TEMPERATURE
TWENTY MILE CREEK WATERSHED PLAN AREA





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

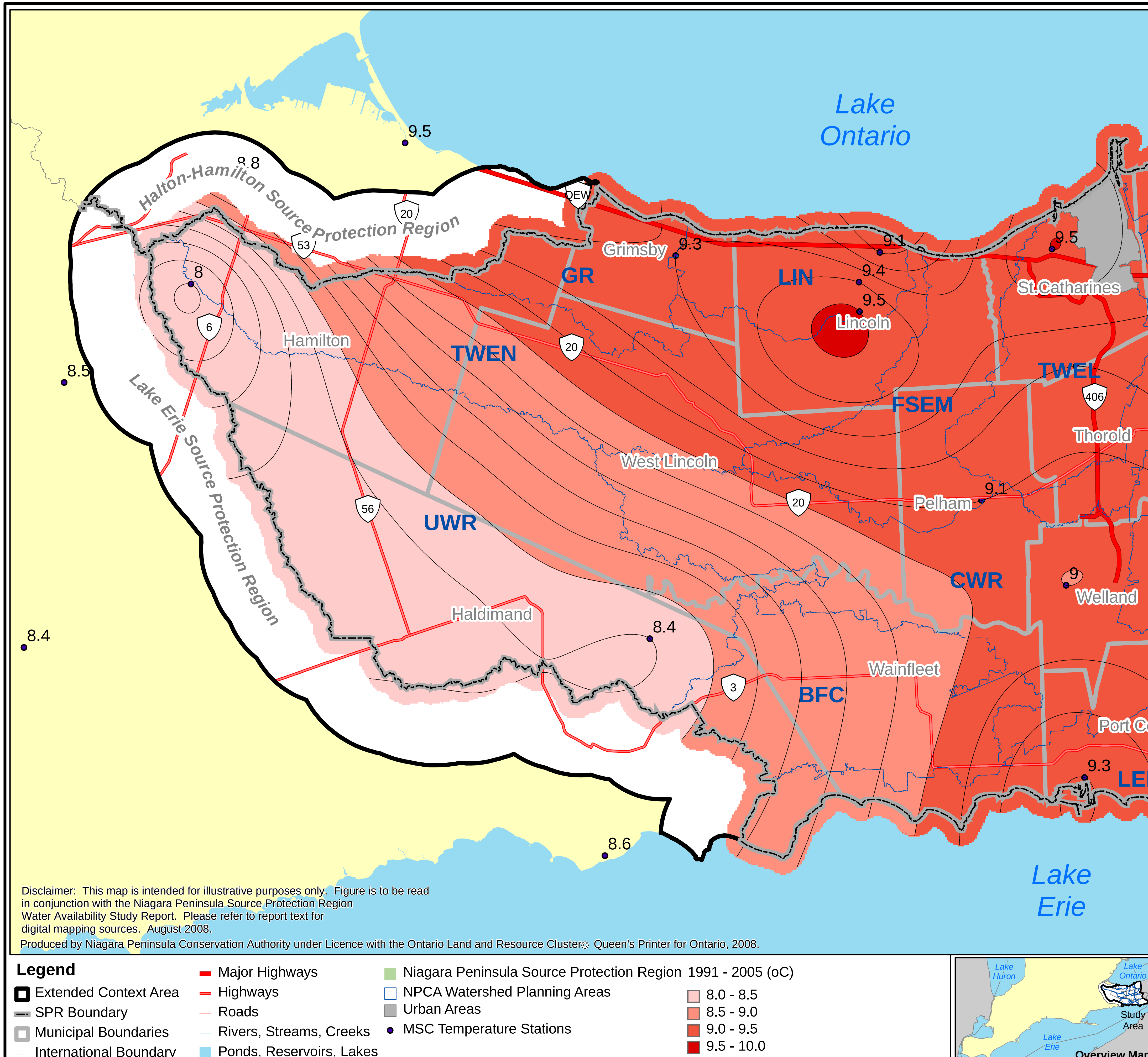
DRINKING WATER SOURCE PROTECTION
Niagara Peninsula Source Protection Region

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



Water Availability Study

Figure 2.5. Mean Annual Temperature

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

Ontario

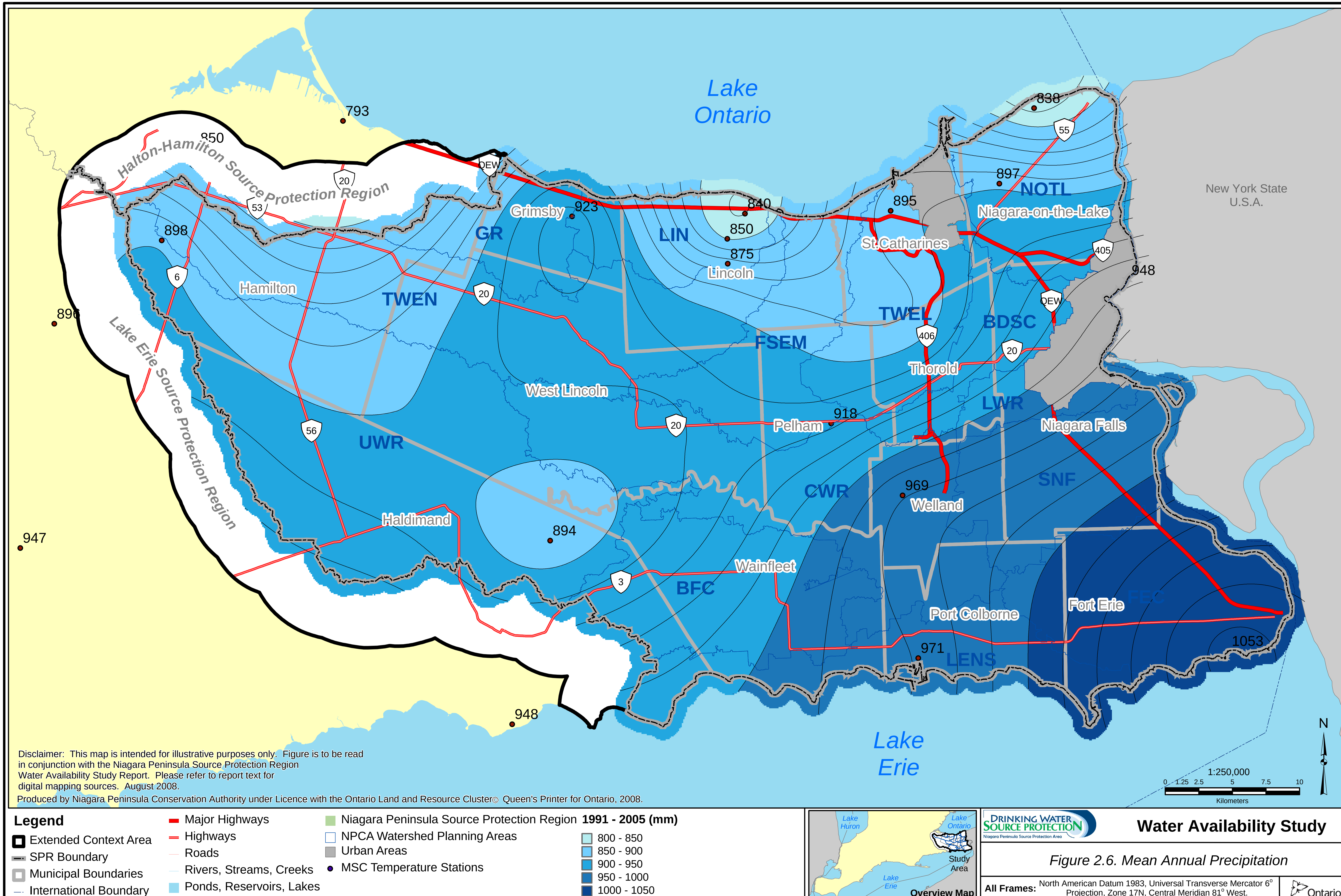


Figure 2.6. Mean Annual Precipitation

Figure 2.7
ANNUAL PRECIPITATION - TWENTY MILE CREEK WATERSHED PLANNING AREA

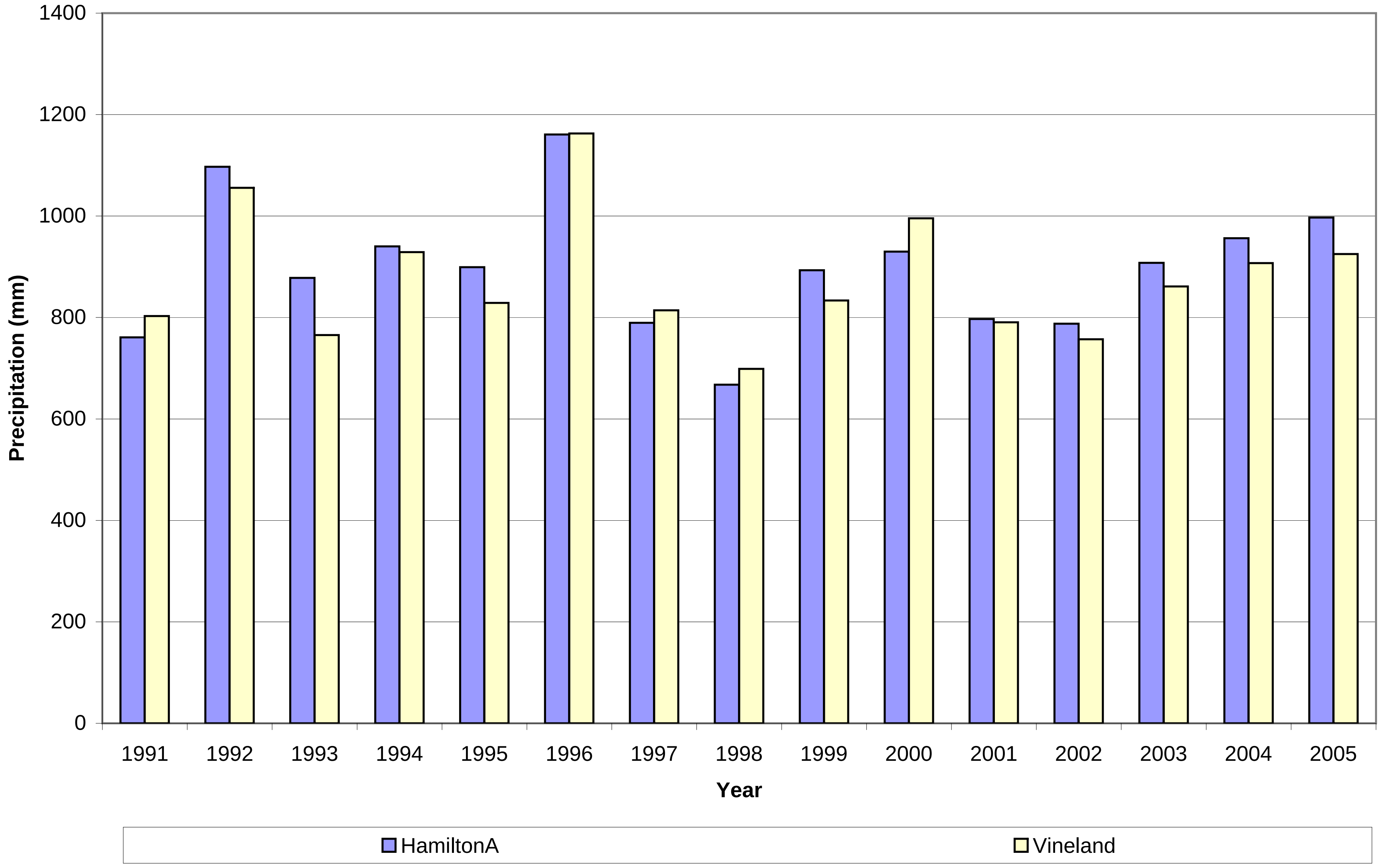


Figure 2.8
ANNUAL SNOW WATER EQUIVALENT
TWENTY MILE CREEK WATERSHED PLANNING AREA

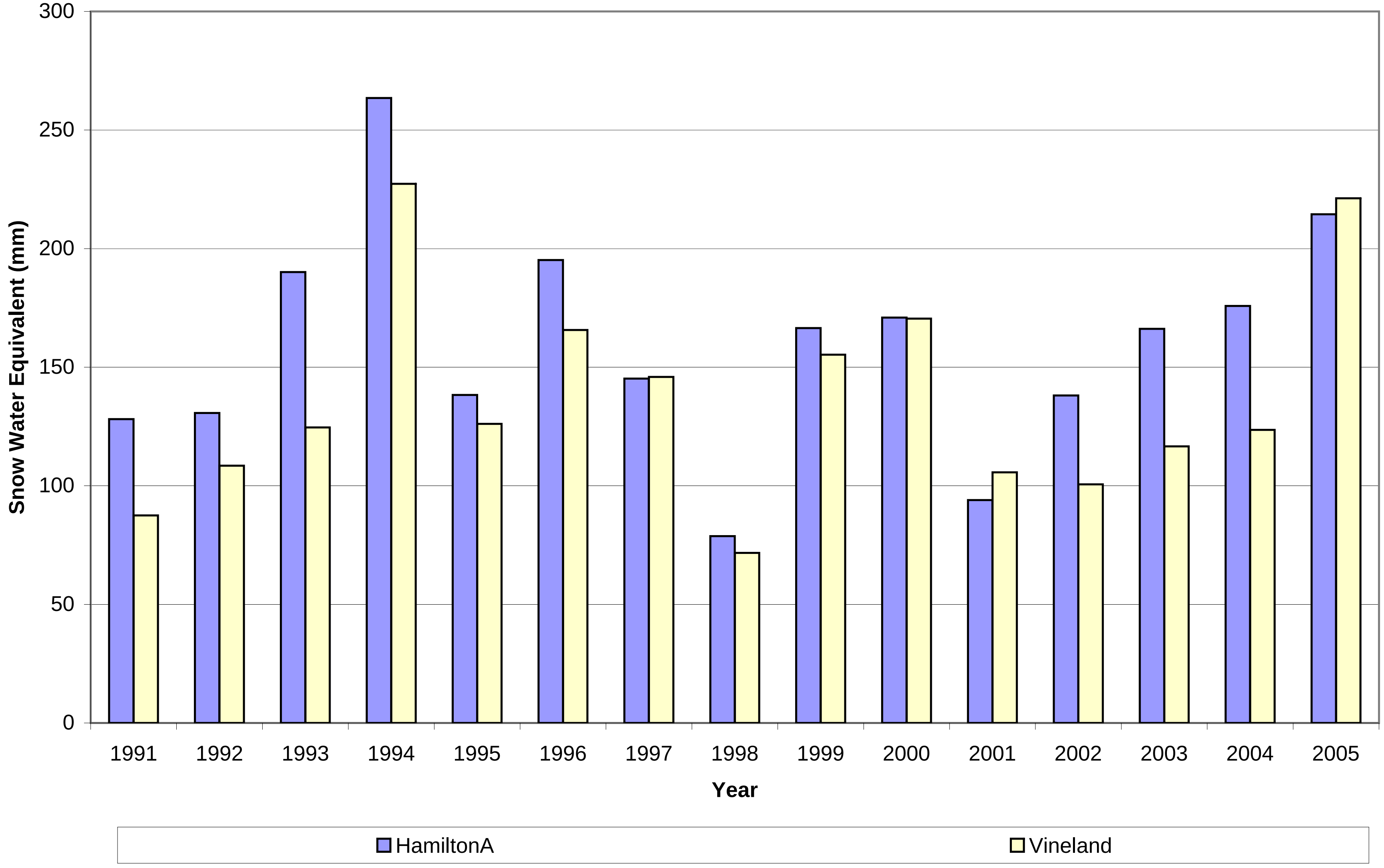


Figure 2.9
MEAN (1991-2005) ANNUAL TEMPERATURE
TWENTY MILE CREEK WATERSHED PLAN AREA

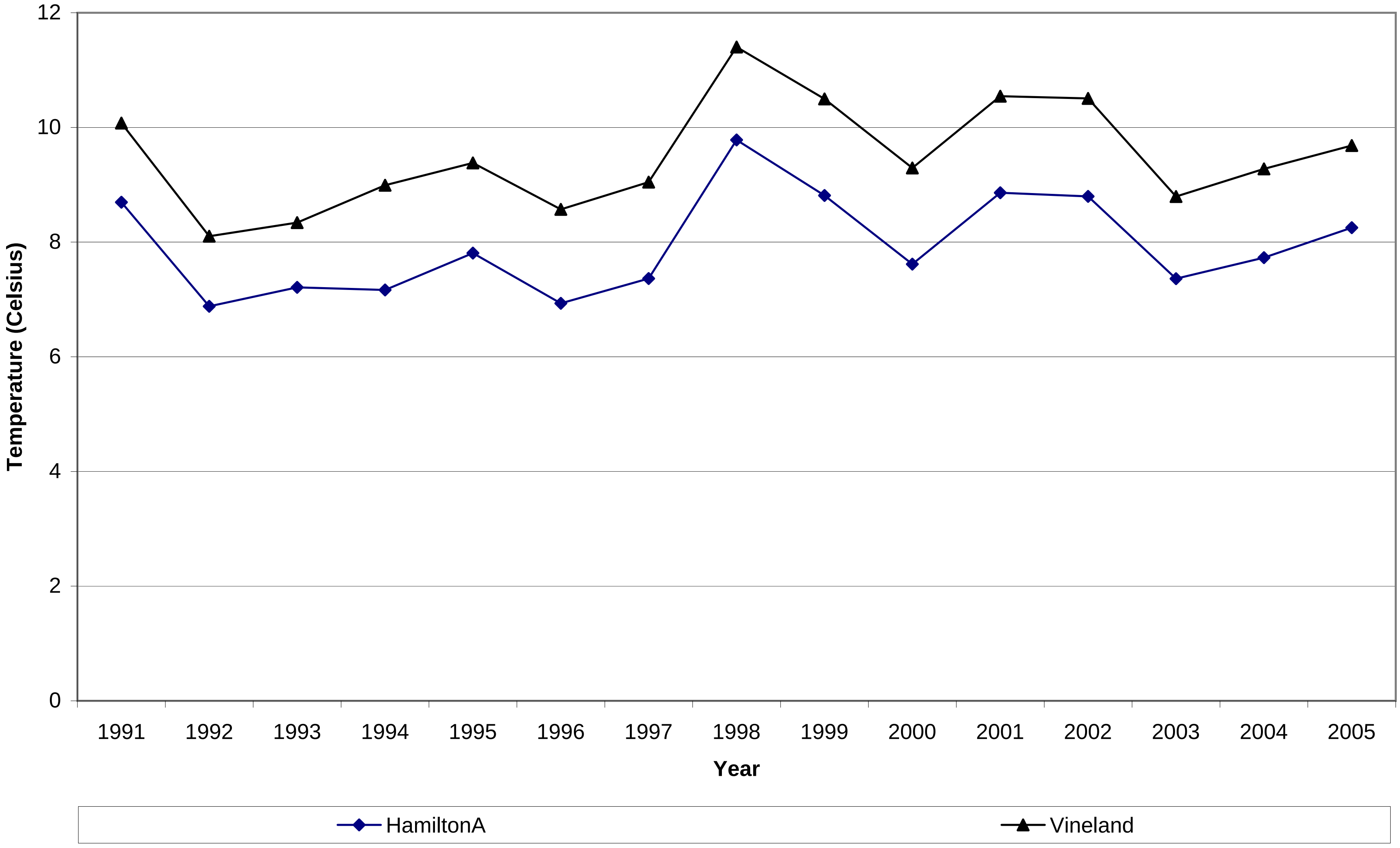


Figure 2.10
ANNUAL NET SOLAR RADIATION

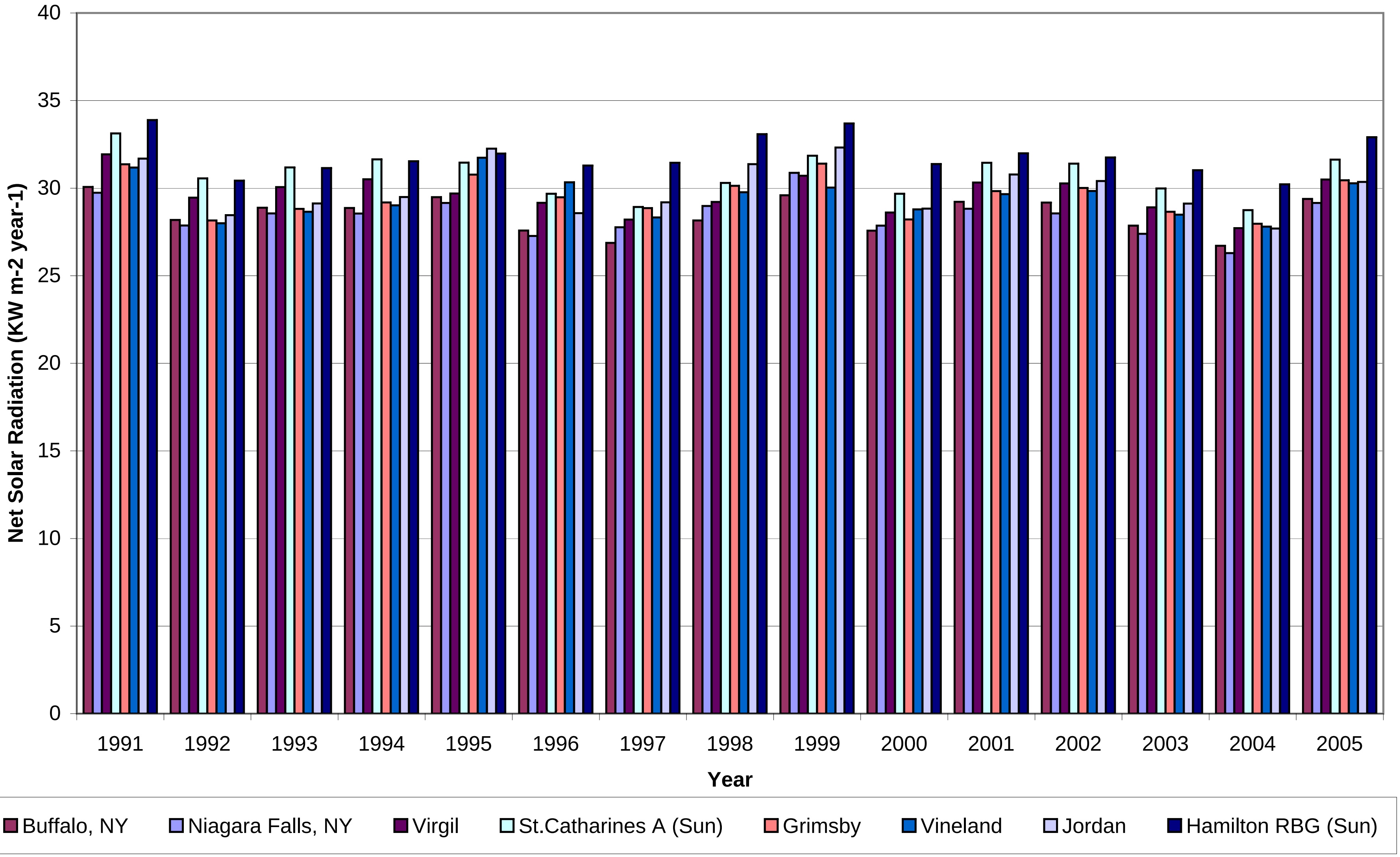


Figure 2.11
MEAN (1991-2005) MONTHLY NET SOLAR RADIATION

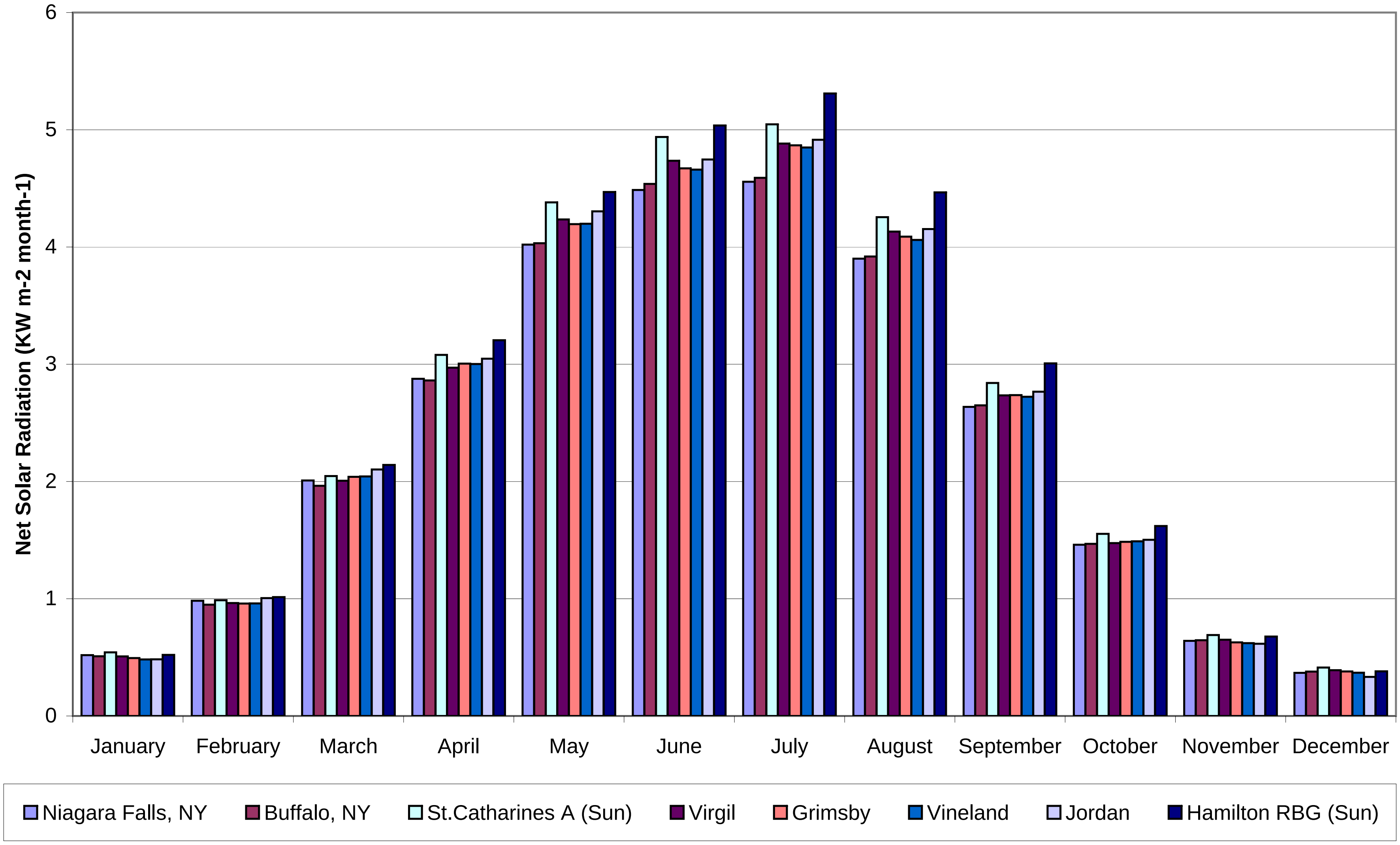
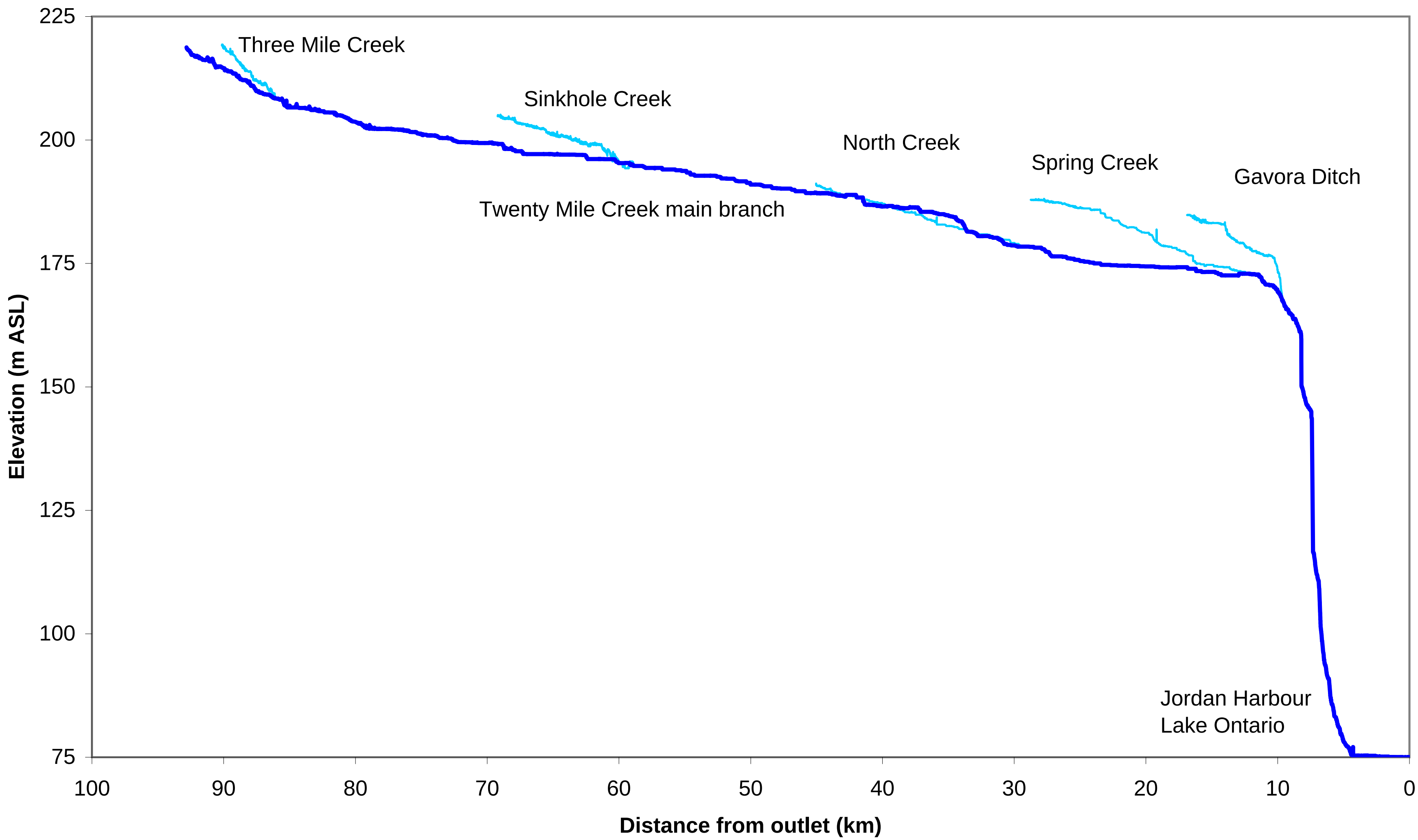
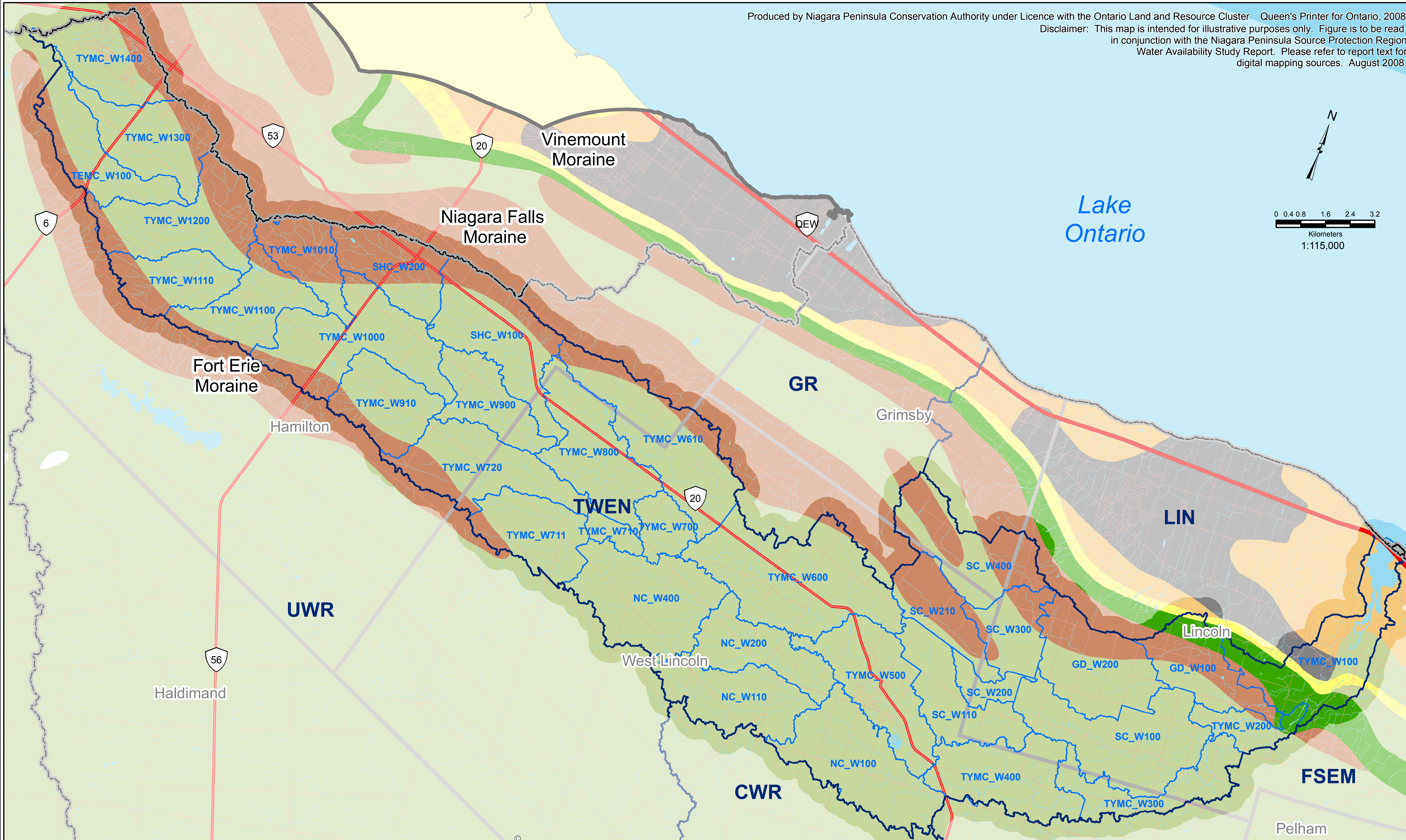
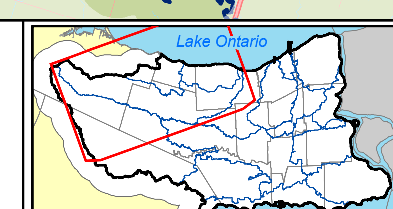


Figure 2.12
Channel Profile of Twenty Mile Creek







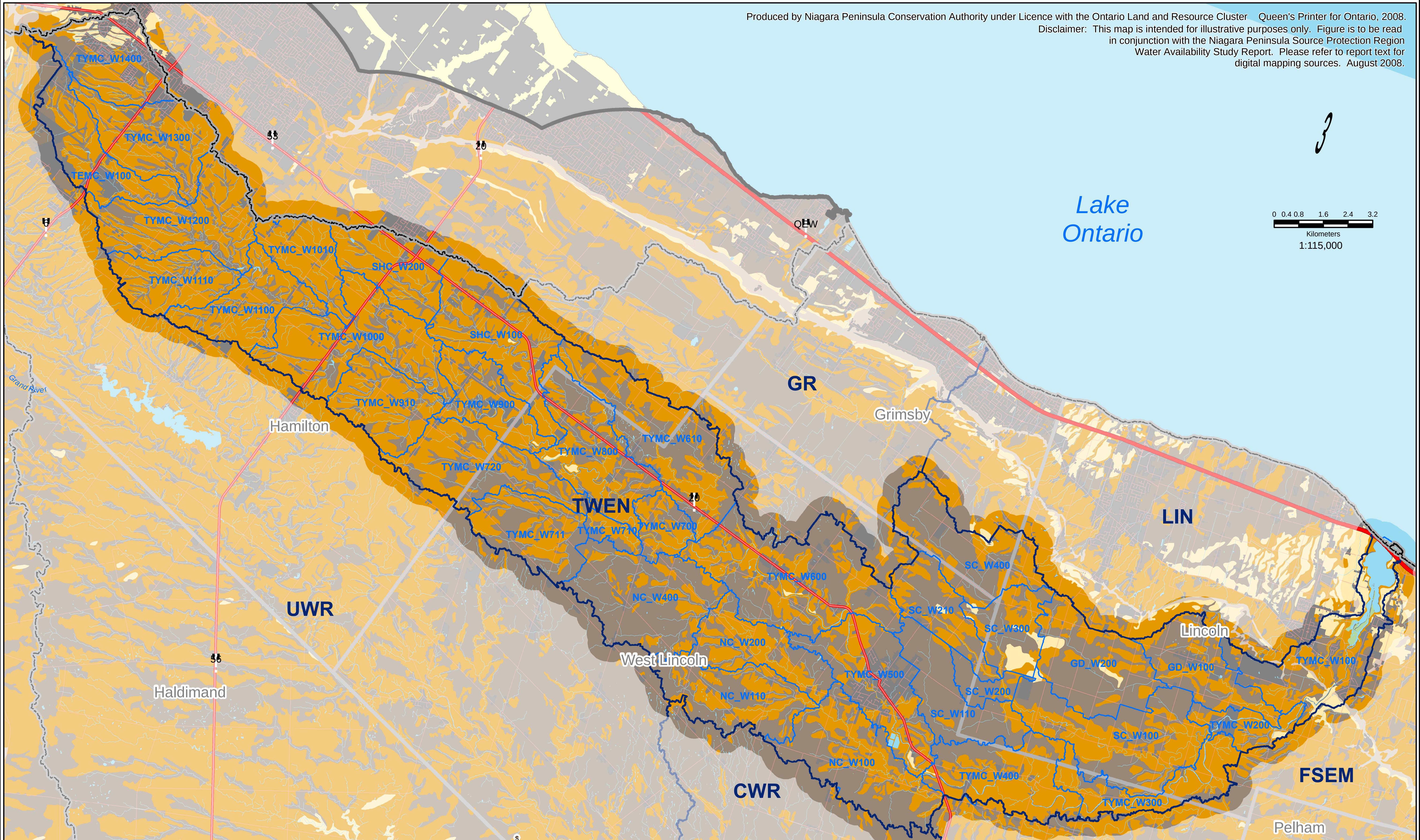
DRINKING WATER SOURCE PROTECTION
Niagara Peninsula Source Protection Area

Water Availability Study

Figure 2.13. TWEN Physiography

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

Ontario



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
TYMC_W100: Subcatchment ID

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

Overview Map — Lake Ontario, Lake Erie

DRINKING WATER SOURCE PROTECTION — Niagara Peninsula Source Protection Region

Water Availability Study

Figure 2.14. TWEN Soils

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

Ontario

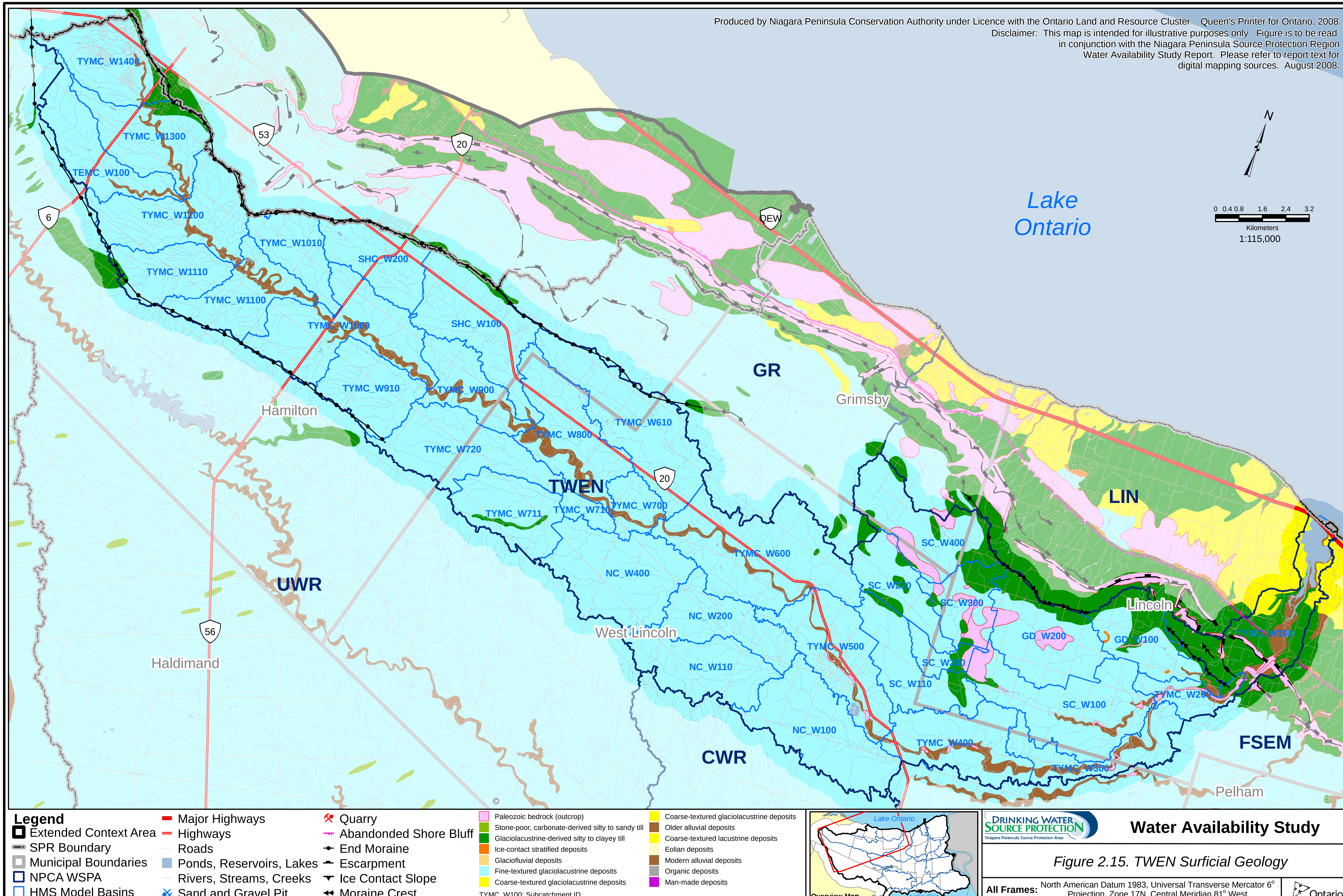
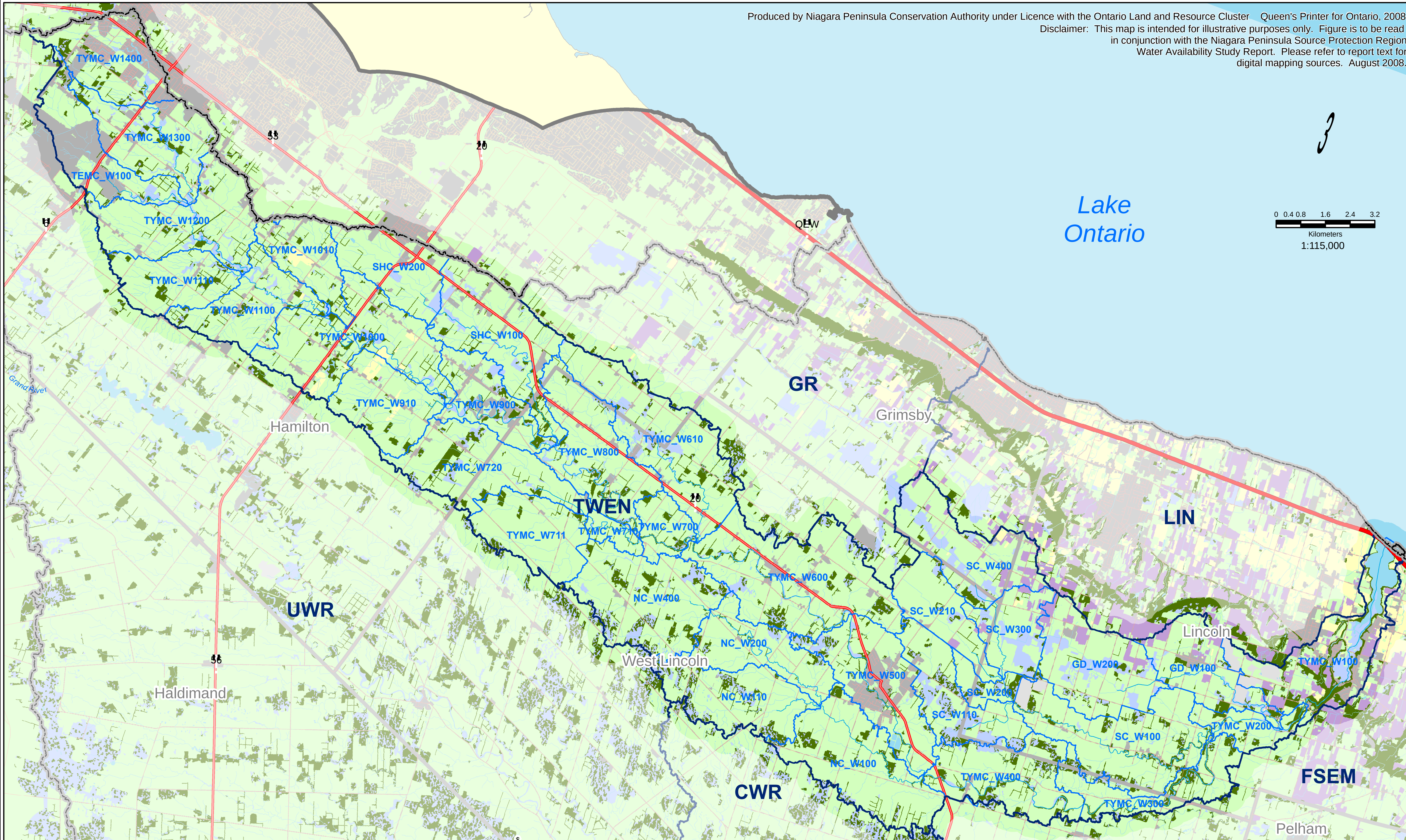


Figure 2.15. TWEN Surficial Geology



Legend

- Extended Context Area
- SPR Boundary
- Municipal Boundaries
- International Boundary
- Major Highways
- Highways
- Roads
- Rivers, Streams, Creeks
- Ponds, Reservoirs, Lakes
- NPCA Watershed Planning Area
- HMS Model Subcatchments
- HMS Model Reaches
- TYMC_W100: Subcatchment ID

Land Cover

- Agriculture
- Wetland
- Built Up / Transportation
- Forest
- Extraction
- Shoreline
- Water
- Orchards
- Vineyards

Overview Map

DRINKING WATER SOURCE PROTECTION
Niagara Peninsula Source Protection Region

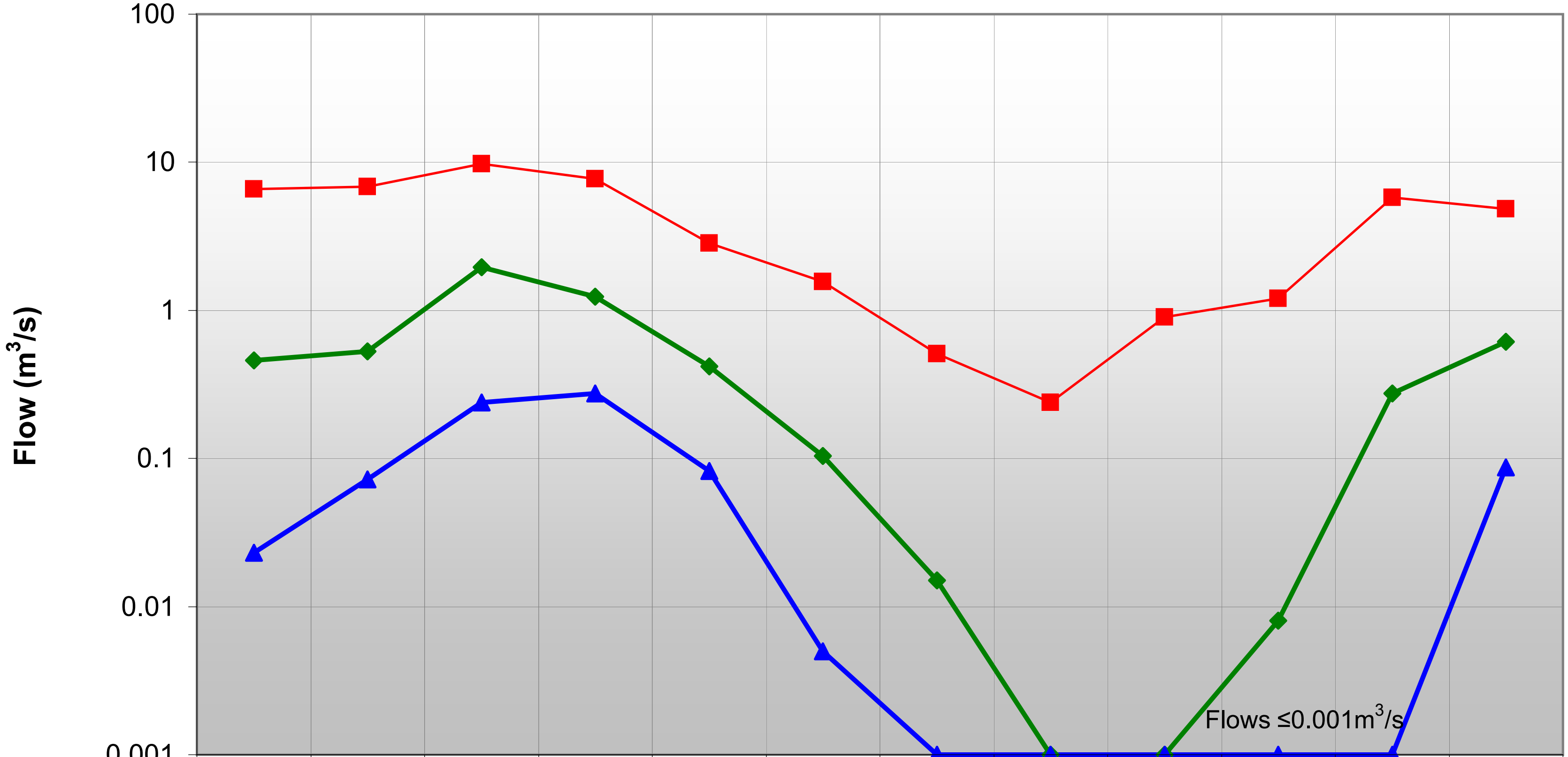
Water Availability Study

Figure 2.16. TWEN Land Cover

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

Ontario

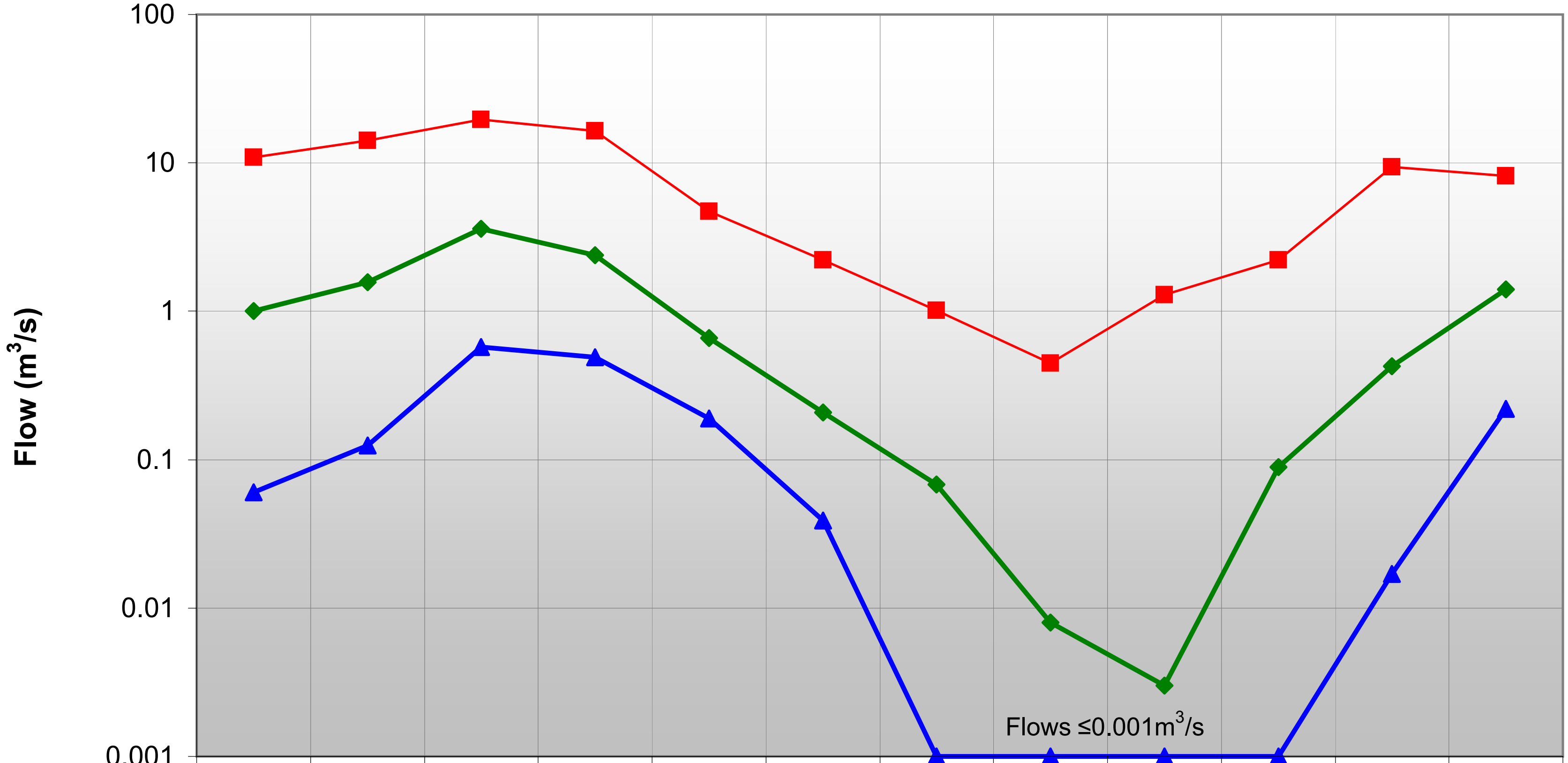
Figure 2.17 - Monthly Flow Distribution (1991-2005) for 02HA020 - Twenty Mile Creek above Smithville



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
10th Percentile	6.59	6.82	9.75	7.76	2.83	1.56	0.507	0.24	0.902	1.2	5.8	4.82
Median	0.46	0.529	1.96	1.24	0.42	0.104	0.015	0.001	0.001	0.008	0.275	0.612
90th Percentile	0.023	0.072	0.24	0.275	0.082	0.005	0.001	0.001	0.001	0.001	0.001	0.087

Month

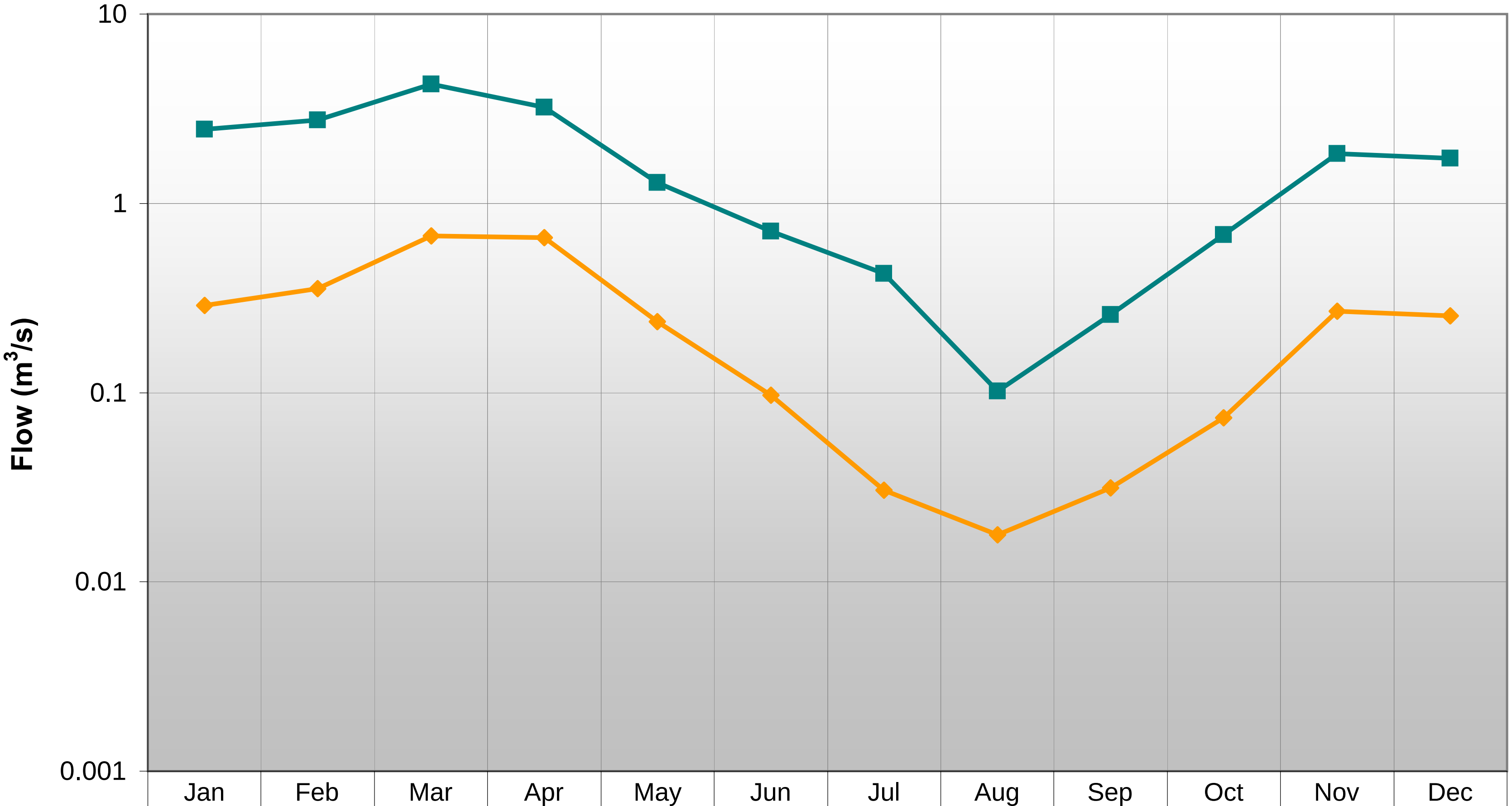
Figure 2.18 - Monthly Flow Distribution (1991-2005) for 02HA006 - Twenty Mile Creek at Ball's Falls



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
10th Percentile	10.9	14.1	19.6	16.4	4.7	2.21	1.01	0.445	1.29	2.22	9.42	8.16
Median	1	1.57	3.59	2.38	0.662	0.208	0.068	0.008	0.003	0.089	0.425	1.4
90th Percentile	0.06	0.125	0.576	0.491	0.189	0.039	0.001	0.001	0.001	0.001	0.017	0.22

Month

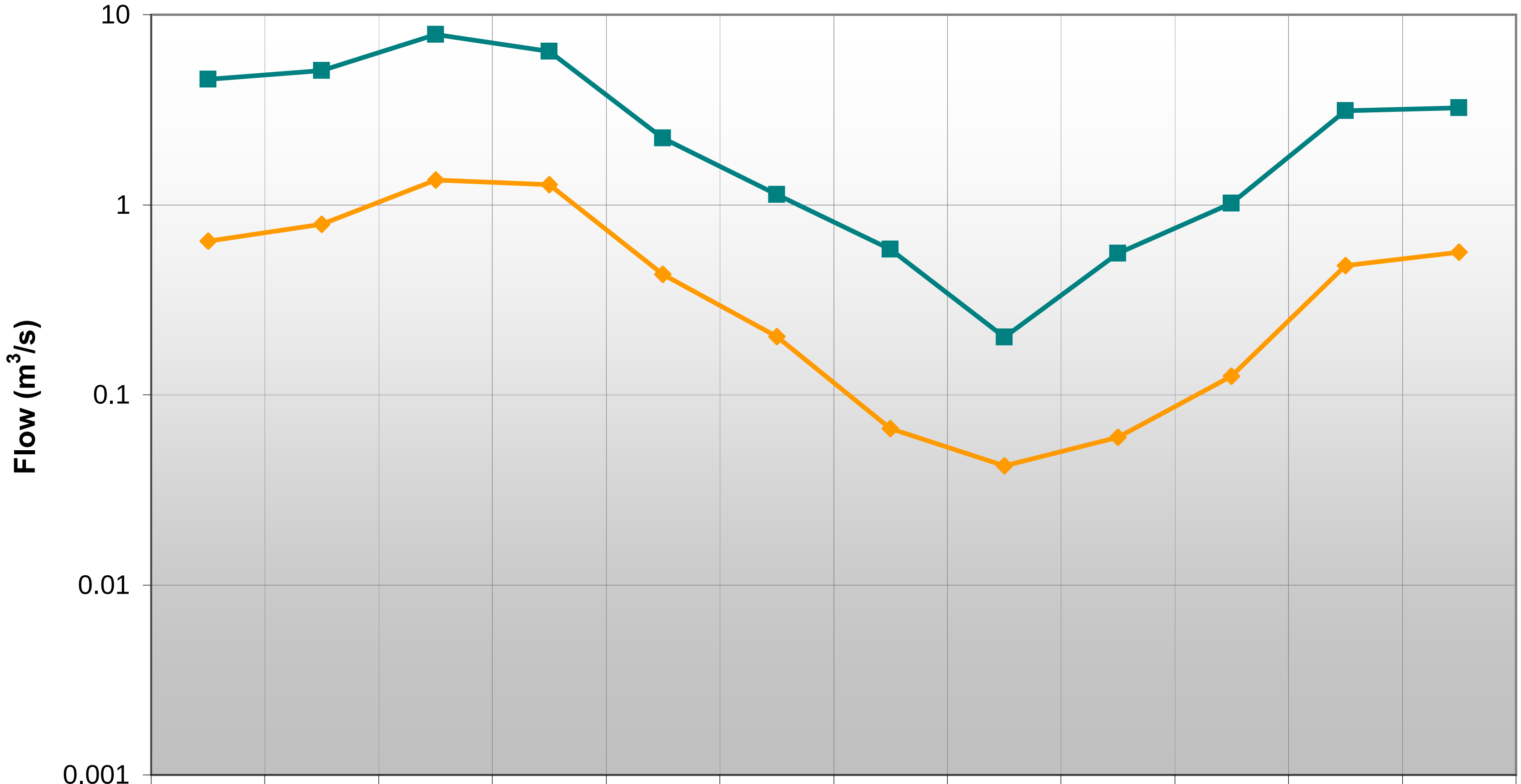
Figure 2.19 - Monthly Mean Streamflow and Baseflow (1991-2005) for 02HA020 - Twenty Mile Creek above Smithville



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Streamflow	2.454129	2.756533	4.251374	3.205816	1.283791	0.713491	0.424694	0.102059	0.258419	0.680975	1.826555	1.726712
Baseflow	0.288867	0.355499	0.674378	0.657175	0.236918	0.09671	0.030506	0.017722	0.03135	0.073743	0.2687	0.254007

Month

Figure 2.20 - Monthly Mean Streamflow and Baseflow (1991-2005) for 02HA006 - Twenty Mile Creek at Ball's Falls



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Streamflow	4.555142	5.079877	7.876948	6.427998	2.236836	1.135264	0.582619	0.20057	0.553613	1.015931	3.116089	3.24388
Baseflow	0.645324	0.787466	1.35272	1.274433	0.43027	0.20224	0.066634	0.042223	0.059584	0.125538	0.478716	0.561497

Month

Conceptualization of Hydrologic Processes in HEC-HMS

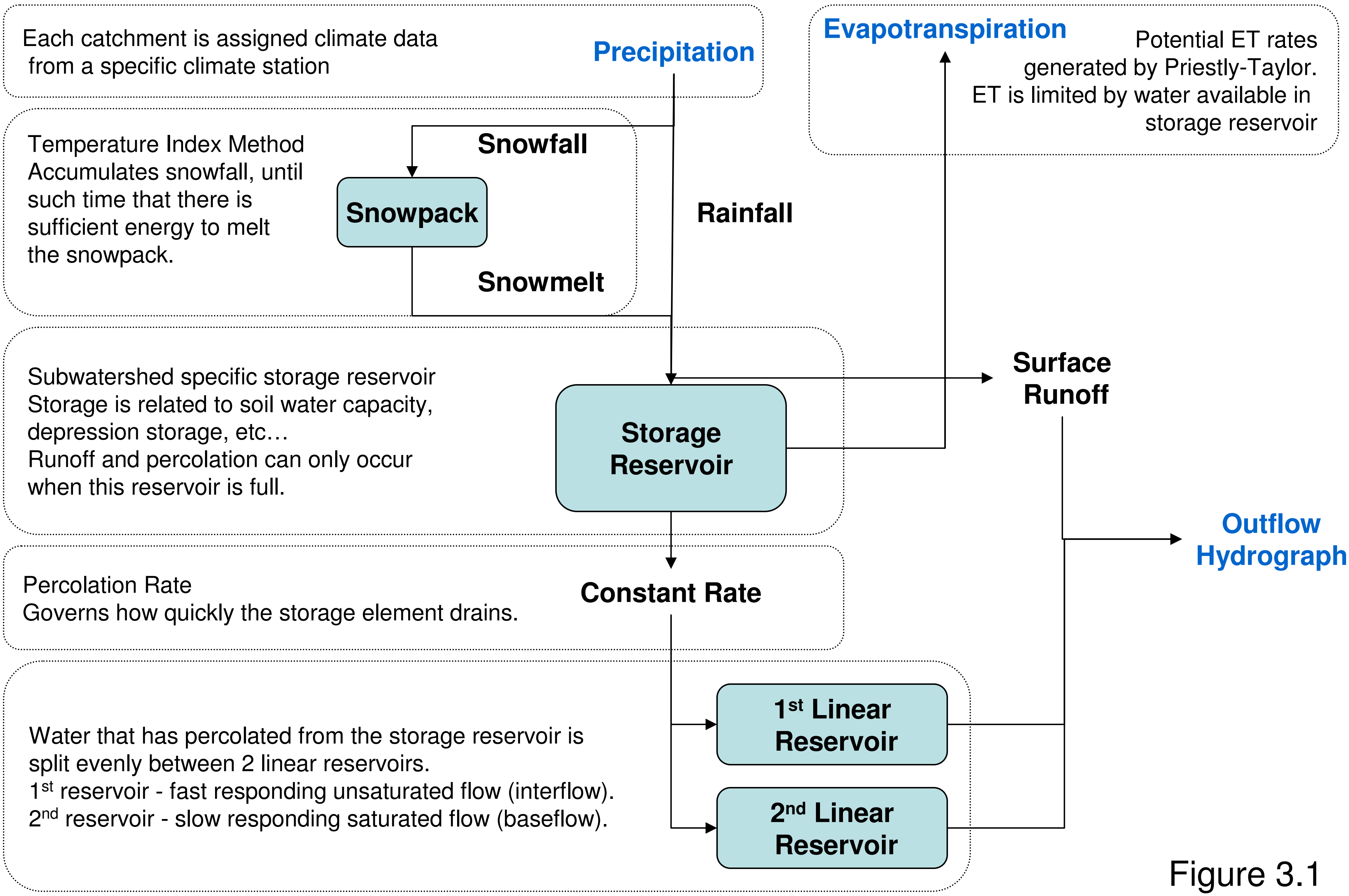
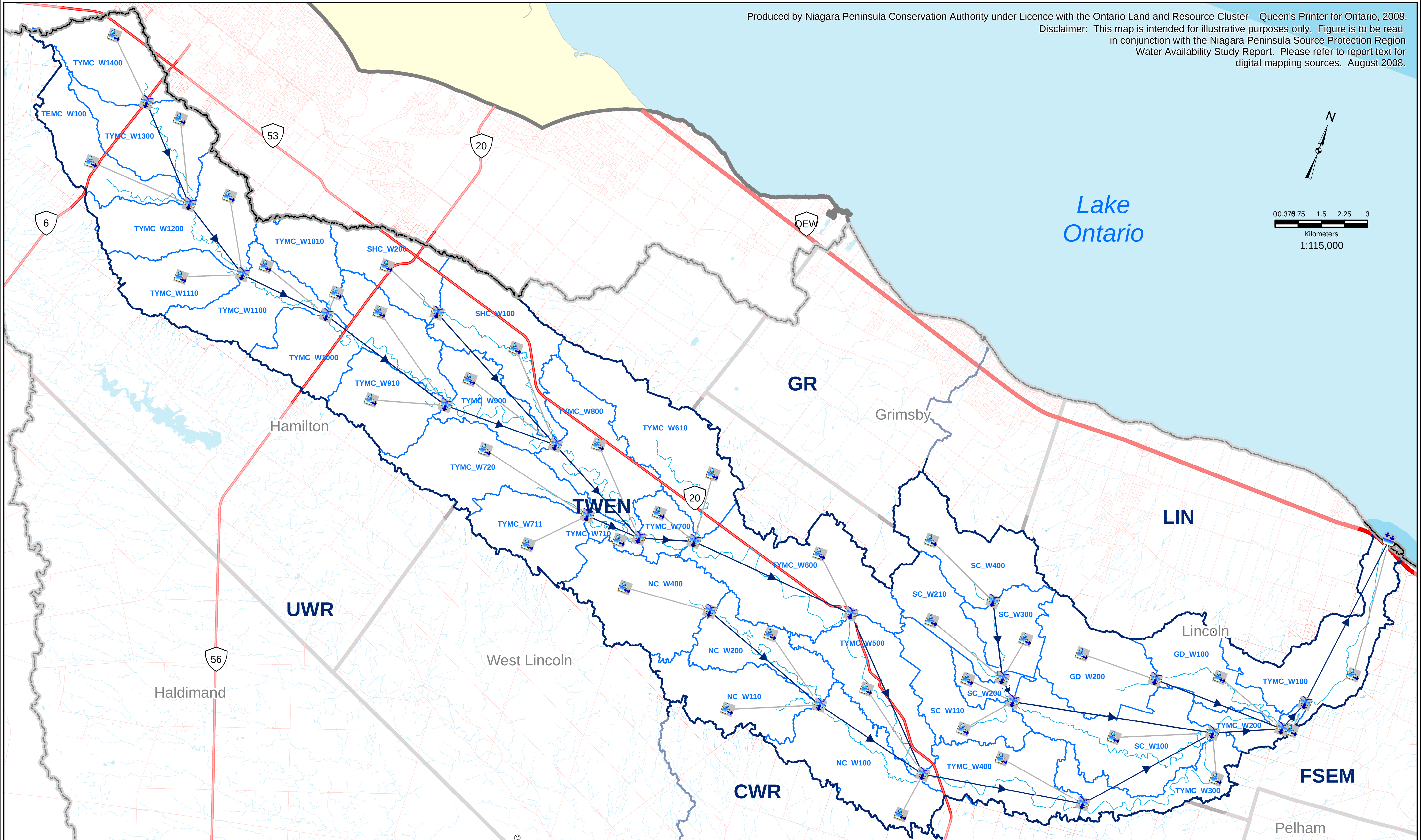


Figure 3.1

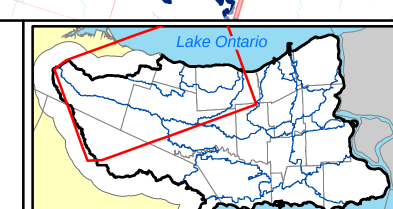


Legend

- Extended Context Area
- SPR Boundary
- Municipal Boundaries
- International Boundary
- Major Highways
- Highways
- Roads
- Rivers, Streams, Creeks
- Ponds, Reservoirs, Lakes
- NPCA Watershed Planning Area
- HMS Model Subcatchments
- HMS Model Reaches
- TYMC_W100: Subcatchment ID

HMS Legend

- Diversion
- Junction
- Reservoir
- Sink
- Source
- Subbasin
- Basin Connector
- Reach



DRINKING WATER SOURCE PROTECTION
Niagara Peninsula Source Protection Area

Water Availability Study

Figure 3.2. TWEN Catchments and HMS Schematic

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

Ontario

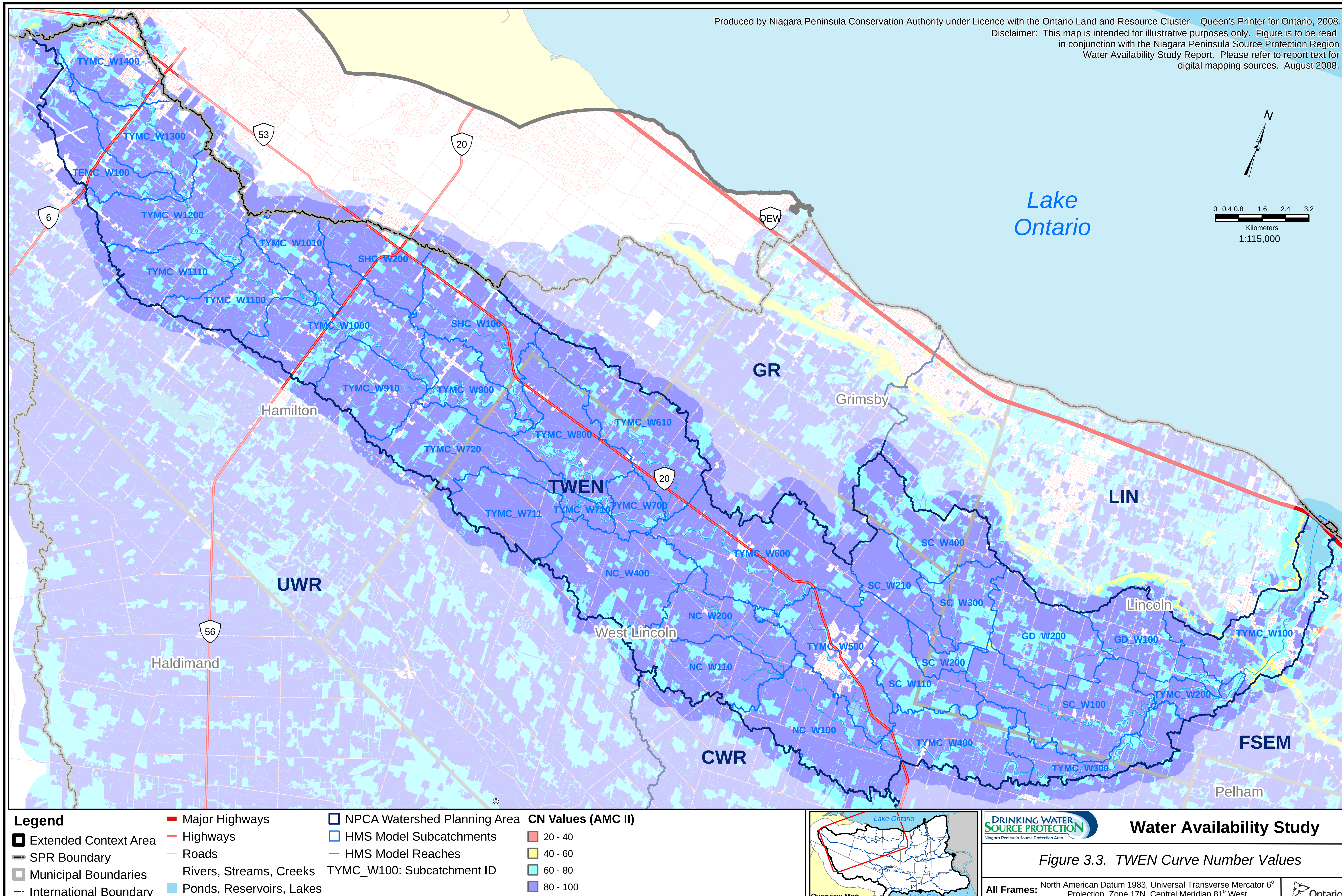
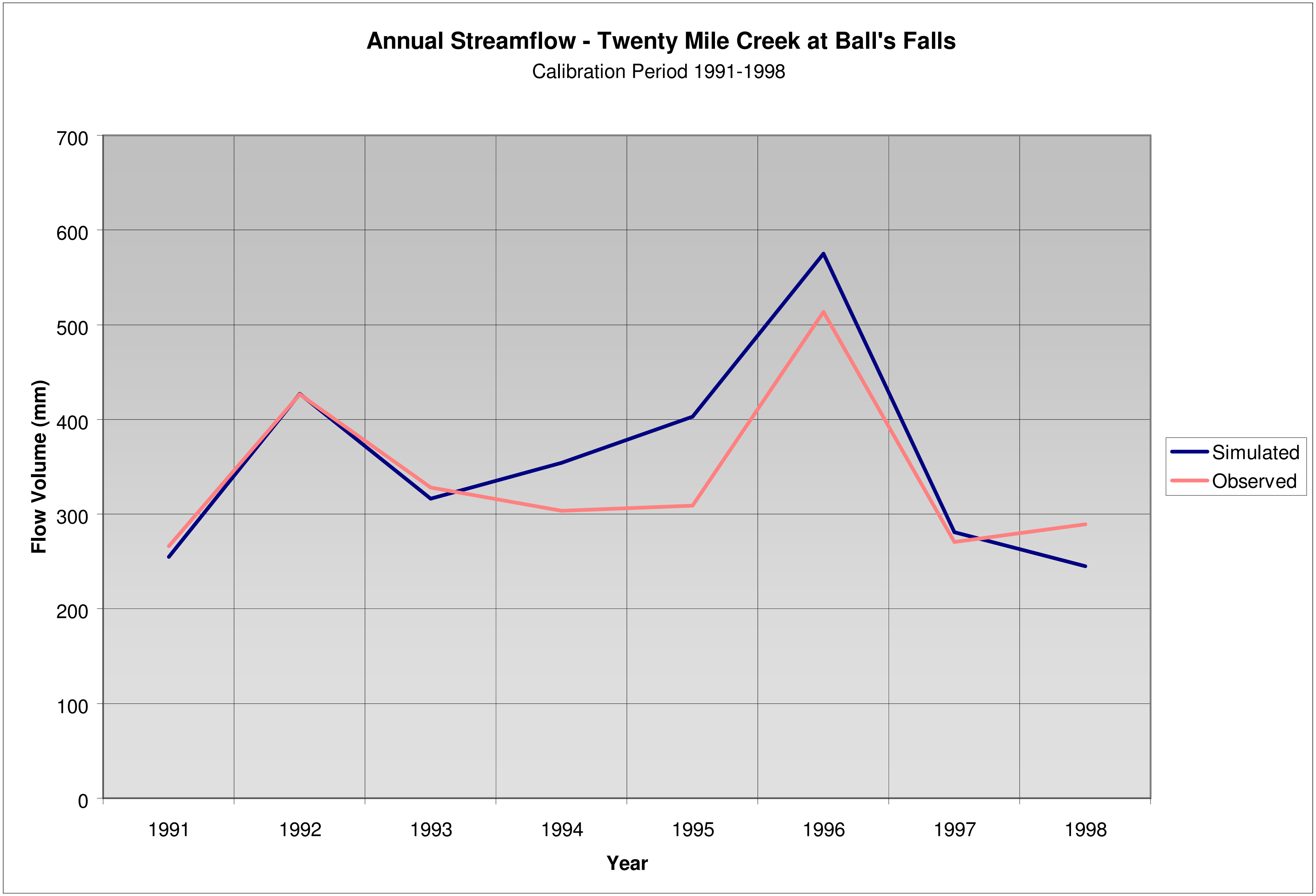
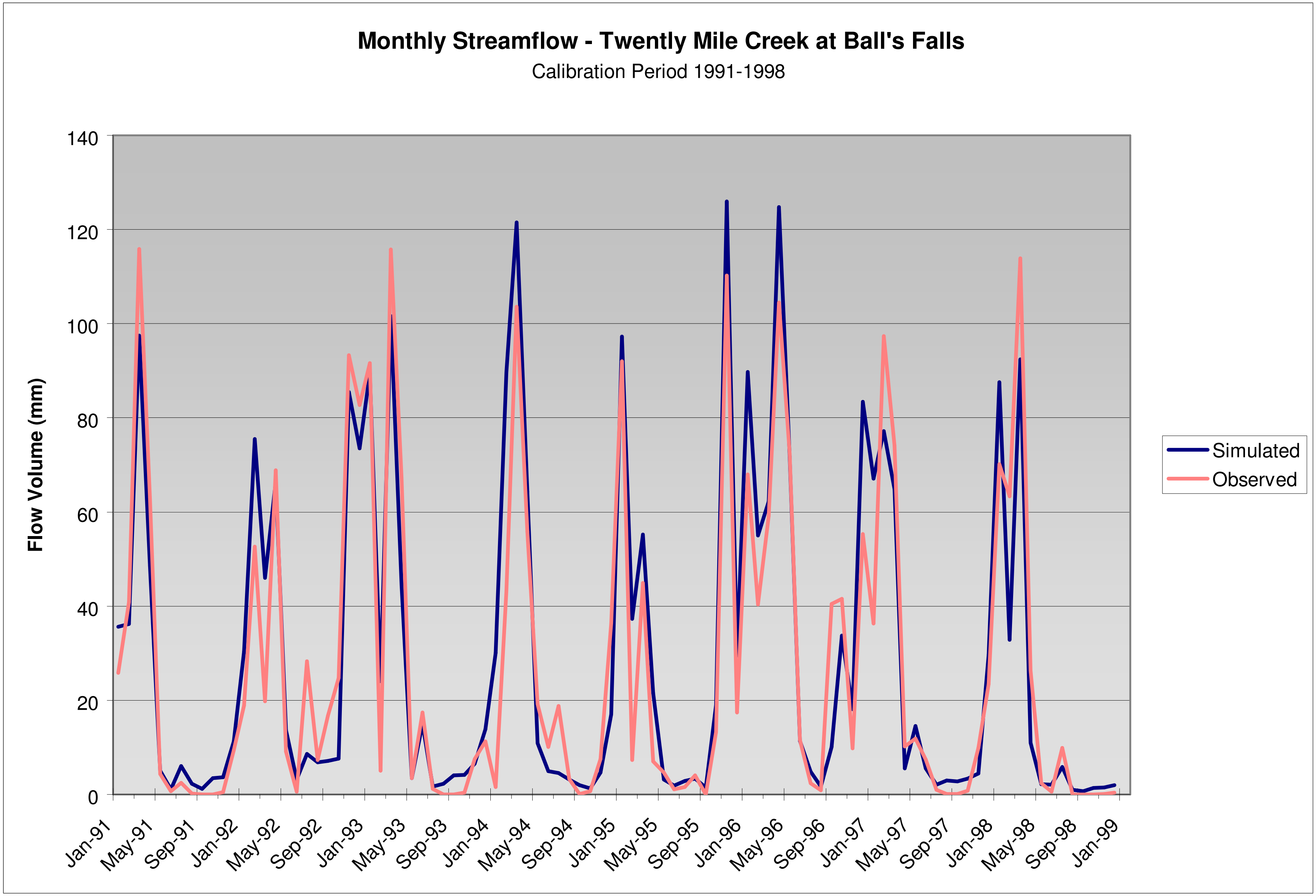


Figure 3.3. TWEN Curve Number Values



Annual Streamflow - Twenty Mile Creek at Ball's Falls
Calibration Period 1991-1998
Flow Volume (mm)
700
600
500
400
300
200
100
0
1991
1992
1993
1994
1995
1996
1997
1998
Year
Simulated
Observed

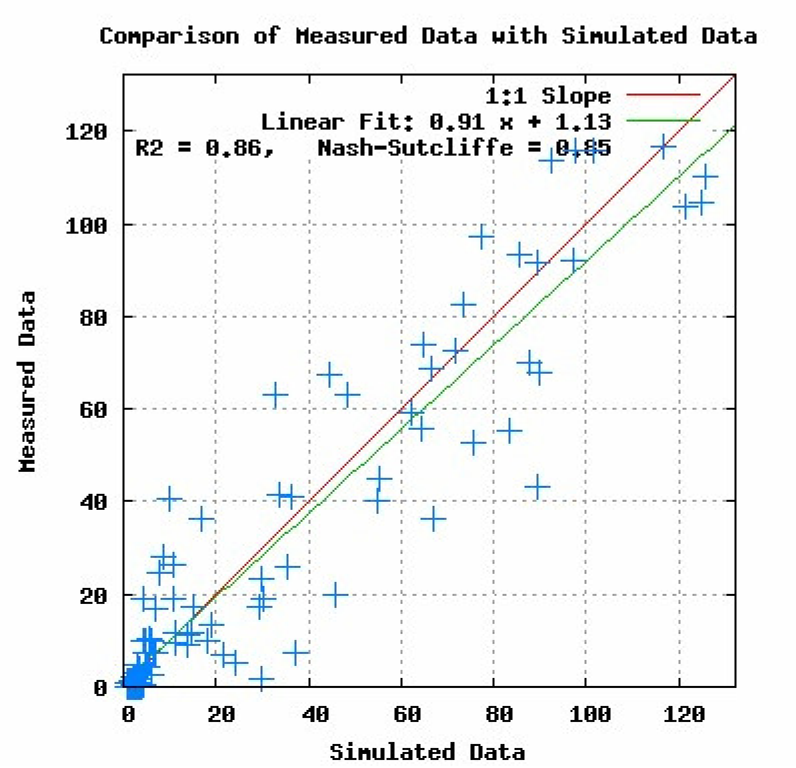
Figure 3.4



Monthly Streamflow - Twently Mile Creek at Ball's Falls
Calibration Period 1991-1998
Flow Volume (mm)
140
120
100
80
60
40
20
0
Jan-91
May-91
Sep-91
Jan-92
May-92
Sep-92
Jan-93
May-93
Sep-93
Jan-94
May-94
Sep-94
Jan-95
May-95
Sep-95
Jan-96
May-96
Sep-96
Jan-97
May-97
Sep-97
Jan-98
May-98
Sep-98
Jan-99
Simulated
Observed

Figure 3.5

Streamflow



Log Streamflow

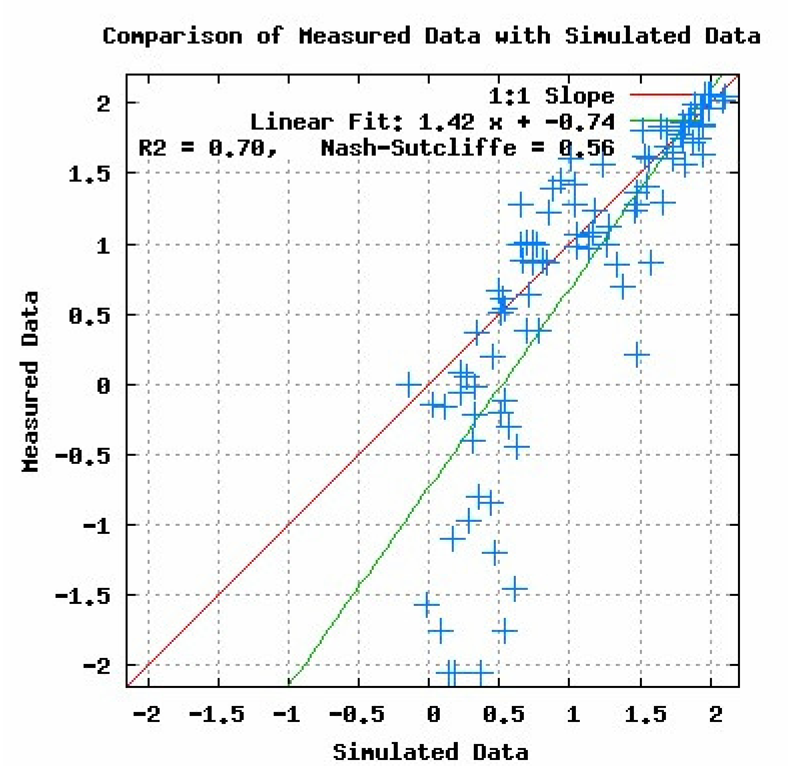


Figure 3.6 - Monthly Calibration Statistics,
Twenty Mile Creek at Ball's Falls,
Calibration Period (1991-1998)

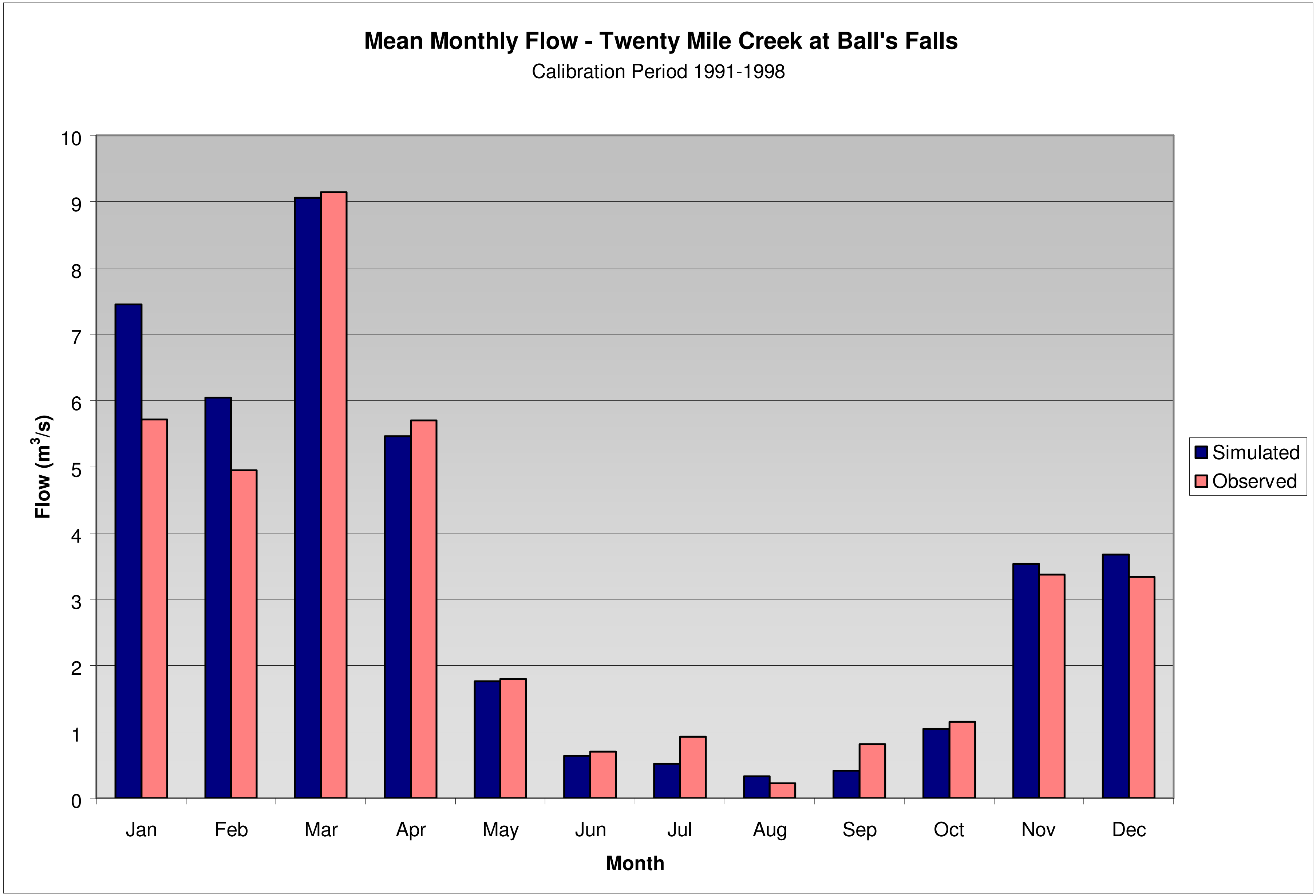
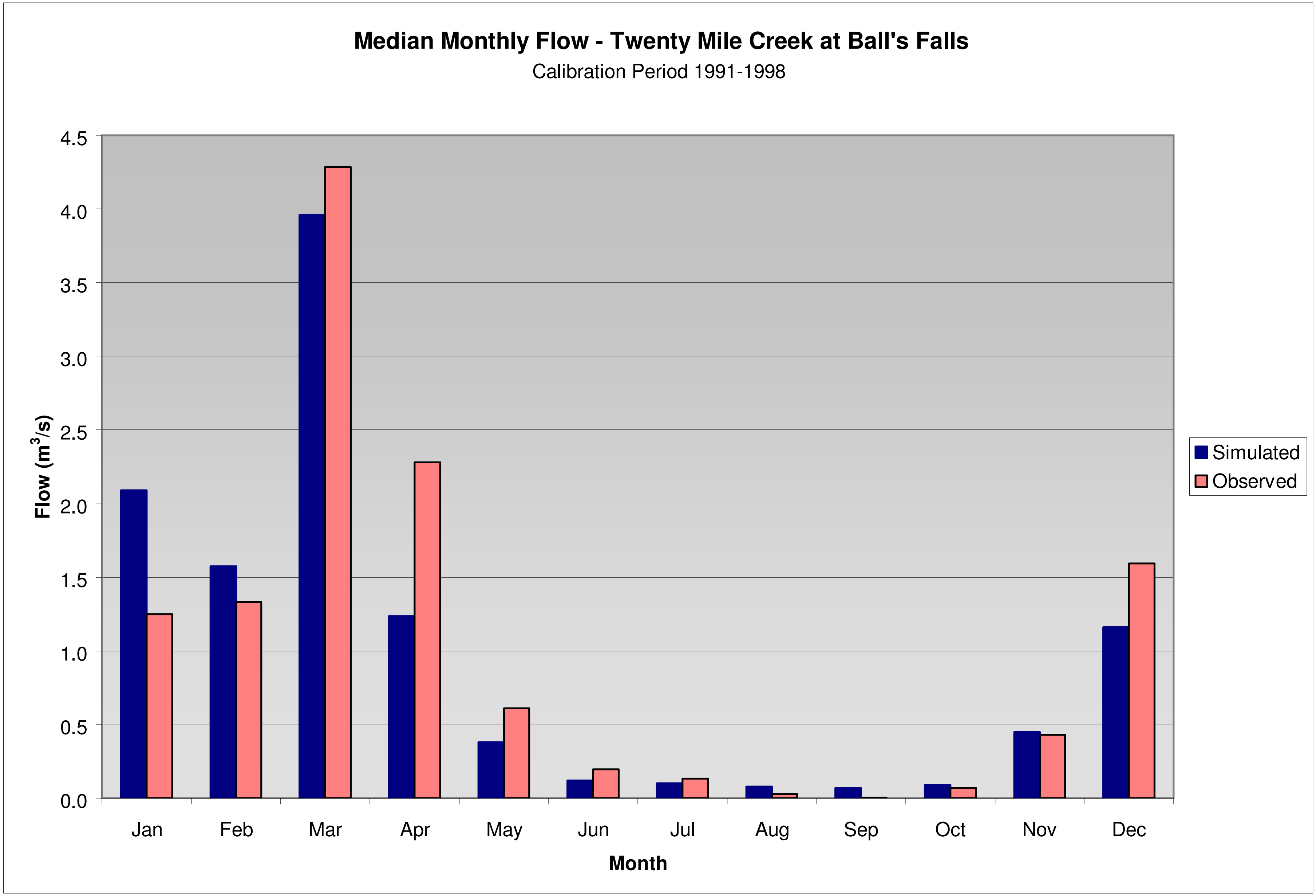
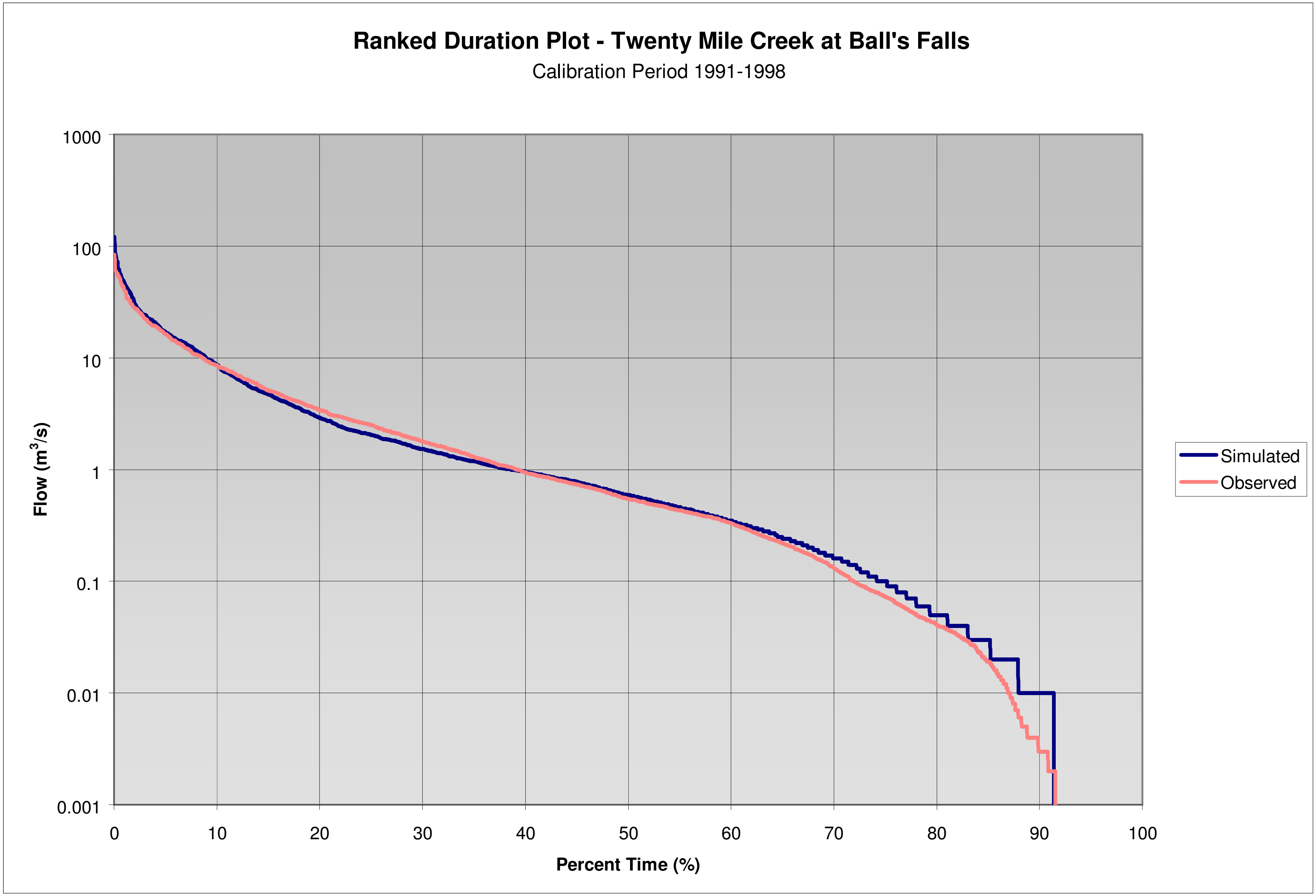

Mean Monthly Flow - Twenty Mile Creek at Ball's Falls
Calibration Period 1991-1998
Flow (m3/s)
0
1
2
3
4
5
6
7
8
9
10
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Simulated
Observed

Figure 3.7



Median Monthly Flow - Twenty Mile Creek at Ball's Falls
Calibration Period 1991-1998
Flow (m3/s)
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Simulated
Observed

Figure 3.8



Ranked Duration Plot - Twenty Mile Creek at Ball's Falls
Calibration Period 1991-1998
Flow (m3/s)
1000
100
10
1
0.1
0.01
0.001
0
10
20
30
40
50
60
70
80
90
100
Percent Time (%)
Simulated
Observed

Figure 3.9

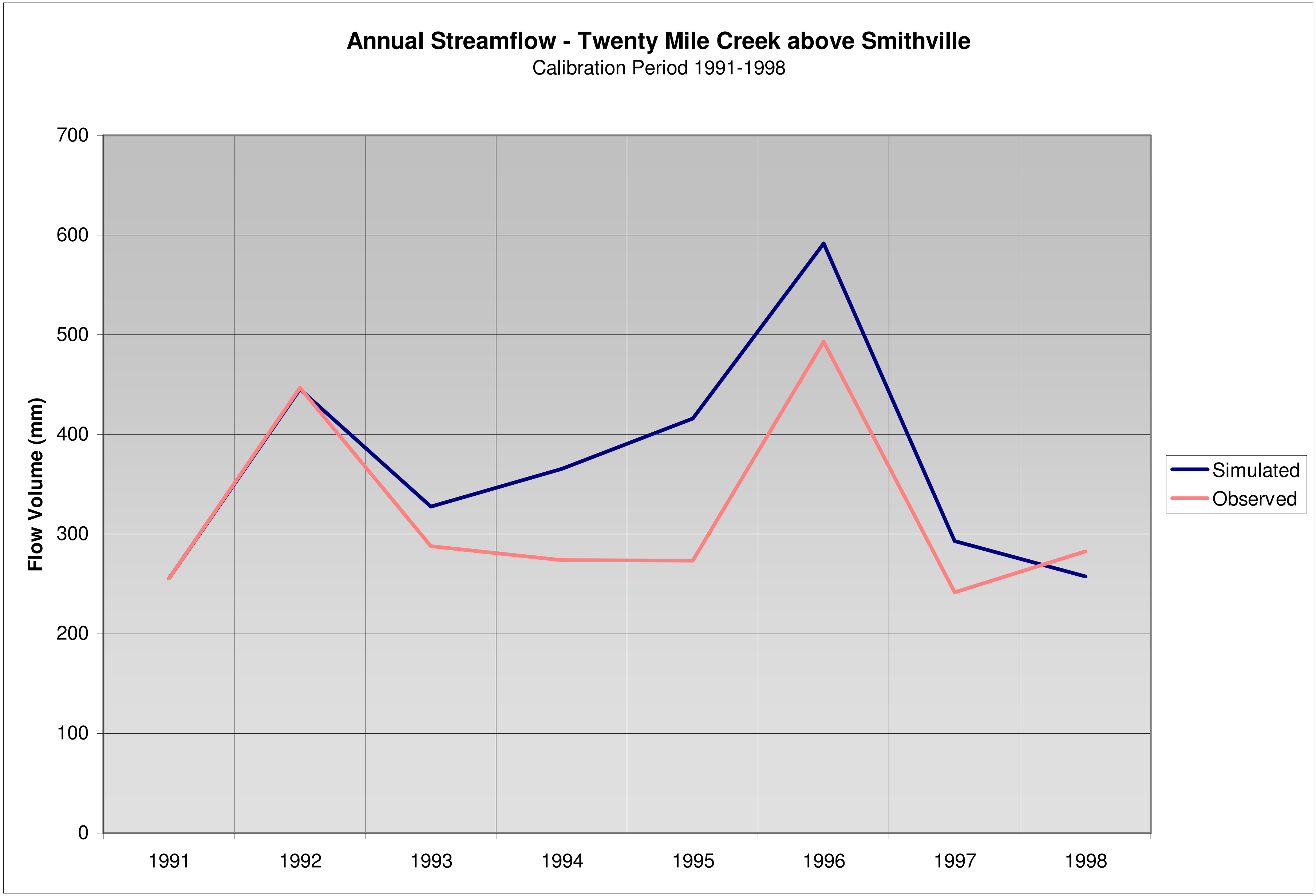
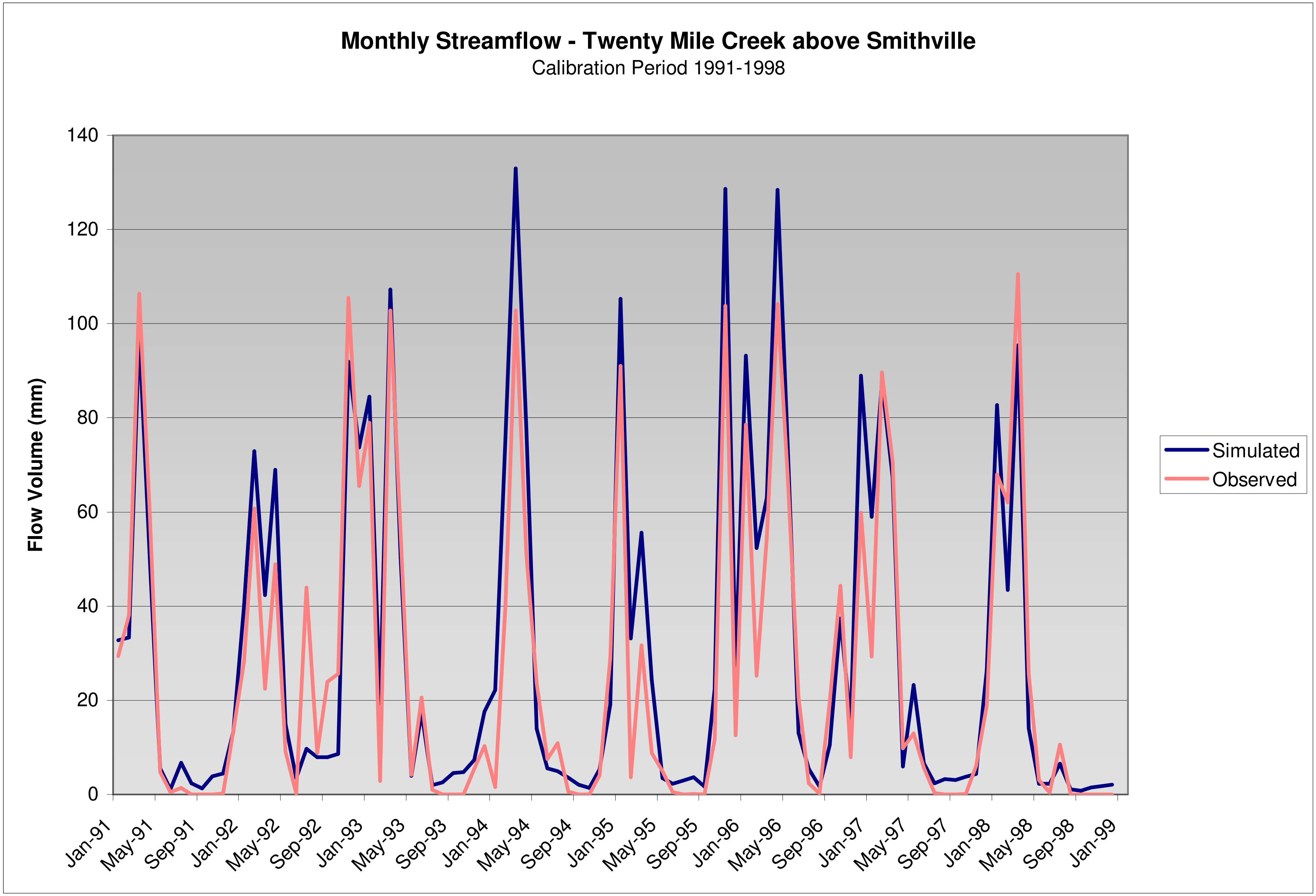

Annual Streamflow - Twenty Mile Creek above Smithville
Calibration Period 1991-1998
Flow Volume (mm)
700
600
500
400
300
200
100
0
1991
1992
1993
1994
1995
1996
1997
1998
Simulated
Observed

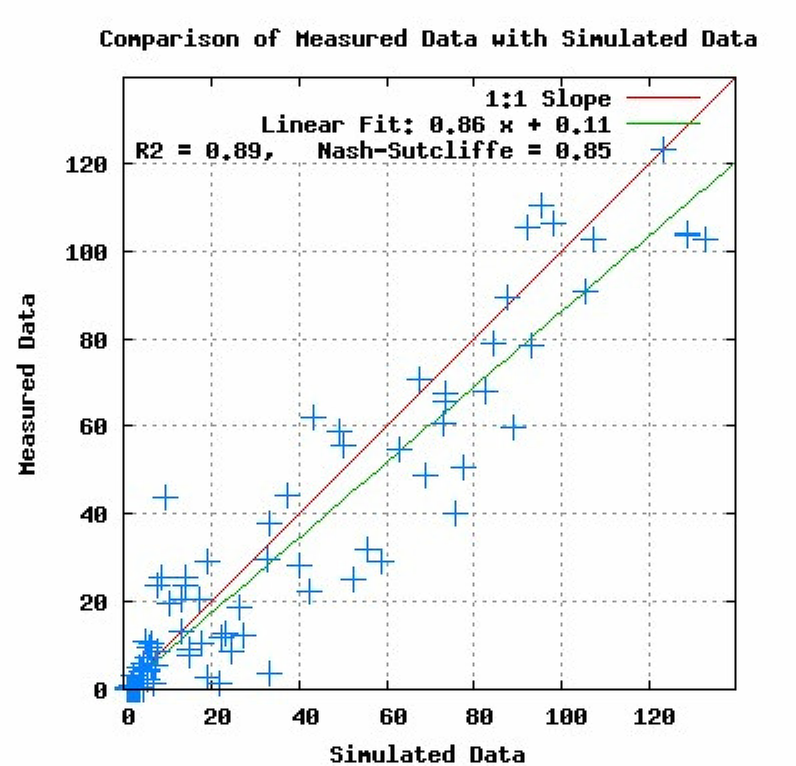
Figure 3.10



Monthly Streamflow - Twenty Mile Creek above Smithville
Calibration Period 1991-1998
Flow Volume (mm)
140
120
100
80
60
40
20
0
Jan-91
May-91
Sep-91
Jan-92
May-92
Sep-92
Jan-93
May-93
Sep-93
Jan-94
May-94
Sep-94
Jan-95
May-95
Sep-95
Jan-96
May-96
Sep-96
Jan-97
May-97
Sep-97
Jan-98
May-98
Sep-98
Jan-99
Simulated
Observed

Figure 3.11

Streamflow



Log Streamflow

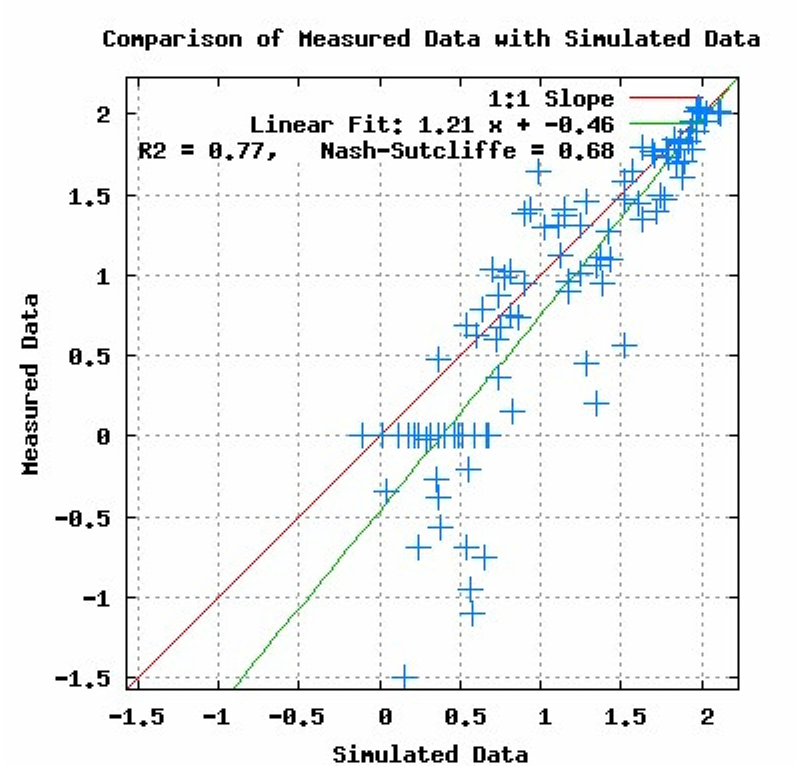


Figure 3.12
Twenty Mile Creek above Smithville
Calibration Period (1991-1998)

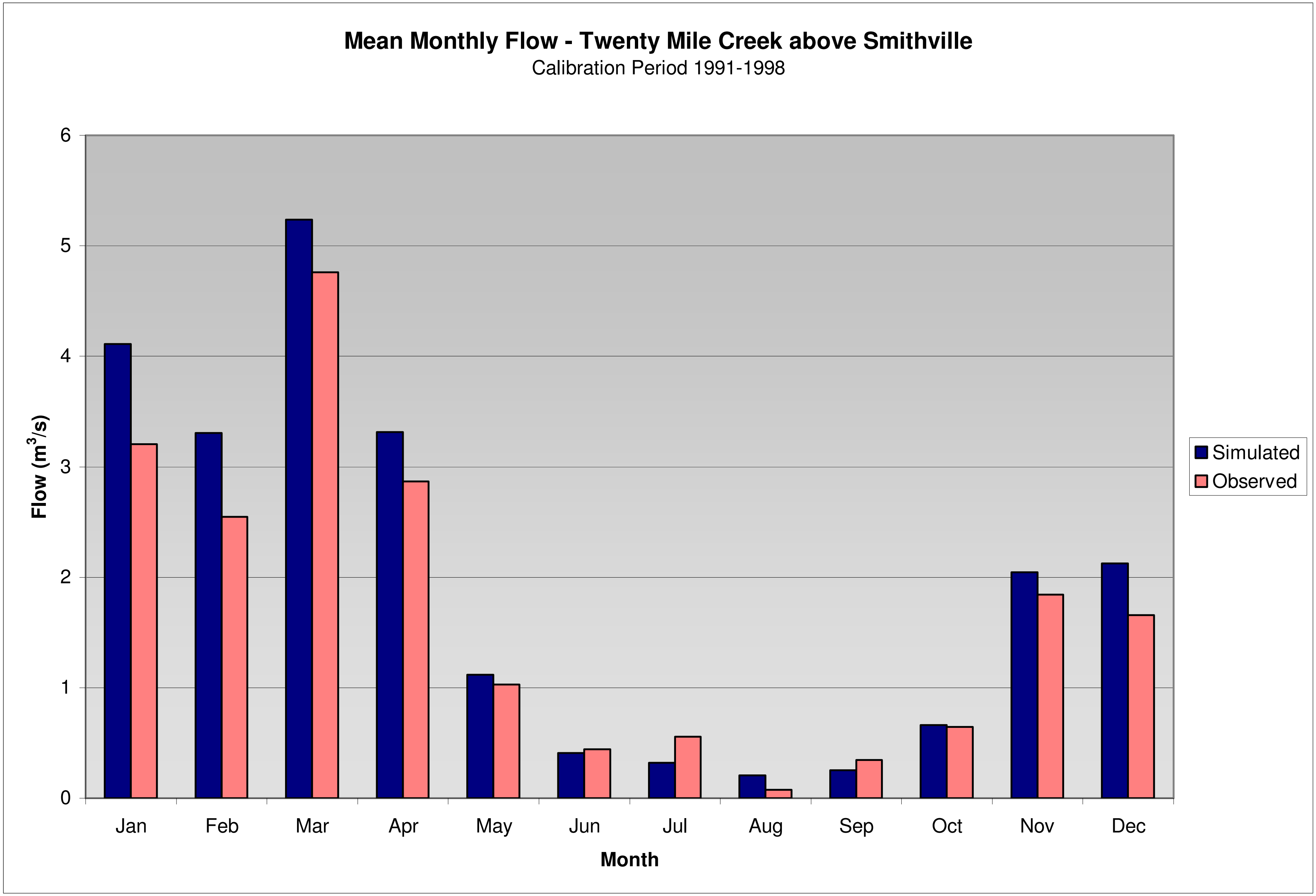
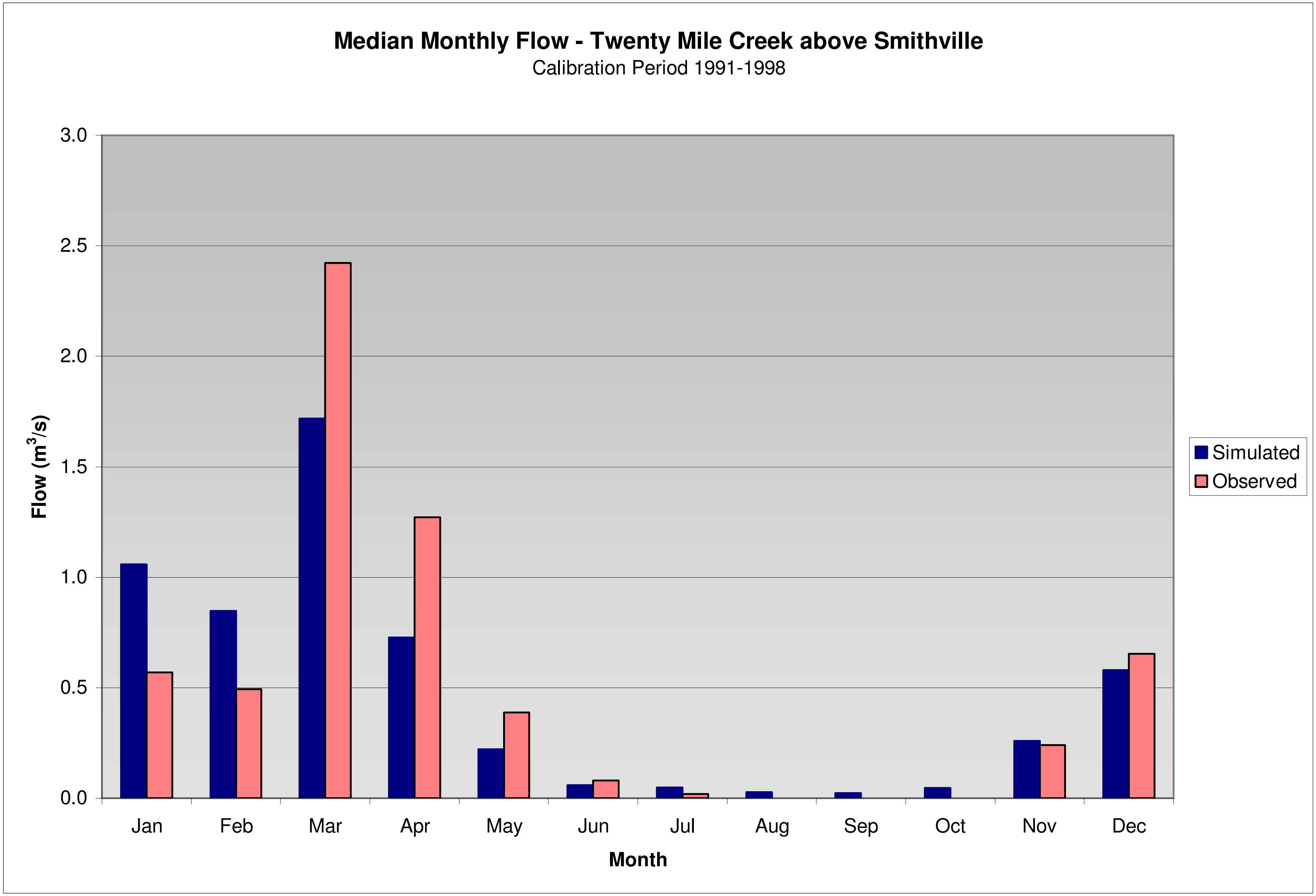
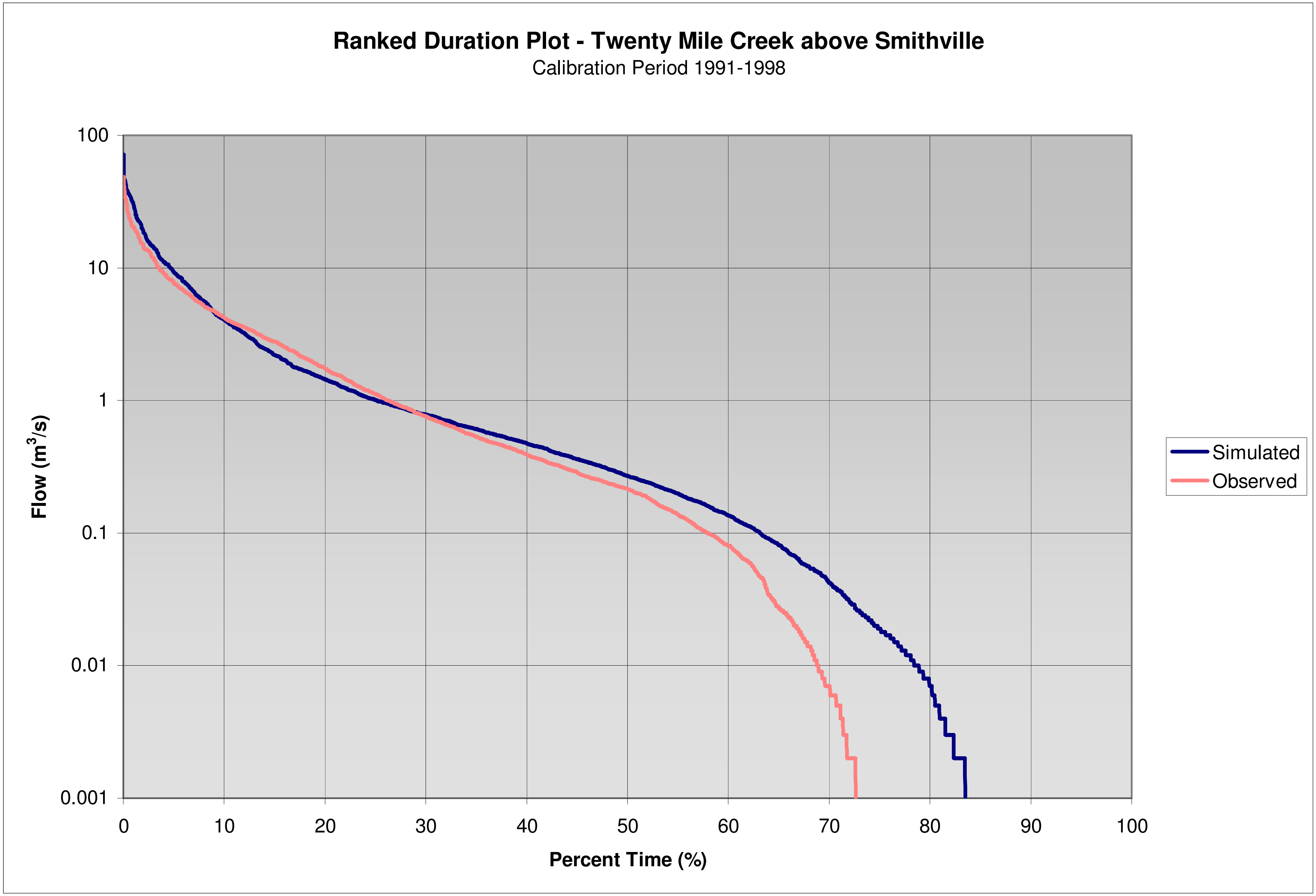

Mean Monthly Flow - Twenty Mile Creek above Smithville
Calibration Period 1991-1998
Flow (m3/s)
6
5
4
3
2
1
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Simulated
Observed

Figure 3.13



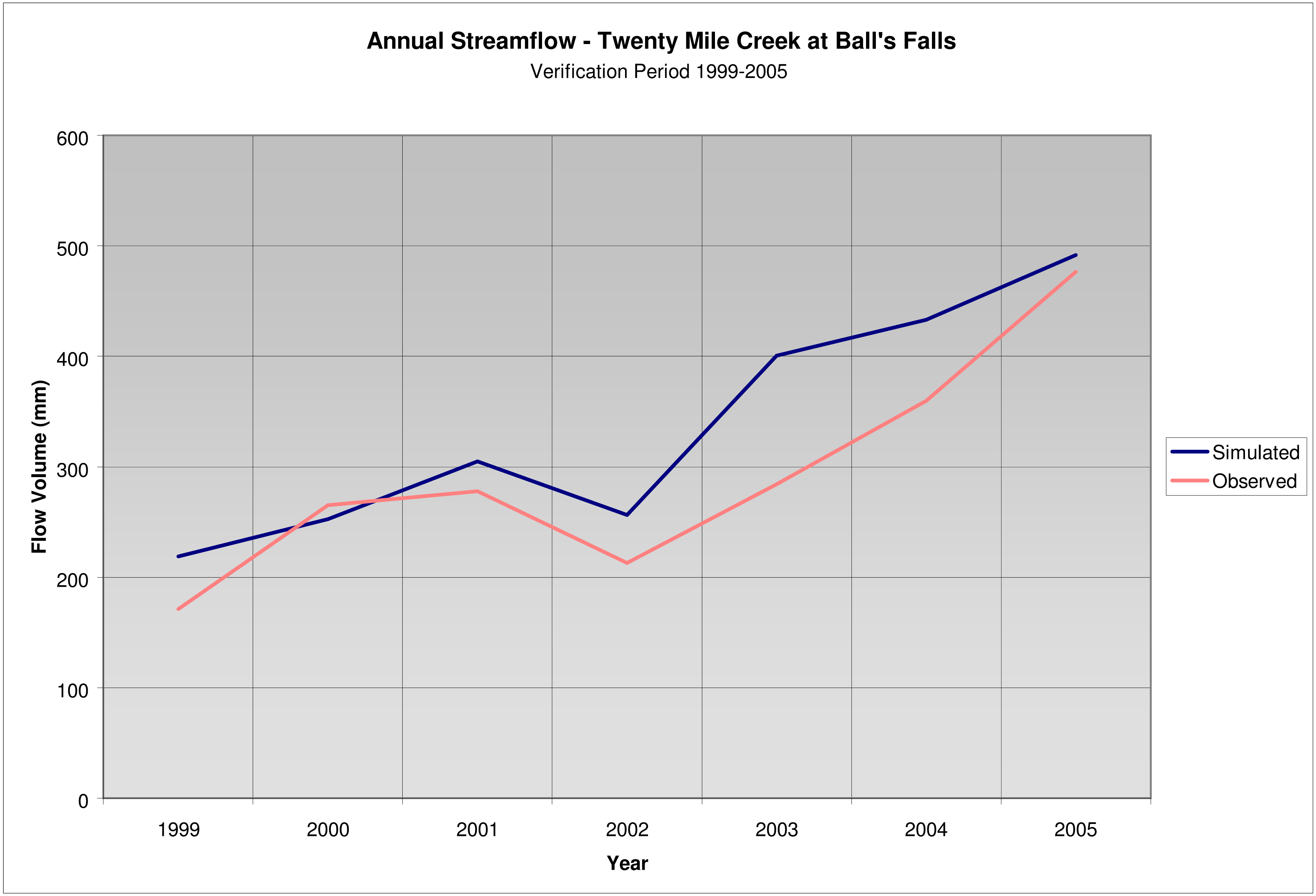
Median Monthly Flow - Twenty Mile Creek above Smithville
Calibration Period 1991-1998
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Flow (m3/s)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Simulated
Observed

Figure 3.14



Ranked Duration Plot - Twenty Mile Creek above Smithville
Calibration Period 1991-1998
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 3.15



Annual Streamflow - Twenty Mile Creek at Ball's Falls
Verification Period 1999-2005
Flow Volume (mm)
0
100
200
300
400
500
600
Year
1999
2000
2001
2002
2003
2004
2005
Simulated
Observed

Figure 3.16

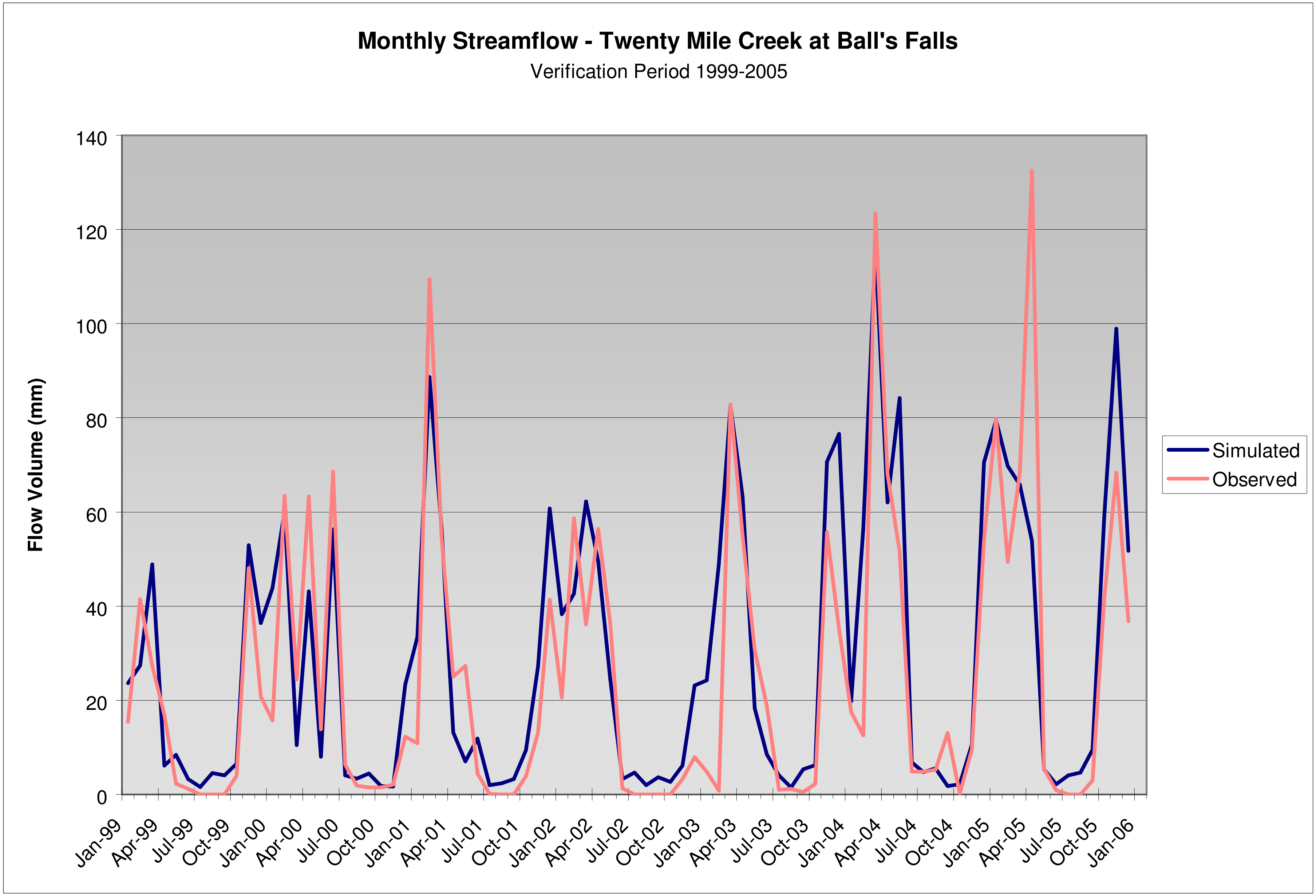
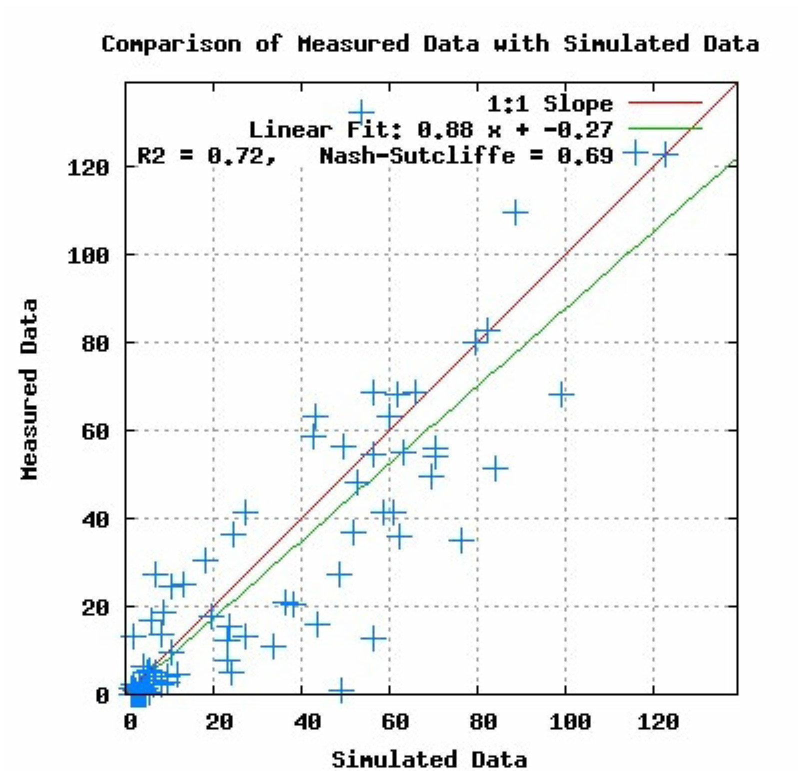

Monthly Streamflow - Twenty Mile Creek at Ball's Falls
Verification Period 1999-2005
Flow Volume (mm)
0
20
40
60
80
100
120
140
Jan-99
Apr-99
Jul-99
Oct-99
Jan-00
Apr-00
Jul-00
Oct-00
Jan-01
Apr-01
Jul-01
Oct-01
Jan-02
Apr-02
Jul-02
Oct-02
Jan-03
Apr-03
Jul-03
Oct-03
Jan-04
Apr-04
Jul-04
Oct-04
Jan-05
Apr-05
Jul-05
Oct-05
Jan-06
Simulated
Observed

Figure 3.17

Streamflow



Log Streamflow

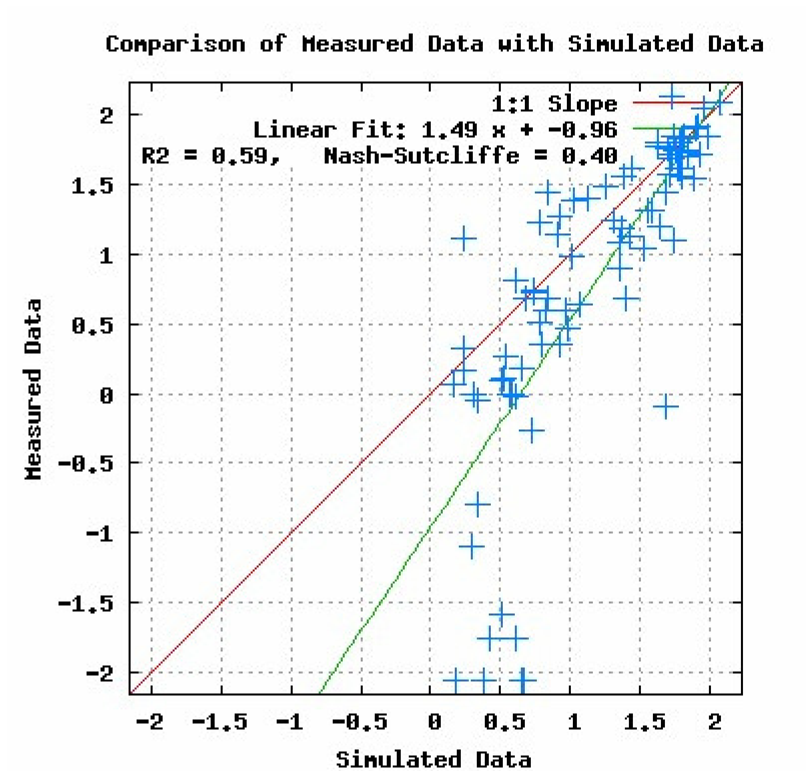


Figure 3.18
Twenty Mile Creek at Ball's Falls
Verification Period (1999-2005)

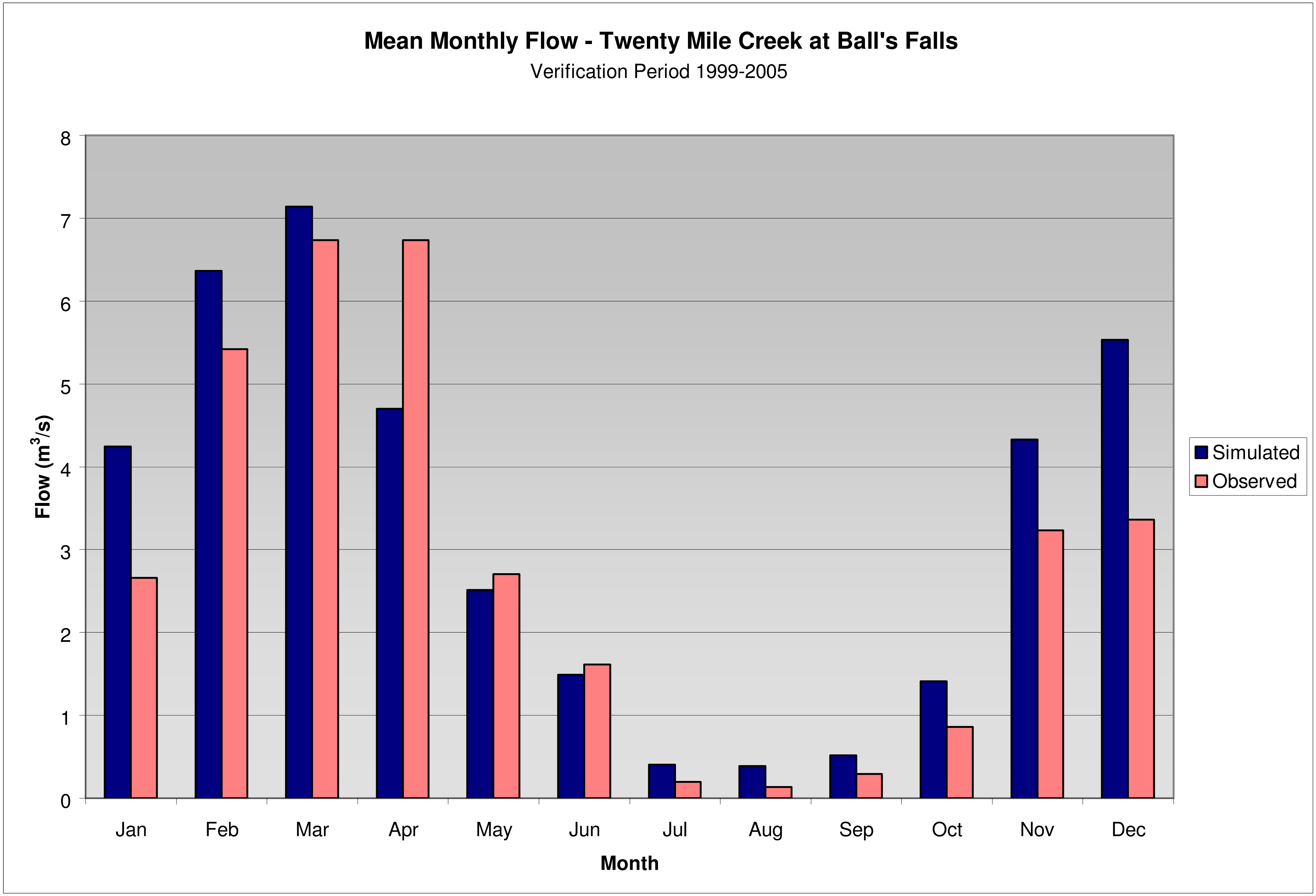
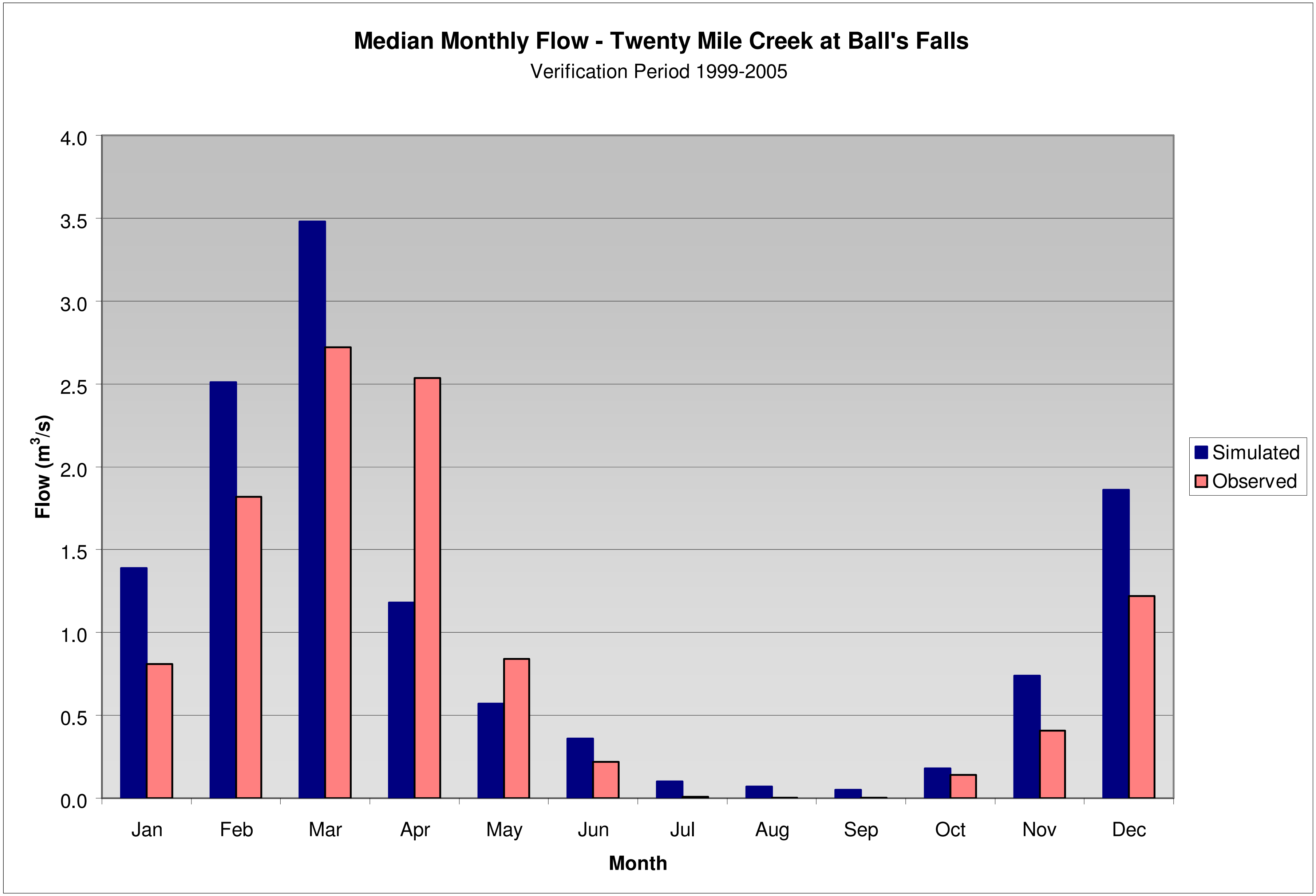
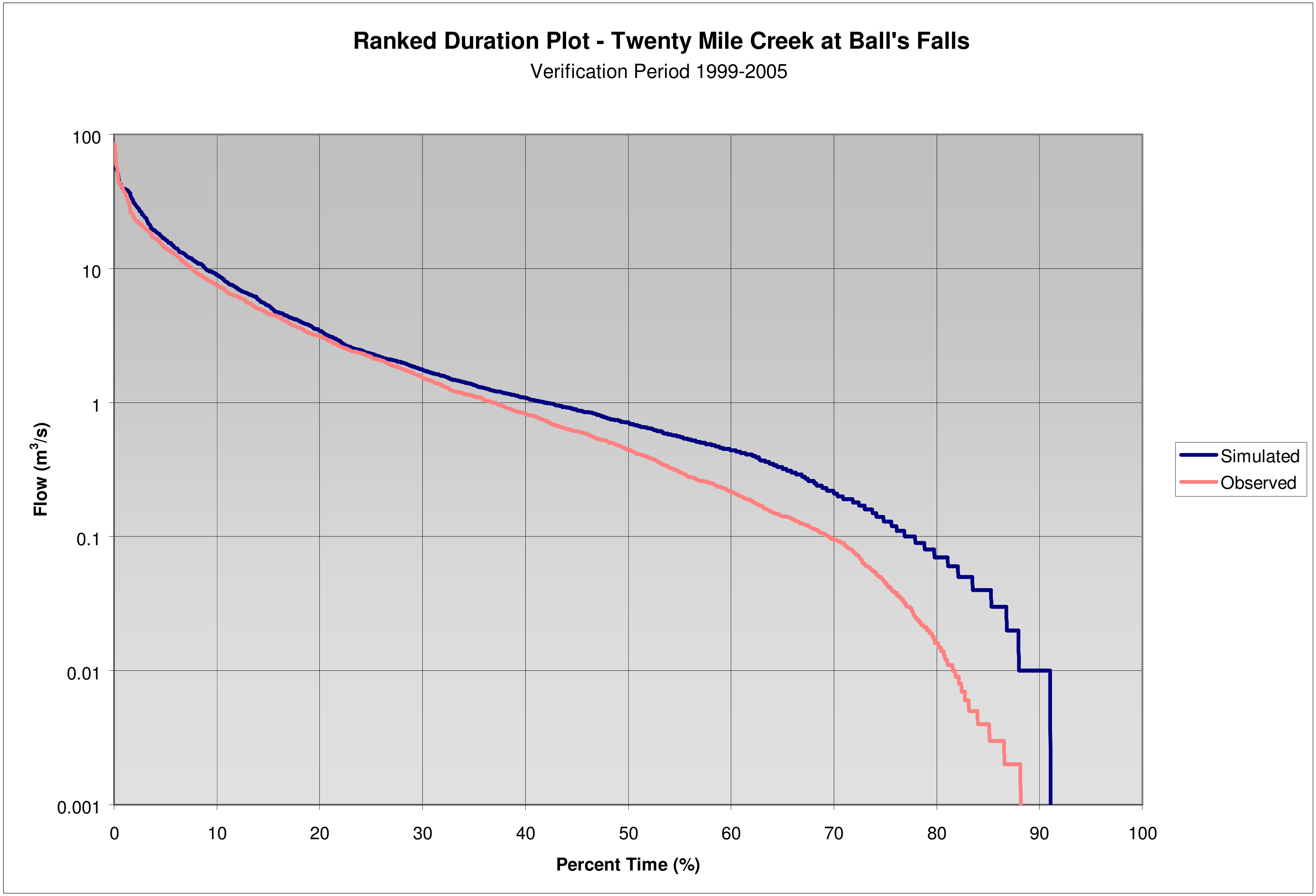

Mean Monthly Flow - Twenty Mile Creek at Ball's Falls
Verification Period 1999-2005
Flow (m^3/s)
0
1
2
3
4
5
6
7
8
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Simulated
Observed

Figure 3.19



Median Monthly Flow - Twenty Mile Creek at Ball's Falls
Verification Period 1999-2005
Flow (m3/s)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Simulated
Observed

Figure 3.20



Ranked Duration Plot - Twenty Mile Creek at Ball's Falls
Verification Period 1999-2005
Flow (m3/s)
100
10
1
0.1
0.01
0.001
0
10
20
30
40
50
60
70
80
90
100
Percent Time (%)
Simulated
Observed

Figure 3.21

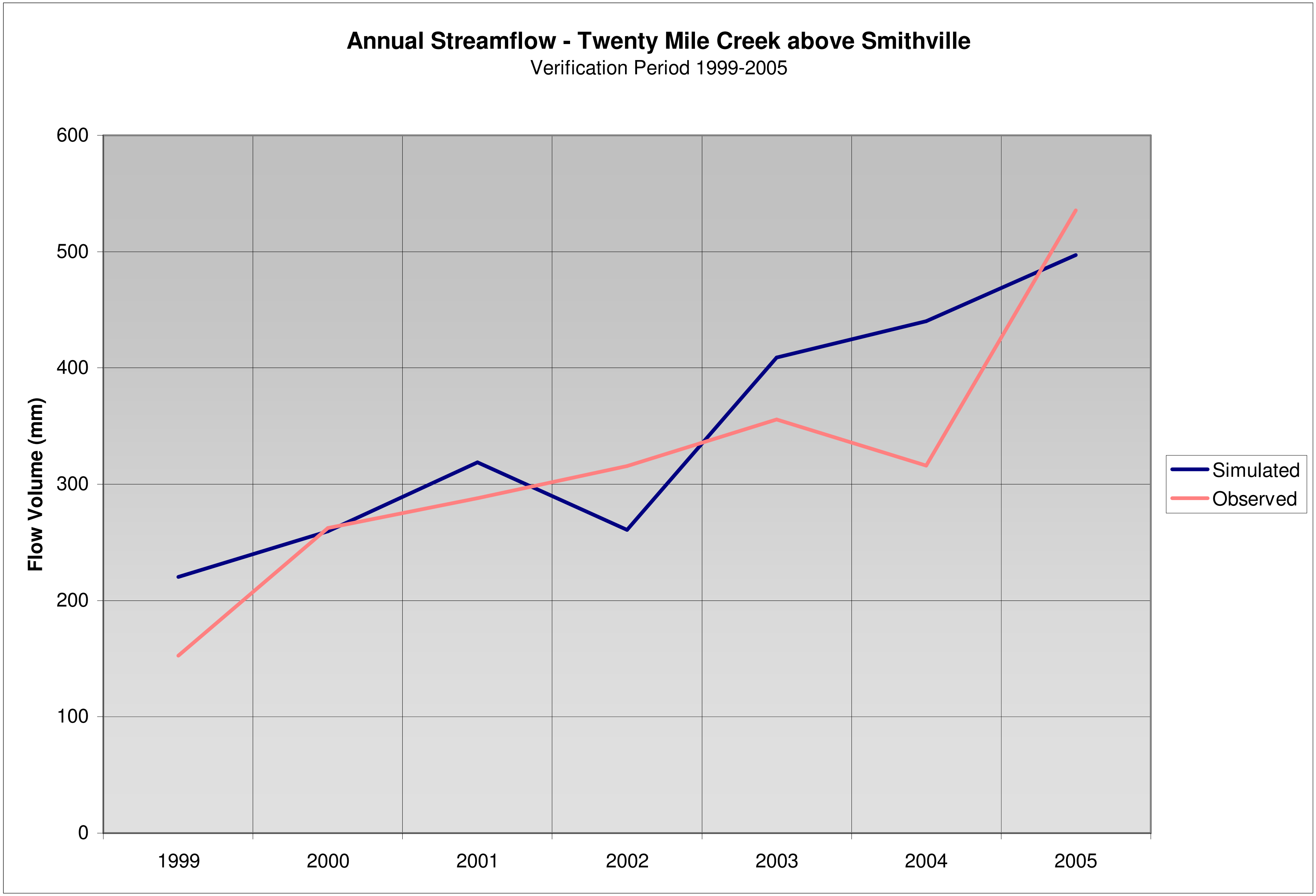
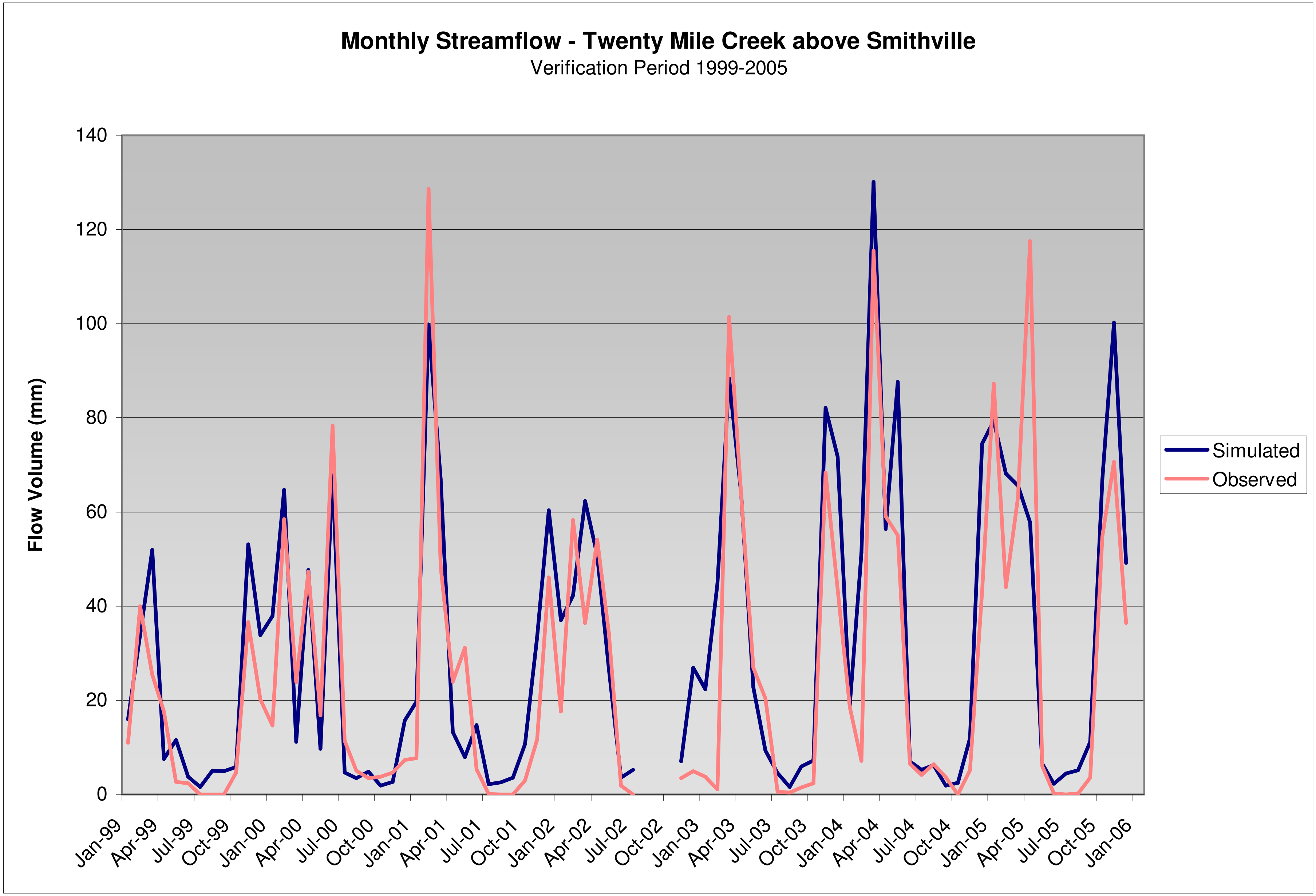

Annual Streamflow - Twenty Mile Creek above Smithville
Verification Period 1999-2005
Flow Volume (mm)
600
500
400
300
200
100
0
1999
2000
2001
2002
2003
2004
2005
Simulated
Observed

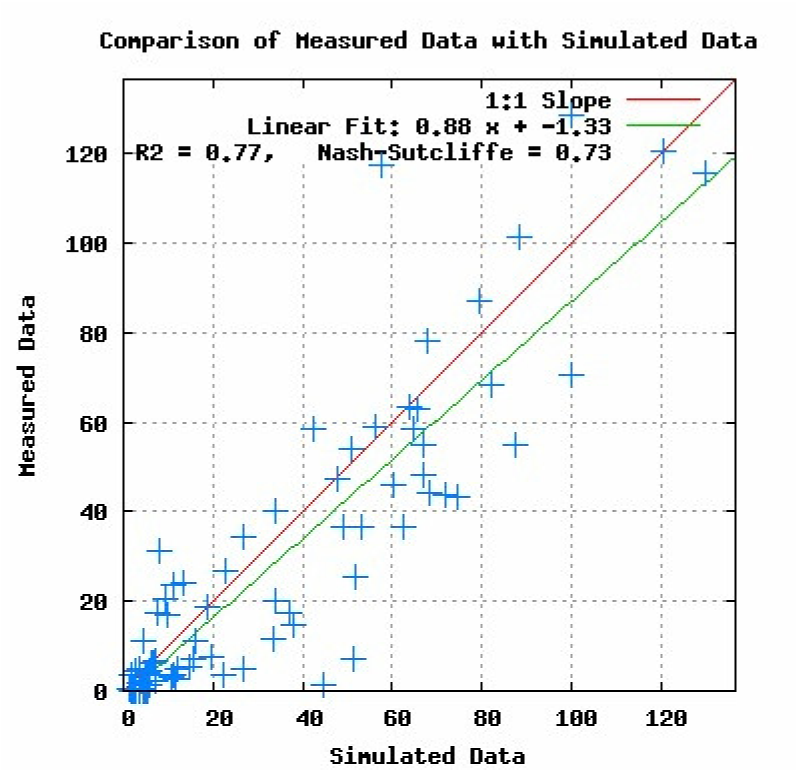
Figure 3.22



Monthly Streamflow - Twenty Mile Creek above Smithville
Verification Period 1999-2005
Flow Volume (mm)
140
120
100
80
60
40
20
0
Jan-99
Apr-99
Jul-99
Oct-99
Jan-00
Apr-00
Jul-00
Oct-00
Jan-01
Apr-01
Jul-01
Oct-01
Jan-02
Apr-02
Jul-02
Oct-02
Jan-03
Apr-03
Jul-03
Oct-03
Jan-04
Apr-04
Jul-04
Oct-04
Jan-05
Apr-05
Jul-05
Oct-05
Jan-06
Simulated
Observed

Figure 3.23

Streamflow



Log Streamflow

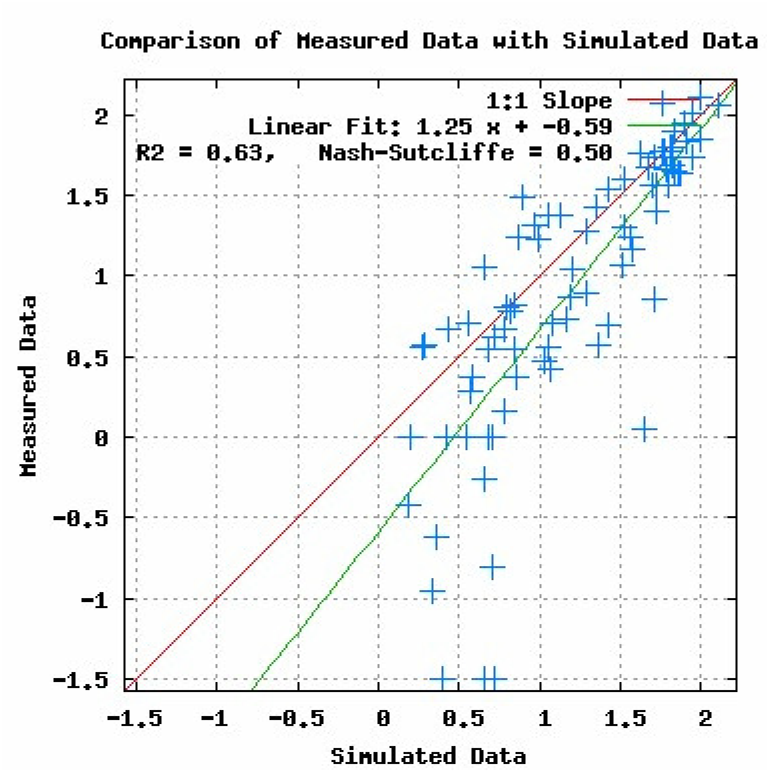


Figure 3.24
Twenty Mile Creek above Smithville
Verification Period (1999-2005)

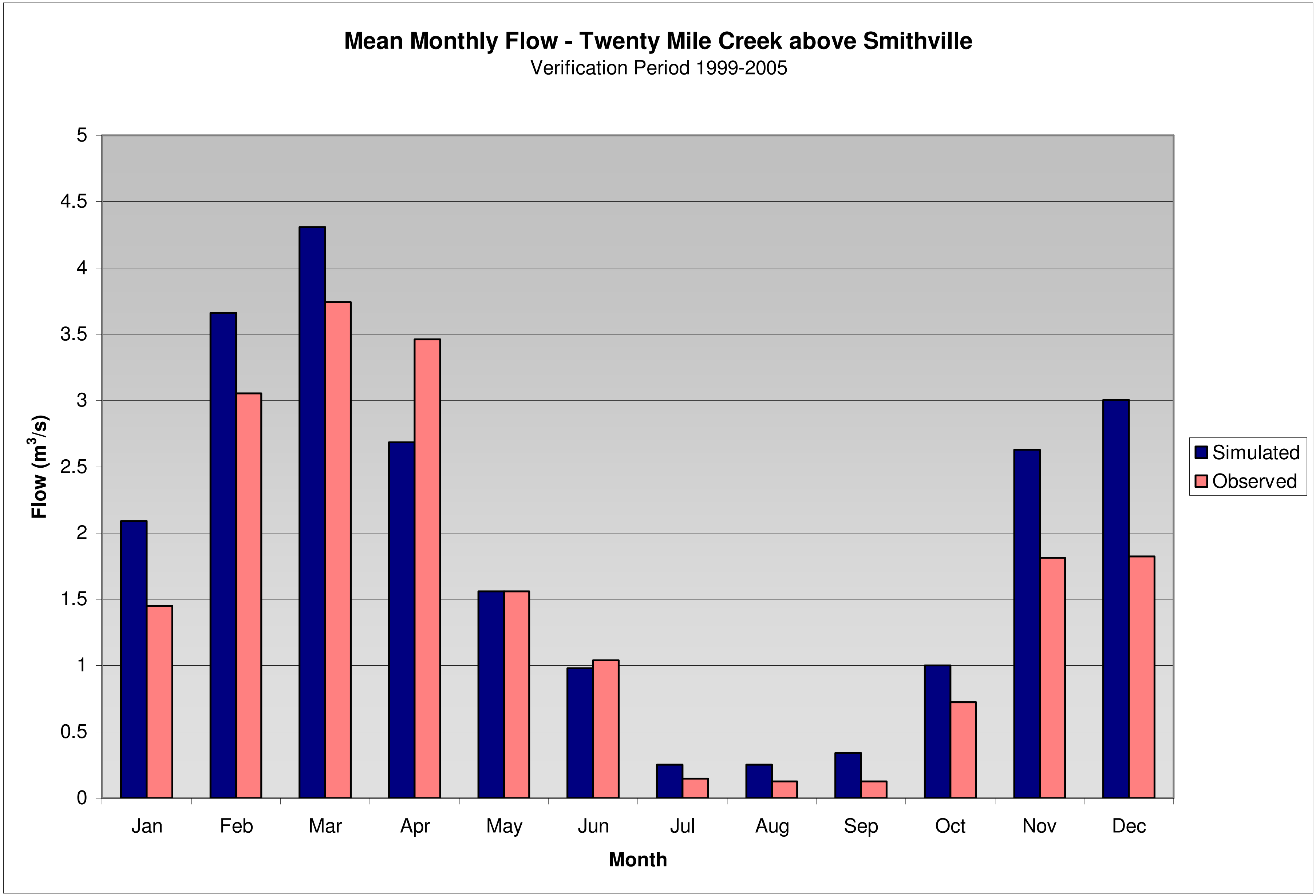
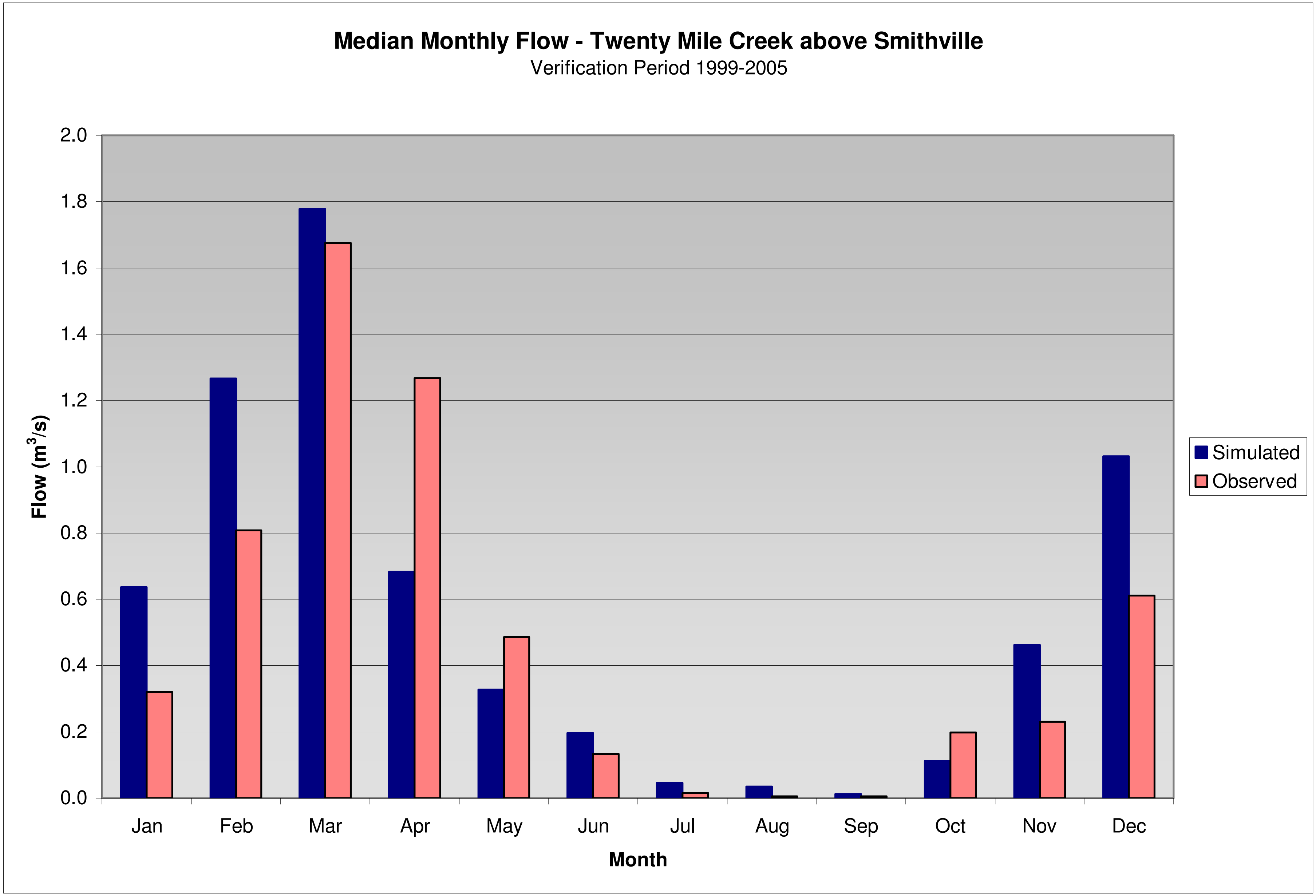

Mean Monthly Flow - Twenty Mile Creek above Smithville
Verification Period 1999-2005
Flow (m3/s)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Simulated
Observed

Figure 3.25



Median Monthly Flow - Twenty Mile Creek above Smithville
Verification Period 1999-2005
Flow (m3/s)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Simulated
Observed

Figure 3.26

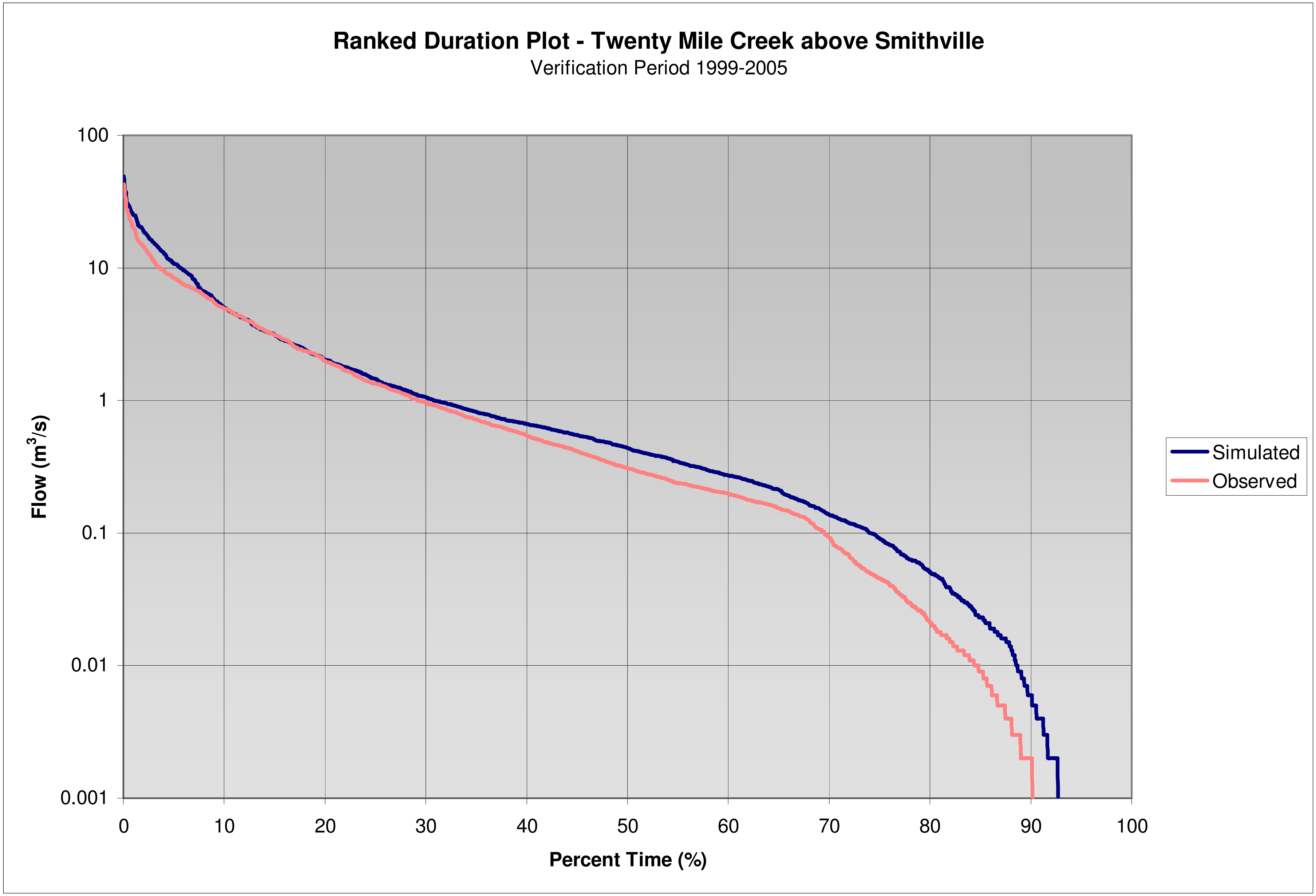

Ranked Duration Plot - Twenty Mile Creek above Smithville
Verification Period 1999-2005
100
10
1
0.1
0.01
0.001
Flow (m3/s)
0
10
20
30
40
50
60
70
80
90
100
Percent Time (%)
Simulated
Observed

Figure 3.27

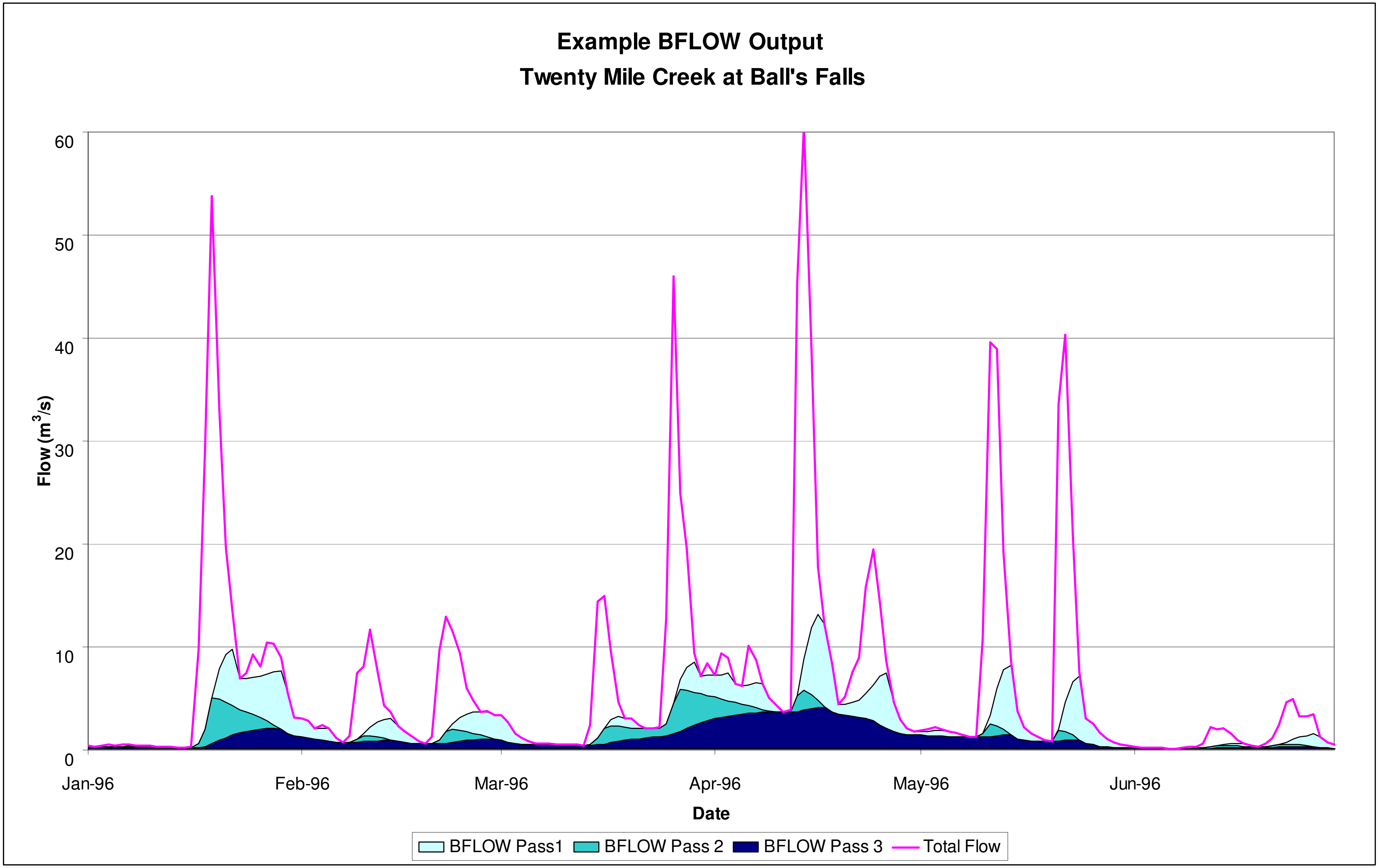
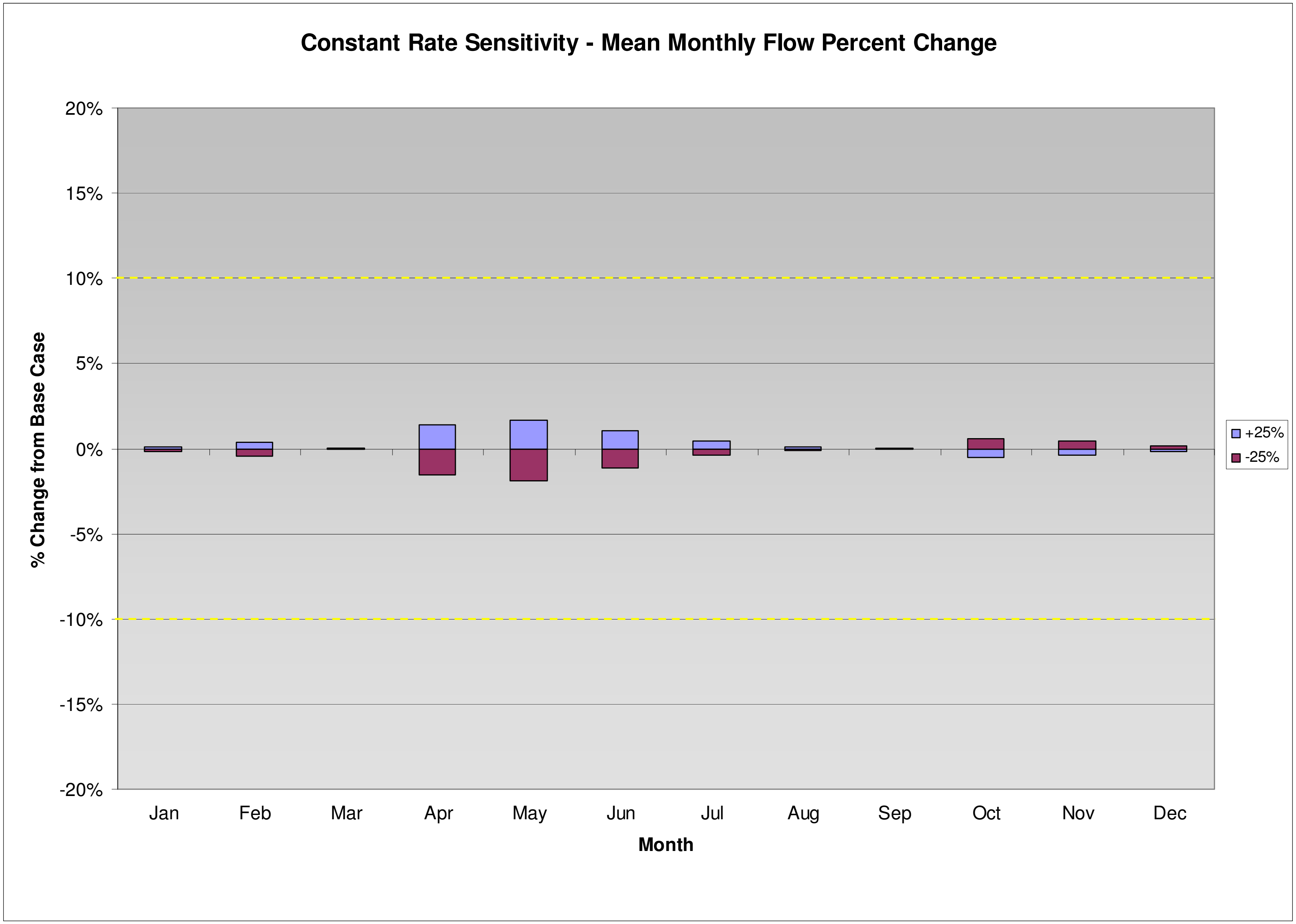
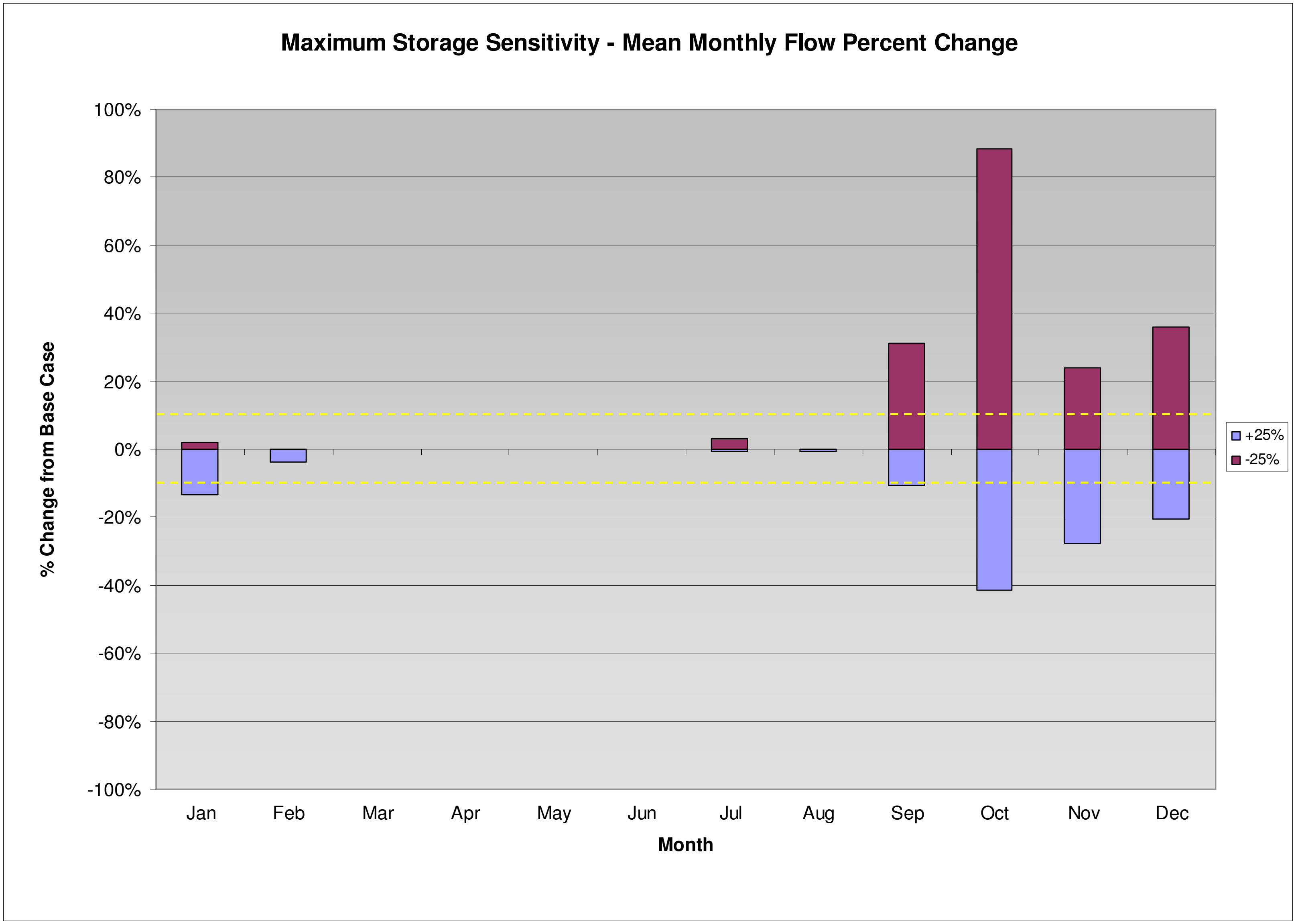

Example BFLOW Output
Twenty Mile Creek at Ball's Falls
Flow (m3/s)
60
50
40
30
20
10
0
Jan-96
Feb-96
Mar-96
Apr-96
May-96
Jun-96
Date
BFLOW Pass1
BFLOW Pass 2
BFLOW Pass 3
Total Flow

Figure 3.28



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 3.29



Maximum Storage Sensitivity - Mean Monthly Flow Percent Change
% Change from Base Case
100%
80%
60%
40%
20%
0%
-20%
-40%
-60%
-80%
-100%
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
+25%
-25%

Figure 3.30

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

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

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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

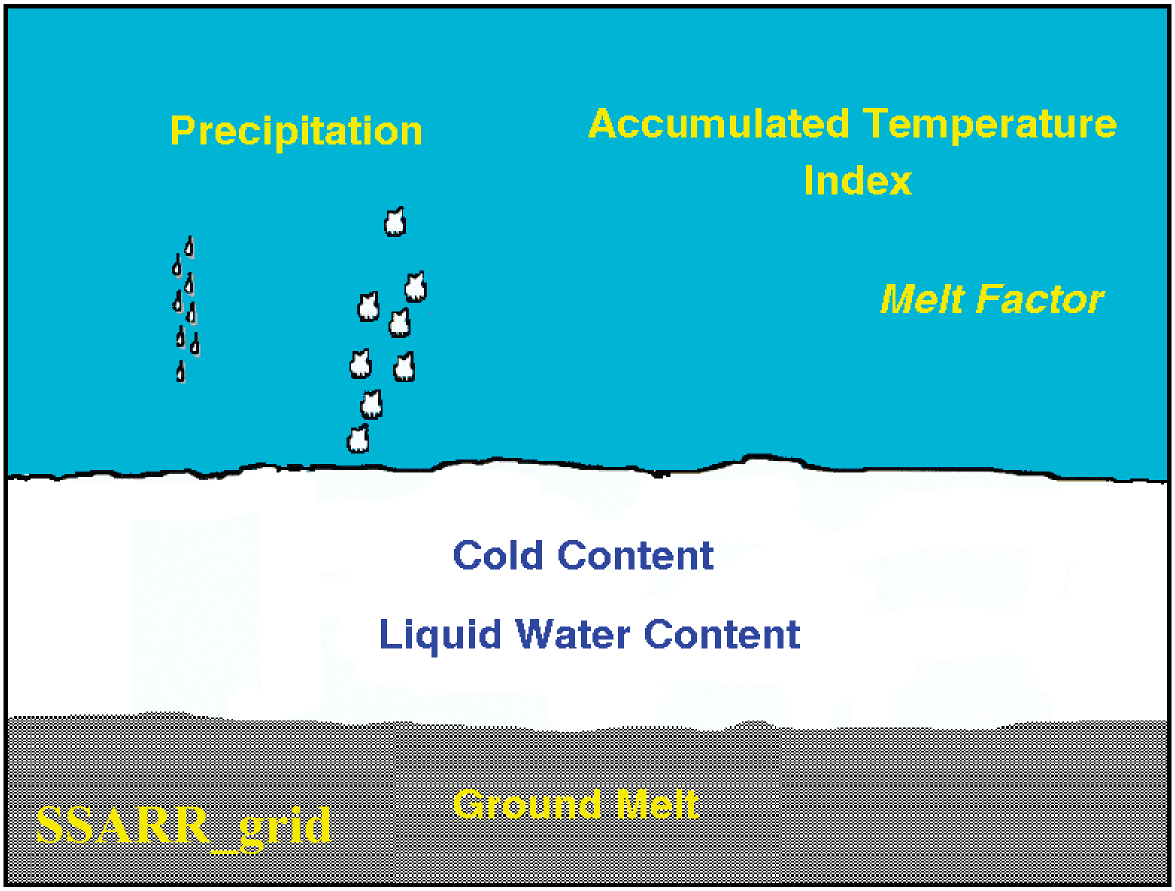
- Often, complete energy budgets are difficult or impossible to estimate. A simpler method, based only on the air temperature, called the Temperature Index (degree-day) method has been developed. It has been widely used with good results.

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

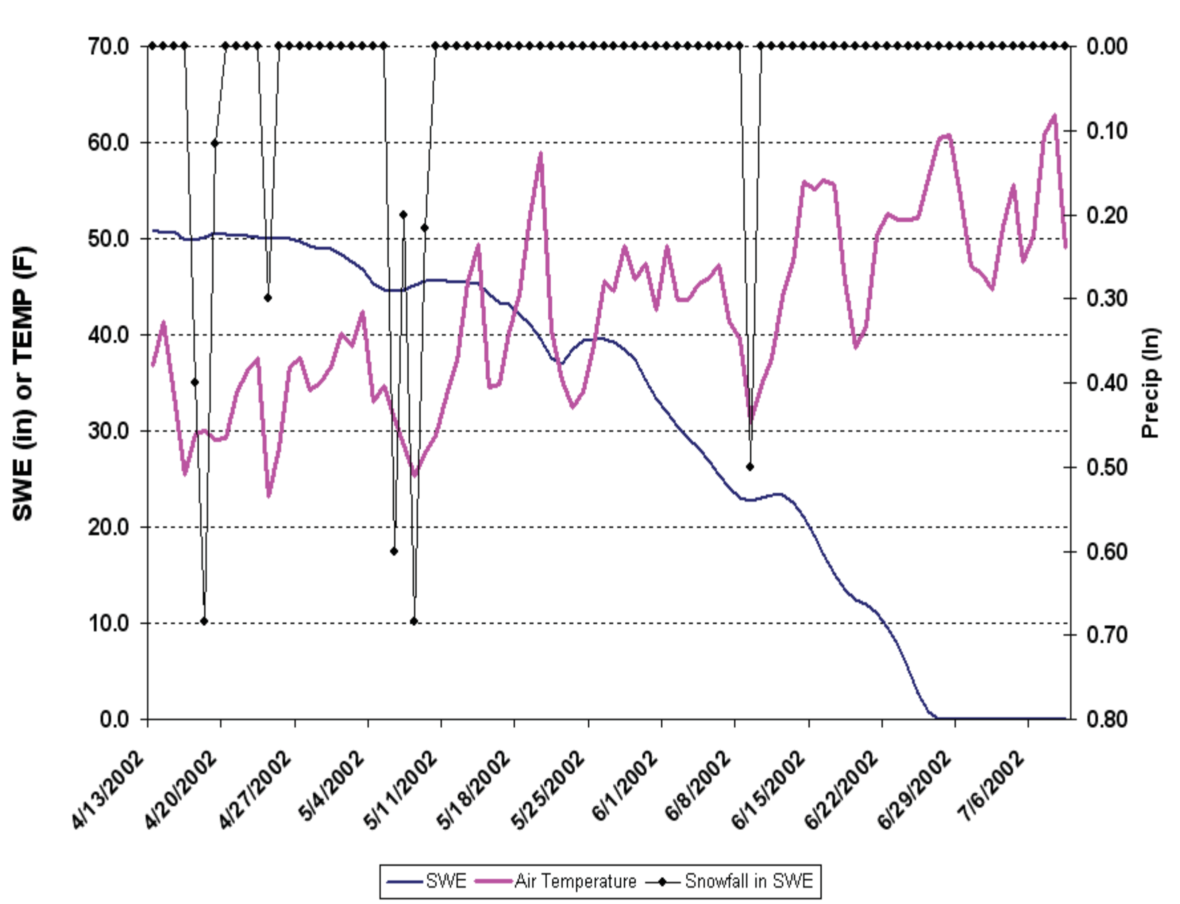
- Temperature Index
- Single snow Layer
  - Cold Content
  - Liquid water content
  - Ground melt

Snowmelt Modeling in HMS

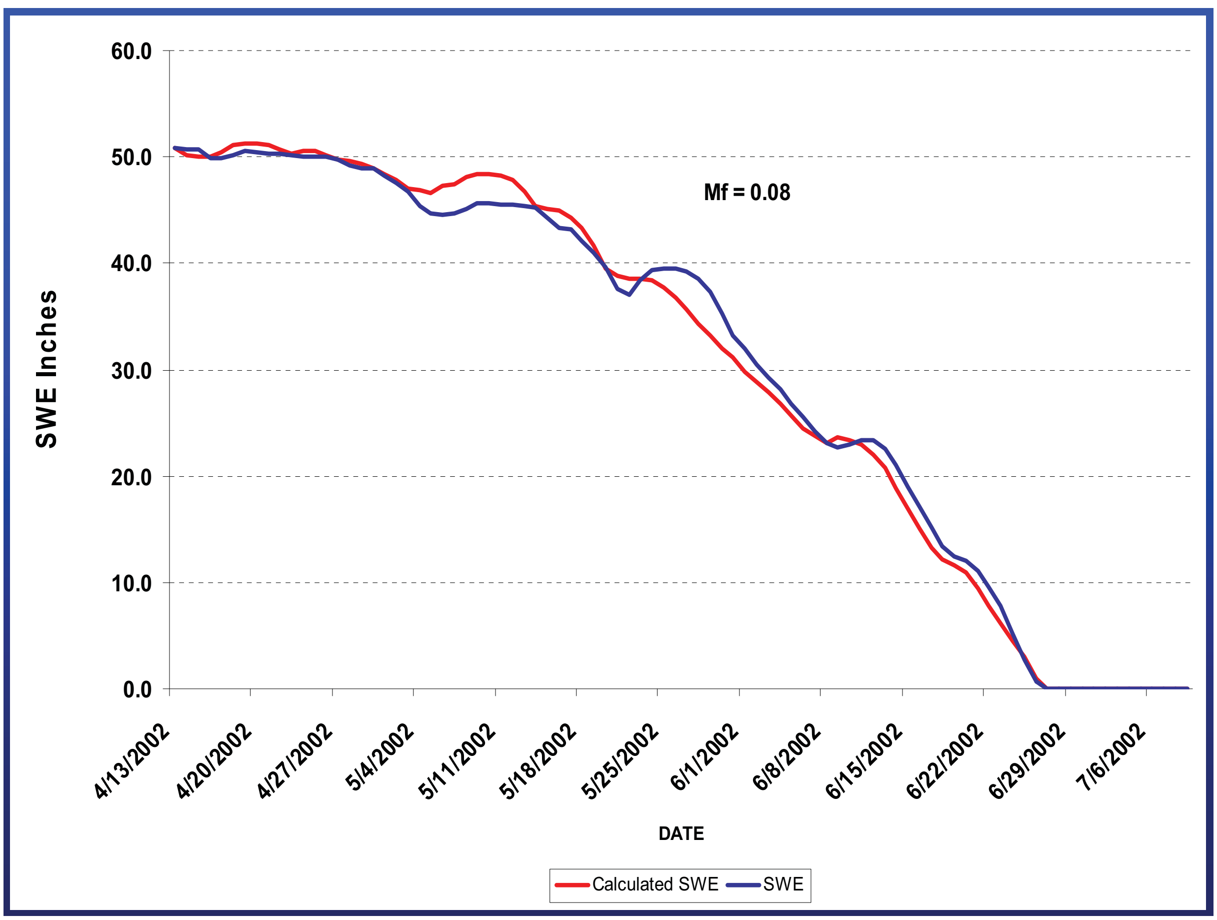
- Watershed
  - Uniform snow cover
    - Watershed temperature & precipitation
  - Elevation bands
    - Initial SWE
    - Temperature
- Distributed
  - Standard Hydrologic Grid 10m – 100km
  - Distributed air temperature & Precipitation

Temperature Index Snow Model

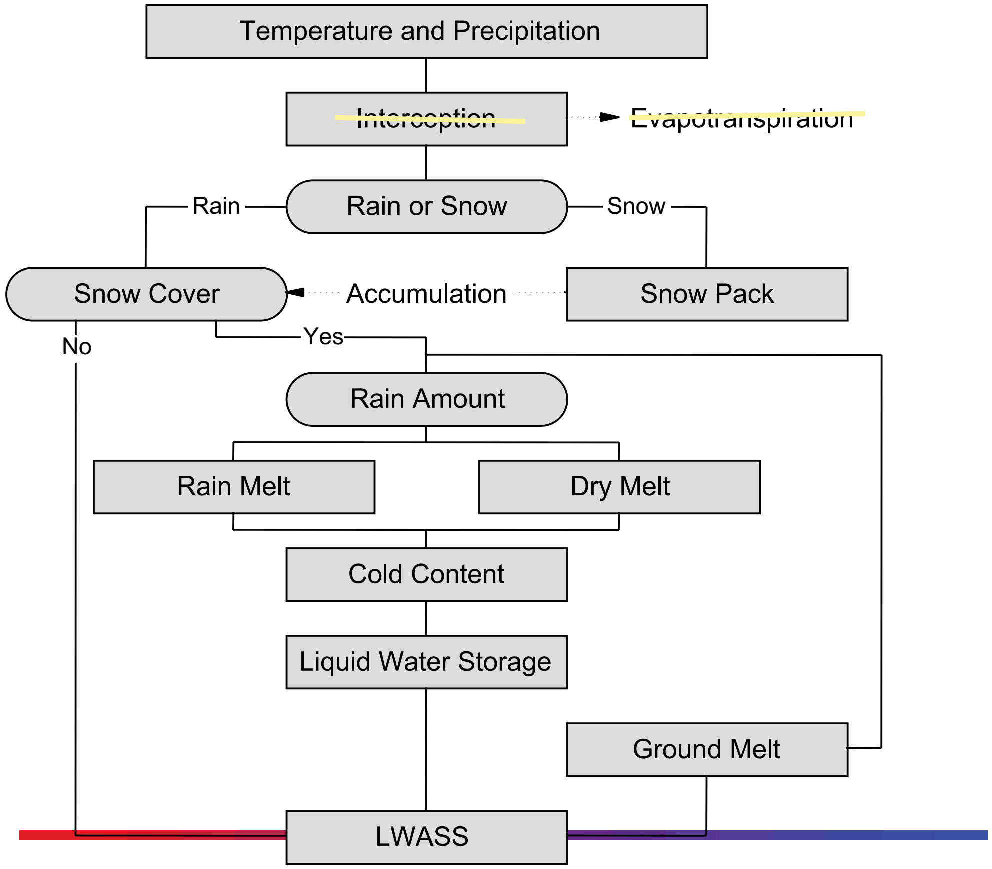
- Snow Melt is estimated as
  - $L_S = M_f (Ta - T_{base})$
  - Mf serves as an index of the total heat transfer at the snow surface which includes long wave, short wave, latent heat, and sensible heat transfer. Also strongly influenced by the wind speed, aspect, slope, vegetation, etc.
  - Mf can be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

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$T > T_{base}$ - 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.

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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.

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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)**

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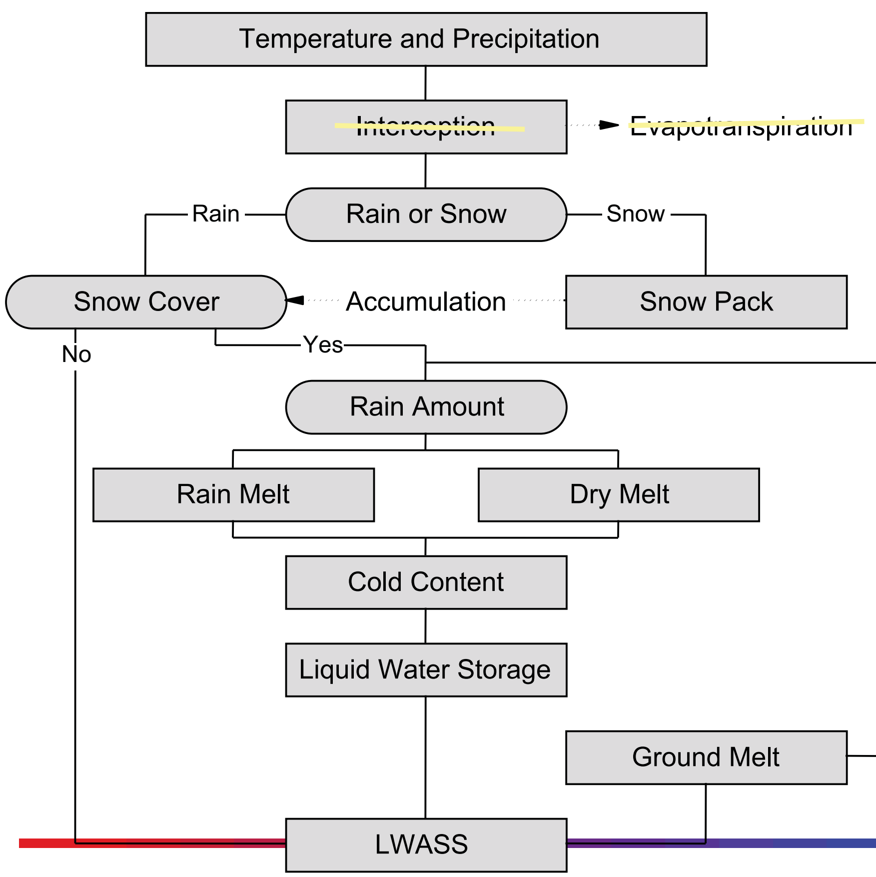
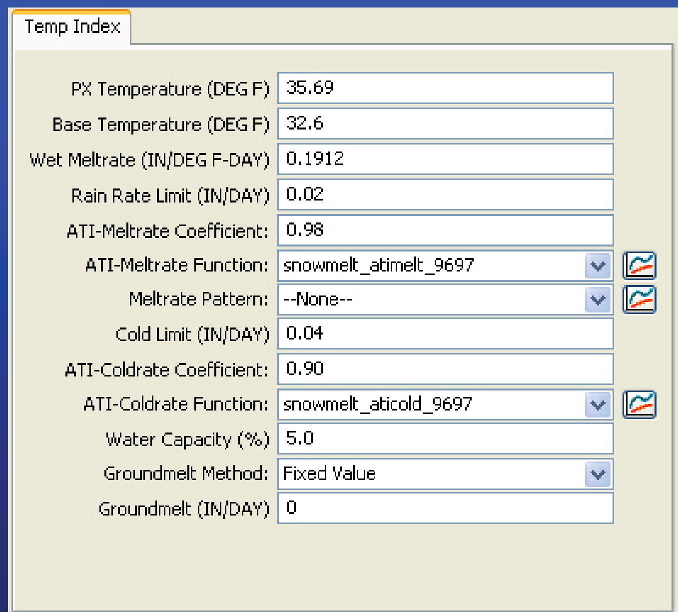


Entering Snow Parameters in HMS



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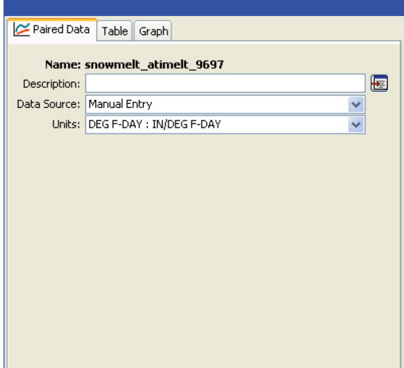
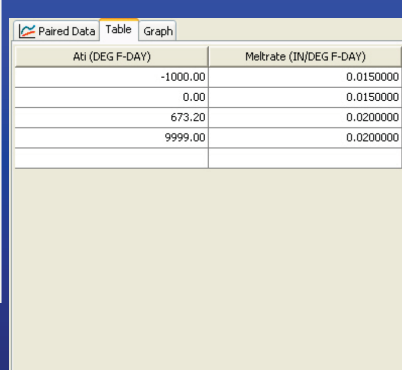
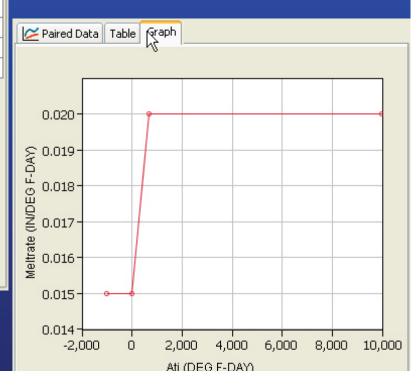
Entering Paired Data







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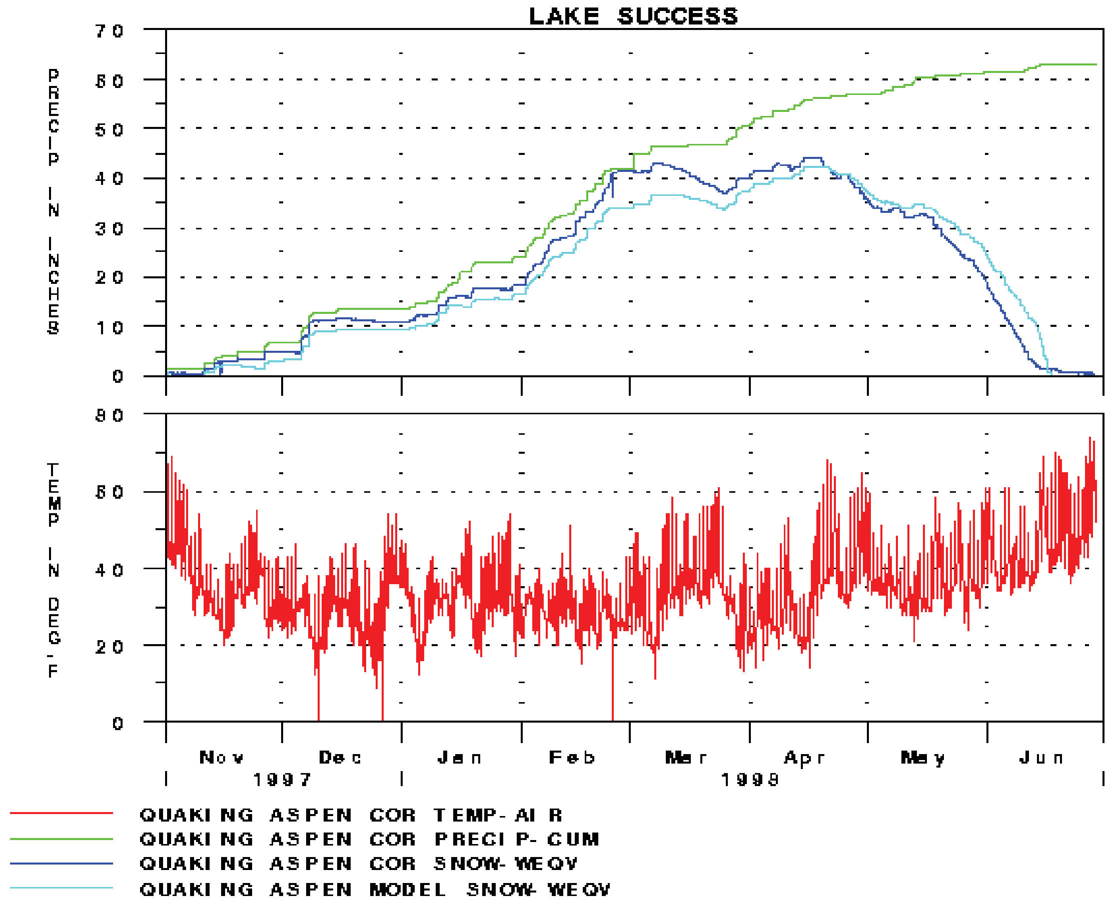
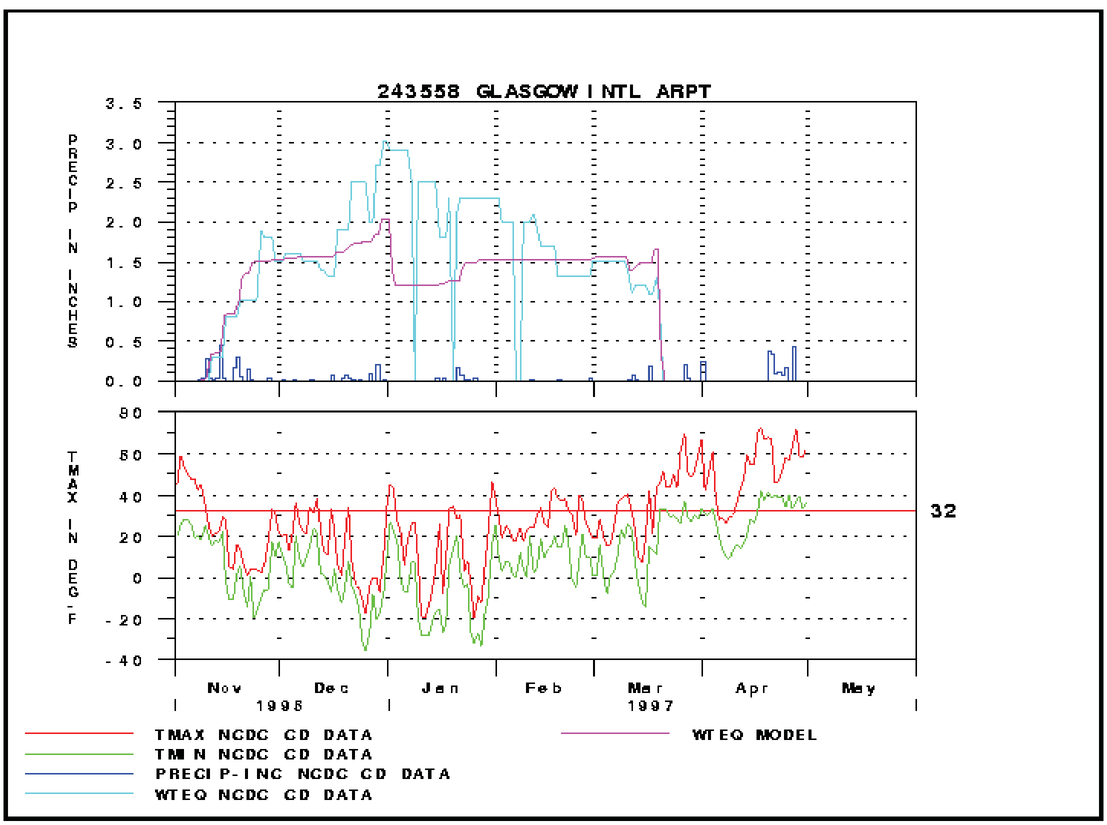

LAKE SUCCESS
PRECIP IN INCHES
TEMP IN DEG. F
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
1997
1998
QUAKING ASPEN COR TEMP-AIR
QUAKING ASPEN COR PRECIP-CUM
QUAKING ASPEN COR SNOW-WEQV
QUAKING ASPEN MODEL SNOW-WEQV


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 Soil maximum infiltration rate 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

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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.

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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.