Water Availability Study for the Upper Welland River Watershed Plan Area Niagara Peninsula Source Protection Area

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NIAGARA PENINSULA CONSERVATION AUTHORITY

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Table of Contents

List of Tables

List of Figures

Appendices

1.0 INTRODUCTION

1.1 Background and Objectives

The Niagara Peninsula Conservation Authority (NPCA) and AquaResource Inc. have completed this Water Availability Study (WAS) of the Upper Welland River Watershed Plan Area (Upper Welland River) 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was developed by NPCA in consultation with the Ministry of Natural Resources (MNR), based upon the March 2007 Draft Guidance Module – Water Budget and Water Quantity Risk Assessment.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 the Upper Welland River, the largest Watershed Plan Area within NPCA at 478 km^2. The study area is located in the City of Hamilton, Haldimand County and the Regional Municipality of Niagara including portions of two local municipalities, the Township of West Lincoln and the Township of Wainfleet (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 Modeling 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 Upper Welland River WSPA.

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); and
- Baseflow Separation and Streamflow Recession (AquaResource Inc., 2007).

These studies are referenced throughout this report. Additional information was also gathered from the Welland River Watershed Strategy (NPCA, 1999) to assist with the Watershed Characteristics section.

1.5 Document Organization

The sections within the report are organized as follows:

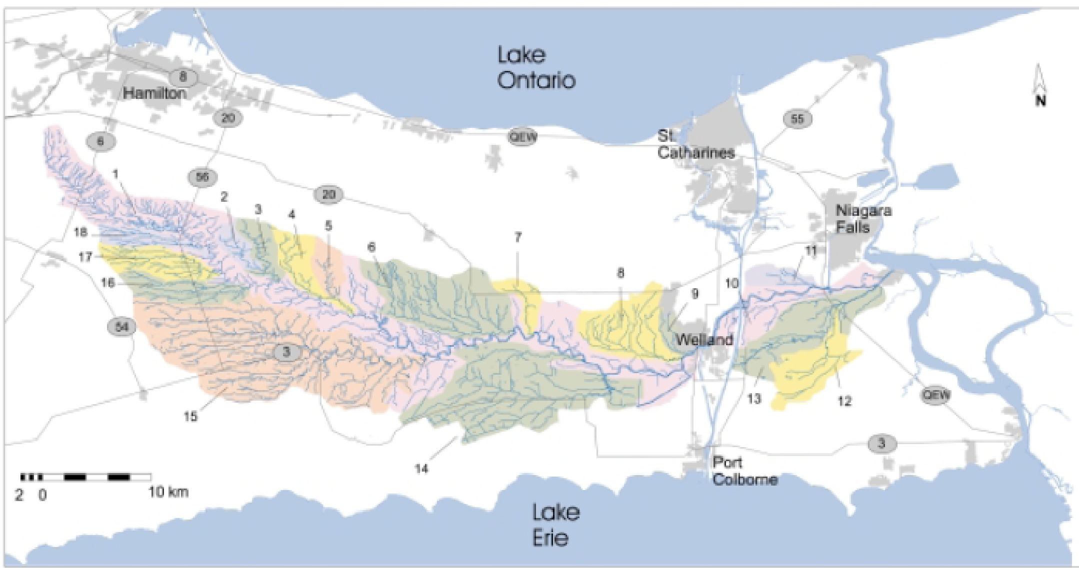
- Chapter 2 – Watershed Characteristics;
- Chapter 3 – Watershed Modelling; and
- Chapter 4 – References.

2.0 WATERSHED CHARACTERISTICS

2.1 General Description of the Watershed

The Upper Welland River WSPA originates in the former Town of Ancaster (City of Hamilton) and traverses the former Township of Glanbrook (City of Hamilton), Haldimand County, the Township of West Lincoln and the Township of Wainfleet. The total drainage area is 478 km^2 the largest WSPA in the NPCA.

Welland River Subwatersheds



1. Welland River West
2. Little Wolf Creek
3. Wolf Creek
4. Mill Creek
5. Moore's Creek
6. Beaver Creek
7. SuckerCreek
8. Coyle Creek
9. Drapers Creek
10. Thompson's Creek
11. Welland River East
12. Tee Creek
13. Lyon's Creek
14. Forks Creek
15. Oswego Creek
16. Elsie Creek
17. Buckhorn Creek
18. West Wolf Creek

The Upper Welland River WSPA consists of fifteen (15) subwatersheds: the main branch of the Welland River (WR), West Wolf Creek (WWC), Buckhorn Creek (BNC), Elsie Creek (EC), Little Wolf Creek (LWFC), Mill Creek (MC), Moore's Creek (MOC), Wilson Creek (WC), Oswego Creek (OC), Unnamed Creek (UNC), Wolf Creek (WFC), James Drain (JD), Chick Hartner Drain (CHD) and Sugar Creek Drain (SCD).

These subwatersheds are shown above as represented in the 1999 NPCA Welland River Watershed Strategy. Wilson Creek is not shown but is part of the Welland River West subwatershed and the Oswego Creek subwatersheds (Unnamed Creek, James Drain, Chick Hartner Drain and the Sugar Creek Drain) are also not shown. Their locations can be seen on Figure 3.2.

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), the Upper Welland River is located in the Niagara Fruit Belt climatic region. Figures 2.2 and 2.3 show the 1991-2005 average monthly precipitation and average monthly temperature (Schroeter and Associates, 2007). Average monthly precipitation ranged from a low of 53 mm at the Hamilton Airport Environment Canada station in February to a high of 91 mm at the Canboro Airport Environment Canada station in November. The average annual range in temperature was 26.5 degrees (Celsius) as shown on Figure 2.3.

Spatial variations in mean annual snowfall, air temperature and mean annual preciptitaion across Upper Welland 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 Upper Welland River appear to range from almost 910-870 mm per year and 160 to 115 mm, respectively, on average across the WSPA. Average annual temperatures range from 8 to 8.8 ^{o}C.

Figures 2.7, 2.8 and 2.9 show the total annual precipitation, total annual snow water equivalent and average annual temperature for the 1991-2005 period respectively for the Hamilton Airport and Canboro stations. The total annual precipitation ranged from a 1998 low of 593 mm (Canboro) to a high of 1161 mm in 1996 (Hamilton), almost double the amount. On average the total annual precipitation from 1991 to 2005 was 896 mm. The amount of snow water equivalent ranged from a low of 62 mm in 2001 (Canboro) to a high in 1994 of 264 mm (Hamilton). Overall 140 mm (16%) of precipitation is delivered as snowfall. The amount of snow received at Hamilton Airport was usually greater than that at Canboro. The average annual temperature was lowest in 1992 at 6.9^{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 Hamilton Royal Botanical Gardens (RBG). 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 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 averages.

2.3 Upper Welland River Channel Topography

The Welland River falls approximately 82 metres (270 feet) in elevation over its entire course. The most significant vertical drop is a 78 metres drop which occurs over the first 55 kilometres (34 miles) with only a 4 metre (15 foot) drop on the lower 80 kilometers (50 miles) of the River. This slight gradient results in a meandering, sluggish river from Port Davidson in the Township of West Lincoln downstream (NPCA, 1999).

The channel profile of the Upper Welland River and its tributaries is shown on Figures 2.12a and 2.12b. The slope of the Welland tributaries (Figure 2.12a) is shown to be fairly similar to one another, as are the Oswego Creek tributaries (Figure 2.12b).

2.4 Physiography

The Upper Welland River WSPA is characterized by smooth, moderately sloping topography within the Haldimand Clay Plain physiographic region (Figure 2.13).

The Fort Erie Moraine serves as a drainage divide on the clay plain between Twenty Mile Creek and the Upper Welland River. A portion of the Dunnville Sand Plain is located in the southern portion of the WSPA.

2.5 Soils

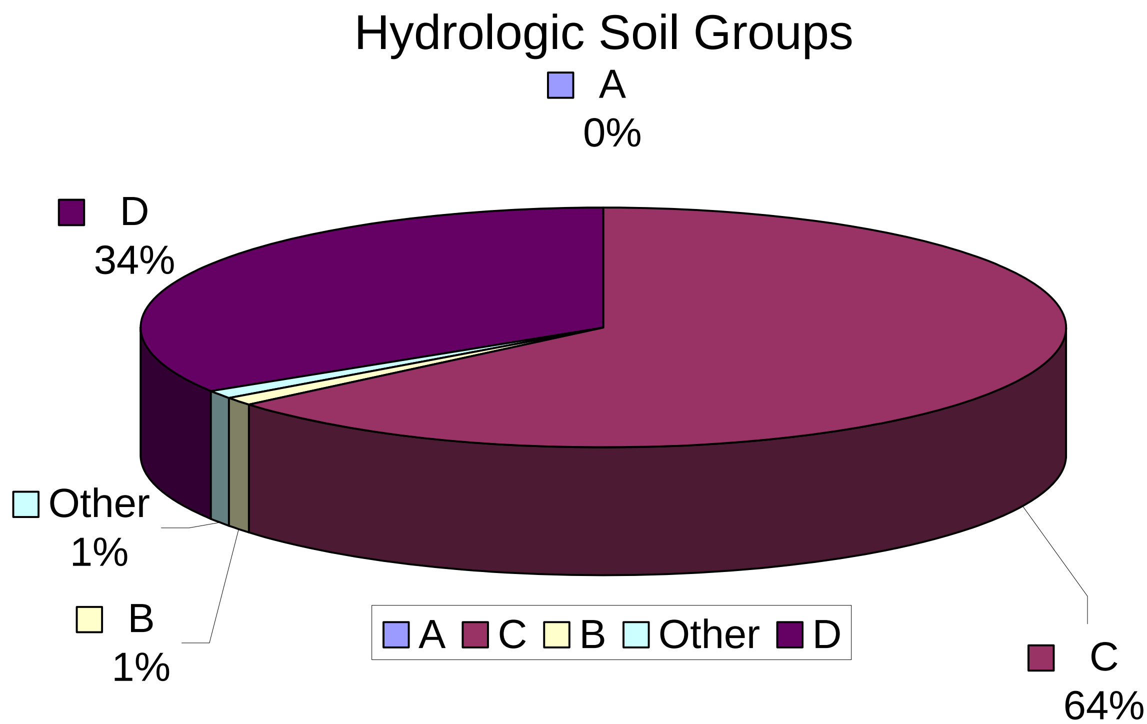
The mapped soils information was provided by the Ontario Ministry of Agriculture and Food and combines three (3) soil survey areas, Haldimand County, Niagara Region and City of Hamilton (Figure 2.14).

The mapped soils 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 64 and 34 percent of the area of the WSPA respectively (as presented below). The remaining portion of the WSPA is mapped as 1% other, 1% 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 the Upper Welland River is largely fine-textured glaciolcaustrine deposits, matching the overlying clayey soils (Figure 2.15). A small portion of the WSPA in the southeastern corner is mapped as coarse-textured glaciolacustrine and lacustrine deposits. The coarseness of the deposits appears less pronounced in the soils mapping (Figure 2.14).

2.7 Land Cover

Land use 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. The largest land use categories making up 85% of Upper Welland River were (i) rural land use 32%, (ii) monoculture 17%, (iii) mixed crop 11%, (iv) deciduous forest 9%, (v) mixed agriculture 8% and (vi) swamp 8%. The SOLRIS results are shown in more generalized form on Figure 2.16.

2.8 Streamflow

AquaResource Inc. completed an analysis of baseflow separation and streamflow recession for NPCA in November 2007. Two (2) stations were available for analysis within Upper Welland River 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
02HA007	WELLAND RIVER BELOW CAISTOR CORNERS	230	01/07/1957	31/12/2005
02HA024	OSWEGO CREEK AT CANBORO	81	01/09/1988	31/12/2005

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	02HA007					02HA024				
Parameter	90th%	Median	Mean	Mean Baseflow	10th %	90th%	Median	Mean	Mean Baseflow	10th %
Jan	0.042	0.679	3.19	0.41	7.690	0.008	0.180	1.12	0.11	2.900
Feb	0.068	0.665	3.43	0.40	8.380	0.015	0.183	1.13	0.14	2.850
Mar	0.314	2.400	4.89	0.86	11.70	0.100	0.719	2.05	0.29	5.360
Apr	0.298	1.900	4.37	0.90	9.920	0.112	0.701	1.68	0.30	4.070
May	0.064	0.558	1.75	0.31	3.670	0.018	0.133	0.67	0.10	1.720
Jun	0.024	0.149	0.80	0.14	1.440	0.001	0.031	0.49	0.05	0.898
Jul	0.005	0.055	0.43	0.06	0.873	0.001	0.007	0.09	0.01	0.269
Aug	0.012	0.060	0.21	0.05	0.542	0.001	0.006	0.08	0.01	0.109
Sep	0.006	0.055	0.59	0.12	1.370	0.001	0.003	0.13	0.01	0.186
Oct	0.020	0.180	0.84	0.15	1.740	0.003	0.020	0.22	0.03	0.739
Nov	0.052	0.383	2.61	0.38	6.960	0.010	0.119	1.05	0.13	2.830
Dec	0.110	0.797	2.28	0.42	6.160	0.020	0.330	1.10	0.14	2.660

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. Welland River below Caistor Corners has monthly median summer flows below 0.1 m^3/s indicating that there are no areas with significant groundwater discharge within the catchment.

The 90th percentiles, or low flows, shows that Oswego Creek at Canboro has had past occurrences of no flow. For a watershed of 81 km^2, such as Oswego Creek, to have zero flow 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. Following the methodology employed in the Water Budget Conceptual Understanding, 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 average annual values for Oswego Creek at Canboro and Welland River below Caistor Corners 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

<u>*Source:*</u> 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 Welland River below Caistor Corners and Oswego Creek at Canboro.

Table 2.7 –Estimated Water Balance from Streamflow Analysis

Gauged Catchment		Total Flow	Runoff	Baseflow	Precipitation	Evapo-transpiration
		mm/year				
02HA007	Welland River below Caistor Corners	311	257	55	911	600
02HA024	Oswego Creek at Canboro	308	265	43	923	615

3.0 WATERSHED MODELLING

The following sections describe the model construction, calibration, and verification of the Upper Welland River HEC-HMS model, and present the water balance estimates.

3.1 Model Description

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

HEC-HMS can be run at a variety of time steps, from 1 minute to 1 day. For the Upper Welland River WSPA, and other models created for this study, HEC-HMS was run on an 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 is 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 on 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 stops 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.

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, as "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 a hydrologic model.

Climate data from two meteorological stations were considered when constructing the Upper Welland River HEC-HMS model. The Hamilton Airport station (ID 6153194) is operated by Environment Canada and the Canboro station (ID 6131165) was operated by Environment Canada until 1971. Environment Canada stations are operated to a national standard, and undergo significant quality assurance/quality control procedures to ensure accurate data collection.

The Hamilton Airport Station is located at the headwaters of Upper Welland River and the Canboro station is located in the central portion of the WSPA. To represent climate within the model, catchments located in the upper portion of the Upper Welland Planning Area were assigned climate data from Hamilton Airport, with the central and lower portions of the WSPA being assigned data from the Canboro 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 is evenly distributed throughout a particular day, the fact that snowfall does not generate an immediate streamflow response, means the impact of such an assumption is negligible.

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

Initial simulations for those catchments assigned to the Canboro climate station, showed the snowmelt period occurring earlier than observed, often in the month of February. Suspecting the climate data, a comparison was made between the Hamilton Airport and Canboro temperatures. The Canboro temperature dataset was found to be significantly warmer than the Hamilton Airport (up to 1.5^0C in February), for only the winter months. The differential for warm season months was minimal. Given the regional nature of temperature, this large difference raised suspicions with the Canboro temperature data. It was found that the Canboro dataset was filled in using data from two other stations: Dunnville and Brantford MOE. After the mid 1990’s, at which point Dunnville closed, the Brantford MOE station was the sole station used for fill-in. The Brantford MOE climate station is located at the Brantford sewage treatment plant (STP), and likely experiences higher ambient temperatures due local heat inputs from the STP. This effect would be largest during the winter months, when the temperature differential between the sewage and local air masses would be the largest. Based on these suspicions, the temperature dataset for the Canboro station was lowered by 0.75°C for the months of December through March. This adjustment resulted in the snowmelt moving from February, into March, which matched observations.

A single hourly net solar radiation station was created for the Upper Welland River 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).

3.2.2 Streamflow Information

Streamflow information was obtained from the two federally operated stream gauges on Upper Welland River, as indicated in Section 2.8. Flow data for Welland River below Caistor Corners, and Oswego Creek at Canboro were imported into HEC-HMS and were used as the primary calibration points for Upper Welland River.

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 are 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, in concert with AquaResource Inc., using the NPCA 2 m DEM. The catchments ranged in size from 4 to 18 km^2. Smaller catchments were explored but were not possible without model time steps less than an 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 catchments and HMS schematic 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 grass reference evapotranspiration. Daily land use layers were created and assigned crop coefficients from Appendix D.

Using the solar radiation and temperature data, 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.

- 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 18 hours was 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, Welland River below Caistor Corners and Oswego Creek at Canboro, were used within the Upper Welland River 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 Welland River below Caistor Corners gauge, were assigned the reservoir constant estimated from the Welland River gauge.

3.2.8 Initial Parameterization – Transform

The lag time associated with the SCS transform method is a function of the Soil Conservation Service (SCS) 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.

3.2.10 Initial Parameterization - Binbrook Dam

The Reservoir Element was used to model the Binbrook Dam. The Outflow Curve Method was applied, using the Elevation-Storage-Discharge Method, which requires the input of a storage-discharge function as well as an elevation-storage function. The initial condition for the reservoir was set to inflow=outflow.

The storage-discharge relationship was set based on a combination of the discharge curves for the 16 inch valve, 30 inch valve, and the glory inlet/emergency spillway. The current operation strategy (which was revised in 1997), was also considered when developing the overall storage-discharge relationship for the reservoir. The current strategy is to hold the reservoir at 650.5 feet above sea level, (fasl) with a discharge target of 5 cubic feet per second. In the case of extreme dry times, this discharge target is lowered to 2 cubic feet per second, with discharge ceasing should the reservoir level drop below 649 fasl (NPCA, 2006). The combined elevation-storage-discharge table, as used in the model, is included in Table 3.2.

Table 3.2 – Simulated Binbrook Reservoir Storage, Elevation, Discharge Curve

Storage	Reservoir Elevation		Discharge	Operation
thousand m^3	masl	fasl	m^3/s	
3,914	197.8	648.9	0.00	Discharge Ceases
4,041	197.9	649.3	0.06	Discharge Lowered to 2 cfs
4,167	198.0	649.6	0.14	Discharge Target of 5 cfs
4,292	198.1	649.8	0.14	Discharge Target of 5 cfs

4,447	198.2	650.1	0.14	Discharge Target of 5 cfs
4,609	198.3	650.4	0.7	100% 16 inch valve
4,770	198.4	650.7	0.7	100% 16 inch valve
4,932	198.5	651.0	2.6	100% 16 inch, 50% 30inch
5,094	198.6	651.4	2.6	100% 16 inch, 50% 30inch
5,256	198.7	651.7	4.5	100% 16 inch, 100% 30 inch
5,418	198.8	652.0	4.5	100% 16 inch, 100% 30 inch
5,602	198.9	652.3	4.5	100% 16 inch, 100% 30 inch
5,885	199.0	652.9	6	100% Valves, Glory Inlet Flow
6,075	199.1	653.2	8	100% Valves, Glory Inlet Flow
6,217	199.2	653.4	10	100% Valves, Glory Inlet Flow
6,359	199.3	653.6	12	100% Valves, Glory Inlet Flow
6,537	199.4	653.9	15	100% Valves, Glory Inlet Flow
6,739	199.5	654.3	18	100% Valves, Glory Inlet Flow
6,942	199.6	654.6	22	100% Valves, Glory Inlet Flow
7,144	199.7	654.9	31	100% Valves, Glory Inlet Flow
7,346	199.8	655.3	43	100% Valves, Glory Inlet Flow
7,549	199.9	655.6	59	100% Valves, Glory Inlet Flow
7,730	200.0	655.9	78	100% Valves, Glory Inlet Flow
7,892	200.0	656.1	99	100% Valves, Glory Inlet Flow
8,054	200.1	656.3	116	100% Valves, Glory Inlet Flow

It is important to note that Binbrook Reservoir is an actively managed structure. As such, it is extremely difficult, and likely impossible, to accurately replicate the human decisions that determine discharges from such a structure on the basis of a stage-storage-discharge relationship alone. Furthermore, the stage-storage-discharge relationship used within the HEC-HMS model, is based on the operating strategy post 1997, and is not reflective of the operations of the reservoir previous to this. These two points are significant causes of uncertainty within the HEC-HMS model.

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 accurately describe the model's ability to replicate observed flows.

The calibration metrics that will be 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: 1999-2005. Model parameters are adjusted to best replicate hydrologic processes and observed flows. Due to gaps in the observed data for Oswego Creek at Canboro in 1995 through 1998, the 1999-2005 period will be used as the calibration period. This period also matches the current operating strategy of Binbrook Reservoir more closely than the 1991-1998 period.
- The Verification Period: 1991-1998. 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.

3.3.2 Calibrated Model Period and Parameters

As described above, the calibration was completed over the 1999-2005 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, as well as the amount of evapotranspiration. The modelled values of the Maximum Storage and the Constant Rate for each catchment are shown in Table 3.3. These values provided the base case for the sensitivity analysis which is documented in Section 3.4.

Table 3.3 - Calibrated Constant Rate and Maximum Storage Terms

Catchment UWR ID	Constant Rate (mm/h)	Max Storage (mm)
BNC_W100	0.20	160
BNC_W200	0.22	162
CHD_W100	0.22	160
EC_W100	0.21	162
EC_W110	0.19	161
JD_W100	0.22	165
LWFC_W100	0.24	161
MC_W100	0.18	163
MC_W200	0.15	150
MOC_W100	0.15	164
OC_W100	0.22	150
OC_W200	0.24	166
OC_W210	0.23	164
OC_W211	0.19	163
OC_W212	0.19	162
OC_W300	0.28	150
OC_W310	0.24	163
OC_W320	0.20	163
OC_W400	0.27	161
OC_W410	0.20	161
OC_W420	0.22	161
OC_W421	0.20	154
OC_W430	0.23	158
OC_W440	0.22	159
OC_W450	0.21	160
OC_W500	0.21	158
SCD_W100	0.24	163
UNC_W100	0.20	162
UNC_W110	0.22	163
WC_W100	0.19	170
WFC_W100	0.21	162
WR_W100	0.21	150
WR_W1000	0.23	150
WR_W1100	0.31	150
WR_W200	0.20	163
WR_W300	0.18	163
WR_W310	0.14	164
WR_W400	0.21	164
WR_W500	0.22	161
WR_W600	0.23	162
WR_W700	0.23	161
WR_W710	0.25	150

WR_W720	0.24	150
WR_W800	0.23	150
WR_W900	0.24	150
WWC_W100	0.23	161

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 the 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 3.4 displays the final adjustments applied to the original crop coefficients.

Table 3.4 – 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 interflow (GW 1) were set to 18 hours. Groundwater coefficients for the reservoir associated with baseflow (GW 2), were initially parameterized based upon recession analysis (AquaResource, 2007); however there is a suspicion that the recession analysis for the Caistor Corners gauge was impacted by upstream reservoir operations. To minimize this, the groundwater coefficient determined for the Upper Twenty Mile Creek, was used for the Upper Welland. Both areas share the same geological deposits, and therefore should have similar hydrogeological characteristics. This adjustment resulted in the groundwater coefficient being lowered by approximately 50 hours, and generated simulated flows which were a better match with observed flows. Table 3.5 includes the final coefficients used for Upper Welland River.

Table 3.5 - Groundwater Coefficients in Linear Reservoir Baseflow Model

WSC Gauging Station	GW 1 Coefficient (hr)	GW 2 Coefficient (hr)
Oswego Creek at Canboro	18	326
Welland River below Caistor Corners and Non-Gauged Catchments	18	278

Included in Figures 3.4 to 3.15 are a number of calibration plots for both Upper Welland River below Caistor Corners (Welland River) and Oswego Creek at Canboro (Oswego Creek). Figure 3.4 compares the simulated and observed annual flow volumes at Welland River for the calibration period. Correspondence is good, with the exception of 2003, with a difference of 85 mm. With the other years matching reasonably well, this difference in 2003 is suspected to be climate driven, rather than an issue with the simulated processes. The simulated total monthly flow volumes at Welland River display good correspondence with the observed flows, as shown in Figure 3.5. The

Nash-Sutcliffe and R^2 coefficients calculated from the monthly mean streamflow values and the log of the monthly mean streamflow values, are shown in Figure 3.6 and Table 3.6. The R^2 value (0.70) and the Nash-Sutcliffe (0.64) show a reasonable fit between simulated and observed flows. The log-scale Nash-Sutcliffe coefficient (0.53) illustrates a reasonable fit for high flows, but a larger discrepancy in the low flow estimations. This may be caused by discharges from Binbrook Reservoir being simulated higher than in actuality.

Table 3.6 - Standard Error, Nash-Sutcliffe and R^2 for Calibration Period (Monthly Mean Flow mm/month)

	WSC Gauge	R^2	Standard Error	Nash-Sutcliffe	Log Nash-Sutcliffe
Calibration Period 1999-2005	Welland River	0.70	17.6	0.64	0.53
	Oswego Creek	0.64	19.9	0.49	0.45

Included in Table 3.7 is the mean monthly observed and simulated flow for Welland River with the difference expressed in mm.

Table 3.7 – Comparison of Mean Streamflow Volume – Welland River Calibration Period

Month	Simulated (mm)	Observed (mm)	Difference (mm)
Jan	25	24	0
Feb	37	45	-8
Mar	65	50	15
Apr	72	54	18
May	25	25	0
Jun	10	12	-2
Jul	3	2	1
Aug	3	3	0
Sep	3	2	1
Oct	7	9	-1
Nov	33	35	-1
Dec	31	27	3

The mean and median monthly simulated and observed flows at Welland River are shown in Figures 3.7 and 3.8, respectively. The comparison of mean monthly flows shows a very good match in flow volumes between simulated and observed flows, with the largest differences during the spring snowmelt period. The comparison of median monthly flows shows the distribution of daily flows throughout each month is reasonable for Welland River, with the most significant differences occurring during the summer months. The overestimation of summer flows is likely related to outflows from the Binbrook Dam but may also 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, shows that for flows greater than the 30 percentile exceedance flow there is very good agreement. Simulated and observed flows begin to deviate below this threshold, although the annualized volume this difference represents (~10mm/year), is quite small. The source of error that leads to the additional 10 mm of water in the lower portion of the flow regime is likely either:

1. HEC-HMS not representing evaporative losses from the reservoir, which results in the reservoir augmenting further into a dry period; or
2. HEC-HMS not representing a transfer of groundwater out of the catchment, which would cause an overestimation of the amount of groundwater returning to the watercourse.

There is also the possibility of the stage-elevation curve being inaccurate at lower elevations/storages, which could result in additional reservoir storage being considered than in actuality.

The annual streamflow volumes at Oswego Creek are also in good agreement, with the largest discrepancy (~65 mm) in 1999 (see Figure 3.10). The simulated total monthly flow volumes at Oswego Creek display reasonable correspondence with the observed flows, as shown in Figure 3.11. The Nash-Sutcliffe coefficients (0.49, 0.45 for log-scale) and the R^2 value (0.64) are shown in Figure 3.12 and Table 3.6.

At Oswego Creek, the mean and median monthly simulated flows show a reasonable match to the observed flows, as shown in Figures 3.13 and 3.14, respectively and in Table 3.8. The discrepancies are largely due to the timing of snowmelt, which is impacted by the climate data at the Canboro climate station. As previously mentioned, the Canboro temperature data was decreased to account for the elevated temperatures reported at the Brantford STP station. However, the uncertainties with the Canboro climate station data may still affect the model results. As was the case with Welland River, the median monthly simulated flows show larger deviations than the mean monthly flow. These discrepancies are due to timing issues, and are often more difficult to reconcile than volume issues associated with mean monthly flow. However, median monthly flows for the summer months match very well.

Table 3.8 – Comparison of Mean Streamflow Volume – Oswego Creek Calibration Period

Month	Simulated (mm)	Observed (mm)	Difference (mm)
Jan	19	22	-3
Feb	58	39	19
Mar	51	48	2
Apr	52	48	3
May	14	29	-15
Jun	5	16	-11
Jul	1	2	0
Aug	1	1	0
Sep	2	3	-1
Oct	8	8	0
Nov	46	39	7
Dec	33	34	-1

The ranked duration plot, included in Figure 3.15, shows that simulated flows are generally in good agreement with observed flows. Both the observed and simulated streamflow datasets estimate the watercourse to reach 0 m^3/s at the 85% exceedance flow.

Model performance for Oswego Creek is poorer than for Caistor Corners, or for gauges on Twenty Mile Creek. Due to the smaller drainage area (80 km^2, compared to >200 km^2), this is to be expected. As hydrologic models are created for smaller areas, there is greater uncertainty that the datasets used to create the models are representative (soils, land cover, climate data). Additionally, hydrologic processes that are insignificant at larger scales, may become significant at more local scales. Obtaining accurate measurements of river flow also becomes problematic when moving to a smaller watercourse.

3.3.3 Verification

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

Figure 3.16 shows the simulated and observed annual total flow volumes at Welland River for the verification period. All years compare reasonably well, with a maximum difference of 120 mm in 1996. Monthly total flow volumes at Welland River are shown in Figure 3.17. At Welland River, the Nash-Sutcliffe and R^2 coefficients are lower than the coefficients for the calibration period, as shown in Figure 3.18 and Table 3.9. The log-scale Nash-Sutcliffe (0.67) is significantly higher than the normal Nash-Sutcliffe (0.27), which illustrates that the discrepancies in the high flows were over-represented, and in fact the fit, over the entire range of flows is quite good.

Table 3.9 - Standard Error, Nash-Sutcliffe and R^2 for Verification Periods (Monthly Mean Flow mm/month)

	WSC Gauge	R^2	Standard Error	Nash-Sutcliffe	Log Nash-Sutcliffe
Verification Period	Welland River	0.60	25.6	0.27	0.67
1999-2005	Oswego Creek	0.45	27.4	0.37	0.58

The mean and median monthly flows are shown in Figures 3.19 and 3.20, respectively. The simulated and observed seasonality of the streamflow are in reasonably good agreement. The elevated observed flows in September may be due to the fall drawdown of the reservoir under past operational practices. Table 3.10 compares the simulated and observed mean monthly streamflow in mm for Welland River. The ranked duration plot in Figure 3.21, shows a very close match in simulated and observed flows, confirming a reasonable simulation of flows for the verification period at the Welland River below Caistor Corners gauge.

Table 3.10 – Comparison of Mean Streamflow Volume – Welland River Verification Period

Month	Simulated (mm)	Observed (mm)	Difference (mm)
Jan	49	44	6

Feb	48	36	12
Mar	71	65	6
Apr	92	45	47
May	19	16	3
Jun	4	7	-3
Jul	4	7	-4
Aug	3	2	1
Sep	2	11	-9
Oct	4	11	-7
Nov	24	30	-6
Dec	24	27	-3

The model verification results were reasonable at Oswego Creek, considering there are only 4 full years of observed data for the verification period. The simulated and observed annual total flow volumes are shown in Figure 3.22; the maximum difference is approximately 110 mm in 1992. Monthly total flow volumes at Oswego Creek are shown in Figure 3.23. The Nash-Sutcliffe coefficient (0.37, 0.58 log-scale) and R^2 (0.45) suggest a poorer fit than the calibration period, for all metrics, with the exception of the log scale Nash-Sutcliffe coefficient, as shown in Table 3.9. Individual charts, and the linear regression are included Figure 3.24.

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 agreement, with the exception of the summer mean flows. These high observed summer mean flows are suspicious in that this amount of discharge (0.2 m^3/s) would be difficult to sustain for such a small watershed located in the Haldimand Clay Plain. In particular, the elevated summer flows during 1992 seem particularly suspect, and may point to an issue with the observed data. Included in Table 3.11 is the mean monthly observed and simulated flow for Oswego Creek with the difference expressed in mm. The ranked duration plot in Figure 3.27, also confirms a reasonable simulation of flows.

Table 3.11 – Comparison of Mean Streamflow Volume – Oswego Creek Verification Period

Month	Simulated (mm)	Observed (mm)	Difference (mm)
Jan	28	46	-18
Feb	37	32	6
Mar	77	91	-14
Apr	88	50	39
May	9	8	1
Jun	2	14	-13
Jul	2	5	-3
Aug	2	6	-4
Sep	1	6	-5
Oct	2	7	-5
Nov	19	38	-20
Dec	27	48	-21

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 change in Binbrook Dam operational procedures, which occurred in 1997, complicates this verification, as the operations of the Dam prior to this time are not replicated within the HEC-HMS model. Given the fact that the model does not reflect pre-1997 operations, and the associated error this introduces, the model performance during the verification phase is acceptable. This indicates that the basic hydrologic processes within the Upper Welland River are reasonably replicated.

3.3.4 Hydrograph Separation Comparison

As described in Section 2, a hydrograph separation exercise has been carried out for 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. The baseflow index (BFI), which is the proportion of separated flow to total flow, was calculated for each BFLOW pass. By 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 3.12 are the calculated BFIs for all three BFLOW passes, for both the simulated and observed flows at the Welland River below Caistor Corners and the Oswego Creek at Canboro gauges.

Table 3.12 – Comparison of BFLOW BFIs

Streamgauge	BFLOW Pass	Simulated BFI	Observed BFI
Welland River Below Caistor Corners	Pass 1	43%	42%
	Pass 2	27%	24%
	Pass 3	21%	17%
Oswego Creek At Canboro	Pass 1	31%	40%
	Pass 2	19%	21%
	Pass 3	14%	13%

For all three passes of the Welland River gauge, the simulated BFI compares very favourably with the observed BFI. The largest difference is in the 3rd pass, with the simulated BFI being larger than the observed. This may be related to inaccuracies associated with Binbrook Reservoir discharges. For Oswego Creek, the most significant difference was found in comparisons of the 1st pass BFIs. The difference decreases as one moves to subsequent passes, with the 3rd pass for Oswego Creek comparing very well.

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. This error, is likely the primary cause for the difference between the simulated and observed 1st pass BFI for Oswego Creek.

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 the 3rd passes, for both Caistor Corners and Oswego Creek, simulated and observed BFIs show good 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 an impact on simulated streamflow (snowmelt parameters, temperature, crop coefficients, precipitation, baseflow recession constants, etc.); however, due to the constraints in the scope of this project, only a limited sensitivity analysis was possible.

Both the Constant Rate and the Maximum Storage were varied by ±25% independently, resulting in the four scenarios. Changes in total outflow, average evapotranspiration, runoff and recharge were calculated and tabulated in the following tables.

- Table 3.13 lists the percent change in total outflow for each scenario, over the base case.

- Table 3.14 displays the percent change in total outflow, evapotranspiration, runoff and recharge for each scenario, over the base case.

Table 3.13 - Sensitivity Analysis Results – Change in Outflow

Month	Constant Rate +25%	Constant Rate -25%	Max Storage +25%	Max Storage -25%
Jan	1.1%	-1.3%	-9.1%	7.1%
Feb	-0.6%	0.7%	-15.8%	11.8%
Mar	-0.6%	0.7%	-6.0%	5.3%
Apr	1.1%	-1.4%	-3.9%	0.6%
May	1.7%	-1.9%	-0.6%	0.1%
Jun	0.8%	-1.0%	-0.1%	0.0%
Jul	1.0%	-1.1%	0.0%	0.0%
Aug	0.2%	-0.2%	0.0%	0.0%
Sep	0.1%	0.0%	-2.5%	63.3%
Oct	-0.8%	0.9%	-66.8%	132%
Nov	-0.7%	0.8%	-34.3%	29.6%
Dec	0.1%	0.1%	-24.9%	25.5%

Table 3.14 - Sensitivity Analysis Results – Change in Water Balance Estimates

Scenario	ET	Baseflow	Interflow	Runoff
1: Constant Rate +25%	0.0%	15.6%	15.6%	-6.6%
2: Constant Rate -25%	0.0%	-18.5%	-18.5%	7.8%
3: Max Storage +25%	6.6%	-14.2%	-14.2%	-13.9%
4: Max Storage -25%	-6.7%	15.5%	15.5%	13.6%

As shown by Tables 3.13 and 3.14, 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 bounds, 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 (see Table 3.14). 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 becoming 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 Upper Welland River 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 Upper Welland River, the Constant Rate can vary by as much as 25%, with a negligible change in streamflow volume. While streamflow is not sensitive to the Constant Rate variation, there is a significant impact on the water balance parameters estimated by the model (+15 to 20% baseflow). Water balance estimates (runoff and baseflow), therefore have a greater degree of uncertainty than the streamflow estimates.

To reduce the 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. This test could be carried out within the Upper Welland River model, or any other WSPA. 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 3.15, presenting the average annual water balance and on a catchment 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 3.15 - Summary of Water Balance Model Results

Catchment UWR ID	Precipitation (mm)	ET (mm)	Interflow (mm)	Baseflow (mm)	Runoff (mm)	Outflow (mm)
BNC_W100	898	573	47	47	230	323
BNC_W200	898	595	49	49	204	301
CHD_W100	894	571	47	47	229	322
EC_W100	898	597	47	47	205	299
EC_W110	898	591	44	44	217	305
JD_W100	894	588	46	46	213	305
LWFC_W100	898	551	56	56	233	345
MC_W100	894	577	41	41	235	316
MC_W200	894	569	38	38	248	324
MOC_W100	894	579	35	35	244	314
OC_W100	894	573	48	48	225	321
OC_W200	894	593	49	49	202	300
OC_W210	894	589	48	48	207	304
OC_W211	894	585	44	44	221	308
OC_W212	894	588	44	44	218	305
OC_W300	894	573	57	57	206	320
OC_W310	894	585	50	50	209	309
OC_W320	894	585	44	44	221	308

OC_W400	894	594	53	53	193	299
OC_W410	894	591	44	44	214	302
OC_W420	894	599	47	47	200	294
OC_W421	894	582	45	45	221	311
OC_W430	894	584	48	48	213	309
OC_W440	894	593	47	47	207	300
OC_W450	894	589	46	46	212	304
OC_W500	894	586	46	46	214	307
SCD_W100	894	584	50	50	209	309
UNC_W100	894	575	44	44	231	318
UNC_W110	894	586	47	47	213	307
WC_W100	894	601	41	41	210	293
WFC_W100	898	570	48	48	230	327
WR_W100	894	556	47	47	244	337
WR_W1000	898	520	53	53	269	376
WR_W1100	898	530	62	62	242	366
WR_W200	894	581	44	44	224	312
WR_W300	894	585	40	40	228	308
WR_W310	894	591	34	34	234	302
WR_W400	894	584	46	46	217	309
WR_W500	898	569	50	50	226	327
WR_W600	898	556	54	54	232	340
WR_W700	898	576	49	49	222	320
WR_W710	898	510	57	57	271	386
WR_W720	898	523	57	57	259	373
WR_W800	898	610	45	45	196	286
WR_W900	898	543	57	57	239	353
WWC_W100	898	564	53	53	226	332
Overall WSPA	**896**	**575**	**47**	**47**	**224**	**322**

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 6 mm, which is equal to <1% of average annual precipitation. The standard deviation for the range of direct overland runoff estimates is approximately 20 mm, which is equal to <2% of average annual precipitation. This stability suggests that the current catchment discretization is appropriate, and refining the catchments smaller than the current average of 10 km^2, would not result in significant changes in water balance estimates.

3.5.2 Stress Assessment

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

Following the methodology in Guidance Module 7, a subwatershed's stress is estimated by comparing the amount of water consumed with the amount of available water. This comparison is made by calculating "Percent Water Demand" as follows, with the terms defined in Table 3.16:

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

Table 3.16 – Percent Water Demand Components

Term	Definition	Calculation
Q_{DEMAND}	Consumptive Demand	Average 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 90th percentile monthly outflow, at a minimum. The 90th percentile flow is defined as the flow that is equaled or exceeded 90% of the time. 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 be experiencing hydrologic or ecologic stress, but rather are identified as requiring additional study to better understand the impacts of the cumulative 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 an average 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 3.17.

Table 3.17– 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 average 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 3.18.

Table 3.18 – Potential for Groundwater Stress Thresholds

Groundwater Potential Stress Level Assignment	Average 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 Upper Welland River are included in Table 3.19. These flow estimates include the direct overland runoff calculated from the upstream drainage area, and the interflow and baseflow component.

Table 3.19 – Surface Water Percent Water Demand Components

Month	Water Supply (Median Flow) (m^3/s)	Water Reserve (90^{th} % Flow) (m^3/s)
Jan	1.97	0.08
Feb	2.58	0.76
Mar	5.55	1.56
Apr	4.43	1.28
May	1.11	0.35
Jun	0.3	0.16
Jul	0.21	0.10
Aug	0.17	0.07
Sep	0.11	0.04
Oct	0.18	0.05
Nov	0.5	0.06
Dec	1.82	0.06

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 streamflow 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 3.20 is the estimated 1991-2005 annual average groundwater recharge rate. Also included is the groundwater reserve value, which is equal to 10% of estimated groundwater discharge (baseflow).

Table 3.20 – Groundwater Percent Water Demand Components

Water Supply (Groundwater Recharge) (mm)	Water Reserve (10% Discharge) (mm)
47	4.7

To complete the groundwater Stress Assessment, groundwater inflow to Upper Welland River 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 WSPA. 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, which 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 with 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).

The representation of Binbrook Reservoir within HEC-HMS is a source of uncertainty. Binbrook Reservoir is an actively managed structure, and as such, is difficult to accurately simulate its discharges. Stage-discharge curves have been developed with the aim to replicate the current operations of the reservoir, although the absolute replication is not a reasonable expectation. Furthermore, the operational procedures of Binbrook Reservoir were altered in 1997, approximately halfway through the modelling period of 1991-2005. Because the reservoir stage-discharge curves were developed based on current operations of the reservoir, they do not reflect operations prior to 1997. This introduces a level of uncertainty into the verification phase of the modelling exercise.

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 Upper Welland River). 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 a very good predictor of streamflow, as is shown in Sections 3.3 and 3.4. Based on 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.

4.0 CONCLUSIONS AND RECOMMENDATIONS

A HEC-HMS continuous hydrologic model has been constructed for the Upper Welland River. It has been successfully calibrated to the 1999-2005 period, and underwent a verification test in the 1991-1998 period. Model performance in predicting streamflow, for both the calibration and verification phase is 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 Upper Welland River 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 the 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 one of the WSPAs, 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. To aid both water quantity and quality investigations, it is recommended that a streamgauge be installed and monitored at the dam outfall. This would generate accurate estimates of rate of discharge, and would also allow one to determine nutrient loadings to the Welland River, from Binbrook Reservoir. Additionally, the installation of a streamgauge on the major inflow watercourse to the reservoir, would also be a benefit to such studies, as well as day-to-day reservoir operations.

Despite the uncertainties inherent with any modelling exercise, the Upper Welland River 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 the Welland River.

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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
UPPER WELLAND RIVER WATERSHED PLANNING AREA
WATER AVAILABILITY STUDY

Catchment UPWE ID	Area (km^2)	Hydrologic Soil Groups (%)				
		A	B	C	D	Other[1]
UWR_BNC_W100	11.87		0.8	66.2	33.0	
UWR_BNC_W200	12.48		0.6	71.2	28.2	
UWR_CHD_W100	8.45	0.2		90.2	9.7	
UWR_EC_W100	14.20			50.8	49.1	0.0
UWR_EC_W110	11.39		0.9	56.0	43.1	0.0
UWR_JD_W100	7.33	0.5		87.2	12.2	0.1
UWR_LWFC_W100	10.16			80.6	19.2	0.2
UWR_MC_W100	8.27			33.9	64.0	2.1
UWR_MC_W200	11.79			19.2	75.6	5.3
UWR_MOC_W100	13.21			21.2	76.4	2.5
UWR_OC_W100	4.66			89.7	4.4	5.9
UWR_OC_W200	15.75		4.8	77.7	16.6	0.9
UWR_OC_W210	10.50		4.7	74.2	21.1	0.0
UWR_OC_W211	10.47			68.6	31.4	
UWR_OC_W212	9.04		0.6	69.4	30.0	
UWR_OC_W300	3.78		17.4	57.0	25.6	
UWR_OC_W310	9.66		5.6	80.1	14.2	0.1
UWR_OC_W320	11.36		0.1	66.0	32.5	1.4
UWR_OC_W400	6.57		15.8	40.6	43.6	
UWR_OC_W410	11.39		0.3	51.7	48.1	
UWR_OC_W420	11.48		4.9	71.1	24.0	
UWR_OC_W421	9.93			45.5	54.5	
UWR_OC_W430	11.15		1.3	57.2	41.5	
UWR_OC_W440	6.79		3.2	80.2	16.6	
UWR_OC_W450	11.29			77.6	22.4	
UWR_OC_W500	13.10		2.8	65.7	31.5	
UWR_SCD_W100	11.87	1.1		93.3	5.6	0.0
UWR_UNC_W100	14.88	0.3		56.7	43.0	0.0
UWR_UNC_W110	5.67			90.6	9.4	
UWR_WC_W100	6.44		0.1	39.4	59.4	1.1
UWR_WFC_W100	13.38			62.4	34.3	3.3
UWR_WR_W100	12.45			60.3	33.7	6.0
UWR_WR_W1000	16.53			75.7	24.3	
UWR_WR_W1100	11.60	2.0	7.4	62.7	28.0	
UWR_WR_W200	14.17		0.7	56.4	37.9	5.0
UWR_WR_W300	8.45			40.6	55.1	4.3
UWR_WR_W310	8.82			12.4	83.8	3.8
UWR_WR_W400	17.60			53.8	43.6	2.6
UWR_WR_W500	8.64		1.1	70.4	26.2	2.3
UWR_WR_W600	11.04			75.6	24.4	
UWR_WR_W700	3.69			75.2	24.8	
UWR_WR_W710	6.39			85.6	14.4	
UWR_WR_W720	11.51			80.7	19.3	
UWR_WR_W800	7.15	0.3		74.4	25.3	
UWR_WR_W900	7.88	0.2		78.9	20.8	
UWR_WWC_W100	13.86		0.1	73.3	26.6	

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TABLE 2.2
HYDROLOGIC SOIL GROUPS BY CATCHMENT
UPPER WELLAND RIVER WATERSHED PLANNING AREA
WATER AVAILABILITY STUDY

Average %		0.7	3.7	64.5	32.8	2.1
% of UPWE		0.1	1.3	63.7	33.9	1.1
Area (km^2)		0.50	6.23	304.35	161.94	5.08

Table Notes:
UWR - Upper Welland River, BNC - Buckhorn Creek, CHD - Chick Hartner Drain, EC - Elsie Creek
JD - James Drain, LWFC - Little Wolf Creek, MC - Mill Creek, MOC - Moores Creek, OC - Oswego Creek
SCD - Sugar Creek Drain, UNC - Unnamed Creek, WC - Wilson Creek, WFC - Wolf Creek
WR - Welland River, WWC - West Wolf Creek
1 - Where soils unmapped or an area of high runoff, i.e. urban areas, water bodies, bedrock at surface

TABLE 2.3
LAND COVER BY CATCHEMENT
UPPER WELLAND RIVER WATERSHED PLANNING AREA
WATER AVAILABILITY STUDY

Catchment UPWE 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
UWR_BNC_W100	2.03	9.13	8.32	19.64		3.91				9.68	0.16	0.33		0.84	4.00	32.92	0.56	2.85	0.02	1.75	1.21	2.63
UWR_BNC_W200	0.82	4.26	10.44	13.18		0.63	0.14			4.47	0.39	0.29			0.78	60.20	0.22	1.85		0.04		2.29
UWR_CHD_W100		5.37		27.74						6.36	0.25	0.22		1.40		50.09	0.12	2.30	0.09	3.89		2.17
UWR_EC_W100		7.99		19.74			0.78			7.16	0.28	0.37	0.04		0.01	58.41	0.81	1.85	0.03	0.71		1.85
UWR_EC_W110		12.89	0.88	22.11		0.26				7.05	0.37	0.22			0.15	47.50	2.11	4.41				2.05
UWR_JD_W100		8.57		28.39			1.78			5.68	1.43	0.26	0.05	2.93		32.52		16.09	0.03			2.27
UWR_LWFC_W100	20.43	1.22	37.23	2.41		11.42				6.51	0.56	0.93		0.01	5.24	6.94	0.15	3.49		0.12		3.36
UWR_MC_W100		8.04		29.72			0.79			12.43	1.20	0.80		0.18		33.18	0.66	10.10	0.01	0.15		2.73
UWR_MC_W200		12.30		27.86			2.29		0.07	12.85	0.82	0.39		2.14	0.00	28.94	0.81	8.99	0.01	0.76		1.76
UWR_MOC_W100		13.07		25.32						14.39	1.84	0.77		0.34	0.03	24.66	0.38	16.52	0.00	0.10		2.57
UWR_OC_W100		10.85		15.53						3.76	0.55	0.93		2.71		47.74	6.43	6.65	0.71	1.57		2.57
UWR_OC_W200	0.03	10.36		18.42		0.02	0.13			10.59	1.31	0.74			0.01	39.57	0.86	14.85	0.55	0.62		1.92
UWR_OC_W210		7.94		29.31			0.06			10.90	1.37	0.56			0.03	37.08	1.81	8.66	0.15	0.33		1.81
UWR_OC_W211		15.23		25.14		0.05	1.28			9.79	0.73	0.66			0.02	41.12	0.03	3.91				2.04
UWR_OC_W212		21.57		14.52			0.28			10.41	0.55	0.86		0.88		44.04	1.22	3.46	0.03	0.03		2.13
UWR_OC_W300		9.11		32.37						8.48	0.28	0.14		2.35	0.02	41.19	0.75	1.68	0.71	0.24		2.67
UWR_OC_W310		12.51		25.79						10.62	0.88	1.40		0.07		41.35	0.67	3.87	0.09	0.46		2.28
UWR_OC_W320		8.29		24.18			0.14			11.63	0.98	1.64		0.73		44.34	0.69	3.46	0.02	1.91		1.99
UWR_OC_W400		11.55		16.59						19.50	1.17	0.55		0.77	0.00	33.53		13.74	0.49	0.15		1.96
UWR_OC_W410		10.22		20.56			0.63			21.22	1.05	1.68		0.02	0.03	33.24	0.35	8.92	0.00			2.07
UWR_OC_W420		6.60		18.77						18.62	1.13	0.51	0.00	0.04		40.59	0.24	11.98	0.02			1.49
UWR_OC_W421		6.77		29.07			0.80			6.94	0.52	0.23				46.56	1.21	6.02	0.05			1.84
UWR_OC_W430		10.76		17.75			0.25			12.75	0.71	0.90		0.08		44.74	0.93	8.52				2.62
UWR_OC_W440		13.11		15.52			0.14			18.85	0.40	1.16		0.14	0.02	43.96	0.46	4.43				1.82
UWR_OC_W450		9.14		15.70			0.96			5.81	1.65	0.36	0.03	0.02	0.00	47.47	0.16	16.55	0.14			2.02
UWR_OC_W500		16.09		15.05			0.01			7.07	1.36	0.71	0.03	0.01		41.51	1.16	15.28	0.12			1.61
UWR_SCD_W100		5.26		38.69			0.58			7.58	0.62	0.88	0.02	0.26		36.98	0.17	6.70	0.01	0.04		2.13
UWR_UNC_W100		5.71		37.77		0.04	0.62			3.44	1.74	0.37		0.73	0.05	34.62	0.22	11.66	0.03	0.06		2.93
UWR_UNC_W110		6.56		34.64			1.66			7.92	1.82	0.38		3.48		27.67	2.54	10.93	0.01	0.30		2.08
UWR_WC_W100		8.75		14.03			0.01			14.89	2.43	0.35		0.09		35.70	0.50	21.22	0.01			2.01
UWR_WR_W100		12.07		23.92			0.77			4.60	1.06	0.84		0.26	0.08	38.43	6.18	4.37	2.40	1.10		3.90
UWR_WR_W1000	9.19		48.11			10.21	1.15			2.78	0.66	0.27	0.50	2.46	9.33		0.85	3.95	0.04	6.46		4.02
UWR_WR_W1100	15.40		35.14			7.90	0.34		0.28	4.37	1.15	0.56	3.05	9.82	9.01		0.81	2.89	0.39	3.38		5.52
UWR_WR_W200		12.80		16.72			0.53			9.75	0.90	1.05				41.41	1.99	10.80	0.58	0.81		2.66
UWR_WR_W300		19.88		9.14			0.14			10.95	1.30	0.68		0.61	0.01	40.79	2.01	11.90	0.01			2.58
UWR_WR_W310		13.29		14.93			1.02			16.70	1.60	0.97		0.58	0.01	34.46	0.62	13.66				2.16
UWR_WR_W400		11.69		21.58		0.00	0.38			11.52	0.91	0.69		0.21		38.35	2.12	9.86	0.01	0.46		2.22
UWR_WR_W500	2.60	11.49	22.20	8.06		4.23	0.13			10.91	0.60	1.83		0.12	4.12	21.52	4.70	3.87	0.01	0.75		2.88
UWR_WR_W600	7.18		47.13			10.52	0.57			7.96	0.99	0.29		0.02	12.07		0.95	7.94	0.05	0.45	1.05	2.85
UWR_WR_W700	8.36		34.44			6.09	2.77			10.08	0.80	0.19	0.51	9.22	14.45		1.07	7.96		0.87		3.20
UWR_WR_W710	3.87		55.80		0.01	9.57				6.25	0.21	0.15		0.82	9.15			1.04		10.19		2.94
UWR_WR_W720	19.80		51.87		0.02	1.98	1.62			4.60	0.45	0.20	0.28	0.78	9.00		0.44	0.93		4.41		3.61
UWR_WR_W800	11.39		32.86			8.24	1.50		0.44	2.58	0.95	0.17	0.53	0.13	9.32		3.67	2.14	24.37	0.17		1.55
UWR_WR_W900	6.27		60.68			8.61	0.05			3.86	0.68	1.62	0.22		10.99		0.64	1.95	0.08	1.48		2.85
UWR_WWC_W100	5.97	0.12	41.47	4.65		11.63	0.14			4.46	0.55	0.51		0.96	5.84	16.98	0.08	3.50	0.03	0.26		2.84
Average %	8.1	10.0	34.8	20.9	0.0	5.3	0.7	0.0	0.3	9.3	0.9	0.7	0.4	1.3	3.6	38.1	1.2	7.5	0.9	1.4	1.1	2.5
% of UPWE	2.6%	8.3%	10.6%	17.4%	0.0%	2.2%	0.5%	0.0%	0.0%	9.1%	0.9%	0.6%	0.1%	0.8%	2.1%	31.9%	1.1%	7.6%	0.5%	1.0%	0.1%	2.5%
Area/Land Use (km^2)	12.4	39.7	50.7	83.2	0.0	10.4	2.5	0.0	0.1	43.7	4.4	3.1	0.6	4.0	10.2	152.4	5.2	36.1	2.5	4.7	0.3	12.0

Table Notes:
UWR - Upper Welland River, BNC - Buckhorn Creek, CHD - Chick Hartner Drain, EC - Elsie Creek, JD - James Drain, LWFC - Little Wolf Creek, MC - Mill Creek, MOC - Moores Creek, OC - Oswego Creek, SCD - Sugar Creek Drain, UNC - Unnamed Creek

TABLE 3.1
CATCHMENT PARAMETERS
UPPER WELLAND RIVER WATERSHED PLANNING AREA
WATER AVAILABILITY STUDY

Catchment UPWE ID	Area (km^2)	Slope (%)	Impervious Area (%)	Curve Number (CN)	Basin Time Lag (hours)	Maximum storage (mm)	Infiltation Rate (mm/hour)
UWR_BNC_W100	11.87	3.6	3.5	83.5	2.6	214.4	1.8
UWR_BNC_W200	12.48	3.2	2.3	83.7	2.4	223.6	2.0
UWR_CHD_W100	8.45	2.8	4.1	83.8	1.9	214.1	2.0
UWR_EC_W100	14.20	2.7	2.2	83.8	3.8	222.5	1.9
UWR_EC_W110	11.39	2.5	2.1	83.8	4.6	217.6	1.7
UWR_JD_W100	7.33	2.3	2.3	82.1	2.9	238.1	2.0
UWR_LWFC_W100	10.16	2.5	3.4	83.2	3.9	218.1	2.2
UWR_MC_W100	8.27	3.0	2.8	82.9	3.7	227.8	1.6
UWR_MC_W200	11.79	2.2	2.1	83.6	2.8	213.3	1.3
UWR_MOC_W100	13.21	2.1	2.6	82.1	4.2	236.4	1.3
UWR_OC_W100	4.66	3.8	3.3	83.4	2.0	204.5	2.0
UWR_OC_W200	15.75	3.1	2.2	80.9	3.8	247.7	2.2
UWR_OC_W210	10.50	3.0	2.0	82.0	2.8	234.0	2.1
UWR_OC_W211	10.47	2.2	2.1	83.4	3.3	226.9	1.7
UWR_OC_W212	9.04	2.6	2.1	83.3	3.4	225.3	1.8
UWR_OC_W300	3.78	3.6	2.8	82.8	1.7	209.1	2.6
UWR_OC_W310	9.66	2.8	2.5	82.6	4.1	229.6	2.2
UWR_OC_W320	11.36	2.5	3.0	82.9	3.7	229.5	1.8
UWR_OC_W400	6.57	3.8	2.0	79.7	2.4	256.2	2.5
UWR_OC_W410	11.39	2.5	2.0	81.2	5.3	257.4	1.8
UWR_OC_W420	11.48	3.1	1.5	80.5	3.5	261.1	2.0
UWR_OC_W421	9.93	2.2	1.8	83.6	3.6	223.1	1.8
UWR_OC_W430	11.15	2.7	2.6	82.0	4.1	243.7	2.0
UWR_OC_W440	6.79	3.5	1.9	81.6	2.8	248.1	2.0
UWR_OC_W450	11.29	2.4	2.0	81.6	3.0	251.5	1.9
UWR_OC_W500	13.10	3.0	1.7	81.8	4.1	243.6	1.9
UWR_SCD_W100	11.87	2.5	2.1	82.5	3.6	231.7	2.2
UWR_UNC_W100	14.88	2.2	3.0	83.2	3.3	223.9	1.8
UWR_UNC_W110	5.67	3.1	2.3	82.6	2.5	229.3	2.0
UWR_WC_W100	6.44	2.2	1.8	80.4	3.5	265.1	1.7
UWR_WFC_W100	13.38	2.9	3.5	82.9	4.1	221.7	1.9
UWR_WR_W100	12.45	3.3	4.4	84.0	3.5	195.9	1.9
UWR_WR_W1000	16.53	4.1	7.2	83.4	2.5	191.0	2.1
UWR_WR_W1100	11.60	4.6	7.2	81.6	2.1	176.1	2.8
UWR_WR_W200	14.17	3.2	3.1	82.3	3.4	228.9	1.8
UWR_WR_W300	8.45	3.5	2.7	82.5	3.4	230.0	1.6
UWR_WR_W310	8.82	2.4	2.2	82.3	3.3	236.0	1.3
UWR_WR_W400	17.60	3.1	2.4	82.2	4.2	235.1	1.9
UWR_WR_W500	8.64	4.0	3.3	82.7	2.9	217.4	2.0
UWR_WR_W600	11.04	4.1	3.1	81.9	3.4	223.6	2.1
UWR_WR_W700	3.69	4.9	3.6	81.8	1.7	220.9	2.1
UWR_WR_W710	6.39	3.4	8.0	83.0	2.0	191.9	2.3
UWR_WR_W720	11.51	4.1	5.8	83.7	2.1	192.6	2.2

TABLE 3.1
CATCHMENT PARAMETERS
UPPER WELLAND RIVER WATERSHED PLANNING AREA
WATER AVAILABILITY STUDY

UWR_WR_W800	7.15	3.6	1.6	86.7	1.8	159.6	2.1
UWR_WR_W900	7.88	4.5	3.6	83.2	1.6	206.3	2.2
UWR_WWC_W100	13.86	3.6	3.0	83.4	3.8	216.6	2.1

Minimum	3.7	2.1	1.5	79.7	1.6	159.6	1.3
Maximum	17.6	4.9	8.0	86.7	5.3	265.1	2.8
Average	10.4	3.1	3.0	82.7	3.2	224.1	2.0

Table Notes:
UWR - Upper Welland River, BNC - Buckhorn Creek, CHD - Chick Hartner Drain, EC - Elsie Creek
JD - James Drain, LWFC - Little Wolf Creek, MC - Mill Creek, MOC - Moores Creek, OC - Oswego Cre
SCD - Sugar Creek Drain, UNC - Unnamed Creek, WC - Wilson Creek, WFC - Wolf Creek
WR - Welland River, WWC - West Wolf Creek

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FIGURES

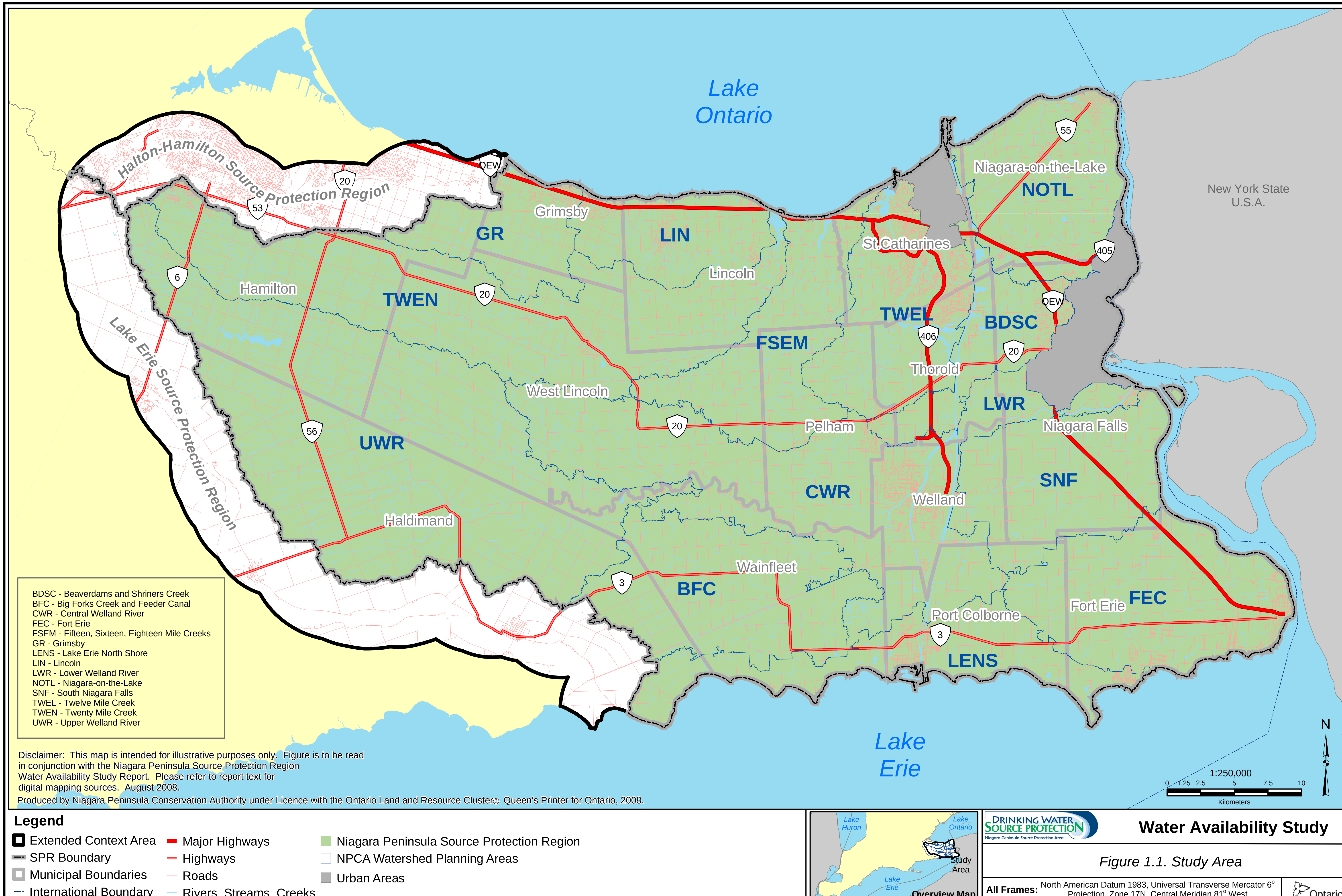
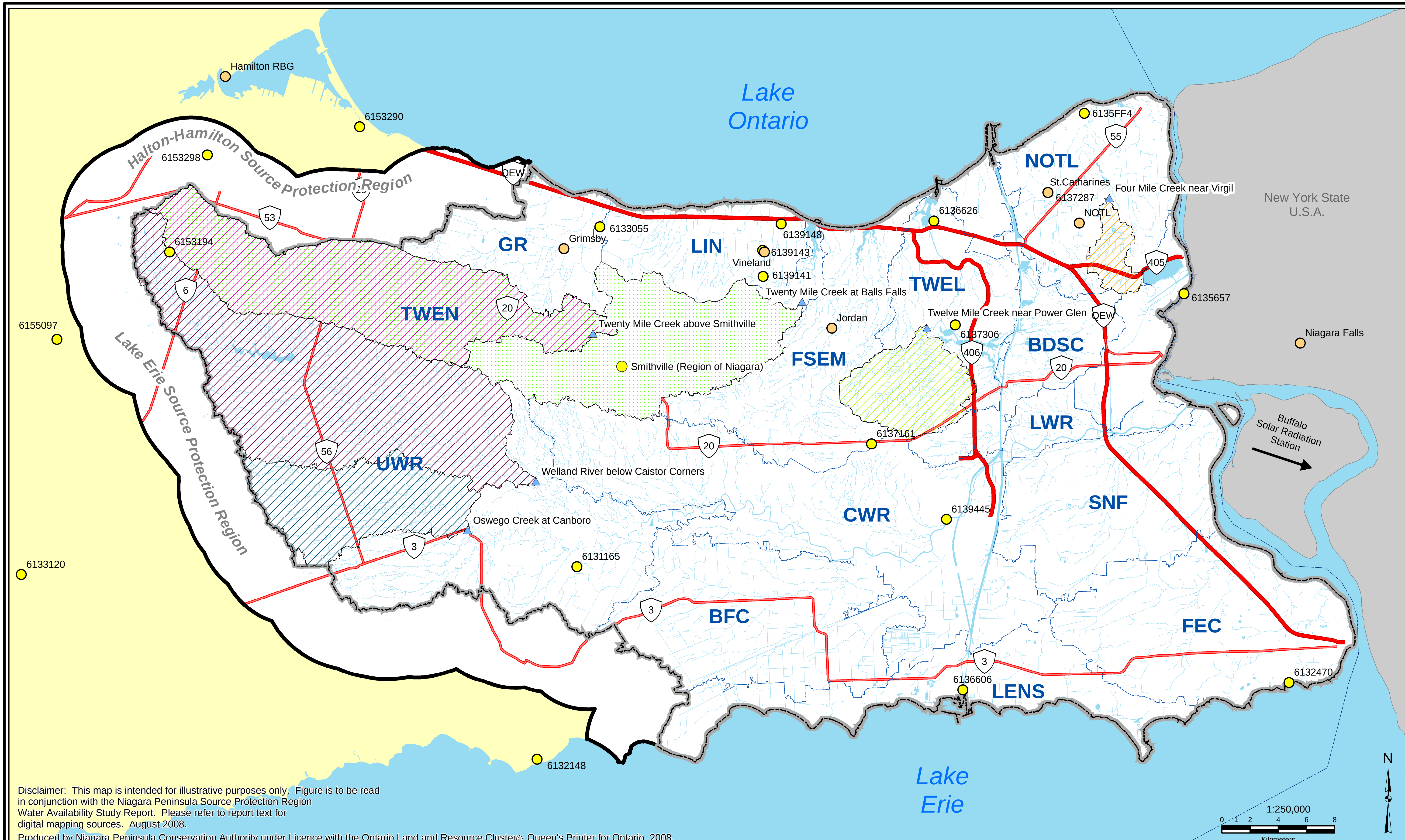


Figure 1.1. Study Area



Legend

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

Water Survey Canada Stream Gage Drainage Area

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

DRINKING WATER SOURCE PROTECTION
Niagara Peninsula Source Protection Area

Water Availability Study

Figure 2.1. Study Meterological Stations and Stream Gauges

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

Ontario

Figure 2.2
MEAN (1991-2005) MONTHLY PRECIPITATION
UPPER WELLAND WATERSHED PLANNING AREA

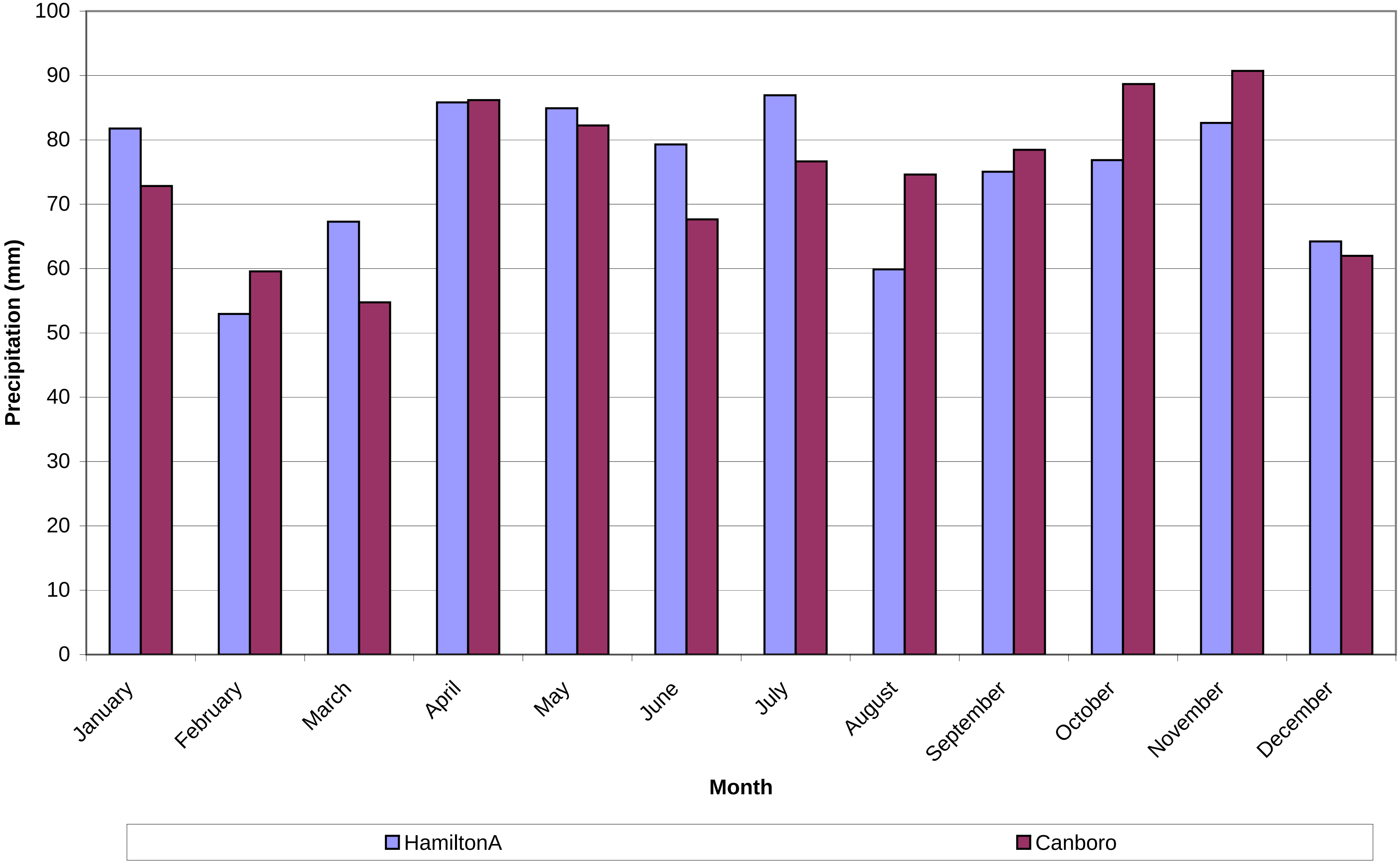
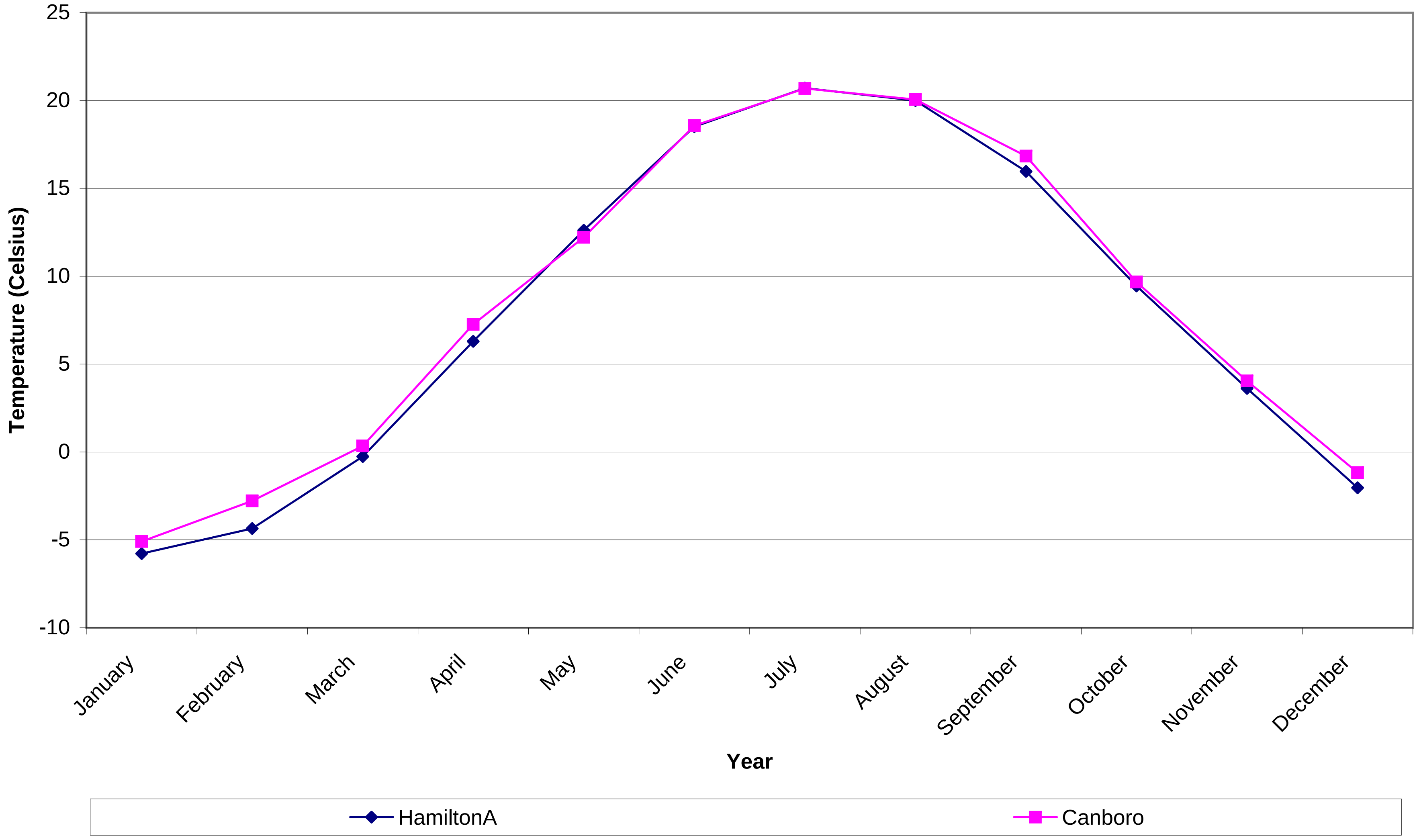


Figure 2.3
MEAN (1991-2005) MONTHLY TEMPERATURE
UPPER WELLAND WATERSHED PLAN AREA



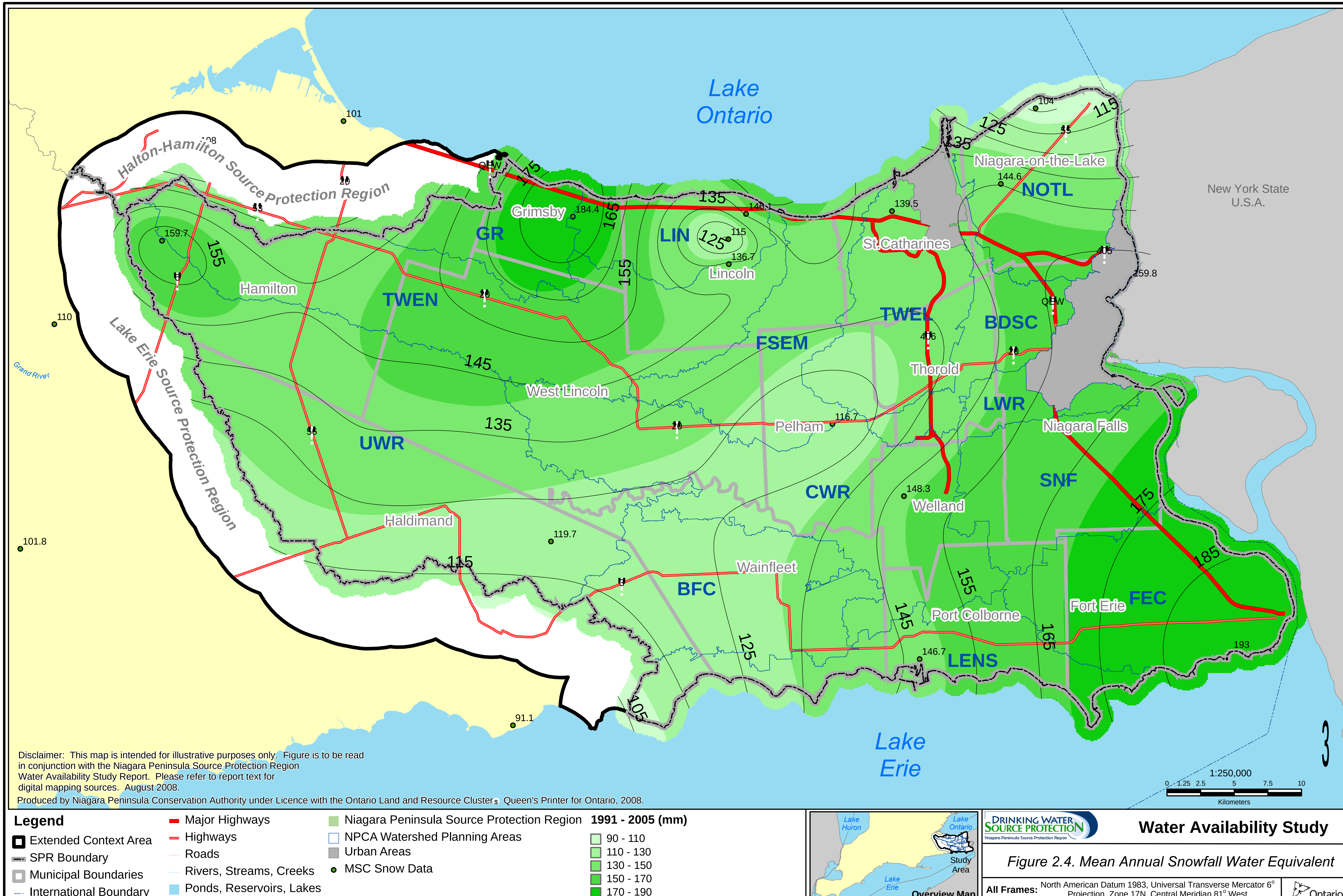
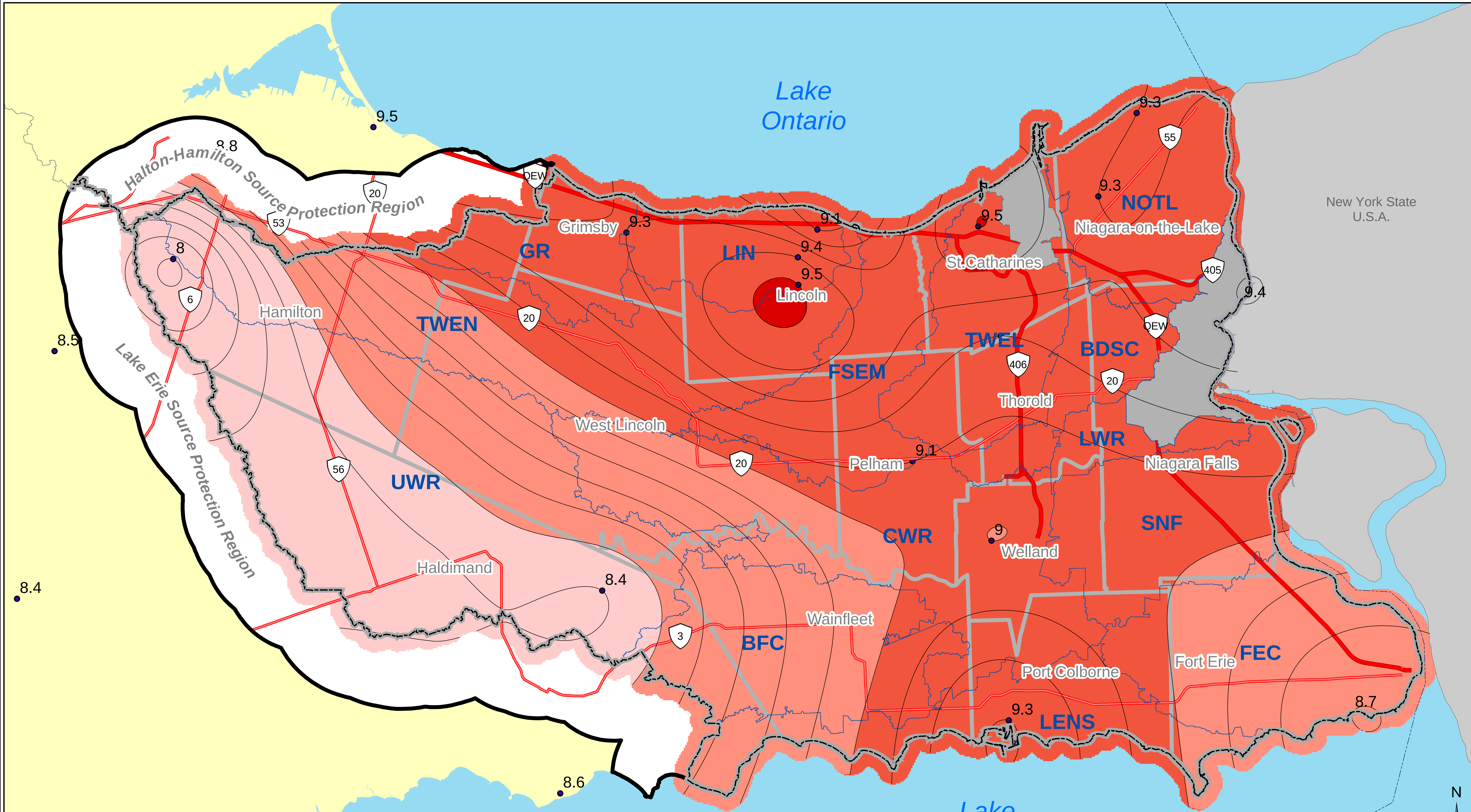


Figure 2.4. Mean Annual Snowfall Water Equivalent



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

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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 Temperature Stations

1991 - 2005 (oC)

- 8.0 - 8.5
- 8.5 - 9.0
- 9.0 - 9.5
- 9.5 - 10.0

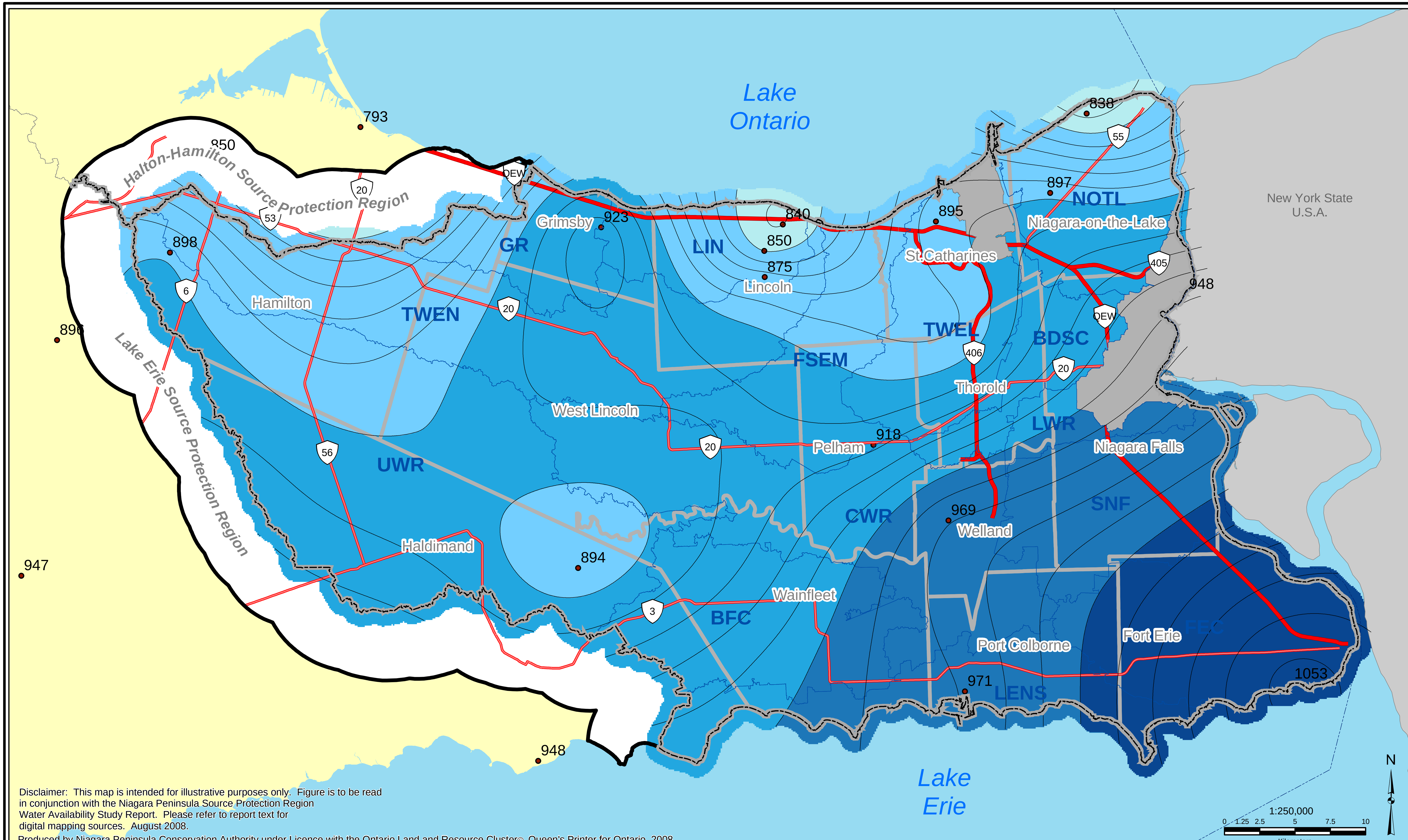
DRINKING WATER SOURCE PROTECTION
Niagara Peninsula Source Protection Area

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



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

Legend

- Extended Context Area
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- Ponds, Reservoirs, Lakes
- Niagara Peninsula Source Protection Region
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- Urban Areas
- MSC Temperature Stations

1991 - 2005 (mm)

- 800 - 850
- 850 - 900
- 900 - 950
- 950 - 1000
- 1000 - 1050

DRINKING WATER SOURCE PROTECTION
Niagara Peninsula Source Protection Area

Water Availability Study

Figure 2.6. Mean Annual Precipitation

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

Ontario

Figure 2.7
ANNUAL PRECIPITATION - UPPER WELLAND WATERSHED PLANNING AREA

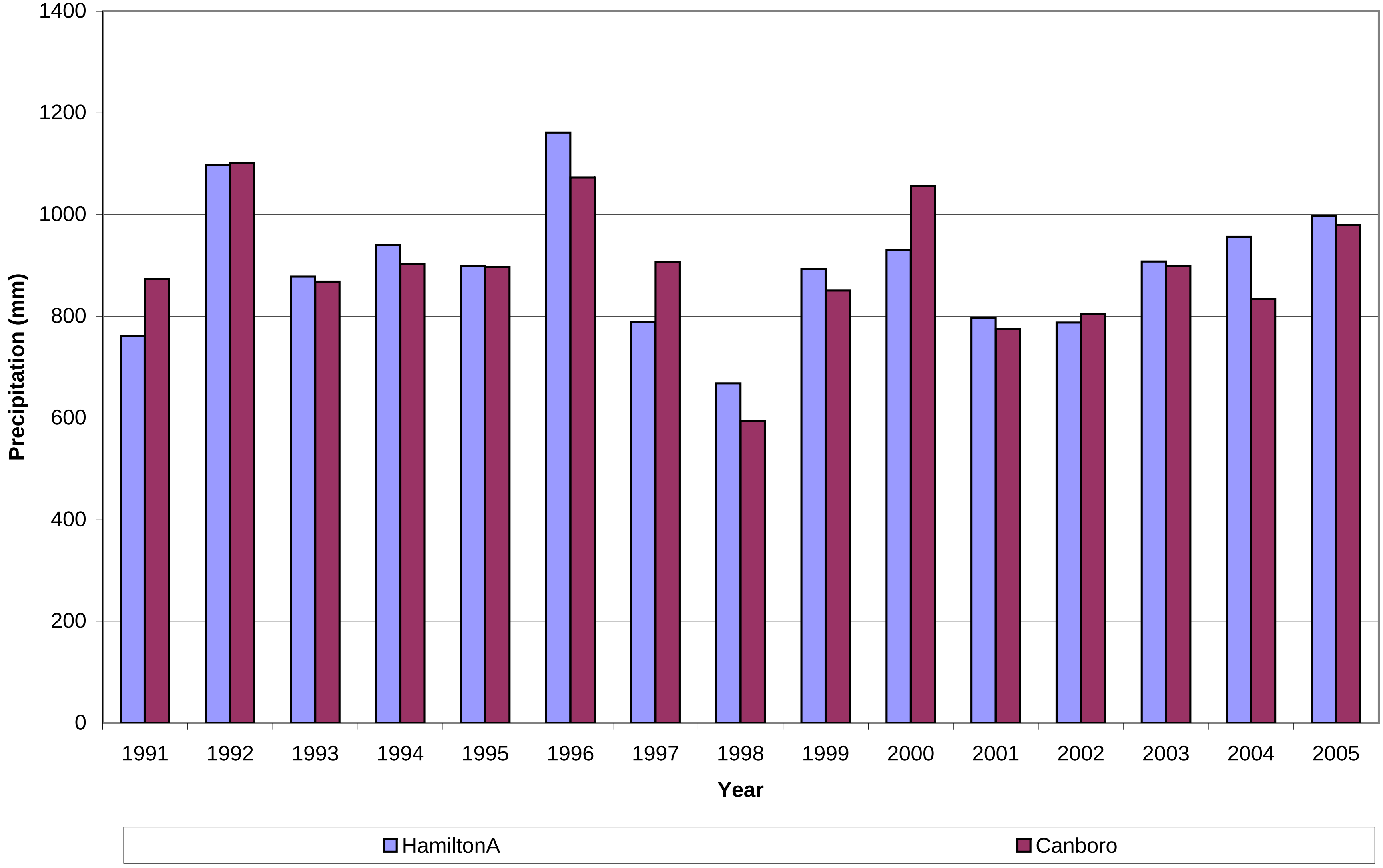


Figure 2.8
ANNUAL SNOW WATER EQUIVALENT
UPPER WELLAND WATERSHED PLANNING AREA

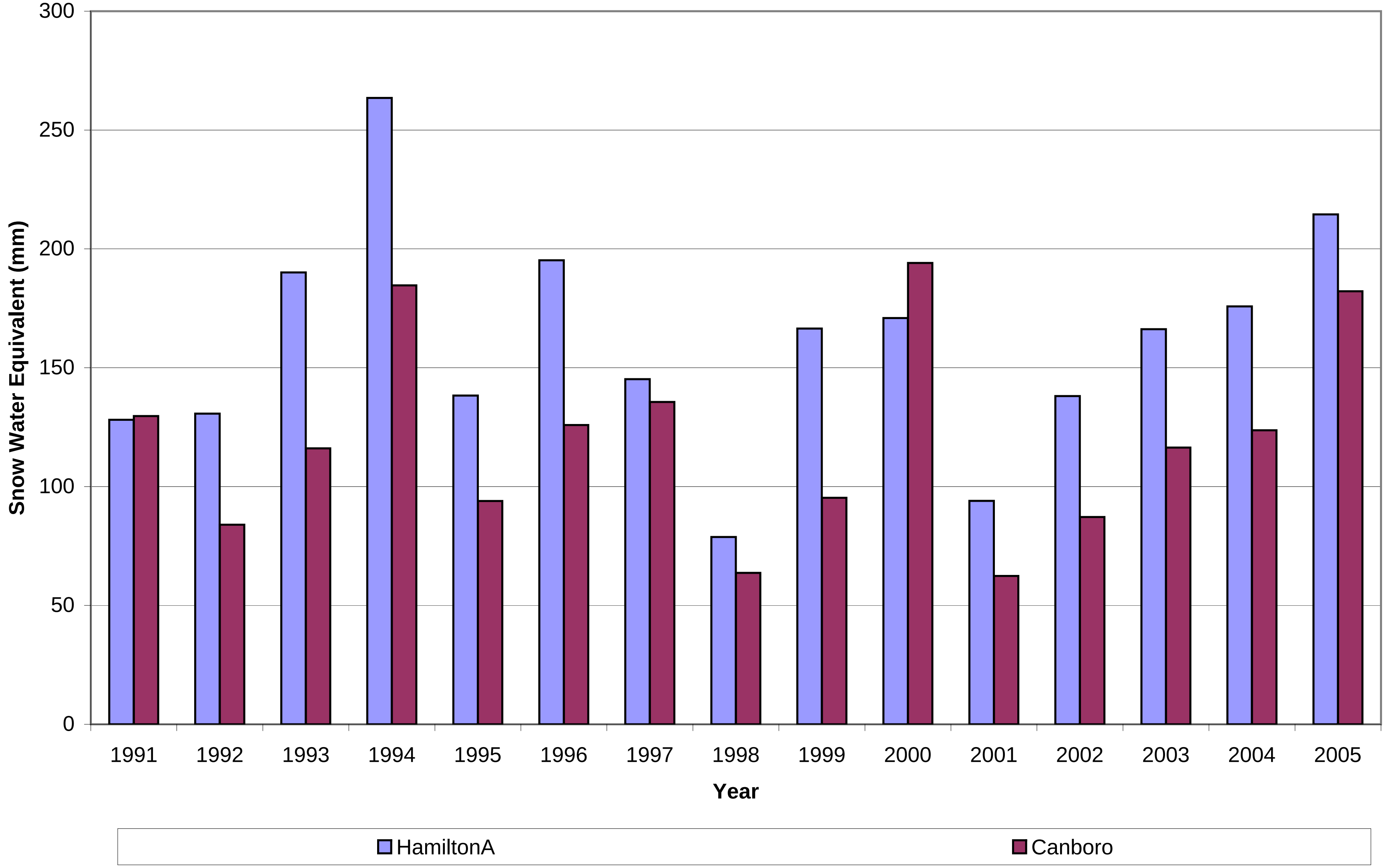


Figure 2.9
MEAN (1991-2005) ANNUAL TEMPERATURE
UPPER WELLAND WATERSHED PLAN AREA

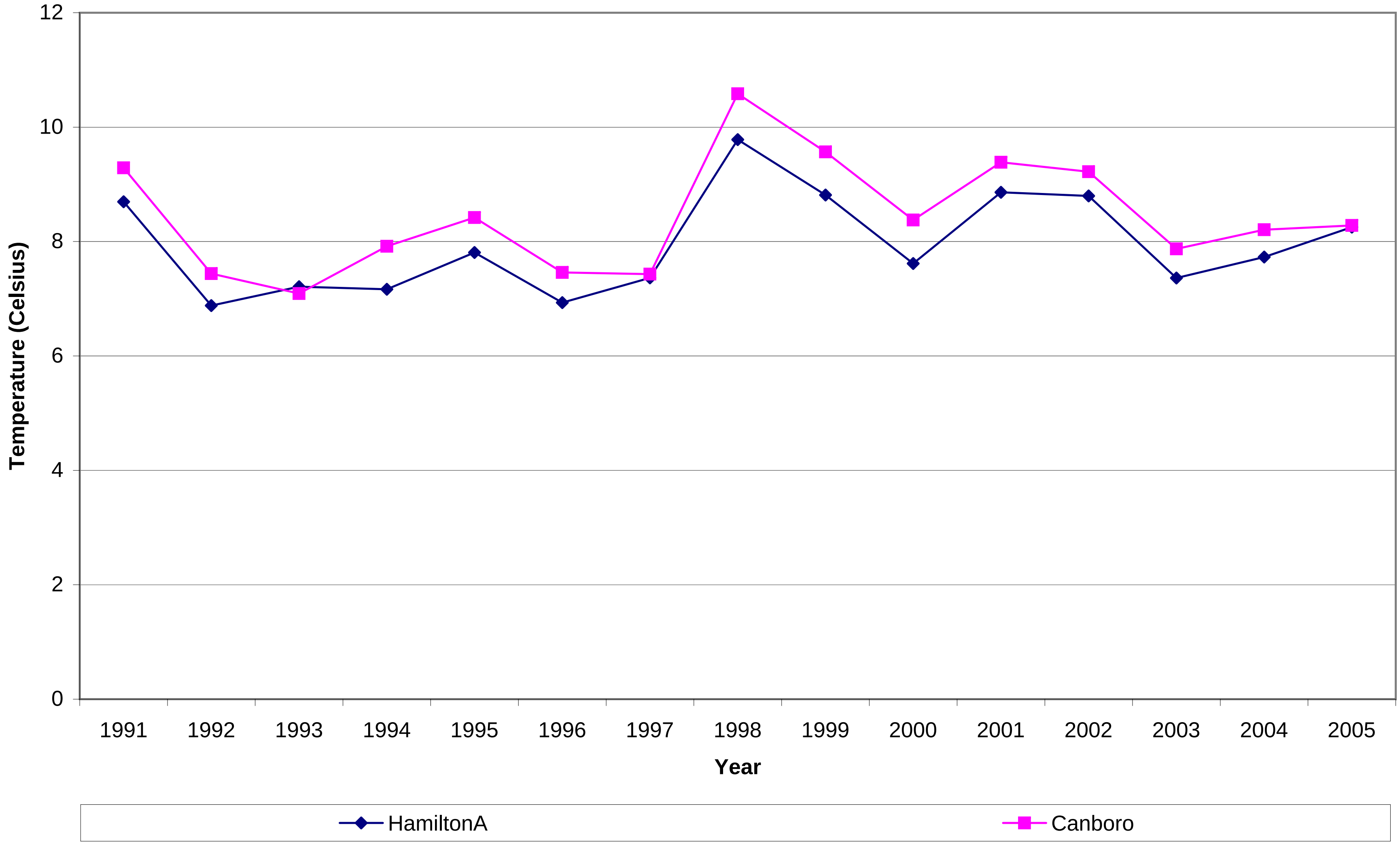


Figure 2.10
ANNUAL NET SOLAR RADIATION

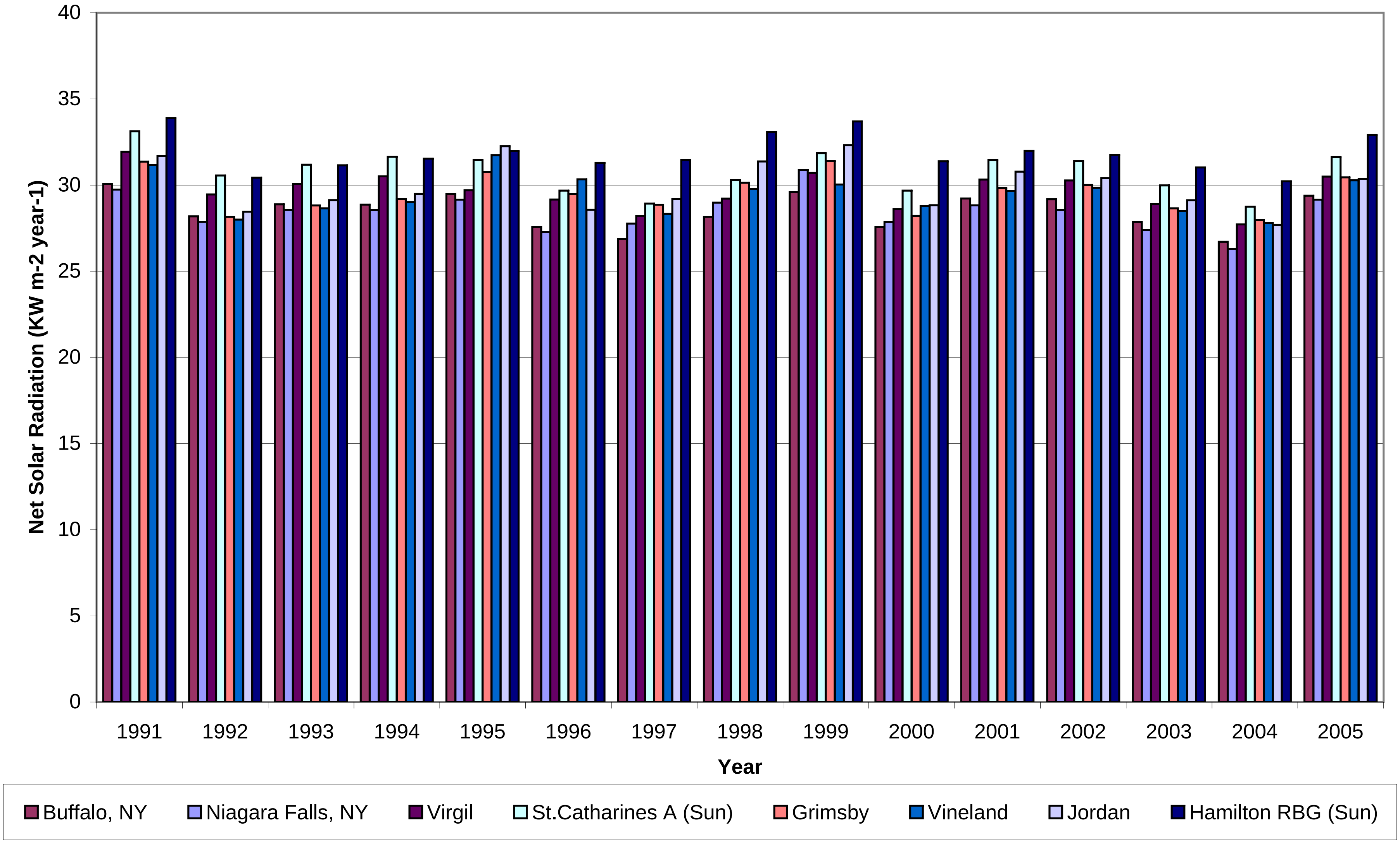


Figure 2.11
MEAN (1991-2005) MONTHLY NET SOLAR RADIATION

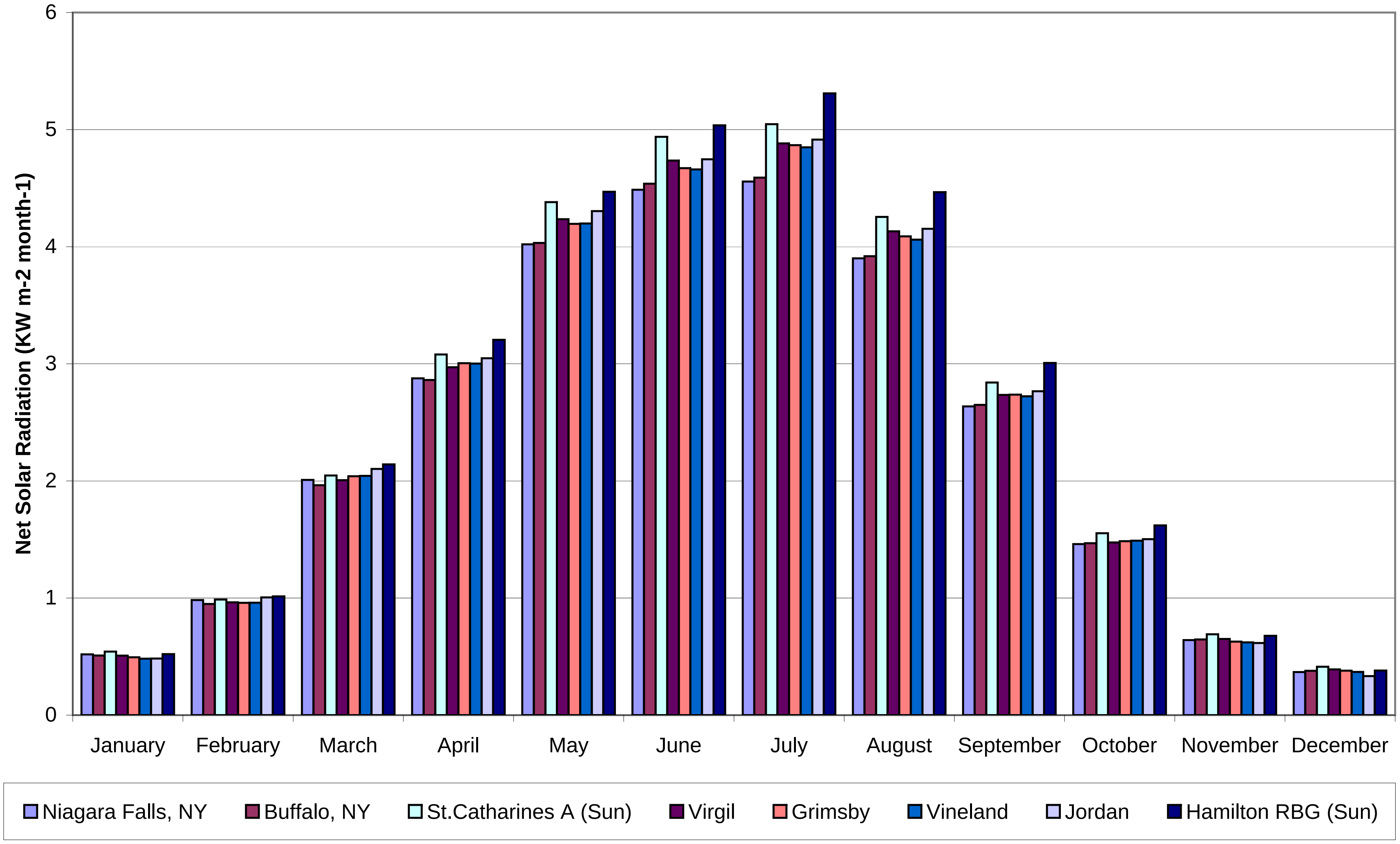


Figure 2.12a
Channel Profile of Upper Welland River
(Oswego Creek system not shown)

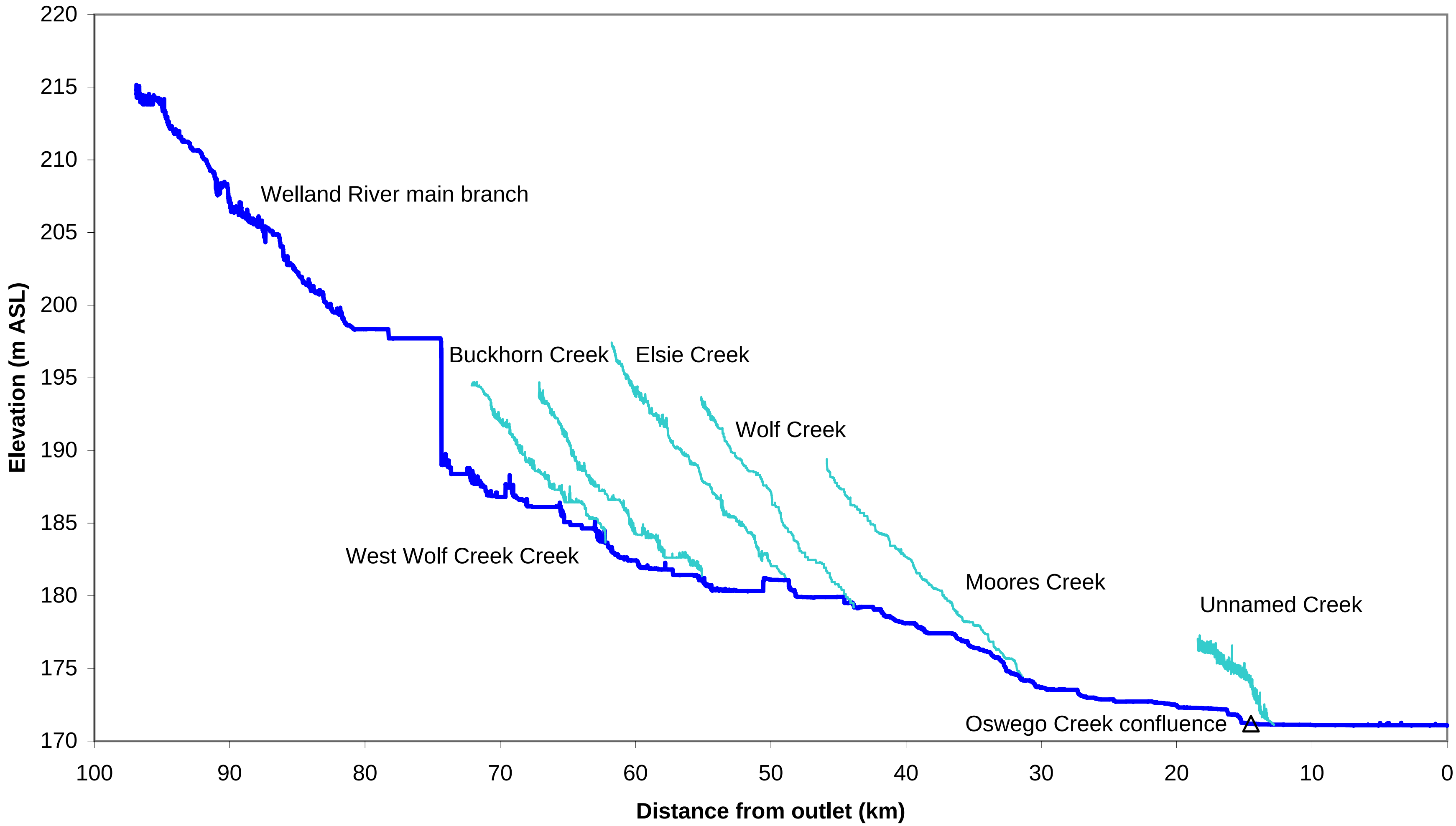
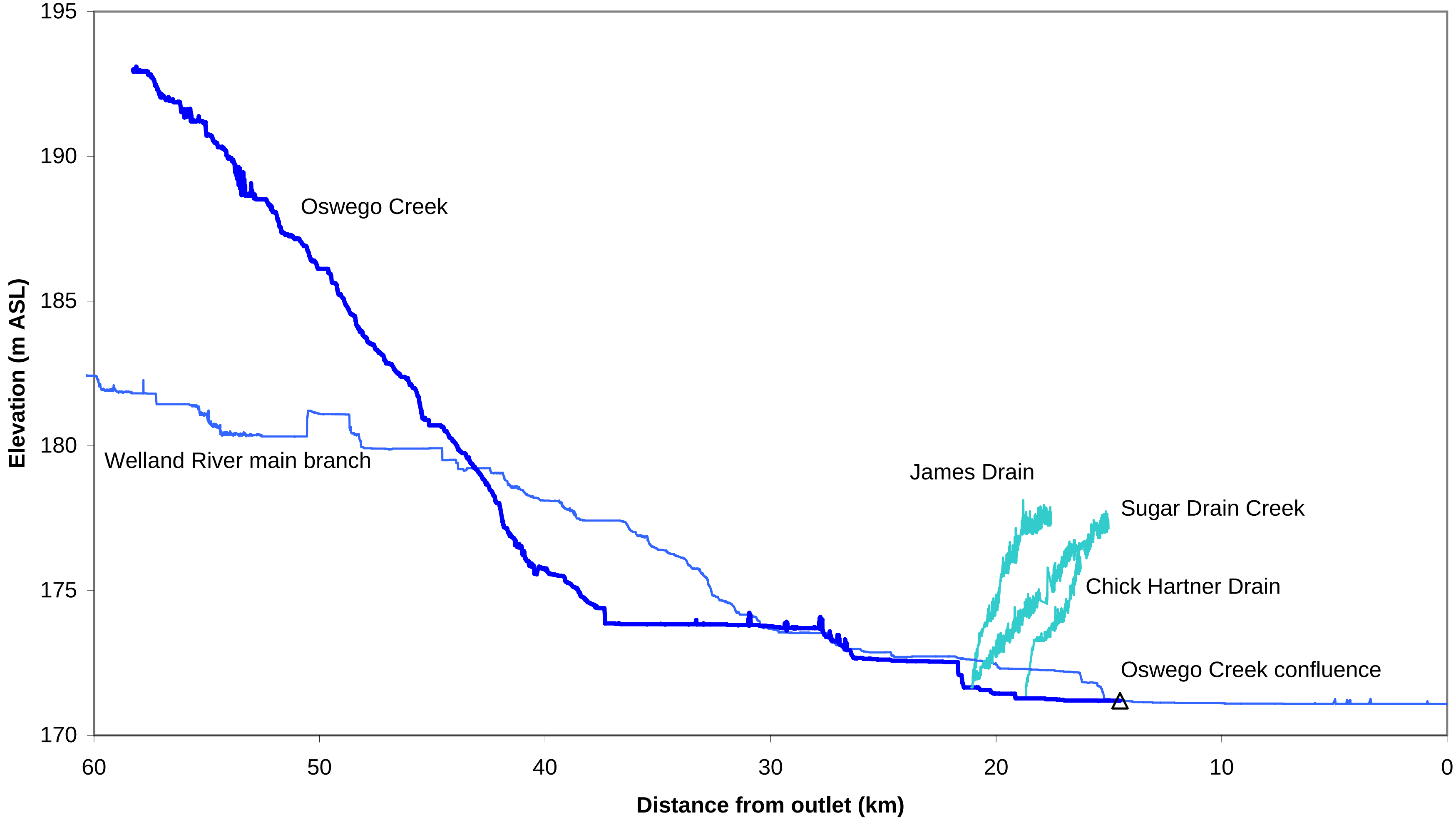
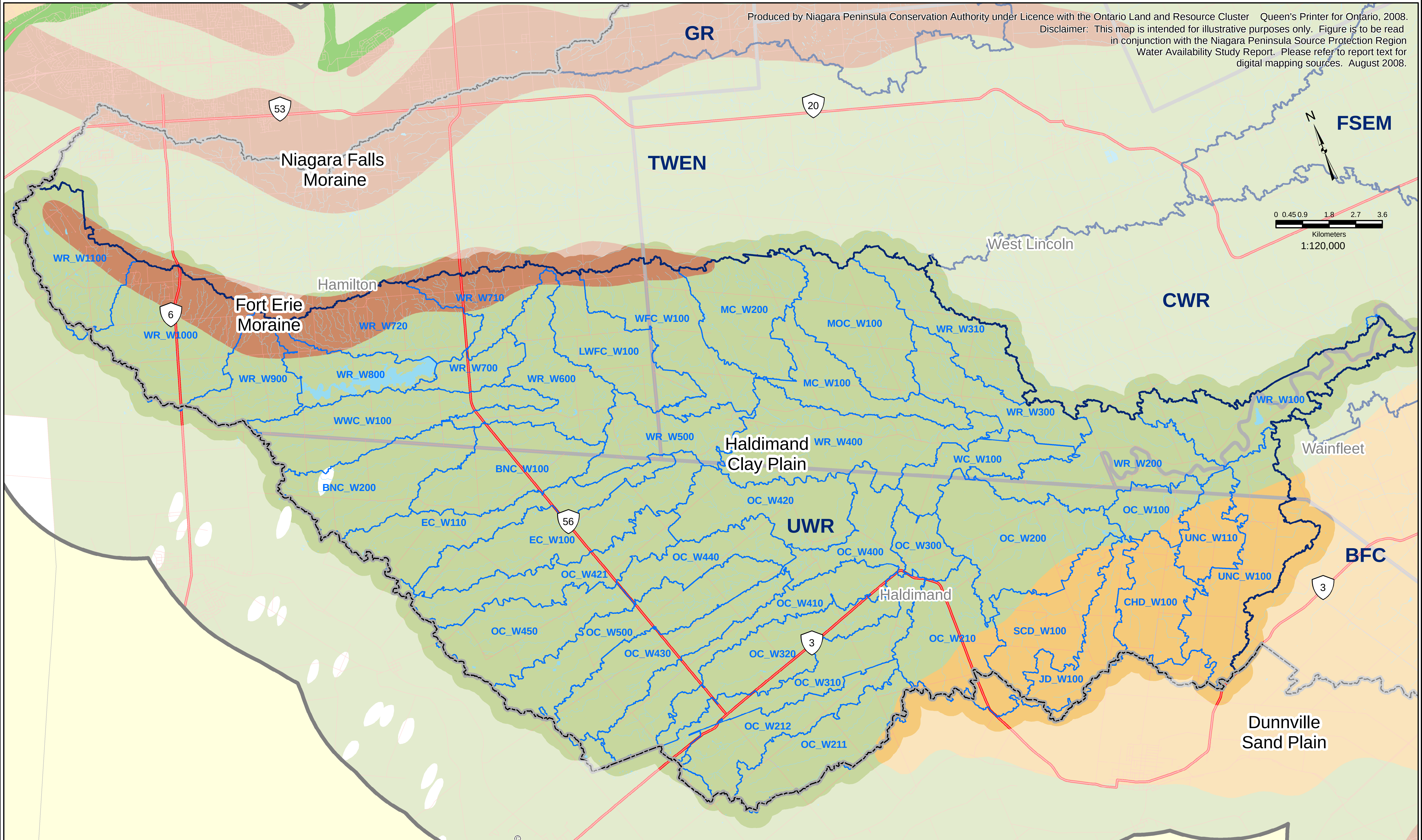


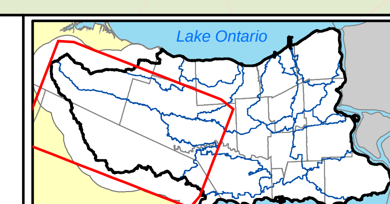
Figure 2.12b
Channel Profile of Oswego Creek
(Welland River Tributaries and Upper portion not shown)





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
- WR_W100: Subcatchment ID
- Beaches and Shorecliffs
- Escarpment
- Clay Plain
- Sand Plain
- Till Moraine
- Kame Moraine
- Peat and Muck
- Limestone Plain
- Shale Plain
- Water



DRINKING WATER SOURCE PROTECTION
Niagara Peninsula Source Protection Region

Water Availability Study

Figure 2.13. UWR Physiography

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

Ontario

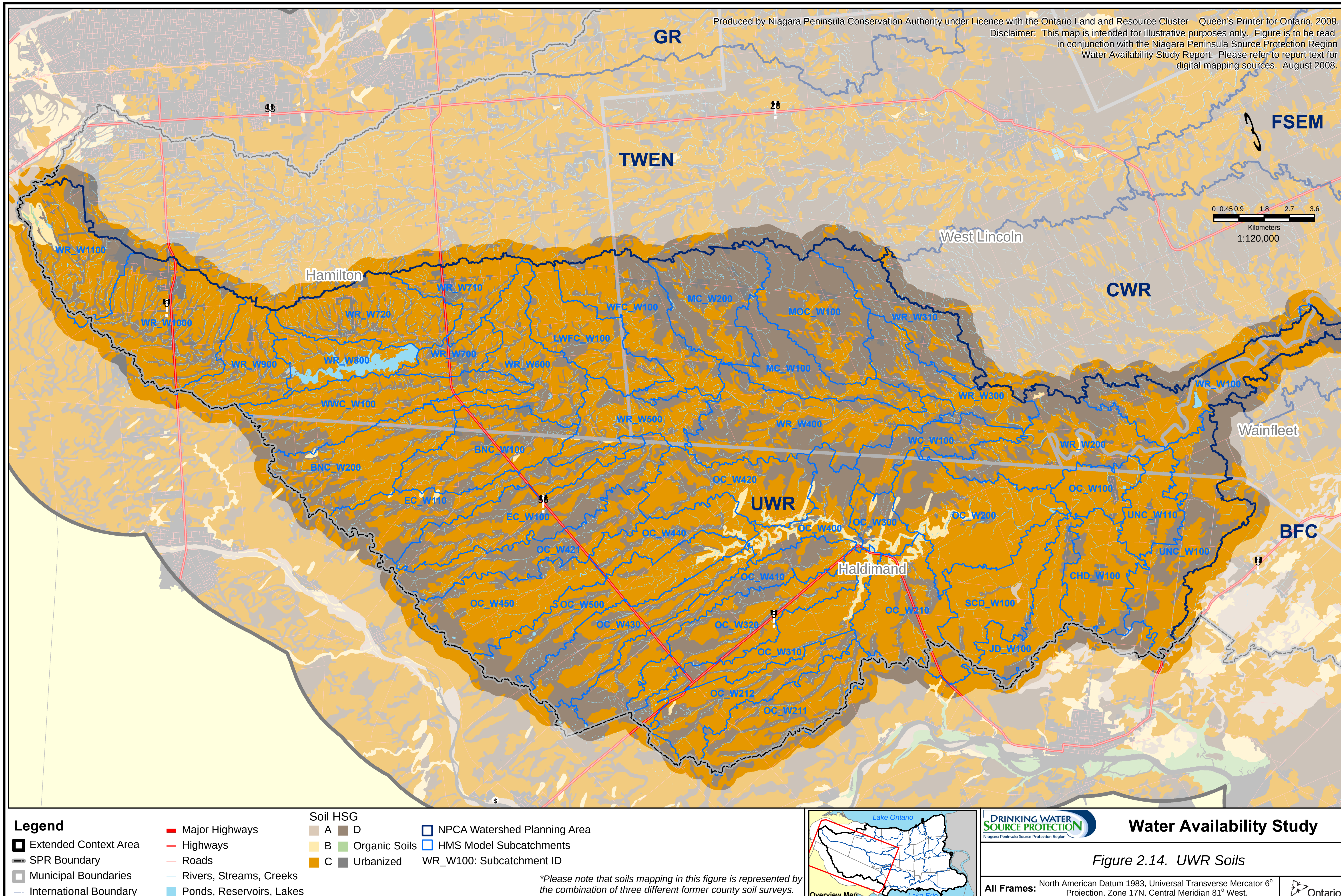
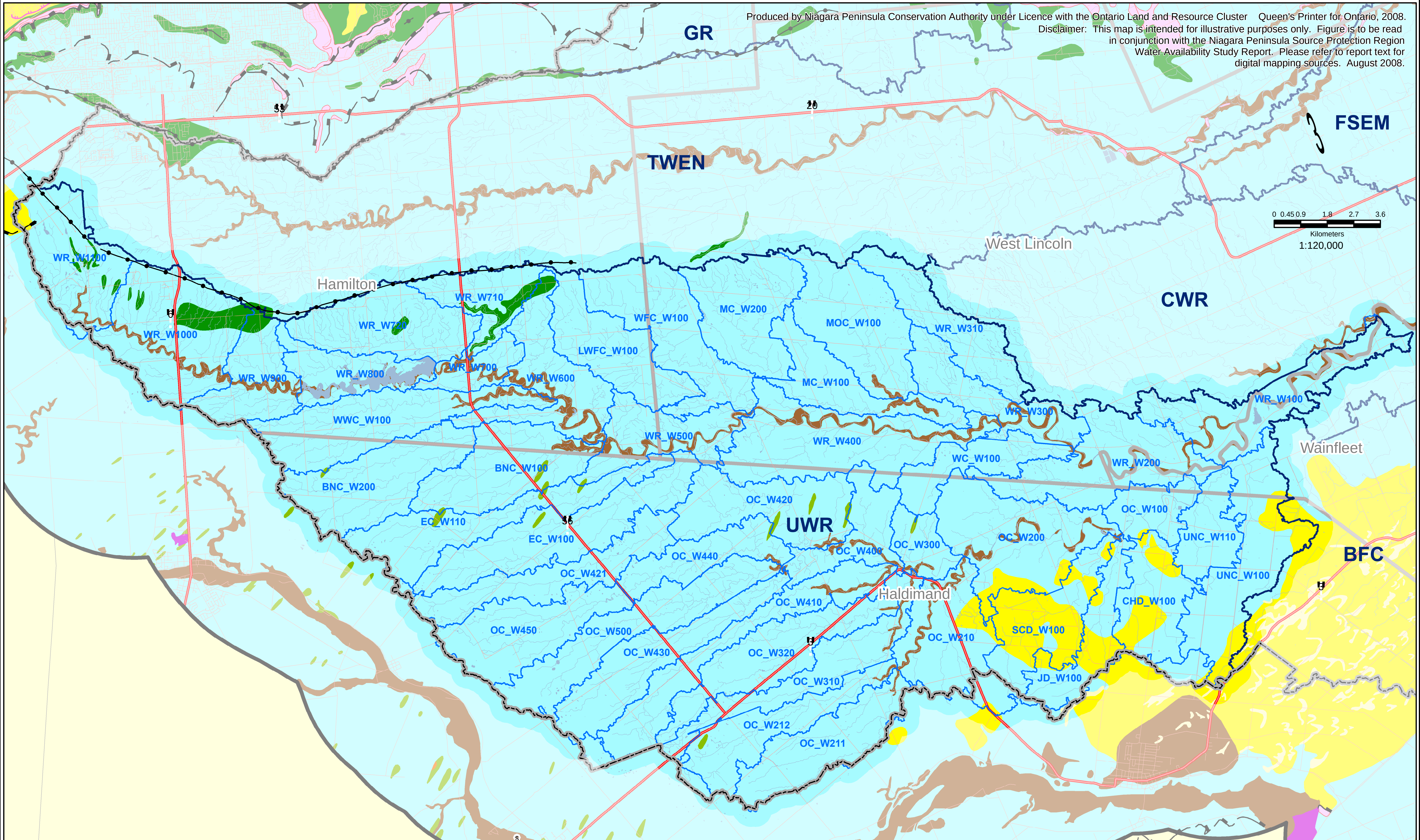


Figure 2.14. UWR Soils



Legend

- Extended Context Area
- SPR Boundary
- Municipal Boundaries
- NPCA WSPA
- HMS Model Basins
- Major Highways
- Highways
- Roads
- Ponds, Reservoirs, Lakes
- Rivers, Streams, Creeks
- Sand and Gravel Pit
- Quarry
- Abandonded Shore Bluff
- End Moraine
- Escarpment
- Ice Contact Slope
- Moraine Crest
- Paleozoic bedrock (outcrop)
- Stone-poor, carbonate-derived silty to sandy till
- Glaciolacustrine-derived silty to clayey till
- Ice-contact stratified deposits
- Glaciofluvial deposits
- Fine-textured glaciolacustrine deposits
- Coarse-textured glaciolacustrine deposits
- Coarse-textured glaciolacustrine deposits
- Older alluvial deposits
- Coarse-textured lacustrine deposits
- Eolian deposits
- Modern alluvial deposits
- Organic deposits
- Man-made deposits

WR_W100: Subcatchment ID

Overview Map — Lake Ontario — Lake Erie

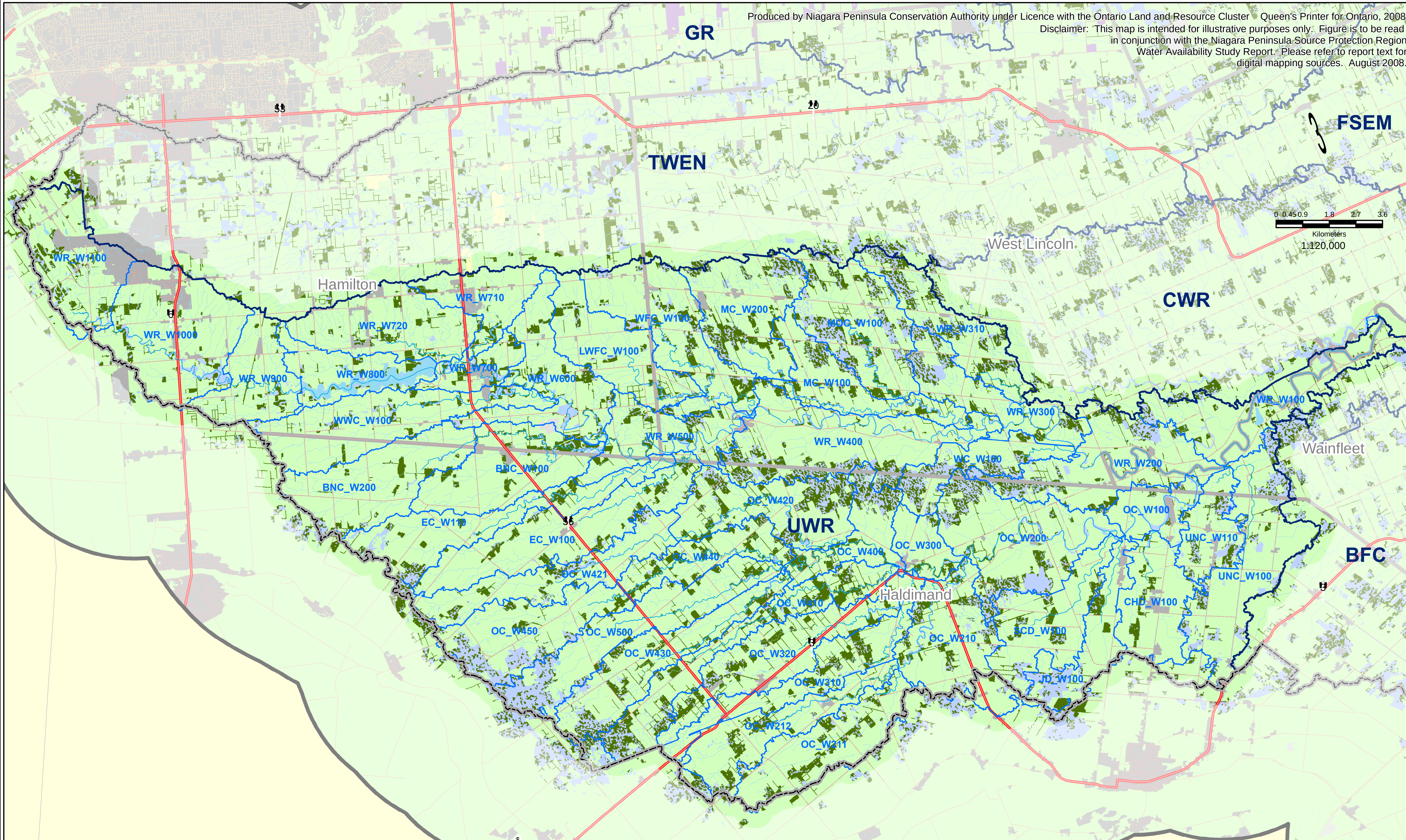
DRINKING WATER SOURCE PROTECTION — Niagara Peninsula Source Protection Region

Water Availability Study

Figure 2.15. UWR Surficial Geology

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

Ontario



Legend

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- Highways
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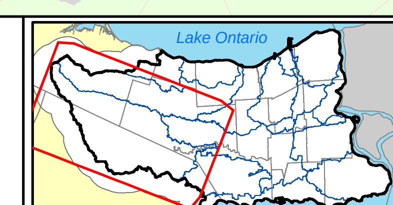
- Rivers, Streams, Creeks
- Ponds, Reservoirs, Lakes
- NPCA Watershed Planning Area
- HMS Model Subcatchments
- HMS Model Reaches
- WR_W100: Subcatchment ID

Land Cover

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



DRINKING WATER SOURCE PROTECTION
Niagara Peninsula Source Protection Region

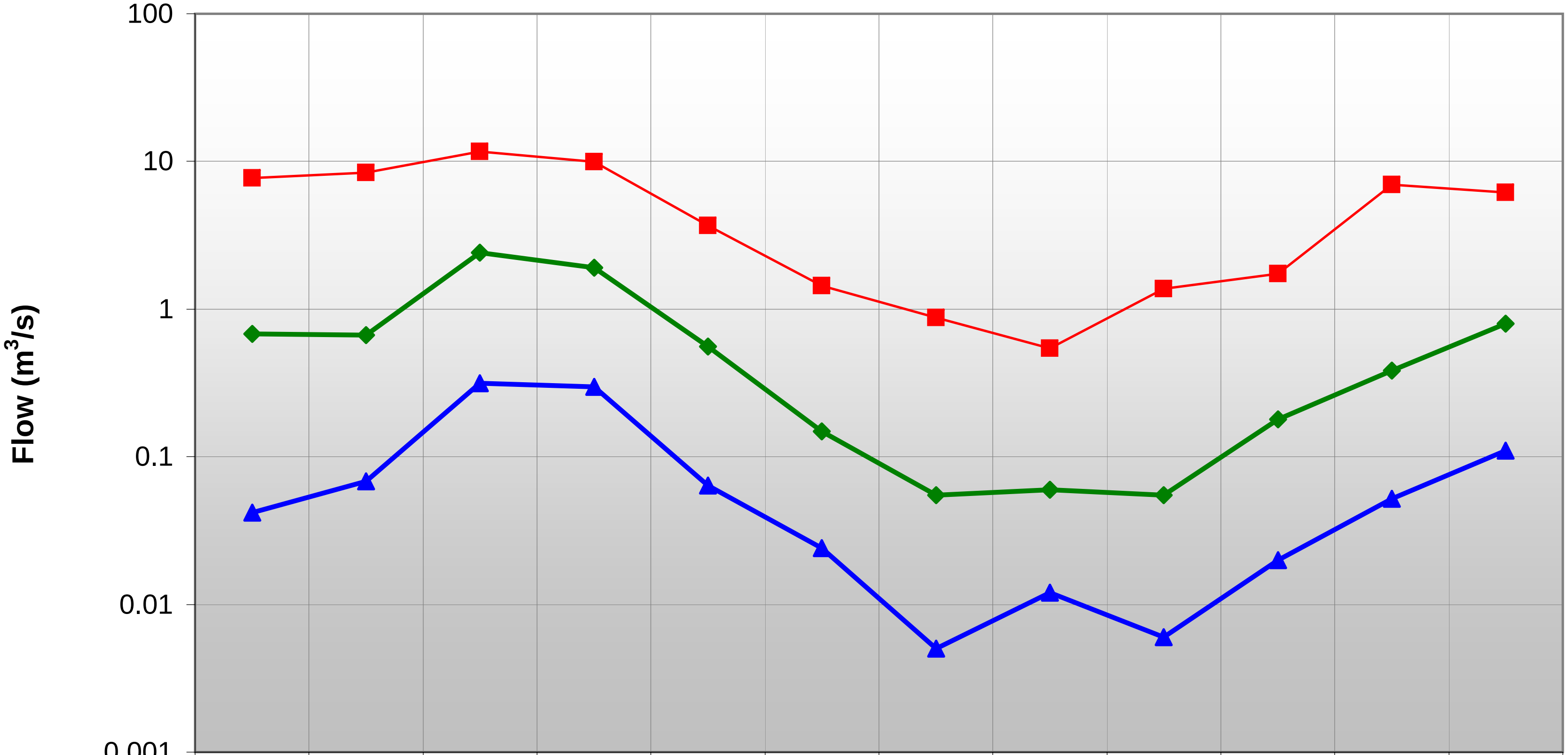
Water Availability Study

Figure 2.16. UWR Land Cover

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

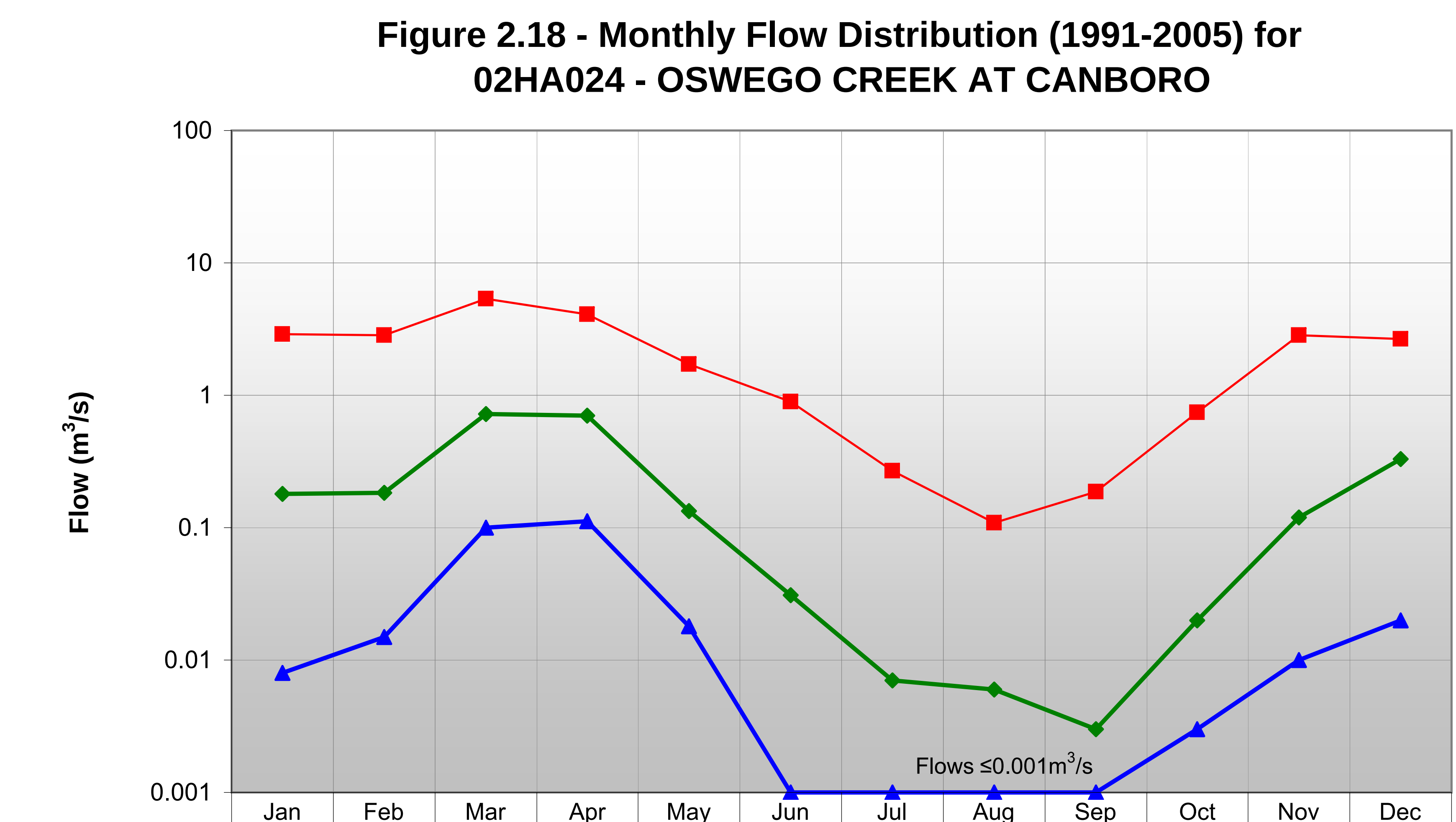
Ontario

Figure 2.17 - Monthly Flow Distribution (1991-2005) for 02HA007 - WELLAND RIVER BELOW CAISTOR CORNERS



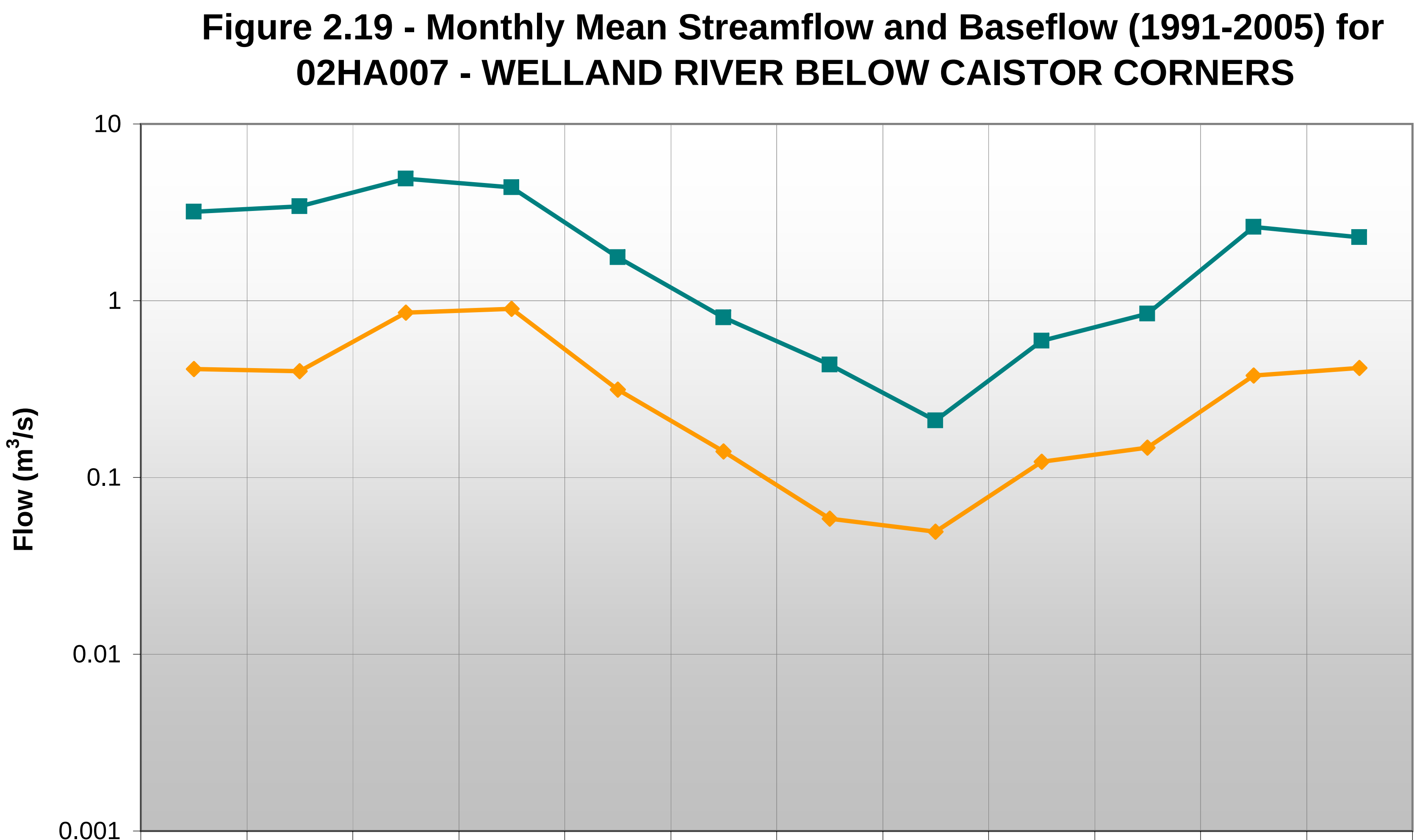
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
10th Percentile	7.690	8.380	11.70	9.920	3.670	1.440	0.873	0.542	1.370	1.740	6.960	6.160
Median	0.679	0.665	2.400	1.900	0.558	0.149	0.055	0.060	0.055	0.180	0.383	0.797
90th Percentile	0.042	0.068	0.314	0.298	0.064	0.024	0.005	0.012	0.006	0.020	0.052	0.110

Month



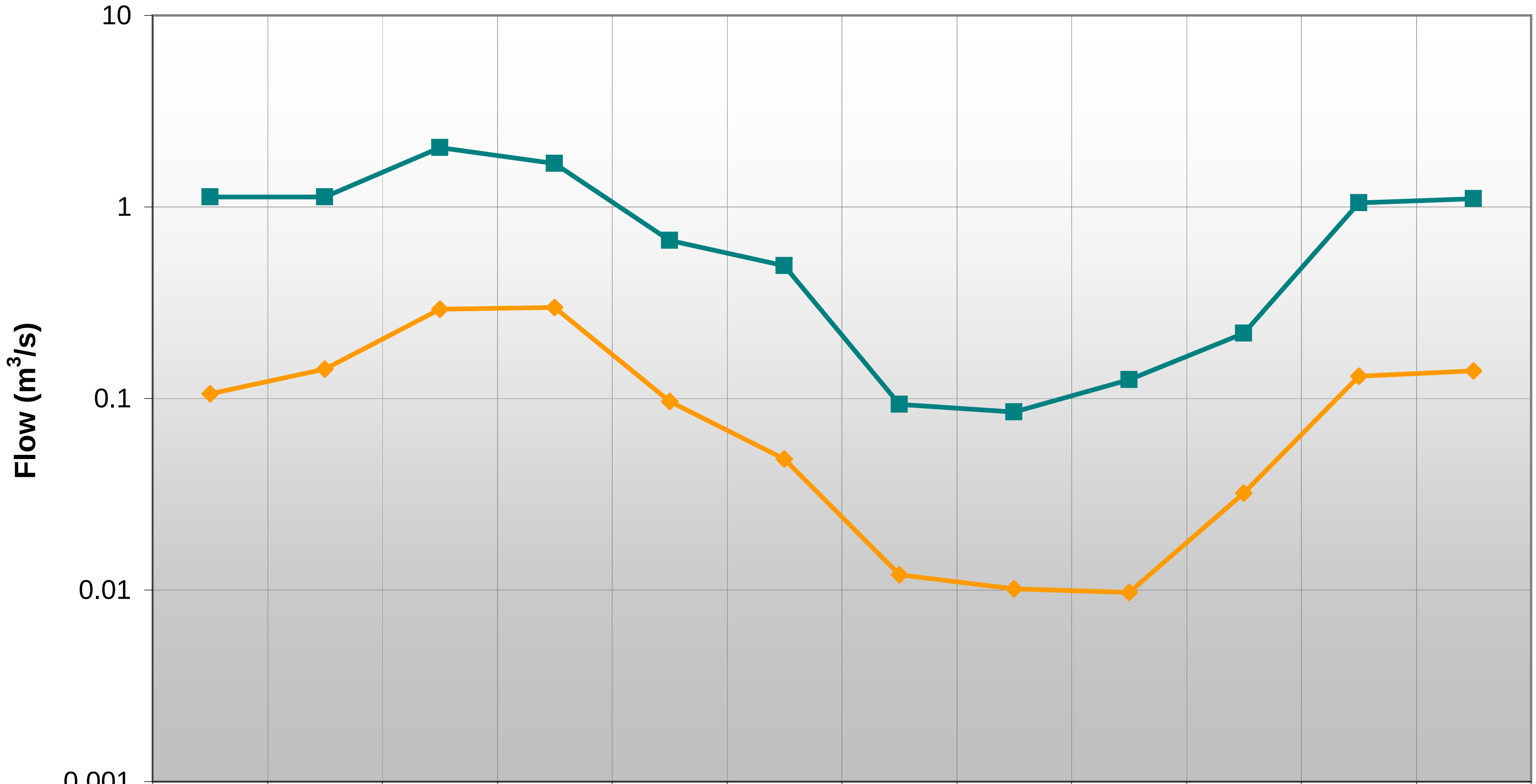
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
10th Percentile	2.900	2.850	5.360	4.070	1.720	0.898	0.269	0.109	0.186	0.739	2.830	2.660
Median	0.180	0.183	0.719	0.701	0.133	0.031	0.007	0.006	0.003	0.020	0.119	0.330
90th Percentile	0.008	0.015	0.100	0.112	0.018	0.001	0.001	0.001	0.001	0.003	0.010	0.020

Month



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Streamflow	3.19	3.43	4.89	4.37	1.75	0.80	0.43	0.21	0.59	0.84	2.61	2.28
Baseflow	0.41	0.40	0.86	0.90	0.31	0.14	0.06	0.05	0.12	0.15	0.38	0.42

Figure 2.20 - Monthly Mean Streamflow and Baseflow (1991-2005) for 02HA024 - OSWEGO CREEK AT CANBORO



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Streamflow	1.12	1.13	2.05	1.68	0.67	0.49	0.09	0.08	0.13	0.22	1.05	1.10
Baseflow	0.11	0.14	0.29	0.30	0.10	0.05	0.01	0.01	0.01	0.03	0.13	0.14

Month

Conceptualization of Hydrologic Processes in HEC-HMS

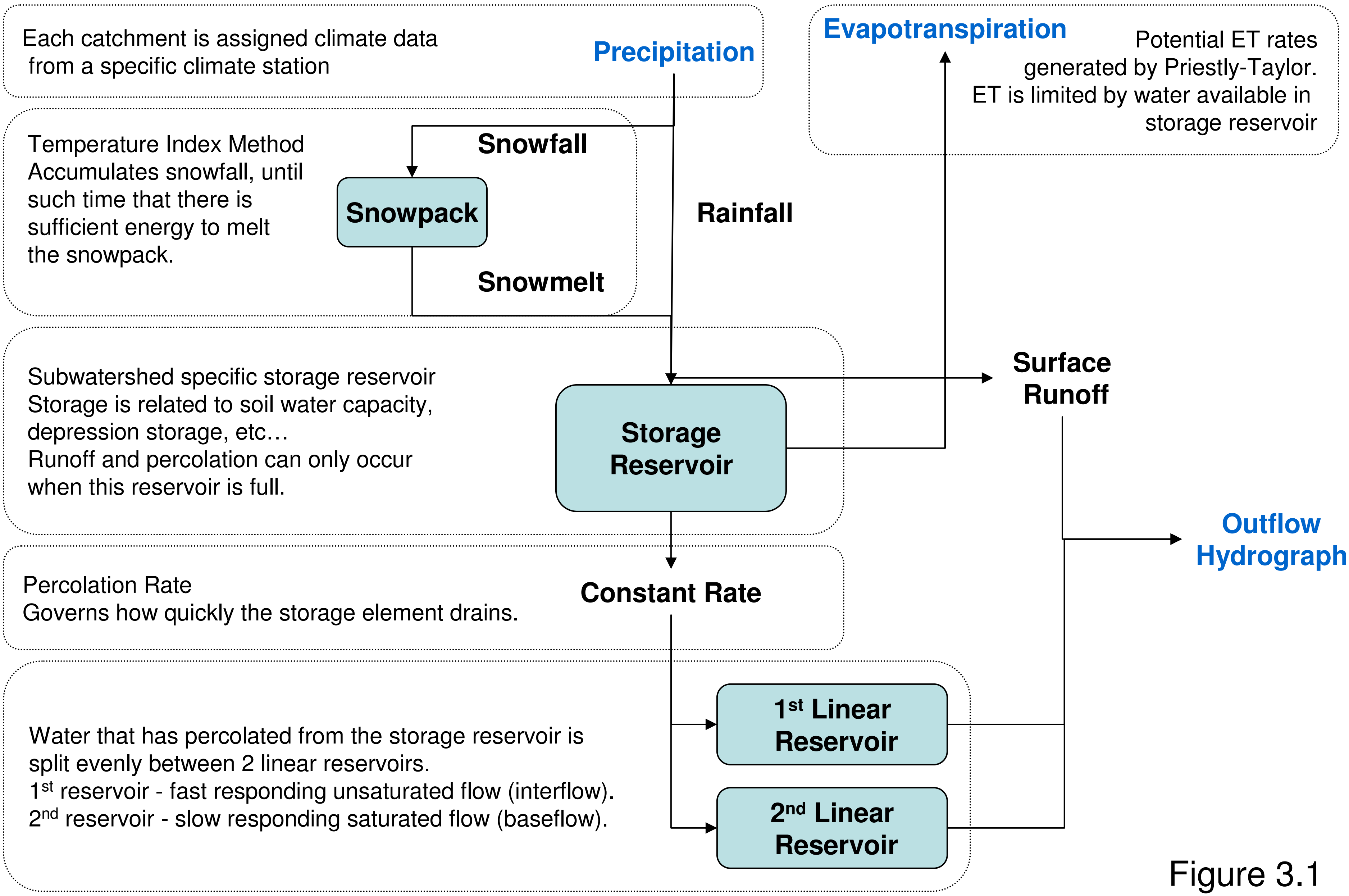
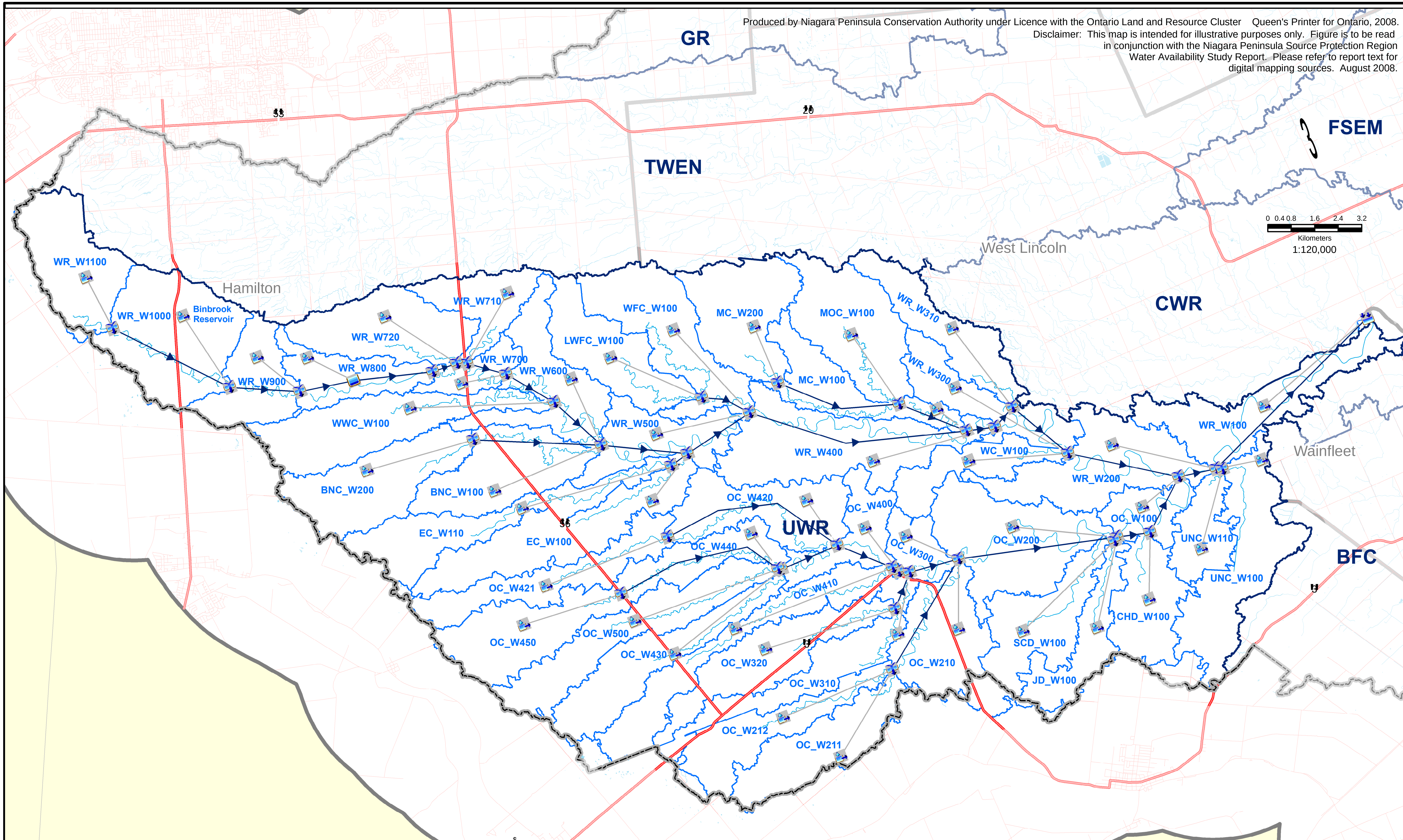


Figure 3.1



Legend

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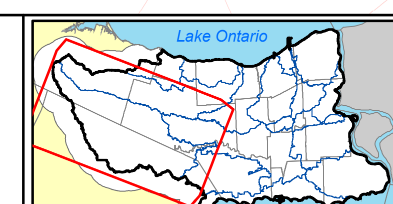
- HMS Model Subcatchments
- HMS Model Reaches
- WR_W100: Subcatchment ID

HMS Legend

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



DRINKING WATER SOURCE PROTECTION
Niagara Peninsula Source Protection Region

Water Availability Study

Figure 3.2. UWR Catchments and HMS Schematic

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

Ontario

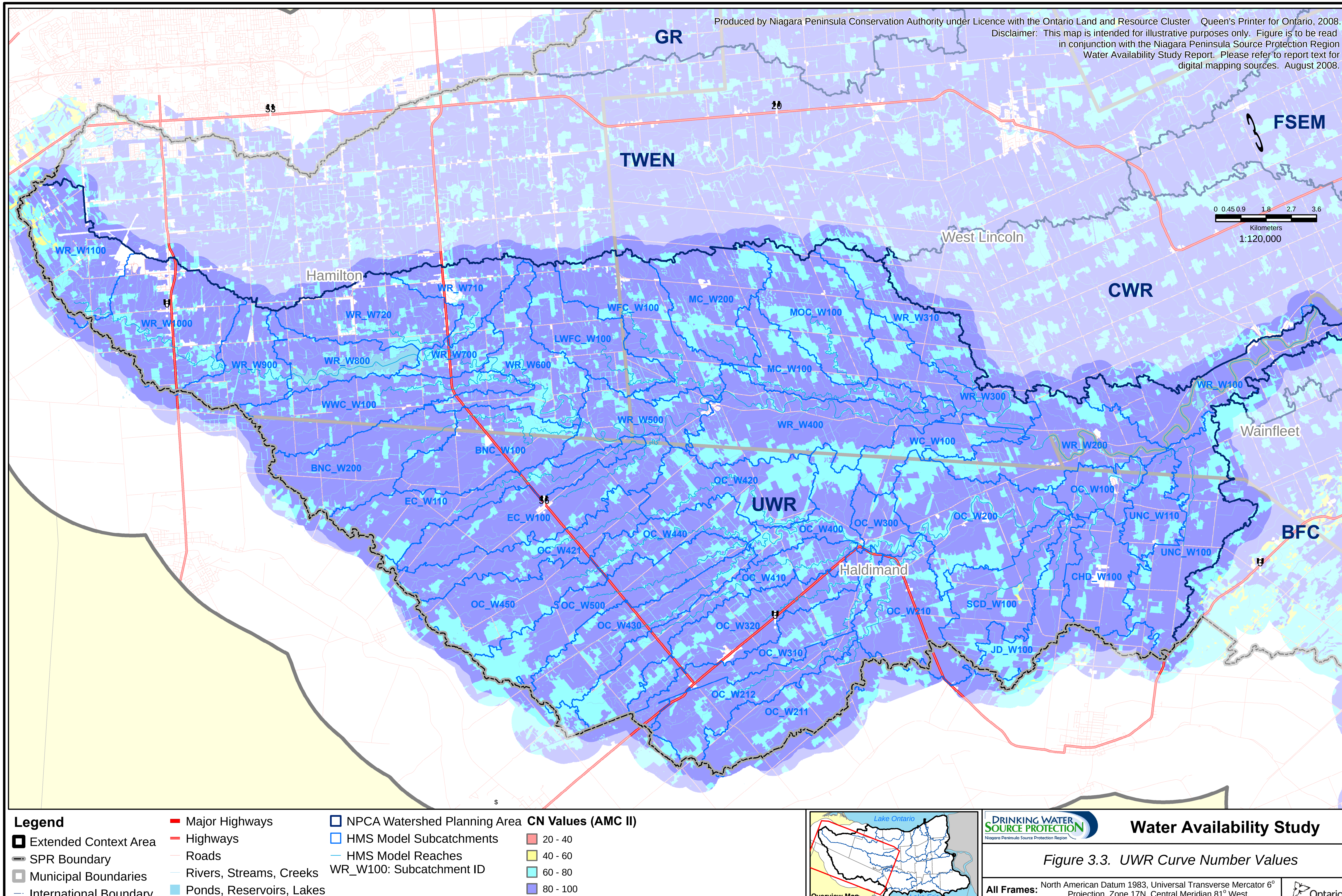


Figure 3.3. UWR Curve Number Values

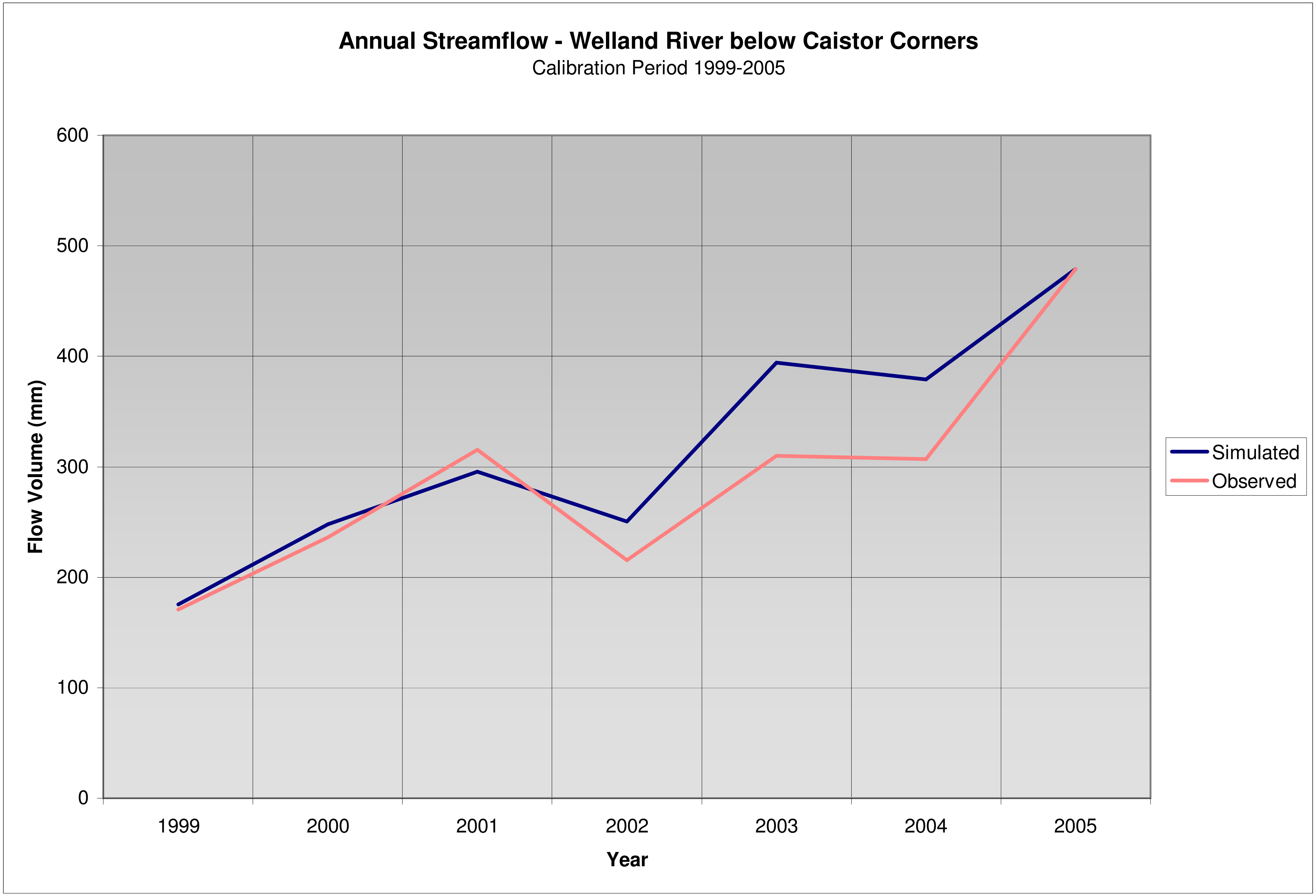
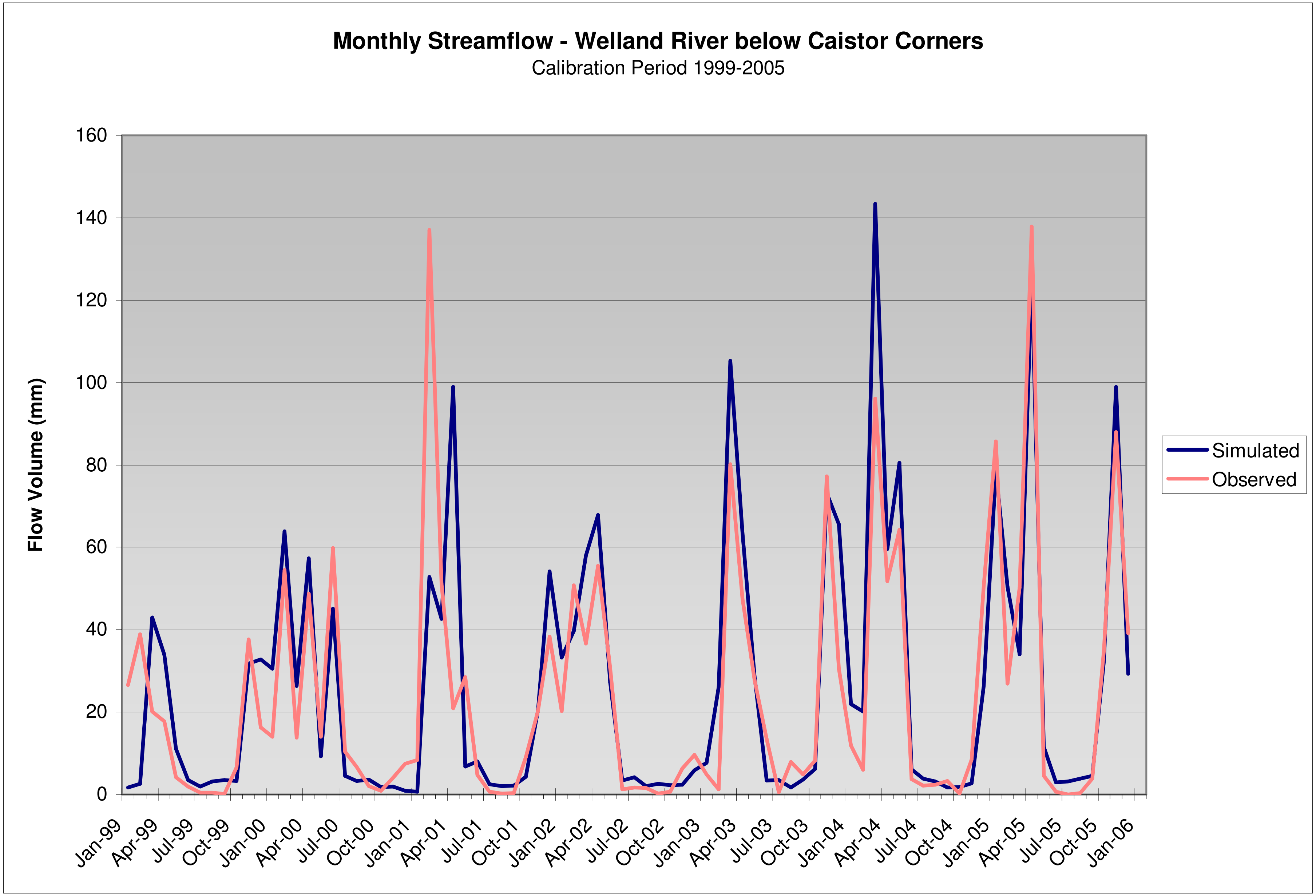

Annual Streamflow - Welland River below Caistor Corners
Calibration Period 1999-2005
Flow Volume (mm)
600
500
400
300
200
100
0
1999
2000
2001
2002
2003
2004
2005
Year
Simulated
Observed

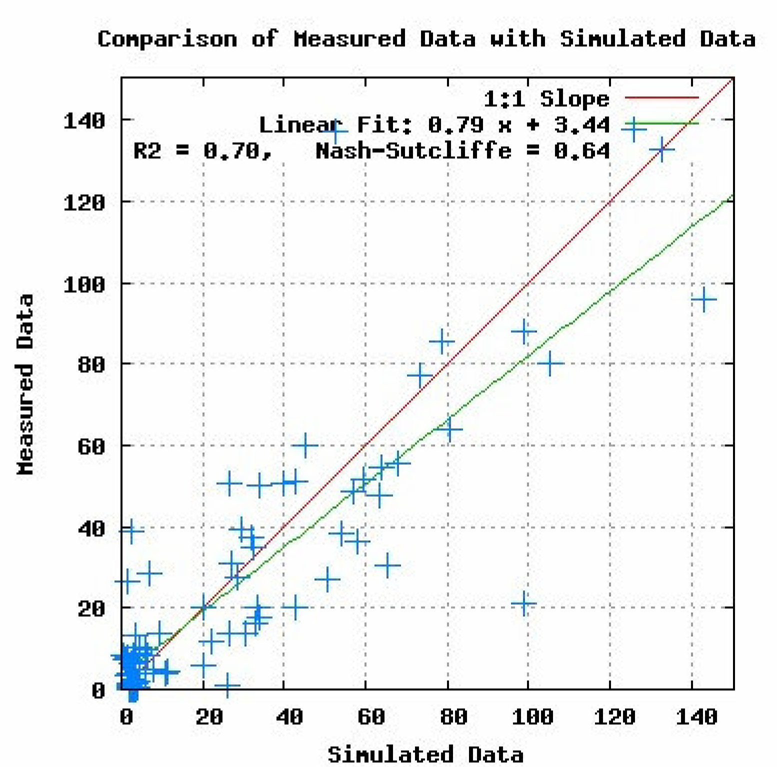
Figure 3.4



Monthly Streamflow - Welland River below Caistor Corners
Calibration Period 1999-2005
Flow Volume (mm)
160
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 3.5

Streamflow



Log Streamflow

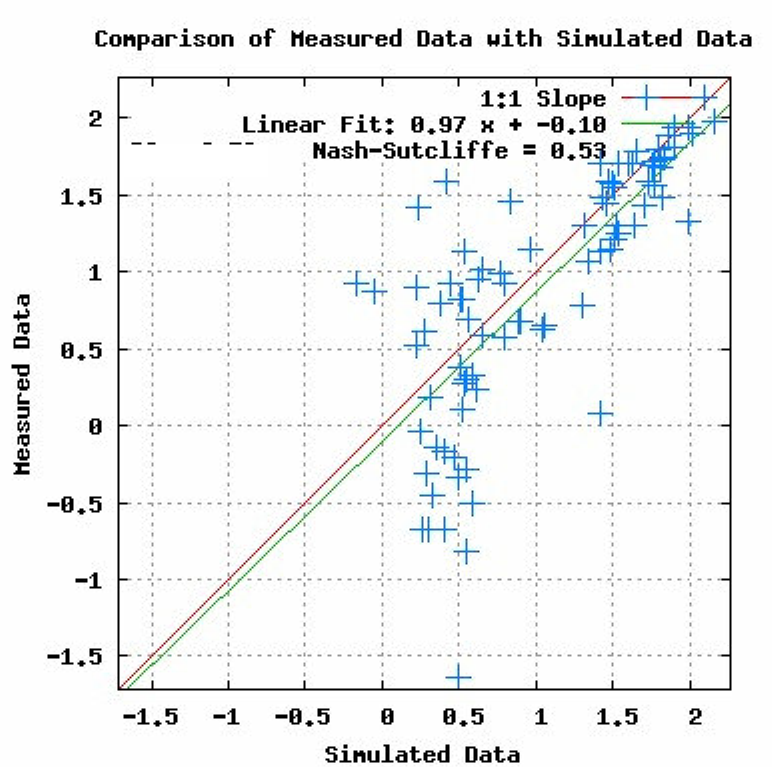


Figure 3.6 - Monthly Calibration Statistics,
Welland River below Caistor Corners,
Calibration Period (1999-2005)

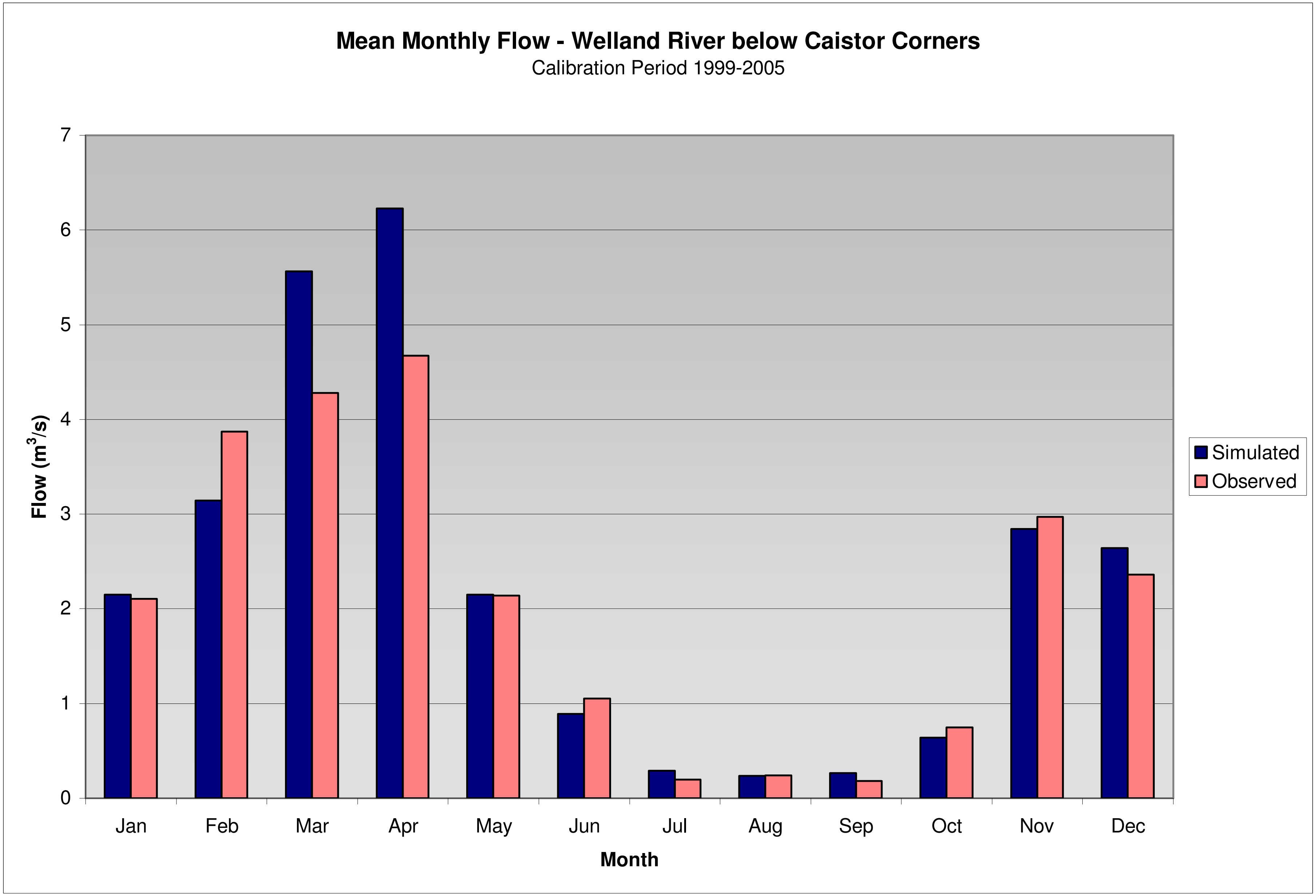
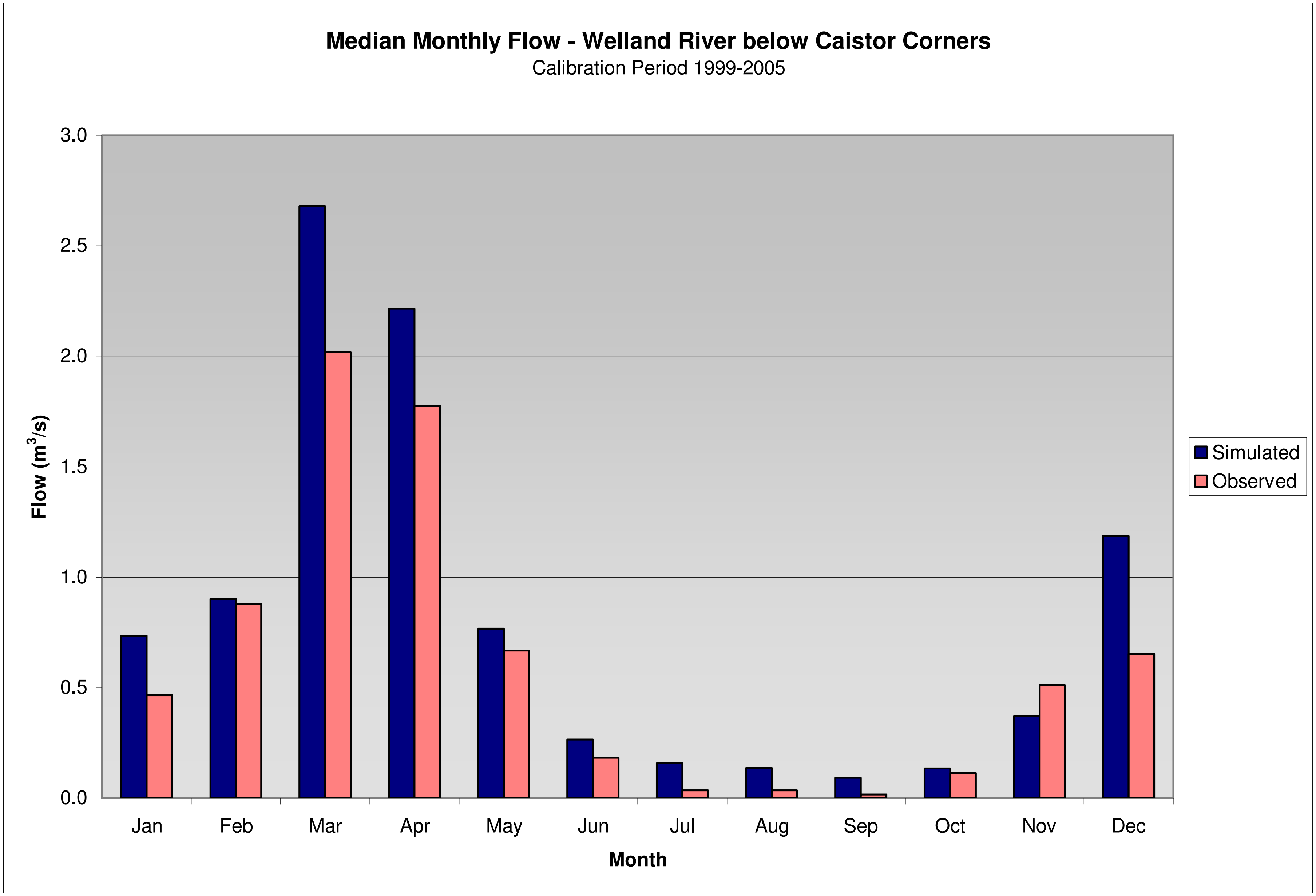
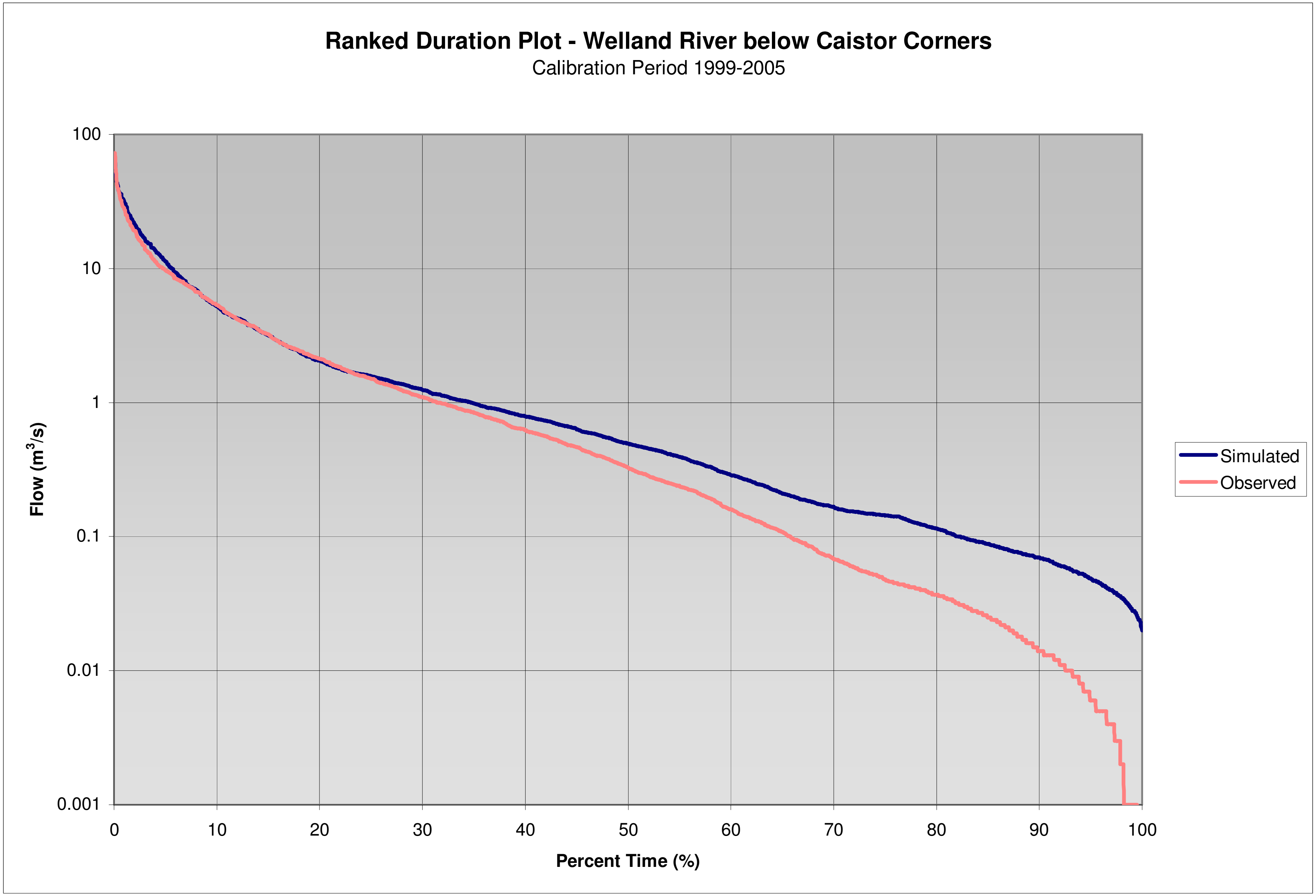

Mean Monthly Flow - Welland River below Caistor Corners
Calibration Period 1999-2005
Flow (m3/s)
0
1
2
3
4
5
6
7
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Simulated
Observed

Figure 3.7



Median Monthly Flow - Welland River below Caistor Corners
Calibration Period 1999-2005
Flow (m^3/s)
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 - Welland River below Caistor Corners
Calibration 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 3.9

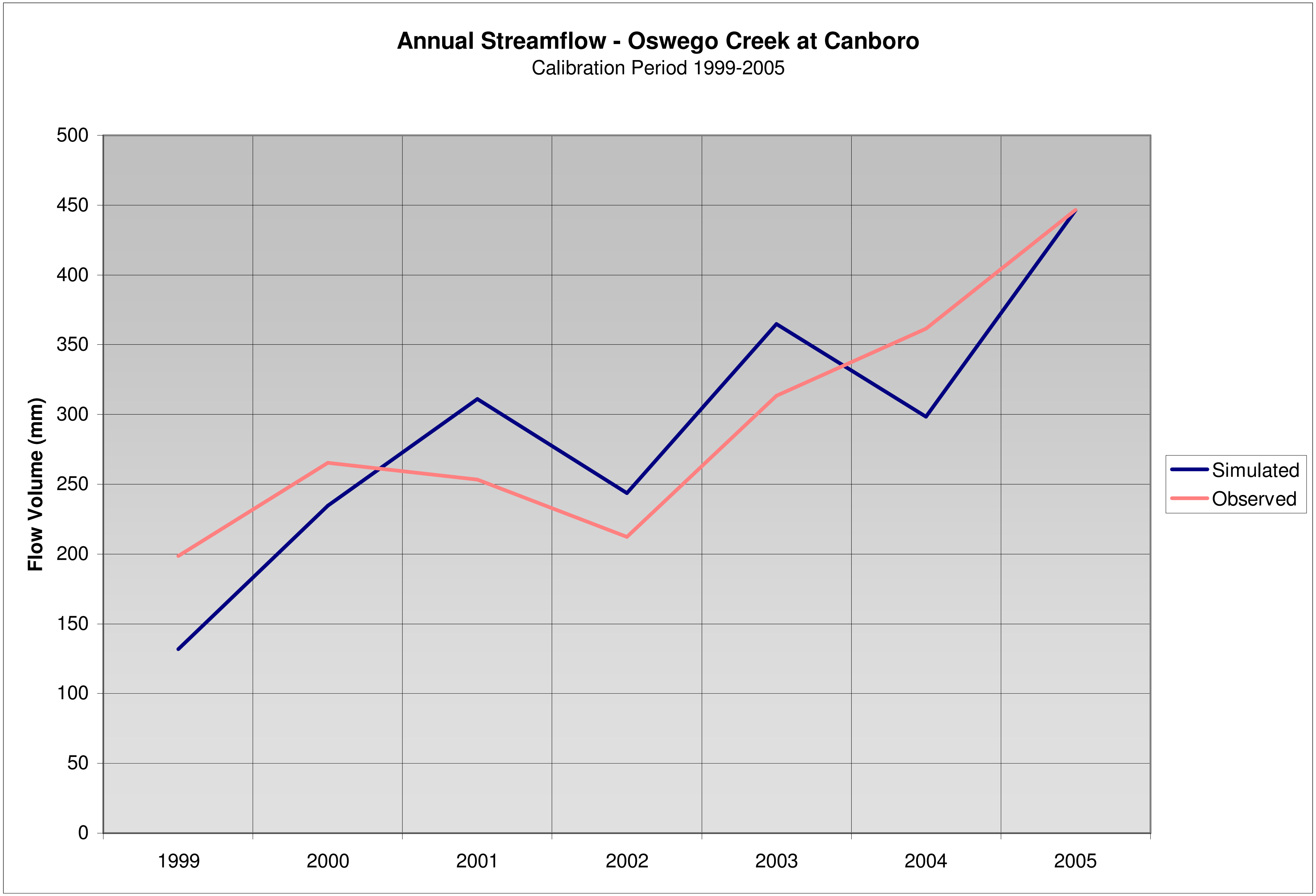

Annual Streamflow - Oswego Creek at Canboro
Calibration Period 1999-2005
Flow Volume (mm)
500
450
400
350
300
250
200
150
100
50
0
1999
2000
2001
2002
2003
2004
2005
Simulated
Observed

Figure 3.10

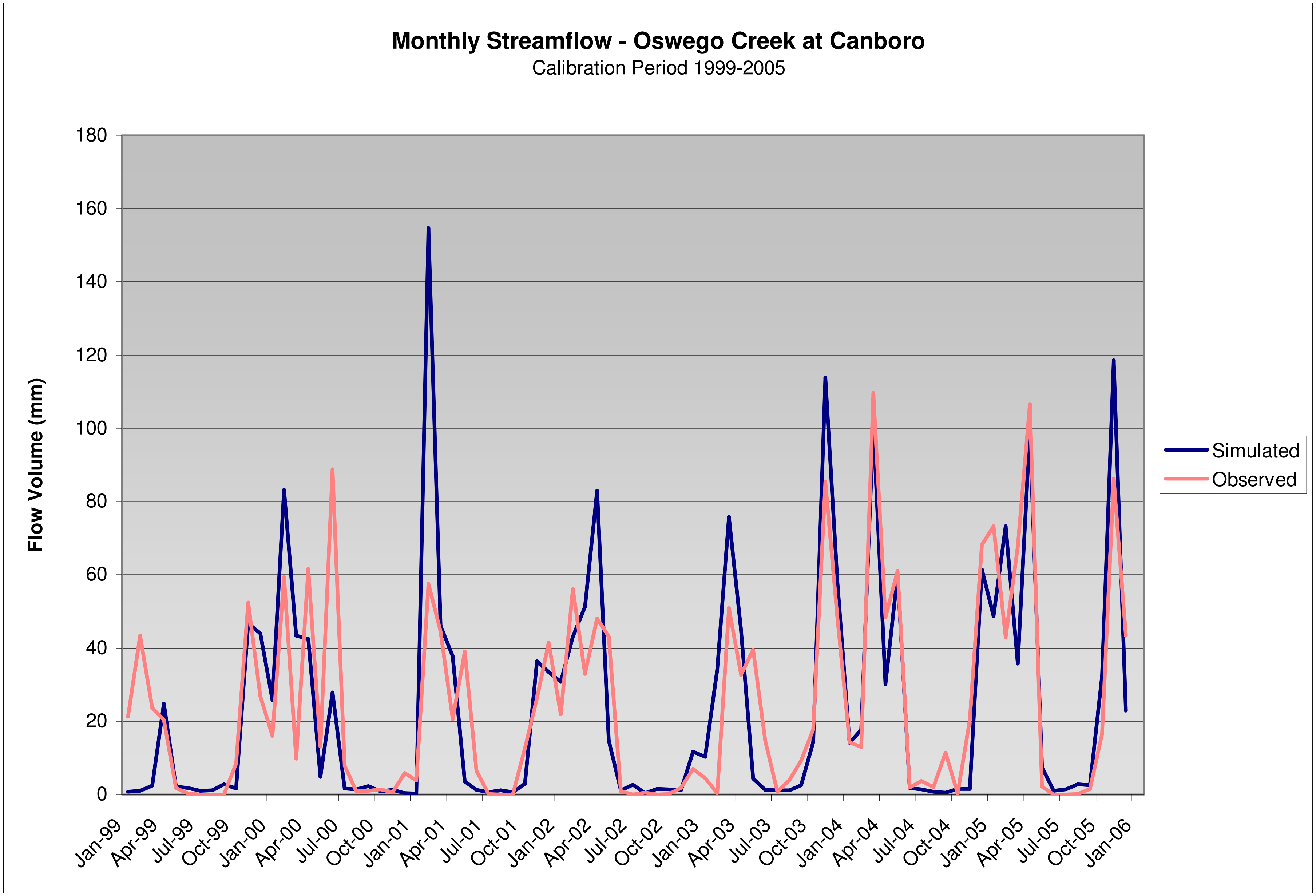
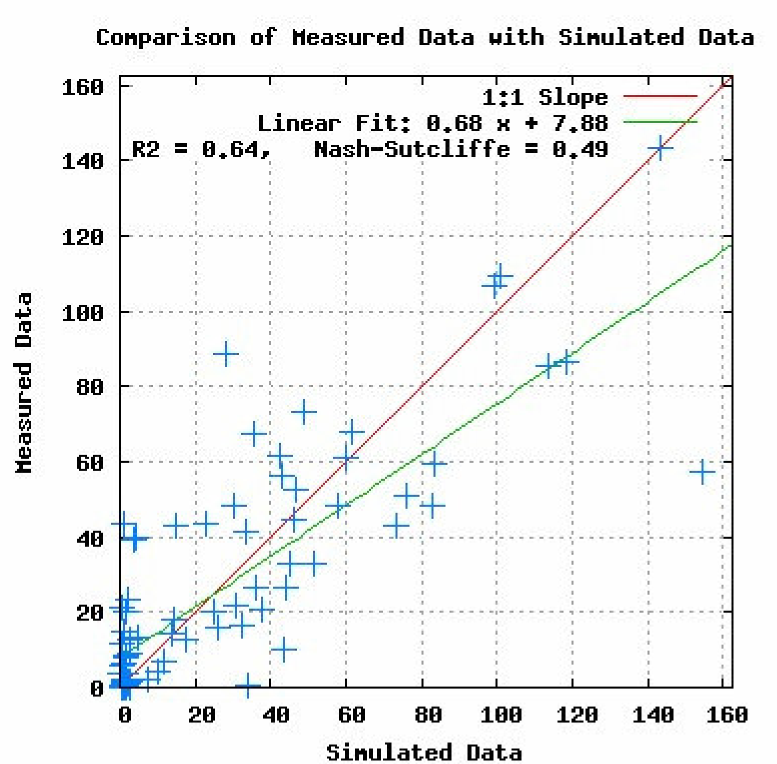

Monthly Streamflow - Oswego Creek at Canboro
Calibration Period 1999-2005
Flow Volume (mm)
180
160
140
120
100
80
60
40
20
0
Jan-99
Apr-99
Jul-99
Oct-99
Jan-00
Apr-00
Jul-00
Oct-00
Jan-01
Apr-01
Jul-01
Oct-01
Jan-02
Apr-02
Jul-02
Oct-02
Jan-03
Apr-03
Jul-03
Oct-03
Jan-04
Apr-04
Jul-04
Oct-04
Jan-05
Apr-05
Jul-05
Oct-05
Jan-06
Simulated
Observed

Figure 3.11

Streamflow



Log Streamflow

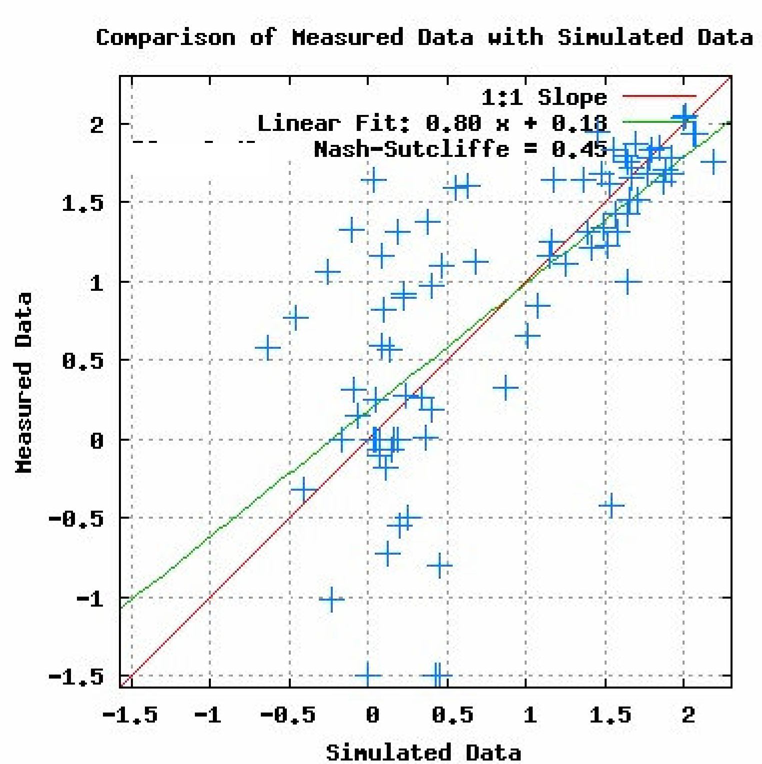


Figure 3.12 - Monthly Calibration Statistics,
Oswego Creek at Canboro,
Calibration Period (1999-2005)

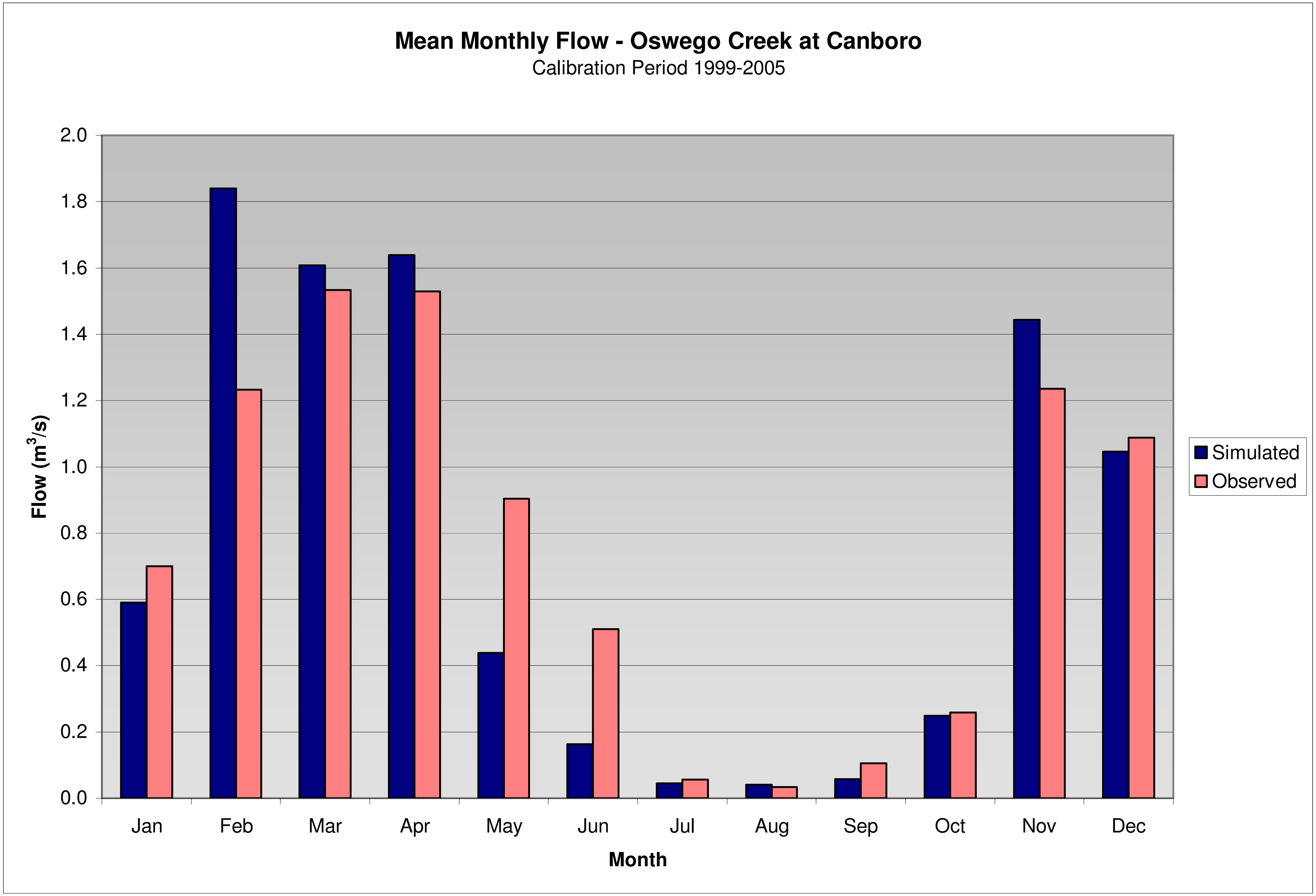
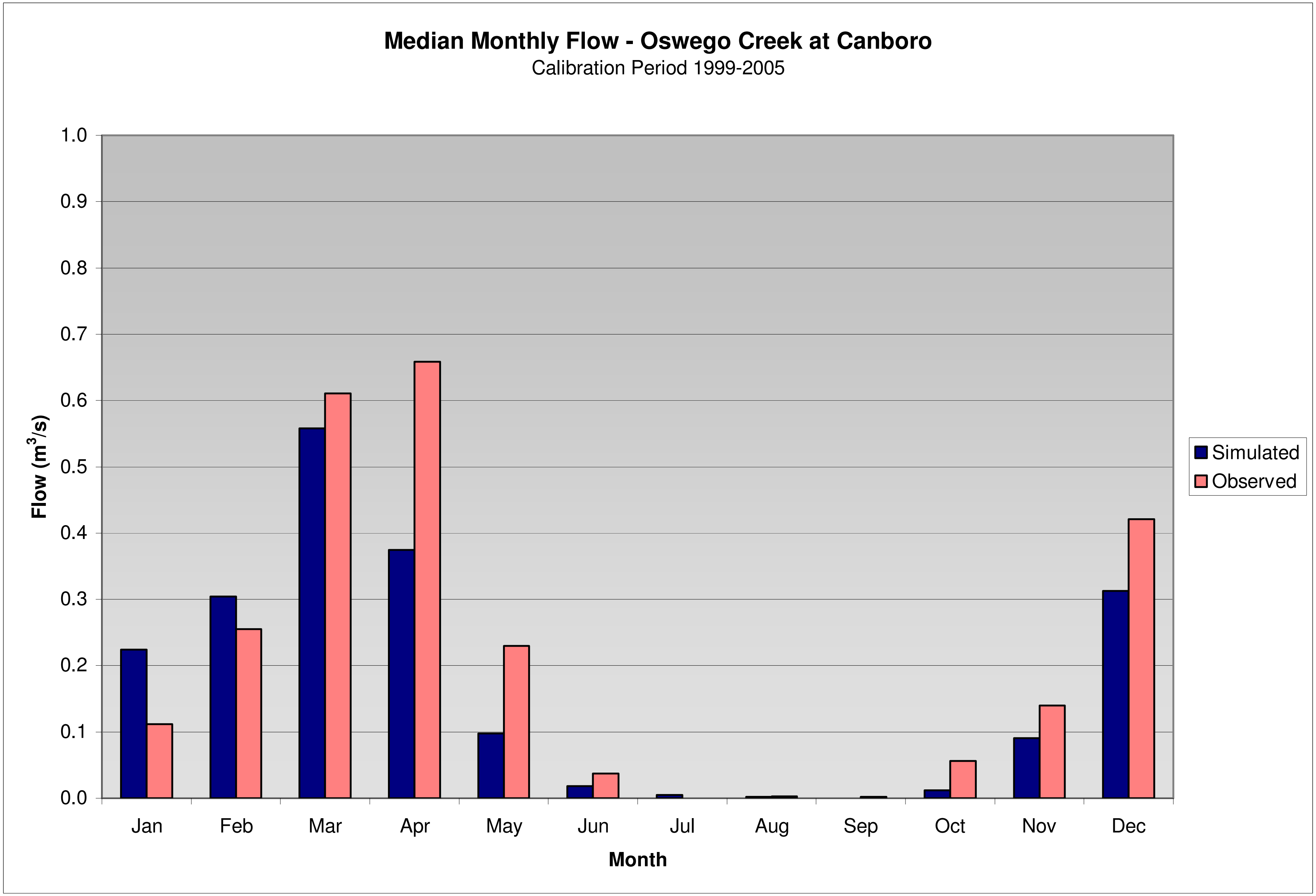
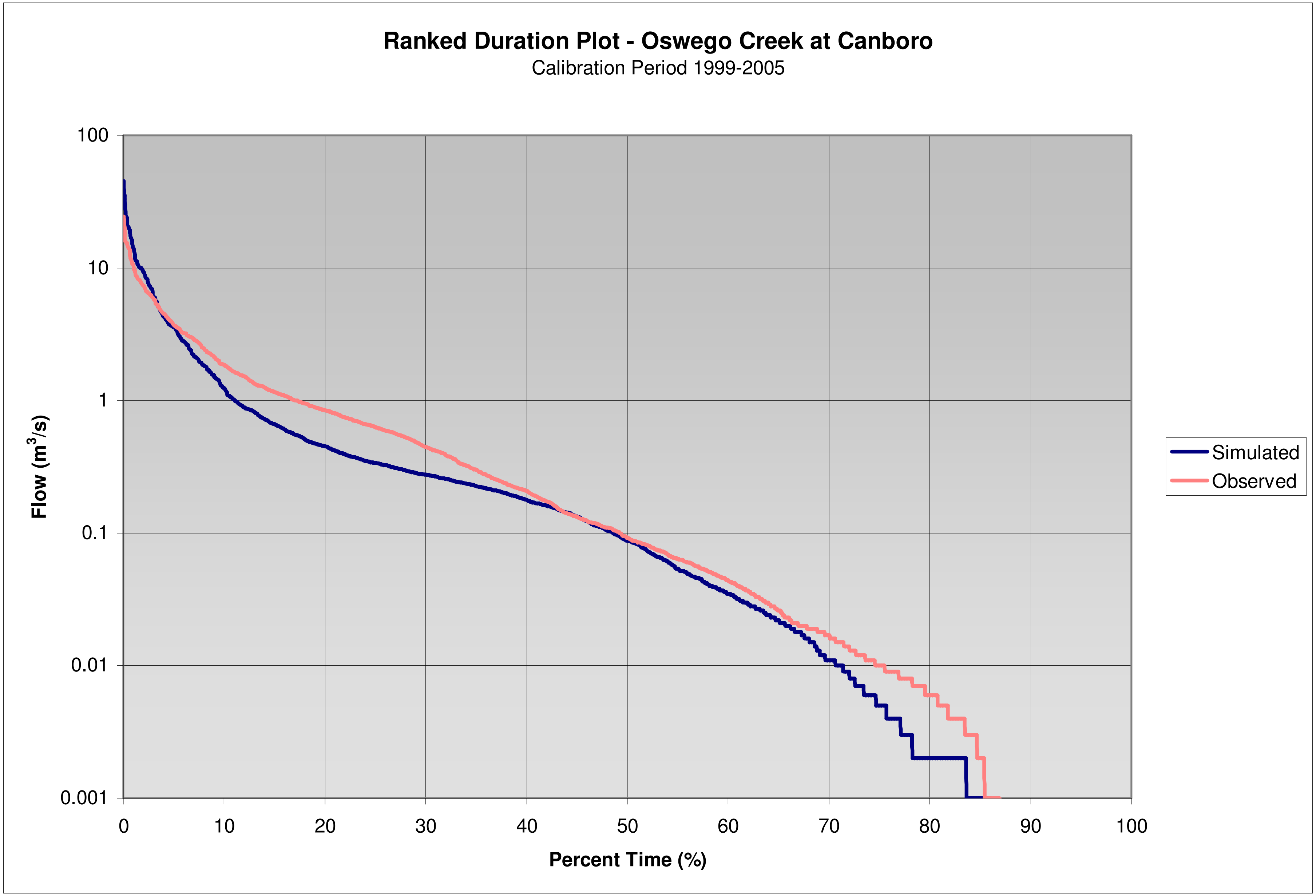

Mean Monthly Flow - Oswego Creek at Canboro
Calibration Period 1999-2005
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Flow (m^3/s)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Simulated
Observed

Figure 3.13



Median Monthly Flow - Oswego Creek at Canboro
Calibration Period 1999-2005
Flow (m^3/s)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Simulated
Observed

Figure 3.14



Ranked Duration Plot - Oswego Creek at Canboro
Calibration 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 3.15

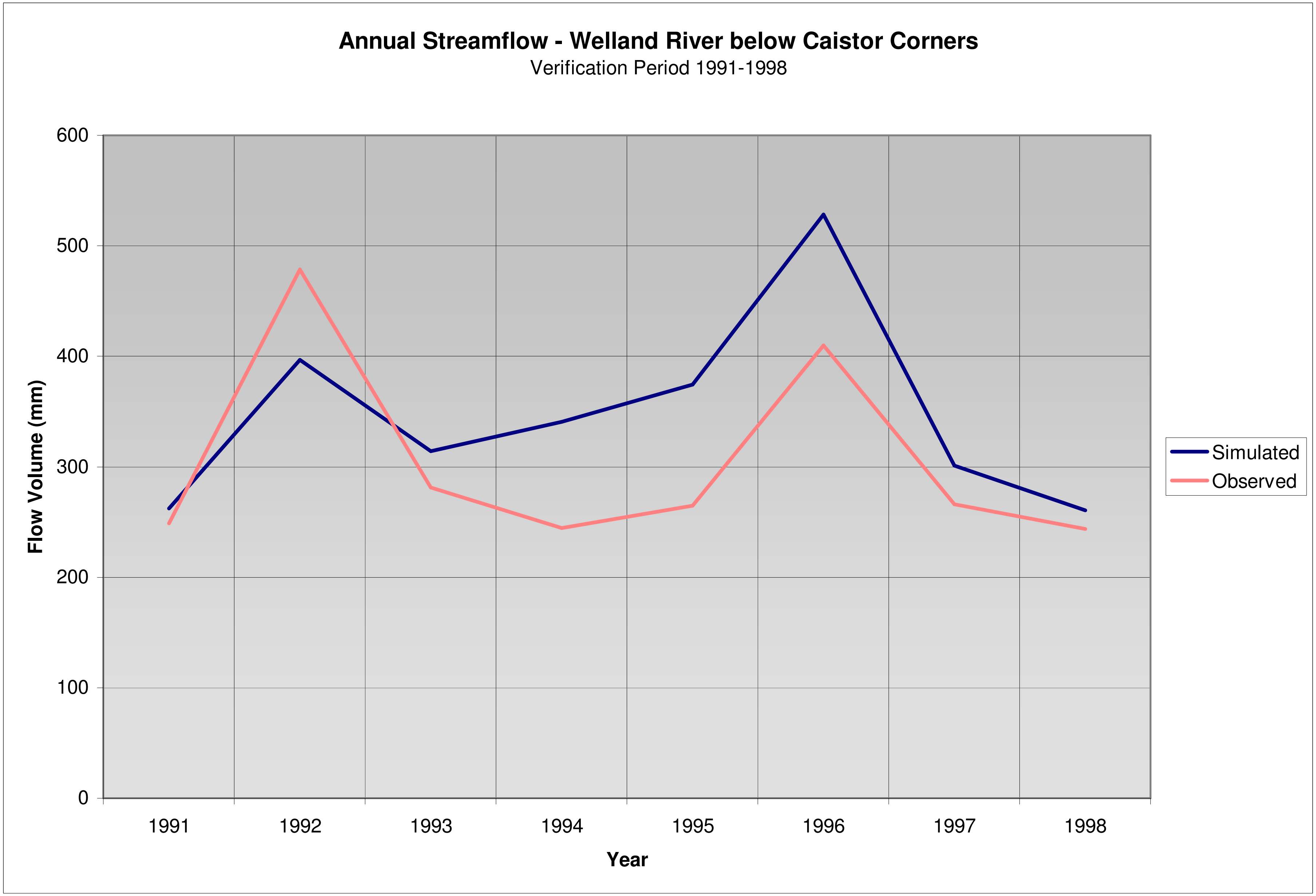

Annual Streamflow - Welland River below Caistor Corners
Verification Period 1991-1998
Flow Volume (mm)
600
500
400
300
200
100
0
1991
1992
1993
1994
1995
1996
1997
1998
Year
Simulated
Observed

Figure 3.16

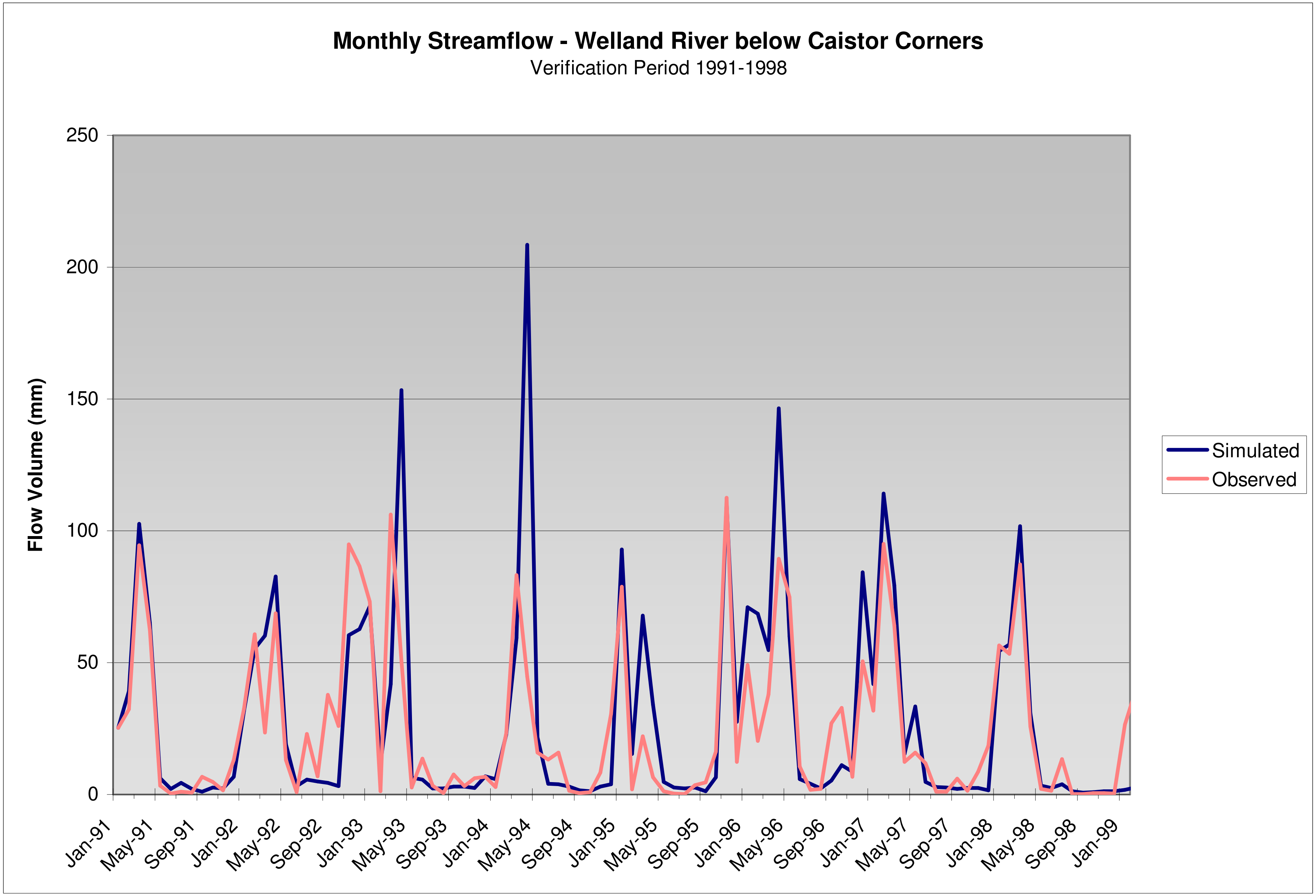
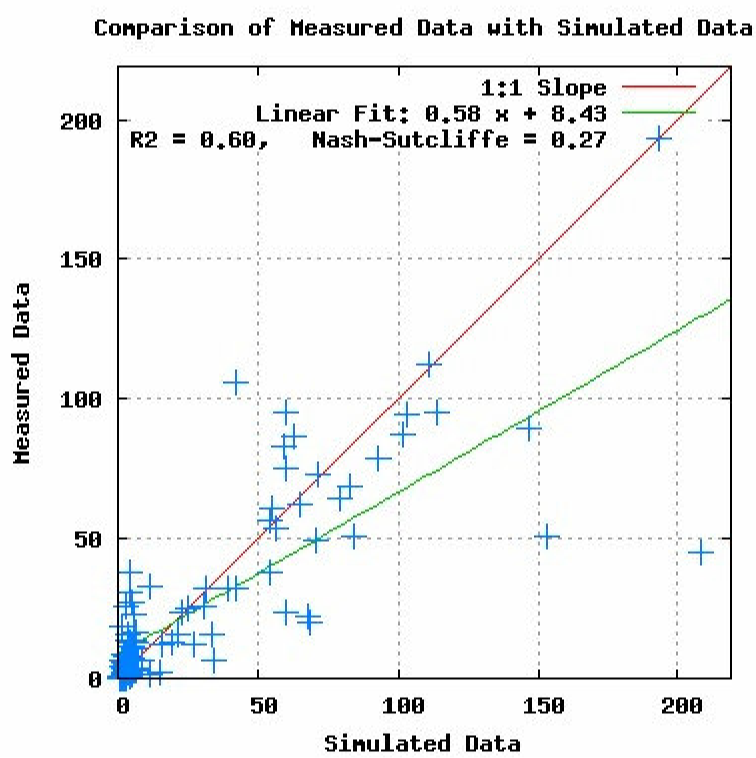

Monthly Streamflow - Welland River below Caistor Corners
Verification Period 1991-1998
Flow Volume (mm)
250
200
150
100
50
0
Jan-91
May-91
Sep-91
Jan-92
May-92
Sep-92
Jan-93
May-93
Sep-93
Jan-94
May-94
Sep-94
Jan-95
May-95
Sep-95
Jan-96
May-96
Sep-96
Jan-97
May-97
Sep-97
Jan-98
May-98
Sep-98
Jan-99
Simulated
Observed

Figure 3.17

Streamflow



Log Streamflow

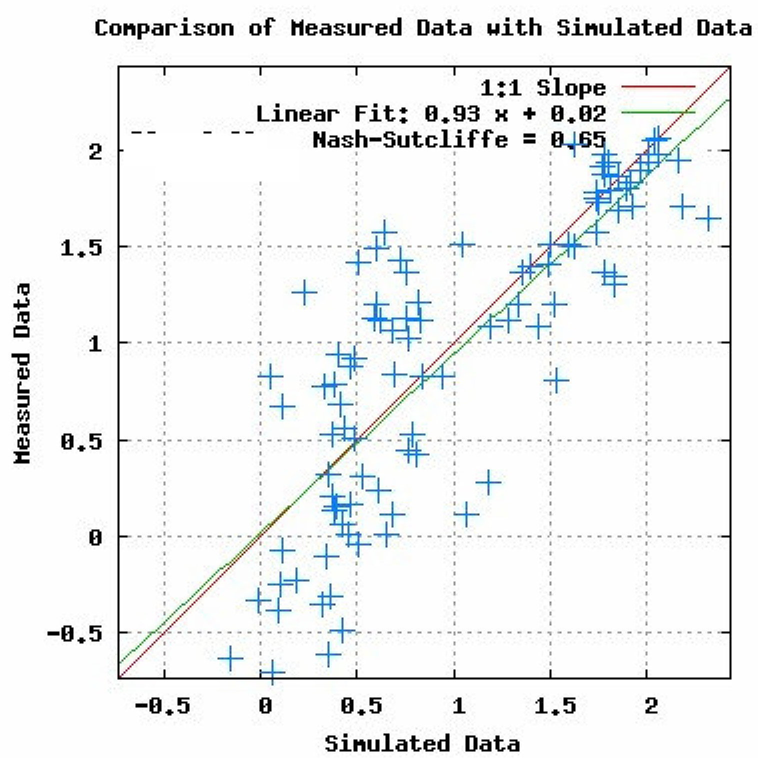


Figure 3.18 – Monthly Calibration Statistics,
Welland River below Caistor Corners,
Verification Period (1991-1998)

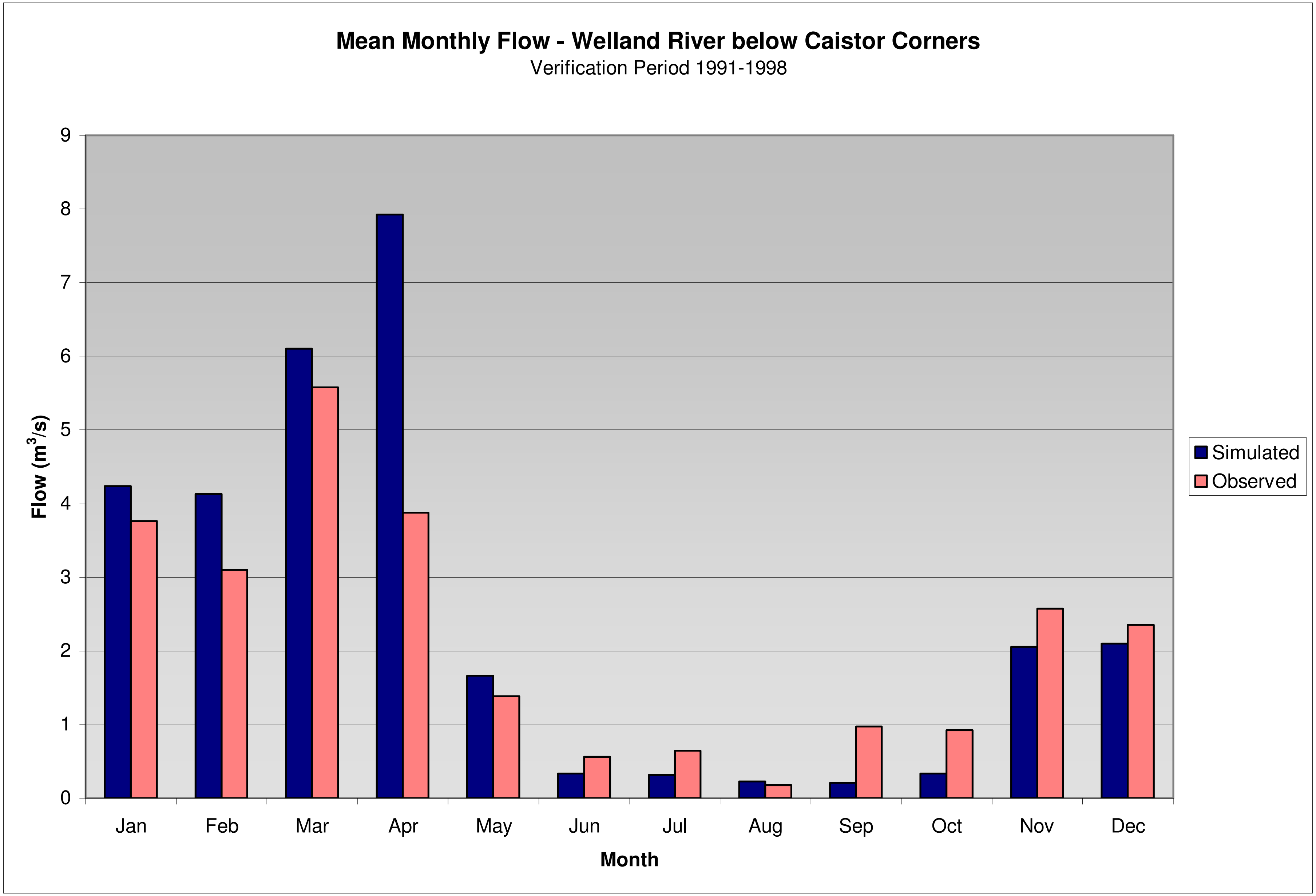

Mean Monthly Flow - Welland River below Caistor Corners
Verification Period 1991-1998
Flow (m3/s)
9
8
7
6
5
4
3
2
1
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Simulated
Observed

Figure 3.19

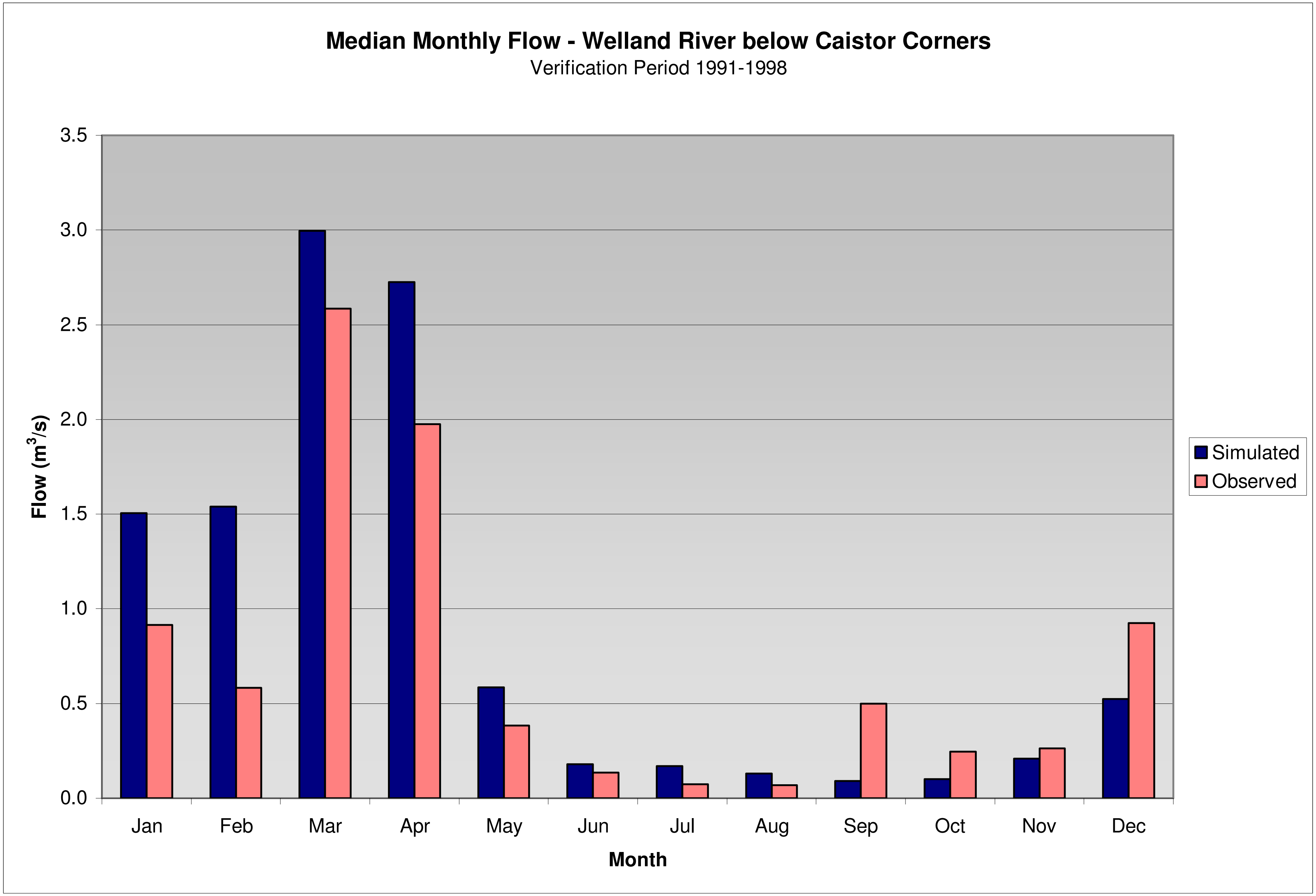

Median Monthly Flow - Welland River below Caistor Corners
Verification Period 1991-1998
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Flow (m3/s)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Simulated
Observed

Figure 3.20

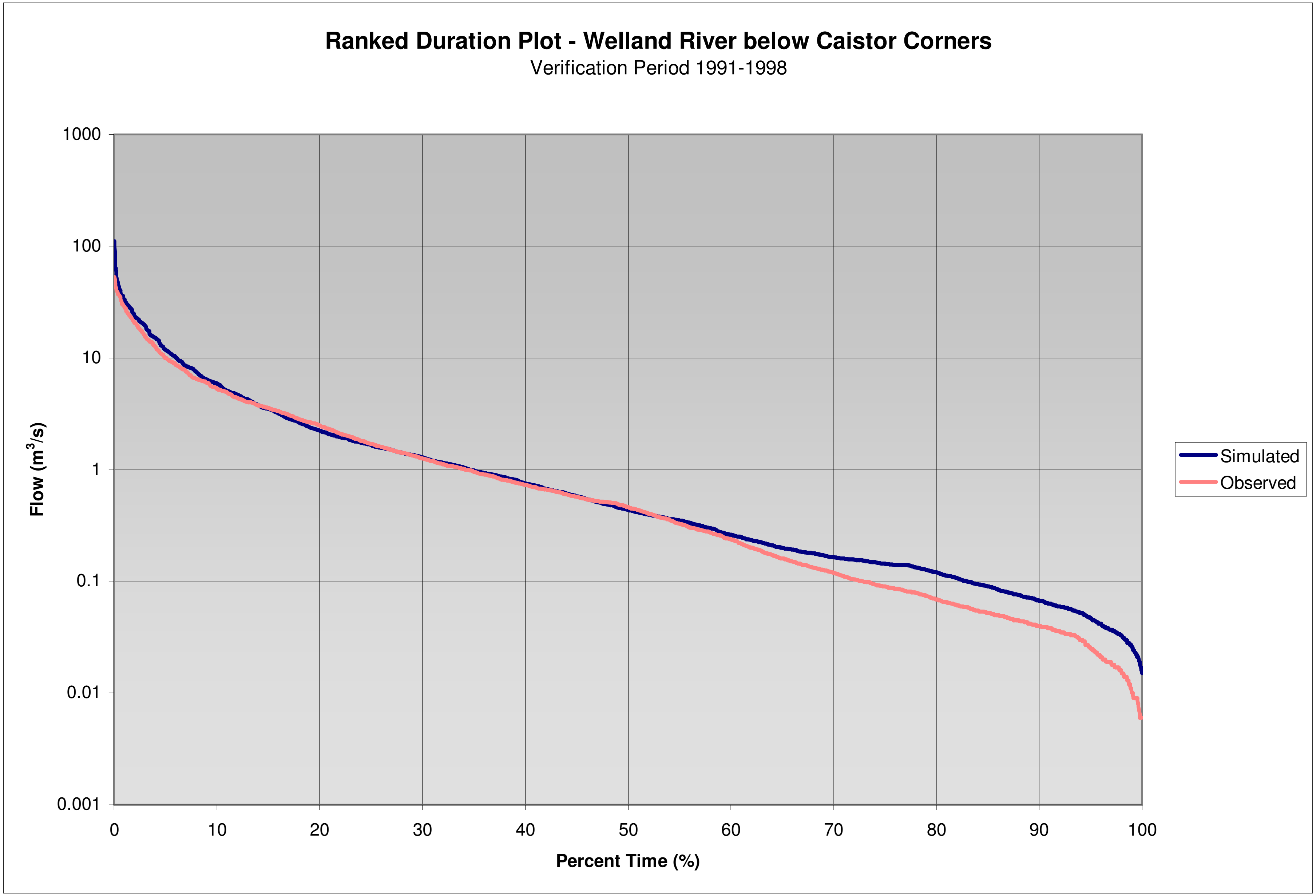

Ranked Duration Plot - Welland River below Caistor Corners
Verification Period 1991-1998
Flow (m3/s)
1000
100
10
1
0.1
0.01
0.001
0
10
20
30
40
50
60
70
80
90
100
Percent Time (%)
Simulated
Observed

Figure 3.21

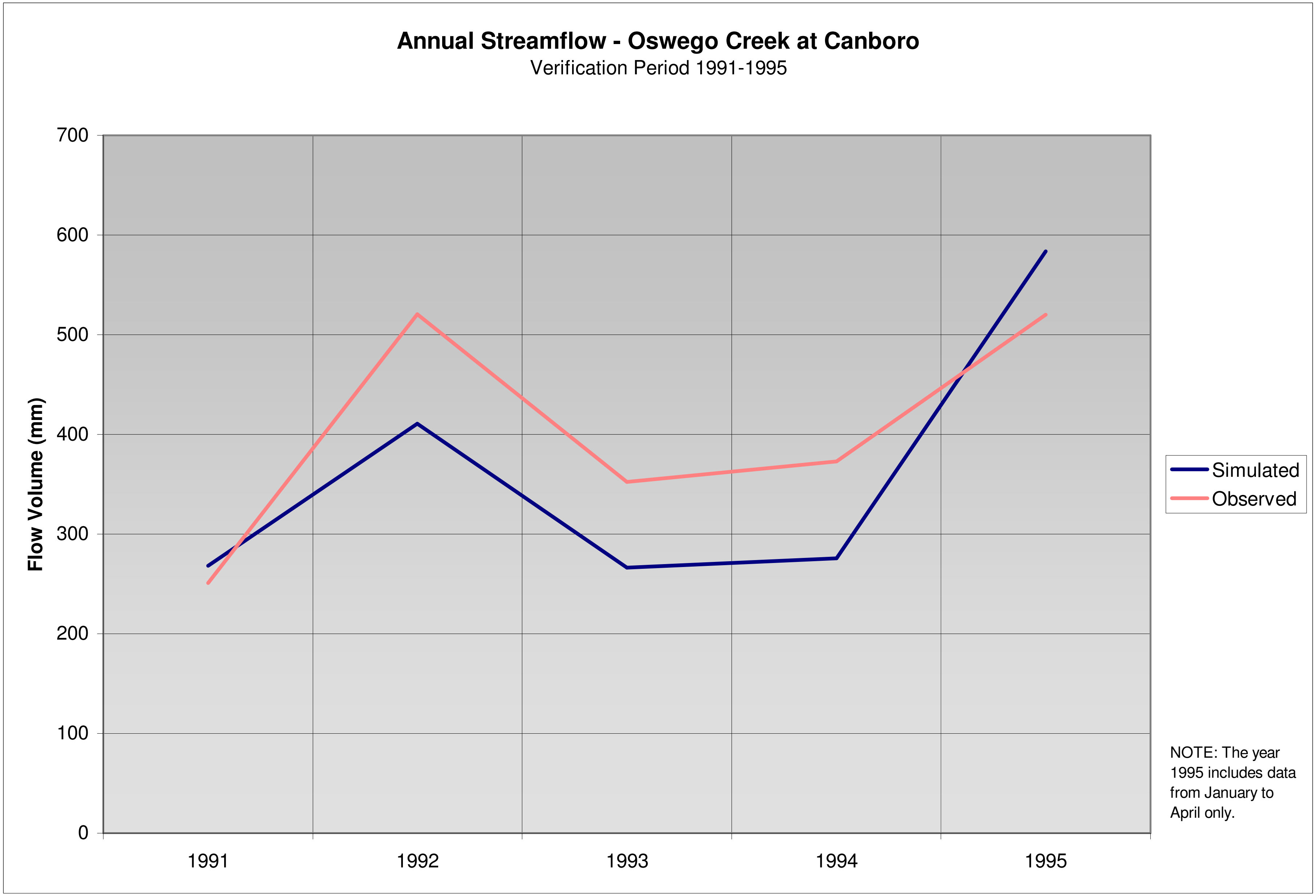

Annual Streamflow - Oswego Creek at Canboro
Verification Period 1991-1995
Flow Volume (mm)
0
100
200
300
400
500
600
700
1991
1992
1993
1994
1995
Simulated
Observed
NOTE: The year 1995 includes data from January to April only.

Figure 3.22

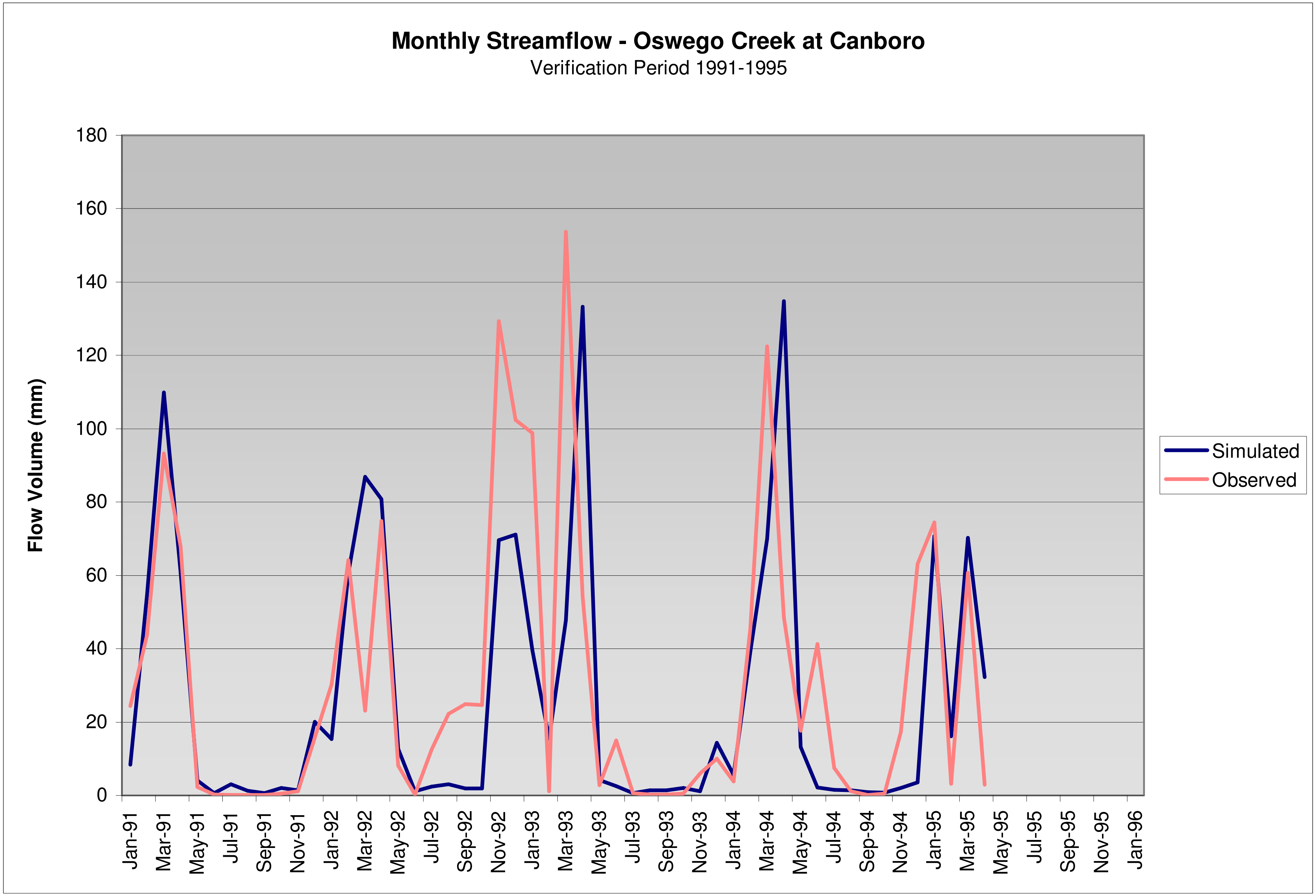
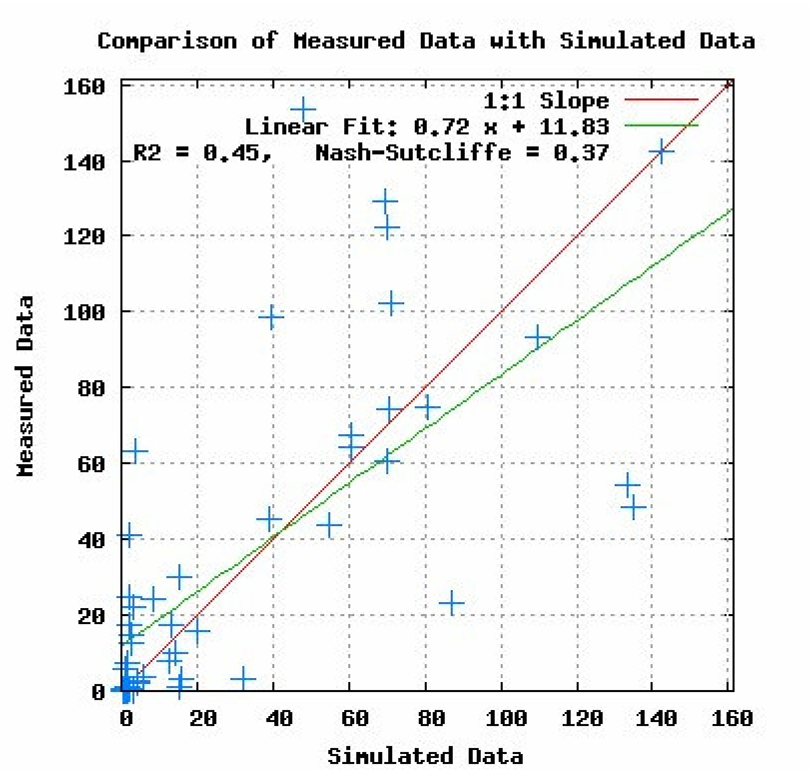

Monthly Streamflow - Oswego Creek at Canboro
Verification Period 1991-1995
Flow Volume (mm)
180
160
140
120
100
80
60
40
20
0
Jan-91
Mar-91
May-91
Jul-91
Sep-91
Nov-91
Jan-92
Mar-92
May-92
Jul-92
Sep-92
Nov-92
Jan-93
Mar-93
May-93
Jul-93
Sep-93
Nov-93
Jan-94
Mar-94
May-94
Jul-94
Sep-94
Nov-94
Jan-95
Mar-95
May-95
Jul-95
Sep-95
Nov-95
Jan-96
Simulated
Observed

Figure 3.23

Streamflow



Log Streamflow

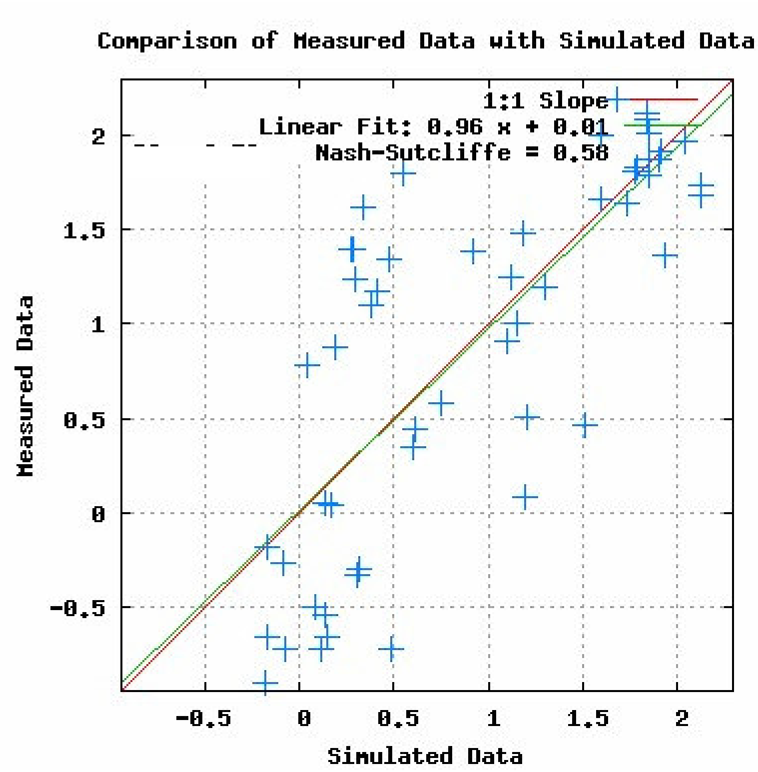
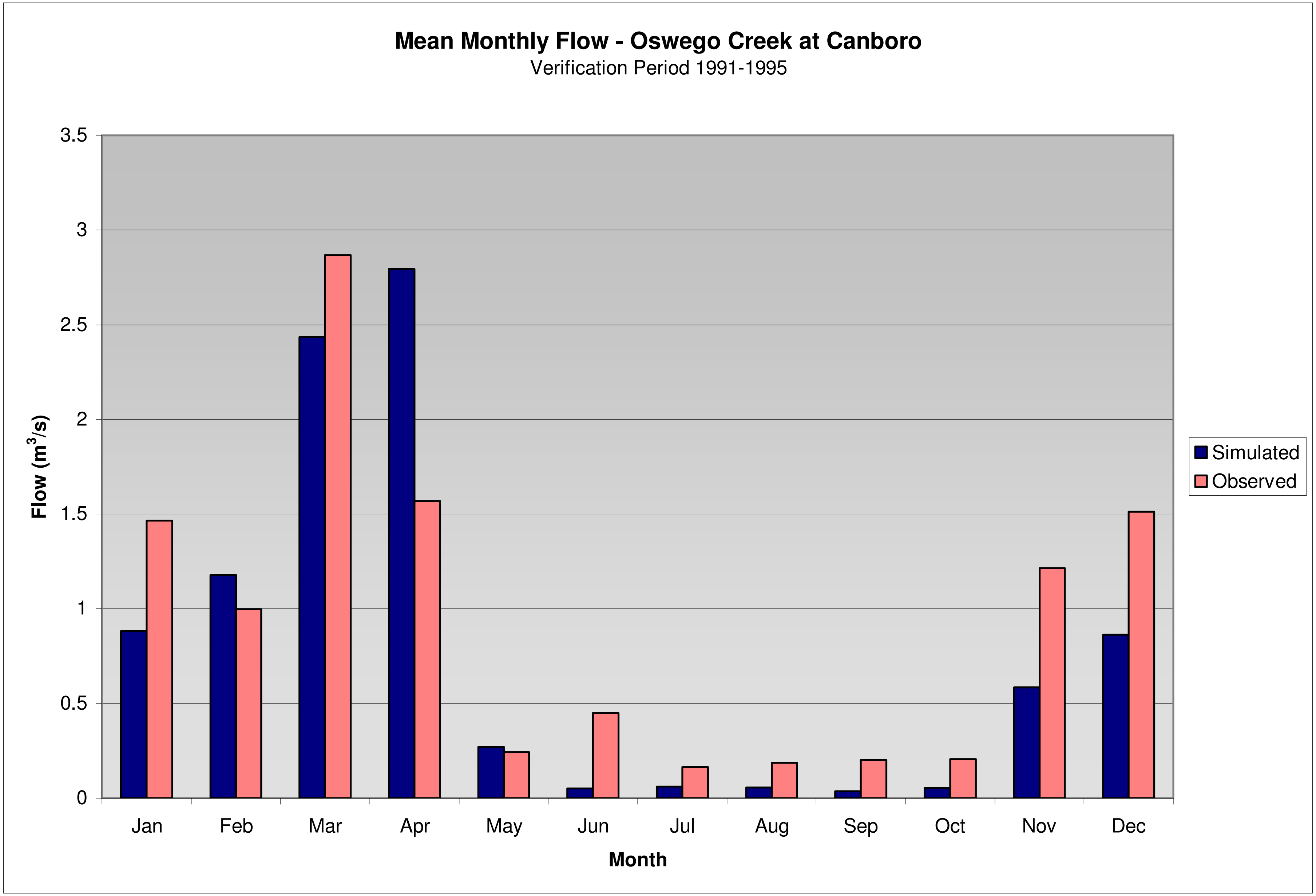


Figure 3.24 – Monthly Calibration Statistics,
Oswego Creek at Canboro,
Verification Period (1991-1995)



Mean Monthly Flow - Oswego Creek at Canboro
Verification Period 1991-1995
3.5
3
2.5
2
1.5
1
0.5
0
Flow (m3/s)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Simulated
Observed

Figure 3.25

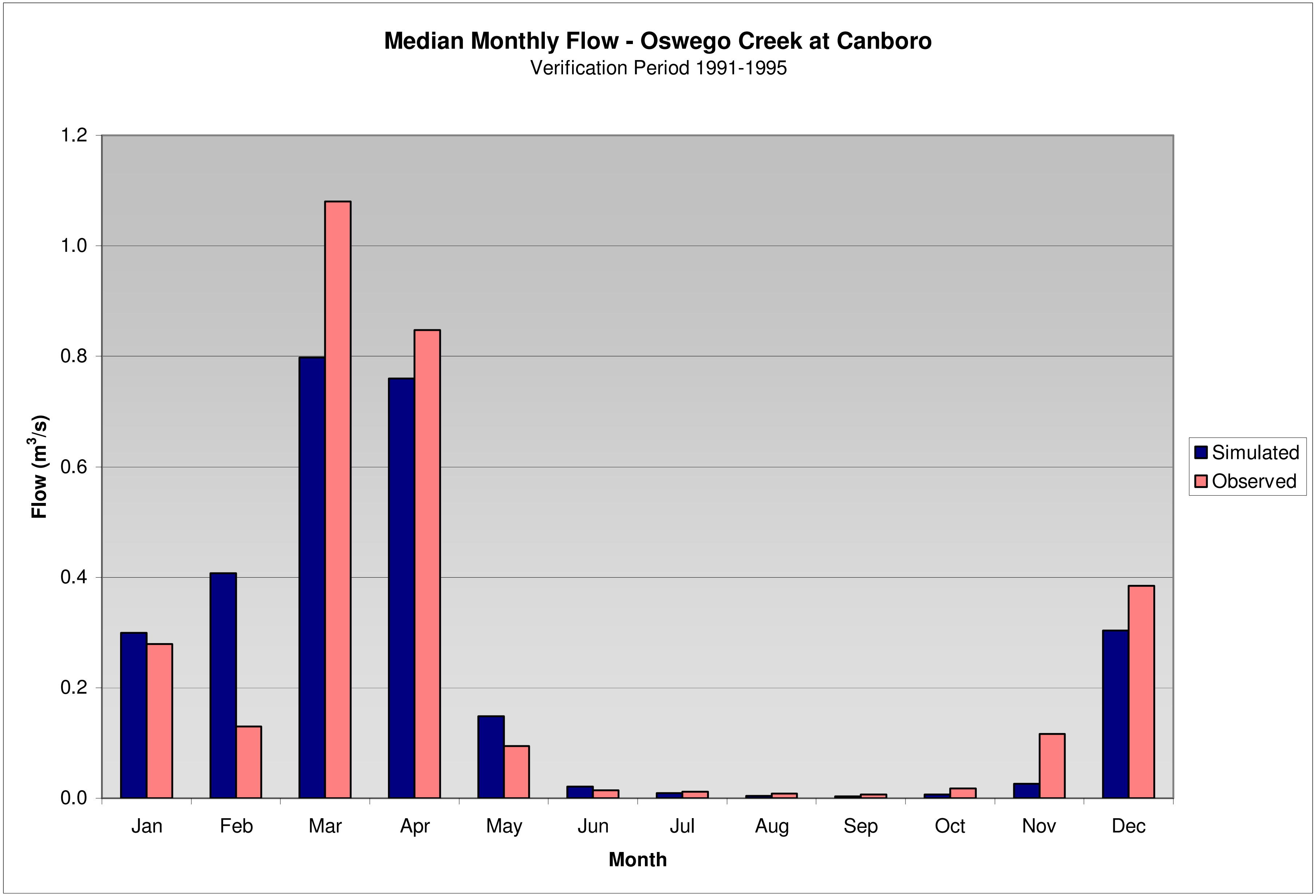

Median Monthly Flow - Oswego Creek at Canboro
Verification Period 1991-1995
Flow (m³/s)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Simulated
Observed

Figure 3.26

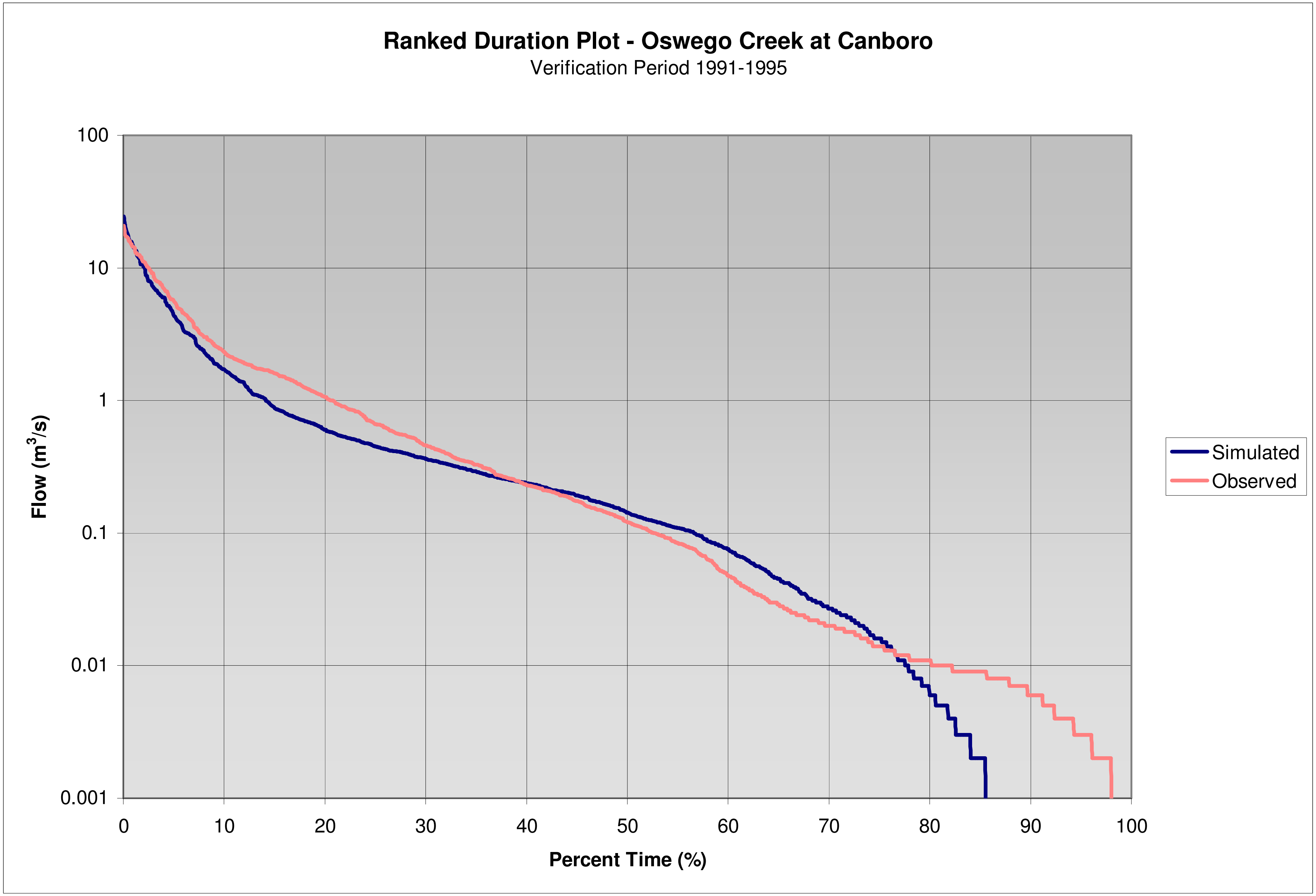

Ranked Duration Plot - Oswego Creek at Canboro
Verification Period 1991-1995
100
10
1
0.1
0.01
0.001
Flow (m3/s)
0
10
20
30
40
50
60
70
80
90
100
Percent Time (%)
Simulated
Observed

Figure 3.27

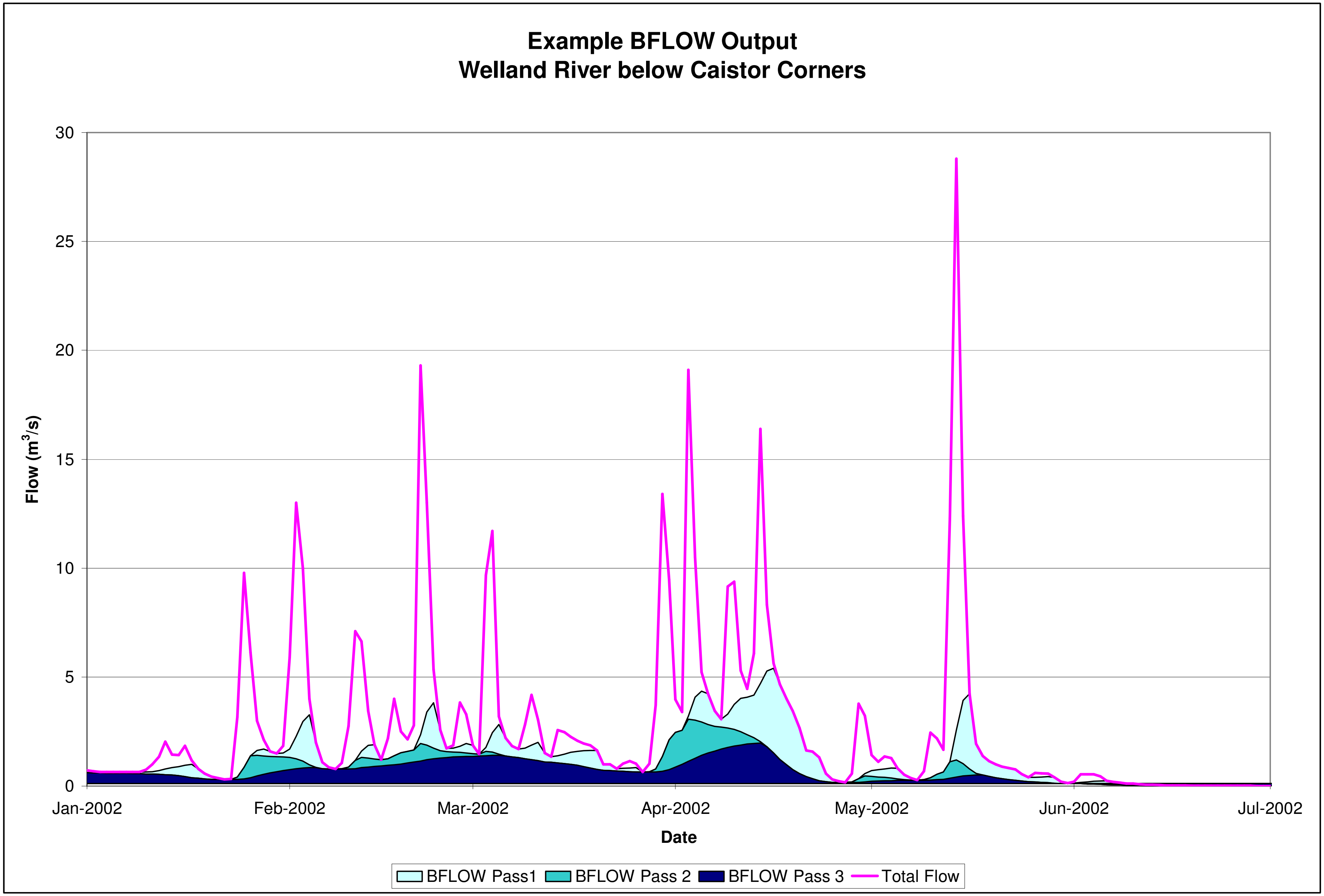
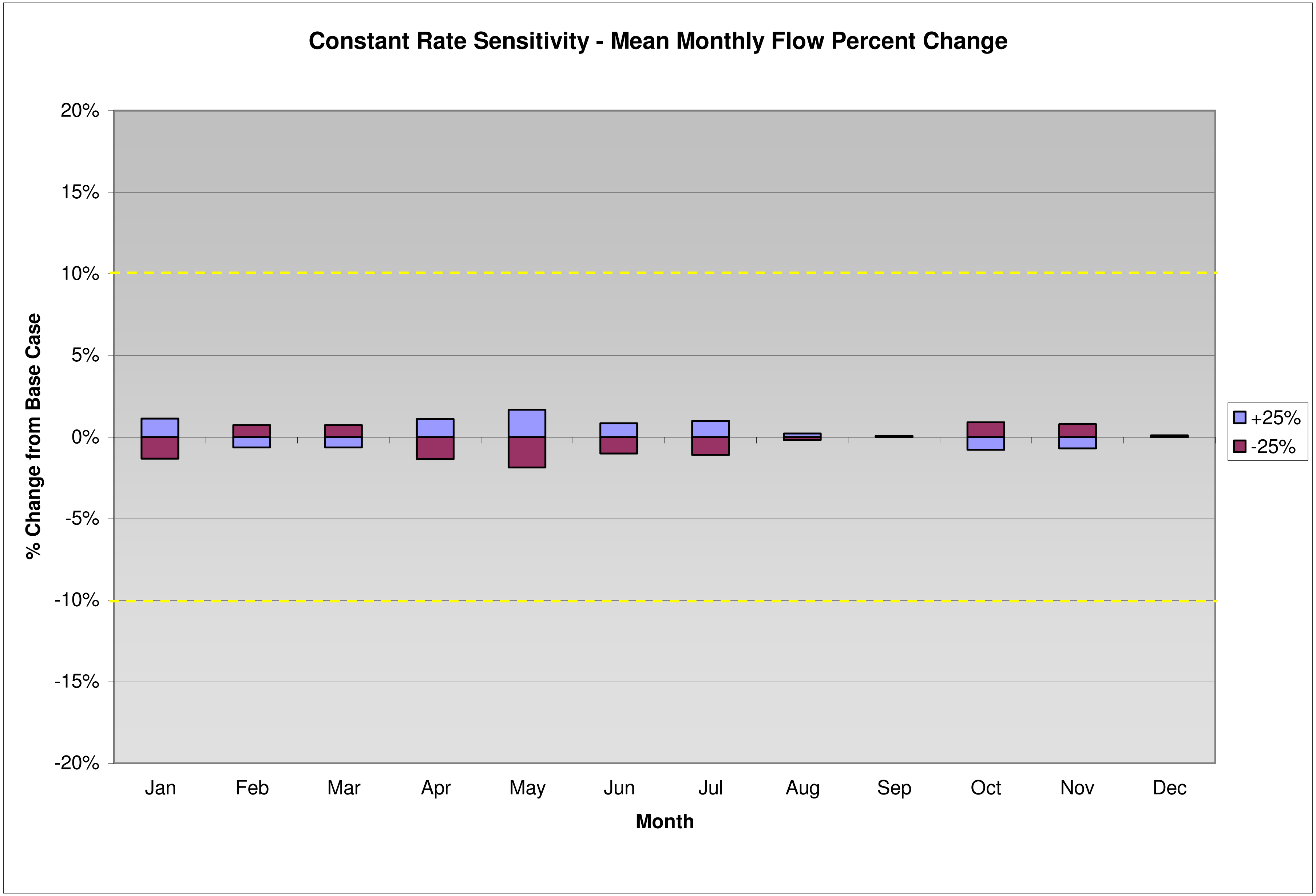


Figure 3.28
BFLOW Hydrograph Separation Example



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

Figure 3.29

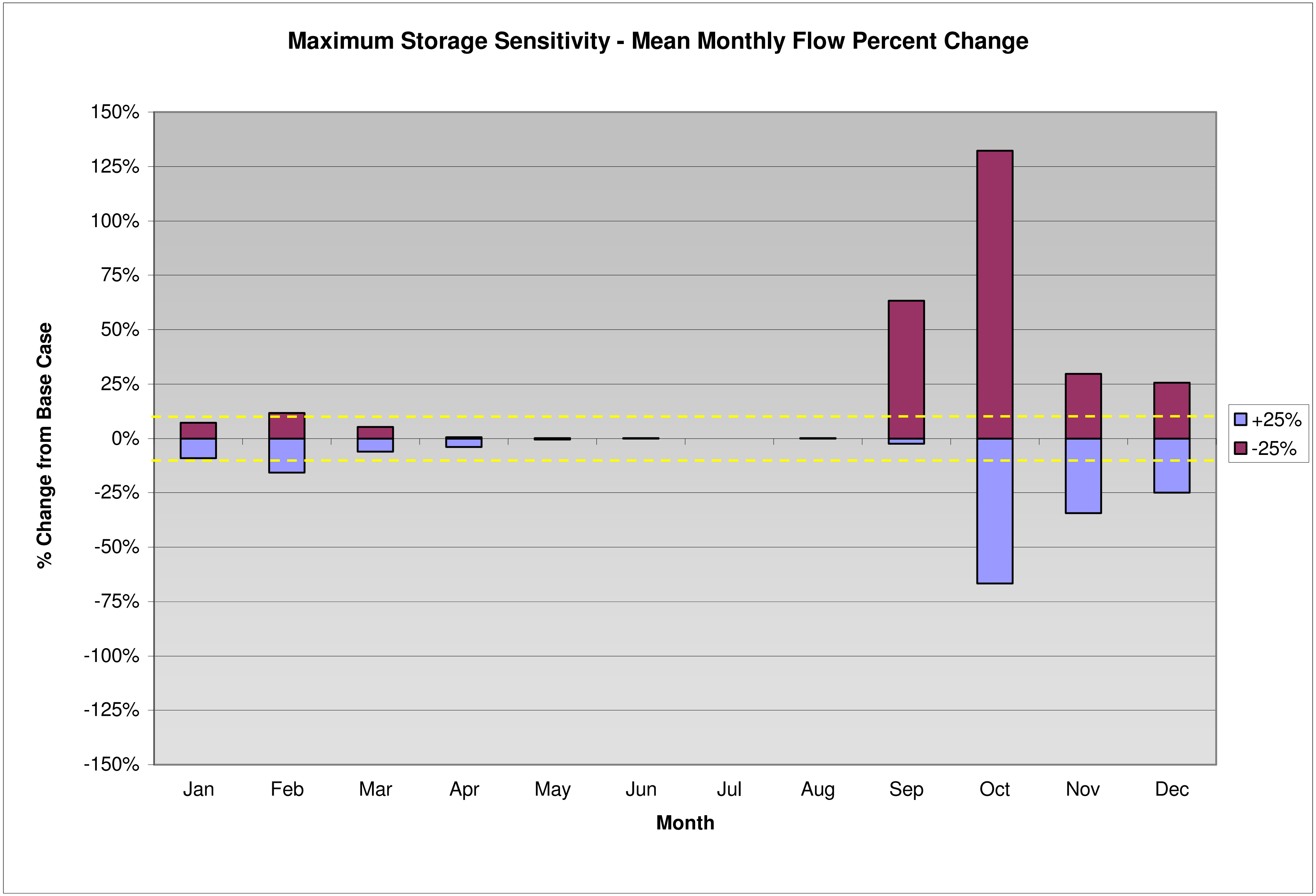

Maximum Storage Sensitivity - Mean Monthly Flow Percent Change
% Change from Base Case
150%
125%
100%
75%
50%
25%
0%
-25%
-50%
-75%
-100%
-125%
-150%
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
+25%
-25%

Figure 3.30

Appendix A

Snow Modeling Overview

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US Army Corps of Engineers

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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

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Snow Modeling Approaches

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

Numerical Snow Models
Heat transfer from snowpack to environment

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

Numerical Snow Models
Representing snowpack physical properties

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

Temperature Index Snow model

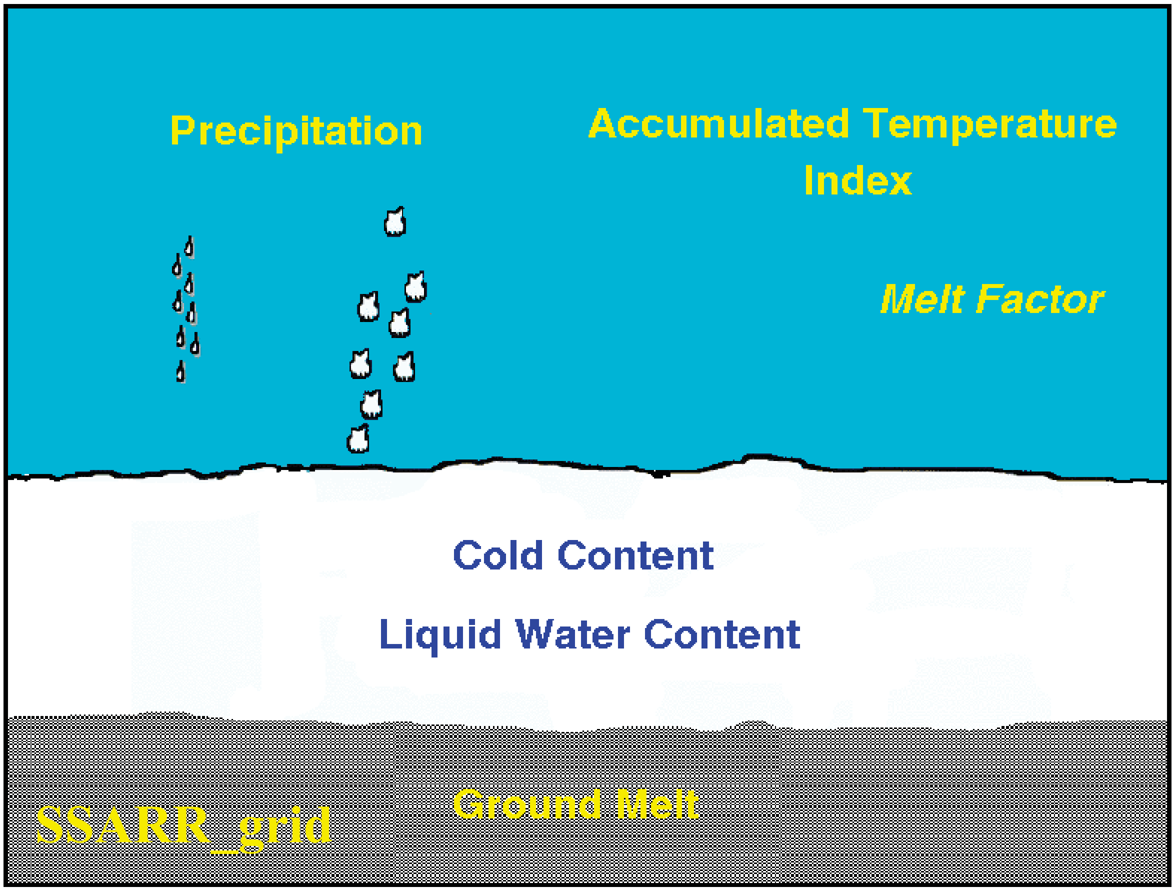
- Often, complete energy budgets are difficult or impossible to estimate. A simpler method, based only on the air temperature, called the Temperature Index (degree-day) method has been developed. It has been widely used with good results.

Numerical Snow Models

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

Snowmelt Modeling in HMS

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



Snowmelt Modeling in HMS

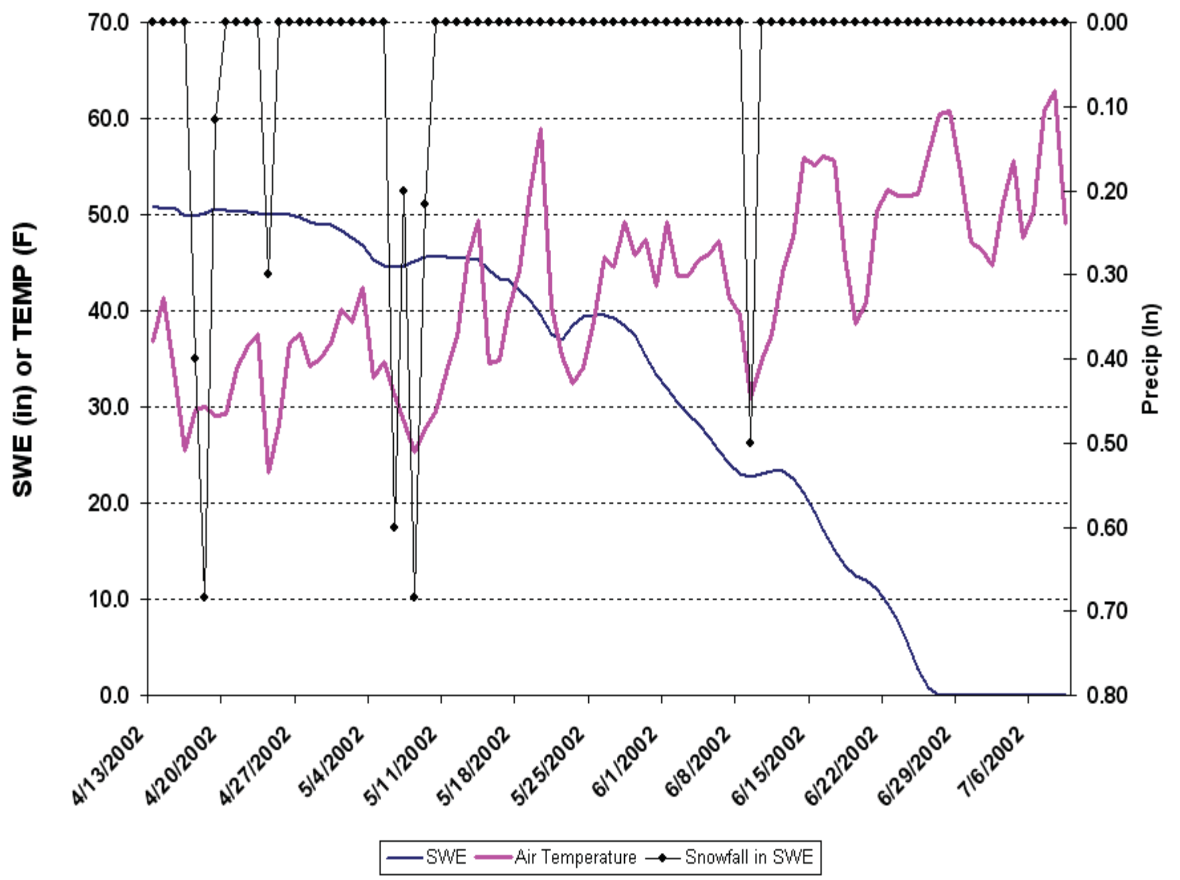
- Temperature Index
- Single snow Layer
  - Cold Content
  - Liquid water content
  - Ground melt

Snowmelt Modeling in HMS

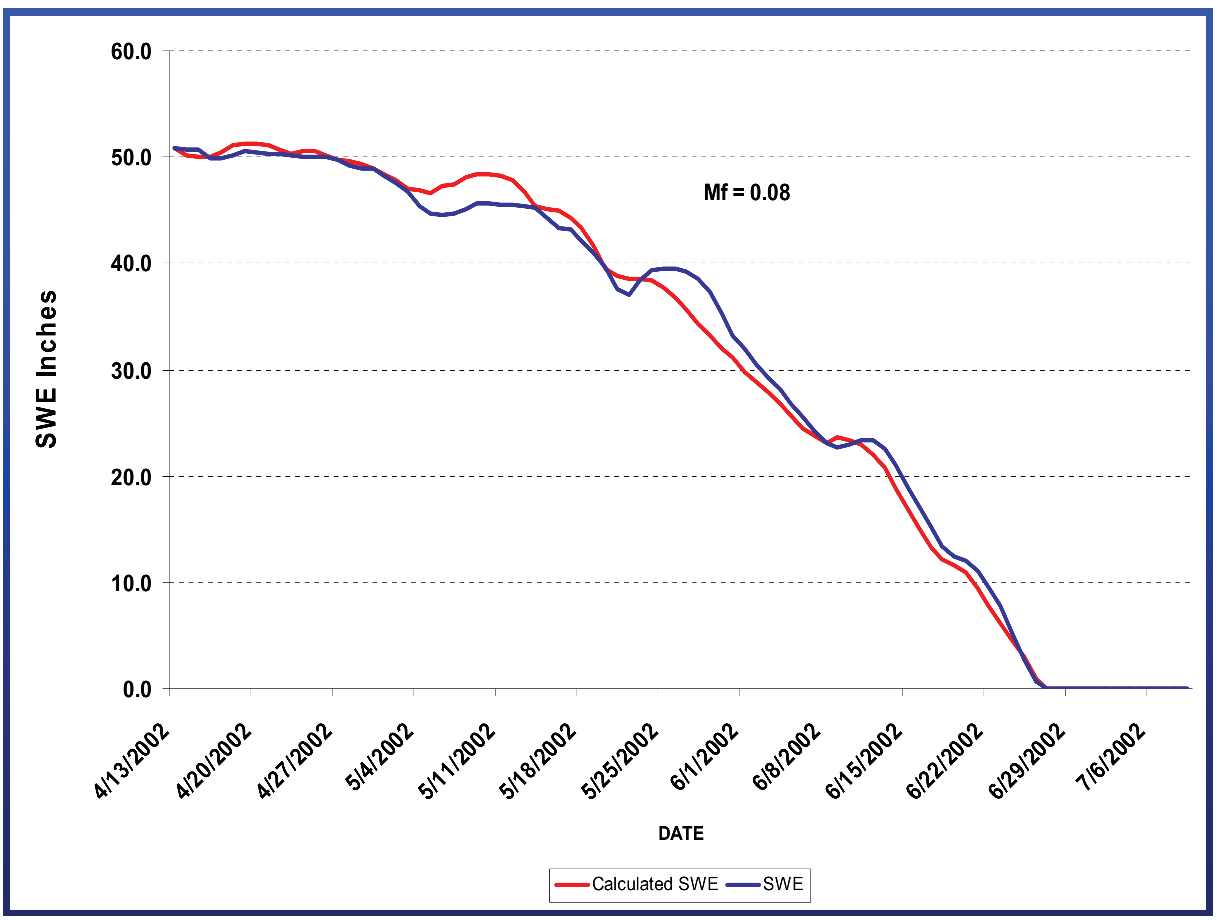
- Watershed
  - Uniform snow cover
    - Watershed temperature & precipitation
  - Elevation bands
    - Initial SWE
    - Temperature
- Distributed
  - Standard Hydrologic Grid 10m – 100km
  - Distributed air temperature & Precipitation

Temperature Index Snow Model

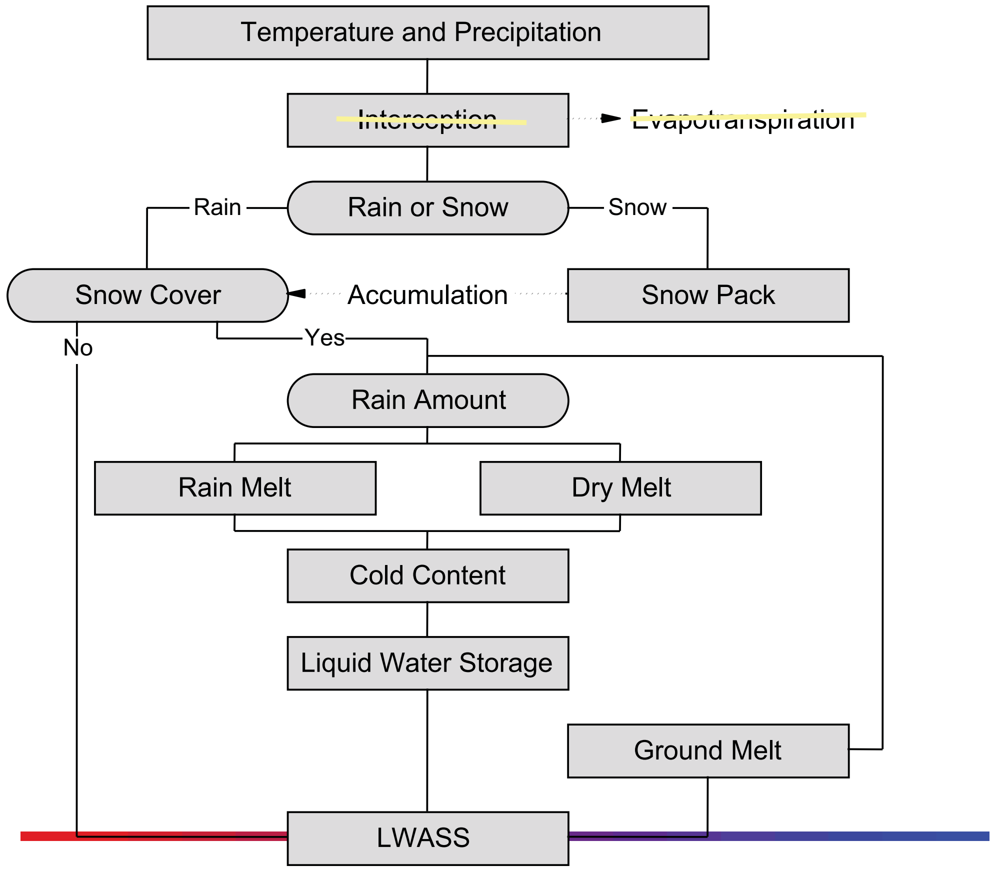
- Snow Melt is estimated as
  - $L_S = M_f (Ta - T_{base})$
  - Mf serves as an index of the total heat transfer at the snow surface which includes long wave, short wave, latent heat, and sensible heat transfer. Also strongly influenced by the wind speed, aspect, slope, vegetation, etc.
  - Mf can be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



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



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



Daly-011

Given precipitation and air temperature for time step

Discriminate between rain and snow using PX temperature

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

Given precipitation and air temperature for time step

Discriminate between melt and non-melt using Base temperature

- **Base Temperature**. The difference between the base temperature and the air temperature defines the temperature index used in calculating snowmelt. The meltrate is multiplied by the difference between the base 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.

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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.

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.

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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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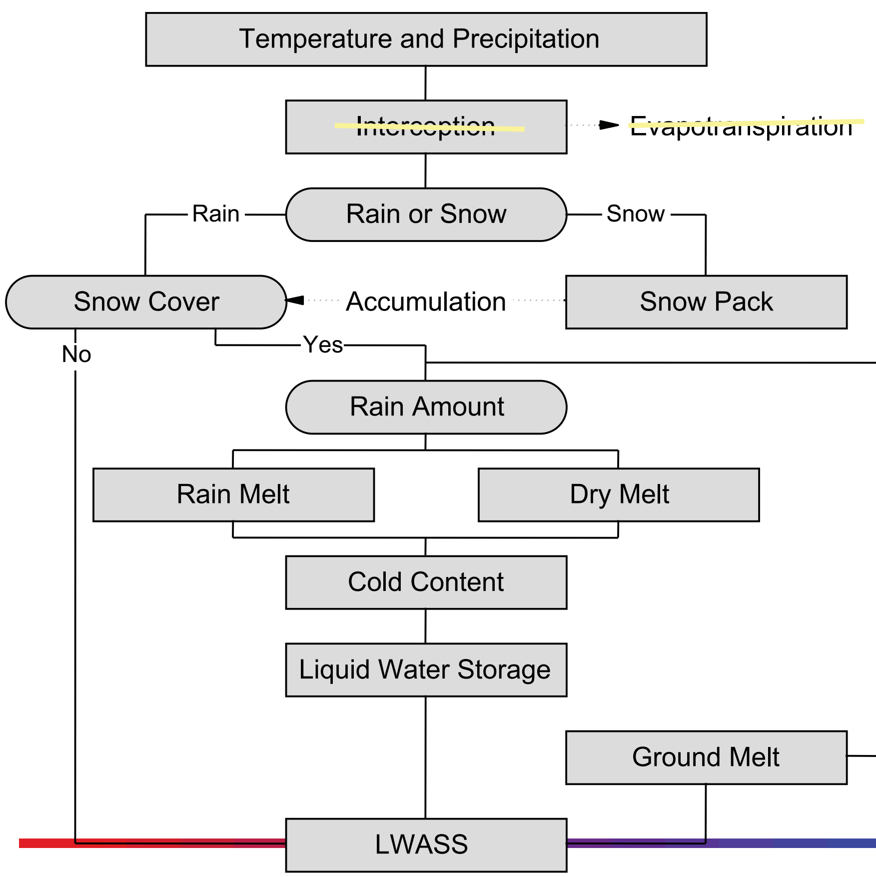

Daly-011

Entering Snow Parameters in HMS

Temp Index

PX Temperature (DEG F)	35.69
Base Temperature (DEG F)	32.6
Wet Meltrate (IN/DEG F-DAY)	0.1912
Rain Rate Limit (IN/DAY)	0.02
ATI-Meltrate Coefficient:	0.98
ATI-Meltrate Function:	snowmelt_atimelt_9697
Meltrate Pattern:	--None--
Cold Limit (IN/DAY)	0.04
ATI-Coldrate Coefficient:	0.90
ATI-Coldrate Function:	snowmelt_aticold_9697
Water Capacity (%)	5.0
Groundmelt Method:	Fixed Value
Groundmelt (IN/DAY)	0

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Engineer Research and Development Center

Entering Paired Data

Paired Data | Table | Graph

Name: snowmelt_atimelt_9697

Description:

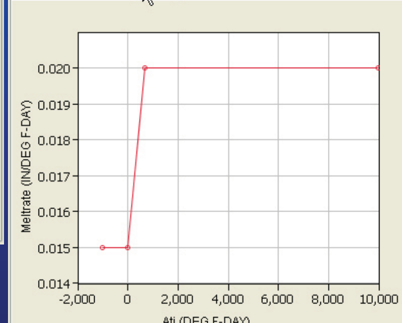
Data Source: Manual Entry

Units: DEG F-DAY : IN/DEG F-DAY

Paired Data | Table | Graph

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

Paired Data | Table | Graph



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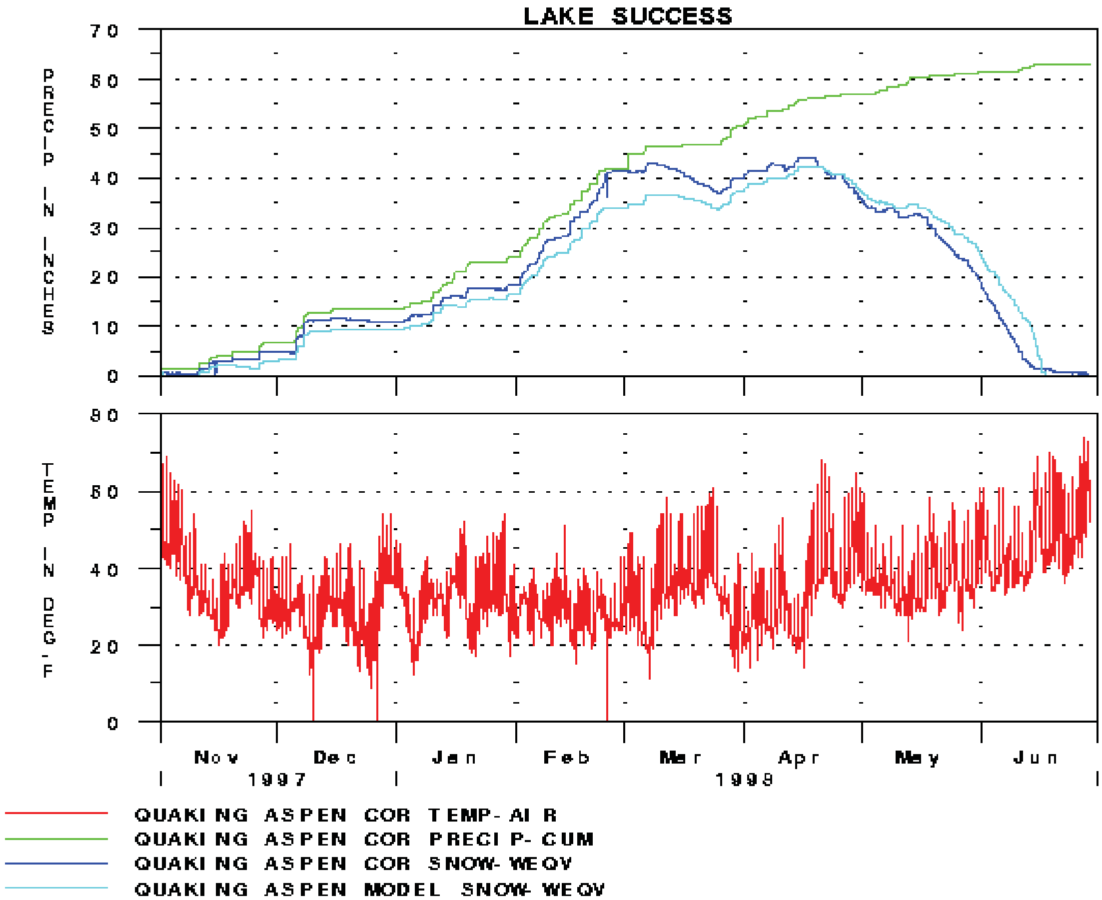
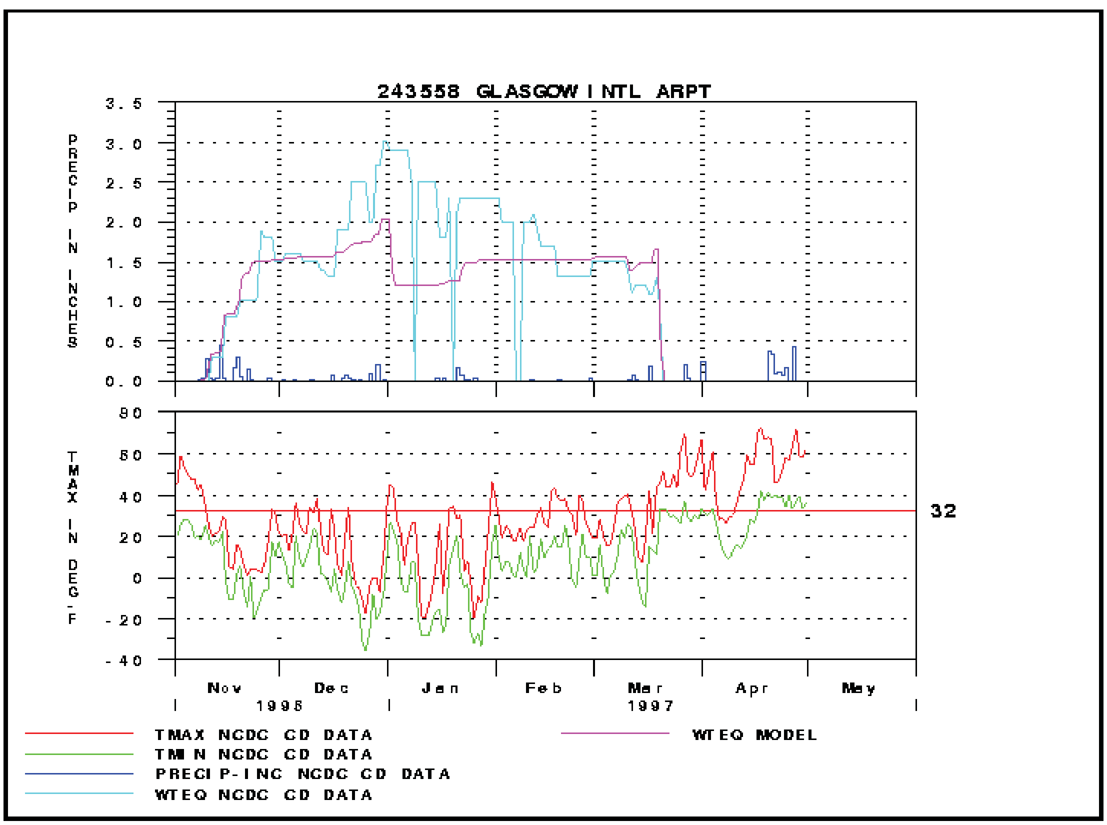

LAKE SUCCESS
PRECIP IN INCHES
TEMP IN DEG. F
Nov Dec Jan Feb Mar Apr May Jun
1997 1998
QUAKING ASPEN COR TEMP-AIR
QUAKING ASPEN COR PRECIP-CUM
QUAKING ASPEN COR SNOW-WEQV
QUAKING ASPEN MODEL SNOW-WEQV


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

WIN

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

Land-Use Evapotranspiration Coefficient Study

Weather INnovations Incorporated (WIN) was contracted by the Niagara Peninsula Conservation Authority (NPCA) to determine coefficients relating evapotranspiration rates to a reference potential evapotranspiration for the highest density land uses in the Niagara Peninsula.

The land uses of greatest interest, the majority of which were identified to be agricultural, were outlined by the NPCA. The crops of greatest density were used to further define the agricultural land use.

Table 1: Identified Land Use

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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.